Water-Supply and Irrigation Paper No. 110

Series { B, Descriptive Geology, 46
0, Underground Waters, 27 }

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

CONTRIBUTIONS

TO THE

HYDROLOGY OF EASTERN UNITED STATES

1904

MYRON L. FULLER

GEOLOGIST IN CHARGE

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(R. S. Sup. Vol. 2, pp. 360, Sec. 74.)

WASHINGTON

GOVERNMENT PRINTING OFFICE

1905

CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., March 31, 1904.

Sir: I have the honor to transmit herewith a manuscript, entitled "Contributions to the Hydrology of Eastern United States, 1904." This paper is the second of a series of contributions relating largely to the hydro-geology of the eastern portion of the country, the first having been published as Water-Supply and Irrigation Paper No. 102, and has been prepared as the result of investigations of underground currents and artesian wells, as authorized by law. It includes 23 short papers by 19 geologists, physicists, and others connected with the eastern section of the division of hydrology. The aim is to present the results of subordinate lines of investigation which, because of their limited length, do not warrant separate publication.

A number of points of unusual interest are considered in the report. A full description of the electrical apparatus devised by Prof. C. S. Slichter for measuring underflow is presented for the first time. The description of the experiment at Quitman, Ga., for determining the liability to pollution of deep wells is an account of a practical investigation which proved to be of great importance in preventing steps that might have led to a serious contamination of the underground waters and a possible epidemic.

Very respectfully,

F. H. Newell,
Chief Engineer.

Hon. Charles D. Walcott,
Director United States Geological Survey.

CONTRIBUTIONS TO THE HYDROLOGY OF EASTERN UNITED STATES, 1904.

M. L. Fuller,
Geologist in Charge.

INTRODUCTION.

By M. L. Fuller.

OBJECT OF REPORT.

The present paper, which is the second of the series of "Contributions to the Hydrology of Eastern United States," includes 23 short reports by 19 geologists and others. Of these the longer papers have been contributed by those connected with the eastern section of the division of hydrology, but several that embody summaries of the water resources of regions covered by geologic investigations have been prepared by members of the geologic branch. The aim in preparing the report is to present the results of subordinate investigations, the length or scope of the reports of which do not warrant their publication as separate papers. In this way there is presented a considerable amount of material of local interest, especially in regions where complete investigations are not practicable. The paper is also intended to afford opportunity for publication of the results of laboratory or other physical, mechanical, or mathematical investigations bearing on underground water supplies.

SUMMARY.

The papers included may be briefly summarized as follows:

Description of the Underflow Meter used in Measuring the Velocity and Direction of Underground Water, by Charles S. Slichter.

The electrical apparatus described in this paper is intended to replace the inaccurate estimation of underflow based on size of material and head, and the troublesome chemical method. Commonly the test wells required by the present method consist of a group of four

2-inch driven wells, one located on the side from which the flow is expected and the other three in the arc of a circle 4 or 6 feet in radius on the downflow side. These are from 24 to 30 inches apart. Electrical connection is made with each well and the upstream well is charged with sal ammoniac or other electrolyte. The appearance of the salt at or near any one of the lower wells is recorded by an electric device, of which there are two types, nonrecording and recording. A full description of the construction and use of the apparatus is given.

The California or "Stove-Pipe" Method of Well Construction, by Charles S. Slichter.

In the larger number of the wells in the gravels, sands, etc., of the Coastal Plain regions of the Atlantic States and elsewhere, the hole is tightly cased throughout, the only point of entrance for the water being at the bottom. Only one water bed can be drawn upon in such wells. In California, and to some extent elsewhere, however, a method is in use whereby, by means of casings perforated at intervals, water can enter the well at a number of different levels. The casing consists of a steel shod "starter," 15 to 25 feet long, and sections of steel pipe 2 feet in length overlapping with flush joints. The casing is forced downward, length by length, by hydraulic jacks to the desired depth. In one well a depth of over 1,300 feet has been reached. After the well has been forced to the required depth a cutting knife, two types of which are figured in the paper, is lowered and slits or holes are cut through the casing at the points where, according to the record, water is known to occur. As much as 400 feet of a 500-foot well may be perforated if the conditions demand it. The type of well described has many advantages in addition to that of rendering several sources of water simultaneously available, and will doubtless be of great value in many localities in the east when the waters at the different levels are under similar heads.

Approximate Methods of Measuring the Yield of Flowing Wells, by Charles S. Slichter.

In this paper descriptions of simple methods and tables for the approximate field determinations of the yield of artesian wells are given. The tables relating to completely filled pipes, both horizontal and vertical, are reprinted from a private report by J. E. Todd, while those relating to measurement of flows from partially filled horizontal and inclined pipes are new. The only instrument required is a foot rule, and the measurement, which consists in measuring the height of the jet in the case of a vertical pipe or its lateral projection in the case of a horizontal pipe, can be made in a few moments. The results are within about 10 per cent of the actual flow, which error is no greater than the average daily variation of flow due to changes of barometric pressure.

Corrections Necessary in Accurate Determinations of Flow From Vertical Well Casings, from Notes furnished by A. N. Talbot.

This paper deals with certain corrections which it is necessary to apply to the figures of the field tables compiled by J. E. Todd and Charles S. Slichter in those cases where refined measurements of flows from vertical well casings are desired. A simple apparatus for measuring the height of the water jet is illustrated, and a diagram showing by curves the coefficients of discharge is given. It was found that with jets less than a foot in height the actual discharge is from 7½ to 12½ per cent lower than the discharge computed from the tables for 2-inch to 6-inch pipes.

Experiment Relating to Problems of Well Contamination at Quitman, Ga., by S. W. McCallie.

Many of the disastrous epidemics which have visited the towns and cities of this country have been traced to polluted drinking water. The present paper deals with a successful effort made to determine the possibility of pollution of the deep wells at Quitman, Ga., the result of which was to prevent a step that might have had fatal results. In a well drilled in 1903 at Quitman a cavity containing what was regarded as a subterranean stream was encountered, and it was thought that such a stream would afford an admirable method of disposing of the city's sewage. Objections were at once raised, however, on every hand, because of the liability of pollution of wells or springs of the region. To test this possibility 2 tons of salt were put into one of the wells, while samples of water from all other wells and springs in the vicinity were taken at short intervals and analyzed. The results showed that the salt had penetrated the deep wells and demonstrated that the emptying of sewage into the underground stream would have resulted in the pollution of the waters of all the deep wells in town and would possibly have led to a serious epidemic.

The New Artesian Water Supply at Ithaca, N. Y., by Francis L. Whitney.

In this paper Mr. Whitney presents an account of the outbreak of the typhoid epidemic of 1903 and the steps taken by various local bodies to obtain a pure supply. The deep wells sunk in the gravels, sands, and clays in the valley of Cayuga Inlet just above Ithaca are described, and the source and geologic occurrence of the supply are discussed. Records of all of the wells are given, the more important being shown by diagrams. The success of the wells, both as to the quantity and the quality of the water, is of special interest, as like supplies could doubtless be obtained at many points in New York and New England which are similarly situated.

Drilled Wells of the Triassic Area of the Connecticut Valley, by W. H. C. Pynchon.

The paper gives a sketch map and section showing the principal geologic features of the area and describes the character and succession of the eastward-dipping series of sandstones, shales, and interbedded or intruded traps throughout the Triassic area of Massachusetts and Connecticut. The geologic discussion is followed by descriptions of a considerable number of wells, in which several points of interest are emphasized, including the nearly uniform water-bearing character of the sandstones, the high percentage of mineral matter present in all the water, and the general absence of flowing wells.

Triassic Rocks of the Connecticut Valley as a Source of Water Supply, by M. L. Fuller.

In this paper a review is given of the occurrence of waters in Triassic rocks of various types, including conglomerates, sandstones, shales, and traps, and the structure, jointing, and faulting of the rocks and their influence on the underground waters are described. Summaries of the conditions favorable and unfavorable to flowing water are given and a number of important conclusions presented. While all of the Triassic rocks except the traps will usually be found to be water bearing, the conditions, because of the interruption of the beds due to faulting or jointing, will rarely be favorable to flowing wells, and high heads can never be expected. The water will in most instances be found to be highly mineralized, but, except possibly in the shallower wells in crowded cities, will rarely be subject to pollution. Attention is called to the need of keeping accurate records and of thoroughly testing each well; and the question of the proper depth of wells is discussed.

Spring System of the Decaturville Dome, Camden County, Mo., by E. M. Shepard.

In the center of this area is a mass of granite (pegmatite) that has apparently been thrust upward through the surrounding Paleozoic limestones and other rocks, which are thereby tilted away from it in all directions. The dome thus formed is surrounded at a distance of several miles by a line of springs, the channels of which seem to radiate from the center of the dome, from which direction the waters appear to come. Several deep flowing wells in similar situations also derive water from the outward-sloping rocks. Descriptions are given of many of the springs, some of which are of immense size and present many points of interest.

Water Resources of the Fort Ticonderoga Quadrangle, Vermont and New York, by T. Nelson Dale.

In this area, which lies on the line between Vermont and New York, there are several important towns, including Ticonderoga in New York, and Proctor, Brandon, Poultney, and West Rutland in Vermont. The land varies considerably in altitude, ranging from low plains near Lake Champlain to ridges 2,700 feet high, such as the one southwest of West Rutland. In general the region is well watered, having numerous springs and streams. The larger streams have, however, become subject to pollution as the industries and towns along their banks have grown up. The limestones or dolomites of the area would doubtless yield water if penetrated by deep wells, but it would probably be hard and in some cases might be liable to pollution. The sandy portion of the drift yields considerable quantities of water, but the clays near the lake give unsatisfactory supplies.

Water Resources of the Taconic Quadrangle, New York, Massachusetts, and Vermont, by F. B. Taylor.

The center of this area falls almost exactly at the point at which the boundaries of the three States mentioned come together. The area is mountainous except in the western third, although it contains valleys with bottoms as low as 350 feet above sea. The drainage is by the Hoosac River, along which, as well as along its tributaries, there are water powers that are either utilized or available. Practically all the cities and towns in the quadrangle obtain their water supplies from mountain streams, but a large proportion of the rural inhabitants procure their supplies from springs. One important mineral spring, developed at a sanitarium, occurs along a probable fault line.

Water Resources of the Watkins Quadrangle, New York, by Ralph S. Tarr.

The paper gives a general description of the water resources of this region, which includes the cities of Elmira and Ithaca, in the southern portion of the State. Special attention is given to the subject of obtaining artesian supplies from the deep gravel-filled valleys, and the steps taken to obtain pure supplies from such a source at Ithaca after the typhoid epidemic of 1903, are described. A number of analyses are given.

Water Resources of the Central and Southwestern Highlands of New Jersey, by Laurence La Forge.

The region treated in this paper is that part of the Highlands which lies south of Andover and Pompton, including about two-thirds of the Highland area of the State. The population is mainly located in villages and is dependent largely upon manufacturing industries for support. The rocks are principally of granitic types, but some conglomerate and quartzite occurs. Lakes and ponds are numerous in a part of the area and streams are abundant and afford numerous water powers as well as the supply for the Morris Canal, while springs are common and furnish water to a considerable number of towns. The surplus water, of which there is considerable, may in the future become of great importance as a source of supply for the large and rapidly growing urban district near New York. The paper describes the needs of this district and the amount and character of the water and its availability as a source of supply.

Water Resources of the Chambersburg and Mercersburg Quadrangles, Pennsylvania, by George W. Stose.

The Chambersburg and Mercersburg quadrangles are located in the Cumberland Valley, in southern Pennsylvania, and include the two important towns from which they are named. They are crossed by several mountain ridges and by many streams that afford water powers, some of which have already been utilized. Many springs are found in the various rocks, especially in the limestone, some of which have been developed as attractive resorts. The public water supplies are obtained largely from spring-fed mountain streams, and in several instances directly from springs.

Water Resources of the Curwensville, Patton, Ebensburg, and Barnesboro Quadrangles, Pennsylvania, by F. G. Clapp.

These quadrangles are situated near the eastern edge of the bituminous coal field, and lie mostly within the limits of Clearfield and Cambria counties. The region is one of high ridges alternating with valleys. Springs are abundant and, except in towns, constitute the main source of water supply. The once noted Cresson Springs are in the area. Many wells obtain abundant supplies, both from the stream gravel and from the rocks. In some places flowing wells are obtained. More than ten towns are equipped with water systems. The majority obtain their supplies from streams, but several procure water from springs or deep wells.

Water Resources of the Elders Ridge Quadrangle, Pennsylvania, by Ralph W. Stone.

This quadrangle lies in Armstrong and Indiana counties, in the west-central part of the State. In general the surface is moderately hilly and is drained by Kiskiminitas River and other streams that flow westward into Allegheny River. Some present available water powers. The region is distinctly a rural district, without large towns, and springs and shallow wells afford the only source of water supply. The Mahoning and Pittsburg sandstones, which overlie the coals of the same name, are the best water bearers.

Water Resources of the Waynesburg Quadrangle, Pennsylvania, by Ralph W. Stone.

The Waynesburg quadrangle is located in Greene County, in the southwest corner of the State. The topography is uniformly hilly, the crests standing generally not over 500 feet above the valleys. The area is drained eastward into the Monongahela by streams of low grade and small volume, with few if any available water powers. The city of Waynesburg obtains its public water supply from a near-by stream, but the water is frequently highly charged with silt and is generally unsatisfactory. The smaller towns depend on shallow private wells. Some of the rock wells yield good supplies, especially those drawing water from the Waynesburg sandstone. In drilling wells to the rock, however, care must be taken not to penetrate the coal. Springs are numerous but small.

Water Resources of the Accident and Grantsville Quadrangles, Maryland, by G. C. Martin.

The area covered by this paper is located in the "handle," in the extreme western portion of Maryland. The topography is essentially that of a plateau, standing between 2,500 and 3,000 feet, above which rise a number of ridges. It is drained by Youghiogheny, Castleman, and Savage rivers, all of which would afford good water supplies. Springs are numerous, especially along the outcrop of the Greenbrier limestone. The possibilities of artesian waters have not been tested, although bore holes sunk for other purposes have given flowing water. It is probable that such flows would be afforded by each of the three synclines which cross the area.

Water Resources of the Frostburg and Flintstone Quadrangles, Maryland and West Virginia, by G. C. Martin.

These quadrangles lie just east of the Grantsville, mainly in western Maryland. They are crossed by a number of ridges that rise as high as 3,000 feet, between which are valleys of considerably lower level. Through these valleys pass the north and south branches of Potomac River and a number of smaller streams. The smaller streams are unpolluted and generally afford good water. Springs abound in the limestone regions. Artesian water is found in sandstones of Carboniferous age, and it is thought that the Oriskany and Tuscarora sandstones probably carry artesian water in the synclines. A large part of the water supply of Frostburg is obtained from an artesian well, but except at Cumberland, there is otherwise little demand for artesian water.

Water Resources of the Cowee and Pisgah Quadrangles, North Carolina, by Hoyt S. Gale.

The Cowee and Pisgah quadrangles are located in the heart of the Southern Appalachians, in the extreme western part of North Carolina. They are traversed by French Broad River and other streams which present available water power at many points. The whole region abounds with springs, generally of pure water, but a few mineral springs, especially chalybeate, occur. Of these the carbonate springs are usually associated with hornblendic gneiss, while the chalybeate waters are associated with pyrite deposits along faults. Very few wells have been sunk in the area.

Water Resources of the Middlesboro-Harlan Region of Southeastern Kentucky, by George H. Ashley.

This region is in a general way a broad basin lying between two high mountain ridges. The surface is cut by deep ravines separated by sharp crests. The rocks are of the Coal Measure series and yield abundant springs, which form the main source of supply of the scattered inhabitants. Shallow wells are frequently relied upon in the bottom lands. No deep wells have been drilled for water, but flowing water has sometimes been obtained from wells drilled for oil. The public supplies of Middlesboro and Pineville, the two principal towns, are obtained from spring-fed mountain streams. Some available water powers exist.

Summary of the Water Supply of the Ozark Region in Northern Arkansas, by George I. Adams.

This area includes portions of the Boston Mountain belt and the Springfield and Salem uplands, the limits of which are shown in fig. 32. The rocks consist largely of Ordovician dolomites and Carboniferous limestones, the former being confined mainly to the Salem upland. Springs are especially numerous in the Boone limestone and chert and the Ordovician dolomites, but some are also found in the Key sandstone. Some of the springs are of immense size, and many have been developed as resorts.

Notes on the Hydrology of Cuba, by M. L. Fuller.

During the American occupation of Cuba much interest was aroused in the water resources of the island, and special attention was given to the problem of water supplies for the various cities. This paper gives, after a résumé of geology, topography, and drainage, a summary of the natural water resources, including underground streams and springs, accounts of the public water supplies, and descriptions of the wells sunk by the War Department for the various military posts. Among the principal water supplies are those of Habana, Matanzas, Cardenas, Cienfuegos, Guantanamo, and Santiago. Underground water courses in the soft limestone, some of them of considerable size, are everywhere present, and springs are very common in many regions. The waters are generally pure, except for the lime, but mineral waters have been exploited for drinking or bathing purposes at a number of localities. The wells drilled by the War Department were located at a considerable number of scattered points. In general they were successful in obtaining supplies at a moderate depth.

DESCRIPTION OF UNDERFLOW METER USED IN MEASURING THE VELOCITY AND DIRECTION OF MOVEMENT OF UNDERGROUND WATER.

By CHARLES S. SLICHTER.

A brief description of the writer's electrical method of measuring the velocities of underground water was printed in the Engineering News of February 20, 1902, and in Water-Supply and Irrigation Paper No. 67 of the United States Geological Survey. The present account will give a more detailed description of the form of the apparatus.

APPARATUS.

The apparatus used is of two types: (1) direct-reading, or hand apparatus, which requires the personal presence of the operator every hour for reading of instruments, and (2) recording apparatus, which requires attention but once in a day. The arrangement of the test wells and manner of wiring the wells is essentially the same in both forms and will now be described.

TEST WELLS.

The test wells may be common 1¼ or 2 inch drive wells if the soil and water-bearing material are easily penetrated, and if the depths to be reached do not exceed 40 feet. For greater depths and harder materials wells of heavier construction should be used. The test wells put down by the Commission on Additional Water Supply for Greater New York in 1903 are suitable for ordinary conditions in the eastern part of the United States, or in any place where the gravels are not too coarse or too compact. These test wells were made of full-weight standard wrought-iron 2-inch pipe, in lengths of 6 or 7 feet, with long threads (1½-inch) and heavy wrought nipples. The well points were 4-foot standard brass jacket points, No. 60 wire gauze. For wells no deeper than 30 feet, closed-end points were driven, but for deeper work open-end points were used. The test wells were driven in place by use of a ram from 150 to 250 pounds in weight, simultaneously hydraulicking a passage for the pipe with water jet in three-fourth inch standard wash pipe. In fine material there was coupled ahead of the open end well point 3 or 4 feet of pipe carrying a shoe coupling, so that the sand, in running in through the open end of the well, would not rise above the bottom of the screen inside of the finished well.

Mr. Homer Hamlin, of Los Angeles, Cal., has devised a powerful drilling rig run by a gasoline engine, which enables him to sink test wells in the bowlder gravel of that locality. He uses a special double-strength casing with flush joints, which he has been able to sink to great depths with his remarkable drilling machine. He has used the electrical method for determining underflow velocities with great success.

The test wells are grouped as shown in fig. 1.

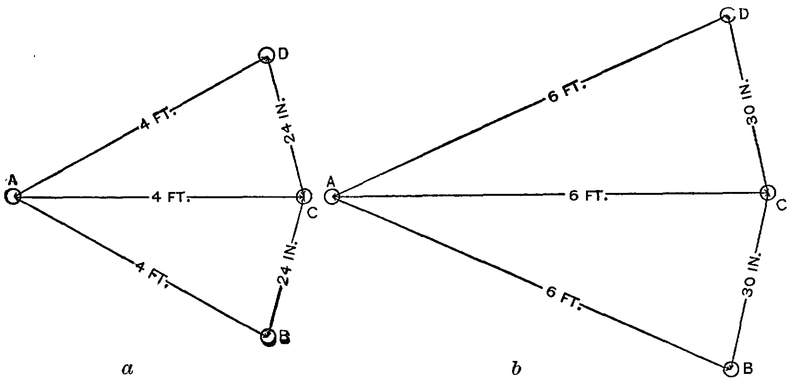
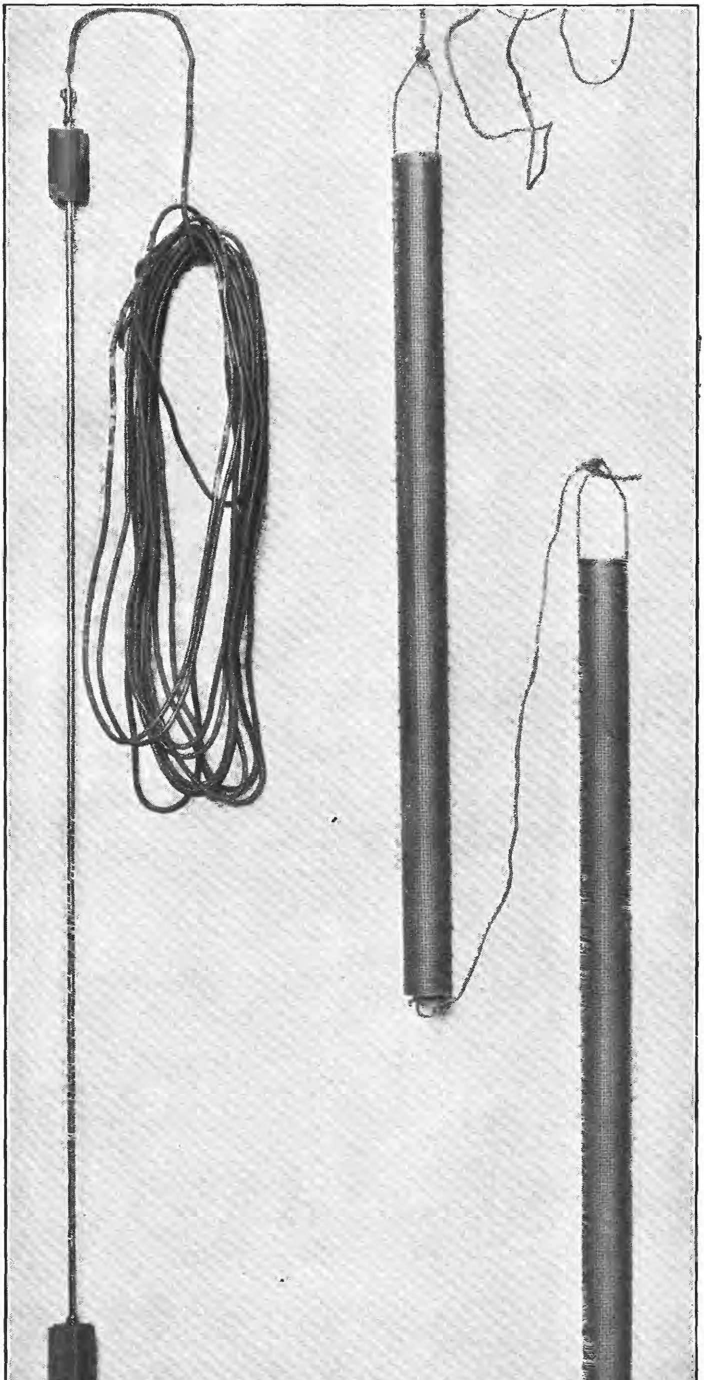


FIG. 1.—Plan of arrangement of test wells used in determining the velocity and direction of motion of ground waters. A, B, C, D are the test wells. The direction A-C is the direction of probable motion of the ground waters. The dimensions given in plan *a* are suitable for depths up to about 25 or 30 feet; those in plan *b* for depths up to about 75 feet. For greater depths the distances A—B, A—C, A—D should be increased to 9 or 10 feet and the distances B—C and C—D to 4 feet. The well A is the "salt well" or well into which the electrolyte is placed.

In case the wells are not driven deeper than 25 feet, an "upstream" or "salt well," A, is located, and three other wells, B, C, and D, are driven at a distance of 4 feet from A, the distance between B and C and C and D being about 2 feet. The well C is located so that the line from A to C will coincide with the probable direction of the ground-water movement. This direction should coincide, of course, with the local slope of the water plane. For deeper work the wells should be placed farther apart, as shown in the right portion of fig. 1. For depths exceeding 75 feet, a radius of 8 or 9 feet and chords of 4 feet should be used, the general requirement being that the wells should be as close together as possible, so as to cut down to a minimum the time required for a single measurement, but not so close that important errors are liable to be introduced by the inability to drive the wells perfectly straight and plumb. On this account the deeper the wells the farther apart they should be placed. The angles B A C and C A D should not exceed 30 degrees.



ELECTRODE AND PERFORATED BRASS BUCKETS USED IN CHARGING WELLS.

METHOD OF WIRING.

Electrical connection is made with the casing of each test well by means of drilled coupling carrying a binding post. Each of the downstream wells, B, C, D, contains within the well point or screen section an electrode consisting of a nickeled brass rod three-eighths inch by 4 feet, insulated from the casing by wooden spools. This electrode communicates with the surface by means of No. 14 rubber-covered

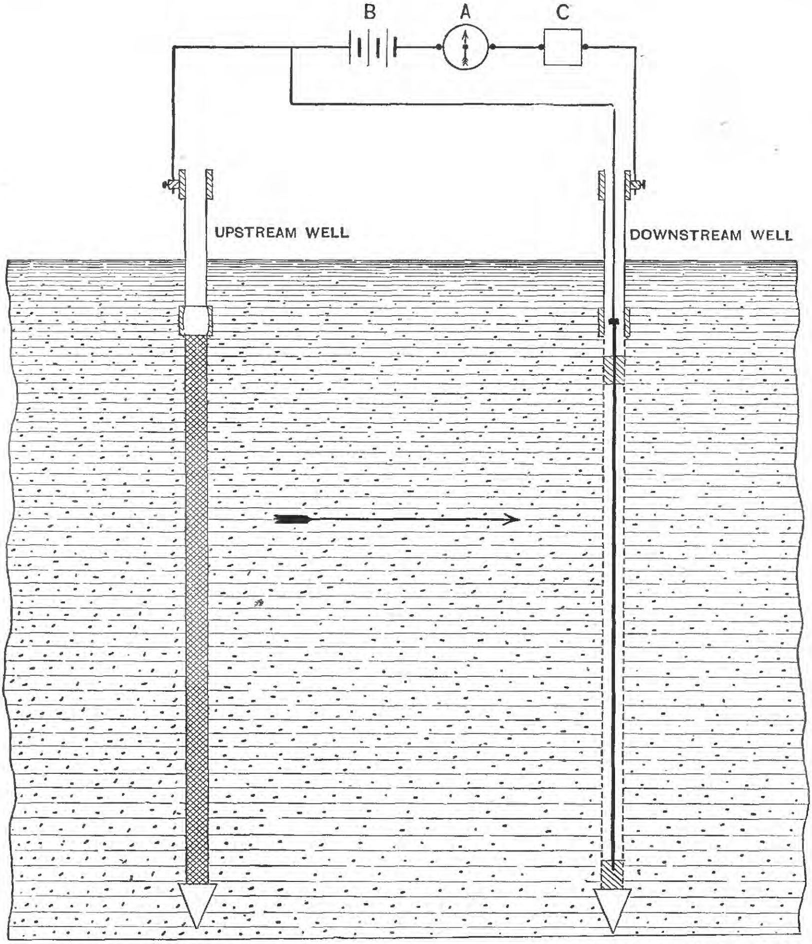


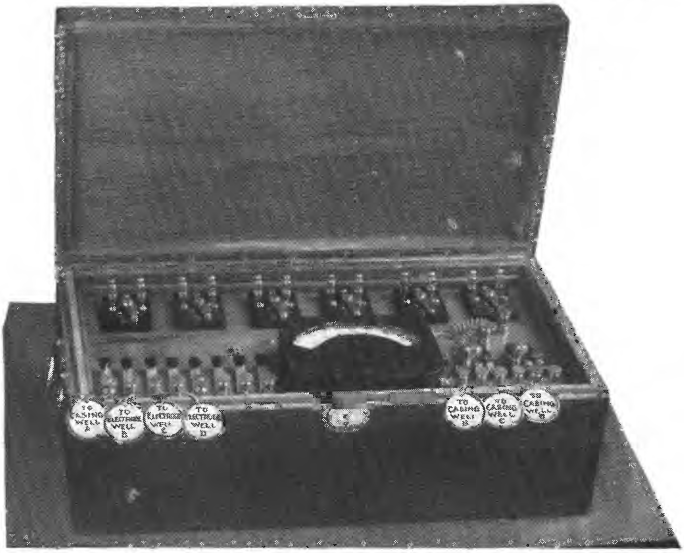
FIG. 2.—Diagram illustrating electrical method of determining the velocity of flow of ground water. The ground water is supposed to be moving in the direction of the arrow. The upstream well is charged with an electrolyte. The gradual motion of the ground water toward the lower well and its final arrival at that well are registered by the ammeter **A**. B is the battery and C a commutator clock which is used if A is a recording ammeter.

copper wire. Fig. 2 illustrates the arrangement of electric circuits between the upstream well and one of the downstream wells. An electrode is shown in Pl. I. At left of cut there is shown an electrode, such as is used in a downstream well. The electrode is 4 feet long, made of three-eighths inch nickeled brass rod. Insulators are of wood. The end of rod receives a No. 14 rubber-covered wire, to which good contact is made by a simple chuck clutch. At right of cut are shown two buckets of perforated brass used in charging wells with granulated sal ammoniac. Size of each is 1¾ by 30 inches. Each of the downstream wells is connected to the upstream well in the manner shown in this figure.

DIRECT-READING METER.

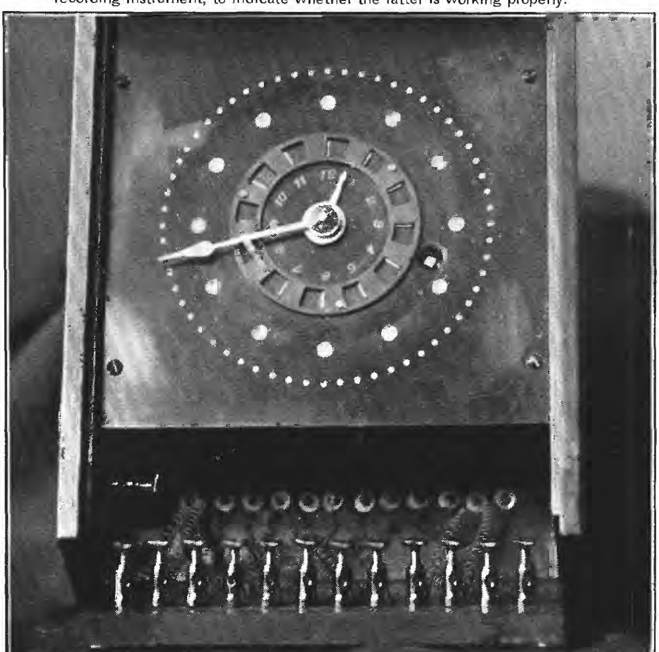
A view of the direct-reading underflow meter is shown in Pl. II, *A*. Six standard dry cells are contained in the bottom of the box, their poles being connected to the six switches shown at the rear of the case. By means of these switches any number of the six cells may be thrown into the circuit in series. One side of the circuit terminates in eight press keys, shown at the left end of the box. The other side of the circuit passes through an ammeter, shown in the center of the box, to two three-way switches at right end of the box. Four of the binding posts at the left end of the box are connected to the casing of well A and to the three electrodes of wells B, C, and D, in order. The binding posts at the right end of the box are connected to the casings of wells B, C, and D. There are enough binding posts to permit two different groups of wells to be connected with the same instrument. When the three-way switch occupies the position shown in the plate, to press the first key at the left end of box will cause the ammeter to show the amount of current between casing of well A and casing of well B. When the next key is pressed the ammeter will indicate the current between the casing of well B and the electrode contained within it. In the first case the current is conducted between the two well casings by means of the ground water in the soil; in the second case by means of the water within well B. By putting the three-way switch in second position and pressing the first and third keys in turn, similar readings can be had for current between casings A and C, and between casing C and its internal electrode. Similarly, with switch in third position, readings are taken by pressing first and fourth keys. The results may be entered in notebook, as shown in Table I.

The principles involved in the working of the apparatus are very simple. The upstream well A is charged with a strong electrolyte, such as sal ammoniac, which passes downstream with the moving ground water, making the ground water a good conductor of electricity. If the ground water moves in the direction of one of the lower wells, B, C, D, etc., the electric current between A and B, A and C, or A and D will gradually rise, mounting rapidly when the electrolyte begins to touch one of the lower wells. When the electrolyte finally



A. UNDERFLOW METER, SHOWING CONNECTIONS WHEN USED AS DIRECT READING APPARATUS.

The switches at back of case throw any of the dry cells in bottom of box in or out of circu t. When used with recording ammeter, only two connections are made, one to each side of battery circuit; but the ammeter is left in circuit with the recording instrument, to indicate whether the latter is working properly.



B. COMMUTATOR CLOCK, FOR USE WITH RECORDING AMMETER.

The clock makes electrical contact at any five-minute interval.

reaches and enters inside of one of the wells B, C, D, it forms a short circuit between the casing of the well and the internal electrode, causing an abrupt rise in the electric current. The result can be easily understood by consulting Table I and fig. 3, in which the current is depicted graphically.

TABLE I.—*Field record of electric current during underflow measurements at station 5, Rio Hondo and San Gabriel River, California, August 5 and 6, 1902.*

[Readings in amperes and decimals of an ampere.]

Time.	Well B.		Well C.		Well D.		Remarks.[a]	
	Casing.	Electrode.	Casing.	Electrode.	Casing.	Electrode.		
8 a. m	0.140	0.360	0.142	0.332	0.150	0.390		
8.15 a. m	Salt.		Salt.		Salt.		1 NaCl	2 NH_4Cl
8.30 a. m	.160		.163		.170			1 NH_4Cl
9 a. m	.168		.170		.180		1 NaCl	
10 a. m	.180	.360	.182	.330	.192	.390		1 NH_4Cl
11.40 a. m	.192	.345	.195	.325	.202	.380		
1 p. m	.202	.340	.202	.320	.210	.370		1 NH_4Cl
2 p. m	.205	.345	.204	.340	.210	.370		
3 p. m	.208	.342	.205	.320	.210	.360	1 NaCl	
4 p. m	.210	.350	.205	.320	.210	.370		
5 p. m	.218	.330	.210	.310	.212	.360		1 NH_4Cl
6 p. m	.225	.330	.210	.310	.218	.360		
7 p. m	.230	.330	.218	.310	.220	.360		
8 p. m	.240	.330	.222	.310	.223	.350	1 NaCl	
9 p. m	.250	.330	.222	.320	.225	.352		
10.30 p. m	.275	.340	.225	.315	.225	.360		
12 p. m	.350	.600	.230	.310	.230	.340		1 NH_4Cl
1 a. m.[b]	.420	.850	.240	.310	.230	.340		
2.30 a. m	.510	1.550	.240	.310	.230	.340		
4.15 a. m	.560	2.000	.240	.310	.230	.340		
5.30 a. m	.550	2.200	.230	.310	.230	.330		
7.45 a. m	.520	2.250	.230	.310	.225	.330		
8.15 a. m		2.250						
9 a. m		2.200						

[a] The electrolyte was lowered into well A by means of a perforated brass bucket, 1¾ by 30 inches in size. The formula "2 NH_4Cl" means that two of these buckets, full of ammonium chloride, were introduced into well A at the time indicated. Each of these buckets held 2 pounds of the salt.

[b] August 6.

The time which elapses from the charging of the well A to the arrival of the electrolyte at the lower well gives the time necessary for the ground water to cover the distance between these two wells. Hence, if the distance between the wells be divided by this elapsed time, the result will be the velocity of the ground water. The electrolyte does not appear at one of the downstream wells abruptly; its appearance there

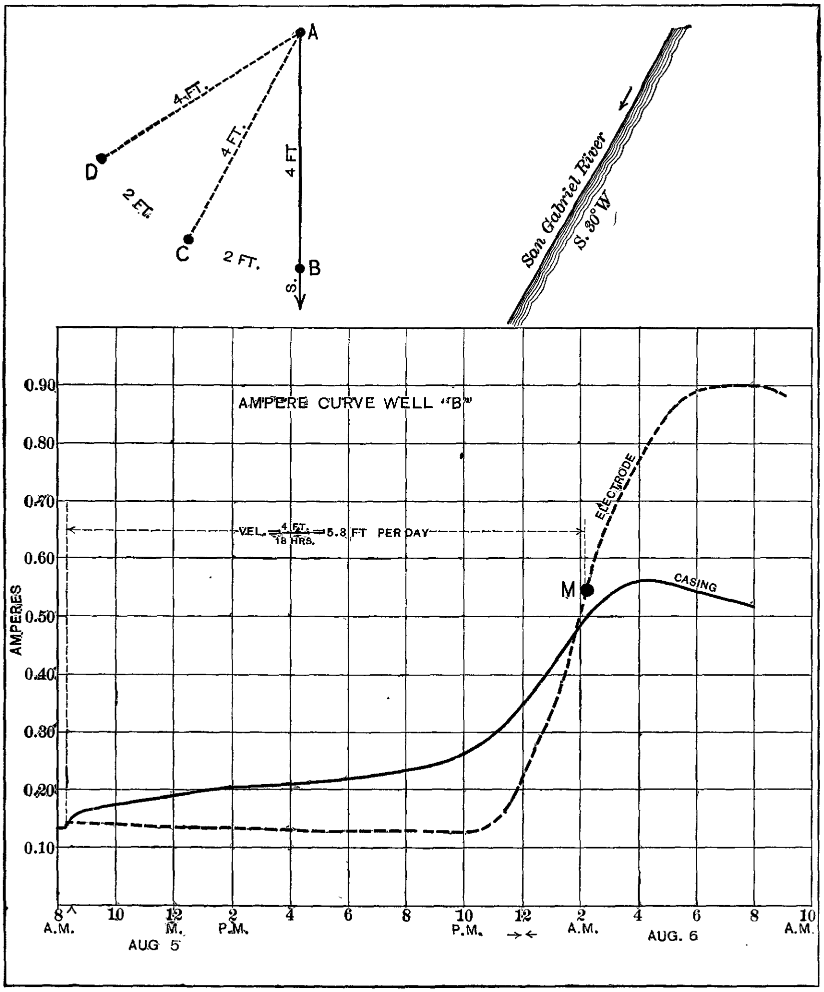


FIG. 3.—Curves showing electric current between casing of well A and casing of well B (heavy curve), and between casing of well B and its internal electrode (dotted curve), at station 5, San Gabriel River, California. These curves illustrate results obtained with the direct-reading form of apparatus.

is somewhat gradual, as is shown by the curves in figs. 3 and 4. The time required for the electrolyte to reach its maximum strength in one of the downstream wells after its arrival at that well (and, hence, the time required for the current to reach its maximum value) may vary from a few minutes in a case of high ground water velocity to several hours in a case of low velocity. The writer formerly supposed that the gradual appearance of the electrolyte at the downstream well was largely due to the diffusion of the dissolved salt, but it is now known that diffusion plays but a small part in the result. The principal cause of the phenomenon is the fact that the central thread of water in each capillary pore of the soil moves faster than the water at the walls of the capillary pore, just as the water near the central line of a river channel usually flows faster than the water near the banks. For this reason, if the water of a river be made suddenly muddy at a certain

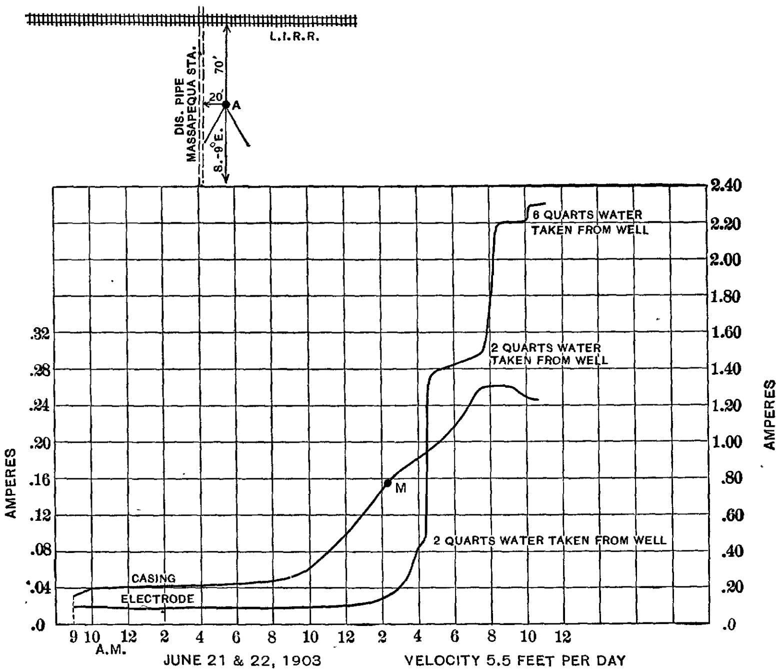


FIG. 4.—Curves showing possibility of use of direct-reading apparatus when well points are not used. The casing in this instance consisted of common black 2-inch pipe, with a few small holes in bottom section. The "casing" curve must be relied upon for determining velocity. The "electrode" curve was obtained by drawing water from well C, as shown on diagram, the charged water being drawn into the well through the small holes and the open end of well.

upstream point, the muddiness will appear somewhat gradually at a downstream point, being first brought down by the rapidly moving water in the center of the channel and later by the more slowly moving water near the banks. The effect of the analagous gradual rise in the electrolyte in the downstream well requires us to select the "point of inflection" of the curve of electric current as the proper point to determine the true time at which the arrival of the electrolyte should be counted. This point is designated by the letter M in figs. 3 and 4.

Owing to the repeated branching and subdivision of the capillary pores around grains of sand or gravel the stream of electrolyte issuing from the well will gradually broaden as it passes downstream. The actual width of this charged water varies somewhat with the velocity of the ground water, but in no case is the rate of the divergence very

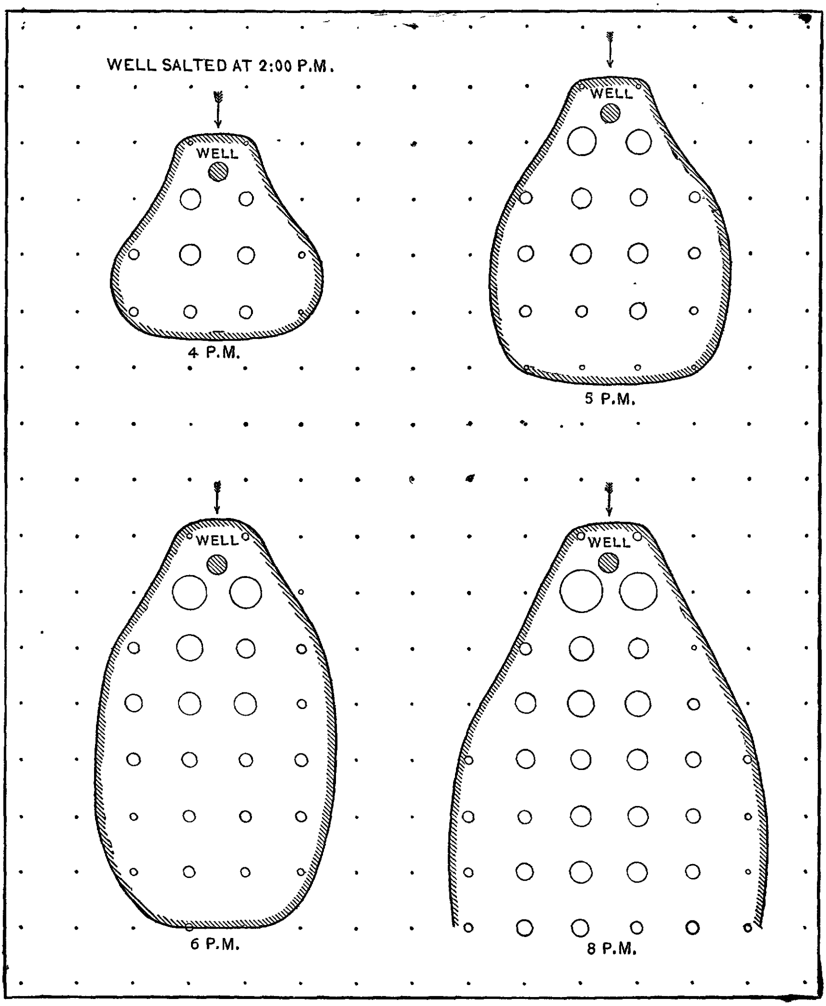


FIG. 5.—Diagram showing the manner in which the electrolyte spreads in passing downstream with the ground water. The shaded circle shows the location of the salted well, and samples were taken from small test wells placed in the sand in rows and columns at intervals of 6 inches, shown by dots in the diagram. The areas of the circles are proportional to the strength of the electrolyte found at their centers. The rough outline indicates the area covered by the charged water at the times specified. The velocity of the ground water (in the direction of the arrows) was 12 feet a day. It can be seen that the electrolyte barely reached a distance of 3 inches against the direction of flow.

great. Figs. 5 and 6 show some actual determination of the spread of the electrolyte around a well in a coarse sand, in one case the ground water moving 12 feet a day and in the other case moving 23 feet a day.

Samples of ground water were taken from small test wells placed only 6 inches apart, and the amount of salt or electrolyte was determined chemically. The amount at any point is indicated by the area of the circles shown in the diagrams. It will be seen that the salt barely showed itself at a distance of 3 inches upstream from the well. Three feet downstream from the well the width of the salt stream was about 3 feet in the first case and about 2 feet in the other.

It is possible to dispense with the circuit between the casing of well A to the casing of each of the other wells, as the short circuit between the well and electrode forms the best possible indication of the arrival of the electrolyte at the downstream well. For cases in which the velocity of ground water is high the circuit to well A is practically of no value, but for slow motions this circuit shows a rising current before the arrival of the electrolyte at the lower well, often giving indications that are of much value to the observer.

The method can be used successfully even if only common pipe be used for the wells. In this case, however, the absence of screen or perforations in the wells renders the internal electrodes useless, and one must depend upon the circuit from the well casing of the upstream well to the well casing of the downstream well. The results in Table II and fig. 4 present such a case.

TABLE II.—*Field record of electric current obtained at station 1, Massapequa, Long Island, June 21, 1903, with direct-reading underflow meter.*

[Readings in amperes and decimals of an ampere.]

Time.	Well B.		Well C.		Well D.	
	Casing.	Electrode.	Casing.	Electrode.	Casing.	Electrode.
8.45 a. m	0.03	0.08	0.03	0.10	0.03	0.09
9 a. m. [a]	....	....	....	....	....	....
9.30 a. m. [b]	.04	.08	.04	.095	.036	.088
10 a. m	.04	.079	.039	.092	.036	.088
10.30 a. m	.04	.079	.04	.097	.039	.087
11 a. m	.04	.079	.04	.095	.059	.087
11.30 a. m	.04	.079	.04	.091	.039	.087
12 m	.041	.079	.04	.092	.040	.087
1 p. m	.042	.079	.04	.090	.040	.088
1.30 p. m	.042	.079	.04	.092	.040	.088
2 p. m	.043	.079	.04	.092	.040	.089
2.30 p. m	.043	.078	.041	.094	.040	.088
3 p. m. [b]	.043	.078	.041	.094	.040	.090
3.30 p. m	.043	.078	.040	.094	.041	.090
4 p. m	.043	.078	.042	.094	.041	.090

[a] 10 pounds of sal ammoniac placed in well A.
[b] 2 pounds of sal ammoniac placed in well A.

TABLE II.—*Field record of electric current obtained at station 1, Massapequa, Long Island, June 21, 1903, with direct-reading underflow meter*—Continued.

Time.	Well B.		Well C.		Well D.	
	Casing.	Electrode.	Casing.	Electrode.	Casing.	Electrode.
4.30 p. m	0.043	0.078	0.042	0.095	0.041	0.090
5 p. m	.043	.078	.042	.096	.041	.090
5.30 p. m	.045	.078	.043	.096	.041	.090
6.30 p. m	.045	.078	.043	.097	.042	.091
7 p. m	.045	.078	.046	.099	.041	.091
7.30 p. m. [a]	.045	.078	.046	.099	.041	.090
8 p. m	.045	.080	.048	.099	.042	.093
8.30 p. m	.049	.080	.049	.100	.043	.094
9 p. m	.048	.079	.050	.100	.043	.094
10.30 p. m	.050	.079	.070	.101	.045	.095
12 p. m	.050	.079	.095	.106	.047	.095
1 a. m. [b]	.051	.079	.120	.122	.049	.099
2 a. m	.051	.079	.147	.152	.050	.100
3 a. m. [a]	.050	.079	.168	.195	.050	.100
4 a. m	.053	.079	.178	.430	.050	.100
4.30 a. m	.053	.079	.188	.470	.050	.100
4.40 a. m	....	....	....	[c] 1.3	....	....
5 a. m	.053	.075	.200	1.4	.050	.100
6 a. m	....	....	.200	1.4	....	....
7.45 a. m	....	....	.260	1.5	....	....
8 a. m	.052	.075	.260	[d] 1.9	.050	[d] .100
8.15 a. m	....	....	....	[d] 2.20	....	....
8.30 a. m	....	....	....	[d] 2.20	....	....
9.15 a. m	....	....	.26	2.20	.049	.099
10 a. m	.050	.072	....	2.20	.049	.099
10 a. m	....	....	.25	[e] 2.30	....	....
11 a. m	....	....	.245	2.30	....	....
11 a. m	....	....	....	[e] 2.30	....	....

[a] 2 pounds of sal ammoniac placed in well A.
[b] June 22, 1903.
[c] Before this reading some water was taken from well C.
[d] About 2 quarts of water was taken from well C before this reading.
[e] After 6 quarts of water was taken from well C.

In this case the wells were not provided with well points, but did possess a 4-foot length of pipe, provided with four or five holes on opposite sides of the pipe, containing small one-half inch washer screens. These few openings are not sufficient to permit the electrolyte to freely enter the well, so that readings between casings must be relied upon for results. As a matter of fact, enough of the electrolyte did get into the well to give small increased readings, but in order to obtain the electrode readings given in the table, water was removed from the downstream wells by a small bucket holding about 6 ounces, so as to force a quantity of the water surrounding the well into the perforated sections. The notes appended to Table II show times of "bucketing" well C, and comparison with the column headed "well C, electrode" shows the effect on the strength of solution in the well. In cases where good well points are used the ground water charged with the electrolyte finds its way gradually and naturally into the well. The well point should be clean enough to allow as free passage into the well as through the soil itself. Second-hand points used for this purpose may show a marked lag in the entry of the electrolyte.

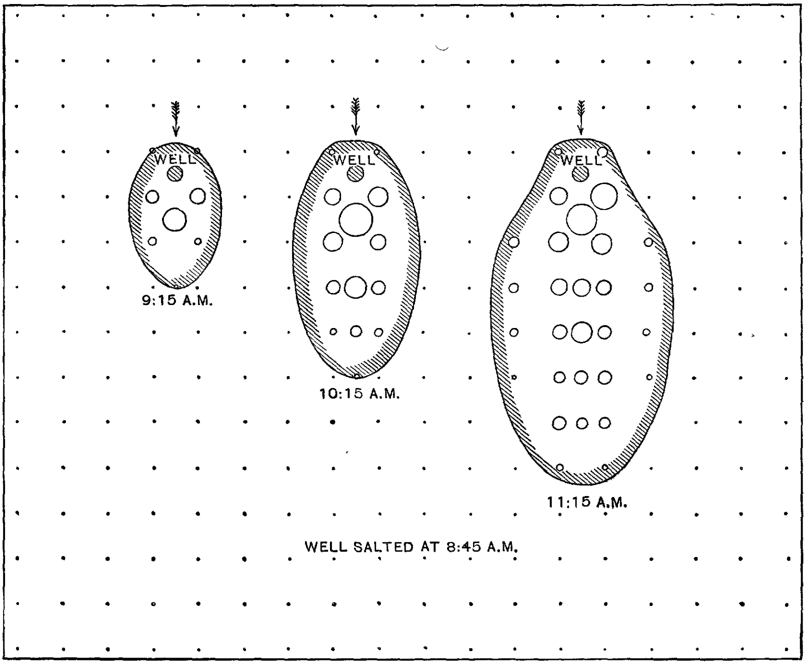


FIG. 6.—Figure showing conditions similar to those shown in fig. 5, but with ground water moving about twice as fast, or 22.9 feet a day. The electrolyte spreads less rapidly for the higher velocities as is seen by comparing this diagram with fig. 5.

