C. J. Blanchard.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 30

WATER RESOURCES OF THE LOWER PENINSULA OF MICHIGAN.—LANE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

IRRIGATION REPORTS.

The following list contains the titles and brief descriptions of the principal reports relating to water supply and irrigation, prepared by the United States Geological Survey since 1890:

1890.

First Annual Report of the United States Irrigation Survey, 1890; octavo, 123 pp.

Printed as Part II, Irrigation, of the Tenth Annual Report of the United States Geological Survey, 1888-89. Contains a statement of the origin of the Irrigation Survey, a preliminary report on the organization and prosecution of the survey of the arid lands for purposes of irrigation, and report of work done during 1890.

1891.

Second Annual Report of the United States Irrigation Survey, 1891; octavo, 395 pp.

Published as Part II, Irrigation, of the Eleventh Annual Report of the United States Geological Survey, 1889-90. Contains a description of the hydrography of the arid region and of the engineering operations carried on by the Irrigation Survey during 1890; also the statement of the Director of the Survey to the House Committee on Irrigation, and other papers, including a bibliography of irrigation literature. Illustrated by 29 plates and 4 figures.

Third Annual Report of the United States Irrigation Survey, 1891; octavo, 576 pp.

Printed as Part II of the Twelfth Annual Report of the United States Geological Survey, 1890-91. Contains "Report upon the location and survey of reservoir sites during the fiscal year ended June 30, 1891," by A. H. Thompson; "Hydrography of the arid regions," by F. H. Newell; and "Irrigation in India," by Herbert M. Wilson. Illustrated by 93 plates and 190 figures.

Bulletins of the Eleventh Census of the United States upon irrigation, prepared by F. H. Newell; quarto.

No. 35, Irrigation in Arizona; No. 60, Irrigation in New Mexico; No. 85, Irrigation in Utah; No. 107, Irrigation in Wyoming; No. 153, Irrigation in Montana; No. 157, Irrigation in Idaho; No. 163, Irrigation in Nevada; No. 178, Irrigation in Oregon; No. 193, Artesian wells for irrigation; No. 198, Irrigation in Washington.

1892.

Irrigation of western United States, by F. H. Newell; extra census bulletin No. 23, September 9, 1892; quarto, 22 pp.

Contains tabulations showing the total number, average size, etc., of irrigated holdings, the total area and average size of irrigated farms in the subhumid regions, the percentage of number of farms irrigated, character of crops, value of irrigated lands, the average cost of irrigation, the investment and profits, together with a résumé of the water supply and a description of irrigation by artesian wells. Illustrated by colored maps showing the location and relative extent of the irrigated areas.

1893.

Thirteenth Annual Report of the United States Geological Survey, 1891-92, Part III, Irrigation, 1893; octavo, 486 pp.

Consists of three papers: "Water supply for irrigation," by F. H. Newell; "American irrigation engineering" and "Engineering results of the Irrigation Survey," by Herbert M. Wilson; and "Construction of topographic maps and selection and survey of reservoir sites," by A. H. Thompson. Illustrated by 77 plates and 119 figures.

A geological reconnoissance in central Washington, by Israel Cook Russell, 1893; octavo, 108 pp., 15 plates. Bulletin No. 108 of the United States Geological Survey; price, 15 cents.

Contains a description of the examination of the geologic structure in and adjacent to the drainage basin of Yakima River and the great plains of the Columbia to the east of this area, with special reference to the occurrence of artesian waters.

1894.

Report on agriculture by irrigation in the western part of the United States at the Eleventh Census, 1890, by F. H. Newell, 1894; quarto, 283 pp.

Consists of a general description of the condition of irrigation in the United States, the area irrigated, cost of works, their value and profits; also describes the water supply, the value of water, of artesian wells, reservoirs, and other details; then takes up each State and Territory in order, giving a general description of the condition of agriculture by irrigation, and discusses the physical conditions and local peculiarities in each county.

Fourteenth Annual Report of the United States Geological Survey, 1892-93, Part II, Accompanying papers, 1894; octavo, 597 pp.