Granulated sal ammoniac is used to dose well A. A single charge may vary from 4 to 10 pounds. If common pipe without points or screen is used for the wells, so that internal electrodes must be dispensed with, doses of about 2 pounds each should be repeated about every hour. The dry salt should not be poured directly into the well, but should be lowered in perforated buckets, as shown in Pl. I. These buckets are $1\frac{3}{4}$ by 30 inches and hold about 2 pounds of the salt. Two of these buckets may be tied one above the other for the initial charge and followed by two more in ten or twenty minutes.

If the wells are not too deep the sal ammoniac may be introduced into the well in the form of a solution. A common bucket full of saturated solution is sufficient. There is an uncertainty in introducing the sal ammoniac in solution in deep wells, as the time required for the solution to sink to the bottom of the well may be considerable.

The ammeter used in the work has two scales, one reading from 0 to 1.5 amperes and the other from 0 to 5 amperes. With a given

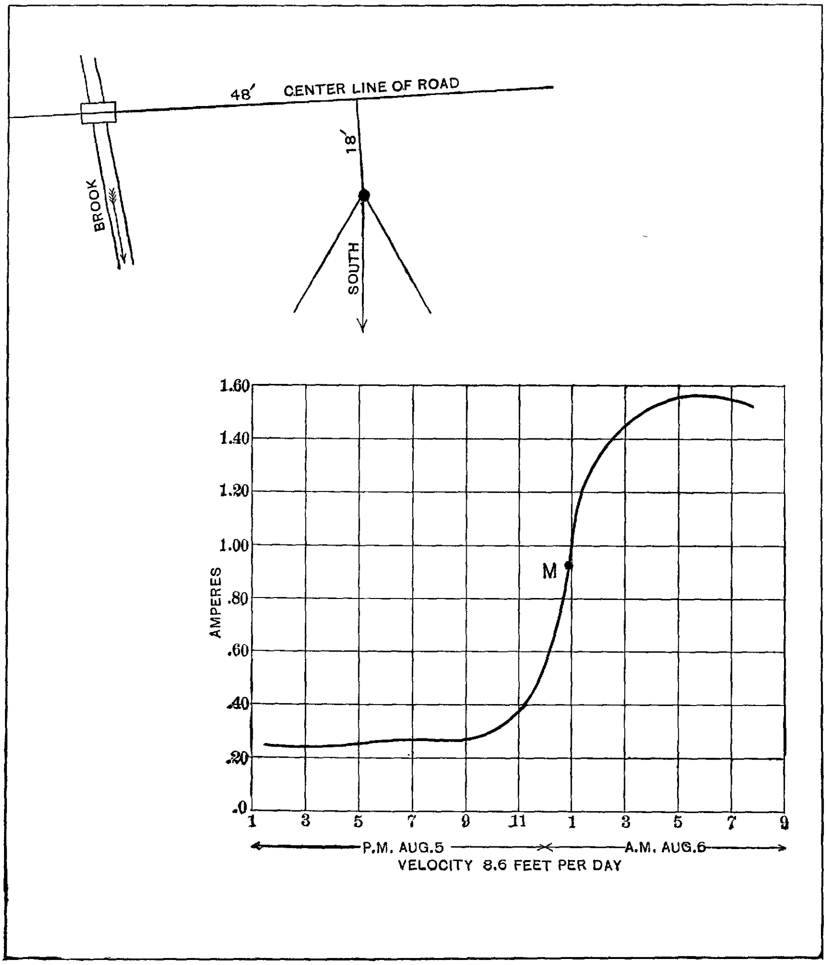
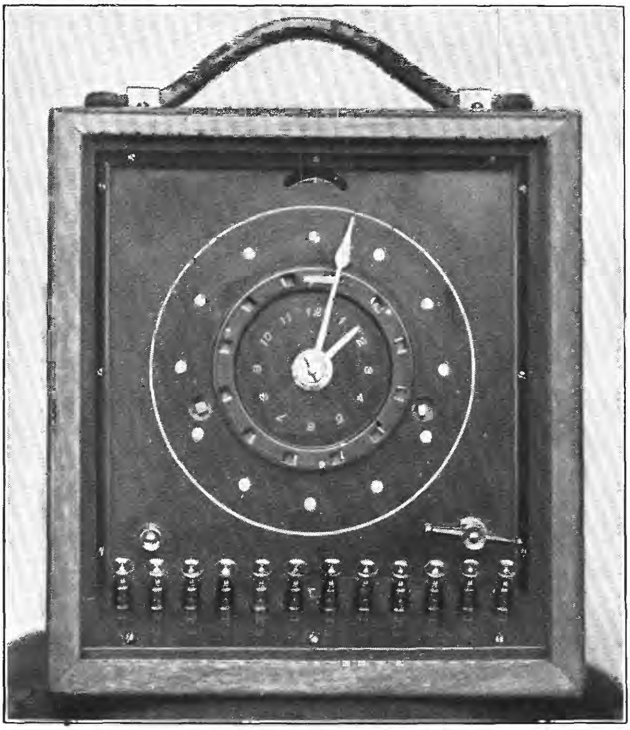


FIG. 7.—Electrical current for well C, station 14, Long Island, plotted on coordinate paper. The record was taken from the chart shown in upper part of fig. 13.

number of cells the amount of current between the upstream and a downstream well will depend, of course, upon several factors, such as the depth of the wells and their distance apart, but more especially upon the amount of dissolved mineral matter in the ground water. The initial strength of the current can be readily adjusted, however, after



A. COMMUTATOR CLOCK, FOR USE WITH RECORDING AMMETER.

The clock works can be removed for cleaning or oiling without disturbing the rest of the mechanism.

B. RECORDING AMMETER, COMMUTATOR CLOCK, AND BATTERY BOX, IN USE IN THE FIELD.

The instruments are shown as arranged in a rough box 16 by 22 by 36 inches, covered with tar paper.

the wells have been connected with the instruments, by turning on or off some of the battery cells by means of the switches at the rear of the box. It is a good plan to use cells enough to make the initial current between one-tenth and two-tenths of an ampere.

SELF-RECORDING METER.

In the second form of underflow meter self-recording instruments are used, so as to do away with the tedious work of taking the frequent observations, day and night, required when direct-reading instru-

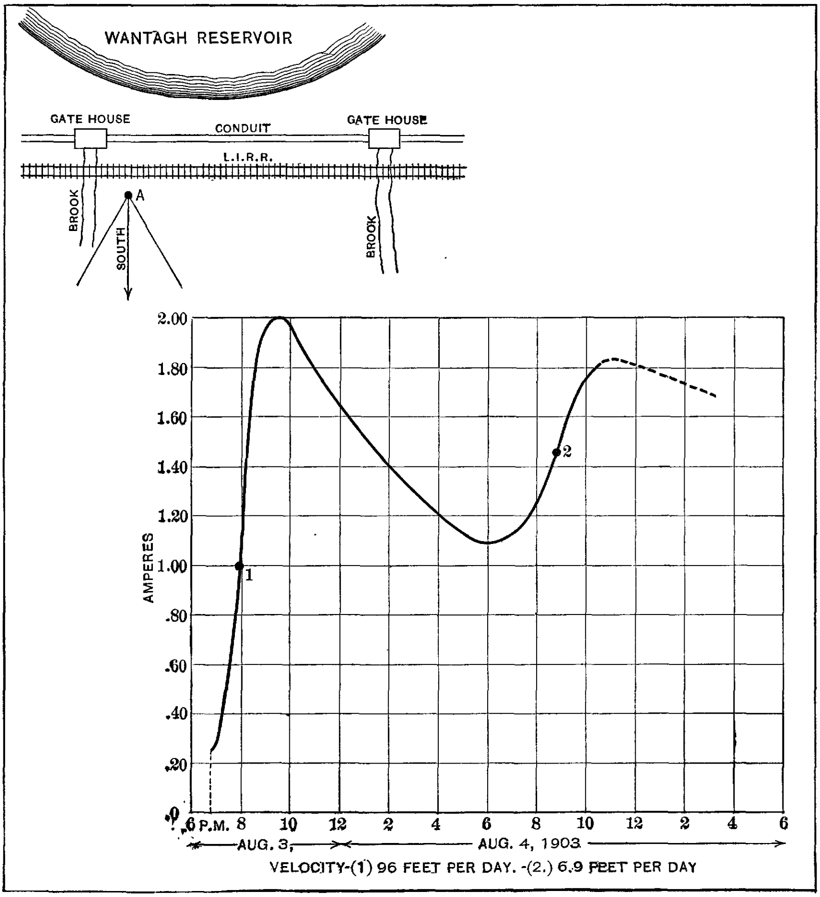


FIG. 8.—Electrical current for well C, station 13, Long Island, plotted on coordinate paper. The record was taken from the chart shown in the lower part of fig. 7. The curve indicates two different velocities in different beds of gravel penetrated by the test wells. One velocity is 96 feet a day; the other 6.9 feet a day.

ments are used. The arrangement of the apparatus is not materially different from that described above. In the place of the direct reading ammeter a special recording ammeter is used, having a range of 0 to 2 amperes. It has been found practicable, although it is a matter of no small difficulty, to construct an instrument of this low range sufficiently portable for field use and not too delicate for the purpose for which it is intended. The ammeter has a resistance of about 1.6 ohms and is provided with oil dash pot to dampen swing of arm carrying the recording pen. The instruments were manufactured by the Bristol Company. The ammeters have gone through hard usage in the field without breakage or mishap. The portability of the instruments will be materially increased by changes in design which are now being made.

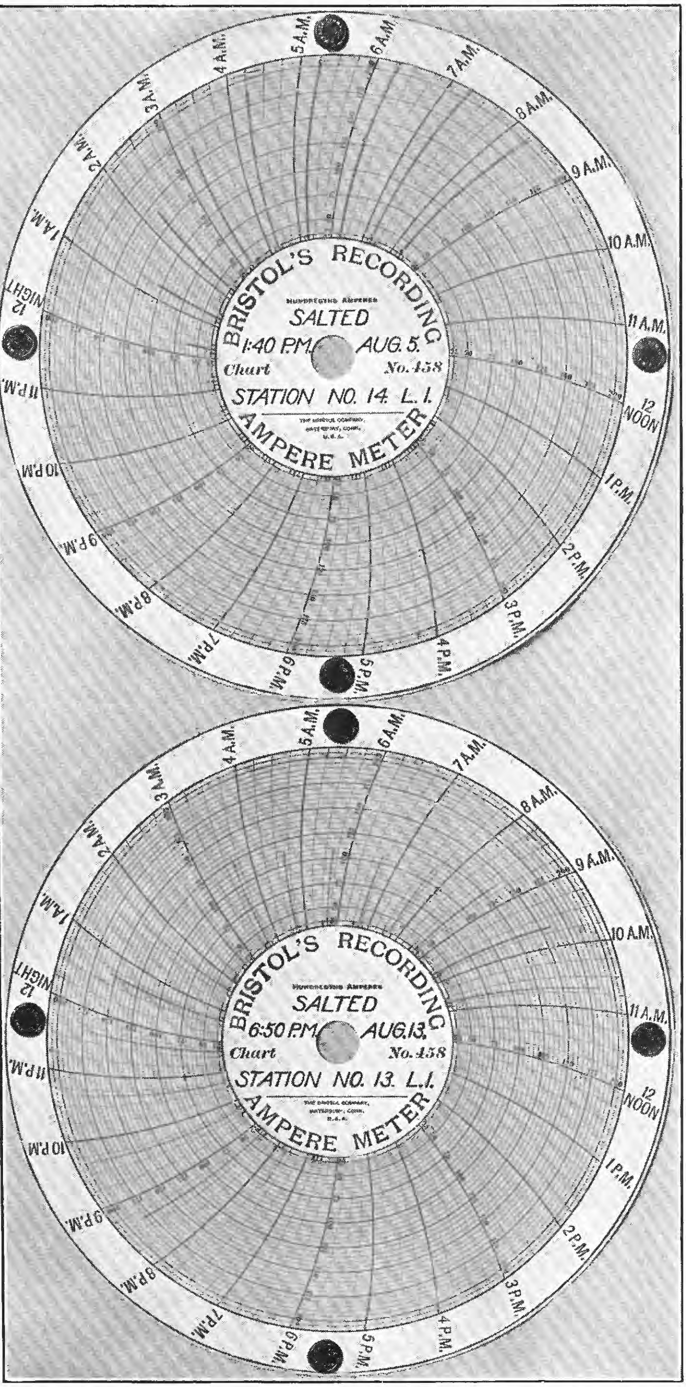
The methods of wiring the wells when the recording instruments are used is slightly changed. In this case one side of the battery circuit is connected to casing of well A and to all of the electrodes of wells B, C, and D. The other side of the battery is run through the recording ammeter to a commutator clock, which once every hour makes a contact and completes the circuit, one after the other, to a series of binding posts. One of these binding posts is connected to the casing of well B, one to the casing of well C, and one to the casing of well D. The time of contact is ten seconds, which gives an abundance of time for the pen to reach its proper position and to properly ink its record.

Pl. II, *B*, and Pl. III, *A*, show two commutator clocks made for this purpose by the instrument maker of the College of Engineering, University of Wisconsin. The clock movement is a standard movement of fair grade, costing about $5. It can readily be taken from the case for cleaning or oiling and replaced. A seven-day marine movement, with powerful springs, is best for this purpose.

It will be seen from the method of wiring the wells that the record will show the sum of the current between well A and well B added to the current between the casing of well B and its electrode. The removal of the connection to well A would permit the record to show the current between the casing of a downstream well and its electrode, but the connection to the upstream well involves no additional trouble, and occasionally its indications are of much service, especially if the velocities are low.

All of the instruments above mentioned can be placed in a common box 16 by 22 by 36 inches, covered with tar paper and locked up. Pl. III, *B*, shows a photograph of the instruments thus arranged. The shelf contains the recording ammeter (shown at left of cut) and the commutator clock (shown at right of cut).

The contacts on the commutator clock are arranged about five minutes apart, so that the record made for the wells will appear on the chart as a group of lines, one for each downstream well, of length corresponding to the strength of the current. The increasing current corresponding to one of the wells will finally be indicated by the lengthening of the record lines for that well. This can be seen by



CHARTS MADE BY RECORDING AMMETER.

consulting the photographs of records shown in Pl. IV. In the upper chart the electrical current for wells B, C, and D at station 14, Long Island, is recorded, in the order named, at 2.10, 2.15, and 2.20 p. m., and hourly thereafter, the current remaining nearly constant at twenty-two to twenty-four hundredths ampere until 10.15 p. m., when the current for well C rises as indicated in the chart. In the lower chart the electrical current for wells B, C, and D is recorded, in the order named, at 6.30, 6.35, and 6.40 p. m., and hourly thereafter. The current for wells B and D remains constant at twenty-five hundredths ampere, but the current for well C is seen to rise as shown in the chart. The record charts are printed in light-green ink, and red ink is used in the recording pen, so that record lines can be readily distinguished when superimposed upon the lines of the chart. A special chart has been designed for this work and is furnished by the Bristol Company as chart 458.

The recording instruments in use have given perfect satisfaction, and the method is a great improvement in accuracy and convenience over the direct-reading method. The highest, as well as the lowest, ground-water velocities yet found have been successfully measured by the recording instruments. By using one or two additional dry cells the instrument may be made quite as sensitive as the direct-reading type.

In using the recording instruments, but a single dose of salt need be placed in the upstream well. If the wells are deep it is important to use enough salt solution to make sure that the salt reaches as far down as the screen of the well point immediately after the solution is poured into the well. A gallon of solution will fill about 6 feet of full weight wrought-iron pipe, so that 10 gallons of solution should be used if the well is 60 feet deep. If the proper amount of solution be not used it will take an appreciable time for the solution to reach the bottom of the well by convection currents, and the results will be vitiated to that extent. As before stated, it is preferable to introduce granulated sal ammoniac into the well in a suitable bucket, in case the depth of the well renders the use of a solution uncertain.

If the ground water runs high in the quantity of total dissolved solids, say more than 100 parts per 100,000 total solids, it is important to run the electric current through the apparatus in a particular direction so as to reduce polarization and lessen the deposit of material upon the electrode. This is accomplished by arranging the batteries so that the positive or carbon pole is connected to the internal electrodes in the downstream wells. The well casings form in this case the negative or other end of the battery circuit, and the available surface is so much greater than it would be if the internal electrodes formed this end of the circuit that little trouble from polarization or falling off of current need be experienced.

THE CALIFORNIA OR "STOVEPIPE" METHOD OF WELL CONSTRUCTION.

By Charles S. Slichter.

INTRODUCTION.

The peculiar conditions of water supply existing in southern California have led to the development of a special type of well which the writer believes to be admirably adapted to conditions found in many places in the eastern part of the United States, especially on Long Island and in the Coastal Plain region of the Atlantic States. It is with the object of calling attention to the importance of this method, by which a large number of water-bearing beds can be drawn upon simultaneously, that the many points of excellence of the California type of wells and methods of well construction are pointed out. In addition to the illustrations accompanying this paper, a number of others showing the rigs, casing, and other appliances used in connection with wells in southern California may be found in the issue of the Engineering News for November 19, 1903.

CONDITIONS IN CALIFORNIA.

The valleys in southern California are filled with deposits of mountain débris, gravels, sands, bowlders, clays, etc., to a depth of several hundred feet, into which a considerable part of the run-off of the mountains sinks. The development of irrigation upon these valleys soon became so extensive that it was necessary to supplement more and more the perennial flow of the canyon streams by ground water drawn from wells in the gravels. This necessity was greatly accentuated by a series of dry years, so that ground waters became a most valuable source of auxiliary supply for irrigation in the important citrus areas in southern California. The type of well that came to the front and developed under these circumstances is locally known as the "stovepipe" well. It seems to suit admirably the conditions prevailing in southern California. In procuring water for irrigation the item of cost is, of course, much more strongly emphasized than in obtaining water for municipal use. The drillers of wells in California were not only confronted with a material which is almost everywhere full of bowlders and similar mountain débris, but also by a high cost of labor and of well casings. It was, undoubtedly, these difficulties that led to the very general adoption in California of the "stovepipe" well.

DESCRIPTION OF APPARATUS AND METHODS.

The wells are put down in the gravel and bowlder mountain outwash or other unconsolidated material to any of the depths common in other localities. One string of casing in favorable location has been put down over 1,300 feet. The usual sizes of casings are 7, 10, 12, and 14 inches, or even larger. A common size is 12 inches. The well casing consists of, first, a riveted sheet-steel "starter," from 15 to 25 feet long, made of two or three thicknesses of No. 10 sheet steel, with a forged steel shoe at lower end. In ground where large bowlders are encountered these starters are made heavier, the shoe 1 inch thick and 12 inches deep, and three-ply instead of two-ply No. 10 sheet-steel body.

The rest of the well casing, above the starter, consists of two thicknesses of No. 12 sheet steel made into riveted lengths, each 2 feet long. One set of sections is made just enough smaller than the other to permit them to telescope together. Each outside section overlaps the inside section 1 foot, so that a smooth surface results both outside and inside of the well when the casing is in place, and so that the break in the joint is always opposite the middle of a 2-foot length. It is these short overlapping sections which are popularly known as "stovepiping."

The casing is sunk by large steam machinery of the usual oil-well type, but with certain very important modifications. In ordinary material the "sand pump" or "sand bucket" is relied upon to loosen and remove the material from the inside of the casing. The casing itself is forced down, length by length, by hydraulic jacks, buried in the ground and anchored to two timbers 14 by 14 inches and 16 feet long, which are planked over and buried in 9 or 10 feet of soil. These jacks press upon the upper sections of the stovepiping by means of a suitable head. The driller, who stands at the front of the rig, has complete control of the engine, the hydraulic pump, and the valves by which pistons are moved up or down, and also of the lever that controls the two clutches which cause tools to work up and down or to be hoisted.

The sand pumps used are usually large and heavy. For 12-inch work they vary in length from 12 to 16 feet, are $10\frac{5}{8}$ inches in diameter, and weigh, with lower half of jars, from 1,100 to 1,400 pounds.

After the well has been forced to the required depth, a cutting knife is lowered into the well and vertical slits are cut in the casing where desired. A record of material encountered in digging the well is kept and the perforations are made opposite such water-bearing materials as may be most advantageously drawn upon. A well 500 feet deep may have 400 feet of screen, if circumstances justify it.

The perforator (see fig. 9) for slitting stovepipe casing is handled with 3-inch standard pipe with three-fourths-inch standard pipe on the inside. In going down or in coming out of the well the weight of the three-fourths-inch line holds the point of the knife up. When ready to "stick" the three-fourths-inch line is raised. By raising slowly on the 3-inch line with hydraulic jacks, cuts are made from three-eighths to three-fourths inch wide and from 6 to 12 inches long, according to the material at that particular depth. In another type of perforating apparatus (fig. 10) a revolving cutter punches fine holes at each revolution of the wheel. This style of perforator is called a "rolling knife." Besides these many other different kinds of perforators are in use in California. In fact, the perforator is a favorite hobby of the local inventors. They all seem to work well.

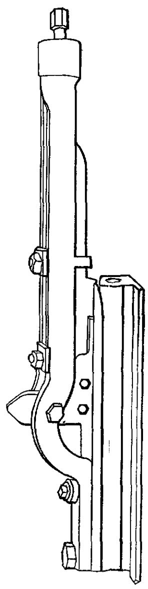


FIG. 9.—Perforator for slitting stovepipe casing.

ADVANTAGES OF CALIFORNIA METHOD.

The advantages of this method of well construction are quite obvious. For wells in unconsolidated material, the California type is undoubtedly the best yet devised. I believe that wells of this type would be highly successful in the unconsolidated coastal deposits on Long Island, in New Jersey, and at similar localities. The absence of bowlders and very coarse gravels in those deposits might possibly make it more advantageous to use the hydraulic jet instead of the ponderous sand bucket in soft material, but this is the only modification that Eastern conditions seem to suggest.

Among the special advantages in the stovepipe construction we may enumerate the following:

1. The absence of screw joints liable to break and give out.
2. The flush outer surface of the casing, without couplings to catch on bowlders or to hang in clay.
3. The elastic character of the casing, permitting it to adjust itself in direction and otherwise to dangerous stresses, to obstacles, etc.
4. The absence of screen or perforation in any part of the casing when first put down, permitting the easy use of sand pump and the penetration of quicksand, etc., without loss of well.
5. The cheapness of large-size casings, because made of riveted sheet steel.
6. The advantage of short sections, permitting use of hydraulic jacks in forcing casing through the ground.

7. The ability to perforate the casing at any level at pleasure is a decided advantage over other construction. Deep wells with much screen may thus be heavily drawn upon with little loss of suction head.

8. The character of the perforations made by the cutting knife are the best possible for the delivery of water and avoidance of clogging. The large side of the perforation is inward, so that the casing is not likely to clog with silt and débris.

9. The large size of casing possible in this system permits a well to be put down in bowlder wash where a common well could not possibly be driven.

10. The uniform pressure produced by the hydraulic jacks is a great advantage in safety and in convenience and speed over any system relying upon driving the casing by a weight or ram.

11. The cost of construction is kept at a minimum by the limited amount of labor required to man the rig, as well as by the good rate of progress possible in what would be considered in many places impossible material to drive in, and by the cheap form of casing.

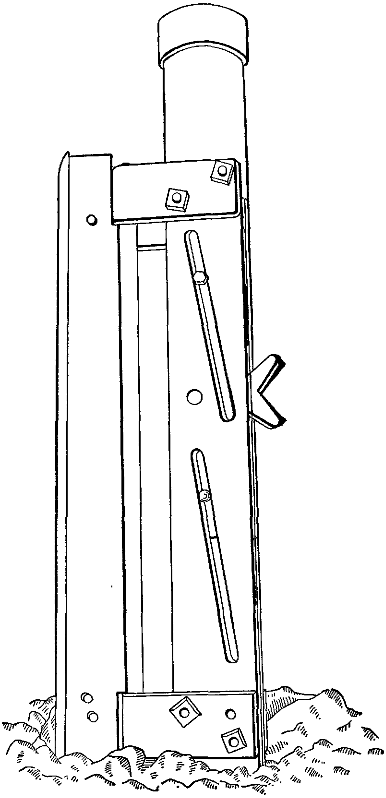


FIG. 10.—Roller type of perforator.

COST OF THE WELLS.

An idea of the cost of constructing these wells can best be given by quoting actual prices on some recent construction in California. According to contracts recently let near Los Angeles, the cost of 12-inch wells was:

Fifty cents per foot for the first 100 feet, and 25 cents additional per foot for each succeeding 50 feet, casing to be furnished by the well owner. This makes the cost of a 500-foot well $700 in addition to casing. The usual type of No. 12 gauge, double stovepipe casing, is about $1.05 a foot, with $40 for 12-foot starter with three-quarter inch by 8-inch steel ring. A good driller gets $5 a day; helpers, $2.50 a day. The cost of drilling runs higher than that given above in localities where large and numerous bowlders are encountered.

The drillers build their own rigs according to their own ideas, so that no two rigs are exactly alike; that is, the drillers pick out the castings and working parts and mount them according to ideas that experience has taught them are the best for the wash formations in which they must work. Fig. 11 shows a common form of rig.

It is not very profitable to name individual wells of this type and give their flow or yield, since conditions vary so much from place to place. From the method of construction it must be evident that this type of well is designed to give the very maximum yield, as every water-bearing stratum may be drawn upon. The yield from a number of wells in California of average depth of about 250 feet, pumped by centrifugal pumps, varied from about 25 to 150 miners' inches, or

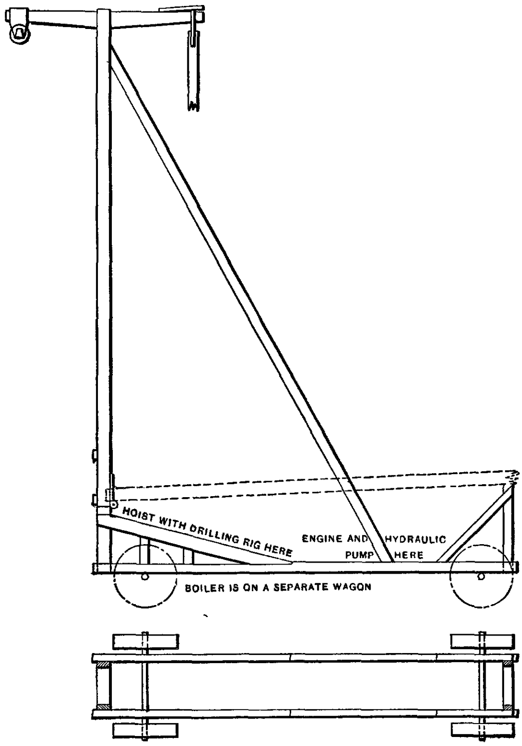


FIG. 11.—Common form of California well rig.

from 300,000 to 2,000,000 gallons a day. These are actual measured yields of water supplied for irrigation.

Among the very best flowing wells in southern California are those near Long Beach. The Boughton well, the Bixby wells, and the wells of the Sea Side Water Company are 12-inch wells, varying in depth from 500 to 700 feet and flowing about 250 miners' inches each, or over 3,000,000 gallons per twenty-four hours. The flow of one of these wells is the greatest I have seen reported. Among the records for depth are those of 1,360 feet for a 10-inch well, and 915 feet for a 12-inch well. A new 14-inch well has already reached a depth of 704 feet.

APPROXIMATE METHODS OF MEASURING THE YIELD OF FLOWING WELLS.

By Charles S. Slichter.

Tables for determining the discharge of water from completely filled vertical and horizontal pipes were prepared a number of years ago by Prof. J. E. Todd, State geologist of South Dakota, who issued a private bulletin describing simple methods of determining quickly, with fair accuracy and with little trouble, the yield of artesian wells. In the following notes the tables and explanations relating to vertical and horizontal pipes are taken from this bulletin. The explanations and tables relating to the measurement in the partially filled horizontal and inclined pipes have been appended by the present writer.

MEASUREMENT OF FLOWS FROM FILLED PIPES.

In determining the flow of water discharged through a pipe of uniform diameter all that is necessary is a foot rule, still air, and care in taking measurements. Two methods are proposed, one for pipes discharging vertically, which is particularly applicable before the well is permanently finished, and one for horizontal discharge, which is the most usual way of finishing a well.

The table on page 39 is adapted to wells of moderate size as well as to large wells. In case the well is of other diameter than given in the table its discharge can without much difficulty be obtained from the table by remembering that, other things being equal, the discharge varies as the square of the diameter of the pipe. If, for example, the pipe is one-half inch in diameter its discharge will be one-fourth of that of a pipe 1 inch in diameter for a stream of the same height. In a similar manner the discharge of a pipe 8 inches in diameter can be obtained by multiplying the discharge of the 4-inch pipe by 4.

In the first method the inside diameter of the pipe should first be measured, then the distance from the end of the pipe to the highest point of the dome of the water above, in a strictly vertical direction—*a* to *b* in the diagram, fig. 12. Find these distances in Table I (A), and the corresponding figure will give the number of gallons discharged each minute. Wind would not interfere in this case, so long as the measurements are taken vertically.

The method for determining the discharge of horizontal pipes requires a little more care. First, measure the diameter of the pipe, as before, then the vertical distance from the center of the opening of the pipe, or some convenient point corresponding to it on the side of the pipe, vertically downward 6 inches, *a* to *b* of the diagram, then from this point strictly horizontally to the center of the stream, *b* to *e*. With these data the flow in gallons per minute can be obtained from Table I (B). It will readily be seen that a slight error may make much difference in the discharge. Care must be taken to measure horizontally and also to the center of the stream. Because of this difficulty it is desirable to check the first determination by a second. For this purpose columns are given in the tables for corresponding measurements 12 inches below the center of the pipe. Of course the discharge from the same pipe should be the same in the two measurements

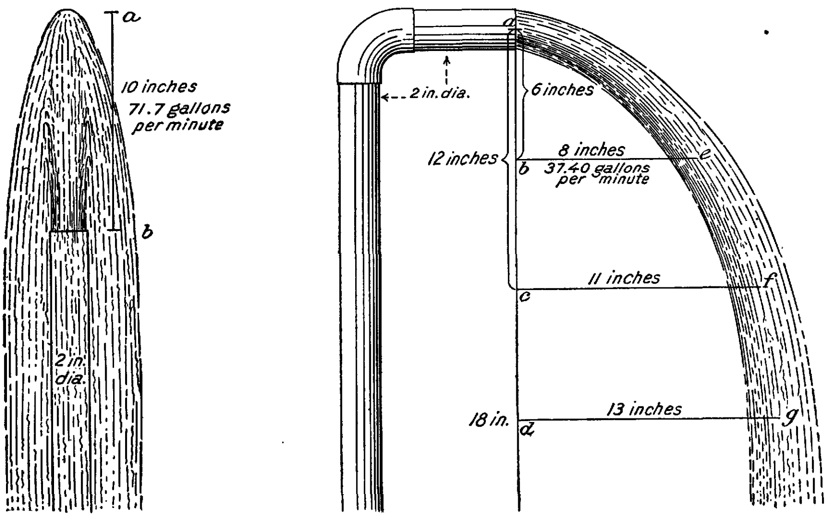


FIG. 12.—Diagram illustrating flow from vertical and horizontal pipes.

of the same stream. Wind blowing either with or against the water may vitiate results to an indefinite amount; therefore measurements should be taken while the air is still.

Whenever fractions occur in the height or horizontal distance of the stream, the number of gallons can be obtained by apportioning the difference between the readings in the table for the nearest whole numbers, according to the size of the fraction. For example, if the distance from the top of the pipe to the top of the stream in the first case is 9⅓ inches, one-third of the difference between the reading in the table for 9 and 10 inches must be added to the former to give the correct result.

In case one measures the flow of a well by both methods he may think that the results should agree, but such is not the case. In the vertical discharge, there being less friction, the flow will be larger; so also in the second method differences will be found according to the length of the horizontal pipe used.

As pipes are occasionally at an angle, it is well to know that the second method can be applied to them if the first measurement is taken strictly vertically from the center of the opening, and the second measurement from that point parallel with the axis of the pipe to the center of the stream, as before. The measurements can then be read from the table.

TABLE I.—*For determining yield of artesian wells.*

[In gallons per minute.]

A. Flow from vertical pipes.						B. Flow from horizontal pipes.				
Height of jet.	Diameter of pipe in inches.					Horizontal length of jet.	1-inch pipe.		2-inch pipe.	
	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	3		6-inch level.	12-inch level.	6-inch level.	12-inch level.
Ins.						*Ins.*				
$\frac{1}{2}$	3.96	6.2	8.91	15.8	35.6	6	7.01	4.95	27.71	19.63
1	5.60	8.7	12.6	22.4	51.4	7	8.18	5.77	32.33	22.90
2	7.99	12.5	18.0	32.0	71.9	8	9.35	6.60	36.94	26.18
3	9.81	15.3	22.1	39.2	88.3	9	10.51	7.42	41.56	29.45
4	11.33	17.7	25.5	45.3	102.0	10	11.68	8.25	46.18	32.72
5	12.68	19.8	28.5	50.7	113.8	11	12.85	9.08	50.80	35.99
6	13.88	21.7	31.2	55.5	124.9	12	14.02	9.91	55.42	39.26
7	14.96	23.6	33.7	59.8	134.9	13	15.19	10.73	60.03	42.54
8	16.00	25.1	36.0	64.0	144.1	14	16.36	11.56	64.65	45.81
9	17.01	26.6	38.3	68.0	153.1	15	17.53	12.38	69.27	49.08
10	17.93	28.1	40.3	71.6	161.3	16	18.70	13.21	73.89	52.35
11	18.80	29.5	42.3	75.2	169.3	17	19.87	14.04	78.51	55.62
12	19.65	30.7	44.2	78.6	176.9	18	21.04	14.86	83.12	58.90
13	20.46	31.8	45.9	81.8	184.1	19	22.21	15.69	87.74	62.17
14	21.22	33.0	47.6	84.9	190.9	20	23.37	16.51	92.36	65.44
15	21.95	34.2	49.3	87.8	197.5	21	24.54	17.34	96.98	68.71
16	22.67	35.2	50.9	90.7	203.9	22	25.71	18.17	101.60	71.98
17	23.37	36.3	52.5	93.5	210.3	23	26.88	18.99	106.21	75.26
18	24.06	37.5	54.1	96.2	216.5	24	28.04	19.82	110.83	78.53
19	24.72	38.6	55.6	98.9	222.5	25	29.11	20.64	115.45	81.80
20	25.37	39.6	57.0	101.6	228.5	26	30.38	21.47	120.07	85.07
21	26.02	40.6	58.4	104.2	234.3	27	31.55	22.29	124.69	88.34
22	26.66	41.6	59.9	106.7	240.0	28	32.72	23.12	129.30	91.62
23	27.28	42.6	61.4	109.2	245.6	29	33.89	23.95	133.92	94.89
24	27.90	43.5	62.8	111.6	251.1	30	35.06	24.77	138.54	98.16
25	28.49	44.4	64.1	114.0	256.4	31	36.23	25.59	143.16	101.43
26	29.05	45.3	65.3	116.2	261.4	32	37.40	26.42	147.78	104.70

TABLE I.—*For determining yield of artesian wells*—Continued.

A. Flow from vertical pipes.						B. Flow from horizontal pipes.				
Height of jet.	Diameter of pipe in inches.					Horizontal length of jet.	1-inch pipe.		2-inch pipe.	
	1	1¼	1½	2	3		6-inch level.	12-inch level.	6-inch level.	12-inch level.
Ins.						*Ins.*				
27	29.59	46.1	66.4	118.2	266.1	33	38.57	27.25	152.39	107.98
28	30.08	46.9	67.5	120.3	270.4	34	39.64	28.08	157.01	111.25
29	30.55	47.5	68.5	121.9	274.1	35	40.45	28.64	161.63	114.52
30	30.94	48.2	69.4	123.4	277.6	36	41.60	29.46	166.25	117.79
36	34.1	53.2	76.7	136.3	306.6					
48	39.1	61.0	88.0	156.5	352.1					
60	43.8	68.4	98.6	175.2	394.3					
72	48.2	75.2	108.0	192.9	434.0					
84	51.9	81.0	116.8	207.6	467.0	Continue by adding for each inch—				
96	55.6	86.7	125.0	222.2	500.0					
108	58.9	92.0	132.6	235.9	530.8					
120	62.2	98.0	139.9	248.7	559.5					
132	65.1	102.6	146.5	260.4	585.9		1.15	0.82	4.62	3.27
144	68.0	106.4	153.1	272.2	612.5					

NOTE.—To convert results into cubic feet, divide the number of gallons by 7.5, or, more accurately, by 7.48.

The flow in pipes of diameters not given in the table can easily be obtained in the following manner:

For ½-inch pipe, multiply discharge of 1-inch pipe by 0.25
For ¾-inch pipe, multiply discharge of 1-inch pipe by 0.56
For 1¼-inch pipe, multiply discharge of 1-inch pipe by 1.56
For 1½-inch pipe, multiply discharge of 1-inch pipe by 2.25
For 3-inch pipe, multiply discharge of 2-inch pipe by 2.25
For 4-inch pipe, multiply discharge of 2-inch pipe by 4.00
For 4½-inch pipe, multiply discharge of 2-inch pipe by 5.06
For 5-inch pipe, multiply discharge of 2-inch pipe by 6.25
For 6-inch pipe, multiply discharge of 2-inch pipe by 9.00
For 8-inch pipe, multiply discharge of 2-inch pipe by 16.00

MEASUREMENT OF FLOWS FROM PARTLY FILLED PIPES.

From Table II, given below, it should be possible, if the wind is not blowing too hard, to determine the flow with an error probably not exceeding 10 per cent. This error is no greater than the fluctuation of the flow due to the daily variations of the barometric pressure in the case of most wells. The results in extreme cases, such as a one-fourth inch stream in a 6-inch pipe, are, of course, still less accurate, and actual measurement by collecting the water in a vessel of definite capacity should be resorted to if possible.

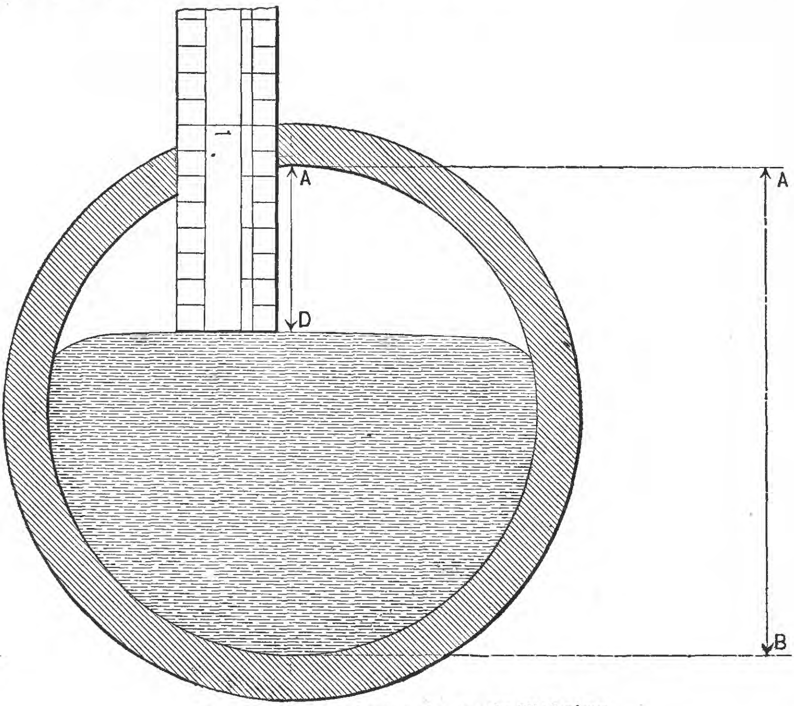


FIG. 13.—Method of measuring partly filled pipes.

TABLE II.—*For estimating the discharge from partly filled horizontal or sloping pipes.*

Fractional part of diameter of pipe not occupied by water. [Obtained by dividing A D by A B in fig. 1.]	Discharge expressed as percentage of discharge from full pipe, same size.	Fractional part of diameter of pipe not occupied by water. [Obtained by dividing A D by A B in fig. 1.]	Discharge expressed as percentage of discharge from full pipe, same size.
0.05	0.98	0.55	0.44
.10	.95	.60	.37
.15	.91	.65	.31
.20	.86	.70	.25
.25	.80	.75	.20
.30	.75	.80	.14
.35	.69	.85	.092
.40	.63	.90	.054
.45	.55	.95	.015
.50	.50	1.00	.000

To estimate discharge from partly filled horizontal or sloping pipe, first estimate discharge from full pipe of same size by means of Table I.

Next measure with a foot rule the dimension A D (see fig. 13) of the empty portion of cross section of the pipe. Divide this by the inside diameter of the pipe, which will give the fractional part of the diameter that is occupied by the empty part of pipe. In Table II find in the first column the number nearest to the above quotient. Opposite this number will be found the per cent of discharge of full pipe which the partially filled pipe is yielding. It is sufficient to measure the distance A D to the nearest eighth of an inch, or at most to the nearest sixteenth of an inch.

EXAMPLE.

Suppose that a 2-inch horizontal pipe has a length of jet of 13 inches at 6-inch level. From Table I this would represent a discharge of 60 gallons per minute from full pipe. Suppose that the distance A D is five-eighths of an inch and A B is 2 inches, or sixteen-eighths of an inch. Dividing 5 by 16 gives 0.31. In the first column of Table II we find 0.30, the nearest to 0.31, and opposite 0.30 in the second column of the table appears 0.75. The discharge from the partly filled pipe is therefore $60 \times 0.75 = 45$ gallons per minute.

CORRECTIONS NECESSARY IN ACCURATE DETERMINATIONS OF FLOW FROM VERTICAL WELL CASINGS.

From notes furnished by A. N. TALBOT.

The method described by Professor Todd is based on certain assumed theoretical conditions. While the error resulting from the method of measurement is usually less than 10 per cent, and while it is of great value in approximate field determinations, certain corrections must be made in order to exactly determine the amount of flow.

The considerations to be taken into account are that in vertical pipes the water will not rise to the height of its full velocity head and that the velocity is not uniformly distributed over the cross section. For velocity heads equal to the diameter of the pipe up to a height of 10 feet this discrepancy is not very great, but for lower values it is considerable. Fig. 15 shows the coefficients for 2-inch, 4-inch, and 6-inch pipes from low heads up to heads of 2 to 3 feet. These range from 0.80 to 0.96. The values above this, until atmospheric resistance becomes great, will not be much different. The quantities found by Professor Todd's table should be multiplied by these coefficients. These values

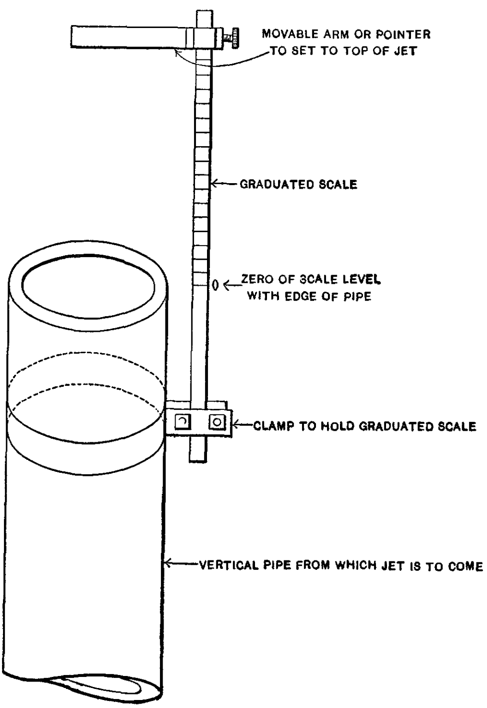


FIG. 14.—Sketch showing application of movable pointer and scale in measuring jets.

are fixed on the assumption that the height of water may be determined by finding the distance from the end of the pipe to the highest point

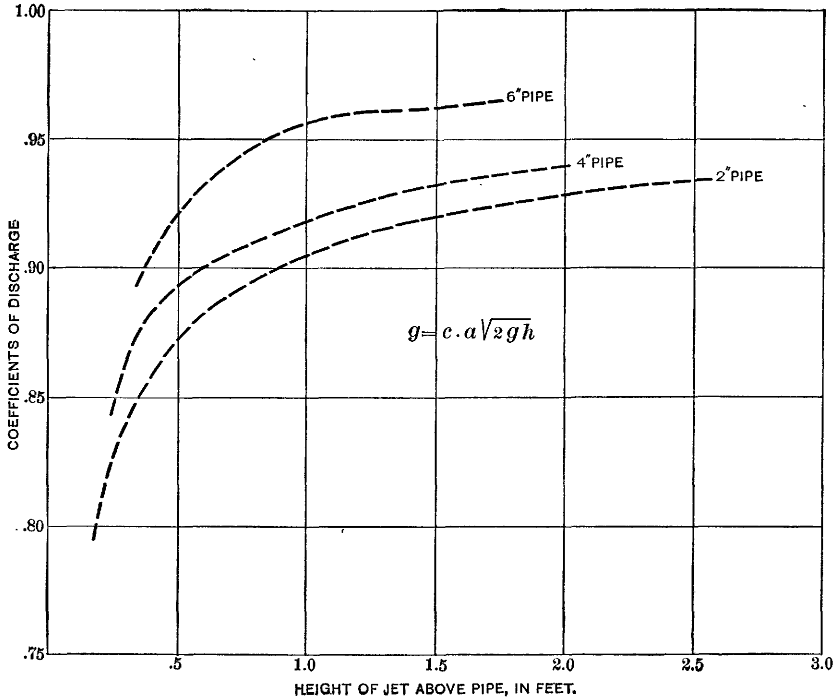


FIG. 15.—Coefficients of discharge for high and low heads.

of the jet by means of a movable pointer and scale, as shown in fig. 14, or by some similar device.

EXPERIMENT RELATING TO PROBLEMS OF WELL CONTAMINATION AT QUITMAN, GA.

By S. W. McCallie.

INTRODUCTION.

During the summer of 1903, a boring for a deep well, constructed by the town of Quitman, Ga., to improve its water supply, penetrated, at a depth of 123 feet from the surface, in limestone, what appeared to be a cavity 6¾ feet deep. Immediately after the cavity had been penetrated by the drill the water rose to within 77 feet of the surface, at which point it remained. In extending the bore hole beyond this depth it was found that all of the water forced into the well to carry out the drillings, and also the drillings themselves, appeared to pass off by the cavity. It was further discovered that any quantity of water, however great, that was forced into the bore hole, did not raise the level of the water in the well above 77 feet, and, on the other hand, that continuous pumping was equally ineffective in lowering the level.

After the sinking of the well to a second water-bearing stratum, at a depth of 321 feet, another well was constructed with a view of testing more fully the water-carrying capacity of the underground cavity, which was supposed to be a channel of a large subterranean stream. The second well, 6 inches in diameter, was put down a few hundred yards southwest of the first well, and only a few feet from the margin of Russell Pond, a small body of stagnant water occupying a nearly circular depression having the appearance of a partially filled lime sink. This well having been extended to the cavernous limestone, a canal was dug to connect it with the pond, and the water was allowed to flow from the pond into the well. The pond, which contained about one-half million gallons of water, was drained by the well in a few hours, without apparently affecting the level of the water in the bore hole, which remained constant at 77 feet from the surface. This test was conclusive to the town authorities that the underground cavity had a capacity to carry off an illimitable amount of water, and it was at once suggested that the town might be able to make use of this so-called underground stream for sewage disposal. This suggestion was soon taken up by the press of south Georgia, and within a short time Governor Terrell received a number of letters importuning him to interfere to prevent the Quitman authorities from using deep wells for sewerage purposes.

At the request of the governor, the writer, who at that time was engaged in the study of the underground waters of Georgia for the State and the United States Geological Survey, made a trip to Quitman to investigate the reports and, if they should be found true, to point out to the people of Quitman the possibility that such a sewerage system might contaminate the wells and springs in that region. When the writer arrived at Quitman he found that the town authorities were seriously considering the question of disposing of the sewage as reported. They were willing, however, to give up the idea of using the supposed underground stream for sewerage purposes if it could be shown that such use would prove injurious in any way whatever. Furthermore, they were willing to cooperate with the State and the United States surveys by paying the greater part of the expense of any experiments that might be necessary to establish this fact.

After some delay arrangements were finally made with the United States Geological Survey for conducting an experiment to determine the possibility of contamination of adjacent wells and springs, the plan adopted for this purpose being what is known as the chlorine method of tracing underground watercourses.

The well into which the chlorine (sodium chloride) was introduced in carrying out this experiment was the Russell Pond well, referred to above. The well has a depth of 120 feet, and shows the following section:

Section of well at Russell Pond, near Quitman, Ga.

	Feet.
1. Surface sand	2
2. Varicolored clay	60
3. Yellow sand	15
4. Gray sandy clay	43
5. Limestone (water bearing).	

The water, which rises to about 77 feet of the surface, comes from the cavernous limestone found in all of the deep wells of Quitman and vicinity.

GEOGRAPHY AND GEOLOGY.

Before the experiment is described in detail a few general notes will be given on the geography and geology of the region, both of which have a certain bearing on the question under consideration.

That part of south Georgia covered in conducting the Quitman experiment lies along the Georgia-Florida State line, and includes the southern part of Brooks and the adjacent portions of Thomas and Lowndes counties. This part of the State is comparatively level, but in parts of Brooks County the surface is more or less rolling, and depressions caused by lime sinks are occasionally seen. The streams, which all flow southward, are usually sluggish, and at points in their course frequently traverse cypress swamps of considerable extent.

The springs of the region are few in number, but are usually large. They are generally found in or near the larger streams, and are often submerged during the wet season.

The geology of the region is typical of the portion of south Georgia that lies along the State line west of Thomasville, and that has been described by Spencer and others. Nearly everywhere throughout the piny woods or the cultivated fields of this section is to be seen a superficial covering or veneer of fine sand, which at some points attains a thickness of 2 feet or more. This sand corresponds probably to McGee's Columbia formation, as it lies directly upon the orange and reddish Lafayette clays.

The Lafayette clays, which are well exposed in numerous cuts along the Coast Line Railroad both east and west of Quitman, are usually stratified below and massive above. On the more elevated lands they attain a thickness of many feet, but along the larger streams they have been partially or wholly removed by erosion so as to expose underlying clays which at certain points along Withlacoochee River, notably at McIntyre Spring, contain large masses of coral. These lower clays are probably Miocene, and belong, no doubt, to Langdon's Chattahoochee group.

Beneath these Miocene clays there is a thick limestone, which is the source of the water supply of all the deep wells at Quitman, Boston, and Valdosta. This limestone seems to belong to Conrad's Vicksburg group, which, according to Dall, forms the lowest member of the Oligocene beds in the southern Tertiary series. As is shown by samples of borings from deep wells, this rock is somewhat variable in character, but seems to consist largely of thick beds of comminuted shells and corals interlaminated with layers of hard, compact limestone. The upper beds of this limestone appear to be cavernous, for cavities, shown by the dropping of the drill, are frequently found in it in the deep wells throughout the region. These cavities are said to vary in depth from 3 to 9 feet, and are always filled with water having a static head that is 40 feet or more higher than the point at which the cavities are struck.

The order of occurrence and the approximate thickness of these several formations are shown in the section of the Russell Pond well, above given. The Boston and the Quitman wells also show similar sections. The dip of the formations is supposed to be toward the south at a few feet per mile.

DESCRIPTION OF EXPERIMENT.

The chlorine method of tracing underground streams, as carried out in the Quitman experiment, was adopted at the suggestion of Prof. C. S. Slichter, consulting engineer of the United States Geological Survey.

A reconnaissance topographic survey of the region surrounding Quitman was made, with the view of finding all springs and wells whose waters stood at a lower level than the water in the Russell Pond well, where the salt was to be introduced, altitudes being determined by aneroid barometer. From all such springs samples of water were collected for determination of the amount of chlorine present. Each of the springs and wells thus sampled was made a station from which, at regular intervals, samples of water were collected by observers who were advised how and when to collect samples. The various stations having been established and samples collected for the determination of the normal amount of chlorine contained in the waters, 2 tons of salt (sodium chloride) were introduced into the Russell Pond well. The salt was put into the well in the form of solution, its introduction beginning at 8 a. m. October 15, and continuing until 8 p. m. October 20. The first ton of salt put into the well was introduced continuously for twelve hours at the rate of 166⅔ pounds an hour, while the second ton was put into the well continuously for one hundred and twenty hours, or five days, at the rate of 16⅔ pounds an hour.

In order to introduce the salt into the well at the above rate and also to insure as complete saturation of the water as possible, five 50-gallon barrels were set about 20 inches apart upon a level platform at the well and connected with one another by pieces of 2-inch iron pipe, firmly screwed into the barrels by right and left screws cut on their opposite ends. The iron pipe was inserted into the barrel nearest the well about 2 inches from the bottom, while the pipe between each succeeding barrel was elevated about 4 inches, so that the one uniting the last two barrels entered them about halfway up. When everything was in readiness for the experiment to begin, each barrel was filled with salt up to the point at which the outflow pipe entered it. The water was then turned into the barrel farthest from the well through a hydrant connected with the public water supply. As the water rose in this barrel to the point of entrance of the pipe it flowed into the next barrel, and so on until the entire chain of barrels was filled. The water now being more or less completely saturated, having flowed over the salt in the bottom of each barrel, was turned into the well through a stopcock so adjusted as to deliver the desired amount of water per minute. By a nice adjustment of the stopcock at the well and of that at the hydrant it was found that this plan of delivering a given amount of brine to the well in a stated time was practically automatic, the attendant having nothing to do except to keep the bottoms of the barrels supplied with salt.

DESCRIPTION OF STATIONS.

The stations from which water was collected were seven in number and are described below. Their locations are shown by the sketch map (fig. 16).

Station No. 1.—The station is the well at the public waterworks, 1,000 feet northeast of the Russell Pond well. The well is 321 feet deep and supplies the town with water. It is cased with 8-inch casing to 122 feet, only a short distance above the first water-bearing stratum. Within the 8-inch casing is inserted a 4½-inch casing which extends from the surface to a depth of 309 feet, at which point it was driven securely into a hard rock so as to form what was supposed to be a water-tight joint, cutting off all the water from the 123-foot water-bearing stratum above. The town water supply is pumped through this 4½-inch casing from the second water-bearing stratum, 311 feet below the surface. The second water-bearing stratum has a static head 2¾ feet greater than that of the first stratum. Nevertheless, it was thought that in case the 4½-inch casing was not absolutely water-tight at the point where it was driven into the rock, continuous pump-

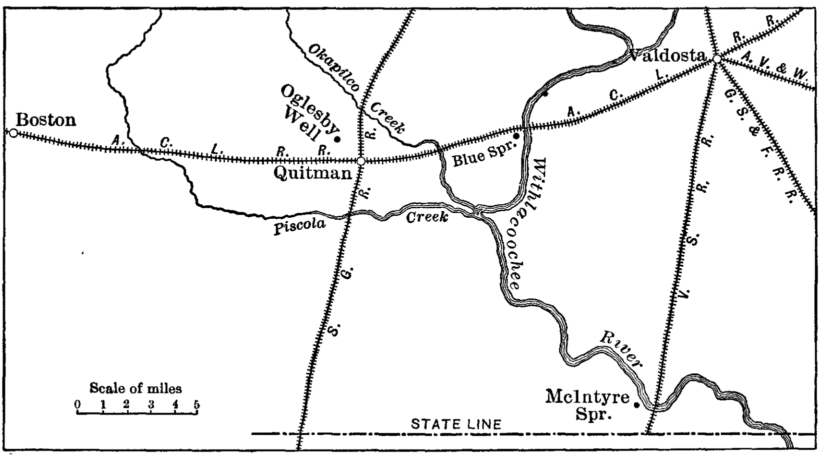


FIG. 16.—Sketch map showing location of Quitman experiment.

ing might lower the static head of the water from the second stratum sufficiently to set up a current from the stratum above, in which event sewage poured into the upper stratum would contaminate the lower.

Station No. 2.—This is the "Old City well," 1,500 feet northeast of the Russell Pond well. The well used for this station is 500 feet deep, and was completed in 1884. It was originally cased to a point some distance below the first water-bearing stratum, but its lower part becoming obstructed by sand or some other material, the 6-inch casing was burst by an explosive at the first water-bearing stratum, in order to obtain water for public use. While the experiment here reported was being carried on, this well, which had not been in use for some months, was connected with the pumps at the waterworks station, so that the water might be procured at regular intervals.

Station No. 3.—This is the Oglesby well, located at the Oglesby Mills, three-fourths of a mile northwest of Quitman. This well was completed in May, 1903, and is only 92 feet deep. It is 6 inches in diameter and is cased to 78 feet. The water-bearing stratum was struck at 87 feet, at which point, it is said, the drill dropped into a cavity 4 feet in depth and immediately thereafter the water rose to within 48 feet of the surface. It will here be noted that the water-bearing stratum in the Oglesby well is much nearer the surface than the first water-bearing stratum encountered in the wells within the corporate limits of Quitman, and also that the static head of the water is nearer the surface. This difference, however, is due entirely to the fact that the ground at this point is lower than that at neighboring wells, and not, as might be supposed, to the occurrence of a different water-bearing stratum.

Station No. 4.—This station was established at Blue Spring, near the right bank of the Withlacoochee River, 6 miles east of Quitman. By aneroid measurement the spring was found to be about on a level with the static head of the water in the Russell Pond well, so that it seemed to be a possible outlet for the supposed underground stream into which the salt was introduced. At the time the samples were collected Blue Spring was flowing about 15,000,000 gallons in twenty-four hours. It was learned, however, that at one time during an extremely dry season, several years ago, the spring entirely ceased flowing.

Station No. 5.—This is McIntyre Spring, about 15 miles southeast of Quitman, only a short distance from the Georgia-Florida State line. The spring is located partially in the Withlacoochee River and appears to furnish a much greater volume of water than Blue Spring. Owing to the great distance of this spring from Quitman it was found impracticable to determine its elevation by aneroid barometer, but judging from the fall of the river it must be several feet below Blue Spring. A flood in the river during the time the samples were being collected submerged McIntyre Spring for some time, so that only a limited number of samples were procured from this station.

Station No. 6.—This is a deep well at Boston, Thomas County, 14 miles west of Quitman. The Boston well has a depth of 290 feet and was completed in June, 1900. It is reported that three water-bearing strata were penetrated in this well, at 120, 160, and 286 feet. The static head of the water in the third water-bearing stratum is said to be 69 feet above sea level, which is 70 feet below the static head of the water in the Russell Pond well.

Station No. 7.—This station is one of the deep wells at Valdosta, 17 miles east of Quitman. The well from which the samples were taken at Valdosta was the 8-inch well, now used to supply the city waterworks. This well is 500 feet deep, but its main water supply is said to come from a stratum at a depth of 260 feet, where the drill is reported to have entered a cavity 4 feet in depth. The static head of the water now in this well is 105 feet above sea level, which is 24 feet below the static head of the water in the Russell Pond well.

Additional station.—In addition to the stations here described there was also one kept up for a short time at the Quitman cotton factory; but, as the well was afterwards found not to be of sufficient depth to reach the water-bearing stratum into which the salt was introduced, it has been omitted in the tables and on the diagrams showing the variation of chlorine in the samples of water collected at the various stations.

SAMPLES OF WATER TAKEN.

The time at which the samples of water were taken at each station, the intervals between samples, and the number of samples themselves are shown in the following table:

Place, time, and number of samples of water taken.

Stations.	Date of first sample.	Interval between samples.	No.
		Hours.	
No. 1	Oct. 15, 12 noon	4	36
No. 2	do	4	31
No. 3	Oct. 15, 4 p. m.	8	30
No. 4	Oct. 16, 6 a. m.	12	40
No. 5	Oct. 19, 6 a. m.	24	[a] 11
No. 6	Oct. 19, 8 a. m.	24	[b] 16
No. 7	do	24	31

[a] Full number of samples not collected on account of high water.
[b] Fourteen samples lost by breakage in shipment.

CORRELATION OF WATER-BEARING STRATA.

In regard to the different water-bearing strata above noted in the Valdosta and Boston wells it might be stated that it was found impossible, with the meager data at hand, to correlate any of them with the water-bearing stratum in the Russell Pond well. In the absence of other data, an attempt was made to correlate the strata by means of chemical analyses of the water, but the results were unsatisfactory.

While it does not seem possible at present to correlate any of the strata with the Quitman stratum, into which the salt was introduced, there is but little doubt that they all occur in the Vicksburg limestone. Furthermore, as previously noted, the static head of the water in the Valdosta and Boston wells is greater than the static head of the water in the Quitman well by 24 and 69 feet, respectively. This would seem to indicate that the water-bearing strata are not continuous throughout the entire region, or that there is a flow converging toward Quitman, a condition not probable.

RESULTS.

Station No. 1.—The normal chlorine in the waterworks well was determined as 5.44 parts per 1,000,000. Four hours after the introduction of the salt in the Russell Pond well the amount of chlorine in the water, as shown by the samples, began to increase, reaching a maximum of 6.80 at 8 p. m. October 15, or twelve hours after the introduction of the salt. From this time on the water continued to show excess of chlorine in varying quantities for about five days, or as long as the salt water was poured in at the other well, finally subsiding to its normal amount on October 21.

Station No. 2.—The normal chlorine in the old Waterworks well appears to be 5.44, although a sample taken just before the experiment showed 6.12. The chlorine content of the water of this well began to rise within four hours after the insertion of the salt, reaching a maximum of 6.97 at 8 p. m. on October 15, from which time it gradually declined, with several fluctuations, until 8 p. m. October 19, after which it remained constant until October 21, at its normal amount.

Station No. 3.—The normal chlorine in the Oglesby well is 5.44. The water of this well was examined at intervals from October 15 to October 29. From October 15 to October 21 there were some fluctuations in the amount of chlorine, which, however, appear to have no relation to the introduction of the salt in the Russell Pond well. At 12 p. m. on October 21 a decided rise was noticed, which continued until 4 p. m. October 22, when it reached a maximum of 6.46. It remained at this point until 12 p. m. of the same day, after which it declined gradually, though with some fluctuations, until 12 p. m. October 26, when the normal was again reached.

Station No. 4.—The normal chlorine at Blue Spring appears to be 5.78 parts per 1,000,000. Tests were conducted from October 16 to November 4, but no variations in the amount of chlorine which could be attributed to the salt inserted at Quitman were observed.

Station No. 5.—The normal chlorine at McIntyre Spring is 5.78, the same as at Blue Spring. Samples were taken from October 19 to November 6, but no variations in the amount of chlorine referable to the introduction of salt at Quitman were noted.

Station No. 6.—The normal chlorine in the Boston well appears to be 6.80, and no persistent variations were observed during the interval from October 19 to November 24.

Station No. 7.—The normal chlorine in the Valdosta well is 5.44. No variations due to the insertion of salt at Quitman were noted.

From the preceding it will be noted that only three stations—namely, the Waterworks well, the Old City well, and the Oglesby well—show variations which can with any degree of certainty be attributed to the effect of salt introduced in the Russell Pond well. It will be observed that the maximum amount of chlorine in the two wells first named occurred at 8 p. m. October 15, just twelve hours after the first introduction of salt into the well. As both of these wells are within a short distance of the Russell Pond well, this result would naturally be expected; yet at the same time it is difficult to explain how the salt made its appearance in the Waterworks well, as it obtains its supply from a water-bearing stratum that lies 200 feet below the one into which the salt was introduced. It was surmised that the casing cutting off the upper water-bearing stratum from the one below did not form a water-tight joint at the point where it was driven into the rock, but allowed the water to flow downward when the pump was in action. In order to determine whether this supposition was true or not, the following test was made: The pump was started and run for a few minutes when a sample of the water was taken to determine the normal amount of chlorin present. There was then introduced through the 8-inch casing into the upper water-bearing stratum 15 pounds of salt in solution, and the pump was again started and run continuously for a half hour. During the time the pump was in operation samples were taken every five minutes. Analyses of these samples showed no increase of chlorine, demonstrating that the salt had not reached the second water-bearing stratum by the way of the suspected joint at the lower end of the 4½-inch casing elsewhere described. This test seemed to show that the chlorine in the original experiment did not reach the water in the second stratum by the way of any defect of the joint at the end of the 4½-inch casing. The test, however, can hardly be considered conclusive, owing to the small amount of salt used and the limited time the pump was operated after the salt was introduced. It is very probable that if the amount of salt had been larger and the samples had been taken at longer intervals, the presence of the salt would have been detected.

In regard to the Oglesby well it will be noticed that the salt was transmitted in a northwesterly direction, notwithstanding the fact that the general flow of underground waters of the region is supposed to be southward rather than northwestward.

In addition to the variation in the amount of chlorine here explained as probably due to the presence of the salt introduced into the Russell Pond well, there are also other variations which, with one exception, are unexplained. The exception referred to occurred at the old City Waterworks well. The diagram for this well shows that the amount of chlorine in the sample taken before the experiment was much higher than the normal. This was probably due to the presence of surface waters which had reached the water-bearing stratum below through the defective casing.

CONCLUSIONS.

From the notes above given on the Quitman experiment the following conclusions may be drawn:

1. The so-called underground stream, in the ordinary meaning of that term, does not exist in the wells investigated.

2. The water, which has a motion of probably not over 200 feet per hour, occurs in a porous, cavernous limestone, several feet in thickness.

3. Sewage introduced into the first water-bearing stratum will contaminate all of the wells in the vicinity that attain a depth of 120 feet or more.

4. The upper water-bearing stratum in the Waterworks well is not completely cut off from the water-bearing stratum below, so that the water from the lower stratum is likely to be contaminated from the stratum above.

THE NEW ARTESIAN WATER SUPPLY AT ITHACA, N. Y.

By Francis L. Whitney.

The object of this paper is to call attention to steps taken at Ithaca to obtain a pure water supply from underground sources after the pollution of the surface sources had given rise to a severe typhoid epidemic. The conditions existing at Ithaca, as regards underground waters, are probably duplicated at many points in New York, New England, and elsewhere, and attention is called to the possibility, under favorable conditions, of procuring adequate supplies, even for towns or cities of some size, from the glacial gravels of the deeply filled valleys of these regions. Such supplies may not always be available, but the possibility that they may be procured can usually be determined by a few inexpensive test wells.

FACTORS LEADING TO CHANGE OF SUPPLY.

Old water supply.—Up to the early part of 1903 the city of Ithaca obtained the larger part of its water supply from Sixmile Creek, a stream entering Cayuga Lake from the southeast at Ithaca. The pumping station was located in the outskirts of the city, on the southeast side. The creek is between 15 and 20 miles long. In general its drainage area is thinly populated, but two towns having an aggregate population of several hundred inhabitants, are located directly on the stream, which, in fact, receives all the drainage from them.

An additional water supply was obtained at Buttermilk Falls, on a small creek about 1½ miles south of Ithaca. There are very few houses in its drainage area.

Cornell University derives its supply from Fall Creek, a stream that empties into Cayuga Lake at its south end.

Typhoid epidemic.—It had long been recognized that these waters, especially that of Sixmile Creek, were liable to pollution, and precautionary systematic examinations of the water were made from time to time. These analyses were made by Prof. E. M. Chamot, of Cornell University. Some difficulty existed in the interpretation of the analyses, because of the fact that a number of flowing salt wells were tributary to the stream, so that it was not possible to determine what part, if any, of the chlorine that the water contained was due to sewage or similar pollution.

The water gave general satisfaction until about the beginning of 1903, when an exceptionally severe epidemic of typhoid fever broke out in the city. Hundreds of residents, including many students of Cornell University, were stricken, and the percentage of deaths was very high. The public was thoroughly aroused to the necessity of taking immediate and radical steps for determining the cause of the epidemic and for furnishing a new water supply, provided the source of danger was found to lie in the old supply.

It was found that the city supply from Buttermilk Falls and the college supply from Fall Creek were unpolluted. Sixmile Creek, on the contrary, was proved to be highly polluted, and it was seen that this was the probable cause of the epidemic.

Proposed dam on Sixmile Creek.—During 1902 the Waterworks Company began the erection of a high dam on Sixmile Creek, in order to provide a supplementary source of supply. The dam was designed to be 90 feet high and 100 feet wide. Many of the citizens of the town and some experts considered the dam unsafe and vigorous protests were made. The protests were, however, without result, and the company continued the work of construction. The feeling against the company became very strong and was doubtless a factor in the controversy which arose over the question of securing artesian water.

Action of water commissioners.—On February 16, 1903, the water commissioners met and discussed the feasibility of installing a filtration plant. The plan was proposed by President Schurman, of the university. Prof. E. M. Chamot testified that such a plant would not act as a perfect sterilizer, although if properly constructed and controlled it would remove 98 to 99 per cent of the bacteria. The plan received little support.

Commissioner Horton called attention to the expense of filtering and the ease with which a company can furnish, without detection, unfiltered water, and advocated artesian wells as a source of supply. It was thought that such wells could be obtained within a radius of 10 miles of the city.

It was urged by Professor Chamot that most of the artesian-well water of the locality was too hard for household purposes, but that it could be used in boilers, as attested by the fact that it had for eight years been used in those at the salt plant without bad effects. A further objection to the use of artesian wells lay in the fact that the city might be liable for damages resulting from the loss of water in adjacent wells. The drilling of test wells, the effect of which it was proposed to observe carefully, was advised as a precautionary measure.

Action of common council.—At a meeting of the common council early in the year President Schurman urged immediate efforts to obtain uncontaminated supplies, stating that it would become necessary to close the university unless a satisfactory supply was obtained by September 1, 1903. He reported that the executive committee and a number of trustees of the university had considered the advisability of sinking artesian wells, and had reported that it would probably not be possible to obtain from such wells the 2,000,000 gallons of water consumed daily by the city. In consideration of the necessity of obtaining pure supplies by September 1, it was recommended that the filtration plant be installed. This proposition was adopted by the council, but it was decided, before proceeding further, to submit the subject to the referendum of the people. A special election was ordered, to take place on March 2, to determine whether the city should undertake the ownership of its water supply. This election resulted in favor of municipal ownership.

Action of committee of one hundred.—Following the election a committee of one hundred was appointed from among the representative men of the city which agreed to subscribe to the amount of $10,000 or more toward procuring an immediate pure supply and for conducting experiments to determine the probability of a permanent supply of artesian water from the Freeville basin. The Fourth street test well, described on a subsequent page, was sunk by this committee.

FREEVILLE ARTESIAN BASIN.

The Freeville basin is a portion of the deep, gravel-filled valley of Fall Creek lying in the vicinity of Freeville, about 10 miles northeast of Ithaca. The watershed contributing to the basin covers 75 square miles, while the basin proper has an area of from 15 to 25 square miles. It was estimated that 10,000,000 gallons of water daily could be obtained from this basin, although the nature of the material and the slope of the hydraulic grade, or underground water surface, was practically unknown. Because of the lack of definite information in regard to the basin and its distance from the city the project of obtaining water supply from it was finally abandoned.

ITHACA ARTESIAN BASIN.

Attention was then directed to the valley in which the city of Ithaca lies. An examination of the geology of the region showed that because of the slope of the rocks to the south, while their outcrop was at a lower level to the north, they could not be expected to yield flowing water. The fineness of the texture of the rocks is also such that their water-holding capacity is small.

The conditions for a supply from the gravels filling the valley, however, are much more favorable. Such wells as had been drilled obtained considerable supplies, and it appeared probable that with additional wells a supply sufficient to meet the needs of the city could be obtained.

The underground water of the region is probably derived by absorption from the waters brought in from the south by Coy Glen, Buttermilk Creek, Enfield Creek, and other streams tributary to the main valley occupied by Cayuga inlet. Cayuga Lake will apparently have little bearing on the water supplies of the gravels, its surface being considerably lower than the mouth of the wells. Prof. G. D. Harris suggested the use of screens adjusted in the casing of the wells at each water bed in order that all producing horizons might be drawn upon.

It was not regarded as essential to the success of the artesian supply that the wells should actually flow, it making very little difference in the cost of distribution whether the water stood a few feet above or a few feet below the surface. Jamestown, in western New York, is supplied with water from a deeply gravel-filled channel. At the start the wells rose perhaps 25 feet above the surface, but as more wells have been sunk into the water-bearing gravels and a considerable supply drawn from them the old wells have ceased to flow, all the larger wells being connected with powerful steam pumps.

It was conceded that the water supply of Cayuga inlet valley would easily supply Ithaca proper, while if necessary the university and portions of the city in its vicinity could be supplied by Fall Creek.

WELLS IN THE ITHACA BASIN.

The Illston well.—The Illston well, which is about 287 feet deep, was sunk by Mr. Illston for the purpose of obtaining pure water for the manufacture of ice. After much labor and expense he succeeded in obtaining a well which gave a pressure of about 13 pounds per square inch and a temperature of 54° F. Tests made by Mr. E. B. Kay on March 6, 1903, showed that, with the pipe 8 feet above ground, 403,142 gallons of water ran from the well daily, the test being made with a weir after the well had run freely for one hour. Mr. Kay estimated that had the test been made at the surface of the ground the result would have been more than 425,000 gallons. By the use of an air lift or other pump the capacity would probably be increased at least 50 per cent, and it is not impossible that 1,000,000 gallons daily might be procured from this well alone. A second test, made March 8, after the well had flowed twenty-four hours, showed an output of 405,000 gallons a day. The flow was even stronger than in the former test. Records at the Cornell chemical laboratories show that the analysis of water from this well is as follows:

Analysis of water from Illston well.

	Parts per million.
Free ammonia	0.480
Albuminoid ammonia	0.005
Nitrogen as nitrites	None.
Nitrogen as nitrates	Trace.
Oxygen consumed	0.644
Chlorine as chlorides	61.640
Total solid residue	304.000
Loss of solids on ignition	78.000

Comparative analyses made by Professor Chamot on the Illston and other waters of this vicinity showed that in 1,000,000 parts the Illston water contained 309 parts solid matter; Fall Creek water, 309 parts; Buttermilk Creek water, 200 parts; springs in vicinity of the city, 165 to 200 parts; city well water, 500 parts, and Forest Home well water, 670 parts per million.

From the analysis it appears that the Illston well water is softer than that of most of the wells and springs in the city or at Forest Home, as soft as the Fall Creek water, and almost as soft as Buttermilk Creek water.

Salt well.—About eight years ago the National Salt Company began to sink its first well to the salt bed. A 14-inch hole was drilled. For the first hundred feet the drill went through a stratum of clay, in which no water was found. At the depth of 100 feet the drill broke through the clay into a gravel bed, upon which the hole was instantly filled with pure, clear water.

After going through the gravel, 100 feet beyond the water vein, the drill was brought to the surface, and in the corner of the derrick house another well, this one 6¼ inches in diameter, was sunk to a depth of about 120 feet, the lower 20 feet being in the gravel. The water from this well was clear, despite the fact that the drill had ground up the gravel and had created a condition which, naturally, would have caused the water to be turbid. A third well, of the same size as the last, was sunk, and then the drilling of the first and deeper well was resumed. After the completion of the plant a pump was attached to one of the wells. The flow was so copious that the engine was shut off to half its power, and for eight years only a small part of the water which might be drawn from the well has been used, although thousands of gallons are consumed daily at the plant.

Fourth street test well.—With the belief that other wells sunk in this vicinity would prove successful a test well was bored near Fourth street. This well was readily drilled to the water-bearing stratum, which was struck at the depth of 91 feet. When the gravel was reached the 6-inch pipe was quickly filled with water. Another length of pipe was then added, and the well was completed at a depth of 123 feet, with 32 feet of pipe in the gravel.

This well was then tested by pumping for several hours with a steam fire engine. Although the engine was worked to its full capacity there was no diminution of the water supply. The well, however, has since become choked with fine sand, which has gradually filled the screen. It is believed, however, that if properly developed it may again be made to yield abundantly.

Wells drilled for temporary supply.—Meanwhile workmen, under the direction of the water board, were drilling several wells for a

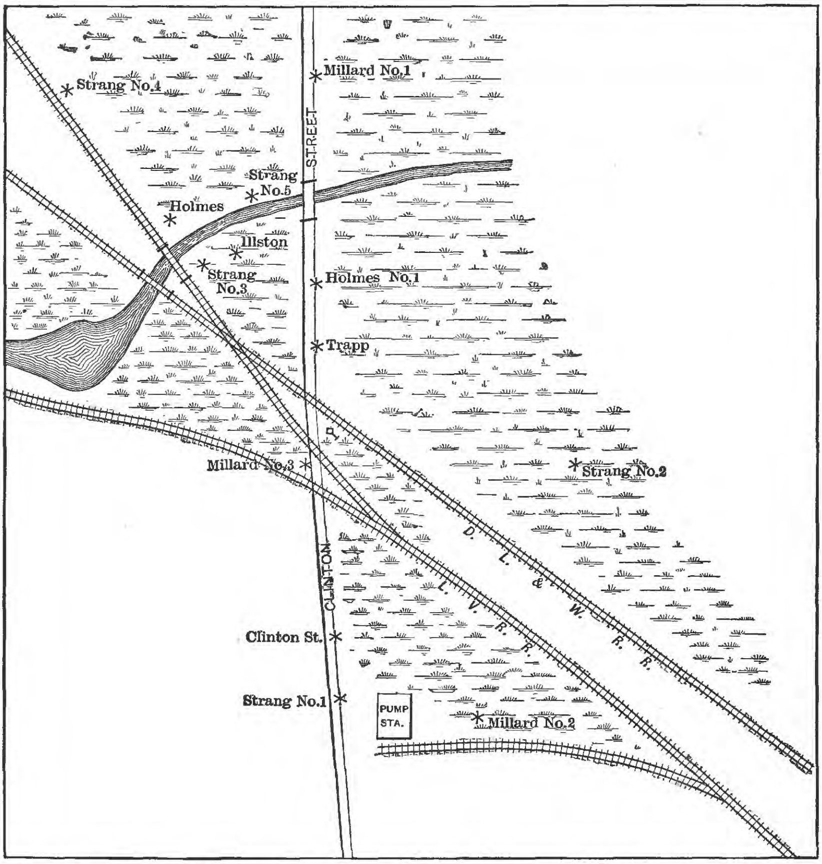


Fig. 17.—Sketch map showing location of temporary supply wells near Ithaca.

temporary supply. These wells are located on the lowlands in the valley of Cayuga Lake, along the lines of the Delaware, Lackawanna, and Western Railroad Company and the Lehigh Valley Railroad Company, near the intersection of Clinton street with the railroads. The lowlands are level and swampy, being only about 3 feet above Cayuga Lake. As shown by the accompanying map (fig. 17) they are within a few feet of the Illston well, south of the city.

The wells were all sunk by a walking-beam drill, assisted by hydraulic jet to remove the fine sand when the water-bearing strata was reached.

Of the 13 wells put down by the board only 3 are dry, 2 ending in black shale, the others in fine sand and gravel. Many have an excellent head, those nearest the Illston well, already described, having the greatest. One, known as Strang No. 3, had, at the time of boring, a static head of 17½ pounds. Some of the wells nevertheless required developing, and were opened by exploding dynamite at their bottoms, the loosened material being then removed by washing. In the Trapp well over 30 pounds of dynamite were used for this purpose.

As already stated, the Illston well yields with an air lift 425,000 gallons daily. The wells sunk for the temporary supply draw their water from the same source. What the wells will yield, however, is not yet known, although it had been found that the water in the various wells is affected by the pumping of others in the series. The water board estimates that the wells when pumped will have a capacity of 3,000,000 gallons daily.

GEOLOGY OF THE SUPPLY.

The diagrammatic sections in Pl. V, together with the written records on pages 64 to 66 indicate the manner in which the materials are distributed in the different wells. It will be seen that there is considerable variation in the upper and lower portions of the wells, although a certain system in the character of the deposits prevails. At the top there is a bed of mucky clay about 6 feet thick. Below this is a pure clay, or a clay containing in some instances considerable amounts of sand or gravel, which extends to a depth from about 50 or more feet, beneath which is from 20 to 50 feet or more of prevailingly sandy or gravelly material, in which some clay may also occur. These strata carry water, which will rise to within about 10 feet of the surface. None of this water is admitted to the wells, but is cased off so as to avoid any possibility of contamination from surface water. The stratum of sand and gravel last mentioned is frequently overlain by logs in a good state of preservation, which the drills penetrate with difficulty. Underlying the gravel and sand is a stratum of clay that extends to depths ranging from 210 to 250 feet, where a mixture of gravel and clay is encountered that extends downward to depths varying from 280 to 290 feet below the surface. The lower part of this stratum was in many cases a very hard and compact hardpan, directly below which is the stratum of gravel and sand from which the supply of water is drawn. As the water is taken only from this stratum, which lies 285 feet below the surface and is protected by a great thickness of clay, surface pollution becomes practically impossible.

The abundant supply can be attributed to the general conditions of the valley. On either side are hills attaining a height of about

1,000 feet and forming an immense catchment area. Underneath the drift are the Portage, Genesee, and Hamilton shales, and other rocks, dipping southward. The slope of the hills being nearly at right angles to the dip of the beds, the water flows downward into the valley instead of percolating through the underlying rocks. At a distance of 8 miles south of the city the floor of the valley is about 472 feet higher than at the wells. The water from the hills of this region finds its way into the gravel and sand deposits of the valley, and by these is conveyed toward the lake.

Wells drilled outside a rather definitely limited area either fail to obtain water or procure only small supplies with little head. Wells drilled along a certain line, however, procure water under considerable pressure. The facts indicate the probable presence of a rather definite and limited water course through sand and gravel overlain by impervious clays.

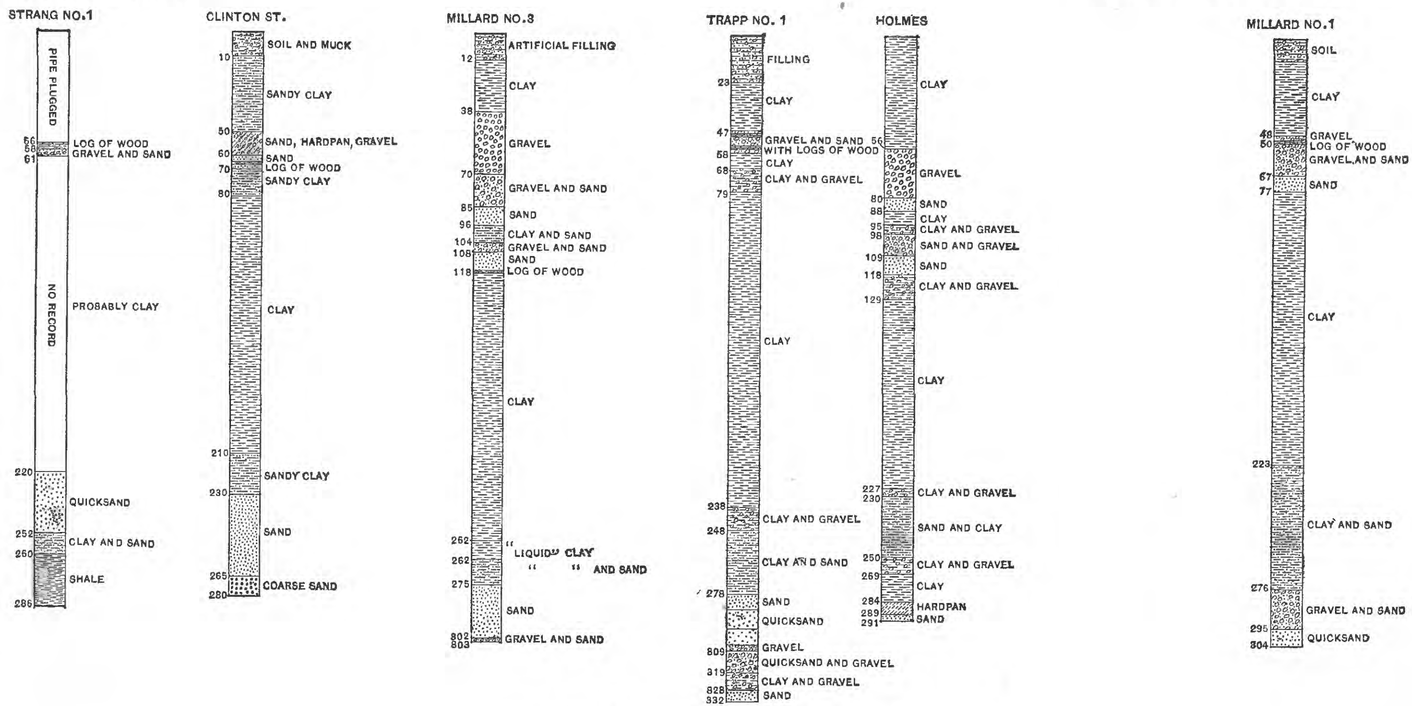
WELL RECORDS.

The sections of six of the artesian wells in the vicinity of Ithaca have been given in Pl. V. Below are given records of a number of additional wells.

SOUTH WELL.

Material.	Thickness.	Depth to base.
	Feet.	*Feet.*
Soil	5	5
Blue clay	7	12
Clay	8	20
Sandy clay and wood	10	30
Sandy clay	10	40
Gravel and clay	10	50
Clay	10	60
Clay and gravel	10	70
Clay	65	135
Sandy clay	65	200
Sand	10	210
Coarse sand	10	220
Coarse to fine sand	10	230
Coarse sand; struck water	2	232

Located 1,500 feet up the valley from Clinton street, Ithaca, and about 70 feet east from the Delaware, Lackawanna and Western Railroad. Authority, Mr. Partridge.



SECTIONS OF TEMPORARY SUPPLY WELLS.

MILLARD WELL NO. 2.

Material.	Thick-ness.	Depth to base.
	Feet.	*Feet.*
Clay	44	44
Sand and gravel	31	75
Quicksand	3	78
Clay	123	201
Clay and gravel	21	222
Quicksand	18	240
Cemented gravel	4	244
Fine sand and clay mixed	7	251
Hardpan	6	257
1 bucket coarse gravel; black sand	1	258
Hardpan	1	259
Struck flowing water		259

STRANG WELL NO. 2.

Driven with plugged pipe	87	87
Fine sand	10	97
Clay	116	213
Clay with large stones	22	235
Thin clay	33	268
Thin clay and fine sand	11	279
Fine sand	8	287
3 or 4 buckets of sand and coarse gravel.		
Fine sand	13	300
Clay and gravel, hardpan	7	307
Clay and gravel with large stone	6	313
Clay and gravel with streaks of fine sand	3	316
Clay and sharp black sand	11	327
Clay, fine sand, and gravel	1	328
Clay and black sand	2	330
Soft black shale rock and sand	12	342
Black shale	10	352
Dry hole.		

STRANG WELL NO. 3.

Pipe driven with end plugged	110	110
Log	2	112
Clay and sand	11	123
Clay	47	170
Clay and sand	70	240
Quicksand	19	259
Black sand and some clay and fine sand mixed	16	275
Do	5	280
Struck water		280

STRANG WELL NO. 4.

Material.	Thickness.	Depth to base.
	Feet.	*Feet.*
Driven with plugged pipe	110	110
Clay and large gravel	10	120
Fine sand	10	130
Clay	112	242
Hard clay and stone	6	248
Fine sand	32	280
Struck water	....	280

STRANG WELL NO. 5.

Driven with plugged pipe	108	108
Clay and stone	7	115
Fine sand	8	123
Clay	121	244
Clay and stone	12	256
Clay	14	270
Gravel; struck water	6	276

PRESENT CONDITIONS.

The total number of wells sunk is 14, of which two, put down in the first prospecting, are at such a distance from the station and collecting well as to make it impracticable to connect with them on account of cost, and three are dry or nearly dry. The remaining nine productive wells vary in flow from 50,000 gallons to 430,000 gallons each per day of twenty-four hours, and the static heads vary from 16 to 18 pounds.

The flow is collected by a system of pipes and laterals and delivered to a circular brick cistern or well, 16 feet in diameter and 18 feet deep, where any gravel or sand is deposited, so that it may not reach the pumps. The walls of the collecting well are 17 inches thick, and are made water-tight by a thick wall of puddled blue clay that entirely surrounds the well and extends from the surface downward to a depth of 6 feet, reaching the stratum of clay underlying the soil.

In the meantime the waterworks company has constructed a filtration plant of the mechanical type, from which those who are willing to take real or fancied filtered water obtain their supplies.

For a permanent supply deep wells in the valley of Sixmile Creek are contemplated, although not yet decided upon. These can be so located that the water may be distributed by a gravity system.

DRILLED WELLS OF THE TRIASSIC AREA OF THE CONNECTICUT VALLEY.

By W. H. C. Pynchon.

INTRODUCTION.

Location and area.—The Triassic area, so called from the fact that it is underlain by rocks of Triassic age, is the lowland belt extending from New Haven in a direction slightly east of north to Northfield, Mass., not far from the New Hampshire line—a distance of about 110 miles (fig. 18). Its width at New Haven is about 3 miles. To the north it expands until at the Massachusetts line it has a width of 20 miles, from which it gradually declines to a width of about a mile at its northern end.

It is an area of soft sandstones and shales, with occasional trap ridges, lying in a broad depression between harder, more or less crystalline rocks. It is traversed from its northern end southward to beyond Middletown by the Connecticut River and is frequently spoken of as the Connecticut Valley lowland.

General conditions.—The sedimentary rocks of the Triassic area vary from coarse conglomerates through sandstone to fine clay shales, interbedded with which are thick sheets of trap. The dip is a little south of east and averages about 14 degrees. The rocks, except the traps, are porous, holding up to 30 per cent of their own volume of water, and the dips are such that artesian flows would ordinarily be expected in the lower valleys. Such flows are sometimes obtained, though, because of disturbance by faulting and the presence of numerous joints, the waters of the area are uncertain as to quantity and as to the height to which they will rise. The Triassic rocks are, nevertheless, a very important source of water, and it is with a view of describing the conditions to drillers and well owners that the following account has been prepared. The region involved in the problem is not limited by geographical but by geological boundaries, being confined to the area of outcrop of the Triassic rocks.

Nature of investigation.—In the Triassic area the occurrence of water is dependent directly upon the texture and structure of the rocks, and is therefore strictly geological. To fully understand its occurrence a knowledge of the geological conditions is necessary. This knowledge may be obtained in part by an examination of the rocks where they are exposed at the surface, but a full insight into the question requires an intimate understanding of the conditions as they are disclosed by borings made for wells. No one is in a better position to know the underground conditions in his own wells than the driller, but his detailed knowledge rarely extends to the wells of other drillers and almost never covers the whole field. It is by combining information obtained from local authorities throughout the entire field and from his own personal observation that the geologist is able to present a comprehensive view of the entire region.

The present paper is a result of the method of investigation outlined above. Published descriptions of the region were consulted, additional field work was done in places concerning which further information was desired, and well records and other information furnished by drillers was collected from all parts of the area.

Collection of well data.—At the beginning of the investigation much information concerning well records was obtained by correspondence. Printed or typewritten blanks, containing a number of questions relating to the owner, location, diameter, and depth of well; quantity, quality, and height of water; materials encountered, additional well owners, drillers, etc., were sent out. The typewritten blanks were returned in almost every case, and a large number of the printed forms were also received. These furnished a good basis for planning field work, which was then undertaken. In the field, personal interviews were had with drillers and well owners and facts relating to the wells were obtained at first hand. These facts were afterwards studied and compared with one another and the resulting information was compiled for publication in the present report.

Special thanks are due to Mr. C. L. Grant and Mr. H. B. King, well drillers, of Hartford, Conn., for records and valuable information relating to wells of the area.

TOPOGRAPHY.

The topography[a] of the region is in general such as might be expected from the general geological structure. The hard crystalline rocks of the eastern and western uplands stand well above the region of soft Triassic sediments, surrounding them like a barrier. At its northern limit the lowland has an elevation of from 400 to 500 feet above sea level, but the land slopes steadily downward toward the south until, in the region of New Haven, there are portions which are only slightly above sea level. As would be expected, the harder sedi-

[a] The entire areas of the States of Connecticut and Massachusetts have been mapped by the United States Geological Survey. The complete series of maps includes about 70 sheets, of which about 15 lie within the area under discussion. The separate sheets are sold by the Survey for 5 cents each—the approximate cost of printing. Lists can be had on application to the Survey.

mentary beds find topographic expression in low ridges following the strike of the rocks in a generally north-to-south direction, their steeper faces being toward the west, as the beds dip eastward. But it is to the highly resistant trap sheets that the valley owes its most striking topographic features. Throughout the whole Triassic area the trap ranges dominate the lowlands in strong ridges that run from north to south and present bold cliffs on the west and gentle slopes on the east. The western cliffs of these ridges are buried in some cases almost to their summits by a heavy talus of fragments which the frost has split from their faces. These slopes of talus, topped by perpendicular cliffs, have a marked individuality, and though of no great elevation have long been spoken of as "mountains" throughout the region. The highest of these ridges in Massachusetts is Mount Tom, about 10 miles northwest of Springfield, which has an elevation of 1,200 feet above sea level, while the most conspicuous in Connecticut is West Peak, in the Hanging Hills of Meriden, with an elevation of 1,007 feet.

GEOLOGY.

PREVIOUS INVESTIGATIONS.

Soon after the beginning of the nineteenth century the geology and the mineralogy of the Triassic area of Connecticut and Massachusetts began to attract attention, papers on the subject having been published by the elder Professor Silliman, of Yale, as early as 1814. The first geologist to make a thorough study of the Connecticut section was Dr. James Gates Percival, who published in 1842, under State auspices, a "Report of the Geology of Connecticut." Dr. Charles Upham Shepard had published in 1837 his "Report on the Geological Survey of Connecticut," but this work was confined almost wholly to the mineral resources of the State. At about the same time the portion lying in Massachusetts received attention from Prof. Edward Hitchcock, of Amherst College. Among the geologists who have since devoted special attention to the region are Prof. J. D. Dana, of Yale, Prof. B. K. Emerson, of Amherst, and Prof. W. M. Davis, of Harvard. The latest and most exhaustive treatise on the Triassic of Massachusetts is Prof. B. K. Emerson's "Geology of Old Hampshire County, Massachusetts."[a] The latest and fullest treatise on the Connecticut section is Prof. W. M. Davis's "Triassic Formation of Connecticut."[b]

The geology of the Connecticut Valley lowland is interesting from many standpoints. The manner in which quiet processes of deposition have alternated with volcanic or other igneous action presents in itself a broad field of study, but the elaborate manifestations of faulting and displacement and the complicated structures and topographic forms

[a] Mon. U. S. Geol. Survey, vol. 29, 1898.
[b] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 1-192.

which have been developed in the region are the chief sources of interest to the geologist. It is not within the province of this paper, however, to take up the geological history of the area, attention being necessarily confined to the existing structure without regard to the processes by which this structure has been produced, except in so far as they influence the underground water supply. It is from this standpoint alone that the following description of the geology and topography of the region is given, the reader being referred for further information to the publications mentioned above.

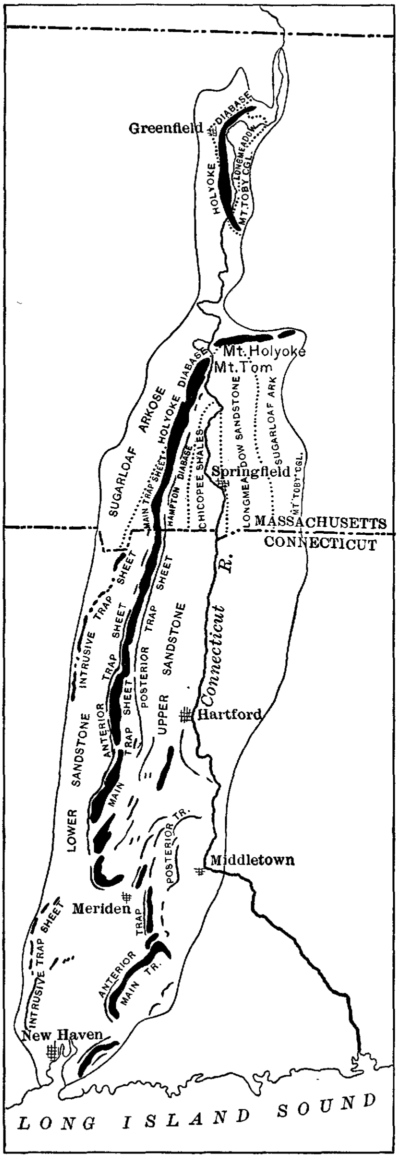


FIG. 18.—Geologic sketch map of the Triassic area of the Connecticut Valley.

GENERAL RELATIONS.

Both the eastern and the western portions of Connecticut are occupied by extensive highlands. These consist of ancient metamorphic rocks, deeply eroded by streams and overlain by glacial drift. The western upland is the more elevated, attaining at one point, Bear Mountain, a height of 2,355 feet above the sea. In Massachusetts this western upland is even more rugged than in Connecticut, and contains within its borders the famous Berkshire Hills. The eastern upland of Massachusetts is, like that of Connecticut, much less rugged than the western. The rocks are highly metamorphosed and deeply dissected by the streams which traverse them. Professor Emerson assigns the chief part of the metamorphosed rocks in Franklin, Hampshire, and Hampden counties, Mass., to the Silurian, a considerable portion to the Cambrian, two much smaller portions to the Upper Devonian and the Carboniferous, and a very small portion to the pre-Cambrian. It is probable that a detailed study of the uplands of Connecticut would show that the rocks comprising them would fall under a similar classification.

CHARACTER OF DEPOSITS.

Nature of the rocks.—Between the eastern and the western uplands, occupying a depression in the older rocks, lies the Connecticut Valley lowland, the limits of which have already been stated (p. 67). Its rocks all belong to the Triassic system. The greater portion of these rocks consists of comparatively soft sedimentary beds which are now so tilted that they have a rather uniform dip eastward of about 15 degrees. Interspersed with these rocks are to be found, however, certain sheets of volcanic lava (trap), generally interbedded between the strata of the sedimentary rocks, in nearly all cases in perfect conformity with the beds they overlie.

General structure.—A section across the Triassic area, as constructed by Professor Davis, is shown in fig. 19. The succession of the sandstones and traps, the uniform eastward dip of the beds of about 15 degrees and their displacement by faulting are strikingly brought out.

Succession and distribution of beds.—The portion of the Triassic area in Massachusetts and that in Connecticut were studied, as stated, by two geologists working independently, and in general the same conclusions were reached by both. The uniformly eastward dip, the

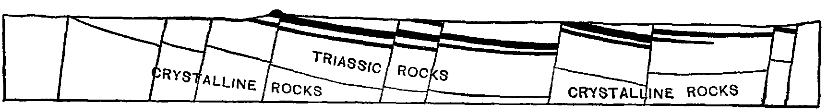


FIG. 19.—Generalized section across the Triassic area of the Connecticut Valley.

succession from lower and older rocks on the west to higher and younger at the center of the area, the presence of conglomerates along the border, the succession of trap sheets, and the presence of great numbers of faults are recognized by both. In the details of mapping, however, different subdivisions of the rocks were made in the two States, and there is some difference of opinion as to the succession of beds in the eastern portion of the valley and the character of the contact along that margin. Fig. 18 shows the distribution of the rocks in both the Massachusetts and Connecticut areas as mapped by Professor Emerson[a] and Professor Davis[b] respectively. In the following table are shown the equivalency of the divisions recognized in the two States. In addition to the formations given for the Massachusetts area there are the minor Black Rock diabase and the Granby tuff or ash beds. In Connecticut there is in addition what has been known as the intrusive trap sheet. These minor beds will be considered on a subsequent page.

[a] Emerson, B. K., Geology of old Hampshire County, Massachusetts: Mon. U. S. Geol. Survey, vol. 29, 1898.

[b] Davis, W. M., The Triassic formation in Connecticut: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898.

Table showing correlation of Triassic rocks in Massachusetts and Connecticut.

Subdivisions of B. K. Emerson in Massachusetts.		Subdivisions of J. G. Percival and W. M. Davis in Connecticut.
Chicopee shales		Upper sandstones, including also Mount Toby conglomerate and part of Sugarloaf arkose.
Longmeadow sandstone and included traps.	Sandstone, shale, etc	
	Hampton diabase (trap)	Posterior trap sheet.
	Sandstone, shale, etc	Posterior shale.
	Holyoke diabase (trap)	Main trap sheet.
	Sandstone, shale, etc	Anterior shales.
	Talcott diabase (trap)	Anterior trap sheet.
	Sandstone, shale, etc	Lower sandstone.
Sugarloaf arkose		
Mount Toby conglomerate		Not differentiated.

DESCRIPTION OF ROCKS.

Mount Toby conglomerate.—This is a coarse conglomerate, composed of fragments of slaty rocks, schist, and quartz, ranging from 2 inches to 4 feet in diameter, which forms a narrow band along the eastern border of the Triassic area in Massachusetts, extending from the Boston and Albany Railroad, near Ellis, southward to the State line, and on the same side from a point just north of Amherst to the extreme northern end of the area. It has not been differentiated in Connecticut, but undoubtedly extends along the eastern border in at least the northern portion of the State.

Sugarloaf arkose ("Lower sandstone" of Davis in part).—This is a coarse buff to pale red sandstone or conglomerate, made up largely of granite fragments that were derived from rocks lying farther west. It forms the western border of the Triassic area in Massachusetts, and bends around and forms the eastern border, except where it is separated from the crystalline rocks by the Mount Toby conglomerate. It is the equivalent of the conglomeratic portions of the "Lower sandstone" of Connecticut, where the latter rests in contact with the western border of the area.

Longmeadow sandstone and its Connecticut equivalents.—The sandstone occurs as a broad band inside of the Sugarloaf arkose belt. It is largely of the red or brown variety of sandstone, known as brownstone, which is so largely quarried, but includes many thin beds of shale. Interbedded with the sandstone are also thick beds of traps, which were laid down as lava sheets at various times during the period when the sandstones were deposited. The Longmeadow sandstone includes the nonconglomeratic portion of the lower sandstones of Connecticut, and the Anterior, Posterior, and a portion of the Upper shales or sandstones of Connecticut.

Talcott diabase (Anterior trap sheet).—This is a massive dark-colored trap that forms an important feature in the Connecticut area, where it is known as the Western trap range, but does not enter Massachusetts. It is a bedded sheet, originally formed as a volcanic flow on an old surface during the period of deposition of the sandstone.

Holyoke diabase (Main trap sheet).—This is a dark, dense trap bed, several hundred feet thick, that extends with a few breaks from the northern to the southern portion of the area. Because of its resistance to erosion it forms a conspicuous ridge, frequently called a mountain, as at Mount Tom and Mount Holyoke. It is sometimes known as the Eastern trap range. Like the Talcott diabase it was laid down as a surface lava flow.

Hampton diabase (Posterior trap sheet).—This is a relatively thin but at the same time persistent sheet that extends with some interruptions from near Mount Tom on the north to Long Island Sound on the south. It does not commonly give rise to a conspicuous ridge. Like the preceding sheets it was a surface flow.

Black rock diabase.—This is a diabase which, instead of flowing out over the old sandstone surfaces, was forced or intruded through the sandstones and the older Holyoke and Hampton traps as dikes or other igneous masses. It is found only in the region southeast of the Mount Tom and Mount Holyoke ridges in Massachusetts.

Granby tuff.—This is a sandstone or conglomerate, made up of volcanic débris, possibly derived from the volcanic eruptions accompanying the intrusion of the Black Rock diabase. Its distribution is much the same as the latter.