Contains papers on "Potable waters of the eastern United States," by W. J. McGee; "Natural mineral waters of the United States," by A. C. Peale; and "Results of stream measurements," by F. H. Newell. Illustrated by maps and diagrams.

(Continued on third page of cover.)

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1899

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR.

WATER RESOURCES

OF THE

LOWER PENINSULA OF MICHIGAN

BY

ALFRED C. LANE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, April 14, 1899.

SIR: I have the honor to transmit herewith a manuscript on the Water Resources of the Lower Peninsula of Michigan, by Dr. Alfred C. Lane, and to recommend that it be printed as one of the series of Water-Supply and Irrigation Papers. This material is a portion of the outcome of Dr. Lane's studies in connection with the geological survey of the State of Michigan, supplemented by statements received in reply to circulars sent throughout the Lower Peninsula of Michigan to well drillers and others likely to be well informed and interested in the subject. The facts thus gathered have been collated with the result of two months' field work during the autumn of 1897. The complete report has assumed such bulk that it has been found necessary to divide it into several parts. The first of these, containing the general conclusions, is herewith presented. The remaining data fall naturally into two classes, the first consisting of analyses of waters and the second of detailed descriptions of the supply at various localities visited. It is hoped that these data may be printed as succeeding papers of this series.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WATER RESOURCES OF THE LOWER PENINSULA OF MICHIGAN.

By Alfred C. Lane.

VARIOUS USES OF WATER.

The region under consideration is generously endowed with water supplies, but it is apparent from experience elsewhere that these may be wasted or seriously depreciated in value by carelessness or lack of knowledge of their extent and limitations. It is a common error to suppose that if the limit to the supply of anything is not clearly in sight that the supply is inexhaustible; for example, the "practically inexhaustible" supplies of pine of the Saginaw Valley of thirty years ago are now nearly gone, and instances are cited of the sale of privileges of cutting the stumps on land already cut over for sums greater than the tracts originally cost. "Inexhaustible supplies" of natural gas have failed; and, in short, it may be said that there is hardly a natural resource whose quantity or quality has not seriously deteriorated through lavish use.

In many parts of the United States formerly as well watered as Michigan there has been apparently a shrinkage of water supply. The streams which at one time carried considerable volumes of water throughout the year are now reported to be, during summer at least, nearly dry. Flowing wells have failed in many regions, either from faulty construction or from the multiplication of deep borings. In order, therefore, that it may be possible not only to utilize the water resources of the area under discussion to the fullest possible extent, but also to guard against causes of failure, it is desirable to bring together all of the information available, combining the facts and drawing broad conclusions.

Although the uses of water are almost infinitely varied, yet all kinds of water are not equally available for all purposes. The wide range in the quantity of water and in its quality leads to an equal diversity in application; for example, Michigan, as a whole, being humid, water has little value for agriculture, irrigation being practically confined to the use of water from city supplies applied to lawns, flower beds, and rarely to fruit trees and market gardens. On the other hand, although water is so abundant consideration must be paid to its quality; that is, to the amount and kind of organic or inorganic matter held in solution or suspension. Another matter of primary importance is the elevation of the water with reference to possible fall, or, in other words, the head available. Upon this latter feature depends whether it can be used as a source of power or whether power must be consumed in raising it.

For certain uses practically the only thing desired is abundance of supply; for example, such city uses as fire protection, flushing sewers, and cleaning streets. The head required is generally obtained artificially. Only in exceptionally favored localities, such, for example, as those close to the edge of the moraine country on the lakeward side, is there head sufficient to obviate the use of pumps. This is the case in Hart, T. 15 N., R. 17 W.; Rochester, T. 3 N., R. 11 E.; and Rose, T. 24 N., R. 3 E.

There are other uses, however, in which quality is the first consideration; as, for instance, cooking and drinking. Finally, as a source of power water must, of course, have head.

Thus the different sources of supply and the different uses have been classified, so that one may see at a glance the more important factors in a given use and the sources which best meet the requirements. The most difficult problems to solve, however, are those where many needs are to be met by one system; where, as in a supply for a city, it is frequently necessary that ample quantity for fire protection and hose use should be combined with at least a good degree of organic purity for drinking purposes and, if possible, with sufficient purity from lime and inorganic salts to be available for laundry use and for boilers. Such cases require special consideration and often present very complex problems.