Intrusive traps in Connecticut.—The intrusive traps are of two types—intrusive sheets and dikes. The former is represented by the important trap sheet that was injected between certain of the lower sandstone beds near the western border of the Triassic area, and that extends from the Massachusetts line southward for nearly 20 miles, and again from near Southington to New Haven. The dikes are represented by smaller and more isolated masses, having approximately vertical attitudes cutting across the bedding of the sandstones.

Chicopee shale.—This is a band of dark-gray shaly sandstone, with some shales, that extends along the Connecticut River from Holyoke southward into Connecticut. In that State it has not been differentiated.

FAULTING.

When first formed both the sedimentary beds and the trap sheets were continuous and unbroken. If simply tilted and subjected to erosion such beds would give rise to continuous ridges, but in reality the latter are broken and their component parts shifted in relation to one another. This shifting is due to movements which have taken place along certain lines of fracture, and which in some regions have broken the rocks into a series of blocks bounded by faults and known as fault blocks. The faults are abundant in the Triassic area, both in Connecticut and in Massachusetts, reaching a high development in the region of the Hanging Hills of Meriden. In direction they commonly run from northeast to southwest, transversely to the strike of the beds, but some northwest-southeast faults occur. In a given district they are usually parallel to one another. In many places they are separated by intervals of only a fraction of a mile, the result being the subdivision of the rocks into long narrow blocks slightly offset as regards one another. In most cases there has also been much movement in a vertical direction.

In these dislocations there is to be found the greatest variation in length of fault line and amount of displacement. At one end of the series stand the small local faults, which can be traced for only a few feet and which show only a few inches of slipping; at the other end may be placed the great fault which separates the Hanging Hills from Lamentation Mountain. This fault crosses the whole lowland from northeast to southwest, penetrating both the eastern and the western uplands and having a total length of about 40 miles.[a] The upthrow is on the east of the fault line and is so great that the lower sandstones under Lamentation Mountain abut against the Posterior shales of Cathole Peaks, the most eastern member of the Hanging Hills. The fault gap between these two portions of the main trap sheet is a mile across. Faults of considerable movement everywhere leave distinct notches in the crests of the various trap ridges. At these points erosion, acting along the fault line, has cut deep gorges, some of which reach the dignity of passes, flanked by long slopes of rocky talus topped by perpendicular cliffs. Excellent examples of these fault gaps are Cathole Pass, between Cathole Peaks and Notch Mountain, and Reservoir Notch, between Notch Mountain and West Peak, both in the Hanging Hills.

Throughout the southern half of the Connecticut area, from about the latitude of Hartford to Long Island Sound, the faults are closely parallel, and run from northeast to southwest, the upthrow always being on the eastern side. As a combined result of this displacement and subsequent erosion there is, as we proceed southward, a constantly recurring recession of the outcrop of the various members of the series, this overlapping arrangement being specially well developed in the vicinity of Meriden. From about the latitude of Hartford northward to the Massachusetts State line the faults, though still oblique in character, run from northwest to southeast. The upthrow is still on

[a] Davis, W. M., The Triassic formation of Connecticut: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2 1898, p. 100.

the eastern side of the fault lines, so that there is still a tendency to an eastward recession of the outcrops, but in a manner the reverse of that which is seen in the southern portion of the valley.

In the Massachusetts area the faults in the Triassic are fewer and of less importance. Faults of both the varieties mentioned occur, as will be seen from Professor Emerson's map,[a] but they produce a less striking effect on the arrangement of the chief ridges of the region.

Certain faults are supposed to occur in connection with the boundaries of the Triassic both in Connecticut and Massachusetts, principally in connection with the eastern boundary, and they have been indicated on the map[b] accompanying the report of Professor Davis.

JOINTING.

Jointing in traps.—Besides the faults there are certain minor lines of regular separation which demand attention. These are the joints which exist in great numbers throughout the mass. Every trap ridge in the lowland shows them in a remarkable degree, but they are especially prominent in the mountains of the main range. The trap sheets are divided by a vast number of these joints, the planes of which run in a direction generally perpendicular to the cooling surface, and along these planes the rock splits up into approximately rectangular blocks of all imaginable sizes. It is these joint planes that form the nearly vertical western faces of the mountains, and in cases where erosion, working on some local fault, has produced an escarpment facing eastward, the cliffs actually overhang. Every trap eminence of any considerable height is fronted by a long talus of broken trap, formed of joint blocks of all sizes which have fallen down from the cliffs above. A little gorge marking the line of a small fault near the crest of West Peak is fairly choked with slabs, some of them 12 feet square and several feet thick, which have been derived from the walls of the gorge. On the top of Rattlesnake Mountain are large blocks of trap that have been detached along joint planes, while at the foot of Talcott Mountain, on the line of the old Albany turnpike, lies a joint block as large as a small house. The blocks range from this size down to an inch square. In some localities the joints divide the trap into sheaves of blade-shaped fragments.

Jointing in sedimentary rocks.—Jointing in the sedimentary beds does not reach the highly developed condition seen in the trap sheets. In the heavy sandstones at the great brownstone quarries at Portland the joints are on a large scale and are indispensable aids in separating the great blocks of building stone. Yet here these lines of fracture

[a] Emerson, B. K., Geology of old Hampshire County, Massachusetts: Mon. U. S. Geol. Survey, vol. 39, Pl. XXXIV.

[b] Davis, W. M., The Triassic formation of Connecticut: Eighteenth Ann. Rept. U. S. Geol. Survey, Pl. XIX.

are potential rather than actual. In the shales the joints become much more numerous and may be regarded as universal. In the city stone pits near Trinity College at Hartford the Posterior trap has been removed for road metal, leaving broad sheets of Posterior shale, marked with ripple marks and mud cracks, exposed to view. One looking down upon this floor from the top of the cliff may see two sets of joint cracks that cross each other at an angle of about 60 degrees and divide the mass into lozenge-shaped sections. Working along these two sets of joint planes and the plane of the bedding, the quarrymen remove blocks of shale averaging about a foot square and 6 to 8 inches thick, which are used as the foundation rock in the construction of the streets. Joint blocks in this shale may be extremely variable in size, and are often not over an inch in any dimension. An examination of almost any mass of shale throughout the lowland will show that the jointing seen in this quarry is typical.

Although jointing in the sediments does not produce such striking results as in the trap, yet the joints themselves extend, the writer believes, to much greater distances, both vertically and horizontally, in the sedimentary than in the igneous rocks. Apparently they frequently become actual fissures in the deep rocks and have a profound effect on the water supply, as will be shown later.

GLACIAL AND RECENT DEPOSITS.

The entire Triassic area has been subjected to the action of the ice sheets that passed over the region in Pleistocene times. The outlines of the harder ridges have been softened and the softer rocks have been worn away in many places by the scouring action of the ice. Deposits of till were formed beneath the sheet and now remain in the shape of the well-known hardpan, while gravel and sand deposits were formed as terraces or valley fillings by the glacial streams throughout the region. Since these deposits were laid down much material has been carried from them by streams and redeposited to form the present flood plains.

The presence of drift over the region is of great importance to the water supply. If the bare surfaces of the rocks were exposed the water would run off rapidly instead of being absorbed, but the glacial deposits, especially the sands and gravels, hold in storage large quantities of water, which is thus kept in contact with the underlying sandstones, by which the water is continually being absorbed.

WELLS OF THE CONNECTICUT VALLEY LOWLAND.

Although there are few flowing wells in the Triassic area there are many wells from which water is pumped, and some of these would yield a supply much in excess of the capacity of the pumps that are used in them.

In the description of wells which follows an attempt is made to present data bearing upon the occurrence, volume, and quality of the water. Most of the records were gathered several years ago, but the area is fairly well covered and the information is comprehensive. In interpreting the figures due weight should be given to the source of information. Depths reported by drillers are likely to be more accurate than those furnished by owners, but on the other hand the quantity is more likely to be accurately stated by the owner. The reports of both owner and driller as to quality are likely to be more optimistic than the facts warrant, but the use to which the water is put—or, better, the uses to which it is not put—usually gives a clue to its actual character.

The records are far from uniform in the character of the points presented, certain features that are of special interest and consequence in one well being of little interest in another, which may show an entirely different set. The greater abundance of the records in the vicinity of the towns along the center of the area makes the data in such situations more complete than for the outlying portions, but the value of the data presented for wells in the outlying regions is probably greater. Data relating to wells that were failures are especially difficult to obtain from either owner or driller. The driller especially is loath to give details which might tend to discourage further drilling. This is unfortunate, as perhaps fully as much information as to the actual underground conditions is afforded by the dry holes as by the successful wells.

WELLS ENTERING THE ROCK.

The typical wells of this area are those which are sunk for the greater part of their depth in the rock, but a short list of wells of the drift, including those which lie in unconsolidated deposits, generally of glacial origin, overlying the Triassic rocks is also given. Certain of these wells are distinctly interesting, as their water supply seems to depend not on the arrangement of the deposits in which they are located, but on the conformation of the surface of the rocks which lie below.

WELLS IN MASSACHUSETTS.

NORTHAMPTON.

No. 1. Belding Brothers' Silk Company.—This well is in its way the most remarkable in the valley, as it was carried to the great depth of 3,700 feet without striking water. Mr. E. F. Crooks, writing for the company, states that at the "depth of 150 feet the drill entered sandstone or conglomerate rock which did not change at any time down to 3,700 feet." Professor Emerson classes the rocks which underlie Northampton as Sugarloaf arkose and gives a list of the beds traversed in drilling this well.[a] It seems probable that this well was driven through a water-bearing stratum at the point where it enters the rock, since a shallower well sunk by the same company to the rock, within a few feet of the former well, draws good water from that depth. This second well will be referred to again among the wells of the drift. The dry well is 8 inches in diameter.

SOUTH HADLEY FALLS.

No. 2. Sans Souci Club.—At the clubhouse of this organization is a private well 74 feet deep and 6 inches in diameter, entering the Longmeadow sandstone at a point 10 or 15 feet below the surface of the ground. The water, which is of medium hardness, supplies all needs of the clubhouse. The well is pumped.

HOLYOKE.

Nos. 3 and 4. American Writing Paper Company (Albion Paper Company Division).—These two wells, which are identical in detail, are 720 feet deep and have a diameter of 8 inches. The water rises within 14 feet of the surface, from which point it is pumped. Each well yields 450 gallons a minute throughout the twenty-four hours of the day, the water being slightly tinged with iron and not used in boilers. The wells enter the Chicopee shale about 50 feet below the surface.

No. 5. Holyoke Cold-Storage and Provision Company.—This well is over 500 feet deep, has a diameter of 3½ inches, and has its bottom in the Chicopee shale. The water, which has been analyzed, can be used in boilers, but is employed mostly for refrigerating purposes. The water is pumped at the rate of 20 to 25 gallons a minute.

No. 6. Riverside Paper Company.—A well, concerning which no data could be obtained, was drilled by this company, but was abandoned because of the mineral matter contained in the water.

WILLIMANSETT.

No. 7. Hamden Brewing Company.—This well is 112 feet deep and has a diameter of 4 inches. It is sunk partly in rock, which is apparently Chicopee shale. The well is pumped at the rate of 60 barrels an hour—that is, about 40 gallons a minute—without lowering the level at which the water stands. The water has been analyzed and is too hard to be used in boilers.

LUDLOW.

No. 8. Ludlow Manufacturing Company.—This well is 150 feet deep and has a diameter of 8 inches for the first 50 feet, below which it is reduced to 6 inches. After passing through 6 feet of made land the

[a] Emerson, B. K., Geology of old Hampshire County, Massachusetts: Mon. U. S. Geol. Survey, vol. 29, 1898, pp. 385–388.

well lies for the rest of its depth in rock, which is mapped as Sugarloaf arkose. The water level is about 21 feet below the surface, but, when the well is pumped at the rate of 20 gallons a minute, the level drops to a point 20 feet lower. The water is called medium hard, but can not be used in boilers.

CHICOPEE FALLS.

No. 9. Overman Wheel Company.—This well is 475 feet deep and 6 inches in diameter, the lower 175 feet lying in the Chicopee shales. The well was drilled to obtain water for drinking purposes only and it supplied all the employees of the big establishment abundantly. It was found, however, that the water was so full of mineral matter that it had a purgative effect on those who drank it and now its use is wholly discontinued. The water has been analyzed.

BRIGHTWOOD.

No. 10. Springfield Rendering Company.—This well was unfinished when the locality was visited in July, 1900. It was drilled by Messrs. King & Mather, of Hartford, who very kindly furnished the data concerning it on the completion of the work, a few weeks later. The well is 200 feet deep and has a diameter of 6 inches. It pumps 150 gallons a minute and meets the demands made upon it—90,000 gallons for a working day of ten hours. The water when analyzed proved to be sufficiently pure for use in boilers. It is sunk 59 feet through earth, the remainder being in the Chicopee shale.

Nos. 11 and 12. Springfield Provision Company.—This company has two wells, concerning which there is some uncertainty as to depth and diameter. They are only a few hundred feet south of the well just mentioned, and it is a matter of no small interest to note the great difference in the character of the water. Well No. 11 has a depth of 160(?) feet and a diameter of 6(?) inches, and pumps 150 gallons a minute without being pumped dry. No. 12 has a depth of 300(?) feet and a diameter of 6(?) inches, pumps 300 gallons a minute, and has never failed. Both wells enter the Chicopee shale at a depth of 60 feet. The water of these wells has been analyzed. It is too hard for boilers, and can not even be used for drinking, because of the mineral matter it contains.

SPRINGFIELD.

No. 13. Springfield Cold Storage Company.—This well is 325 feet deep and 8 inches in diameter, 290 feet of its depth lying in the Chicopee shale. The company has also a shallower well, 35 feet deep, which would bring it down to the surface of the rock. The two wells together yield 30 gallons a minute to the pump. The water is not fit for boilers, and is used only for condensing purposes.

Nos. 14, 15, and 16. Springfield Brewing Company.—No. 14 is 100 feet deep and 4 inches in diameter. The pump renders 150 gallons a minute. The analysis shows that the water carries considerable mineral matter.

No. 15 is identical in every respect with No. 14.

No. 16 is 300 feet deep, 4 inches in diameter, and yields only 60 gallons a minute. The water is poor in quality, and is used only for washing purposes.

All of these wells are pumped. The water is not used for boilers as the city water, which is very satisfactory, is already in use. Wells Nos. 14 and 15 go only to the rock, and are therefore to be reckoned among the wells of the drift, under which head they will be mentioned again.

No. 17. Morgan Envelope Company.—This well was originally 212 feet deep and flowed at the surface at the rate of 7 gallons a minute. It was afterwards sunk to 325 feet, but there was no gain in the supply. A deep-well pump was then put in at a depth of nearly 200 feet, and a supply of 25 gallons a minute is now obtained. The well runs for "60 feet through dirt, clay, hardpan with gravel," and then for "265 feet in sandstone rock." This rock is apparently the Chicopee shale. The water has been analyzed and proves to be a very good drinking water, though hard. In a working day of 10 hours from 5,000 to 6,000 gallons are commonly used. The diameter of the well is 6 inches.

No. 18. Kibbe Brothers Company, candy manufacturers.—This well is 252½ feet deep, 6 inches in diameter, and pumps 25 gallons a minute—the capacity of the pump. An analysis of the water made at Amherst College showed that it contains only a small amount of solid matter. It is not used for boilers, but is employed in the making of candy and for drinking purposes. The well runs first through about 40 feet of clay, the balance being in "sandstone"—probably Chicopee shale.

No. 19. Fiske Manufacturing Company.—The well of this company is 365 feet deep and 4 inches in diameter. It is pumped, but the amount of water obtained is unknown. The water has been analyzed and is not used in boilers. About two-thirds of the well lies in rock, probably the Chicopee shale.

Though the map indicates that many of the foregoing wells are sunk in the Chicopee shale, they nevertheless lie very close to its contact with the eastern area of Longmeadow sandstone.[a] This will perhaps account for the "sandstones" noted in the original records furnished.

Nos. 20 and 21. Highland Brewing Company.—These wells are used by the Highland branch of the Springfield Breweries Company. No. 20 is 424 feet deep, of which about 365 feet are in rock. Its diameter is 10 inches. It pumps 80 gallons a minute, the water rising to within 30 feet of the surface.

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[a] See map accompanying Professor Emerson's monograph.

No. 21 is 200 feet deep, of which about 160 feet are in rock. Its diameter is 8 inches. It pumps 60 gallons a minute, the water rising to within 15 feet of the surface.

Both of these wells yield water of excellent quality, which can be used in boilers. The brewery stands upon the terraces lying east of Connecticut River and in consequence is about 100 feet above the level of the Springfield wells previously mentioned, which are pretty close to the east bank of the river. The rock underlying this portion of the town is mapped by Professor Emerson as Longmeadow sandstone.

No. 22. Joseph H. Wesson, 13 Federal street.—This well is 276 feet deep and 6 inches in diameter. No estimate could be obtained of the quantity yielded, except that the pump would "furnish a 1-inch stream constantly." "The water is used only for drinking, but is pronounced good for boilers by Professor Wood, of Harvard." One hundred and fifty-one feet of the well lie in rock which is presumably Longmeadow sandstone.

Professor Emerson's monograph[a] contains a number of valuable items concerning the water supply of the Triassic area. Notes relating to several of the wells mentioned by him are subjoined.

OTHER WELLS IN TRIASSIC AREA IN MASSACHUSETTS.

No. 23. Daniel Brothers' paper mill.—This mill is on Westfield Little River, south of Westfield. The well was carried to a depth of 1,100 feet, but proved unsuccessful and is now closed up.[b] The rock at this locality is Sugarloaf arkose. It is an interesting and suggestive fact, as has been remarked before, that the only wells in the lowland which have been carried to exceptional depths, merely to meet with failure, have been sunk in this rock.

No. 24. Mount Holyoke College, South Hadley.—This well was carried to a depth of 450 feet in Longmeadow sandstone, the full record of the borings being given by Professor Emerson.[c] The water, when analyzed, was found to contain common salt in large amount.

No. 25. Montague Paper Company at Turners Falls.—This well was carried to a depth of 875 feet in Longmeadow sandstone. The record of the borings is given by Professor Emerson.[d] The appended analysis of a sample from the well shows that the water has nearly the composition of bittern.[e]

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[a] Mon. U. S. Geol. Survey, vol. 29.
[b] Ibid., p. 389.
[c] Ibid., p. 382.
[d] Ibid., pp. 380-381.
[e] Ibid., p. 750.

Analysis of deep well water at Turners Falls, Mass.

[C. A. Goessman, analyst, 1874.]

	Parts per million.
Potassa	6
Soda	51
Magnesia	63
Lime	633
Chlorine	6
Sulphuric acid	996
Silicon	Trace.
Total	1,755

Other wells.—Other wells mentioned are two of the Parsons Paper Company, of Holyoke, which reached depths of 510 feet and 685 feet, respectively.[a]

WELLS IN CONNECTICUT.

THOMPSONVILLE.

No. 26. Connecticut Valley Brewing Company.—This well is 52 feet deep and 6 inches in diameter, having 40 feet of its depth in the rock. The water rises within 7 feet of the top, a good many feet above the level of the Connecticut River, which is only a stone's throw away. The pump raises 31 gallons a minute, which lowers the well 8 feet, but no farther. The water is moderately hard, has been used in boilers, and keeps a uniform temperature of 51° F. the year round.

No. 27. Isaac Allen, Enfield street.—This is a private well, 67 feet deep and 6 inches in diamater. It is sunk 50 feet in rock, the last 5 feet, it is said, being in granite—a manifest impossibility. Mr. Allen states that a spring of soft water was struck at a depth of about 45 feet and a spring of hard water at the bottom, the mixture making an excellent drinking water. The well furnishes more than double the quantity of water that can be used in house and barn. The water is 45 feet deep in wet weather and 30 feet in dry. The temperature is 52° F.

SUFFIELD.

Nos. 28 and 29. Town water supply of Suffield.—These wells are owned by Paulus Fuller. No. 28 is 230 feet deep and has a diameter of 6 inches, and No. 29 is 240 feet deep and has a diameter of 8 inches. These two wells together pump at the rate of 300 gallons a minute into a standpipe containing 293,000 gallons. The water rises within about 60 feet of the surface and is rather highly mineralized. It can be used in boilers, however, but gives some scale. The wells enter rock about 10 feet below the surface of the ground.

No. 30. Public well, Suffield Village.—The depth of this well is 140 feet and its diameter is 6 inches. The water stands about 90 feet below

[a] See Mon. U. S. Geol. Survey, vol. 29, pp. 383-385, where a full record of the borings is given.

the surface and is raised by a common force-pump. It is used for drinking purposes only.

Additional Suffield wells.—The wells tabulated below are 6 inches in diameter and are in greater part in rock. The data were furnished by Mr. C. L. Grant, well driller.

Serial No.	Owner.	Depth of well.	Depth of water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
31	F. A Fuller	40	34	8
32	A. C. Harmon	45	39	3
33	Second Baptist Church	60	47	4
34	M. T. Newton	63	49	10

WEST SUFFIELD.

No. 35. West Suffield Hotel.—This well is 78 feet deep and 4 inches in diameter, and pumps 50 gallons of moderately hard water a minute. The water is said to have grown harder since the well was sunk. About 50 feet of the well is in rock.

No. 36. Mrs. John D. Loomis.—Depth, 100 feet; diameter, 4 inches; yield, 4 to 5 gallons a minute. Almost no water was found until a depth of nearly 95 feet was reached.

TARIFFVILLE.

No. 37. A. B. Hendryx.—Depth of well, 284 feet; depth of water, 278 feet; yield, 48 gallons a minute. Greater part of well is in rock. Data furnished by C. L. Grant, well driller, of Hartford.

BLOOMFIELD.

No. 38. Douglas & Cowles.—Depth, 100 feet; diameter, 6 inches. Well flows at the surface. Greater part of well is in rock. No data of yield given. Data furnished by Grant.

WINDSOR.

No. 39. Windsor Water Company.—Depth of well, 386 feet; depth of water, 326 feet; diameter, 6 inches. The pump yields 30 gallons a minute, which lowers the water 5 feet. The series through which the well was sunk is as follows: Sand, 17 feet; clay, 56 feet; hard red gravel, 50 feet; the remainder in sandstone with the exception of two layers of slate. Four analyses of the water have been made, according to which it ranges from moderately hard to excessively hard. It would seem that the water is extremely free from organic impurities, but shows sulphate of lime to the extent of 590 parts to the million, It is extremely hard to the soap test. When first drawn the water is said to give off a strong odor of sulphur.

No. 40. Christianson Brothers, Wilson Station.—Depth, 113 feet; diameter, 6 inches; yield, 50 gallons a minute. The well was drilled in the bottom of an old open well and lies in the rock. The water is good only for drinking and garden use. It is said that when the well was first drilled the water had a very strong odor, which disappeared after the well had been used a while. Data furnished by King and Mather.

No. 41. Misses Crompton, Windsor Heights.—One hundred and forty feet deep, but of small diameter. The water, which is raised by a pump, is of medium hardness. About 500 gallons per week is the ordinary consumption. The bottom of the well is in rock.

No. 42. Dr. H. J. Fisk, Windsor Heights.—About 135 feet deep and of small diameter. The water is pumped and hardly supplies the needs of the house and barn. It is of medium hardness, much softer than that of the neighboring surface well. The well was originally 85 feet deep, but was always more or less turbid. It was then deepened and the trouble disappeared. It enters the rock. For analysis see No. 7, table on pages 108–109.

No. 43. C. D. Reed.—Depth of well, 101 feet; depth of water, 89 feet; diameter, 6 inches; yield, 25 gallons a minute. Greater portion lies in rock. Data furnished by Grant.

HARTFORD.

No. 44. Hubert Fischer Brewing Company.—This well is 500 feet deep and has a diameter of 8 inches. The water rises to the surface of the engine-room floor, and is pumped at the rate of 75 gallons a minute. There is a difference of opinion as to whether the water is suitable for boilers. The well is drilled in the Upper sandstones, but unquestionably pierces the Posterior trap sheet, which outcrops at no great distance to the west.

Nos. 45, 46, 47, 48, and 49. Hartford Light and Power Company.—The wells of this company all lie in the rock. The data were furnished by Mr. Grant, who drilled them.

Data concerning wells of Hartford Light and Power Company.

Serial No.	Depth.	Yield per minute.
	Feet.	*Gallons.*
45	200	120
46	228	150
47	201	120
48	200	150

The above wells are all 6 inches in diameter. The deeper well described below has greatly diminished the supply of the earlier wells enumerated above. The data concerning this fifth well (No. 49) are as follows:

Depth, 620 feet; diameter, 12 inches. The meter has shown a capacity of 125 gallons a minute. The well is pumped and gives a more copious supply of water in rainy weather than in dry. The water is very hard from sulphate of lime and can not be used in boilers, but is employed for condensing. The well lies in rock. These wells are said to have seriously depleted the supply of water in the well of the neighboring Plimpton Company.

No. 50. Capewell Horsenail Company.—This well was drilled by Mr. C. L. Grant, who furnished the following data: Depth, 250 feet; diameter, 8 inches. The well is in rock and flows. Elisha Gregory, a well driller of New York City, states in his "Torpedo Circular" that the well was torpedoed by him at a latter date and that as a result the yield of the well was increased from 15 gallons a minute to 35 gallons. It is reported that the quality of the water was injured by the process. Inquiry at the office of the company shows that at last accounts the water was not used for anything, so heavily is it charged with mineral matter. For analysis see No. 3, table on pages 108–109.

No. 51. Patten's dyeing and carpet-cleaning establishment.—Depth, 110 feet; diameter, 6 inches; yield, 150 gallons a minute (data furnished by Grant). The amount which is ordinarily pumped is about 70 gallons a minute. The well lies in the rock. The water is unfit for boilers.

No. 52. Ropkins & Company, brewery.—Depth, 200 feet; diameter, 6 inches; yield, 60 gallons a minute (data by Grant). The ordinary yield of the well is 25 gallons a minute and it flows if left standing. The water is too hard for boilers.

No. 53. New England Brewing Company.—Depth, 462 feet; diameter, 10 inches. The ordinary yield to the pump is 350 gallons a minute, but 400 gallons a minute have been pumped without making any apparent impression on the well. The water is too hard for boilers.

No. 54. Columbia Brewing Company—This was formerly the Herold Capitol Brewing Company. Depth, 300 feet; diameter, 6 inches; yield, 250 gallons a minute (data by Grant). The amount of water pumped for common use is about 80 to 90 gallons a minute. The water is too hard for boilers.

No. 55. Armour & Company.—Depth below grade, 436 feet; actual depth below floor of basement, 420 feet; diameter, 6 inches. The water flows about 1 inch over the top of the pipe when allowed to stand, which brings the water level above the surface of a large part of the neighboring land. The ordinary yield is about 150 gallons a minute throughout the twenty-four hours, but a much larger yield could be obtained if desired. At the time these data were obtained no report had been received on the sample of water sent for analysis.

No. 56. Long Brothers hotel.—Depth, 200 feet, of which 186 feet are in the rock. Diameter of the portion which is in the rock, 6 inches. The well is pumped and yields a maximum supply of 35 gallons a minute. The water is too hard for boilers or for laundry work, but it is claimed that its quality is steadily improving.

No. 57. Brady Brothers, bottlers.—Depth, 277 feet, of which 244 feet lie in the rock. Diameter, 6 (?) inches. The well will yield 25 gallons a minute, but the amount usually pumped is 9 gallons a minute. The water has never been tried in boilers, but is used for making all kinds of soft drinks. At times it becomes clouded, but in a few days it clears again.

The above data were obtained from Brady Brothers.

No. 58. Brady Brothers.—Mr. Grant reports the following data concerning a well drilled for Brady Brothers, which is probably another than the one just described: Depth, 159 feet; diameter, 6 inches; yield, 29 gallons a minute.

No 59. "Allyn House."—Depth, 318 feet, of which 288 feet are in rock. Diameter, 4½ inches; yield, 60 gallons a minate. The ordinary consumption for eighteen hours is 30,000 gallons. The water, which has been analyzed, is too hard for boilers, but has improved in quality with time

No. 60. W. C. Wade, corner State and Front streets.—Depth, 125 feet, of which 113 feet are in rock. The maximum yield is 200 gallons a minute, though only 50 gallons a minute are in common use, chiefly for refrigerating purposes. The water, which rises to within 13 feet of the surface, is a little too hard for boilers. Its summer temperature is 54° F.

No. 61. W. C. Wade, "Public Market."—Mr. Grant sends data of a well drilled for Mr. Wade at the "Public Market," about one-third of a mile from the well above mentioned, as follows: Depth, 225 feet; depth of water, 183 feet; yield, 28 gallons a minute.

No. 62. Keney Park.—Depth, 200 feet; diameter, 6 inches. The well flows, but the yield was not given. Data by Grant.

No. 63. Keney Park.—Depth of well, 170 feet; depth of water, 138 feet; yield, 5 gallons a minute. Data by Grant.

Other wells in Hartford.—The following list of wells in Hartford was obtained from Mr. Grant. The wells are all 6 inches in diameter and have the greater part of their depth in rock.

Additional wells in Hartford.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minut
		Feet.	*Feet.*	*Gallons.*
64	F. C. Rockwell	115	111	60
65	E. C. McCune	110	87	18
66	Frank S. Tarbox	57	48	5
67	.....do	67	56	3
68	T. C. Moore	60	40	3
69	G. E. Hubbard	37	37	8
70	.....do	62	40	12
71	St. Mary's Home	100	97	15
72	Walter S. Mather	37	37	3
73	J. Dart & Son	24	12	3
74	.....do	74	Flows.	22
75	Hotopp & Carlsson	155	130	10
76	Wm. O'Brien	50	30	11
77	Addison & Impey	63	36	5
78	Johnson & Weeks	49	29	10
79	Wm. Rogers	110	35	5
80	Peter Peterson	50	40	3
81	A. Hepburn	50	39	5
82	C. L. Bailey	48	27	12
83	H. J. Abbey	35	18	3
84	Andrew Nason	28	16	4
85	B. L. Chappell	50	34	4
86	G. E. Hurd	50	39	4
87	M. H. Ericksen	37	24	10
88	O. W. Crane	60	30	2
89	C. A. Green	50	38	3
90	J. C. Parsons	136	86	1
91	O. Bengston	50	25	10
92	F. H. Seymour	70	40	8
93	G. J. Maher	65	47	11
94	A. M. Weber	75	50	5
95	D. F. Keenan	140	111	10
96	The "Linden"	240	215	45
97	Hartford Woven Wire Mattress Co	246	230	10

WEST HARTFORD.

No. 98. H. O. Griswold.—Depth, 152 feet; diameter, 6 inches. The water has been analyzed, and contains three times as much lime as is desirable in drinking water. In consequence it is very hard and is used very little. The ordinary depth of the water is 137 feet, but it has been lowered by pumping to within 40 feet of the bottom. The well runs through loam and hardpan for 10 feet, the balance being in rock.

Other wells in West Hartford.—The following supplementary list is furnished by Mr. Grant. All the wells are 6 inches in diameter, except No. 101, which is 4 inches.

Additional wells in West Hartford.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
99	Paul Thomson	40	18	12
100	James Thomson	110	95	35
101	E. C. Wheaton	135	115	34
102	Mrs. K. Gallagher	53	44	2½
103	G. V. Brickley	30	15	12
104	W. E. Howe	62	18	2
105	H. C. Long	41	25	12
106	L. N. Burt	52	39	4
107	P. H. Reilly	206	160	42
108	D. F. Crozers	101	87	32

Well No. 107, which is in the trap, lies on the ridge south of the village of West Hartford. The trap belongs to the Posterior sheet, and is comparatively thin. The thickness of the trap at this point has not been determined, but at least two-thirds, and possibly three-fourths, of the depth of the well must be in the Posterior shales which underlie the sheet. On comparing this depth with the depth of water in the well, it will be readily seen that it is very probable that the water does not come from the trap at all, but from the underlying shale. In consequence the well can not with propriety be classed as a well of the trap.

BURNSIDE.

No. 109. East Hartford Manufacturing Company.—Depth of well, 398 feet; diameter, 6 inches. No estimate of the yield in gallons could be obtained, but the well is said to flow constantly 1 inch deep over the top of a 10-inch pipe. If this statement is correct, this is the largest flowing well in the lowland. The water has been analyzed by Springfield chemists and found to carry considerable mineral matter, and is too hard for boilers. The well is entirely in rock.

No. 110. J. H. Walker, paper mill.—The water of the well is excellent for drinking, but hard. Measurement showed the well to be pumping 8 to 10 gallons a minute. As it is separated from the last-mentioned well only by the breadth of the Hockanum River, the rock conditions are probably the same as in that well.

SOUTH MANCHESTER.

M. S. Chapman.—These are four private wells, each 6 inches in diameter, used, as I understand, to supply fish ponds. Their depths and the amounts of water they yield are shown below:

Wells of M. S. Chapman.

Serial No.	Depth.	Yield per minute.
	Feet.	*Gallons.*
111	225	30 to 40
112	125	10 to 12
113	75	2½
114	75	None.

The wells enter the rock at a depth of 20 feet, and the first three flow at the surface of the ground. The water is of good quality and, it is said, can be used for any purpose, although it is distinctly hard by the soap test.

No. 115. Cheney Brothers, silk manufacturers.—This is one of the most remarkable wells in the lowland, and the data concerning it have been carefully preserved. The well is 457 feet deep, and its diameter is 8 inches for the first 383 feet, below which it is only 6 inches. The well flows at the surface at the rate of 250 gallons a minute, while the experiment of pumping 650 gallons a minute for ten consecutive minutes lowered the water level only 10 or 12 feet below the surface. The water is unfortunately very hard, but the well is used to its full capacity in washing colored silks, the water of the well remaining at the proper temperature summer and winter. Below the first 12 feet the entire well is in red sandstone. For analysis see No. 6, table on pages 108–109.

NORTH MANCHESTER.

No. 116. F. J. Sharp.—Depth of well, 100 feet; depth of water, 99 feet; diameter, 6 inches; yield, 10 gallons a minute. The water has been analyzed and proves to be very hard. Eighty-one feet of the well lie in red sandstone.

No. 117. American Writing Paper Company (Oakland Paper Company division).—Depth, 300 feet; diameter, 4 (?) inches. The water flows over the top of the pipe at a rate of probably 10 to 12 gallons a minute. The water is hard and is used for drinking purposes only. The well lies entirely in the rock, which, in the stream near by, is seen to be rather loose in texture and to be filled with fragments of the crystalline rocks of the neighboring eastern upland.

The wells east of Hartford along the Valley of Hockanum River, comprising Nos. 109 to 117, inclusive, all flow at the surface of the ground, except No. 114, which is dry, and No. 116, which rises to within 1 foot of the surface. In general the yield of these wells is exceptionally large, but the water is uniformly hard.

WETHERSFIELD.

The following data were kindly furnished by Mr. Grant concerning wells at this place.

Wells in Wethersfield.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
118	J. H. Rabbett	30	28	8
119	Rev. Lynch	70	40	35
120	C. I. Allen	192	85	15

No. 120 is in trap rock. All are 6 inches in diameter.

ROCKY HILL.

No. 122. W. E. Pratt.—This well is located in the thin posterior sheet of trap. It was drilled in the bottom of an old open well, 20 feet deep, which entered the rock for a distance of 6 feet. From this point the well was drilled 30 feet through trap when it broke into the underlying sedimentaries, which it pierced to the depth of 1½ feet. This well therefore gives a section of 14 feet of soil, 36 feet of trap, and 1½ feet of sedimentary rock—a total depth of 51½ feet. This brings the bottom of the well about 50 feet above the surface of Connecticut River, which flows by it only a few hundred feet eastward. The diameter of the well is 6 inches and the maximum amount of water obtainable is a little less than 1 gallon a minute. The well pumps dry in thirty minutes. The water is fair for drinking, but is excessively hard.

No. 123. J. K. Green.—Depth of well, 26 feet; depth of water, 25 feet; diameter, 6 inches; yield, not given. The well is in trap rock. Data by Grant.

KENSINGTON, BERLIN JUNCTION.

No. 124. New York, New Haven and Hartford Railroad power house.—Depth, 300 feet; diameter, 6 inches; yield, 120 gallons a minute. Data by Grant. Water is raised by a common pump. It is permantly hard and unfit for boilers.

Wells at Berlin and Berlin Junction.—The following list of wells at Berlin and Berlin Junction was furnished by Mr. Grant. All are 6 inches in diameter.

Additional wells at Berlin and Berlin Junction.

Serial No.	Owner.	Depth of well.	Depth to water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
125	Berlin Brick Co	60	49	....
126	....do	70	62	....
127	Yale Brick Co	100	81	10
128	F. L. Wilcox	71	40	....
129	J. B. Smith	200	130	6

NEW BRITAIN.

No. 130. Hotel Russwin.—The depth of the well is 152 feet, and the depth of the water at the lowest 130 feet, but if the well is allowed to stand the water flows at the level of the engine-room floor, which is 10 feet below grade. The ordinary consumption is fully 10,000 gallons a day. The water is very pure and can be used for all purposes. Certain features of this well which have a distinct bearing on the theory of underground flow will be considered in connection with the discussion of that subject.

Other wells.—The following list is from Mr. Grant:

Additional wells at New Britain.

Serial. No.	Owner.	Depth of well.	Depth to water.	Yield per minute.
		Feet.	*Feet.*	*Gallons.*
131	Dennis & Co	195	....	40
132	A. J. Sloper	70	....	45
133	A. B. Johnson	60	....	12
134	W. E. Bradley	40	22	4
135	J. P. Curtis	250	237	12
136	William Derby	50	31	6
137	F. B. Wischek	50	38	6

Nos. 132 and 134 are sunk in the trap of the Posterior sheet and may lie entirely in volcanic rock. All the wells are 6 inches in diameter.

CROMWELL.

Nos. 138 and 139. New England Brownstone quarry.—The wells are 63 feet and 132 feet deep, respectively. The water, which was raised with a pump, was thoroughly tried in the boilers and was found totally unfit for the purpose.

MIDDLETOWN.

No. 140. Goodyear Rubber Company.—The well, which is 384 feet deep and 6 inches in diameter, pumps about 40,000 gallons in twenty-four hours, or nearly 30 gallons a minute. The water is called good, but has not been tried in the boilers on the ground that it would probably prove too hard. It is reported that the well flows at the surface. For analysis of water from a Middletown well, see No. 9, table on pages 108–109.

MERIDEN.

Nos. 141–145. Edward Miller & Co.—There are on the premises of this company five artesian wells, all 8 inches in diameter, ranging from 250 to 300 feet deep, and bored into red sandstone rock, which at this place lies from 6 to 10 feet below the surface of the ground. The output of these wells was measured when they were first bored and varied in the different wells from 10 to 80 gallons per minute. The supply thus measured was obtained by means of an ordinary suction pump, which, operated at the rate named, lowered the water about 25 feet below the surface—as low as it could be pumped with that form of apparatus. A few years ago the Pohle air system was installed for raising the water from the wells. This system works by compressed air and forces the water from depths of 70 to 90 feet. With this apparatus a very greatly increased output was obtained, which now supplies all the needs of the company. The water from these wells is all discharged into one large system, from which it is circulated through the factory. It is not easy to determine exactly the amount of water used, but by estimate it is between 75,000 and 100,000 gallons a day of ten hours. There is no doubt a much larger quantity than this could be obtained if needed. The water is satisfactory for all manufacturing purposes except for making steam, for it holds considerable mineral matter in solution and is rather hard for use in boilers.

No. 146. Foster, Merriam & Co.—The well is 300 feet deep, 200 feet of which are in rock. The well flows at the surface if allowed to stand, and pumps, at the maximum, 10,000 gallons an hour—about 170 gallons a minute. The water is too hard for boilers and contains a certain amount of sand. The outer pipe is 8 inches in diameter and the inner 6 inches.

No. 147. International Silver Company, Factory "E" (Meriden Britannia Company).—Depth of well, 560 feet; depth of water when the well is not pumped, 555 feet; diameter, 6 inches. No data of yield could be obtained. The water is very hard and wholly unfit for boilers. The section traversed in drilling is as follows: Soil, 9 feet; gravel, 18 inches; quicksand, 90 feet; balance mostly rock.

No. 148. Meriden Curtain Fixture Company.—Depth, 305 feet; diameter, 6 inches. The amount of water in common use for a working day of 10 hours is 15,000 gallons, or about 25 gallons a minute. The water is suitable for use in boilers. About 255 feet of the well are in rock.

WELLS AT OTHER PLACES IN NEW HAVEN COUNTY, CONN.

The following data, which have been put in tabular form, were received from Mr. Grant:

Additional wells of Connecticut Valley.

Serial No.	Town.	Owner.	Depth of well.	Depth to water.	Yield per minute.
			Feet.	*Feet.*	*Gallons.*
149	Yalesville	G. I. Mix & Co.	100	....	40
150		J. H. Yale	67	22	3
151		C. W. Michaels	90	72	....
152	West Cheshire	Cheshire Manufacturing Co.	150	....	100
153	Mount Carmel	Chas. Wheeler	50	17	6
154		Sylvester Peck	36	21	5
155		H. D. Clark	60	Flows.	22
156	Quinnipiac	C. T. Stevens	40	Flows.	4
157	North Haven	F. L. Stiles	83	....	35
158		I. L. Stiles & Son	102	....	30
159		H. P. Smith	116	100	18
160		N. W. Hine	125	115	16
161	Whitneyville	H. Stadtmiller	85	58	5
162		J. H. Burton	50	40	22
163		W. F. Downer	67	40	5
164		W. F. Downer	50	42	7
165		Edward Davis	56	47	11
166		Edward Davis	13	11	20
167		G. W. Ives	65	52	8
168		Mr. Brock	50	35	24
169		Mr. Johnson	58	33	25
170		W. Mansfield	48	37	....

These wells are all 6 inches in diameter, and probably all of them enter rock, except, possibly, No. 166.

NEW HAVEN.

No. 171. Hoyt Beef and Produce Company.—Depth, 600 feet, of which 200 feet only are in rock; diameter, 6 inches. The well flows at the rate of 3 gallons a minute, yielding water of very good quality which has not been analyzed.

No. 172. Lavigne Automatic Machine Company.—Depth, 95 feet; diameter, 6 inches; yield, 12 to 15 gallons a minute. The data concerning the quality of the water seem to be favorable in a general way. The well passes through 53 feet of quicksand and 42 feet of red sandstone.

No. 173. New England Dairy Company.—Depth about 160 feet; diameter of outside pipe 6 inches, and of inside pipe 4 inches; yield, 20 gallons a minute. About 95 feet of the well are in rock. The water can be used in boilers. For analysis see No. 12, table on pages 108-109.

OTHER WELLS NEAR NEW HAVEN.

The following data from New Haven and other towns of the lower valley are from Mr. Grant:

Additional wells at New Haven, Northford, and Montowese.

Serial No.	Town.	Owner.	Depth of well.	Depth to water.	Yield per minute.
			Feet.	*Feet.*	*Gallons.*
174	New Haven	G. W. Ives & Son	50	Flows.	
175		do	200		10
176		Seamless Rubber Co	160		10
177		H. H. Olds & Co	75	40	5
178		N. W. Capin	245	134	40
179	Northford	L. A. Smith	50	Flows.	
180	Montowese	J. F. Barnes & Co	36	32	7

All are 6 inches in diameter.

FAIR HAVEN.

No. 181. J. R. King.—Depth, 203 feet; diameter, 6 inches. When pumped at the rate of 40 gallons a minute the water level did not fall at all. The well is entirely in rock, and no water was found until after a depth of 100 feet was reached. The water gave no scale when used in boilers. Data are from R. A. Mather, of King & Mather, well drillers.

WELLS STOPPING AT SURFACE OF ROCK.

Another group of wells of an entirely different nature from those of the previous list comprises the deep wells of the drift, which were sunk to the top of the rock and stopped at that point. Data concerning a few of these are given on the following pages.

WELLS IN MASSACHUSETTS.

NORTHAMPTON.

No. 182. Belding Brothers' Silk Company.—This well is a close neighbor of the famous dry well, No. 1, of this paper. It passes at a considerable depth through a dense layer of some sort and then continues through gravel to the rock, which is here 150 feet below the surface. The yield of 20 gallons a minute does not materially affect the water level, which is about 20 feet below the surface of the ground. The water, which has not been analyzed, can be used in boilers, but is principally employed in dyeing. The diameter of the well is 12 inches.

SPRINGFIELD.

Nos. 14 and 15. Springfield Breweries Company.—These wells and the rock well belonging to the same company have been mentioned on an earlier page of this paper, under the numbers here given, and do not need further description. It is interesting, however, to note that the quality and quantity of the water changes as soon as the rock is entered.

No. 183. Phelps Publishing Company.—Depth, 78 feet; diameter, 2½ inches; yield, 10 gallons a minute. The water is too hard for boilers but is excellent as drinking water. This well, which stops at the rock, is pumped.

No. 184. Cooley's Hotel.—This is a driven well, 86 feet deep and 2½ inches in diameter, that yields over 20 gallons of water a minute. The water is soft and could probably be used for boilers. The well runs to the surface of the rock, at which point the water is obtained.

WELLS IN CONNECTICUT.

MERIDEN.

Nos. 185, 186, 187, 188, and 189. Bradley & Hubbard Manufacturing Company.—In 1890, five wells, each 8 inches in diameter, were driven to the rock by this company, reaching the following depths: No. 1, 203 feet; No. 2, 208 feet; No. 3, 256 feet; No. 4, 327 feet; No. 5, 281 feet. Only Nos. 1, 2, and 3 are used, as Nos. 4 and 5 did not produce water enough to pay for connecting. No estimate of the amount of water obtained from Nos. 1, 2, and 3, separately, can be given; but the three wells together furnish about 6,000 gallons an hour. None of the wells flow. The water is of fair quality, but is rather hard for use in boilers.

These five wells, all over 200 feet deep, run to the rock only. Besides their interest from the standpoint of the water supply, they give some very interesting suggestions concerning the depth of the unconsolidated deposits at this point, and they hint at the presence of a very deep depression in the underlying sedimentary rocks along the general line of the great fault which separates the Hanging Hills on the west from Lamentation Mountain on the east.

It should be noted that in this paper no account is given of those wells which lie wholly in the unconsolidated deposits of the area and which do not come into relation with the rock at all. There are many of these wells, and they seem to be especially in favor in the region lying between Springfield and Holyoke and along the Chicopee River. They present innumerable local problems of a diverse and often complicated nature, and any results which might be obtained from their study would be of relatively little economic importance.

TRIASSIC ROCKS OF THE CONNECTICUT VALLEY AS A SOURCE OF WATER SUPPLY.

By M. L. Fuller.[a]

INTRODUCTION.

In the foregoing paper of Mr. W. H. C. Pynchon detailed descriptions have been given of a large number of wells of the Triassic area of Massachusetts and Connecticut, together with a considerable amount of data relating to the quantity and quality of the water supplies which are obtained. Many facts bearing upon the occurrence of the waters have been presented and certain deductions that are of local application have been made.

The purpose of this paper is to supplement the foregoing by a general summary of the water conditions in their broader relations and to point out the significant features of the water supply of the region. The effort has been made to describe these features as concisely as possible rather than to present elaborate discussions.

In addition to the conclusions presented, a few notes on points of special interest to the driller have been appended.

UNDERGROUND WATER CONDITIONS IN THE AREA.

SOURCES OF WATER.

CONGLOMERATES.

Near the edge of the area, where the Triassic beds are in contact with the adjacent crystalline rocks, both on the eastern and western sides, there are somewhat marked bands of conglomerates which were deposited along the shores of the Triassic sea that occupied the basin.

[a] The descriptive portions relating to wells are based on the field observations of Mr. W. H. C. Pynchon and are compiled from notes furnished by him. The present writer alone, however, is responsible for the interpretations of the various features and for the views expressed in regard to the nature, condition, and prospects of the water supplies in the Triassic area.

The pebbles of the conglomerate were derived from the adjacent crystalline rocks, and some of them are of large size. The matrix is of various degrees of fineness, ranging from coarse sand to clay. In Massachusetts the conglomerate on the west side of the Triassic area is known as the Sugarloaf arkose and on the east side in part as the Sugarloaf arkose and in part as the Mount Toby conglomerate, the latter occurring in a narrow belt between the Sugarloaf arkose and the crystalline border in the southern part of the State. The same bands extend into Connecticut and possibly continue throughout the entire southern part of the area, but they have not yet been differentiated in that region.

The conglomerates of the western border would at first sight seem to offer greater possibilities for the storage of artesian waters than any other rocks in the valley. They present their upturned edges to the waters that pour down from the western upland and are comparatively undisturbed by fracture and displacement, but because of their situation, outside of the immediate Connecticut Valley, where the principal towns are located, very few deep wells have been sunk in them, and it is therefore impossible to say whether actual results would agree with the assumed conditions. The few deep wells near the western border of which records are at hand do not reach the average depth of those of the central portion of the valley, and the fact that these few wells obtain only very moderate supplies is therefore inconclusive. Farther away from the border, as at Northampton, a well was sunk to a depth of 3,700 feet through rocks classed by Professor Emerson as Sugarloaf arkose without encountering water. Again, near Westfield, a well was sunk at Daniel Brothers' paper mill to a depth of 1,100 feet in the Sugarloaf arkose, likewise without success. In fact, so far as is known, nearly all wells that have reached great depths without procuring water have been sunk in the conglomerate or arkose.

On the eastern side of the valley the conditions are less favorable than on the west. The eastward sloping beds of the narrow belt of Mount Toby conglomerate that lies at its contact with the crystalline rocks along the eastern edge of the area abut against a system of faults that presumably constitutes an extended line of leakage, drawing water from the adjacent conglomerates.

SANDSTONES.

Distribution and character.—The sandstones, because of their great area and their water-holding capacity, are the principal source of water in the Triassic area. Except for the conglomerate belts along the eastern and western boundaries, the shale band near Connecticut

River at the center of the valley, and the trap ridges, the main portion of the area of Triassic rocks is underlain by sandstone. Many important towns are located in the sandstone area and a large number of wells obtain good supplies of water from this rock.

In character the sandstones vary from fine to coarse grained, and are usually some shade of red or brown in color, though buff and other varieties are known. They are often of very even texture and frequently occur in thick beds, so that from many standpoints they constitute an admirable building stone, for which purposes they are extensively quarried, especially at Longmeadow in Massachusetts and Portland, Cromwell, and Tolland in Connecticut. They are interspersed with beds of shale ranging in thickness from mere films up to beds many feet thick, which frequently serve as confining strata for the water-bearing beds.

A test of the brownstone from Portland, Conn.,[a] shows that this sandstone when previously dried and then immersed in water for three months will increase in weight from 150 to 154 pounds, showing an absorptive ratio of 4 to 150 or about one-fortieth of the weight of the block. This is equivalent to approximately 2 quarts of water to every cubic foot, and shows that, under favorable conditions, the rock has immense capacity as a reservoir.

Water supply.—The sandstones may be studied to good advantage in the quarries which lie within their borders at Longmeadow, Cromwell, or perhaps best of all in the great brownstone quarries at Portland, directly across the Connecticut River from Middletown, Conn. Here great pits have been opened in the sandstone to a depth of 200 feet, and the water-bearing character of the rocks may be studied. Although the sandstone when quarried contains a certain amount of "quarry water" when first removed from the pit, no water appears to percolate from the face of the stone, but water everywhere emerges from along the bedding planes, especially along the shaly partings, where, dripping down, it darkens the quarry walls over large surfaces.[b] The water flows chiefly down the slope of the dip and enters the rock in greatest amount during the spring months, at which period slight amounts may also enter from the opposite side. The beds slope from the Connecticut River toward the quarry, but the fluctuation in the amount of water entering the quarry with the season indicates its derivation directly from rainfall or melting snows. Throughout the busy season pumps keep the quarries sufficiently clear of water to permit work to be done.

A well showing features somewhat analogous to those seen at the

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[a] Stone, vol. 9, June, 1894, p. 20.