USES WHERE QUANTITY IS IMPORTANT.

TRANSPORTATION ON THE GREAT LAKES.

The great extent of shore line and the use of the waters of the State for transportation require some notice, especially in their bearing on other water uses. Michigan is more cut up by the Great Lakes than any other State, having some 1,600 miles of shore line, and the commerce on the Lakes is growing at a remarkable rate. The commerce past Detroit is greater than that past any other port in the world The harbor master of Sand Beach estimates that a boat passes within sight every five minutes, day and night.

If commerce increases in the future as in the past, it may be doubtful whether the Great Lakes, and rivers like the St. Clair and Detroit, independent of the question of sewage emptied into them, will be sufficiently free from organic impurities to be available for city water supplies. At present the Great Lakes are the source of the water supply of most of the cities and towns on their shores.

NAVIGATION ON THE SMALLER LAKES AND RIVERS.

On many of the larger inland lakes, in which Michigan is so rich, and on some rivers tugs have been employed, mainly for pleasure or for towing logs. The lower parts of the rivers are used for harbors. Along the west shore, as at Manistee, Ludington, and Frankfort, the lower reaches of all the rivers are practically lakes. These lakes are separated from Lake Michigan by sand bars, which often have to be cut, after which the lakes make good small harbors. In this way Charlevoix Harbor has been connected with Pine Lake by a short cut, and Cheboygan is located on a river the mouth of which serves as a harbor. In the part of the State lying between Traverse City and Cheboygan it has been possible, with some artificial aid, to establish an extensive system of inland navigation. It may be noted, too, that for a long distance from its mouth the Saginaw River and its various branches are practically at lake level. In fact the watershed between the Grand River and the Saginaw, near Ashley, is only about 87 feet above the lake level, so that if, as has been suggested, a canal were to be built to cut off the long northern voyage by the Straits of Mackinac from Chicago and Milwaukee, it would be far easier to construct it along this line than any other. On the Michigan side Grand River is navigable nearly to Grand Rapids. Besides Saginaw River up to St. Charles, the mouths of Black River at Port Huron, of Thunder Bay River at Alpena, and of Huron River are used for short distances. Transportation by boat has, however, been checked along Saginaw River and other streams by their extensive use for the transportation of logs, to say nothing of the fact that they are very crooked.

LOG DRIVING.

A glance at the map will show that the branches of the Saginaw diverge in every direction, from north-northeast to east-northeast, and they have served to transport the pines to Saginaw and Bay City. For miles along their course the rivers have been packed solid with logs. Lumbermen's dams have been constructed along the headwaters, their object being to accentuate and regulate the floods. The Saginaw Valley has now, however, been converted into farming country, and Saginaw has its city water supply—which, fortunately, is not much used for drinking—from these rivers. In considering the use of the Saginaw and its branches for such purposes the fact must not be forgotten that for a large part of the year they are stagnant water, with the current setting up and down with the changes in the wind and in the level of the bay, and that they are lined with rotting logs. It is no wonder that the analyses of such streams show much organic matter. There are all along the shores of the peninsula, at the mouths of the more important streams, towns of considerable size which obtained their start as sawmill towns and which are, or were, supported by the occupation of turning the logs floated down to them into merchantable lumber. The size of such towns is roughly proportional to the drainage area of the streams which furnish them their raw material and supply them with harbors.

CITY USES.

One of the most important uses of water is as a protection against fire, and this use has, indeed, called into existence most of the city water supplies. Many towns—e. g., Weston (T. 8 S., R. 3 E.) and Grayling (T. 26 N., R. 3 W.)—now have their water supply in this first stage of development.

Michigan towns are invariably built of wood, at least at first, and even the largest cities are composed chiefly of wooden buildings. Fire protection is consequently essential to the existence of the cities. Saginaw, Cheboygan, Ontonagon, and Bad Axe are but a few of the towns that have been devastated by fire. For fire protection the prerequisite is an ample supply of water. The necessary head is nearly always obtained artificially, partly by the use of steam pumps and partly by fire engines. A few of the smaller towns have sufficient natural head.