[b] Stone, vol. 9, pp. 42–43, 1898.

quarries is located at the bottling establishment of M. M. Bacon, on Morris street, Hartford. It is an open well, 34 feet deep and about 2½ feet in diameter, about 14 feet of its depth being in shales. In one corner of the bottom of this well is a fissure large enough to allow the insertion of the fingers, from which the water flows in such abundance that it is impossible to keep the well dry enough for convenient cleaning. The draft on this well is a thousand gallons a day the year round, and in summer it will amount to half as much again. Though this well is in a city of 90,000 inhabitants, and is situated at the foot of a considerable drainage slope, yet the analysis which the city made of the water shows that it is very pure.

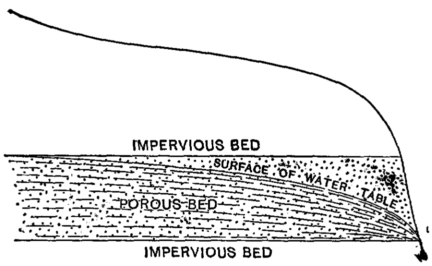

FIG. 20.—Depression of water surface at point of leakage in sandstone.

From the fact that the entrance of water into the quarries and in the well mentioned is from the bedding planes, it might appear that but little was contained in the body of the sandstones themselves. This appearance is, however, probably due to the artificial conditions of the exposures in the quarries. The sandstone, because of its open and porous texture, probably behaves much like a homogeneous mass of sand, from which the flow or leakage takes place along its contact with an underlying impervious bed or at the level of saturation. In such a mass the water table, as the upper surface of the water body which it contains is called, is depressed at the point of leakage, but rises gradually as the distance from the point of outflow increases (see fig. 20). Thus, in a sandstone bed it is but natural that the outflow should be only at its base, although perhaps a few feet back from the exposed face the whole bed may be saturated. This is true of practically all natural outcrops, even of the famous water-bearing Dakota and similar sandstones of the central West.

SHALES.

Character.—The largest body of shales in the Triassic area occurs near the central part of the valley, in the vicinity of Connecticut River. They are known in Massachusetts as the Chicopee shale, are grayish in color, and are interbedded with many sandstone layers. At the bottom they grade into the Longmeadow sandstone. In addition to the Chicopee shales, occasional thin shaly beds occur in the sandstones or conglomerates throughout the entire area.

Theoretically shales are not at all adapted to hold ground water, but in the shaly rocks under discussion there is considerable lime, and possibly, in the deeper portions, salt and gypsum, which by solution may readily give rise to channels for underground waters. The interbedded sandy layers and the bedding planes themselves would also furnish numerous channels for the passage of such waters.

Water supply.—That the shales bear considerable quantities of water is apparently shown by the success of the wells at Holyoke, Springfield, and other points in the belt of the Chicopee shales, although it is not impossible that the deeper wells enter the underlying Longmeadow sandstone and obtain a part of their supply from that formation. Among such wells may be mentioned Nos. 3, 4, 5, 7, 9, 10, 11, and 12, mentioned by Mr. Pynchon in the preceding paper. Wells 16 to 22 generally start in the Chicopee shales, although several of them may penetrate sandy beds, probably of the underlying Longmeadow sandstones.

Depth of wells.—Of the wells noted, two are between 100 and 200 feet, five between 200 and 300 feet, four between 300 and 400 feet, two between 400 and 500 feet, and three over 500 feet. This indicates that in general the wells must be fairly deep in order to obtain satisfactory supplies in the shale area.

Character of water.—Because of the presence of lime and other soluble mineral substances the waters from the shales are generally highly mineralized and can seldom be used in boilers.

TRAPS.

Catchment conditions.—Of the rocks of the Triassic area the traps present the most unfavorable conditions for water storage. This is because of the lack of porosity of the rock itself and of the absence of bedding planes along which the water might flow. Superficially they are extensively jointed and would absorb and hold much water if the open joints reached any considerable depth. It is probable, however, that below a relatively few feet from the surface the joints are in many places not sufficiently open to admit the passage of water. Moreover, the form of their outcrops is most unfavorable for the reception of the surface waters, as their exposed edges stand high above the surrounding plain, and usually rest upon an elevated pedestal of sediments. The western faces of the trap ridges, on which side they are most eroded, are precipitous cliffs, while their unbroken eastern slopes, plunging downward toward the plain at an angle of about 15°, send the waters collected from the rains in rushing brooks to the lowland. Indeed, throughout the valley the foot of the eastern slope of the Main sheet of trap is the favorite location for reservoirs. Hartford receives its water supply from a chain of such lakes that stretches for several miles along the eastern foot of the Talcott Range, while there are at least five reservoirs that use as their watershed the back slopes of the Hanging Hills. Farther down the valley Beseck Lake, Paug Pond, and Lake Saltonstall derive their supply from similar sources.

Wells in the trap.—Among the more interesting of the wells deriving their supply from the trap are those at Cedar Mountain, Wethersfield, just southwest of Hartford (No. 121, B. and C., of Mr. Pynchon). These wells are on the property of Dr. Gordon W. Russell, who sunk the wells largely as an experiment, and who has shown much interest in scientific matters. The mountain is a part of the ridge of the Main trap sheet, and has a maximum elevation of about 360 feet above the sea. Its western face is very steep, dropping 250 feet to the plain within a distance of two-fifths of a mile, and is actually precipitous near the summit. The eastern face slopes more gradually, dropping about 120 feet to the valley, occupied by shales, about three-fifths of a mile distant. It is in all respects a typical trap ridge.

Well A is an ordinary open well and was dug to supply the needs of the farm house. It was opened 9 or 10 feet to the rock, but the water became shallow in summer. It was then sunk 1 or 2 feet into the loose, greatly jointed surface trap, and has since given an abundance of water for domestic uses. The supply, however, fluctuates regularly with the wetness or dryness of the season. From the well mouth the mountain side with its drift covering rises steadily for two-fifths of a mile to the west till it reaches the crest, which is about 100 feet above the well. The supply is clearly the surface water contained in the soil and in the heavily jointed upper surface of the trap, the source also of a little stream which lies a little farther up the ridge.

Well B is located about 200 feet south of well A. It passes through 9 feet of soil and then through about 290 feet of trap rock, at which point the string of drilling tools wedged fast, possibly along a joint plane. The well is 6 inches in diameter. On illuminating it brightly for a considerable depth, by light reflected from a mirror, it appeared that no water came into it except from the shattered upper surface of the trap sheet, as in well A. The drill had not entered the underlying sediments when the well was visited in 1902, notwithstanding the fact that the bottom of the well was much below the level of the western plain.

Well C is located about three-fourths of a mile farther south and a little farther east than the other two wells. It has a depth of 103 feet. It was thought from the residue brought up by the sand bucket that the well entered the sedimentary beds below, but in view of the record of well B and the thickness of the Main sheet, this is extremely doubtful. Water was struck at a depth of 38 feet from the surface, in a joint, the yield being 32 gallons an hour. At the present depth the well is capable of giving 90 gallons an hour, the water probably coming through joints from a level below the well bottom, and rising to within 25 feet of the surface. During the drilling light was reflected down the bore and water was seen coming in through the trap, and, in the opinion of the driller, Mr. H. B. King, of Hartford, from the down-hill side. However this may be, we have here a well near the summit of the mountain whose bottom is above the level of the lowlands on either side, with water coming in through the trap and rising to a point about 175 feet above the plain three-fourths of a mile to the west and about 70 feet above the valley one-fourth of a mile to the east. The top of the well is about 280 feet above sea level.

GEOLOGY.

STRUCTURE.

Attitude of beds.—The dip of the beds of the Triassic area averages about 15°, or nearly 2,000 feet to the mile. The catchment area of an individual bed having a dip as steep as this is very narrow as compared

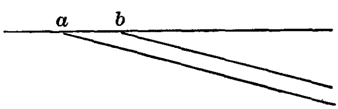

FIG. 21.—Outcrop of bed dipping 15°.

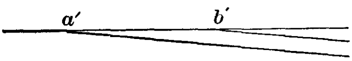

FIG. 22.—Outcrop of bed dipping 5°.

with that of a more gently inclined bed. Thus, in figs. 21 and 22 beds having the same thickness and dipping 15° and 5°, respectively, are represented as outcropping on a level surface. It will be seen that the catchment area is smaller at the outcrop of the more steeply dipping bed.

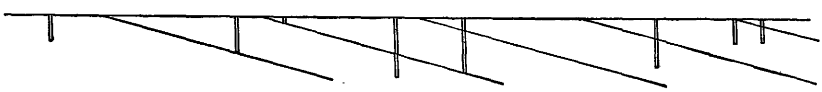

FIG. 23.—Conditions and beds encountered by wells.

Because of the steep dips and the rapidity with which the beds are carried to great depths a single water horizon is available only within very narrow limits. In fact, in going from west to east practically every well, unless the wells are very close to one another or penetrate to a great depth, draws from a separate horizon (see fig. 23). This is the explanation of the great variability in the quantity and quality of the water drawn from wells in the Triassic area.

Along the western rim of the area the Triassic rocks lie about 200 feet higher than in the lowlands of the Connecticut Valley. If the beds were continuous and were near enough to the surface in the center of the valley to be reached by the drill, artesian flows would probably be uniformly obtained. In reality, however, the beds are not continuous, but are broken by faults along which the waters can escape, and, moreover, they lie at such great depths that they can not be economically reached. The bed from which a 500-foot well draws its supply will outcrop within about a quarter of a mile of the well.

Direction of movement of water.—Although extensive artesian fields are unknown, and are in fact not to be expected, isolated flowing wells sometimes occur. A number have been mentioned in the description of the wells by Mr. Pynchon, pages 76 to 96 of this report. In most instances the water moves down the dip, but in a few wells the reverse seems to be true.

A well of the Connecticut Valley Brewing Company, at Thompsonville (No. 26 of Mr. Pynchon's list), is located on a neck of land that projects westward into the Connecticut River, to which a steeply sloping bank is presented. The water is obtained from the rock about 30 feet from the surface, the water-bearing bed rising toward the

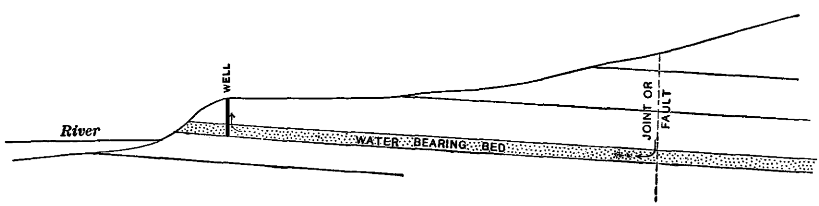

FIG. 24.—Underground conditions in Thompsonville well.

river and outcropping in the steep bank mentioned. The well yields 8 gallons a minute, a quantity many times greater than any amount that could be absorbed from the steep and narrow catchment area. The water can not possibly come from the river, as its level is about 25 feet higher than the level of the water in the river, but must come up the dip from the east. As the beds never bend upward and appear at the surface, but maintain their uniform dip to the east, the water can not be derived from any outcrop lying farther east. Joints or faults apparently present the only means by which the water can be supplied (fig. 24).

A well drilled a few years ago on Talcott Mountain, near the site of the "Old Talcott tower," of local fame, was situated on the crest of the ridge at a point a little over 900 feet above the sea. The face of the mountain falls away steeply to the west 700 feet in two-fifths of a mile. At a depth of 200 feet the drill passed through the trap into the underlying sediments, and at this point the only water was found. Presumably it was in small quantity, as the drilling was carried 700 feet farther, but without results. As the crest of the mountain is 700 feet above the western plain, and as the trap was left at a point only 200 feet down, the contact upon the face of the mountain must be over 500 feet above the plain. This would bring the outcrop of the contact only a little over one-tenth of a mile west of the well and on a precipitous portion of the mountain face. It is thought probable by Mr. Pynchon, who reported the well, that the water found, however small the quantity, came up rather than down the slope of the beds. Well No. 52, Ropkins & Co., Hartford, is probably of the same general type, as when allowed to stand the water rises in the well far above the water levels of the Park and Connecticut rivers, which are close by.

JOINTS.

Occurrence.—Joints are especially numerous throughout the Triassic area, the traps, conglomerates, sandstones, and shales all showing many of them. In the traps, as has been pointed out, the rock is sometimes superficially broken up into a mass of small blocks, among which the water freely circulates.

Joints are also well developed in the shales. This may be seen readily in the city quarry at Hartford, previously mentioned, where the shales forming the floor of the quarry are traversed for long distances by joint cracks that divide the rock into the diamond-shaped blocks already described. In this quarry a number of feet of the indurated shale have been removed, leaving an escarpment of sedimentary rocks, averaging fully 10 feet high, immediately below the trap. The joint planes bounding this face cut through many layers, some of them probably traversing the whole vertical distance. An examination of any fairly extensive outcrop of shale within the lowland will show that jointing is developed everywhere to the same extent.

The sandstone beds are likewise commonly jointed when exposed at the surface, but to what depth pronounced jointing extends is unknown, although the jamming of drills in certain wells may indicate that fissures extend to considerable depth in the sandstone. Thus in the well of the Hubert Fischer Brewing Company, of Hartford (No. 44), the drill, after penetrating "blue stone," entered what seems to have been a conglomerate, soon after which it became jammed, presumably by encountering a joint plane. On its liberation water began to flow. Again, at Hotel Russwin, New Britain, a well penetrated 140 feet of sandstone, etc., without finding enough water to keep the drill wet, but at that depth the drill became jammed in what appeared to be a crack about 2 inches wide. As in the preceding well, an ingress of water followed the loosening of the drill. The apparent breadth of the crack may in reality be due rather to the presence of soft, decomposed rock along the joint plane than to an actual opening of the size indicated.

Effect.—Several different, and in two instances entirely opposite, effects are produced by the joints of the Triassic rocks. Superficially they greatly favor absorption of water, and it is probable that the shallow supplies, especially those reached by wells 50 feet or less in depth, are greatly increased by their presence. Doubtless the most common result of the jointing, however, is to break the continuity of the shale or other confining beds associated with the water horizons, and thus to permit sufficient leakage in most instances to destroy the prospects of artesian flows. In a few cases, on the other hand, the supplies of deep beds seem to be derived from joints rather than from outcrops, as was notably the case of the Thompsonville well (No. 26), described on page 82, where the water, as indicated in fig. 24, appears to have passed down the joint and up the dip of the sandstone bed nearly to its outcrop, giving, in fact, true artesian conditions.

FAULTING.

Occurrence.—Although jointing disturbs the continuity of the beds almost universally, it does not do this so profoundly as do the manifold faults that cross the area in several directions, especially from north to south. Reference to the map accompanying Professor Davis's paper[a] will show that important faults exist in great numbers, but numerous as they are, as shown on the map, a many times greater number of faults, too small to be recorded, yet of sufficient size to entirely destroy the continuity of the beds in their immediate vicinity, occur in the area. When the extensive brecciation and local bending of the strata that must take place along the greater faults—faults having a length to be reckoned in miles and an upthrow to be calculated in hundreds and in some cases thousands of feet—are taken into consideration, it may be readily seen how thoroughly and extensively the continuity of the strata is destroyed.

Effect.—The effect of faults is much the same as that of joints, but, because of the relatively greater influence of faults at considerable depths, it is even more important. As the jointed upper portions of traps and other rocks are reservoirs of water, so the fault breccia, or the crushed material along faults, forms an important source of water. Among successful wells located almost upon the breccia of faults may be mentioned Nos. 44, 45, 46, 47, 48, 49, and 55 of Mr. Pynchon, lying near the fault cutting off the north end of Cedar Mountain, near Hartford. Wells Nos. 124, 125, 126, and 127 at Berlin and No. 130 at New Britain are almost on fault lines, while the town of Meriden

[a] Davis, W. M., The Triassic formation of Connecticut: Eighteenth Ann. Rept. U. S. Geol. Survey, Pl. XIX.

with its wells is bounded on the northwest and the southeast by the two greatest faults in the whole lowland, the distance between the faults at this point being only 1¾ miles.

COMPOSITION OF TRIASSIC WATERS.

Many facts bearing on the composition of the Triassic waters are given by Mr. Pynchon in the preceding paper, especially those bearing on the practical question of their adaptability for boiler use. The analyses of the waters of most of the wells described by Mr. Pynchon are not now available, but the results of the chemical examinations of a number of similar waters from Triassic rocks are given in the following table.

Analyses of waters from Triassic rocks of Connecticut.

[Compiled from H. E. Gregory's report, Water-Supply and Irrigation Paper No. 102, pp. 127-159.]

Number.	County.	Town.	Owner.	Source of water.	Depth of well.	Character of material.	Iron.	Calcium.	Magnesium.	Iron oxide.	Iron and aluminum oxides.	Lime.	Lithia.	Iron carbonate.	Calcium carbonate.	Magnesium carbonate.	Sodium carbonate.	Calcium sulphate.	Magnesium sulphate.	Calcium nitrate.
1	Hartford.	Bloomfield	H. C. Douglas et al	Well	101	Rock	15						1		54			1,108	525	
2		Crescent Beach	Atwood Collins	do	94	do	Tr.													
3		Hartford	Capewell Horse Nail Co	do	250	Red rock				1					158			272	155	158
4		do	City	do	250	Blue slate														
5		Simsbury	W. L. Cushing	do	218	Sandstone														
6		South Manchester	Cheney Bros	do	457	Red sandstone					1					41	25	1,503		
7		Windsor	H. J. Fisk	do	135							241							241	
8		Windsor Locks	Windsor Locks Water Co	Spring		Trap														
9	Middlesex.	Middletown	L. D. Brown & Co.	Well	292	Brown sandstone.														
10		do	W. E. Wilcox	Spring										1	24	22		2		
11	New Haven.	Highwood	Marcus Wooding	do		Sandstone														
12		New Haven	New England Dairy Co	Well	157															
13		do	F. B. Shuster Co	do	72			74	11											
14		do	G. D. Watrous	do	75	Rock														
15		do	W. S. Swayne	Spring		do														
16		North Haven	B. F. Judd	do		Trap														

Analyses of waters from Triassic rocks of Connecticut—Continued.

[Compiled from H. E. Gregory's report, Water-Supply and Irrigation Paper No. 102, pp. 127–159.]

Number.	County.	Town.	Owner.	Source of water.	Depth of well.	Character of material.	Sodium chloride.	Potassium chloride.	Chlorine.	Carbon dioxide.	Sulphuric acid.	Phosphoric acid.	Organic and volatile matter.	Total mineral matter.	Hardness.	Silica.	Sodium sulphate.	Potassium sulphate.	Analyst.
1	Hartford.	Bloomfield	H. C. Douglas et al	Well	101	Rock	337					60	410	2,523		20			Unknown.
2		Crescent Beach	Atwood Collins	do	94	do			22					132	26				Do.
3		Hartford	Capewell Horse Nail Co	do	250	Red rock	37							940		18	222	6	Do.
4		do	City	do	250	Blue slate			13		358			628	240				H. E. Smith.
5		Simsbury	W. L. Cushing	do	218	Sandstone			2					69	28				Do.
6		South Manchester	Cheney Bros.	do	457	Red sandstone	4							1,636		21	32	8	Unknown.
7		Windsor	H. J. Fisk	do	135				10										Do.
8		Windsor Locks	Windsor Locks Water Co	Spring		Trap							20	56	29				S. P. Wheeler.
9	Middlesex.	Middletown	L. D. Brown & Co	Well	292	Brown sandstone.			10					110	52				Unknown.
10		do	W. E. Wilcox	Spring			2							61		10			Do.
11	New Haven.	Highwood	Marcus Wooding	do		Sandstone			3					60	23				H. E. Smith.
12		New Haven	New England Dairy Co	Well	157				10					110	52				Do.
13		do	F. B. Shuster Co	do	72				44		26			404					Unknown.
14		do	G. D. Watrous	do	75	Rock			3					48	35				H. E. Smith.
15		do	W. S. Swayne	Spring		do			3					93	23				Do.
16		North Haven	B. F. Judd	do		Trap			2					32	6				Do.

One of the striking features of these wells and springs is the great variability of the waters. Those of the traps are comparatively low in mineral matter, carrying in one case, at North Haven (No. 16), as low as 32 parts per million of dissolved solids. From 400 to 2 500 parts per million are common in waters from the sandstones and shales (Nos. 1, 3, 6, and 13). Such amounts make the water unfit for boiler use, even where the mineral matter is mainly present as carbonate (lime). The analyses show that not only is lime present in large amounts, but that there are considerable quantities of the much more objectionable sulphates. The three springs mentioned are very low in mineral, the water in two of them, if not in all three, coming from the trap.

SUMMARY OF WATER CONDITIONS.

ESSENTIALS OF ARTESIAN FLOW.

In 1885 Professor Chamberlin published a paper[a] that explained the principles of artesian flow and called attention to many of the special conditions that tend to determine the success or failure of

FIG. 25.—Ideal section showing the requisite conditions of artesian wells.

artesian wells. The conditions favorable to true artesian flow are as follows:[b]

1. A pervious stratum to permit the entrance and the passage of water.
2. A water-tight bed below to prevent the escape of 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 at the well.

The requisites as outlined above apply only to sedimentary rocks, but the principle on which artesian flow depends is equally applicable

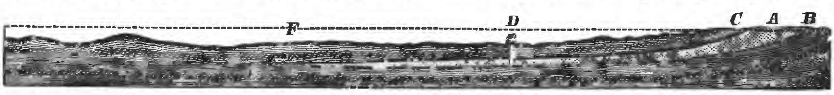

FIG. 26.—Section illustrating thinning out of porous water-bearing bed.

to other rocks, the essential feature being simply that the water be confined and that the outlet through the well be considerably lower

[a] Chamberlin, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rep. U. S. Geol. Survey, pp. 125-173.
[b] Ibid., p. 13.

than the catchment area at which the water enters. A bedding, joint, or fault plane or other fissure in the insoluble rocks, or a solution passage in limestones sometimes affords favorable conditions for

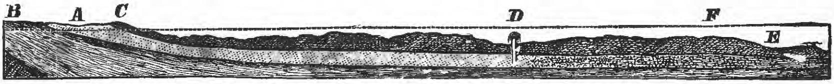

FIG. 27.—Section showing transition from porous to impervious bed.

artesian flow, but such features are usually of limited and local development and are therefore a far less common source of water than the widely distributed beds of sedimentary origin.

CONDITIONS IN THE TRIASSIC AREA FAVORABLE TO FLOWS.

The conditions in the area that are favorable to artesian flow may be summarized as follows:

1. There are many porous beds which water may readily enter and through which it may find ready passage.
2. Water-tight beds, serving to confine the waters, frequently occur both above and below the water-bearing sandstones.
3. The beds are so inclined that the edges at which the waters enter are often higher than mouths of the wells.
4. The edges of the beds are so exposed that water can be readily absorbed.
5. The rainfall is adequate for large supplies.
6. In some places joints and faults appear to conduct water downward to the porous sandstones, which thus obtain their supplies.

CONDITIONS IN THE TRIASSIC AREA UNFAVORABLE TO FLOWS.

The conditions unfavorable for flowing wells in the area may be stated as follows:

1. The beds are so highly inclined that the areas exposed at the surface for the catchment of waters are small.
2. The inclination of the beds is such that, except in very deep borings, the outcrop is near the well and is at only a slightly greater altitude.
3. The rocks are so cut by joints and faults that ready escape is frequently afforded for the rock waters, thus neutralizing the several favorable conditions noted.

CONCLUSIONS.

The conclusions reached as to the underground water conditions on the area may be summarized as follows:

1. Rock waters are generally present in almost all of the rocks of the Triassic area.
2. In the sedimentary beds the rock waters appear to be most abundant in the sandstones, less abundant in the shales, and least abundant in the arkose and conglomerates occurring around the rim of the area. Little water is ordinarily afforded by the traps.
3. Many of the conditions favorable to artesian flows are locally present, and flowing wells will occasionally be found.

4. Because of the frequent interruption of the continuity of the water-bearing beds by joints and faults, artesian flows will be relatively rare and confined to small areas.

5. The dips are so steep that the water-bearing beds usually outcrop within a short distance from the wells and at only a slightly greater elevation; hence the head will probably never be great, and for ordinary purposes pumping will always be necessary.

6. Because of the steepness of the dip different wells, except where close together, will rarely pass through the same series of beds, but will generally show wide differences in the materials encountered and the quantity and quality of water procured.

7. Supplies sufficient for many ordinary manufacturing processes will be obtained from wells in the Triassic sandstones, but such enormous supplies, amounting to several thousand gallons a minute, as are obtained from some of the wells in the loose, porous beds of the Coastal Plain will not be found. The amounts given in the description of the wells in the paper by Mr. Pynchon indicate the character and limitations of the supplies that may reasonably be expected.

8. The waters will generally be highly mineralized, and it will usually be impossible to use them in boilers. The waters of the traps will on the whole probably be found freest from mineral matter and those of the shales will show the highest mineral content. The contrast between these waters and the pure soft waters of the crystalline rocks of the surrounding area is very striking.

9. The water will commonly be free from pollution by sewage or other extraneous matter. High chlorine, usually regarded as an indication of sewage contamination, may result from the solution of matter from the rocks, especially from the shales. In cities, however, where the rocks outcrop, as they frequently do, within the corporate limits, the water should be used for drinking only after it has been thoroughly tested, as surface waters may in some instances pass readily into the rocks. The wells should be carefully cased and packed to prevent water from passing downward along the pipe.

10. The source of the water supply is mainly the rainfall in adjacent regions. When the rocks outcrop at the surface, the water may be absorbed directly, but probably the greater amount is absorbed from the ground water in the glacial drift which overlies the rocks over large areas.

11. The waters pass through the rocks in part by general seepage and in part by following bedding, joint, or fault planes. The former method is more common in the porous sandstones, the latter in the shales and traps.

NOTES ON WELL DRILLING.

TESTING OF WELLS.

Attention has been called by Mr. Pynchon to the failure of a number of very deep wells, notably the 3,700-foot well at Northampton and the 1,100-foot well near Westfield. Although such wells have failed to obtain supplies, practically all of them encounter water in small amounts, which is generally cased off as the well proceeds. No such well should ever be abandoned without a thorough test of every water horizon, however small. The casing, if possible, should be raised above the level of the water-bearing bed, a pump inserted, and the supply measured. When it is impossible to remove the casing, it can be destroyed at the water horizon by a shot of nitroglycerin, which will also at the same time tend to loosen up the surrounding rock and increase the flow. Supplies have frequently been developed at horizons which were not at first thought worthy of testing and which were originally drilled through without stopping and cased off.

Anything that tends to increase the chances of success of wells is to the ultimate advantage of the driller. A complete failure, such as the well at Northampton, while it may cause the owner to sink the particular well to a great depth and thus give temporary employment to the driller, will tend to deter others in the vicinity from drilling, and will in the end result in a decrease in the total amount of drilling done. If such failures can be partially or wholly prevented, the drilling business will be proportionately benefited. The drillers themselves should use all possible effort to make every well successful, for each successful well is likely to lead, sooner or later, to the sinking of others.

KEEPING OF RECORDS.

One of the chief factors in the development of a well, as has been pointed out, is the thorough testing of each water horizon. Detailed notes should therefore be made of the character of material penetrated by the drill and the amount and quality of the water from each horizon, wherever encountered, and the depth of each horizon should be determined by actual measurement. The memory can not be relied upon and should not be trusted to recall the depths at which water may be struck, for although the facts are firmly impressed upon one at the time, they are gradually lost sight of during later development, so that if, at the completion of the well, it becomes necessary to test any particular horizon only a general guess as to its depth and as to the character of the material at that point can, in many instances, be made. Many wells have resulted in failure because the water horizons passed through in the earlier stages of the drilling and cased off could not be relocated.

PROPER DEPTH OF WELLS.

Nothing can be farther from the truth than the popular fallacy that water can always be found in great quantities if the well is only drilled deep enough. On the contrary, it is almost universally the case in this region that wells of moderate depth yield the most abundant supplies. The reason for this lies in the fact that all of the rock waters originally come from the surface and decrease in amount as the depth becomes greater. In the upper rocks joints and other crevices are both more numerous and more open than in the deeply buried rocks, and the absorptive and water-holding capacities of the upper rocks are correspondingly greater. Being subject to weathering and solution by circulating waters, the rocks near the surface are also much more porous than those lying deeper.

The depths to which wells should be sunk will differ greatly in different areas. What would be a shallow well in many regions would be a deep well in the Triassic region. In general, wells in this area that are under 300 feet in depth give the best supplies, while very few find their main supplies below 500 feet. There would probably be few exceptions to the principle that two 250-foot wells will give more water than one 500-foot well. This is even more true of the deeper wells. For the cost of the 3,700-foot well at Northampton fifteen or more 200-foot wells could have been sunk, and a good supply of water would almost certainly have been obtained.

It can therefore be said that success in procuring large supplies in the Triassic area is generally to be obtained rather by drilling a number of shallow wells than a single deep one.

SPRING SYSTEM OF THE DECATURVILLE DOME, CAMDEN COUNTY, MISSOURI.

By E. M. Shepard.

DESCRIPTION OF DOME.

The magnitude of the springs of the Ozarks, especially of the group gushing to the surface in Camden and adjacent counties in Missouri, has long been noticed, and the remarkable rounded mass or boss of

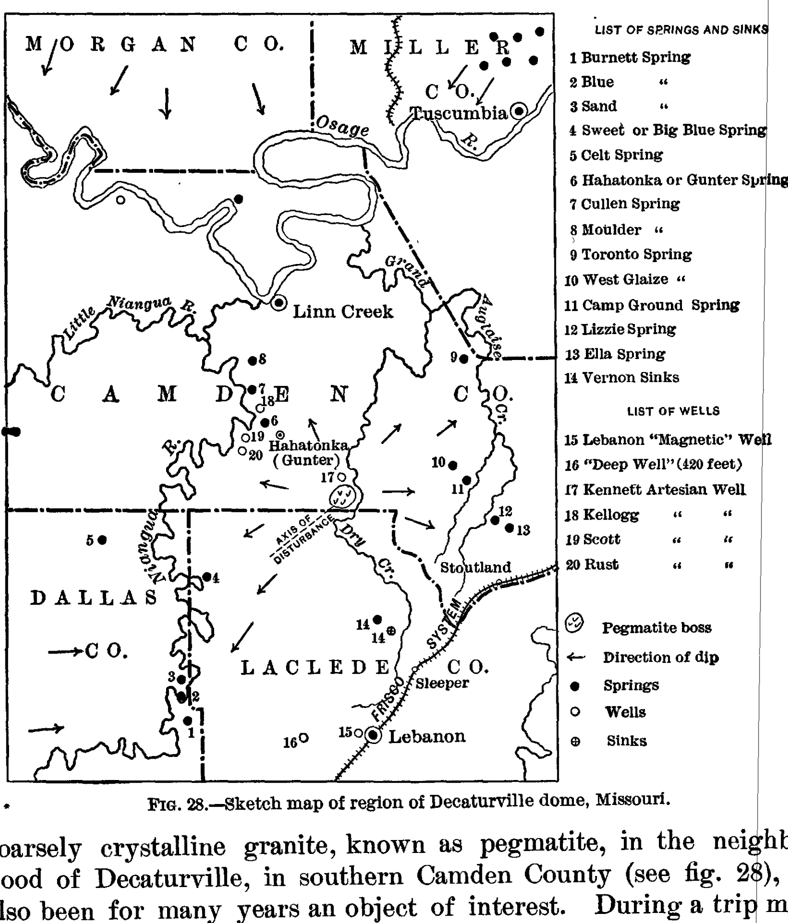

Fig. 28.—Sketch map of region of Decaturville dome, Missouri.

coarsely crystalline granite, known as pegmatite, in the neighborhood of Decaturville, in southern Camden County (see fig. 28), has also been for many years an object of interest. During a trip made through this region early in the summer of 1903 to investigate the underground waters of the State, the idea occurred to the writer that some relation existed between the granite mass and the system of great springs and sinks that surrounds it for a distance of from 8 to 12 miles, or possibly farther. Subsequent study has confirmed this opinion and has revealed a unique condition of underground drainage.

In 1869 some miners who were prospecting for lead laid bare, close to the surface, a small area of granite or pegmatite, frequently called graphic granite because of a peculiar crystalline structure resembling the letters of an ancient alphabet. This is situated at the crest of a low, dome-shaped hill covering about 6 acres and elevated about 40 feet above the level of the land in the immediate neighborhood. The miners were led to prospect here by finding some small rounded bowlders of quartzite and graphic granite at the surface. This small exposure of granite is located near the town of Decaturville, in the southeast corner of the SW. ¼ of sec. 32, T. 37 N., R. 16 W., near the

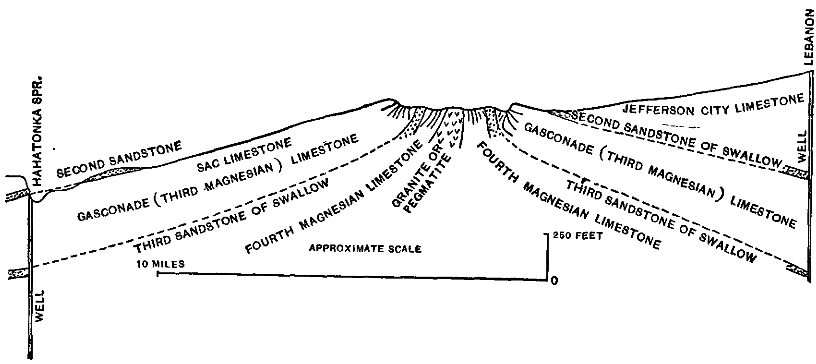

FIG. 29.—Ideal cross section from Hahatonka Spring to Lebanon.

line between Camden and Laclede counties, on land now owned by Mr. Samuel Wheeler. The excavation was only 20 feet long, 10 feet wide, and probably 30 feet deep, though it is now partially filled up. When first opened the material immediately beneath the soil consisted of an incoherent layer, several inches in thickness, of kaolinized feldspar and mica, which gradually merged into a true pegmatite, made up mainly of the variety of feldspar known as microcline, with some albite and oligoclase feldspars and numberless small masses of quartz. On the south side an irregular, sheet-like mass of fine-scaled to somewhat granular, ferruginous, micaceous schist (evidently metamorphosed gouge) was found. The mica was all common muscovite. Scattered over the surface of the hill were lenticular or irregular masses of polished, compact quartzite, somewhat resembling glacial bowlders of the same material. If, as the writer believes, these are the metamorphosed remnants of a fractured intercalated layer or bed of sandstone in the original dolomite, they form, with the mica-schist, the only evidence of metamorphism found. Most of these bowlders have been carried away, many of them having been thrown into the old pit and many used in the construction of an adjacent stone wall.

The dike or boss is surrounded by siliceous magnesian limestone, corresponding to Swallow's Fourth Magnesian limestone. The greatly tilted and in many places nearly vertical ledges indicate great disturbance. The limestone here, while not metamorphosed, is decidedly altered, being highly silicified as well as pitted and honeycomed to a remarkable degree. A quarter of a mile away to the north, east, south, and west, these ledges outcrop in a way that reminds one strongly of coral reefs exposed at low tide. Great parallel ridges, tilted at every angle and some nearly vertical, stand up in irregular segments about the granite hill. To the southwest for over 2 miles, along the narrow valley of Spencer Branch, the disturbance is very great. The axis of this lateral disturbance extends S. 52° W., and the rocks on both sides of the valley dip strongly toward this axis.

About 500 feet southwest of the hill three small shafts were sunk several years ago. The surface was covered with soil mixed with an earthy hydrated iron sesquioxide. In the first shaft, 27 feet deep, a mass of very soft earthy galena, 2 feet wide and 3 feet thick, was found. This seemed to extend about 8 feet to the northeast. The second shaft was 12 feet deep, contents unknown. The third was 53 feet deep, and Mr. Wheeler, the owner of the land, states that granite was found at the bottom. A very impure earthy galena, mixed with zinc silicate and iron pyrites, was found in three V-shaped pockets or flat openings, one above the other, which pitched strongly to the west, toward the prolonged axis of disturbance. About a quarter of a mile to the southwest, along this axis, Mr. Wheeler sunk a fourth shaft, depth unknown, at which, on the dump, there were exposed masses of a highly silicified rock mixed with a curious iron breccia and conglomerate, with scattered masses of earthy limonite.

Surrounding the pegmatite outcrop, except at the southwest, is an irregularly broken circle of low hills that stand about 60 feet above the general level of the basin, making the whole area resemble somewhat the contour of an old crater. The Third sandstone of Swallow outcrops in vertical ledges that form an irregular circle about three-fourths of a mile in diameter around the pegmatite outcrop. This sandstone was first observed just south of the hotel at Decaturville, where a large exposure may be seen. The vertical beds here are about 25 feet thick. The false bedding and the more siliceous, irregular layers, standing out as ridges, are characteristic of this formation. The sandstone is somewhat hardened at the surface. Farther west, other outcrops of vertical sandstone ledges are found in juxtaposition with vertical ledges of the Fourth Magnesian limestone on the inner side, and vertical ledges of Gasconade limestone, or the Third Magnesian limestone of Swallow, on the outer side. Two of these outcrops are particularly striking, one near the center of the south line of section 29 and the other near the point where the road crosses the dry branch of Banks Creek, which heads to the southwest, close to the granite outcrop near the southwest corner of the same section. Farther west and south another striking vertical outcrop of this sandstone forms a "backbone." An interesting feature of these sandstone outcrops is the fact that, on either side of them, the dips of the Gasconade limestone and Fourth Magnesian limestone range from vertical to a strong inclination inward toward the sandstone, a condition very difficult to explain, but which may possibly indicate a second and more local uplift. A few hundred feet southwest of the pegmatite outcrop several shafts already described have been opened and small amounts of earth, impure galena, and zinc ore have been found.

Within a radius of a mile or two of this pegmatite outcrop Mr. W. S. Rush, of St. Joseph, has sunk a number of diamond-drill holes to a depth of several hundred feet, and in no case did he strike the pegmatite. These holes were all sunk in search of mineral. A third of a mile north of Decaturville, in the southwest quarter of section 28, is a small outcrop of Hannibal shales and Sac limestones (Devonian). The limestone contains cavities filled with calcite and is somewhat altered structurally, though its lithological characters serve to identify it without much doubt. The shales, presumably the Hannibal, are greatly altered and are of a bright-yellow color and of a soft, clay-like texture. The blue color which everywhere else characterizes these shales has evidently been destroyed by the heat attending the uplift. In the valley a few hundred feet to the south is a tilted outcrop of greatly altered dolomitic limestone, which is doubtfully referred to the Jefferson City limestone (Second Magnesian of Swallow), or possibly to the First Magnesian of Swallow.[a] As far as the writer knows, these are the highest rocks exposed anywhere in this county or the adjoining counties to the south. It is significant to note that these upper beds retain to a considerable degree their dolomitic character. In other words, these remnants of superincumbent beds have not undergone replacement by silicification, as has been the case in lower beds, which will be described later.

There is evidence of two distinct periods of uplift, both of which must be post-Devonian. From data obtained in other parts of the Southwest it is presumed that the first uplift was post-Carboniferous, when the great dome of the Ozarks was first elevated. From the

[a]The above locality was recently visited by Dr. E. O. Ulrich and the writer. From fossils there obtained Doctor Ulrich determined that these beds probably belong to the Richmond formation of the Ordovician.

obscure evidence furnished by the lateral anticlines that merge into the main axis of the Ozarks at divergent angles—anticlines which, the writer believes, were formed in post-Tertiary time, when the lead and zinc ores of the Southwest were probably deposited—he would date the second uplift at this point in geological time.

In passing in any direction outward from the center of maximum disturbance one may readily note that the rocks tilt less and less strongly away from the pegmatite hill (see figs. 28, 29).[a] This is strikingly shown along the bluffs of Banks and Spencer creeks.

SPRINGS.

From what has been said it is evident that the area of upturned strata surrounding the pegmatite hill—an area 3 or 4 miles in diameter—forms a splendid catchment basin, which contributes to the supply of the great fountains that lie in the surrounding region. Studies of the counties adjoining Camden, particularly on the west, northwest, north, and northeast, indicate a general dip of the strata toward the dome. The water from the catchment basin around the dome therefore meets in a trough, at considerable depth, the circulating water derived from the outside area, and the body of water thus gathered from the drainage on both sides, being under pressure, is forced up to the surface. Where erosion has cut sufficiently deep into the valleys of the Big Niangua, Osage, and Auglaize rivers, which surround the pegmatite hill on the west, north, and east, great springs issue at a distance of from 8 to 15 miles from the granite outcrop. Along the course of Spencer and Banks creeks, which drain this same territory to the northwest, numerous small springs issue, the valleys not being cut deep enough to tap the larger supplies below.

Bennett or Bryce Spring.—The springs of the Decaturville system will be taken up in order from the southwest. The first and largest of the group is the Bennett or Bryce Spring, situated on the west side of Dallas County near the Laclede County line, in sec. 1, T. 34, R. 18, at an altitude[b] of 940 feet, 150 feet below the pegmatite hill and about 15 miles southwest of it. It issues from the lower beds of the Gasconade limestone, the Third Magnesian of Swallow. The temperature of the spring was 57.5° F. when the air temperature was 86° F. Swallow, who visited it in 1853, gives the temperature of the water at 58° F. and that of the air at 60° F. The calculated flow was 172,388,800 gallons a day, but Swallow's figures give only 81,084,810 gallons a day, a remarkable variation in volume. This wonderful

[a] Except at a point 10 miles northeast of Decaturville, in the SW. ¼ of T. 38, R. 14, where the rocks are greatly disturbed and tilted along a northeast and southwest axis. Whether this is a continuation of the Decaturville axis or not can not be determined at this time.

[b] All the altitudes given in this paper, except that of Lebanon, were determined by a series of barometric observations and are believed to be approximately correct.

spring lies in a narrow valley about 600 feet wide. It boils up with great force from a vertical, cave-like opening into a large oval basin (see fig. 30). The spring was sounded to a depth of 22 feet. Mr. Trueman Atchley, who has lived near it for many years, states that he has seen it with one-tenth less water than normal and once 3 feet higher than normal, a condition which would give it twice the flow above calculated. The channel just below the outlet of the spring has become somewhat filled up with gravel, so that the water surface has been raised above the height of the place of outlet. Mr. Atchley states that before the outlet was thus choked he has seen the spring so low that he could walk around the upper portion of the cave-like opening. He states, also, that this opening descends 20 feet vertically

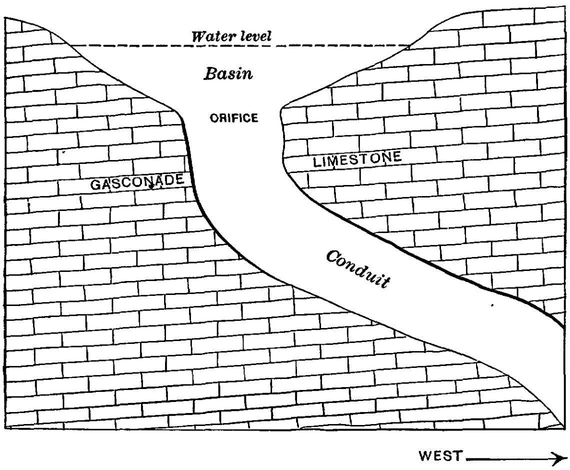

FIG. 30.—Diagrammatic cross section of Bennett Spring.

and then slants southwestward to an unknown depth at an angle of 40° to 50°. When visited by the writer the water of this spring boiled up strongly over an area about 20 feet in diameter and to a height of 2 or 3 inches above the general level of the pool. The spring forms a river that is 100 feet wide and averages 1½ feet in depth, with a rapid current.

Farther west, in Dallas County, the rocks have a general eastward dip. To the southeast, toward the town of Lebanon, the strata are nearly horizontal. There is apparently a tendency to form a synclinal trough at this point.[a] The water from the catchment basin passing along the line of disturbance extending from the pegmatite hill to the southwest, through the lower beds of the Gasconade limestone (the

[a] There seems to be here, as elsewhere in the Ozarks, a tendency to torsional strain, or twisting, in the flexures, which would operate to elevate the area to the south and depress that to the north. This would account for the absence of springs and the great depth of water-bearing strata to the south, as well as for the "extinct spring" at the Vernon Sink, and the immense size of the springs to the northwest.

Third Magnesian of Swallow) and the Third sandstone of Swallow below, meet the drainage from the west in this syncline, and the body of water thus gathered is forced to the surface through a crevice that has been gradually enlarged by continued erosion. A year ago a field was plowed just above this spring, and a heavy freshet washed down a large quantity of gravel which partially stopped its outlet. For several hours the water pushed itself through this obstruction in great intermittent jets, 3 or 4 feet high, with a noise that could be heard a quarter of a mile away.

Blue Spring.—About 1½ miles north of this point is Blue Spring, situated on the west side of the Niangua River. It showed a temperature of 59° F. when the air temperature was 70° F., and is at an altitude of about 900 feet. It issues from a whitish, clayey sand, and is badly choked with water cress, logs, and rubbish. The outcropping rocks indicate the middle or lower beds of the Gasconade limestone. It has a flow of 5,170,000 gallons a day.

Sand Spring.—About a quarter of a mile north of the last spring, on the same side of the river and in the same geological horizon, is Sand Spring, at about the same altitude, also badly choked with water cress, and with a flow estimated to be about the same as that of Blue Spring.

Sweet or Big Blue Spring.—This spring is in the northwest corner of Laclede County, in the NE. ¼ of the NE. ¼ of sec. 30, T. 36, R. 17, at an altitude of about 850 feet. The temperature of the water was about 58° F. when the air was 94° F. This spring issues from a vertical cave opening at the base of a bluff 40 feet high; probably the lower or middle beds of the Gasconade limestone. It has been sounded to a depth of 150 feet. The water is clear, cold, and free from weeds. It flows a distance of 150 feet westward into Niangua River. About 50 feet farther north Sweet Branch, a small, sluggish stream, empties into the Niangua. Sweet Spring is but about 5 feet above the level of the river and is subject to overflow at every rise of the stream. Situated as it is, at the junction of Sweet Branch and the Niangua, it is frequently choked with sediment from these two streams. Between the spring and the river a large area covered with treacherous mud and sand indicates that the basin of the spring was once much larger than it now is. Farmers in the vicinity state that the flow has decreased fully one-half within the last few years. The flow was calculated at 14,037,000 gallons a day. This spring lies just north of the extension of line of disturbance which runs southwestward from the Decaturville uplift.

Celt Springs.—Situated in the northeast corner of Dallas County, 7 miles northwest of Sweet Spring, are found three large springs whose waters unite to form Mill Creek. These were not visited, but they undoubtedly belong to the drainage system of the pegmatite hill.

Hahatonka or Gunter Spring.—This spring is situated 9 miles northwest of the pegmatite hill in Camden County, sec. 2, T. 37, R. 17, at an altitude of about 745 feet, or 345 feet below the height of the hill. The temperature of the water was 57° F. when the air was 88° F. The spring issues from the foot of a bluff 250 feet high, and after running for about 800 feet through a deep, narrow canyon whose walls rise at one point to a height of a little over 300 feet, it empties its waters into an artificial lake, covering 90 acres, situated in the valley of the Niangua. A small island about 100 feet high divides the stream near its outlet into the lake. The scenery in the vicinity of this spring is extremely picturesque. The spring has been sounded to a depth of about 40 feet, at which point the conduit bends to the south. The spring has its source in the Gasconade limestone, 150 feet below the base of the Moreau sandstone (Second sandstone of Swallow). It is very difficult to measure the flow of this spring, owing to the irregularities of the stream. The writer calculated 14,760 cubic feet per minute, or 158,982,912 gallons a day. A Philadelphia engineer estimated 13,800 cubic feet per minute. Professor Shaw, of the Engineering School of Missouri State University, calculated 15,000 cubic feet per minute, while Colonel Scott, an electrical engineer residing at Hahatonka, obtained the same result as Professor Shaw. The district in the vicinity of this spring possesses great interest both from a scenic and a geological standpoint. Evidences of great erosion from underground waters, showing former outlets of this great spring, are everywhere seen. At one time it doubtless had its outlet at the Big Red Sink, one-half mile to the southwest. A few hundred feet on the other side of the bluff from which the spring now issues is a sink, 150 feet deep and 600 feet long, which is open at one end and spanned by a great natural bridge. This undoubtedly marks an old cavernous channel of the great spring. In fact, most of these sinks and canyons mark the site of ancient cavernous outlets.

Cullen Spring.—This spring flows out of a bluff of Gasconade limestone, about 1 mile north of Hahatonka. Its water is clear and cold, and its flow is estimated at about 1,000,000 gallons a day.

Moulder Spring.[a]—In the northeast quarter of sec. 18, T. 38, R. 17, about 4 miles northwest of Hahatonka and about 12 miles northwest of Decaturville, is Moulder Spring, heading in a ravine about 1½ miles long that extends northward from Niangua River. The spring boils up strongly from a bed of coarse gravel 25 feet in diameter, and is estimated by Colonel Scott to be about one-sixth the size of Hahatonka Spring. It issues from the Gasconade limestone, and has its head in the tilted beds which surround the pegmatite hill.

Toronto Springs.—At Toronto, 6 miles northeast of Montreal, in

[a] The writer was unable to visit either Moulder, Cullen, or Toronto springs, all probably belonging to this system, and is indebted to Colonel Scott, of Hahatonka, for data concerning them.

the SW. ¼ of the NE. ¼ of sec. 25, T. 38, R. 15, are several large springs that boil up with great force out of gravelly beds in the Gasconade limestone, flow eastward a short distance, and empty into Auglaize River.

Wet Glaize Springs.—These are two fine springs situated in the NE. ¼ of sec. 24, T. 37, R. 15, about 8 miles a little north of east of Decaturville. One is located near the foot of a bluff of Gasconade limestone 40 feet high, and the other, which is the larger of the two, is about 300 feet farther east, rising from a gravel bed at about the same level. A dam 16 feet high forms a pond of about 10 acres, which covers these two springs. As the pond had been lowered and the gate closed just before the writer arrived at these springs it was impossible to measure their flow, but from what could be learned in regard to them it is probable that their capacity is about 40,000,000 gallons a day. As described by their owner, they both boil up with considerable force out of gravel beds, rolling and tossing up large pebbles. Their location can be marked on the surface of the pond from the disturbance of the waters. They also receive their supply from the catchment basin around the pegmatite hill and the cavernous Gasconade limestone, which, with the Third sandstone of Swallow, forms a great reservoir for all this spring system. Their altitude is about 825 feet, or 265 feet below the outcrop of pegmatite.

Camp Ground Spring.—This spring is located about one-half mile south of the Wet Glaize Springs. A large basin has been hollowed out from the side of the hill by this spring, which boils up from a bed of gravel in a remarkable manner. It issues from a number of holes about 5 inches in diameter, raising and tossing the gravel with great force and making the surface of the spring somewhat resemble a cauldron of boiling water. The water temperature was 55° F. when the air was 84° F. The flow could not be determined, owing to the masses of water cress that choked the outlet. It is stated that it takes thirty-six hours after a heavy rain for this spring to show an increase in its flow.

Armstrong Springs.—These are situated about 9 miles a little south of east of Decaturville, and are at an altitude of about 895 feet.

Ella or West Spring.—This is located in the NW. ¼ of the NE. ¼ of sec. 6, T. 36, R. 14. The temperature of the water was 56° F. when the air was 86° F. The water boils up powerfully from holes in the rock, one of which, 3 feet in diameter, has been sounded to a depth of 30 feet. A bluff of Gasconade limestone, 50 feet high, outcrops just above this spring. The flow was calculated to be 19,112,896 gallons a day. About 12 hours after a heavy rain the volume increases, and the waters become slightly turbid.

Lizzie or East Spring.—This rises from a deep, narrow gorge, on the side of the valley opposite the Ella Spring. Its flow was estimated to be about 3,000,000 gallons a day. The temperature of the water was 56° F. when that of the air was 90° F.

SINKS.

Vernon Sinks.—About 8 miles a little east of south of Decaturville are several sink holes of considerable interest. These lie in a line away from the pegmatite outcrop, in sec. 18, T. 35, R. 15. The main, or Vernon Sink, is about 120 feet in diameter, and about 50 feet deep to the water level. In very dry times the water level sinks 40 feet and exposes a cave-like opening that extends 300 feet or more on an incline due west. A drill well was sunk about 200 feet west of this sink to a depth of 60 feet, and reached the cave opening. A pump was inserted,

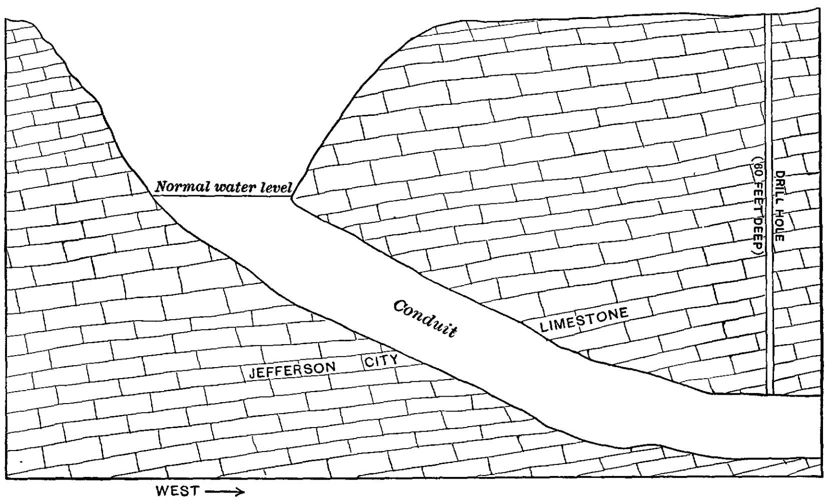

FIG. 31.—Diagrammatic cross section of Vernon Sink.

and the water obtained is constantly used, being clear and cold and never muddy or turbid. It is possible that this may be the mouth of a former outlet of the Decaturville system of springs, the water level standing at an altitude of about 1,080 feet, 10 feet below the catchment basin. Some of the enormous springs in southern Morgan County, and in western Miller and Pulaski counties, possibly belong to this system, and will furnish interesting material for future study.

ARTESIAN WELLS.

In addition to the springs that have been described, artesian wells may be expected in this district wherever the general surface of the country is sufficiently below the level of the catchment basins. Mr. J. N. Kennett, of Decaturville, sunk a drill hole 300 feet for ore one-third of a mile northeast of the pegmatite hill and 40 feet lower than that elevation. A weak flow of water was struck at 200 feet. On the south edge of Hahatonka Lake, Colonel Kellogg sunk a drill hole for mineral to a depth of 864 feet. Water rose in this pipe 30 feet above the ground and threw a jet 6 feet higher. The strong flow was struck at 840 feet, but the force has gradually decreased until the water only flows gently over the pipe at the surface of the ground. This water is slightly charged with sulphuretted hydrogen. It is to be noted that elsewhere artesian wells from this formation are strongly saline, and highly charged with sulphuretted hydrogen, the absence of which in this region is significant of one of the great changes wrought by powerful underground drainage. The Rush artesian well, on the west side of Banks Creek, about 2 miles southwest of Hahatonka and at about the same altitude as the Kellogg well, was sunk to a depth of 780 feet. Water rises 30 feet above the ground, the first flow having been struck at 630 feet. The water temperature is 59° F. when the air is 84° F. There is a slight odor of sulphur. The flow of this well has never decreased. The Scott well, one-eighth of a mile north of the Rush well, on Banks Creek, was sunk to a depth of 740 feet. The first water was struck at 680 feet, and it flows only slowly from the pipe at the surface of the ground. The last three wells all passed through beds of siliceous limestone, only the Kellogg well entering sandstone (Third sandstone of swallow) to a depth of 3 feet. These wells show the enormous thickness of the Gasconade limestone at this point. Another artesian well, situated in the big bend of the Osage, in the NW. ¼ of sec. 22, T. 40, R. 18, was sunk to a depth of 800 feet, and obtained a strong flow of water. This well was not visited, but it probably belongs to the Decaturville drainage system.

SURFACE WATERS.

The region around Decaturville, bounded by Bennett, Sweet, Hahatonka, Wet Glaize, and Armstrong springs, is almost destitute of surface water, the inhabitants being dependent for their supply upon ponds, cisterns, and a few drilled wells. For example, Mr. Haun, who lives between Sweet Spring and Decaturville, drilled 130 feet, and has only from 3 to 6 feet of water, which is quickly pumped dry. The little town of Eldridge, nearby, is wholly dependent on cisterns and ponds for water. Mr. F. M. Cossairt, at Chauncey, Camden County, 6 miles due north from Decaturville, sunk a well 144 feet deep, and struck water at 119 feet, at which level it remains. He states that wells in this vicinity reach water at depths ranging from 100 to 125 feet, and generally have to go to sandstone. At Lebanon, 15 miles due south of Decaturville, in a well sunk to a depth of 1,000 feet, the water stands 360 feet below the surface. About 5 miles west of Lebanon, at nearly the same altitude, a farmer sunk a well 420 feet deep, in which water stands 400 feet below the surface. A pump can not lower it.

COMPOSITION OF SPRING WATERS.

Partial quantitative analyses of a number of the springs of the Decaturville system show a nearly uniform composition quite similar to that of the Lebanon "Magnetic" well, except in a slight increase in chlorides.[a]

The following is the analysis of the Lebanon well, made by Mr. L. G. Eakins, of the U. S. Geological Survey:

Analysis of water from Lebanon well.

	Parts per million.
Silica	11.2
Alumina	32.0
Sodium chloride	Trace.
Magnesium sulphate	6.0
Ferrous carbonate	Trace.
Calcium carbonate	81.1
Magnesium carbonate	52.8
Sodium carbonate	29.1
Total solids	212.2
Free carbonic acid	69.8

CHERT BEDS.

One of the most interesting deductions drawn from the study of the underground waters of this region is their probable connection with the origin of the enormous beds of chert that occur here. Though this point can be but briefly touched upon at this stage of the investigation, it should not be left without notice. All who have visited this region have observed its wonderful deposits of chert, particularly in the Jefferson City and Gasconade limestones. These formations are usually largely dolomitic, particularly the Jefferson City limestone, which contains large masses of dolomite ("cotton rock"). In the district surrounding Decaturville, however, the dolomite is almost entirely absent, and beds of chert seem to have taken its place, especially above and below the sandstone horizons. The chert beds are of great thickness, and are composed of knotted, irregular, frequently lenticular, sometimes agatized, shattered masses. Frequently these shattered masses are recemented into chert breccias. The shattering and cementing by resilicification of the chert beds in many places is another evidence of the second uplift, before referred to, in this region.

The writer has long believed that many of our chert deposits have been formed by replacement, and the evidence in this district points strongly to this conclusion. Briefly, it may be stated that during the period of the uplift of the pegmatite boss, the great heat generated

[a] The presence of sodium carbonate in the waters of this district—an unusual occurrence elsewhere in these formations—is significant of its probable source from the albite (soda feldspar) of the pegmatite; and the same fact also calls attention to the probable magnitude of the pegmatite boss.

was retained by the superincumbent beds (since eroded), and that percolating water, intensely heated, aided by the alkalies derived from the decomposed feldspar and lime, dissolved from the rocks their silica, which gradually replaced the lime and magnesia in the dolomites and converted them into cherts. This replacement seems to have been especially marked above and below the sandstone horizons—so much so as to make it very difficult to separate the Moreau sandstone from the Gasconade limestone below, and the Gasconade limestone from the Gunter sandstone, by which it is underlain, for the reason that the Gasconade limestone merges, through massive chert beds, into the sandstone horizons, both above and below. This is so strikingly the condition in Miller County that State Geologist Buckley, in his report on Miller County, now in press, includes the Moreau sandstone (Second sandstone of Swallow), a part of the Jefferson City limestone (Second Magnesian of Swallow), and part of the Gasconade limestone (Third Magnesian of Swallow) in one formation, which he has named the St. Elizabeth formation, or complex.[a] It will be noted that this special chert replacement predominates along the main line of water flow on both sides of the sandstone horizons.

The study of the Decaturville dome has led the writer to believe that the association of massive chert beds with several other great spring districts in the Ozarks has a deeper significance than that which is usually recognized in considering these beds as merely the reservoirs or channels for the distribution of underground waters, and it is hoped that this brief sketch may throw some light on the origin of the chert beds, as well as emphasize the importance of underground drainage as a geologic agent.

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[a] See also Biennial Report of the State Geologist of Missouri to the Forty-second General Assembly, Jefferson City, 1903, p. 14.

WATER RESOURCES OF FORT TICONDEROGA QUADRANGLE, VERMONT AND NEW YORK.

By T. Nelson Dale.

INTRODUCTION.

Geography.—The Fort Ticonderoga quadrangle is located on the Vermont-New York boundary line, about midway of the length of Vermont. Three-fourths of its area is in Vermont and the remainder in New York. It comprises four small quadrangles—the Ticonderoga, Brandon, Whitehall, and Castleton—each of which contains about 225 square miles. The area includes considerable portions of Rutland and Addison counties, Vermont, and of Essex, Warren, and Washington counties, New York. The principal towns are Ticonderoga and Whitehall in New York, and Proctor, Brandon, Poultney, Fair Haven, and West Rutland in Vermont.

Relief.—The relief of the region varies from an altitude of 100 feet near the shores of Lake Champlain to over 2,700 feet a few miles southwest of West Rutland. Roughly it may be divided into three belts—an eastern belt lying mainly east of a line extending from East Middlebury, through Bomoseen Lake, to Poultney; a middle belt lying between the eastern belt and Lake Champlain, and a western belt, west of Lake Champlain. The first includes the northern end of the Taconic Range, which consists of high, irregular ridges and isolated hills, several points of which reach 2,000 feet or more, and one, Herrick Mountain, rises to over 2,700 feet. It includes also in its northern half a part of the west side of the Green Mountain Range, consisting of ridges, with Mount Moosalamoo rising to over 2,600 feet. In the second belt the land generally varies from 100 to 1,000 feet in altitude. Many extensive terraces are developed at altitudes between 300 and 550 feet. Above these many hills rise to a level of 1,000 feet or more Much of the area is covered by a considerable thickness of drift which has much modified the topography of the region. The third belt is mountainous, with maximum elevations varying from 1,400 feet in the northern part of the area to 1,900 feet in the southern part. The major features of the topography are due to rock structure or composition, but some are due to ice action or to Glacial or post-Glacial deposits.

Drainage.—The drainage of the southern half of the area is westward to Lake Champlain and then northward to the St. Lawrence. In the northern half it is northward by Lake Champlain and Otter Creek. Two other considerable streams—the Middlebury and Leicester rivers—besides Mill Brook, a smaller stream farther south, issue from the mountains and empty into Otter Creek. These streams drain a considerable region lying east of the quadrangle, and comprise the output of innumerable forest springs and rivulets.

WATER SUPPLIES.

General conditions.—The southern half of western Vermont is generally well watered, both because of a copious rainfall and because of the presence of two mountain ranges—the Taconic on the west and the Green Mountain on the east—which are both well wooded and drained by numerous brooks. As the Taconic Range ends in about the center of the quadrangle, one of the chief sources of water supply there ceases, the conditions becoming very different farther northward.

The western border of the Green Mountain Range, with the exception of certain deforested tracts in Goshen and minor clearings in Ripton, is densely forested, and is therefore rich in springs and brooks, so that the question of water supply in the eastern third of the quadrangle is rarely a serious one. In fact, no one familiar with this area can fail to be impressed with the abundance and purity of the water.

Cold springs and brooks.—Some of the water is unusually cold. About three-fourths of a mile southwest of Brandon village is a well dug in a mass of glacial gravel, the pebbles of which are cemented together by calcium carbonate, forming a quasi conglomerate. This well has long attracted attention on account of the very low temperature of its water throughout the summer months, and has also been investigated by geologists.[a] It is known locally as "the frozen well."

As pertinent to this subject, although belonging to the Mettawee quadrangle, the following data are added: Three-fourths of a mile northwest of the top of Dorset Mountain and 1,700 feet below it, in the township of Danby, is a brook of crystal purity, in which the temperature on September 22, 1891, was but little above that of ice water. As the top of Dorset Mountain is only 3,804 feet high the following explanation was adopted: The summits of the Taconic range usually consist of shattered schist ledges covered with thick moss and forest. Ice formed between the blocks in winter may be protected by the dense vegetation and may be the source of such ice-water brooks. Ice-water springs also occur occasionally at the foot of exposed, sun-heated slate-quarry dumps in Washington County, N. Y., in places where no

[a] See Hitchcock and Hager, Rept. Geol. Vermont, vol. 1, 1861, pp. 192–208.

mountain drainage could possibly come. These springs also maintain a low temperature throughout the hot summers. Another brook of low temperature, known as Cold Brook, occurs 3½ miles southeast of Dorset Mountain, in Dorset Hollow. On July 20, 1900, a very hot day, it was cold enough to form a mist about itself. It issues from a limestone cave, through which its course lies for one-half to one-fourth of a mile, and which is at times presumably more or less filled with snow or ice.

Town supplies.—Because of the vitiation of the water, owing to the building of towns, as in the case of the portion of Otter Creek below Rutland and Proctor, streams are no longer safe sources of drinking water. This has been amply demonstrated by the prevalence of typhoid at Middlebury, just north of this quadrangle, as long as Otter Creek water was used, and by its cessation as soon as that use ceased. Where springs or brooks are not available, shallow wells, especially in the lowlands, usually obtain sufficient supplies. The practical utilization of springs as a source of water supply has been demonstrated within a few years at two points north and south of this quadrangle. Water has been brought from a spring on Niquaket, a mountain a mile north-northeast of the southeast corner of the quadrangle, through pipes for a distance of over 4 miles to the village of Pittsford, which is located on a sandy terrace 130 to 150 feet above Otter Creek. A similar system now supplies the village of Middlebury with water from a spring on the Green Mountain range. But for the use of Silver Lake (altitude 1,241 feet) as a summer resort, it would be admirably adapted for a similar purpose, as it is a natural reservoir fed by forest mountain springs.

Geology of the supplies.—The geologic structure of Otter Creek valley seems unfavorable for artesian wells because the marble and dolomite beds, which underlie its gravel and clay, generally lie in small and overturned folds. It is possible, however, that borings which should penetrate that formation (1,000 feet or more thick) and the underlying quarzite and schist (1,600 feet or over) to the basal gneiss of the Green Mountain range (pre-Cambrian) might be productive.

There is a longitudinal belt about 7 miles wide, measured westward from the foot of the Green Mountain range, underlain by dolomite and marble, in which any wells reaching those beds would inevitably furnish water more or less calcareous. There are also on the Green Mountain range areas of dolomite which would have a like effect. Such an area covers about 6 square miles at the southeast corner of the quadrangle. A narrow strip of dolomite extends also 5 miles from Sucker Brook south, inclosing Silver Lake, and must needs add a small percentage of lime to the tributaries of Mill and Sucker brooks. The rocks of the Green Mountain range, with rare intercalations of dolomite, are in other places quartzose, micaceous, and feldspathic, and are thus adapted to furnish the very best of water, except where springs or brooks drain extensive swamps and add organic matter. The occasional disappearance of brooks into caves in the limestone areas is a factor which should be taken into consideration in some of the hydrographic problems.

In the lower levels of the towns of Orwell, Whiting, and Cornwall, along the western edge of the quadrangle, plastic clays, which probably formed the sea bottom of the Lake Champlain region during the "Champlain submergence," introduce conditions very different from those prevailing along the foot of the Green Mountain range, where the superficial deposits are generally more sandy. The effect of these impervious clays, together with that of deforestation in the last generation or two, has been to bring about great scarcity of water. This is very apparent in the northern part of the middle belt, where driven wells, reaching to or into the shales underlying the clays and operated by windmills, are a necessity on many farms, and where the rarity of public watering troughs on the highways is as marked as the poverty of the brooks.

Water power.—East Middlebury River, Mill Brook, and Leicester River have long been utilized in a small way for driving sawmills and other wood-working machinery, etc. The fall of all these streams is considerable. Middlebury River falls 517 feet between Ripton and East Middlebury, a distance of not quite 3 miles. Leicester River, the outlet of Lake Dunmore, falls 171 feet in its course of 1¼ miles from the lake to Salisbury village. Mill Brook falls 636 feet between Goshen and Forestdale, a distance of 3 miles. Besides the above, and as yet not utilized for power, there is Sucker Brook, which has a fall of 529 feet in a distance of 1½ miles above Lake Dunmore. Silver Lake, the outlet of which flows into Sucker Brook, is 670 feet above Lake Dunmore. The narrow gorges through which these streams flow and their greatly swollen condition in spring offer difficulties, however, which must be considered in any scheme for their complete utilization.

WATER RESOURCES OF THE TACONIC QUADRANGLE, NEW YORK, MASSACHUSETTS, VERMONT.[a]

By F. B. Taylor.

INTRODUCTION.

Geography.—The center of the Taconic quadrangle falls almost exactly on the point at which the States of New York, Massachusetts, and Vermont come together. The area included is about 35 miles long from north to south, and 20 miles wide from east to west, containing a little over 900 square miles. The region lies mainly in Rensselaer County, N. Y., Berkshire County, Mass., and Bennington County, Vt. North Adams, Mass., Bennington, Vt., and Hoosick Falls, N. Y., are the leading towns.

Relief.—All of the land of the quadrangle is moderately high, except along the larger streams, where it is sometimes as low as 350 feet above sea level. The area is mountainous, except in the western third, the ranges having a trend a few degrees east of north. The principal mountain masses are the Hoosac on the east, rising to a maximum height of about 2,800 feet, Greylock, and the Green Mountains in western Massachusetts and Vermont, rising to heights of from 2,500 to 3,700 feet, and the Taconic Mountains, along the New York boundary line, rising from 2,200 to 2,800 feet. The western third of the quadrangle partakes of the nature of a compound plateau, the northern portion standing at an altitude of from 800 to 1,200 feet, and the southern at from 1,500 to 1,800 feet. The topographic expression of the region depends to a considerable degree upon the structure and composition of the rocks.

Drainage.—The drainage of nearly the entire area of the quadrangle is by the Hoosic River northwestward to the Hudson River above Troy. A small area in the southwest portion, however, drains southwestward to the Hudson, 25 miles below Albany.

WATER RESOURCES.

SURFICIAL WATERS.

The surface waters include all the running and ponded surface waters which result from rains and melting snows or which are fed by springs.

[a] The field work on the surficial geology of this quadrangle is only about half completed, the unfinished part being confined mainly to the western half. The conditions as regards water supply are, however, much the same throughout the area.

Rainfall.—The mean annual rainfall of this area is about 42 inches, but the rainfall varies by 35 to 40 per cent of this amount between extremes in different years.

Water power.—The relief of this area is considerable, the altitudes ranging from 3,764 feet above tide on Glastenbury Mountain, and 3,505 feet on Greylock Mountain, to about 300 feet above tide on Hoosic River, where it passes out of the quadrangle. Many of the smaller streams descend 1,500 to 2,000 feet in a few miles and afford excellent opportunities for the development of small water powers. The mountains are mostly forest clad, so that the run-off of rain water is somewhat checked and opportunity is afforded for its absorption into the glacial drift, and to some extent into the rocks. The drift, though patchy and irregular in thickness and distribution, covers most of the surface, except the steep slopes and the highest knobs and ridges. In a general way the drift is slightly coarser and more porous on the mountains than in the valleys. The rocks—mainly gneisses, quartzites, and schists in the mountains—are not of themselves porous enough to absorb much water, but they are cut by numerous joint cracks, and some of the rainfall finds its way into these, from which it issues in springs. The great number of perennial mountain brooks shows that the drift and the rocks are effective reservoirs for water storage.

The Hoosic, the largest river, crosses the quadrangle diagonally from southeast to northwest. It descends within the area from an altitude of about 1,100 feet above tide to 300 feet. The principal water powers on this river are at Adams, North Adams, and Hoosick Falls, though there are several others at smaller villages, such as Cheshire, Braytonville, Blackinton, Williamstown Station, and North Pownal. The other principal water powers in this area are on the Walloomsac at Bennington, Papermill Village, and North Hoosick; on Paran Creek at North Bennington; on Green River at Williamstown, and on the north branch of the Hoosic at Briggsville and in North Adams. Small powers are also used at Hancock and Garfield on Kinderhook Creek, at Berlin and Petersburg on the Little Hoosic, and at South Shaftsbury on Paran Creek. Besides these there are a great many smaller developments of power for private use in all parts of the area. Many farmers utilize brooks for power to run dairy and grinding machinery. The demand for power on the rivers is greater than the supply, so that even when the streams are at more than their average volume the supply is insufficient for the mills of the larger towns. In dry seasons the supply is much reduced, but does not fail altogether.

Lakes and ponds.—Natural ponds are not so numerous in this area as in some other parts of New England. There are about 30, large and small, shown on the map, and some artificial ones also. Only two or three are as long as 1 mile. The largest is Pontoosuc Lake, on the southern boundary, but this lies mostly outside of the quadrangle and its outlet is southward. The level of many ponds has been raised by dams so as to increase their capacity as reservoirs, and other reservoirs have been made by damming narrow valleys. The largest reservoir, which is just south of Cheshire, is 3 miles long and one-fourth to one-third of a mile wide.

City and domestic water supplies.—So far as known all the cities and most of the villages get their water supply from mountain brooks. Some farmers get their water from brooks, but most of them derive their supply from springs.

UNDERGROUND WATERS.

Except so far as revealed by springs, nothing is known of the distribution or quality of the underground waters of this area. The water of the mountain springs, whether issuing from drift or from the rock, is generally of excellent quality. No bored wells have yet been noted within the area and dug wells are few. Those seen were all sunk into the drift, generally to depths less than 20 feet. In the relatively low area north and west of Bennington and Hoosick Falls wells are probably more common, but most of this area remains to be investigated. In a general way the character of the rocks and the geologic structure seem to afford no certain promise of success in boring artesian or flowing wells. The artesian wells at Dalton, a few miles south of this quadrangle, appear to flow from a great fault crack which was struck accidentally by an experimental boring.

Mineral springs.—The only important mineral spring thus far noted is Sand Spring, on the north side of Broad Brook, about 1½ miles north-northwest of Williamstown station. The following information relating to this spring was obtained from Dr. S. Louis Lloyd, who owns the spring and runs a sanitarium and baths at that place. The spring boils up through white sand and flows 400 gallons a minute without noticeable variation, even during periods of extreme drought. The temperature of the water is 76° F. winter and summer. Its purity and mineral contents give it valuable medicinal properties for both drinking and bathing. A circular issued by the proprietor gives the following analyses, made by Leverett H. Mears, professor of chemistry in Williams College:

Chemical analysis of water of Sand Springs.

	Parts per 100,000.
Lithium chloride	0.0353
Sodium chloride	.0768
Acid calcium carbonate	3.2249
Acid magnesium carbonate	2.6479
Calcium sulphate	.7262
Aluminum sesquioxide	.0325
Iron sesquioxide	.0075
Silica	.7026
Sodium carbonate	.4641
	7.9178

Sanitary analysis.

		Parts per 100,000.
Color, odor and sediment		None
Solids	Total	12.6200
	Volatile	2.4600
	Fixed	10.1600
Chlorine		.1300
Ammonia, free		.0000
Ammonia, albuminoid		.0018
Nitrogen as nitrites		.0000
Nitrogen as nitrates		.0152

Gas analysis.

Carbon dioxide	.30
Oxygen	11.34
Nitrogen	88.36

This spring issues from the drift-covered slope north of Hoosic River and stands somewhat more than 100 feet above it. It appears to lie almost directly in line with a prominent fault which runs north and south along the east side of Mason Hill in Vermont, emerging a little more than a mile south of the point where the fault passes from view under the drift. Considering its relatively high temperature, its constancy of volume and temperature, and its mineral properties, it seems probable that the water of this spring comes from the fault and hence from a deep-seated source.

There may be other mineral springs in the quadrangle, but none are known at present.

INFLUENCE OF WATER SUPPLY ON SETTLEMENT.

The presence of water power has been the main influence in locating the cities and villages of this area. Four cities—Adams, North Adams, Hoosick Falls, and Bennington—all owe their location to this cause, and the positions of most of the villages have been determined by the same influence. Farmhouses in this area are usually located with reference to convenience of access to some spring or brook. The area is comparatively poor in agriculture. Except in the northwestern part, the valleys are narrow and the hill farms are generally stony and barren. With the decline of agriculture, farmers had to find other ways of making a living. Many of them—the hill farmers especially—have met the difficulty by keeping "city boarders," and most of them have found it profitable, as is abundantly proved by the better appearance of their places. The region is justly famed as a summer and autumn resort for health and pleasure, and the prosperity of a considerable part of its population depends much upon the annual coming of visitors. Pure drinking water and the scenic charms of clear, rapid, mountain brooks constitute important factors among the many attractions that draw summer visitors to this region.

WATER RESOURCES OF THE WATKINS GLEN QUADRANGLE NEW YORK.

By Ralph S. Tarr.

LOCATION AND DRAINAGE.

The Watkins Glen quadrangle is located in south-central New York, and includes the areas mapped on the Elmira, Waverly, Watkins, and Ithaca topographic sheets of the United States Geological Survey. In it are located Elmira, Ithaca, and a number of smaller cities and towns. It is crossed by a portion of the divide that rises between the Oswego and Susquehanna drainage systems, and includes some of the headwaters of each system. Chemung River crosses the Elmira and Waverly quadrangles in the southern part of the area, carrying through Elmira the drainage of 2,055 square miles of country. Next in size to the Chemung Valley are the two northward sloping valleys occupied by Cayuga and Seneca lakes, with drainage areas of 1,593 and 707 square miles, respectively. Throughout the quadrangle one effect of glaciation has been to cause changes in divides, which have turned streams from one drainage area into another. As a result, many of the streams flow in valleys that are out of proportion to the volume of water they carry; some large valleys contain small streams, some large streams flow in small valleys. This condition has an important bearing on the distribution of underground water, whose direction of movement may consequently often be directly opposite to that of the surface water.

None of the streams of this area are of value in navigation; but the Chemung Valley was the site of a canal, now abandoned after having been operated at a loss. Both Cayuga and Seneca lakes are seats of navigation, but this shared the decline of the Erie Canal, with which the lakes are connected by short branch canals. Many hydrographic problems connected with these lakes have not yet been investigated.

The overdeepening of the two lake valleys, possibly by ice erosion, has left the tributaries hanging far above the level of the lakes. In descending to lake level the tributaries therefore have high grades, and in the short time since the Glacial epoch have been unable to do more than form steep-walled gorges through which the water flows in a series of rapids and falls. These gorges, falls, and rapids are exceedingly picturesque, and in the case of Taghanic Falls, Watkins Glen, and Havana Glen, have won wide reputations. The water power of some of these streams is used for running grist and other mills; that of Fall Creek furnishes power for generating the electricity used at Cornell University and gave opportunity for the construction of the hydraulic laboratory. Through general deforesting the value of the streams for purposes of power is decreasing.

WATER SUPPLY.[a]

The surface streams are used by the towns in the area as a source of municipal water supply, in some cases, as at Ithaca and Elmira, after filtration. The need of such filtration was forcibly impressed upon the people of Ithaca by an epidemic of typhoid fever in 1903, which resulted from the pollution of creek water, then supplied unfiltered. All the surface waters are notably hard, as the following analyses show. The hardness results from the solution of lime and other salts from the shales and from the glacial deposits, which consist in large measure of ground-up shale and limestone. So much lime is at times carried in solution that springs, on emerging, precipitate it, forming deposits of calcareous tufa.

The condition of this surface water is clearly illustrated by the following analyses of two creeks whose mouths only are within the Watkins quadrangle, but whose waters have been studied with especial care because of their relation to the Ithacan water supply.

Results of examination of water from Fall Creek at Ithaca.

[Parts per million. Prof. E. M. Chamot, analyst.]

Date.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Hardness (alkalinity).	Carbon dioxide.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1903.									
February 13	35.00	....	0.071	0.031	Tr.	2.08	......	....	......
February 14	55.00	....	.071	.031	Tr.	1.82	......	....	......
February 16	33.00	....	.078	.023	Tr.	1.54	2.25	65.8	1.24
February 17	18.00	....	.094	.028	0.002	1.35	1.25	80.1	2.24
February 18	24.00	....	.082	.016	.002	1.818	1.50	80.1	1.714
February 19	22.00	....	.082	.023	.002	1.667	1.50	84.7	2.19
October:[b]									
Maximum	42.00	150.00	....	....	....	....	......	103.0	......
Minimum	.25	13.00	....	....	....	....	......	55.0	......
November:[b]									
Maximum	10.00	104.00	....	....	....	....	......	108.8	......
Minimum	.25	13.00	....	....	....	....	......	63.8	......
December:[b]									
Maximum	1.00	25.00	....	....	....	....	......	115.0	......
Minimum	.20	6.00	....	....	....	....	......	87.5	......

[a] I take pleasure in acknowledging the assistance of Mr. Lawrence Martin in obtaining data concerning the water resources; of Mr. C. C. Vermeule, engineer for the Ithaca water board, and his assistant, Mr. Getman, who supplied me with carefully kept records and samples; and of Prof. E. M. Chamot, of Cornell University, for analyses and other information about the chemical features of the problem.

[b] Daily observations.

Results of examination of water from Sixmile Creek at Ithaca.

[Prof. E. M. Chamot, analyst.]

	Raw water before filtration.											
	Bacteria per c. c.			Turbidity.			Color.			Alkalinity.		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
1903-4.												
October	7,220	36,000	850	(*a*)	1,800	0.25	45	128	2.5	81	134.0	45.0
November	5,460	23,000	800	31	160	.8	63	160	18.0	82	92.5	60.0
December	2,900	8,600	900	8	35	.75	33	85	14.0	89	97.5	80.0
January	6,200	520,000	1,000	13	2,500	5.0	14	40	10.0	76	100.0	45.0
February	13,400	97,000	1,500	46	400	6.0	11	24	4.0	72	85.0	35.0
March	28,600	115,000	2,500	220	3,000	5.0	13	24	5.0	57	87.5	40.0
April	7,330	50,500	1,500	104	400	40.0	11	20	5.0	54	67.5	37.5
May	7,300	35,000	450	40	500	10.0	13	24	5.0	72	95.0	55.0
June	7,500	62,000	450	47	250	7.0	15	34	5.0	94	125.0	60.0
July	1,050	6,500	350	57	95	28.0	9	27	3.0	127	130.0	120.0
August	2,400	18,000	400	76	200	45.0	20	45	1.0	127	140.0	110.0
September	1,200	2,800	500	57	80	18.0	9	20	3.0	131	140.0	125.0
Average	7,550			58			21			91		

a Too variable to average.

It goes almost without saying, that springs and wells are common in this area, and that their waters resemble in hardness the creek waters at low stage. Many of the wells, especially on the hill farms, are in rock; others are in glacial drift; and some are in post-Glacial deposits. Most of the shallow wells show decided fluctuation with season. The most copious springs occur in the regions of outwash gravels and near the margins of alluvial fans, into which the stream water often sinks, reappearing as springs.

In a number of places in the area there are deep wells in which the water rises nearly or quite to the surface. This is true, for example, just south of Watkins, at Montour Falls, near Breesport, and in the outwash gravels in and near Elmira. In only one place, however, have the water resources of the glacial deposits been extensively exploited, namely, at Ithaca. Prior to the introduction of a city water supply the town of Ithaca depended upon wells, and even at the present time many of these are in use. Some of these are shallow dug wells that receive the drainage of a densely populated hill slope. Others are in gravels of alluvial fans, built where Sixmile and Cascadilla creeks emerge from their gorges upon the Ithaca delta plain. Many of the Ithaca wells are, however, driven, and furnish artesian water. The depth which these wells reach varies, being in most cases from 80 to 100 feet, and in some of the wells the water has head enough to permit piping to the second floor. They are both overlain and underlain by an extensive stratum of clay. In the table following the first seven analyses show the general character of this water.

Sanitary analyses of well waters at Ithaca.

[In parts per million. Prof. E. M. Chamot, analyst.]

No.	Location of well.	Date.	Depth of well.	Turbidity.	Color.	Odor.	Total solids.	Loss on ignition.	Total hardness.	Alkalinity.	Chlorine.	Free ammonia.	Albuminoid ammonia.
		1903.	*Feet.*										
1	Tompkins street	June 13	100	....	....	....	....	....	....	260.0	27.0	....	....
2	Utica street	Mar. 19	80	....	....	....	....	....	....	197.5	32.6	....	....
3	Wood street	July 7	120	....	....	....	....	....	....	140.0	59.0	....	....
4	Madison street	Apr. 3	85	....	....	....	....	....	....	135.0	14.8	....	....
5	Plain (South) street	July 7	96	....	....	....	....	....	....	100.5	16.0	....	....
6	Adams street	June 15	100	....	....	....	....	....	....	165.0	39.5	....	....
7	Albany (South) street	July 7	104	....	....	....	....	....	....	155.0	60.0	....	....
8	Salt works well	Feb. 17	120	None.	None.	H_2S	314.5	109.5	176.5	145.8	38.5	0.083	0.013
9	Illston well	Feb. 7	280	None.	Slight.	H_2S	....	....	200.0	197.5	45.0	.565	None.
		1899.											
10	Do	Apr. 10	280	None.	Slight.	H_2S	304.0	78.0	....	....	61.6	.480	.005

Sanitary analyses of well waters at Ithaca—Continued.

No.	Location of well.	Date.	Nitrogen as nitrites.	Nitrogen as nitrates.	Oxygen consumed.	Bacterial colonies.	Growth in phenol-peptone-glucose.	Behavior in Dunham solution.	Remarks.
		1903.							
1	Tompkins street	June 13	0.0004	None.	1.375	1,800	Coli-like; gas	Uniformly turbid; strong indol.	
2	Utica street	Mar. 19	.005	0.45	1.40	1,440	Slight; gas	Coli-like; very foul; strong indol.	Sunk in 1896. Flows in cellar.
3	Wood street	July 7	None.	None.	.425	12	No growth	No growth	CO_2=5.0. Flows.
4	Madison street	Apr. 3	None.	Trace.	1.30	70	Weak; no gas	Slight turbidity; no indol.	CO_2=5.0. Flows. Sunk about 1878.
5	Plain (South) street	July 7	None.	None.	.675	430	Vigorous; gas	Turbid; indol	Driven.
6	Adams street	June 15	None.	Trace.	.50	10	No growth	No growth	Flows.
7	Albany (South) street	July 7	None.	None.	.525	46	None	do	CO_2=4.5. Flows in cellar.
8	Salt works well	Feb. 17	None.	None.	.450	25			CO_2=6.
9	Illston well	Feb. 7	None.	Trace.	.450				CO_2=3.309.
		1899.							
10	Do	Apr. 10	None.	Trace.	.644	10	No growth	Very slight turbidity.	

Toward the western side of the valley a well, 120 feet deep, known as the "Fourth street well," was drilled by a committee of citizens during the typhoid epidemic. The flow of water from it was estimated to be about 100,000 gallons a day. Near it is a well to the same water-bearing bed, which is pumped by a salt company for use in dissolving salt to form brine. It yields from 300,000 to 400,000 gallons a day by pumping. Its composition is shown by analysis No. 8, in the accompanying table. Just south of the city, near the western side of the delta plain, 2 deep wells have been put down by a committee of citizens, and 11 by the Ithaca water board. These 13 wells are not far apart, and most of them are very near an artesian well, known as the "Illston well," that was bored several years ago. This well showed a flow of over 300,000 gallons a day, by weir measurement, in the spring of 1903. Two of the wells reached rock, one at a depth of 260 feet, the other at a depth of 342 feet. Of the 13 wells, 9 are flowing, and the engineer of the water board estimates that they have a total capacity, when pumped, of between 2,000,000 and 3,000,000 gallons daily, which is more than ample for the city of Ithaca. A number of wells are clustered around the Illston well, and reach the same water-bearing series at a depth of about 280 feet. That the various wells tap the same water-bearing layers is evident from their influence upon one another. The pressure in the Illston well, for example, is reduced from 18 to 12 pounds when all the adjacent wells are flowing. Whether the estimated capacity of the wells will be actually reached when all the wells have been pumped for a while remains to be seen.

These 14 wells reveal a set of conditions in the Ithaca delta as follows:[a] Below an upper series of beds of soil and muck about 10 feet thick is a bed of clay varying in thickness from place to place and underlain at depths ranging from 60 to 90 feet by water-bearing sands and gravels that vary in thickness from 30 to 60 feet. Beneath the sand and gravel is a great depth of uniform clay, attaining a thickness of 120 to 150 feet. Then sandy clays, quicksands, sands, and gravels are encountered. Even in wells drilled but a few feet apart the sections through the water-bearing layers differ, as one would expect in glacial sands and gravels. This variation makes well boring very uncertain. Several of the wells reached a quicksand so filled with water and under such pressure that it rose in the pipe faster than it could be removed. The more successful wells reached either gravel, or sand with gravel, from which the sand could be jettied out, leaving a protecting mass of pebbles around the pipe mouth. Amid such varying conditions the sinking of a well in this region is very much of a lottery, even though it be true, as it seems to be, that the sand-

[a] Tarr, R. S., Artesian well sections at Ithaca, N. Y.: Jour. Geol., vol. 12, 1904, pp. 69–82.

gravel series beneath the clay is very extensive and everywhere water bearing.

The beds in which the wells are located are a part of the series of ice-front deposits associated with the stand of the glacier in this region. The source of the water is unquestionably the moraine series that occupies the bottom of the valley of the Cayuga Inlet, farther south. This being the case, the water supply must be great. That the water has long been underground is indicated by the analyses (Nos. 9 and 10 in the table)[a] and by its temperature, which in both August and December was 52° F. The Ithaca experiment will be watched with interest, for if only two-thirds of the estimated capacity of the wells is realized it will show a set of conditions in glacial deposits favoring, in a very limited region, the development of an extensive water supply.

[a] The analyses of the water of the Illston well doubtless represent approximately the condition of the water in the neighboring wells of which analyses are not yet available.

WATER RESOURCES OF CENTRAL AND SOUTHWESTERN HIGHLANDS OF NEW JERSEY.

By LAURENCE LA FORGE.

INTRODUCTION.

Location.—This region, that part of the Highlands south of Andover and Pompton, about two-thirds of the Highland area of the State, includes portions of the Morristown, Lake Hopatcong, Hackettstown, Delaware Water Gap, Somerville, High Bridge, and Easton quadrangles, and comprises parts of Morris, Warren, Hunterdon, Somerset, and Sussex counties, covering an area of about 685 square miles. The limestone valleys lying within the Highlands are usually considered a part of the area and will be so regarded in this paper, together with the partially inclosed valleys, such as the Pohatcong and Pequest valleys, which extend between the Highland ridges for some distance, but open out into the Great Valley.

Population.—The population of the area is a little over 75,000. This includes the entire population of such places as Morristown, Boonton, and Bernardsville, which lie partly within the Highlands, but not the population of places like Clinton, Pompton, or Morris Plains, which are just outside the base of the Highlands, nor of places like Philipsburg and Belvidere, which are more properly comprised in the Kittatinny Valley. Of these 75,000 people, somewhat over two-thirds live in towns and villages, the strictly rural population averaging less than 35 per square mile. There are 20 towns and villages having 500 or more inhabitants, and about 50 more having from 100 to 500 inhabitants. The rate of increase for the area as a whole is about 1 per cent a year, but the actual increase is confined to the larger manufacturing towns in the valleys and to the parts of the southeastern border which are becoming popular suburbs of New York. In all of the upland portion and throughout the larger part of the valleys of the northern and central parts of the area the population is decreasing, there being a steady drift away from these localities. This, however, when the whole area is considered, is slightly more than offset by the influx from outside to the manufacturing towns and popular residence localities.

Industries.—The agricultural industry of the region is not so important as formerly, being now largely confined to the valleys and the peach-growing districts on the less rugged uplands of the southern portion. Lumbering is conducted on a small scale. Iron mining, formerly carried on in a small way at many places in the area, has become concentrated at a few important points and the mines elsewhere have been abandoned. There is a considerable and growing amount of manufacturing in the larger towns, mainly connected with the iron industry. The eastern slope of the Highlands, notably about Morristown and Bernardsville, has become a popular suburban region and is being rather thickly settled, while certain of the wilder and more beautiful of the upland districts, such as those on Mine and Schooley mountains and about Budd, Cranberry, and Hopatcong lakes, are favorite outing places, and of late years have a considerable summer population.

Climate, soil, etc.—The average temperature of the Highland region for the year is about 47°, the average for the winter being about 27°, and the ground and streams are usually frozen during the greater part of the winter. The average annual rainfall ranges from 38 to 48 inches in various parts of the region, and from 30 to 55 inches in different years. Usually there is somewhat more precipitation in summer than in winter. The average annual snowfall is about 5 feet, which is equivalent to about 6 inches of rain, so that about 12 to 15 per cent of the precipitation falls as snow.

North of the terminal moraine the soil is largely glacial material, entirely so along the moraine and in the filled valleys. South of the moraine the bulk of the soil in the valleys is also of glacial derivation, consisting of outwash plains in front of the moraine and of stream-washed drift lower down the valleys, but there are also areas of clay soil resulting from the weathering of the limestone and shale. On the uplands the soil is derived from the disintegration of the gneiss and is as a rule stony and not very fertile.

Forests cover a large proportion of the area, a proportion ranging from 90 per cent and more at the north and northeast to 30 per cent or less at the south and southeast. A greater percentage of the upland than of the valleys is forested, and a greater proportion of the glaciated area than of that lying outside the moraine. Except in parts of the limestone valleys and the plains of washed drift the soil is not very fertile, and the region, on this account and because of the ruggedness of a great part of it, is not well adapted for cultivation. The forest-covered area is increasing, as much of the land that was formerly cultivated is being abandoned.

TOPOGRAPHY.

The Highland region is a dissected plateau, lying about 500 feet above the lower country on either side, and bounded on the southeast by the Piedmont Plain and on the northwest by the Great Appalachian Valley, here known as the Kittatinny Valley. Northeastward the Highlands continue into New York, and to the southwest they extend past the Delaware for some distance into Pennsylvania.

The belt trends northeast to southwest and consists of several roughly parallel ridges and valleys which have nearly the same trend, but are not without local irregularities. A considerable portion of the original plateau surface remains as the summits of the broader ridges, reaching elevations of 1,200 to 1,300 feet in the northwestern part and declining gently both southeastward and southwestward. The highest point in the area, standing at an altitude of 1,333 feet above sea level, is in the town of Jefferson, northeast of Lake Hopatcong. The descent of about 500 feet from the plateau to the lower regions on each side is rather abrupt, and the longitudinal valleys within the highlands have been cut down about the same amount toward their lower ends.

DRAINAGE.

Lakes and ponds.—As there is abundant rainfall in the region and much comparatively level upland surface, with deep soil on most of the unglaciated portion, and natural storage basins everywhere in the glaciated portion, the entire area is well watered. On the slopes there are abundant springs, none very large, but many which never fail, and which can be depended on as sources of supply. Since much of the area is forested and other conditions are favorable to the absorption of water by the rocks, a large proportion of the rainfall becomes ground water, and a large part of the remainder is stored for a time in natural or artificial reservoirs.

Lakes and ponds are abundant in the glaciated area, the principal ones being enumerated in the following list. Of these several are entirely artificial, and nearly all the rest have been enlarged by raising the outlet level. Five are supply reservoirs for the Morris Canal and most of the others are or have been mill or forge ponds.

Principal lakes and ponds in central and southwestern highlands of New Jersey.

Name.	Area of water surface.	Area of drainage basin.	Elevation.	Drainage system.
	Acres.	*Square miles.*	*Feet.*	
Lake Hopatcong	2,443	25.4	928	Musconetcong.[a]
Budd Lake	475	4.5	933	Raritan.
Green Pond (Morris County)	460	1.7	1,045	Rockaway.
Stanhope reservoir	339	4.9	859	Musconetcong.
Split Rock Pond	315	5.3	815	Rockaway.
Denmark Pond	172	4.5	818	Do.
Cranberry Lake	154	3.0	771	Musconetcong.
Green Pond (Warren County)	117	5.2	399	Pequest.
Stickle Pond	110	1.7	783	Pequanac.
Forge Pond	96	10.1	775	Rockaway.
Shongum Pond	70	2.9	698	Do.
Waterloo Pond	68	(?)	640	Musconetcong.
Allamuchy Pond	56	1.8	775	Pequest.
Durham Pond	47	(?)	880	Rockaway.
Panther Pond	41	0.5	766	Pequest.
Bear ponds	38	0.6	977	Musconetcong.
Dixon Pond	35	3.5	560	Rockaway.
Wright Pond	31	3.4	743	Musconetcong.
Stag Pond	23	0.3	820	Do.

[a] Lake Hopatcong is naturally drained down Musconetcong River, but it supplies water for the summit level of the Morris Canal, so that a considerable part of its drainage actually passes down the Rockaway.

In addition to the lakes and ponds named above, there are about 100 small mill ponds and reservoirs, all artificial and mostly outside the moraine, and about 30 glacial kettle holes, which contain ponds each several acres in extent.

Swamps are numerous within or immediately in front of the glacial boundary, and largely increase the amount of storage on some of the streams. The largest, but also the lowest in elevation, are the Great Meadows of the Pequest and the long swamp on the upper course of the Black River. The rugged forest-covered area in Sussex and northern Morris counties contains scores of small mountain swamps, caused by glacial choking of old drainage channels, many of which lie at the very heads of the streams, at elevations of 1,000 feet or more.

Streams.—The region is drained partly by streams flowing along longitudinal valleys to the Delaware, and partly by streams flowing in both longitudinal and transverse valleys and reaching New York Bay. The principal rivers are the Pequest, Musconetcong, Raritan, and Passaic, the two last named being the largest and most important streams of the State. The entire region, except areas traversed by Pohatcong Creek and some minor streams that flow directly into the Delaware, is drained by these four rivers.

Pequest River is not properly a highland stream, its source and most of its headwaters being in the Kittatinny Valley, but in the lower part of its course it flows in a valley which separates Jenny Jump and Mohepinoke Mountains from the rest of the Highlands, and throughout its length it receives a part of the Highland drainage. At the head of Great Meadows, where it enters the Highlands, it is at an elevation of 532 feet. From here to Townsbury, where it escapes from the terminal moraine, it falls but 22 feet in 10 miles. This part of its course is through the bed of a temporary lake which was formed behind the moraine after the retreat of the ice, and until a few years ago, when extensive drainage works were completed, the meadows were an impassable morass. From Townsbury to Buttzville, where the river emerges again from the Highlands, it falls 130 feet in 6 miles and considerable water power is developed along this stretch.

Pohatcong Creek rises near Mount Bethel at an elevation of 1,000 feet and falls 400 feet in 5 miles to the valley at Karrville, along which it flows for 18 miles farther, reaching the Delaware at 135 feet elevation. Small water powers are developed at several points.

The ultimate source of the Musconetcong is in the town of Sparta, north of the area under consideration, at an elevation of 1,200 feet. It flows through Lake Hopatcong at 928 feet, Stanhope reservoir at 859 feet, and Waterloo Pond at 640 feet, emerging from the moraine at Hackettstown, 12 miles from its source, at 560 feet. From here to the Delaware, 31 miles below, it falls 430 feet. Lubber Run, its principal tributary, falls 450 feet in 10 miles from its source to where it joins the main stream near Waterloo Pond. Abundant water power is developed at a number of points on both streams.

Raritan River, the largest in the State, drains the central and southern parts of the area through three principal tributaries—the North and South branches and Black River—and empties into Raritan Bay, an arm of New York Bay. South Branch, the principal stream, rises in Budd Lake at 933 feet and falls 270 feet in 3 miles to Bartley, where it reaches the low-lying German Valley, along which it turns and runs 11 miles to Califon, falling 200 feet on the way. Here it plunges through a narrow gorge 6 miles long and emerges from the Highlands at High Bridge at an elevation of 220 feet. It carries a large volume of water and furnishes abundant power at many places. North Branch is not so large; its ultimate source is near Calais at an elevation of 1,000 feet. It falls 600 feet in the first 6 miles, but is here hardly more than a brook. From Ralston it cuts through Mine Mountain in a gorge of uncommonly picturesque beauty and emerges upon the lower plateau at only 180 feet. Though of small volume, it has a swift current and is utilized for power at several points. Black River, the third branch, rises in the moraine a little east of the southern end of Lake Hopatcong, crosses the Succasunna Plains, falling only 200 feet in 11 miles, and then drops 440 feet through a gorge 6 miles long in the Eastern Range, leaving the Highlands at Pottersville Falls at 240 feet.

The remainder of the area is drained by Passaic River, which empties into Newark Bay, another arm of New York Bay. The main stream is of little importance in its Highland portion. It falls only 289 feet in 5 miles from its source near Mendham to where it leaves the gorge at 280 feet elevation. The Whippany, another small branch, rises near Mount Freedom and falls 500 feet in 3 miles, but is here a mere brook. For the next 3 miles along Washington Valley to Morristown it is sluggish and flows through swamps most of the way. It leaves the Highlands at 310 feet and lower down becomes an important power stream. The Pequanac, another tributary of the Passaic lying altogether outside this area, drains a part of the northeastern corner.

The largest branch of the Passaic, and the most important in this area, is the Rockaway. This river rises high on the plateau to the north of the area, enters it in the Longwood Valley at about 750 feet, flows southwestward nearly to Wharton, where, at 660 feet, it turns eastward and cuts obliquely through the Eastern Range, emerging below Boonton at 240 feet. In the last 1½ miles of its gorge it falls 250 feet, furnishing one of the fine water powers of the State. It has a large flow and is an important stream both for power and for water supply.

GEOLOGY.

The rocks of the Highlands proper are granitic and hornblendic gneisses, hornblende and biotite-schists with lenses of magnetite, highly metamorphosed limestone and serpentine, and narrow bands of conglomerate and quartzite, also considerably metamorphosed. The origin of the gneisses and schists is uncertain, but a part at least were certainly igneous, and some of the remainder were probably of sedimentary origin. Throughout much of the area they are arranged in bands differing more or less in character, and the strike of these, as well as of the lenses of serpentine and iron ore and of the strips of sedimentary rocks, usually differs but little from the northeast-southwest trend of the ridges and valleys.

These rocks are for the most part very resistant to weathering, and give a bold, rugged character to the topography occupying the higher portions of the area, but the longitudinal valleys throughout most of their length are cut in much less resistant limestones and shales. These valley rocks and the strips of sediments on the ridges are of Cambrian, Ordovician, and Silurian age, while the gneisses and schists are pre-Cambrian. The age of the metamorphic white limestones is not yet settled. There are a few dikes of diabase and amphibolite in certain areas, but as a rule intrusive rocks are wanting.

The terminal moraine of the Wisconsin ice sheet crosses the area from Denville to Buttzville, and in the northern third of the region considerable areas of rock surface are found on the ridges, while the valleys are filled with sand and gravel to a depth of 200 feet in places. Glacial modifications of drainage are numerous, and in this part of the area a number of swamps drain in several directions.

WATER RESOURCES.

Importance of region.—This region, together with its northeastward extension into New York, is perhaps the most important in the United States from the point of view of water supply, because of its proximity to the great metropolitan area about New York City and its natural advantages as a collecting ground. The population of the portion of New Jersey east of the Highlands and north of Somerville and New Brunswick is over 1,100,000, and of that part of New York south of the Highlands and exclusive of Long Island, nearly 2,300,000. While the cities and towns of a considerable part of this area are still supplied with water from local sources, much of the region is rapidly becoming so thickly settled that in a short time it will be impracticable, except in a few limited cases, to depend longer on the local supply, both because of its inadequacy and of the increasing danger of pollution. The need of further supply for New York City is again becoming pressing, and because of the limited area of the Highlands within the State of New York, from which area the present supply is drawn, it may be necessary to go far up the Hudson or outside the State limits into Connecticut or New Jersey for additional water. Besides the population already mentioned, that of Brooklyn and Queens boroughs and Nassau County on Long Island amounts to 1,300,000. A considerable part, possibly all, of the supply for this territory can probably always be obtained from the deep water-bearing gravels of Long Island, but in the future legal complications may interfere with the obtainment from this source of the quantity needed, and at least a part of the supply may have to be procured from the mainland.