To insure an ample supply of water the fluctuations of level of the water surface must be taken into consideration, and not merely the seasonal fluctuations, but, if the Great Lakes are drawn on, the sudden fluctuations to which they are peculiarly subject. The Saginaw River and its branches, as has been said, are at lake level and subject to these fluctuations, the current running sometimes upstream and sometimes downstream. As the present waterworks are arranged, the water for both East and West Saginaw is taken from settling basins, and on at least one occasion, in the fall of 1895,[1] the level was lowered dangerously near that of the intake pipe. If water should fail in the midst of a fire like that which, on May 20, 1893, in a few hours destroyed property to the value of $650,000, the city would be practically destroyed. There is more than a mere chance of this coincidence, for, as will be shown later, low water may be caused by strong southwest winds. Such warm, dry, strong winds are likely to occur. In fact, such a wind is said to have been blowing 50 miles an hour at the time of the fire just mentioned. If a dam were built across the river so as to check the reversal of its current, it would not only guard against this danger but would prevent the carriage of the sewage of the city into the water supply. The water of the regular supply at Saginaw is not fit to drink unless it is boiled or filtered, and the city has drilled 29 wells to the underlying sandstones in order to obtain water suitable for drinking.

The possibility of retreat below the level of intake is probably the only danger to be guarded against in the use of lakes and rivers for

[1] See Annual Report of Water Board of East Saginaw, 1896, p. 10.

water supply for fire protection. The fluctuations of mean lake level have been about 7 feet during the century. To allow for exceptional low water due to strong winds, it would be well to have intake pipes at least 10 feet below high-water level.

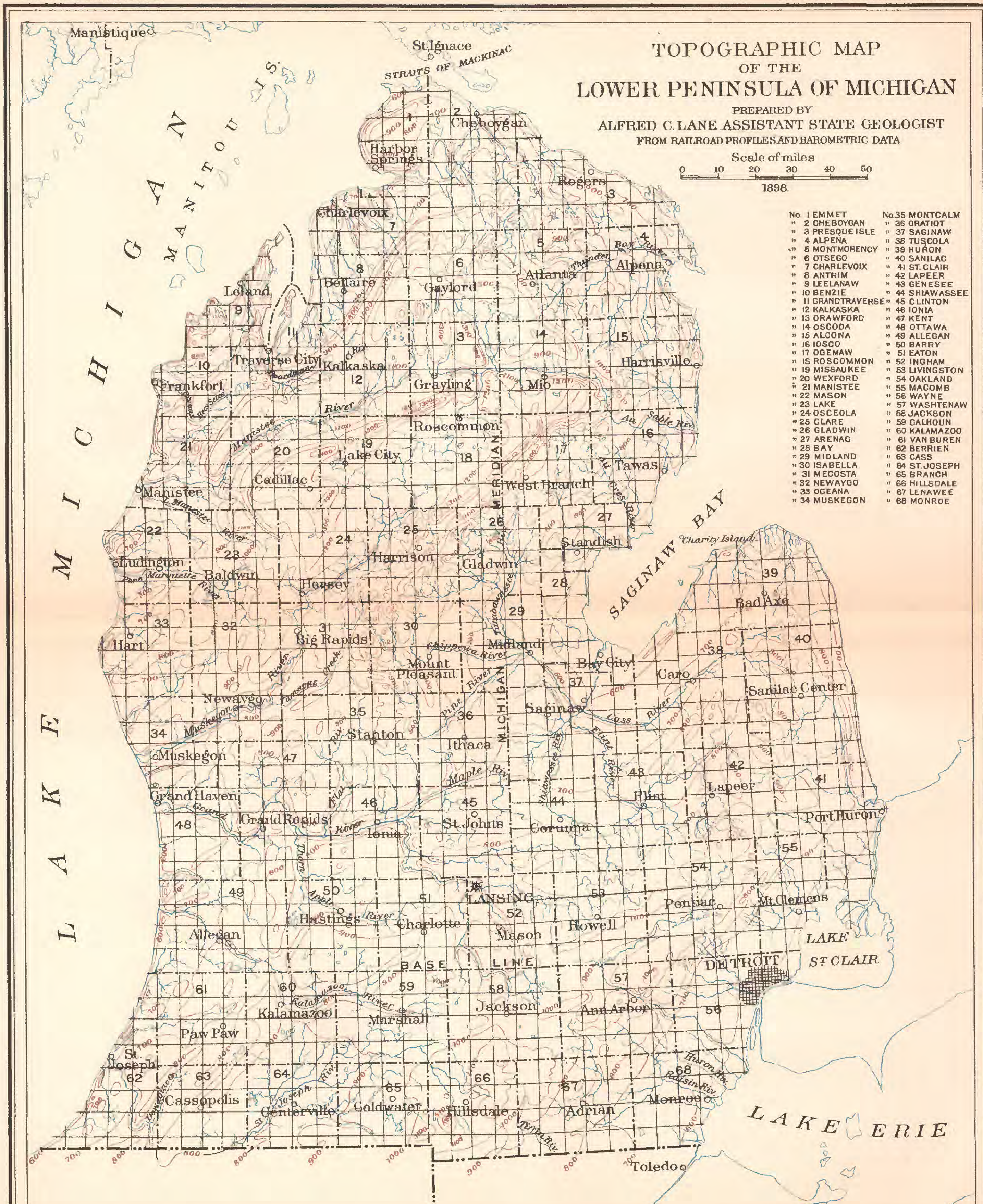
Almost all kinds of wells are likely to fail to satisfy the demands of the large towns, and one hears continually, in towns that are supplied from wells, of steps taken to procure more water. Often where the water supply is from wells, as at Mount Pleasant, the plant is so arranged that in fire emergency use may be made of some additional body of water for supplementary supply. But in such a case the water should be taken through a filter gallery, as otherwise there will be constant suspicion and complaint that the engineer is substituting the inferior supply, which of course he should not do without warning.