Natural advantages.—The Highlands lie in immediate proximity to this belt of dense population, forming its natural boundary on the northwest. The rainfall is abundant, the region is thinly settled and largely forested, and most of it is poorly adapted to the purposes of agriculture. There are many and capacious natural storage basins, and the whole district is so elevated that water may be delivered by gravity and under considerable head to the more densely peopled district. There is but little local contamination, and the region is so poorly adapted to ordinary uses that the sequestration of large parts of it as gathering and storage grounds for metropolitan water supplies is practicable at relatively small expense. These advantages have long been recognized, and the Highlands have repeatedly been pointed out as the future source of water supply for the cities of northern New Jersey, and the conservation of the Highland waters for that purpose has been often urged.

MINERAL SPRINGS.

There is but one mineral spring of note in the area, the formerly well-known Schooley Mountain Spring, located on the western slope of Schooley Mountain, about 2 miles south of Hackettstown. The result of an analysis of its water as given by Peale[a] is shown below:

Analysis of water of Schooley Mountain Spring.

	Parts per 1,000,000.
Calcium sulphate	28.7
Calcium carbonate	24.3
Magnesium carbonate	27.4
Iron carbonate	9.9
Sodium carbonate	9.9
Sodium chloride	7.4
Silica	12.7
Alumina	2.4
Ammonia	Trace.
Carbon dioxide (dissolved gas)	Undet.

This spring was formerly a popular resort; buildings were erected about it and the water was sold to visitors, but it is now abandoned and the water is no longer used.

WATER POWER.

The climatic and topographic conditions being favorable, the amount of available water power along the streams of the Highland region is considerable and it has been largely utilized. Of late years a notable change has been made in the use of this power, as the number of plants making use of water power has diminished, but the total amount utilized remains about the same. This is due to the fact that whereas there were formerly numerous small sawmills, flour mills, iron forges, and the like, each using a little power, many of these have been abandoned, but there are in place of them several large establishments which have been erected at favorable points and which use a considerable amount of power.

From a census of water powers of the State,[b] made by the geological survey of New Jersey in 1890, it appears that in the region discussed in this paper there was a total of about 11,500 horsepower used, 3,000 horsepower being used by mills on the Musconetcong and branches, 2,200 on Rockaway River and branches, and 4,500 on the two branches of the Raritan and their tributaries, the remainder being developed along various small streams, the Pequest standing at the head of these.

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[a] Peale, A. C., Mineral springs of the United States: Bull. U. S. Geol. Survey No. 32, p. 43.
[b] Vermeule, C. C., Final Rept. Geol. Survey New Jersey, vol. 3; appendix 1, water powers.

The largest development is in the gorge at Boonton, where there is a fall of 250 feet from the pond at Powerville to Old Boonton, with an estimated available horsepower of over 2,000, of which about 1,600 was utilized. At Highbridge, on the Raritan, about 1,200 horsepower is developed, and considerable amounts are used at Hughesville and Riegelsville, on the lower Musconetcong.

Though a much larger amount of power than has yet been utilized could be made available on these streams by proper conservation of the water in ponds, and the amount of manufacturing thus considerably increased, the fact must be recognized that the uses of water for power and for city supply conflict, and that one must necessarily largely preclude the other. If, as seems highly probable, the larger part of the stream and pond water in this region will before many years have passed be sequestrated for municipal supplies, the developed water powers of the Highland region are not likely to be further increased, but will probably be considerably diminished, at least on the Rockaway and Raritan and their branches.

THE MORRIS CANAL.

One of the largest users of water in the Highlands at the present time, and one which controls the water rights of several of the largest and most important storage reservoirs, is the Morris Canal, which traverses the region from Philipsburg to Boonton, passing through Washington and Hackettstown, crossing the low divide near Lake Hopatcong, thence, via Dover and Rockaway, issuing from the Highlands through the gorge at Boonton. It rises from 156 feet at Delaware River to 913 feet at the summit level, and then descends to 288 feet on the level below Boonton and to tide water at Jersey City. At Powerville and at Dover the boats are locked into and out of the Rockaway; therefore the whole flow of the stream is available at these points if needed for the purposes of the canal. Again, along the Musconetcong, from Stanhope to Saxton Falls, the waters of the canal and river mingle at several points.

Lake Hopatcong, Cranberry and Stanhope reservoirs, and Bear and Waterloo ponds are controlled by the canal corporation, and the water of these bodies is used for the canal supply. All except Lake Hopatcong supply the western slope of the canal, and the water thus reaches the Delaware. The Hopatcong feeder enters the canal at the summit level and furnishes the whole supply for the part of the eastern slope within the Highlands, except the water taken from Rockaway River. Nearly all the water drawn from Lake Hopatcong, therefore, passes down the eastern slope and reaches New York Bay, instead of following the original course of drainage from the lake to the Delaware.

Gagings have shown[a] that the canal appears to use very nearly the

[a] Vermeule, C. C., Final Rept. Geol. Survey New Jersey, vol. 3, Appendix 1, Water Power, p. 196.

whole supply which can be obtained from the reservoirs in their present condition—in fact, the whole available supply in a dry season—as well as an unknown amount from the streams at the points where the waters are mingled; but by raising the dams and increasing the storage the reservoirs could be made to supply all the water needed by the canal in the driest seasons, as the rainfall on the catchment basin is ample when carried over by storage. It would seem, then, that the continued use of the canal would preclude the collecting of any surplus water from the upper Musconetcong and Lubber Run watersheds. Nearly all the water used by the canal, however, goes to make good the leakage, which is large on account of the hillside location of long stretches of the canal and the nature of the soil. From measurements made by Messrs. J. J. R. Croes and G. W. Howell this leakage has been estimated at 1.74 cubic feet per second per mile, and nearly the whole of this is returned to the streams, hence it again becomes available for storage in reservoirs on the lower courses of the streams and is not entirely lost as a source of municipal supply.

The use of water for the ordinary purposes of the canal impairs to a very considerable extent its quality for domestic water supply, though, indeed, the water of the canal is used to some extent for that purpose in some of the towns along its course. Unfortunately, in one or two of the larger towns the canal receives the discharge of sewers, and throughout its length it is the receptacle of more or less refuse of all sorts, so that the use of its water for household purposes ought to be discontinued. The bulk of the leakage occurs by percolation through the soil, and hence the escaped water is to some extent purified by the filtration it undergoes in the process; but much of it escapes as overflow at the spillways, and the filtration of much of the rest is probably imperfect, as it is likely that long-continued leakage along certain lines has established little channels in the soil through which the water percolates with little or no filtration.

The water, then, of valley streams which derive a large part of their flow from the leakage from the canal is still of doubtful purity for domestic use, but, in view of the comparatively small pollution which the canal water must suffer and the large dilution which the escaped water undergoes by mingling with stream water derived from other sources, as well as the purification which would be brought about by its storage in large reservoirs on the lower courses of the streams, it is probable that the escaped water is not unfit, after such dilution and purification, to be stored for a metropolitan supply, especially if the reservoirs are large enough and the dilution is ample. It should be noted in this connection, however, that for some time there has been a movement to bring about the abandonment of the canal. Should this be accomplished, it would set free for other uses the large quantities of water at present required for the purposes of the canal, and would remove that particular source of pollution.

LOCAL WATER SUPPLIES.

Requirements.—There are about 20 towns and villages in or upon the immediate border of the part of the Highlands discussed in this paper that are large enough to need water systems, and 10 of them have such systems. With the exception of Morristown and Dover these places are all of less than 4,000 population, and the amount of water needed for their supply is comparatively small. The total population of those towns that have a water supply is about 32,000, and of those towns that are likely to need such a supply within the next ten years is about 8,000, so that the total number of people for whom local supplies of any magnitude must be reserved is not great.

Present sources.—As will be seen from the accompanying table, those towns that have public water-supply systems procure water from mountain springs, except Dover and Morristown, which procure a part of their supplies from drilled wells. It will also be noticed that municipal ownership is rare, only Dover, Hackettstown, and High Bridge owning their systems. Most of the systems are owned by companies, and in one or two cases the ownership is private and only part of the village is supplied by the system. The present sources of supply are ample for all present needs as well as for the near future, while in the cases of all but the largest towns it is probable that an ample supply for all future needs can always be obtained from sources now available.

The data incorporated in the table were procured by correspondence with officers of the various towns or of the water companies. No report was received from Gladstone, and the data given are derived from the best information available for that village.

List of municipal water systems.

Town.	Population in 1900.	Source of supply.	Kind of system.	Ownership.	Sufficiency of supply.	Quality.
Morristown	11,267	Springs and drilled wells	Gravity and pumping.	Private	Ample	Good.
Dover	5,936	do	do	Town	do	Do.
Boonton	3,901	Springs	Gravity	Company	Not reported.	Not reported.
Washington	3,580	Springs and mountain stream	do	do	Fair	Good.
Hackettstown	2,474	Mountain stream	do	Town	Abundant.	Very good.
High Bridge	1,377	Spring	do	do	Ample	Good.
Bernardsville	1,300±	Springs	do	Company	do	Do.
Netcong	941	Brook	Not reported.	Private	Not reported.	Not reported.
Clinton	816	Springs	Gravity	do	Plenty	Good.
Gladstone	300±	Spring	do	do	(?)	Slightly hard.

The water, being taken directly from mountain springs or from drilled wells in favorable locations, is in all cases pure and wholesome, and there is slight danger of contamination. Morristown and Hackettstown report analyses that show water of exceptional purity. For all except the larger towns the springs furnish an ample supply, and hence drilled wells have been resorted to only where the population is so large that the supply from springs has been insufficient.

SURPLUS SUPPLIES.

Since the local population that requires a public water supply is not large, and since the supply is in all cases drawn from wells or springs and not from streams or large ponds, the effects which the needs of this population will have on the available supply for metropolitan purposes is negligible. On the other hand, since for most of those towns an ample supply can in the future be obtained from the present sources, their available supply is not likely to be affected injuriously by the utilization of the lake and stream water for the needs of the large cities. Many of the towns along the eastern bases of the Highlands seem destined to have a large increase of population in the future as metropolitan suburbs, and provision must be made for a greater supply for these, but they are fortunate in being located near small streams that flow from the hills, which are of sufficient volume to supply all their needs, but which run at too low an elevation or furnish too small a quantity of water to be used to advantage for the supply of cities at a distance. The growing manufacturing centers at Washington and about Dover and Wharton may also require larger amounts of water in the future than can be obtained from springs and drilled wells, but the needs of these places may be met without seriously diminishing the supply needed for city purposes. Washington especially, being located on Pohatcong Creek, which flows to the Delaware and is not so situated as to be used to advantage by the cities lying east of the Highlands, will probably always have a sufficient supply for local needs. Shongum Pond and Den Brook may easily be made available for a supply for Dover, and might well be reserved for that purpose.

Needs of the metropolitan area.—The need of water for the metropolitan area has already been briefly mentioned. Leaving out of consideration the 3,400,000 inhabitants of the New York part of the metropolitan district, there are over 1,100,000 in the New Jersey portion—about 60 per cent of the population of the State. The population of this congested area is increasing at the rate of 40 per cent in a decade, and should the increase continue at the same rate in fifty years the population of the New Jersey portion of the area alone will be a little less than 6,000,000. To keep pace with this increase there must necessarily be a gradual abandonment of the local sources of water supply and a turning to more distant regions where the supply will be both larger and in less danger of contamination. Newark has already taken this step, and Jersey City is at present providing for a supply from the Rockaway, at Old Boonton. Other large cities of the district must soon take similar measures.

It has long been known that there is no better region to which to turn for this purpose than the Highlands, where, not more than 25 miles from any of the cities of the district, a pure and abundant supply of water is available. Some of the cities of the metropolitan area are at present consuming about 95 gallons of water a day per capita, and though this amount seems excessive and implies waste of the water, still, to provide for possible contingencies, a source of supply which will be capable of furnishing 100 gallons a day per capita if necessary should be secured. On this basis, if the population of the New Jersey portion of the metropolitan district continues to increase at the present rate, in fifty years the inhabitants will require a supply of not less than 500,000,000 gallons a day.

Amount of supply.—According to the estimates of C. C. Vermeule,[a] the amount of water which can be collected on each of the watersheds of this region with proper storage is as follows:

Rockaway River (above Boonton), 78 million gallons a day; Raritan River (Highland branches), 92 millions; Musconetcong (above Hampton), 82 millions; a total of 252 million gallons a day. An equal or greater amount could be collected from the Ramapo, Wanaque, and Pequannock rivers in the northeastern Highlands, so that the amount of water in the Highlands which could be used for metropolitan supply is upwards of 500 million gallons a day, an amount very much in excess of the present needs of the New Jersey portion of the metropolitan area, and sufficient to meet the wants of this area for a long time. This estimate takes no account of the waters of the Highland portions of the Passaic and Whippany, which are small in amount and issue from the hills at so low an elevation as not to be advantageously used to supply places at a distance; nor of the Pohatcong and Pequest, which flow to the Delaware, and the waters of which could not be carried to the eastern side of the Highlands without considerable expense. Furthermore, these last streams drain limestone areas, and their waters are not so desirable for use as those of the more strictly Highland streams.

The water of the four important Highland streams which flow eastward, the Rockaway and Black rivers and the North and South branches of the Raritan, can be collected in storage basins at or near the points where they issue from the Highlands and delivered by gravity, making them easily available, and at relatively small expense.

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[a] Vermeule, C. C., Water supply: Geol. Survey of New Jersey, vol. 3, pp. 145, et seq. The writer desires here to acknowledge his indebtedness to this book, which is a mine of valuable information regarding the water resources of New Jersey and has been used freely in the preparation of this paper.

The North Branch of Rockaway Creek, in Hunterdon County, could also be used to advantage by the construction of a reservoir near Mountainville, and, it is estimated, would furnish more than 8 million gallons a day. The waters of the Musconetcong could be made available by the construction of a storage basin at Hampton and a tunnel through the hill to Glen Gardner, and thence to the South Branch of the Raritan; or a part of the Musconetcong could be utilized by the construction of a reservoir in the upper valley and a tunnel through Schooley Mountain. Furthermore, Lake Hopatcong, which drains naturally to the Musconetcong, lies so close to the divide that its waters could be diverted to the Rockaway and thus about 17 million gallons a day could be added to the flow of that stream.

There is a variation of over 50 per cent between the least and greatest rainfall in the Highland region, and thus a very great variation in the amount of water collectible in dry and wet years, but the estimates of Mr. Vermeule are conservative and are based on the computed flow for the driest eighteen consecutive months on record, and the amount of water given as available for the different streams may be relied upon under all conditions.

Character of the water.—The water of the Highlands in its natural state is of the very best quality, and a more satisfactory supply from this point of view could not be desired. Under present conditions, however, the water of the larger streams and of one or two of the lakes suffers contamination from several sources, and this must be guarded against before the water will be entirely fit for use. The Rockaway receives, above the reservoir now being constructed for the Jersey City supply, the sewage of Boonton, Rockaway, Dover, and Wharton, with an aggregate population of 14,000. This sewage, however, is all to be diverted before the reservoir is put into service, and the topography of the region is such that this can be done with little trouble. Hackettstown, with 2,500 inhabitants, is situated on the middle course of the Musconetcong, and there are increasing summer colonies on the shores of Hopatcong and Budd lakes, while there are still one or two important iron-mining localities in the region, besides a large blast furnace at Wharton. All these are to a considerable extent sources of contamination, but in nearly all cases the drainage can be conducted out to points below the sites where storage basins could be most advantageously constructed.

Though the village population is rather large in some other parts of the region, as along the stretch of German Valley, where the villages from Kenville to Califon have an aggregate population of over 3,000, it is as a whole not increasing, and the rural population nearly everywhere is decreasing, so that the danger of contamination other than from the large towns and manufacturing centers seems likely to decrease rather than increase in the future.

Availability.—Here, in immediate proximity to a large and rapidly growing urban district, for which there will be need in the not very distant future of an abundant water supply, is a region which is especially fitted by its natural advantages to be the gathering ground for that water supply—a very nearly ideal gathering ground. It seems certain, if the growth of the metropolitan population continues at its present rate, that in a few decades it will be necessary to utilize very nearly all the available water obtainable in the Highlands for the needs of that population and to conserve the supply by the construction of storage reservoirs. For this purpose it will therefore be necessary to set apart considerable portions of the region, both to provide room for the storage basins and to prevent contamination within their catchment areas.

This seems inevitable, and, like all work of the kind, it can be done at less expense and at greater advantage now than later, and, as a further motive for early action, it should be noted that the present need is great. When there are also taken into consideration the manifest adaptability of this region for use as a State park and the desirability of preserving its natural beauty for the enjoyment of the people of the densely settled area to the east, together with the fact that this use of the region would not conflict with its use as a source of water supply, the argument for the sequestration of a large part of the Highland area by State action, with the conservation of its natural beauty as well as its waters for the use of over one-half of the people of the State, becomes more potent. Indeed, it may well be a subject for interstate action, since, as has been shown, the needs of the population on the New York side of the Hudson are likely soon to be greater that can well be supplied from watersheds within the bounds of New York State, while since the advantages of the Highlands as a recreation ground would be as easily available to the people of New York as to those of New Jersey, the former State could well afford to share with the latter the expense of sequestration of the region, especially since a considerable part of the New York Highlands could advantageously be included within the area which it is desirable to reserve for this purpose.

WATER RESOURCES OF THE CHAMBERSBURG AND MERCERSBURG QUADRANGLES, PENNSYLVANIA.

By George W. Stose.

The Chambersburg and Mercersburg quadrangles are located in southern Pennsylvania, about midway between the eastern and western limits of the State, their southern boundaries lying within 2 miles of the Pennsylvania-Maryland line. They include a portion of the Cumberland Valley, extending from South Mountain at Waynesboro, Franklin County, to Tuscarora Mountain on the west, and a small portion of Fulton County about McConnellsburg.

The principal streams in this area are the Conococheague, flowing from South Mountain westward across the area; the West Branch of the Conococheague, flowing from north to south and joining the Conococheague at the southern boundary of the area; Licking Creek and Back Creek, tributaries of the Conococheague; and Little Antietam Creek, issuing from South Mountain, in the eastern portion of the area. All of these streams have a plentiful flow of water throughout the year. They are dammed at many places for water power to run grist, saw, and woolen mills. Many of the minor streams are similarly utilized on a smaller scale. At the mill above the village of Markes an electric plant has been erected, which supplies Mercersburg and some of the smaller neighboring towns with light. Electric railways are being constructed in the area, and the mountain streams, especially Buck Run at Cove Gap, are contemplated as a source of power. The mountain streams have not been utilized to great extent for this purpose, but they promise to be a fruitful source of power by reason of their constant supply of water, the feasibility of damming, and the large fall which may be obtained.

All the streams in the mountain valleys and ravines furnish good-sized flows of pure, limpid water. On reaching the open limestone valley the water rapidly sinks into the mountain wash and disappears, ultimately finding its way into subterranean fissures in the limestone. There are many large springs in the limestone area, but no system of underground channels has been observed. The water from these limestone springs is also pure and sparkling as it flows from its rock caverns, but this is due to its high content of lime carbonate, which is subsequently precipitated as mechanical sediment. On this account it is not so desirable for domestic uses as the pure mountain water, and most of the larger towns pipe their water from the mountains.

Chambersburg, the county seat of Franklin County and the railroad center of the area, obtains its water from Conococheague Creek, from which it is raised 100 feet to reservoirs on the shale hills opposite the town. This creek emerges from the mountains 12 miles east of Chambersburg, where it is fed by many mountain streams. It is in general a large stream, but at this distance from the mountains it is often muddy and at times low, and is subject to contamination by waste from small towns and mills along its course. The water is therefore not of the best quality. A purer and more desirable supply could be obtained from Rocky Spring or Falling Spring, about 4 miles distant, the waters of both of which, however, are hard; or, better still, from Crawford Springs, which issue from the sandstones of South Mountain, 7 miles east of the town.

Waynesboro obtains its water from a small mountain stream in South Mountain 4 miles to the east, where a receiving reservoir has been constructed 250 feet above the town. The distributing reservoir is located on a shale hill to the north of the town. Fayetteville, although it depends chiefly on well water, pipes part of its supply from springs in South Mountain.

The State Soldiers' Orphans' Industrial School at Scotland has a water system of its own, utilizing some small springs on the premises and pumping the water to an elevated tank. Greencastle takes its water from several limestone springs that supply a reservoir situated 2 miles east of the town and 150 feet above it.

Fort Loudon has incased a spring on the east side of Cove Mountain, 1 mile west of the town, and the water is made to flow continually through the old public pumps on the main street, from which the inhabitants help themselves. This supply is unusually pure and cool on account of its continual flow and because it does not stand in an open reservoir. A similar flowing public pump is located at Foltz, at which place the waters of Buck Run are taken where it issues from the mountains. A company has been formed to pipe this water from a point farther back in the mountains to the town of Mercersburg (4 miles southeastward), which at present has only private wells.

McConnellsburg, west of the mountains, is supplied from a spring and reservoir on the mountain slope 200 feet above the town and 1½ miles distant. The other smaller villages in the area depend on private wells and springs for their supply.

In South Mountain there are several noted springs. Mont Alto Park, formerly belonging to the Mont Alto Furnace Company, but recently purchased by the State as a timber reserve, is located in a gap through which flows a stream that is supplied by a number of fine springs, which issue from the sandstone. Pearl and Tarburner springs are the best known. The mountains at the gap have a dense growth of large pine and fir, preserved by the Mont Alto Company, and the park which that company established here, with its pure mountain stream and springs, and outlooks on the heights above, is one of the most attractive resorts in South Mountain. All that it lacks to make it complete is a hotel.

At Crawford Springs, in South Mountain, 2 miles north of Fayetteville, Doctor Crawford once conducted a health resort. A hotel was located here, and baths were built over the springs. The Tarburner Spring was, and is still, similarly utilized. Springs are plentiful in Tuscarora Mountain also, but none have been developed for special purposes.

There are several large limestone springs in the area, marked by beds of water cress and by stately weeping willows. At Falling Spring and Aqua, 3 miles east of Chambersburg, there are numerous large springs, which join to form a good-sized stream. These issue from sandy beds in the limestone series on the sides of an anticline.

Rocky Spring, 4 miles north of Chambersburg, flows from the limestone at a fault contact with overlying shales. This large spring is one of the chief sources of Back Creek.

Blue Spring, 3 miles southwest of Mercersburg, issues in a large pool from the center of a flat anticline in the limestone, but again flows through a cavern before it finally emerges to form one of the chief sources of Licking Creek.

Mount Holly Springs, about 25 miles northeast of this area, along South Mountain, is a very attractive summer resort. The springs issue from the sandstone cut by the gap, and a pretty park has been built around them. Two hotels located here entertain a large number of summer visitors. A paper mill in the gap uses the pure mountain water directly from the springs and makes a high grade of bond paper, which is used by the Government. Another paper mill uses the town water, which is piped from a reservoir at Cold Springs, 3 miles to the southwest. This is not so fresh nor so clear as the water at the upper mill, and consequently the paper is not of so high a grade.

WATER RESOURCES OF THE CURWENSVILLE, PATTON, EBENSBURG, AND BARNESBORO QUADRANGLES, PENNSYLVANIA.

By Frederick G. Clapp.

These quadrangles are situated near the eastern edge of the bituminous coal field in the west-central part of Pennsylvania. The first three named cover a north-south belt lying mostly in Clearfield and Cambria counties, but include small portions of Bedford and Blair; the Barnesboro lies west of the Patton, in Cambria and Indiana counties. Within the area itself there are no large towns; but Clearfield, with 5,000; Altoona, with 29,000; and Johnstown, with 36,000 inhabitants, lie, respectively, 4, 5, and 10 miles outside. Throughout the region are scattered a number of flourishing mining and other towns having a population of less than 3,000, and some of the better parts of the basins support a scanty farming population. About one-half of it consists of extensive barren tracts, either forested or burnt over, which are very sparsely inhabited.

The Ebensburg quadrangle contains some of the highest land in the State, the anticline along the crest of Allegheny Mountain forming the water parting between the Conemaugh and Little Juniata rivers. A second belt of high land enters the area along the Viaduct and Laurel Hill anticlinal axes; a third, less continuous, along the Nolo axis, in the Barnesboro quadrangle; and a fourth, a broad, high wilderness along the Driftwood axis, cuts across the northwest corner of the Curwensville quadrangle. With a few exceptions the principal streams flow in a northeast course, following in a general way the anticlinal axes. The largest river is the West Branch of the Susquehanna, which rises on the west side of Laurel Hill near Carrolltown and flows 40 miles before finally leaving the area. Chest Creek, a tributary to the Susquehanna at Mahaffey, has a total length of 31 miles. Clearfield Creek, flowing northeastward from Cresson along the western slope of Allegheny Mountain, has 22 miles of its length within the area. Other less important streams are the Conemaugh River, Two Lick, Black Lick, Anderson, and Little Clearfield creeks. The grade of the streams is usually light, and none of them are used for power except locally. In a few instances, the most important of which are at Patton and Curwensville, the water supply for towns is taken from neighboring creeks.

With the exception of small tracts of Pottsville sandstone, and of an area of lower Carboniferous and Devonian rocks in the southeastern part of the Ebensburg quadrangle, the region is covered entirely by the Lower Productive and Lower Barren Coal Measures, and, as the dips are very gentle, rarely exceeding 200 feet in a mile, springs are numerous throughout, furnishing the farming population with abundant drinking water of excellent quality. Several of the smaller towns obtain their water supply from this source. The principal exceptions to the general abundance of springs are on the barren sandstone flats covering the crests of many of the ridges and in some of the shales of the barren measures, where they form hilltops along the Wilmore and Johnstown basins. The water of the region is nearly always soft.

At Cresson station is situated the Cresson Springs Hotel, now closed, but formerly a summer resort of the Pennsylvania Railroad, which made much of the water from a "magnesia spring" coming from a shale bed some distance above the Mahoning sandstone. A mile southeast of the town are an "iron spring" and a "sulphur spring," located at the horizon of the Upper Freeport coal. Several hotels at Cresson and Altoona are reported to serve water from these springs, and it is also sold extensively in Pittsburg. The following analyses of the waters were made by Prof. F. A. Genth:[a]

Analyses of water in springs near Cresson station, Pa.

[In parts per 1,000,000.]

	Iron spring.	Alum spring.	Magnesia spring.
Sulphate of ferric oxide	Trace.	571.0	....
Sulphate of alumina	27.4	362.6	....
Sulphate of ferrous oxide	401.5	278.0	....
Sulphate of magnesia	386.1	473.6	....
Sulphate of lime	836.5	687.4	1.9
Sulphate of lithia	Trace.	.8	....
Sulphate of soda	28.1	12.0	....
Sulphate of potash	5.5	7.3	....
Chloride of sodium	.7	.4	21.0

[a]Second Geol. Survey Pennsylvania, Rept. HH, p. 36.

Analyses of water in springs near Cresson station, Pa.—Continued.

	Iron spring.	Alum spring.	Magnesia spring.
Bicarbonate of iron	86.1	64.1	0.3
Bicarbonate of manganese	Trace.	....	Trace.
Bicarbonate of lime	60.3	....	.4
Phosphate of lime	.5	Trace.	.1
Silicic acid	20.7	32.0	15.6
Chloride of magnesium	....	....	9.6
Chloride of calcium	....	....	22.3
Bicarbonate of magnesia	....	....	7.1
Bicarbonate of soda	....	....	24.4
Bicarbonate of potash	....	....	3.5
Alumina	....	....	.1
Nitrous acid	....	....	Trace.
Carbonic acid (free)	....	....	11.3
	1,853.4	2,489.2	117.6

The drinking and cooking supply of the towns is obtained from various sources, a tabulated list of which is given below. Several of these are worthy of especial note. Curwensville obtains its principal supply from mountain springs situated 2 to 3 miles from the town, which have been analyzed and found to be exceedingly pure. In the middle of the summer these springs sometimes run low, and at such times the water of Anderson Creek is used, being pumped to a system of sand beds through which it is filtered. Whenever a change is made to creek water the company gives notice to consumers that it should be filtered or boiled before using. The most extensive use of creek water is at Patton, where the water of Chest Creek is used almost entirely, being pumped by the Patton Water Company unto reservoirs. This water is of very good quality. In addition to the appended list Altoona and Holidaysburg must be mentioned, as they obtain their water supply principally from within the Patton and Ebensburg quadrangles. The former place uses water from Burgoons Gap Run, below Delaney; the latter from Blairs Gap Run. The Pennsylvania Railroad supply in the vicinity of Cresson comes from a reservoir in Bear Rock Run, several miles distant.

Sources of supply of the principal towns.

Name.	Population.	Source of supply.	Quality of water.
Gallitzin	2,700	Pumped to reservoir from mountain stream $1\frac{1}{2}$ miles north of town.	Reported fairly good.
Patton [a]	2,600	Pumped to reservoirs from Chest Creek.	Good.
Curwensville	1,900	Mountain springs Anderson Creek when springs run low.	Excellent. Must be filtered.
Cresson	1,700	Reservoir on hillside east of town.	
Hastings	1,600	Reservoir in ravine above Stirling No. 8 mine.	
Ebensburg	1,600	Artesian wells	Good.
Spangler [a]	1,600	Reservoir in ravine below Benedict.	Contaminated by drainage.
Barnesboro [a]	1,500	Reservoir in ravine below Benedict.	Contaminated by drainage.
Lilly	1,300	Small stream 2 miles east of town fed by mountain springs.	Supposed to be good.
Coalport [a]	900	Wells	Good.
Portage	800		
Carrolltown	800	Pumped from spring	Reported to be best quality.
Mahaffey	700	Piped to town from wells and springs.	
Irvona	700	No waterworks; supply obtained from wells.	
Grampian	600	Two private water lines from springs within the borough limits supply about one-third of town; rest of supply from wells.	Wells are good; water from private lines has been questioned, as it is in danger of contamination.

[a] Discussed in the text.

The poorest source of supply is probably that of Barnesboro and Spangler. These two towns have granted a franchise to a private company by which they are furnished with water from a reservoir in the ravine southeast of Spangler. Above the reservoir has been built the mining town of Benedict, the drainage of which dangerously contaminates the Barnesboro and Spangler supply. Several alternative sources have been suggested, the most practicable plan proposed probably being to use the water from Lancashire No. 8 mine, which is supposed not to be seriously polluted, and which is now pumped to a private reservoir. The use of this water or that from some still less contaminated ravine in the vicinity might afford relief, but it is doubtful whether the improvement would be more than temporary. Barnesboro and Spangler, together with the neighboring towns of Moss Creek, Cymbria, Bakerton, Hastings, and Benedict, all within a radius of 3 miles, comprise a growing mining community which, if it increases in population at the present rate, will in a short time contaminate all the water in the vicinity. It is improbable that any of the ravines containing outcrops of workable coal can escape contamination within the next few years.

Conditions similar to those in the vicinity of Barnesboro exist on a smaller scale at many other mining towns, both within and without the area under consideration. While many of these towns now have satisfactory water supplies, a large number have not, and it seems probable that the question of water supply will soon become serious. Since only temporary relief can be afforded by change from one surface source to another, it will be necessary to prospect below ground.

Heretofore the abundance of good springs in the region has made it unnecessary to sink many wells, although shallow wells are frequent along the valleys of the larger streams and in most of the towns, and deep wells have been sunk at a number of places. The most abundant of these are in the vicinity of Ebensburg and Chest Springs. At Ebensburg they furnish the water supply of the town, which is consequently of the best quality. On the hills immediately east of Chest Springs a number of wells have been drilled in the barren measures and sometimes reach to depths exceeding 100 feet before striking water. Isolated wells were observed at farmhouses on the ridges southeast of Curwensville, south of Mahaffey, and in the vicinity of Marron. At a point directly south of Lumber City a tank has been erected on a hill to contain water for irrigating an orchard. This is the only case of irrigation known in the region. At the tanneries in Curwensville, on the flood plain, several wells have been drilled, which supply abundant water from horizons 100 to 200 feet below the top of the Pottsville formation. At the Westover tannery there is a well 182 feet in depth. The only flowing well observed was at Wilmore. This has a strong flow, due to a head of 1,000 feet, caused by the anticlinal structure of Allegheny Mountain on the east and indicates that if from any cause water should ever become scarce an abundant supply could probably be obtained by sinking artesian wells along the Wilmore basin. Similar conditions, but with a smaller head, must prevail in the other basins. It would seem, therefore, that the only true and permanent remedy for poor water supply in the coal-mining towns will be to drill artesian wells along the deeper basins. In view of the far-reaching importance of pure drinking water, it can not be urged too strongly that test wells be put down at well-chosen points in the several basins.[a] This is the only way to determine with absolute certainty whether or not such a supply is available.

[a] Since this report was written the pure-water problem has been successfully solved by the borough of Coalport, which has had two wells drilled into the Pottsville sandstone. These wells are reported to find little water in the sandstone itself, but to obtain a good supply from the fire clay directly below the Brookville or "A" coal. The water has a very pleasing taste and exists in sufficient quantity to supply the entire town. A good head is obtained by pumping to a reservoir on the hill.

WATER RESOURCES OF THE ELDERS RIDGE QUADRANGLE, PENNSYLVANIA.

By Ralph W. Stone.

The Elders Ridge quadrangle is located in west central Pennsylvania, between the valleys of Cowanshannock Creek and Conemaugh River, and covers an area of about 225 square miles. The boundary line between Armstrong and Indiana counties extends from the northeast corner of the quadrangle to Kiskiminitas River, in the southwest corner.

The topography of the quadrangle is hilly. The extremes of altitude range from 825 feet on Kiskiminitas River, near Salina, to 1,625 feet, the elevation of the top of Watt Hill, the highest point in this vicinity. Although the difference in altitude between the highest and lowest points is therefore about 800 feet, the average distance between the valley bottoms and the uplands is not more than 300 feet. A few small areas, each comprising less than a square mile, are approximately level. These are the terrace and flood-plain deposits along the larger streams. Some of the ridges appear comparatively flat topped when viewed from an elevation. The valleys are narrow and, as a general rule, without notable flood plains.

The drainage of this quadrangle is westward into Allegheny River. The largest stream is Kiskiminitas River, which crosses the southwest corner for a few miles. It is shallow, has a number of rifts, and can not be navigated except by rowboats, and even by them only for short distances. The main tributary of the Kiskiminitas in this quadrangle is Blacklegs Creek, the largest stream in the southern half of this territory. It rises in the vicinity of Parkwood and West Lebanon and flows southwestward to its mouth at Saltsburg. This stream is so small that it can be forded at a number of places, and its grade is so gentle that a dam near its mouth backs the water up for a considerable distance.

Crooked Creek flows across the northern half of the quadrangle from east to west, and receives the waters of Plum Creek and Cherry Run. East of Girty the valley of Crooked Creek is comparatively broad, but from that point westward the stream flows through a deep and narrow gorge, with bluffs often 200 feet high. The stream can be forded at but few places in this quadrangle, and carries a sufficient volume of water, even during the low summer stages, to furnish power for a number of grist mills. Dams have been built across it at Cochran Mills, South Bend, and Idaho. It falls 130 feet from Shelocta to Cochran Mills, a distance of nearly 18 miles as the stream flows, and furnishes sufficient head for water power at frequent intervals. Cherry Run, a tributary to Crooked Creek at Cochran Mills, drains the northern portion of the quadrangle. At least one mill derives its power from this small stream. Plum Creek, formed by the junction of its north and south branches, joins Crooked Creek above Idaho and brings in a considerable amount of water. It drains the northeastern corner of the quadrangle and flows across a broad alluvial plain. Its grade is very gentle and it has not yet been utilized at any point for water power. All of the streams in this quadrangle have much steeper grades toward their sources, and in many places are doing rapid cutting in the neighborhood of the divides.

So much of the country has been cleared of timber that, although the rainfall is moderate, after heavy storms the streams rise suddenly and at that time carry enormous volumes of water. The excessive supply, however, runs off almost as quickly as it appears, and damage is done only to such property and crops as are located on the flood plains.

The largest settlement in the Elders Ridge quadrangle is Avonmore, on Kiskiminitas River, which, according to the census of 1900, has a population of 630. The water supply of this village is derived from wells sunk into the sands and gravels of the river terrace on which it is built. Wells dug but a few feet into this loose material obtain a sufficient supply of good water.

The next largest place is Elderton, with a population of 300. It is situated in the northern part of the quadrangle, on a small plateau, at an elevation of 250 feet above Plum Creek. The village water supply is obtained by private wells of the suction and chain type.

This quadrangle is distinctly a rural district, devoted to agriculture, and, as is usual in such cases, depends almost entirely on wells and springs for its water supply. On a few farms windmills are in use for elevating water to private tanks. Roadside springs with water troughs are common, and water can be obtained at almost any point by sinking wells a very short distance beneath the surface. The rocks that are commonly known as good water bearers are the Mahoning sandstone, which lies immediately above the Upper Freeport coal and outcrops over the greater part of this quadrangle, and the Pittsburg sandstone, which overlies the Pittsburg coal and is found in the southern portion of the quadrangle west of Blacklegs Creek.

WATER RESOURCES OF THE WAYNESBURG QUADRANGLE, PENNSYLVANIA.

By Ralph W. Stone.

The Waynesburg quadrangle is located in the southwestern corner of the State of Pennsylvania, in the eastern half of Greene County, its southern boundary being 2 miles north of the West Virginia State line and its western boundary about 15 miles east of the western line of the State. Its dimensions are about 13 by 17 miles, and it comprises about 229 square miles.

The topography of this quadrangle is uniformly hilly. The difference in elevation between the bottoms of the valleys and the crests of the ridges does not exceed 500 feet. The ridges in a general way trend northwest-southeast, but can not be said to have any conspicuous features. This part of Greene County is distinctly an agricultural district, and is reached by Monongahela River and by a narrow-gauge railroad from Washington County.

The drainage of the quadrangle is eastward to Monongahela River. The Monongahela itself crosses the northeast corner of the quadrangle for about 2 miles. Owing to slack-water conditions, this stream is navigable throughout the greater part of the year and affords an outlet for the products of the country about its headwaters at all times, except when it is choked with ice. Without its dams and locks the Monongahela would be little better than a broad creek. The principal tributaries of the river in this quadrangle are the north and south forks of Tenmile Creek, and Muddy, Whiteley, and Dunkard creeks. The north fork of Tenmile enters from Washington County and joins the south fork at the village of Clarksville, a short distance from the Monongahela. The south fork of Tenmile pursues the longest course of any stream in the quadrangle, having its rise in the west-central part of Greene County and extending entirely across this territory in a winding northeast direction. Muddy and Whiteley creeks have low grades in much of their courses. In fact, the streams in this quadrangle have no high grades, except near their headwaters. They are subject to flood and to seasons of slight flow, and in summer are likely to diminish to such an extent that the water stands along their courses in pools, with only a very small volume of running water. It seems that there is not sufficient supply for water power at any one point.

The village of Waynesburg is the largest settlement in the district and has a population of about 3,500. The next largest village is Jefferson, which has a population of 310, and there are a number of smaller hamlets. These villages are located for the most part on the stream courses, where travel is easier than along the uneven crests of the ridges.

Waynesburg derives its water from the south fork of Tenmile Creek, at the western end of the village. It is pumped to a reservoir on the hill north of the village at an elevation of 250 feet above the main street. As the creek carries considerable silt after every heavy rain, the supply is often muddy, although it passes through a sand filter before reaching the reservoir. For days at a time the water drawn from faucets is so heavily charged with sediment as to be almost useless. There seems, however, to be no other adequate supply immediately available. The proposition to drill deep wells has been considered but never tried. Many of the people in Waynesburg—in fact, most of them—use well water for drinking purposes. In most places a well sunk from 17 to 30 feet will reach bed rock and furnish a sufficient amount of fairly pure hard water. The system of waterworks at Waynesburg is the only one in the quadrangle.

The village of Jefferson is located on a terrace deposit of clays and gravels, and obtains its water supply from wells sunk from 20 to 60 feet through this material to bed rock. The supply is sufficient, and but few of the wells have been known to go dry, except during a protracted drought. The water is hard. In all of the other villages in the Waynesburg quadrangle the water supply is obtained from private wells, which are from 15 to 50 feet deep.

Springs are comparatively abundant in this country, and the water comes from various formations. The Upper Washington limestone is a frequent water producer. Springs from this stratum are numerous in Franklin and Washington townships. It is believed that the Waynesburg sandstone, which overlies the Waynesburg coal, and often has a thickness of 40 feet, is usually a water-bearing rock. Wells sunk into it yield an excellent quality of water, but care has to be taken not to penetrate to the coal.

The Waynesburg Cold Storage Company drilled an 8-inch well 134 feet deep at its plant in the village in March, 1901. This well struck water in the Waynesburg sandstone and yields a supply which the pump has never been able to exhaust. Although the pump raises 75 barrels an hour, day and night, there is always about 90 feet of water in the hole. The water is soft and is used for the ice plant.

WATER RESOURCES OF THE ACCIDENT AND GRANTSVILLE QUADRANGLES, MARYLAND.

By G. C. Martin.

INTRODUCTION.

Geography.—The Accident and Grantsville quadrangles are located in the "Handle" at the extreme western extension of Maryland. A strip about 2 miles wide, belonging to Pennsylvania, is included in the northern portion of each quadrangle, while a smaller and narrower strip of territory belonging to West Virginia is included in the western portion of the Accident quadrangle. Of the territory in Maryland all but a small area in the southeastern corner of the Grantsville quadrangle lies in Garrett County. Each quadrangle measures approximately 17¼ miles from north to south, 13¼ miles from east to west, and contains about 235 square miles. Friendsville, Md., in the Accident quadrangle, and Elklick, Pa., and Barton, Md., in the Grantsville, are the largest villages.

Relief.—The topography of the Accident quadrangle is mainly that of a plateau which has been deeply cut by streams. The surface of the upland lies in general between 2,500 and 3,000 feet, the highest parts being in the southern and eastern portions. There are no well-defined ridges rising noticeably above the general level of the uplands. The valleys, especially along the main drainage lines, are of the nature of canyons, whose bottoms are frequently from 500 to 1,000 feet below the plateau. In the Grantsville area there are three ridges rising nearly or quite to 3,000 feet, crossing the quadrangle with a northeast-southwest trend, between which plateaus, similar to that of the Accident quadrangle, are developed at an altitude of, between, 2,500 to 2,800 feet.

Drainage.—The drainage of the Accident quadrange is northward by the Youghiogheny to the Monongahela. In the Grantsville area the drainage is in part north by Castleman River to the Youghiogheny in Pennsylvania, and in part southward by Savage River to the Potomac.

WATER RESOURCES.

STREAM SUPPLIES.

Youghiogheny River.—The Youghiogheny and its tributaries drain almost the entire area of the Accident quadrangle. It is a large, pure stream whose capacity is far in excess of any probable demand. The only contamination of the main stream comes from the villages of Sang Run, Krug, Friendsville, and Selbysport, and from a few sawmills. The tributaries are all very pure.

Castleman River.—This stream drains the northwest half of the Grantsville quadrangle. It is a large, uncontaminated stream, but there is no demand for its waters in the agricultural region through which it flows in this quadrangle.

Savage River.—This stream drains the central part of the Grantsville quadrangle. It is a large, pure stream and furnishes the water supply for the towns of Piedmont, W. Va., and Westernport, Md.

Georges Creek.—This stream drains the southeast corner of the Grantsville quadrangle. The main stream and the lower courses of its tributaries are so polluted by sewage and mine water as to be totally unfit for any purpose. The headwaters of the tributaries are pure and would furnish good supplies of pure water for the many mining villages in the Georges Creek valley which are annually ravaged by typhoid fever.

SPRING WATER.

There are a great many large, pure springs along the belts of outcrop of the Greenbrier limestone. These belts extend (1) along the western foot of Big Savage Mountain; (2) along the eastern front of Meadow Mountain; (3) along the western front of Negro Mountain; (4) along the eastern front of Winding Ridge; (5) through the valleys of Deep Creek and Marsh Run from Thayerville to McHenry, thence westward to Sang Run and along Youghiogheny River for a distance of 2 miles north and south of Sang Run; and (6) along the northern and eastern edge of the Cranesville valley.

These springs are similar both in geologic relations and in the properties of their water to the group of springs from which the celebrated Deer Park spring water is obtained. The Deer Park springs are about 6 miles south of the southern limits of this folio, and are situated along the direct continuation of the line of springs at the western foot of Big Savage Mountain.

ARTESIAN WATER.

The possibility of obtaining artesian water has never been properly tested in this region. It is, however, probable that the synclines that underlie the valleys of Georges Creek, Castleman River, and Youghiogheny River are artesian basins, and would yield plenty of good artesian water from various horizons.

Several bore holes made in the coal-bearing portions of the synclines have yielded flows of water. This water came from the Coal Measures, and was therefore strongly impregnated with sulphur and iron. It is probable that deeper holes would yield better water from the purer porous sandstones which underlie the Coal Measures. There is, however, no present demand in the region for artesian wells, for the numerous pure streams and springs yield a supply of water that is sufficient for all needs.

WATER RESOURCES OF THE FROSTBURG AND FLINTSTONE QUADRANGLES, MARYLAND AND WEST VIRGINIA.

By G. C. Martin.

INTRODUCTION.

Geography.—These quadrangles are mostly in western Maryland, lying just east of the Grantsville quadrangle. Like the latter they cover a narrow strip of Pennsylvania along their northern borders, and include on the south a considerable area lying south of Potomac River and belonging to West Virginia. The portion in Maryland, except a small area in the northeastern part in Garrett County, falls in Allegany County. The West Virginia area is divided between Mineral County on the west and Hampshire County on the east. Cumberland and Frostburg, Md., are in the Frostburg quadrangle, but there are no large towns in the West Virginia portion of the area or in that part of Maryland that is included in the Flintstone quadrangle.

Relief.—The southwestern half of the Frostburg and nearly all of the Flintstone quadrangle is crossed at intervals of a few miles by ridges varying in altitude from 3,000 feet on the west to 1,500 feet or less on the east. Between these ridges, plateaus having altitudes varying from about 2,700 feet on the west to 900 feet on the east are developed. The plateaus, however, exhibit very little of their original level surface, being cut by numerous streams to depths of many hundred feet. The ridges are due to upturned hard rocks of Silurian, Devonian, and Carboniferous age, while the plateaus are composed mainly of Devonian shales and softer coal-bearing rocks of the Carboniferous.

Drainage.—The quadrangles are drained by the Potomac River, which enters the Frostburg area at its southern boundary, flows northeastward to Cumberland, and thence southeastward across the Flintstone area. The minor streams follow in general the trend of the ridges, those of the north flowing southwestward to the Potomac and those on the south northeastward to the same river.

WATER RESOURCES.

STREAM SUPPLIES.

North Branch of Potomac River.—The North Branch of the Potomac flows through the southern part of this area for a distance of 38 miles. It furnishes the public water supply for the city of Cumberland. The quantity of water is far in excess of the amount needed, but the quality is extremely bad. The water is, in fact, so polluted that it is entirely unsuitable for domestic or industrial use. The polluting matter consists of the refuse from a number of sawmills and tanneries, the drainage from a large number of coal mines, the chemicals from paper mills, dye works, woolen mills, and gas plants, and the sewage of Piedmont, Westernport, Keyser, Cumberland, and other towns. There is great need of some purer supply.

South Branch of Potomac River.—The South Branch of the Potomac is a large stream, which flows through this area for a distance of about 6 miles. It contains at all seasons a large amount of pure water. It is not used at present, and there is not likely to be any future demand for it. It is, however, very important, as it serves to dilute the impurity of the main stream of the Potomac, and thus improves the quality of the water supply of the city of Washington.

Georges Creek, Braddock Run, and Jennings Run.—These streams flow through the thickly populated mining regions in the western part of this area, and are so badly polluted by sewage and mine water as to be entirely worthless.

Smaller streams.—The headwater streams of the entire region, situated as they are largely in forested areas, are unpolluted and would furnish pure water supplies for the smaller towns. Evitts Creek, Patterson Creek, and Town Creek are the largest of the unpolluted streams, and all contain pure water for the entire length. Their water is not used at present.

SPRING WATER.

The largest springs in this region are on the belts of outcrop of the limestone formations. The lines of upper contacts of the Greenbrier limestone and the Helderberg limestone are marked by a great many springs of large, constant flow and great purity. One of these springs, at the contact of the Mauch Chunk shales and the Greenbrier limestone, at the western foot of Big Savage Mountain, furnishes a large part of the water supply of the town of Frostburg. This supply could be greatly increased by the development of other springs in neighboring localities. The town of Lonaconing, which is at present very poorly supplied with contaminated water, could get a similar supply on the western slope of Big Savage Mountain. The celebrated Deer Park spring water comes from a series of large springs not many miles southwest of this region in this same belt of outcrop of the Greenbrier limestone. A series of similar springs might be developed along the eastern part of the Dans-Piney-Little Allegheny Mountain range which would furnish a partial or even a complete supply of pure water for the city of Cumberland.

The line of contact between the Oriskany sandstone and Helderberg limestone and a large part of the areas of those formations contain a great many large springs which are important for local rural use.

ARTESIAN WATER.

Part of the water supply for the town of Frostburg is obtained from an artesian well 1½ miles west of that town, on the eastern slope of Big Savage Mountain. Water is said to have been found in sandstones of Carboniferous age at depths of 81, 182, 527, and 1,200 feet. The amount of water procured from the various horizons is not known; nor is it certain whether the water is derived from contaminated horizons near the surface or from deeper pure sources. If this well reached the Mauch Chunk-Greenbrier horizon and the shallower water were cased off an ample pure supply would result. There is an area of about 90 square miles in the northwest central part of the Frostburg quadrangle where, in the Georges Creek syncline, this Mauch Chunk-Greenbrier water horizon could be struck at depths of from 1,000 to 2,400 feet. The water will not rise anywhere in these wells above an elevation of 2,700 feet above sea level, and is probably drained out of the syncline in the vicinity of Braddock Run and Jennings Run to the level of 1,000 feet.

It is highly probable that the Oriskany and Tuscarora sandstones contain artesian water in their synclinal areas. There are areas to the north, northeast, and south of Cumberland where artesian wells, if properly located with regard to the local details of structure, would be almost certain to strike pure flowing water in the Oriskany and Tuscarora sandstones. Similar conditions exist over a large proportion of the Flintstone quadrangle, but except in the vicinity of Cumberland there is no demand for artesian water.

WATER RESOURCES OF COWEE AND PISGAH QUADRANGLES, NORTH CAROLINA.

By Hoyt S. Gale.

The Cowee and Pisgah quadrangles are in western North Carolina, their southernmost limits overlapping into South Carolina. They include parts of Macon, Jackson, Swain, Haywood, Transylvania, Buncombe, and Henderson counties in North Carolina. Their total area is about 1,950 square miles.

Geographically these quadrangles are situated in the heart of the southern Appalachian Mountains, covering an area of comparatively high and roughly dissected country. The headwater valleys of French Broad River, in the Pisgah quadrangle, and of Little Tennessee River, in the Cowee quadrangle, include the greater part of the open country they contain. The smoothly graded débris slopes of these and some other valley bottoms are in strong contrast with the sharp dissection of the territory in general. However, the area contains numerous remnants of old plateaus, recording several distinct periods of ancient peneplanation, and many examples of the original mature topography, as yet untouched by readjusting drainage, are found high up about the uppermost headwaters. Still above these plateau levels rise many residual peaks.

Drainage.—The larger part of the drainage belongs to the Mississippi River system. The Blue Ridge, the main divide between the Mississippi and the Atlantic waters, passes through the southern halves of the two quadrangles. Most of the streams south of this divide have worked their grades back to steep slopes, often escarpments, at their very heads. The Mississippi drainage north of the divide has, however, been less active in its channel cutting, being held up by greater difficulties in its paths and the longer route traversed to reach the sea level. Most of the remnants of old land topographies spoken of above are thus found on the Mississippi side of the Blue Ridge. Subsequent incision of these stream channels has not yet receded upstream far enough to affect grades at the headwaters.

The Cullasaja River is a good example of the streams on the Mississippi side of the Blue Ridge. Heading on the slopes of the residual peaks in the vicinity of Highlands, and also on the Highlands plateau, of about 3,800 feet elevation, it collects its waters from a drainage basin of smooth, well-rounded slopes. About a mile below Highlands it comes to the edge of this plateau and begins to drop off in cascades and falls, and its valley becomes steep sided and deep. The immediate locations of the falls are determined by the harder ledges of rock. In most cases here, as elsewhere in this region, these ledges are granite. In the next 6 miles the river drops 1,200 feet, an average grade of 200 feet in a mile. For the remainder of its course to Franklin its grade again flattens out. Along this stretch is the plateau of Little Tennessee River. From Rabun Gap, the main head of the Little Tennessee, to Franklin this river falls about 100 feet in 25 miles, or 4 feet to the mile. Below Franklin the Little Tennessee comes to the edge of this lower plateau and falls off more rapidly again.

French Broad River is in character very similar to the Little Tennessee. Along both rivers the lower plateaus are at an elevation of about 2,100 feet above sea level, and into them both streams have slightly incised their channels. The French Broad runs a course of about 45 miles from its main forks near Eastatoe Ford to the point where it leaves the Pisgah quadrangle. In this distance it falls from 2,180 feet to 2,000 feet above sea level—180 feet in 45 miles, or 4 feet in a mile. Streams so well graded are very exceptional in this region.

The west fork of Tuckaseegee River gathers into a stream of considerable size the waters of an upper plateau level of about 3,600 feet. Just below Glenville, in Jackson County, it comes to the plateau edge and drops 900 feet in 6 miles, or 150 feet to the mile. The East Fork similarly drops over 100 feet a mile for more than 10 miles.

The heaviest grades are south of the Blue Ridge. The descent is here concentrated into one steep slope from the Blue Ridge plateau down to the Piedmont Plateau. The intermediate levels that occur on the Mississippi streams do not occur here, so that the Blue Ridge is characteristically an escarpment overlooking the Piedmont Plateau. Cæsars Head is a feature of this escarpment. Ten miles west of Cæsars Head the Blue Ridge and the escarpment diverge, and an upper plateau intervenes between the main divide and the fall line of the streams. This plateau extends about 20 miles westward, as far as Whiteside Mountain. Streams heading within this belt, therefore, have flat headwater grades similar to those of Cullasaja River in the Mississippi drainage. However, the drop from the Blue Ridge plateau to the Piedmont Plateau is far greater than any that occurs on the Mississippi side of the divide. For example, the Toxaway River is 3,000 feet at Lake Toxaway, and in 5 miles it falls to 1,300 feet, or at the rate of 340 feet in a mile. It would seem that these streams offer much available power, but the falls are almost always difficult of access and most of them are distant from present lines of transportation.

Springs.—This is on the whole a region sparsely settled and little developed commercially or industrially, and little or nothing is known concerning the uuderground waters except as they issue in springs, or perhaps through the few existing wells. The country is abundantly supplied with springs, except along the gravel and bowlder deposits, which form the valley bottoms of the larger streams. The water is for the most part very pure. The rocks are typically siliceous or micaceous, containing little readily soluble material either in themselves or in their soils. The soils are loose and coarse, usually sandy rather than clayey, and do not afford much material that will stay in suspension in the water. However, mineralized waters do occur in numerous instances. These can be separated into at least two classes. Besides the granites and micaceous gneisses, a more basic rock, containing much hornblende and other iron minerals, traverses the region in long, narrow bands. Springs issuing along these bands are frequently heavily charged with iron. Their occurrence is rendered noticeable by the deposits of iron hydrates that accumulate about them. A spring that forms an excellent example of this class issue directly from a narrow outcrop of hornblende-gneiss just below the dam at Fairfield Lake, in Jackson County.

Another type of mineralization of spring waters has been noted where formation contacts, and especially zones of faulting, show a development of pyrite, with perhaps other minerals. Weathering of these to a soluble form stains the rocks with copperas and impregnates the water that flows through them. Sulphur and iron waters observed at a number of localities undoubtedly obtain their mineral content in this way. The most accessible and best known sulphur and iron water occurs at Waynesville, at the "Haywood White Sulphur Springs," but the writer is not prepared to say how it originates.

In considering the underground waters it is necessary to distinguish at least three definite types of topography and surface drainage which are conspicuous in this region. The thinly covered ledges of the residual peaks that stand above the old plateau levels shed water rapidly from their steep slopes. Flow within these massive rocks must be slight, except through cracks and fissures. On the plateau levels, however, prolonged weathering has produced a heavy cover of soil which must be comparatively porous. This is well supplied with water from the residuals, and on the other hand well supplied with outlet drains at the plateau edges, and a strong and constant underground flow must result within this cover. In the stream bottoms, at lower levels, are graded plains of wash débris, from which the water does not often come to the surface to form springs. Here the water supply, if not taken from the stream itself, must be drawn from wells or piped from neighboring hillsides. As the larger towns are usually situated in the open valley lands they are least easily supplied with pure water. All of the countv seats within the area are so situated.

WATER RESOURCES OF THE MIDDLESBORO-HARLAN REGION OF SOUTHEASTERN KENTUCKY.

By George H. Ashley.

This area, which takes its name from the towns of Middlesboro and Harlan, is a belt of country occupying the region between Pine Mountain on the north and Cumberland Mountain on the south, and is located in Bell and Harlan counties, in southeastern Kentucky. It extends from the headwaters of Yellow Creek, near the Kentucky-Tennessee line, in a course about N. 60° E. to Big Black Mountain, a distance of about 60 miles. At its western end the belt is about 10 miles wide, at the eastern end about 15 miles wide, and its area about 750 square miles.

The topography is that of a basin bounded on the north and south by two high mountain ridges and limited on the east and west by the divides at the heads of the streams draining toward the middle of the basin and passing out by way of the Cumberland River through Pine Mountain at Pineville Gap. The region between the ridges has now been cut down by the rivers until only sharp ridges remain. These commonly vary from 2,500 to 3,400 feet in altitude. The streams are generally from 500 to 2,000 feet below the crest, the Cumberland River having an altitude of 980 feet where it leaves the basin. The slopes of the hillsides are nearly all steep, the only flat lands being narrow belts along the streams. The hills throughout the basin are generally forested.

Geologically the area is a synclinal basin, the axis of which lies to the north of the center, or nearer to Pine Mountain. In the center of the basin the dips are slight, but run up to nearly or quite vertical on the flanks of the bounding ridges. The rocks consist of alternating beds of sandstone, shale, and coal, the sandstones predominating.

Many cabins are scattered over the slopes and crests and in the ravines throughout the hilly region. In fact, the majority of the inhabitants are located among the hills, though the prosperous habitations are nearly all in the towns or along the river bottoms.

Along the bottoms water is obtained either from shallow wells in the river gravels or from near-by springs. In the hilly region springs are especially abundant and constitute the chief source of supply, even up to the very crests, although a few shallow wells have been dug on the hilltops. In times of prolonged drought the springs occasionally fail, and recourse is had to streams, which, however, are sometimes so low that water appears only in isolated pools. The waters of the springs and wells are noncalcareous and are of good quality.

The town of Middlesboro obtains water from Little Yellow Creek, a stream that flows along the foot of Cumberland Mountain and is fed from large springs from sandstone. The water is pumped from an artificial lake made by a concrete dam across the creek to a reservoir on a near-by hilltop. The pumping station is a mile from the center of the town. A large spring, which formerly came out a little below the summit of Cumberland Gap, was diverted by the building of the railroad tunnel and is now piped to town for the use of the local tannery. A number of deep wells have been bored at Middlesboro for oil, but, though obtaining no oil, at least one of them—that at the mouth of Bennett's Fork—gives an abundant flow of water from the Lee conglomerate. One well is 750 feet deep. Similar artesian water might be found elsewhere, but no other wells have yet been drilled.

Pineville is supplied from a small tributary of Hagan Mill Branch of Cumberland River. It is a small stream fed by springs on the south side of Pine Mountain, 1½ miles east of the gap. The pumping station is located on the Cumberland River.

Water power on a very small scale is obtained at a number of places on Cumberland River and on its forks and branches. At only two points is there promise of considerable power, one of which is on Shillaly Creek. This stream rises on a broad plateau between Cumberland and Brushy Mountain, and attains a considerable volume before it descends into the deeper valley. Martins Fork of Cumberland River heads near Shillaly Creek and descends in a similar but more gradual manner, and with somewhat larger volume.

SUMMARY OF THE WATER SUPPLY OF THE OZARK REGION IN NORTHERN ARKANSAS.

By George I. Adams.

During the progress of geological work in the Ozark region of northern Arkansas considerable data has been collected in regard to the water resources. This paper is intended as an outline of the conditions of occurrence of the springs, which are numerous and important. They are in many cases the heads of streams, with which the area is well supplied.

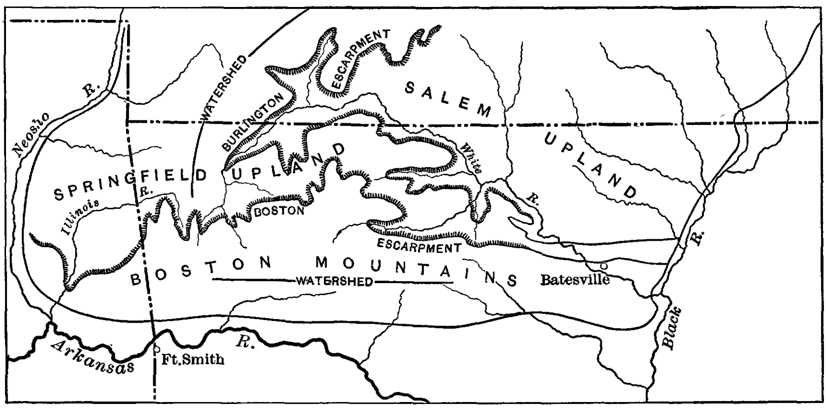

Fig. 32.—Sketch map of Ozark region in northern Arkansas.

The accompanying sketch map of a portion of the State shows the location and extent of the Ozark region. Observations have been largely confined to the western part of the area, but some of the springs in the eastern part have been noted, so that the geologic relations of the ground waters as outlined is thought to be consistent for the whole.

THE OZARK REGION AND ITS DIVISIONS.

The Ozark region in Arkansas includes two distinct types of country, the characters of which are determined by the structure and extent of the rock formations. The southern of these is the Boston Mountains, a dissected highland which extends from the vicinity of Batesville westward to the Indian Territory line. To the south it blends with the Arkansas Valley region. Its northern border is outlined by the Boston escarpment, which is very irregular, being cut by numerous stream valleys, between which are irregular peninsula-like promontories,

North of the Boston Mountains and at a lower level is the more even country that forms a part of the Ozark Plateau, which extends northward into Missouri. The surface features are closely related to the nearly horizontal rock formations. The rocks which outcrop in this area belong principally to two classes. They may be spoken of as the Mississippian limestone and the Ordovician dolomites. The Mississippian limestones are higher geologically and the area in which they outcrop is known as the Springfield upland. The area of the Ordovician dolomites is nearly coextensive with the Salem upland. These two divisions of the plateau are separated by a more or less distinct escarpment, known as the Burlington escarpment, which has a height of approximately 300 feet.

When viewed in a broad way the higher portions of the Springfield and Salem uplands are seen to fall in a slightly warped plain, which is dissected by the streams. The drainage of the western portion of the Ozark region in Arkansas is tributary to Illinois and Elk rivers, which find their way around the western end of the Boston Mountains into Grand River and eventually into the Arkansas. The remaining streams that head in the region are tributary to White River, which flows in an irregular course northward and then southeastward around the eastern end of the Boston Mountains. In the eastern portion of the Salem upland there are a number of streams which enter the State from Missouri. Some of these are tributary to White River within the Ozark region, while others enter Black River, which flows along the eastern border. The larger creeks, and especially the rivers, are perennial. The minor ones flow during most of the year, but during the drier seasons the water in them stands in pools or has a decreased flow, which is contributed by springs. The fact that the country is well watered is largely due to the nature of certain rock formations which hold a large content of water.

SPRINGS OF THE OZARK REGION.

The horizons of the springs are in large measure determined by certain formations which afford easy channels for the underground water, and by others which are impervious and guide the flow along the dip of the rocks to their outcrops. The following classification of the springs of the region is tentative only; further observations and more detailed study will probably enable a classification to be proposed which will more fully cover the conditions existing.

SPRINGS RELATED TO THE LIMESTONES IN THE BOSTON ESCARPMENT.

The rocks that outcrop in the Boston Mountains are principally sandstones and shales. There are, however, two limestone formations which, although usually but from 5 feet to 50 feet thick, are persistent.

The lower is known as the Pitkin limestone and the upper as the Brentwood. The effect of these formations on the topography, as the result of their manner of weathering, is to produce benches. Their outcrops, although often concealed, are frequently seen as conspicuous ledges. The ground water finds an easy path along the bedding planes and joints of these rocks, and because of slight undulations of the formation it converges at certain points and issues as springs. The occurrence of these springs at the headwaters of Illinois River in the vicinity of Prairie Grove, and at many other localities, influenced the early settlers in their selection of sites for homes. A spring of this type is seldom found which is not the site of a settlement, and in some cases they have determined the location of towns.

SPRINGS RELATED TO THE BOONE LIMESTONE AND CHERT.

The principal formation in the Springfield upland is the Boone limestone and chert. Circulating water finds easy channels along its bedding planes and joints, and, as is often the case in such rocks, numerous solution channels, and occasionally caves and sinks, have been formed in it. A large amount of the underground water in the Boone chert is contributed to the streams without appearing as springs. In some places, however, it issues at the heads of valleys or at levels above streams, and forms important springs. A few of the springs are so large that their waters have been dammed or conducted by means of flumes to furnish power for small mills. At many towns they are the source of water supply, and in some instances the locality is utilized as a summer resort, as at Monte Ne, for example.

SPRINGS RELATED TO THE SHALE BED AT THE BASE OF THE BOONE LIMESTONE.

In the western part of the Ozark Plateau a bed of shale ranging from a few feet up to 50 feet in thickness lies underneath the Boone formation. The influence of this impervious bed upon the circulation of the ground water is to carry it along its upper surface with the dip to the outcrop. Many springs issue at the base of the Boone limestone, just above the shale. The best known is Eureka Spring, which has become famed as a health resort. While many of the springs occurring at this horizon do not carry a large volume of water, they are of considerable importance as a source of domestic supply to individual households or neighborhoods.

SPRINGS RELATED TO THE SANDSTONE AT THE TOP OF THE YELLVILLE DOLOMITE.

Descending in the geologic section the next important formation as a source of springs is this sandstone. It is a loosely cemented sandstone, and the waters which issue from it are "softer" than those previously mentioned—that is, they carry but little lime. The water issuing from the sandstone does not usually afford a large supply, but because of its softness it is particularly desirable.

SPRINGS RELATED TO THE YELLVILLE DOLOMITE.

The Yellville dolomite outcrops over nearly the entire area of the Salem upland. Its rôle as a water reservoir is similar to that of the Boone formation. However, there are local beds of shale and argillaceous layers in the Yellville formation, and in some instances they guide the ground water to a point of outcrop. The springs from the dolomite are numerous, but much of the water issues directly into the streams without appearing as springs. The formation as seen in its natural exposures exhibits, especially along the bluffs, solution channels showing the point of issuance of ground water before the streams had cut their valleys down to their present positions. Within the area of the Yellville formation there are many sink holes and caverns. The ground water undoubtedly moves in important channels. At Mammoth Springs, a station on the Memphis Railway on the

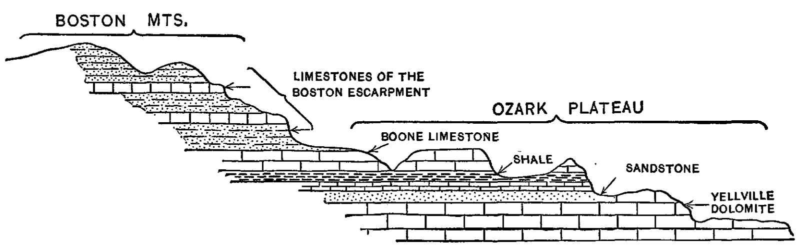

FIG. 33. Diagrammatic section showing principal horizons of springs in northern Arkansas.

northern border of the State, the water issues with such volume that it is often spoken of as a small river. It contributes, as do many of the springs of the region, to the natural beauty of the scenery and the enjoyment of pleasure seekers.

Many of the springs of this region are more or less renowned, and some have been frequented for many years as health resorts. Analyses of the waters from some of them have been made, and certain of them are reputed to have medicinal value and in rare instances do contain unusual minerals in solution. It may be said of the springs of the region in general that they are particularly pure and wholesome. As such they are valuable for domestic purposes, and in some instances as a supply for small towns. A few of them are regarded as possessing therapeutic qualities which render them valuable in specific ailments. None of the springs in this region are hot springs. On the contrary, the temperature of them in summer time is such as to render them cool and potable. The country is at present sparsely settled. No doubt more of the springs which are now allowed to run to waste will, because of their surroundings, become valuable as pleasure and health resorts.

NOTES ON THE HYDROLOGY OF CUBA.

By M. L. Fuller.

INTRODUCTION.

The problems of the water resources of Cuba were brought forcibly to the attention of those interested in the island during the period of occupation by the American army. Notwithstanding the great abundance of water on the island as a whole, it was found that in many of the relatively level strips along the shores the supply was frequently both insufficient and of a poor quality. This led, in a considerable number of instances, to the sinking of wells by the War Department. The attention given, both by the Americans and the natives, to the question of utilizing more fully the splendid natural resources of the island will doubtless, under the present improved conditions, lead to the introduction of pure supplies in many villages.

At many of the mineral springs hotels and baths were constructed and resorts developed by the Spanish. Some of the springs are equal to many of the famous spring resorts of Europe and America in natural beauty of surroundings and in the quality of their waters, and will probably in a few years become popular with many Americans. The caves, though having many natural attractions, are in many instances inaccessible, and have been until recently almost unknown to people outside the regions in which they occur.

The purpose of the present notes is to give a summary of the natural and artificial water resources of the island, including town water supplies and springs and the underground drainage with its resulting caverns.

Acknowledgments.—The facts included in the following notes have been drawn from a number of different sources, but in their presentation it is impossible to give separate credit in each case. The portions relating to the topography and geology are mainly based on the "Report on a Geological Reconnaissance of Cuba," made to Brig. Gen. Leonard Wood by C. W. Hayes, T. W. Vaughan, and A. C. Spencer, published in Cuba in 1901; those relating to water supplies from reports of Assistant Engineer O. Giberga, Maj. H. F. Hodges, and Resident Engineer H. F. Labelle, published in "Civil Report of Brig. Gen. Leonard Wood, January 1 to May 20, 1902," volumes 5

and 6; those relating to mineral water from a report by Mrs. H. C. Brown incorporated in the preceding; those relating to subterranean caves and streams from "Island of Cuba," by Lieut. A. S. Rowan and M. M. Ramsey (Henry Holt, New York, 1896); and those relating to wells in part from published reports of the War Department, but mainly from written memoranda furnished directly by that Department to the United States Geological Survey.

GEOGRAPHY AND TOPOGRAPHY.

The island of Cuba is located south of the State of Florida, the meridian of Washington crossing it about 200 miles from its eastern end. The distance of the nearest point of Cuba from Key West is 86 miles. The length of the island is 730 miles, the breadth from 20 to 90 miles, and the area about 43,000 square miles.

In general terms the island may be said to possess a central highland belt, reaching from Cabo de Maysí on the east, first northwestward and then southwestward to Cabo de San Antonio on the west, attaining an elevation of 2,500 feet and becoming somewhat mountainous in places, but elsewhere dropping nearly to sea level.

The surface may be divided into five topographic provinces, three of which are essentially mountainous while the other two are of low or moderate relief. The easternmost of these topographic divisions coincides approximately with the Province of Santiago. In this province, taken as a whole, there are two principal mountain groups. The southern is an east-west ridge, known as the Sierra Maestra, extending from Cape Cruz to the vicinity of Puerto de Guantanamo, and from there continued by a geologically distinct ridge of the same trend to Cape Maysí. The loftiest mountains of Cuba, some of which are higher than any peaks in the eastern United States, occur in this range. The northern range merges with the southern near the eastern end of the province, but diverges westward, the intervening area constituting the undulating plain of the well-known Cauto Valley, which westward merges with the more extended plains of Puerto Principe. The second topographic division corresponds closely with the Province of Puerto Principe, and is made up of plains or rolling open country broken by occasional hills or low mountains rising above the general level. The third division includes the mountainous portions of the Province of Santa Clara. The island is here crossed by a mountainous belt made up of a number of subordinate groups, the highest point of which is 2,900 feet in altitude. The fourth topographic district comprises the western portion of Santa Clara Province, all of Matanzas and Habana provinces, and the eastern portion of Pinar del Rio. This region, like that of Puerto Principe, is made up of low, flat, or rolling plains, broken by occasional hills several hundred feet in height. The fifth division comprises the greater portion of Pinar del Rio, and is characterized by a prominent range of mountains reaching to a height of 2,000 feet. The coast is bordered at many points, especially on the south side of the island, by marshy belts, while the shore is often fringed with reefs and keys.

GEOLOGY.

The structure of the island in a broad way is anticlinal. The geologic axis, which coincides roughly with the topographic axis, is marked by masses of serpentine, granite, and folded and metamorphic slates and schists, on the flanks of which, dipping gradually away, lie the later sedimentary formations. The dip is strongest to the north. Of the later sedimentary beds the oldest appears to be a semicrystalline blue limestone, which may be as old as the Paleozoic. It is, however, only locally developed, the first persistent beds being the hard gray limestones of the Cretaceous. These are overlain by Eocene limestones and glauconitic sands, sometimes interbedded with volcanic rocks, and by a great thickness of limestone, marls, etc., of Oligocene age. During the accumulation of these rocks the land was deeply submerged, at times possibly completely, except for occasional peaks in southern Santiago Province. In Miocene times the land was uplifted above sea level, where it has remained, except for a possible subsidence of 100 feet in Pliocene times and a number of minor oscillations in Quaternary times, during which the Quaternary shelves of elevated reef rocks were formed. The uplift was greatest along the old axis, the result being the tilting of the beds on both flanks.

The limestones, which are the predominant rocks of the island, constitute nearly its entire surface except along the axis of the island. They are in general distinctly stratified, but their internal structure has been greatly changed by the action of percolating waters, nearly all traces of fossils having been destroyed. Their present thickness is from 800 to 1,000 feet. Since their deposition they have been removed by erosion from portions of the higher lands, while in some of the less elevated lands, although they form the surface, they are frequently cut through by streams.

DRAINAGE.

The highlands of the island are characterized by the presence of abundant springs of considerable volume. While a considerable number of these flow from the metamorphic and igneous rocks, the larger springs are from the limestones which cover a large part of the island. The waters are of that extreme transparency which characterizes the limestone springs of the adjacent mainland at Florida. It is from these springs, or in some instances from underground streams, that the surface streams of the island take their rise. The run-off by these streams is very great, as the high rainfall usually occurs as showers of short duration, the water finding its way quickly down the steep hillsides into the streams. The portion of the rainfall sinking into the ground passes into the porous limestone, through which it finds its way by general seepage or by way of caverns and other underground channels back to the streams. In some instances whole streams disappear into the limestone only to reappear near the margin or beneath the sea.

The arrangement of the streams in Cuba is very simple, their courses being nearly all normal to the coast and their lengths, therefore, very short. The divide between the northward and the southward flowing streams lies near the axis of the island, being generally somewhat nearer the north than the south coast. In the eastern and western provinces the divide corresponds with the mountainous belts, but in the central province it falls on a level plain and is extremely indefinite. In the mountainous regions the valleys, while moderately steep-sided, are fairly wide, but where they cut through the tilted plateau along the northern coast canyon-like valleys have been formed. An exception to the ordinary arrangement of streams is found in Santiago Province, where the Rio Cauto, the largest river of the island, has a trend nearly due west. The length of this stream is 150 miles, and it is navigable for shallow craft for a distance of 50 miles.

Lakes are very rare on the island, although a number occur in the midst of the dense vegetation of the marshes near the coast. Many of these are hardly known to the inhabitants themselves. A very few small lakes are also found in the mountains. The most noted of these is Lake Ariguanabo, which lies 20 miles southwest of Habana. Its surface is 6 square miles in area and it is drained by a stream which, after flowing on the surface a short distance, disappears into a subterranean passage. It is inhabited by fish, which are supposed to have worked their way upward to the lake through this passage.

CLIMATE.

The climate of Cuba is tropical and insular. The year is divided into a rainy and a dry season, the former extending from May to October. Two-thirds of the total precipitation, which amounts to about 50 inches at Habana, falls within this period. The rainfall inland is considerably higher. The average temperature for August is from 89° to 91°, while in December, January, and February it is 10° to 15° lower. The temperature of the north coast is somewhat lowered by the persistent northeast trades. The relative humidity is very great, amounting to an average of 80 per cent.

WATER SUPPLY.

CITY WATER SYSTEMS.

Notwithstanding the extremely numerous springs and streams of pure water, few public supply systems have been installed, and these only in the largest cities and towns. In the smaller cities and villages the supplies are obtained from a variety of sources. Shallow wells are generally used where water is obtainable, regardless of the fact that they are almost invariably subject to contamination. Cisterns are frequently used, but generally furnish insufficient supplies to meet the needs of the people. To supply this deficiency water is often peddled about the streets in kegs and other receptacles. Even where pure city supplies are at hand the poorer classes, in many instances, are not inclined to connect with the pipe systems because of the expense, but prefer to continue to purchase their supplies from peddlers. In some towns water has been at times so scarce that it has commanded almost fabulous prices.

Habana.—The first water-supply system for the city of Habana was installed at the close of the sixteenth century, when a dam was built across the Almendares River about a mile above Puentes Grandes, and the water brought to the city through an uncovered aqueduct known as the Zanja Real, which reaches the city at a point near the present reservoir. From this point the zanja divides into many branches, the water ultimately making its way into the bay and sea through Matadero, Agua Dulce, and San Lazaro creeks and the city sewers. The water in this aqueduct is now so contaminated as to be unfit for drinking in the built-up portions of the city, and is at present mainly used for irrigation and power. The water rates paid, however, are so low that the expense of keeping the zanja in repair is greater than the income derived from it.

The second system of water supply dates from 1837, when the Almendares River was diverted at a point about 4½ miles above the city. The water was conducted by a 20-inch iron pipe laid to the city, together with a limited number of distributing pipes, the system being known as the aqueduct of Fernando VII. An attempt was made at filtration, but the methods proved defective and in times of heavy rain the supply was turbid from surface wash. The filters, however, although of an antiquated type, were found by the Americans to be in good condition and were cleaned and maintained, in order that they could be utilized to bring in the Almendares water in case of a break in the Vento aqueduct.

The supply from the river proving insufficient a new system was projected in 1858. By this plan a group of 400 springs near Vento, on the banks of the Almendares, about 8 miles above the city, were enclosed in a masonry structure 150 feet in diameter at the base, 250 feet at the top, and 60 feet deep. Masonry dams were built around the top to keep out the surface wash. The water is carried under the river through an inverted siphon consisting of two heavy iron pipes in a masonry tunnel, and thence by gravity through an underground masonry aqueduct to the Palatino reservoir, about 4 miles from the city. From the reservoir the city is supplied by gravity through a system of distributing mains. The construction of the system met with many interruptions, but the works were finally completed about 1893. The supply is about 40,000,000 gallons a day, against 1,333,000 gallons a day of the earlier system.

In 1886, during the construction of the Vento aqueduct and before its completion and the construction of the reservoirs, a branch main, 20 inches in diameter, was run from the Vento aqueduct at a point opposite the filter beds to those beds, and the water of Almendares River was cut off from the beds and the Vento water supplied to the city through the aqueduct of Fernando VII. Since the completion of the Vento system neither this branch main nor that portion of the aqueduct of Fernando VII south of Palatino has been used. They have, however, been maintained in good condition, so that in case of accident to the Vento system below the branch main the city could be supplied with Vento water through this branch and the Fernando VII aqueduct.

Casa Blanca and Regla were formerly dependent upon cisterns or local wells more or less contaminated, or upon water supplied from the Habana mains, which was carried across the harbor in boats and sold at the rate of 2 cents a gallon. In 1899 an iron pipe was laid across the harbor to a pumping station at Cabana Fortress, from which the water is pumped to a 200,000-gallon tank on the hills, whence it flows by gravity to Cabana Fortress, the barracks, and the town of Casa Blanca. Regla is supplied by a gravity main connected with the Habana supply. A pumping station was installed in 1898 near the Palatino reservoirs for the purpose of furnishing supplies for the camps at Quemados, Marianao, and to Camp Columbia, Aldecoa, Principe, and several hospitals, and other places. A project was also started to supply the town of Arroyo Naranjo from springs at Calabazar. Plans were also made for supplying Pirotecnia, Carmelo, and other localities.

The only large sections of Habana now without Vento water are the higher portions of Jesus del Monte and La Vibora and the high sections of Vedado, all of which will have to be supplied by pumping, as they are above the limits of the gravity supply. Detailed plans and estimates were prepared and submitted for the supply of the former places, at an estimated cost of $36,500, but the work was not undertaken by the Americans on account of the lack of funds. Studies were made for the supply of the higher parts of Vedado.

A concession was granted to a private company by the Spanish in 1894 to supply and sell Vento water to the lower portions of Vedado and Carmelo. Some work was done, but the system was found to be incomplete and in bad condition, and the concession was annulled by order of the governor of Habana in 1899. This order was revoked, however, in 1900. The conditions are still very unsatisfactory.

During the Spanish control cast and wrought-iron pipes, principally the latter, were used for house-service connection, and, owing to the rapidity with which they are destroyed by the salts and acids of the soil, breaks were frequent. Many of the distributary pipes were also old and the connections were frequently faulty and complicated. Many of the valves of the old system were found to be almost entirely destroyed. A large amount of repairs, including the replacement of much pipe, the installation of many new valves, and the inspection of 400 fire hydrants and installation of 100 new ones were made by the Americans.

In certain parts of the city leakage was very great and an investigation was made by the Americans, with the result that the daily consumption was decreased from 35,419,342 to 28,760,800 gallons, or from 144 to 117 gallons per capita. The consumption is still high, especially for the hours between 1 and 2 a. m., when the legitimate consumption should be very small. Probably much of this loss is due to leaks that can not be readily located because of the porosity of the soil, which favors rapid absorption of the leakage.

The regulations governing the water supply of the city do not admit of proper control and regulation of the service. In 1902 the installation of water was made compulsory in those portions of the city that are supplied with mains and the installation of meters was required in manufacturing establishments or other institutions using large quantities of water. This order greatly increased the revenues and secured a more just distribution of charges.

During the American occupation it was observed that for a day or two after a freshet a quantity of turbid water entered the main spring or "taza" at Vento. It was at first thought that this was caused by the river water entering the spring through the valves regulating the overflow, which were not designed to resist pressure from the outside, but experiments made later showed that the trouble was due not only to this leakage, but chiefly to underground connections between the outer springs and the main springs. When the river rises beyond the level of the main spring, the head thus formed forces the water through these connections into the spring. Apparently the only way to prevent this is to build a tight wall around the outer springs and carry it above the highest flood level, or else to tightly cover these springs and provide automatic waste valves which will close when the river rises to the danger point.

During the period of the American occupation the Vento aqueduct and the Palatino reservoirs were maintained in good condition, the reservoirs being thoroughly cleaned at least once a month. These are, however, insufficient in size, holding less than half a day's supply, and should be enlarged. The aqueduct is large enough for present needs, but a new one is desirable to provide for the possibility of accident to the present one. The supply from the springs is ample for present and future needs, and the water is excellent in quality, being almost pure organically, but hard from limestone in solution.

Matanzas.—The city of Matanzas has had an abundant supply of excellent water since 1872. The source is Bello Springs, from 7 to 10 miles from town. As in other Cuban cities, many have failed to take advantage of the public supply but continue to obtain their supply by purchase or from shallow wells and springs.

During the American occupation the problem of supplying the jail was investigated. The water is now obtained from a cistern and pumped into an elevated 23,000-gallon tank, from which it is distributed to the jail for use in baths and closets. Since installing the tank the average daily consumption from the water company's mains has been reduced from between 5,000 and 10,000 gallons to about 500 gallons, the average charges at the same time falling from $95 to $3.85, the latter sum being paid for water still obtained from the company for drinking and cooking purposes. The total cost of the installation was $357.

Cárdenas.—Cardenas has been supplied since 1872 with pure water from a subterranean river about a mile distant. Brackish wells and cisterns are still depended upon by some of the people, while others have until recently purchased their water from street peddlers.

Cienfuegos.—Until a few years ago this city was supplied by cisterns or by peddlers, but waterworks were being introduced at the time of the American occupation.

Guantanamo.—This town was formerly supplied by an underground stream flowing from a cave, but work on a new supply was begun in 1899 by the Americans, who built a dam across Guaso River, 9 miles from Guantanamo. This dam was completed in 1901 and yields a supply of 955,152 gallons of excellent water daily, or 120 gallons per capita. The total cost was $210,166.32. The work was turned over to the municipality in February, 1902.

Puerto Principe.—The water supply of Puerto Principe is derived chiefly from artesian wells, five of which were drilled during the American occupation. Of these, two are in the northern part of the city, one in the western, one in the central, and one in the southern. The two wells in the northern part of the city are each 486 feet deep, situated side by side, and supply about 25,000 gallons of water daily to the public buildings and to the public who call for it. At this place the water is pumped by steam, the pumps being run day and night. At the other wells—one near Carmen Hospital, where a good and abundant supply was obtained at a depth of 188 feet; one in the market place, 207 feet deep, and one at the Matadero, 154 feet deep—60-foot tower windmills, with 10,000-gallon tanks, have been erected. The tanks are placed 30 feet above the ground.

Santiago.—Santiago has long been supplied with water from Boniato River, a neighboring stream, the water being conducted to the city by an aqueduct. This was cut by the American army during the siege of the city, but was repaired during the American occupation. Prior to this time the supply was only about 9 gallons per capita from June to February, while in March, April, and May the stream was so low that only 2.5 to 5 gallons were obtainable. After certain improvements had been made, measurements showed the supply capable of yielding 800,000 gallons daily, or 18.6 gallons per capita, but the supply was decreased 162,000 gallons daily by the necessity of cutting a part off from the lower part of the city in order to secure sufficient head to supply certain of the higher portions. An additional supply of 30,000 gallons was obtained by cleaning and repairing the old reservoir built in 1860 and connecting it with the city mains. The northern part of the city was supplied from the reservoir, while the southern part was supplied by the direct mains. Pumps were also installed to increase the supply in dry seasons.

As approximately 3,000 people live on the stream within a mile of the intake the water was badly polluted and there was constant danger of epidemics. This, taken in connection with the deficiency of supply, made it imperative to look for a new source. Detailed investigations were accordingly made by the Americans, the country for 30 miles around the city being examined with a view to procuring a new supply. The sources considered were (1) a gravity supply from Baconao River; (2) a gravity supply from Cauto River, and (3) a pump supply from wells in the San Juan Valley.

In the proposed Baconao system the water would be taken from a point about 21 miles above the mouth of the river, from which it would be conducted 19 miles to Daiquirí and 18.5 miles farther to Santiago. Nearly the whole of the line is of easy access, and the location would require very little costly road making. The estimated total cost was $2,844,812 and the annual cost of operation $169,000.

A supply from Cauto River could be brought in by pumping through the Maniel or Rio Frio Pass from a point about 2½ miles below Dos Palmas, a distance of 25 miles from Santiago. The country is favorable to the construction of a conduit, and good locations for dams and power stations are available. The estimated cost was $1,451,127, and the annual cost of operation $105,000.

The preliminary surveys having shown that still better results would be obtained from a well system in the San Juan Valley, a detailed investigation in that region, including the drilling of test wells, was undertaken. The portion of the valley under consideration lies just south of the Sierra Maestra, and drains to the sea through a gorge 500 feet wide at La Laguna. The underflow through the river gravels is very high in some of the branches, and the water is of good quality, notwithstanding the river waters themselves are frequently much polluted. The well sections show: (1) A surface layer of brown clay and vegetable matter from about 4 to 16 feet in depth; (2) a water-bearing stratum of sand, gravel, bowlders, and broken coral rock, 11 to 30 feet thick, with an average of 25 feet; (3) blue, yellow, or brown clay, 5 to 20 feet thick; and (4) a series of sands, gravel, broken coral rock, clay, etc. The coral bed rock has not been reached except along the borders of the valley, where it is near the surface. The following record may be given as typical:

Record of well at Santiago, Cuba.

Strata.	Thickness of strata.	Depth from surface.
Soil	21	21
Fine sand	16	37
Gravel	13	50
Coarse gravel	6	56
Yellow clay	14	70
Blue clay	6	76
Fine sand	17	93
Sandstone	7	100
Coral rock	18	118
Hard coral rock	8	126
Fine sand	9	135
Yellow clay	8	143
Sand and gravel	7	150
Clay	5	155
Sandstone	6	161
Gravel and sand composition	9	170
Total	....	170

The area of the local underground reservoir to be drawn upon for the supply is estimated as 3½ square miles, and the probable yield computed as from 1,235,000 gallons a day in dry seasons to perhaps 2,434,000 gallons in wet seasons. The average rainfall is estimated at about 60 inches, the run-off as 13.5 per cent, and the total supply of underground storage 23,000,000 gallons a day. If 60 per cent of the 15 feet of storage gravel is utilized the supply is good for 410 days, which, considering the fact that the dry season lasts only four or five months, is amply sufficient. The water of the lower gravels can also be utilized in case of any deficiency of the upper supply. Infiltration galleries, gang-tube wells, and large caisson wells were considered as methods of collecting the water, the latter being finally recommended. San Juan Hill was selected as the best site for the pumping plant. An examination of the water by G. C. Whipple, of Brooklyn, N. Y., showed slight organic matter, low free ammonia nitrites and nitrates, and high chlorine, as well as carbonates and sulphates—especially the former. Storage in the dark, to prevent algous growth, was recommended. The cost of installation was estimated at $408,650 and that of operation as $92,000 annually. Both figures are much lower than either of the other systems proposed.

Manzanillo.—This town formerly had a water system deriving its supply from the river Yara, but it proved unhealthful and was abandoned. Cisterns now furnish the main supply.

SPRINGS.

Owing to the great porosity of the limestone which forms the surface over a large part of Cuba, and which rapidly absorbs and almost as rapidly discharges its waters, springs are very numerous. They are of all sizes, from small rills up to almost river-like streams. Some of the springs seep from the porous limestone, but many of them issue from more or less cavernous orifices. They issue at all altitudes, from the higher portions of the hills down to the lowland border, or even at sea level. It is probable that the marshy tracts bordering the south coast at many points are in part due to the emergence of the underground water through the limestone. Not all of the water comes to the surface of the land as springs, but some passes outward and emerges from the sea bottom along the coast, where in many instances the fresh water can be seen bubbling up through the salt water. Such springs occur in Habana Harbor and at many other points. The fresh water which emerges as copious springs on some of the keys is probably of the same origin, coming from the mainland through subterranean passages in the limestone.

Most of the spring waters of the island are highly calcareous, but are usually not otherwise especially high in mineral matter. They form pure supplies for a number of cities, including Habana, Matanzas, and Cardenas, while at other points not having public supplies, as at Marianao, the water is obtained from adjacent springs and sold through the town. Although by far the larger number of springs are of the pure calcareous type, there are a number of mineral springs upon the island. These are described under "Mineral waters," below.

SUBTERRANEAN STREAMS AND CAVES.

Probably very few regions in the world so abound in caves and subterranean passages as the island of Cuba. The porous limestone permits a free entrance of water which, by its passage, dissolves out caverns of various shapes and sizes. Although the underground passages are very numerous they are not usually large, and the caves generally lack the great beauty of many of the stalactite-hung caves of the harder types of limestone.

Many streams disappear from the surface into the limestone. Of such streams the Rio San Antonio, in the province of Habana, is the most noted. This stream issues, with a width of several feet and a strong current, from Lake Ariguanabo, flows a short distance through the town of San Antonio de Los Baños, and then enters a cavern and disappears from the surface. In a similar manner the Rio Guanajay flows on the surface for about 12 miles and then disappears into the limestone near the village of San Andrés. The Rio Jatibonico del Norte rises in the Sierra de Jatibonico and alternatelv disappears and reappears in a succession of cascades. The Rio Mayarí, near Santiago, and the short stream called Moa both pass through caverns in their courses. Many other streams throughout the island pass at one point or another in their course under natural rock arches.

Among the larger or more noted of the caves are those of Resolladero Guacanaya, in Guaniguanico; María Belén, in the Sierra de Añafe; that of Cotilla, near San José de las Lajas, 15 miles southeast of Habana; the magnificent caves of Bellamar in Matanzas; the caves of San José de los Remedios; and the caverns of Cubitas, of Gibara, of Yumurí, of Holguín, and of Bayamo; while north of Guantánamo are the noted Monte Líbano caverns.

The Bellamar caverns, 3 miles distant from Matanzas, are extensive and possess a high temperature. The air is supposed to have certain curative properties, and the caves are resorted to by invalids. At Baracoa are caverns that have an unusual development of stalactites and contain animal remains of unknown date.

MINERAL WATERS.

Cuba possesses some true mineral springs, although these are small in number compared with the common springs. Little use is yet made of them for drinking purposes, and almost nothing is done in the way of shipment. On the other hand, however, they are extensively used for bathing at various watering places and health resorts. The portion of the following notes relating to the province of Pinar del Rio and to a part of Habana Province was compiled by Mrs. H. C. Brown for the report of Brigadier-General Wood.

Province of Pinar del Rio.—Of the numerous health resorts of Cuba. that of San Diego de los Baños enjoys a particularly large share of popular favor. The town was founded in 1843, and before the numerous wars decimated the population contained 8,007 inhabitants, but at present it counts little more than a quarter of that number. The left bank of the river which flows beside the town bubbles with sulphurous springs, some warm, others cold. The best known of these are called Templado, Tigre, and La Paila. On the authority of Dr. José Miguel Cabarrouy, medical director of the baths, the following analysis of the waters of Templado and Tigre is given:

Analysis of mineral water at San Diego de los Baños, province of Pinar del Rio, Cuba.

	Per cent.
Hydrogen sulphide	0.152
Carbonic acid	.062
Sulphate of lime	.974
Chloride of sodium	.032
Bicarbonate of magnesia	.080
Alumina	.006
Total	1.306

The density of these waters is given as 1.014. They contain, besides the ingredients noted above, undetermined quantities of silicic acid, carbonate of iron, nitrogen, oxygen, and organic matter. The Templado produces 860,000 liters in twenty-four hours, and the Tigre 240,000, without any variation according to seasons. The water is colorless, has the disagreeable odor of sulphuretted hydrogen, and tastes slightly sulphurous. It has a temperature of about 34° C.

The spring called La Paila shows the following analysis:

Analysis of water from Mineral Spring La Paila, province of Pinar del Rio, Cuba.

	Per cent.
Sulphate of lime	1.068
Chloride of sodium	.022
Bicarbonate of magnesia	.120
Carbonic acid	.084
Alumina	.012
Total	1.306

The waters, which have a temperature from 22° to 25° C., show traces of sulphuretted hydrogen, silica, carbonate of iron, oxygen, nitrogen, and organic matter.

The waters of San Diego de los Baños have proved to be of special value in cases of skin disease, rheumatism, and nervous affection. The place has a wide patronage and makes pretensions as a popular resort.

Springs of mineral water are also reported from the municipal district of Mariel. In the district of San Cristóbal are springs called Soroa.

Province of Habana.—The most prominent springs of Habana Province are found at Guanabacoa, Madruga, and Santa María del Rosario.

The principal use of the mineral water at Guanabacoa is made by the Santa Rita baths, which are constructed of stone and are popular with many of the residents of Habana.

Madruga has warm and sulphur baths, supposed to possess curative properties in cases of skin disease, and also springs of mineral water that is reported to be excellent for stomach troubles. The town is a popular watering place, having several hotels which are extensively patronized from March to October.

The baths of Santa María del Rosario are famous for their medicinal qualities. The principal springs that supply the baths are three in number. The waters of the first, which is called Mina, Templado, or Palmita, issues from an orifice in the rock 3.80 meters below the surface. The water from this spring is clear and colorless, has the odor of sulphuretted hydrogen, and is disagreeable to the taste. It is cold, reaching a temperature of only 22° C. Its reaction is alkaline. The water of the second spring, called Tigre, comes from a well 6.04 meters deep. Although clear and transparent, it has a light yellow color, an odor more pronounced than that of La Mina, and a stronger taste than the first. Its temperature is 21.5° C., and its reaction is freely alkaline. The spring called La Paila is only a meter deep. The water is clear and colorless and has an odor and a taste more pronounced than the water of the other two springs. It is colder, having a temperature of 19.50° C. Analysis of the waters shows appreciable amounts of sulphur and hydrogen sulphide.

Isle of Pines.—There are many natural springs all over the Isle of Pines, and those of Santa Fé have an established reputation for their curative properties, both in Cuba and abroad. The waters are said to be particularly rich in iron and magnesia, and contain also oxygen and carbonic-acid gases, chloride of sodium, sulphate of lime, carbonate of lime, chloride and nitrate of calcium, and silica. The temperature of the waters is generally about 82° F. Some of the larger springs flow a stream of water the size of a man's body.

WELLS SUNK BY THE WAR DEPARTMENT IN CUBA.[a]

Cienfuegos.—A well was sunk by the army authorities at this point to a depth of 111 feet. A good flow of water was obtained. The following is a record of the materials penetrated:

	Feet.
Clay and sand	1- 86
Blue clay	87-101
Blue clay and gravel	102-111

[a] Compiled from reports and memoranda of the War Department.

Gibara.—Two wells were drilled at this point by the Bacon Air Lift Company, at a cost of $2,500. The first well was started August 8, 1900, but was abandoned at a depth of 212 feet, because of the telescoping of the pipe. A new well was then started. This obtained water at 75 feet and again at 90 feet, but the flow was small. At 560 feet a strong flow of salt water was obtained and the well was then abandoned. The diameter of the casing was 8 inches at the top and 6 inches at the bottom. The failure of this well was seriously felt, as the cistern supply on which the town depended was very insufficient. Several other wells were drilled to a depth of about 600 feet with like results.

Guanajay.—A well was here sunk to a depth of 40 feet, which resulted in a failure.

Holguin.—Most of the supplies at this place are from surface wells and are satisfactory in amount except at times of drought. The water is derived from disintegrated granite and is somewhat liable to surface contamination. It is hard and contains considerable mineral matter. During the American occupation the public wells were deepened and cleaned, and windmills were erected. An artesian well was begun on November 20, 1900. A strong flow of excellent water is reported to have been obtained at 61 feet, but was cased off with the hope of finding more abundant water at a deeper level. Hard water was encountered, however, and the bit broke at 160 feet, at which depth the well ceased. A later well went to a depth of 400 feet, a small amount of water being found at a depth of 125 feet, but none below. A steam pump and tank were put in, and the well gave a supply sufficient for the barracks, but not for the town.

Matanzas.—Wells were drilled by the Government to depths of from 330 to 400 feet, but resulted in failure.

Pasa Cabellos.—The wells sunk by the War Department at this point were 78 feet deep and gave 60,000 gallons during a ten-hour pumping test.

Pinar del Rio.—A well begun by the War Department on April 5, 1899, was drilled to a depth of 285 feet, but resulted in a partial failure, the water being very hard and carrying some sulphur. The formation from a few feet of the surface to the bottom of the well is stated to consist of alternate layers of soft and hard rock, parts of which approach clay in character. Water in small quantities was found at 35, 80, and 145 feet, and in smaller amounts between 200 and 285 feet. There are 158 feet of 6-inch casing in the well. The water rises within 95 feet of the surface. The well will not furnish more than one gallon a minute and is regarded as a failure, as the well is pumped down to 150 feet in a half-hour with an ordinary hand pump. The water rises to its former level in about thirty minutes. It cost about $1,800.

Puerto Principe.—A number of wells were drilled by the War Department at this point. The first one of importance appears to have been started on May 1, 1899. It is located on the grounds on which the cavalry barracks were situated in the city of Puerto Principe, and its mouth has an elevation of 337 feet above sea level. The ground in its vicinity is practically level. During the first 30 feet the well passed through decomposed granite, but from 30 feet to the bottom it was drilled through hard crystalline rock of various colors and hardness. The first water of consequence was struck at 95 feet, and rose to within 30 feet of the surface. The boring was continued, however, to a depth of 264 feet without obtaining any decided increase in the amount of water. At this point the drill was once more withdrawn and a pumping test made lasting two days. Five hundred gallons were pumped hourly without lowering the working head of the water more than a few feet. It was, however, decided to push the well to a greater depth. A month later, when the well had reached a depth of 457 feet, the drill was again withdrawn, and the well was tested by a 2-inch pump attached to the walking beam of the well rig and making 30 strokes to the minute. It extended 150 feet down the well, and during the two days an average of 502 gallons of water an hour was raised. At the beginning of the pumping the water stood 30 feet from the surface, but fell rapidly during the first hour, at the end of which it stood at a depth of 43 feet from the surface. During the continuance of the pumping, however, doubtless by reason of the removal of silt from the pores of the adjacent rock, the water slowly rose until, at the end of the fifth hour, it had reached a level of 41 feet from the surface. On standing over night the water returned to its original level of 30 feet, but during the first hour's pumping again fell to a level of 41 feet below the surface. On August 30 the drills were replaced and the well was pushed to a depth of 474 feet. Previous to the sinking of the well, the supply of the barracks had been obtained by hauling water, all of which had to be boiled, from a creek 3 miles away. The test of the well proved that it would supply more than 500 gallons an hour without lowering the water more than 11 feet from its normal level, and it was estimated that from 2,000 to 3,000 gallons an hour could be obtained without lowering the level more than 30 feet. The water is clear, without sediment, and is sparkling and palatable. An analysis of water made at the Military Hospital No. 1 at Habana is given below:

Analysis of water from Puerto Principe.

Odor, none; taste, faint saline; color, no color, very clear; some matter in suspension composed mainly of precipitated salts.

	Parts per 1,000,000.
Free ammonia	None.
Albuminoid ammonia	None.
Chlorine, 0.2	2

	Parts per 1,000,000.
Sulphuric acid as sulphates	35
Sulphureted hydrogen	None.
Total solids	305
Phosphoric acid	Trace.
Silicic acid (silicates)	22
Iron, none; other metals not tested.	
Calcium	69
Magnesium, pyrophosphates	105
Potassium and sodium, somewhat in excess.	

This water is free from harmful materials and is suitable for all domestic purposes.

The water was piped to the barracks and furnished a satisfactory supply. In addition a considerable amount was shipped to Nuevitas by rail.

A second well was begun October 10 and completed December 15, 1900. Its diameter was 8 inches, and it was drilled to a depth of 202 feet. The supply proved ample, and is used in the public buildings of the vicinity. The water stands 135 feet below the surface. Good water was found above 200 feet, but the deeper waters are reported to be brackish. Another well was begun in the market place December 15, 1900. Still others have been described under water supplies.

A well on a proposed site for a military post, presumably near Puerto Principe, is given in the reports of the War Department. It was 8 inches in diameter and 510 feet deep, the water rising to within 8 to 12 feet of the surface. The supply is reported to be of excellent quality.

Santiago.—The army officials report that there is good reason to believe that an abundant supply of water can be obtained from artesian wells along the south coast of Cuba at this point. An examination of the San Juan Valley shows a gathering ground with slight run-off, the remainder reaching the sea by subterranean drainage. It has been proposed to intercept this by tunnels. Some of the shallow wells obtain large flows, but unless carefully located are liable to become contaminated by seepage from the surface. One well, 14 feet in depth, is reported to have so large a flow that it could not be kept down by a pump of 500 gallons capacity.

Triscornia.—An 8-inch well sunk at this point to a depth of 401 feet obtained only a limited supply of water more or less impregnated with salt and unfit for general use.

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