However, the demand on a public water supply is very heavy, and in this demand the use of water with the garden hose, the only form of irrigation prevalent in Michigan, is no inconsiderable factor. Almost universally where a city water supply exists it is used with hose upon lawns and gardens. This use is generally lavish, though not infrequently checked somewhat by regulations limiting the use to certain hours, prohibiting the use of sprinklers all night, etc. Thus, in Saginaw, where the city water supply is little used for drinking, an average of 6,678,651 gallons a day were pumped in the year ending February 29, 1896, which, for a population of 45,000 (18,000 users), is more than 148 (371) gallons per capita, a quantity much larger than has been considered necessary in England, viz, 30 gallons a day per capita; and, as we have just said, well water is very largely used for domestic purposes. In East Saginaw, in the same year, 313,705,672 gallons were pumped in June and July, against 263,225,916 in April and May (hours of fire pressure 26½ to 18), while in West Saginaw the corresponding figures are 158,018,960 and 132,089,771 (hours of fire pressure 14 to 13), showing an increase of nearly 20 per cent in summer use, largely through the use of garden hose. Besides these there are other considerable city uses—flushing sewers and urinals, washing sidewalks, windows, and streets, running water motors, etc. For all these the quality of the water is comparatively unimportant. Indeed, the very sewage matter which renders it unfit for drinking, and the sulphates and carbonates of lime which render it less available for laundry and boiler use, are an advantage, rather than otherwise, when sprinkled on gardens. The difficulty in city water supply arises in the antagonism of these two classes of uses—those which demand an indefinitely large supply regardless of quality, and those which require a high degree of purity. Michigan cities usually consume 100 to 200 gallons a day for each inhabitant. The introduction of meters would result in some saving. The use of garden hose is often lavish and in violation of rules. The use of a meter should be compulsory where garden hose is employed. Unfortunately, the need of quantity has too often been considered alone, and even the most rudimentary precautions for purity have been neglected.

West Saginaw takes its water direct from the river, under a dock close to the heart of the city and near a large sewer, the settling tank being 75 by 22 feet and the river current variable. The water is of a muddy-green color, with a good deal of bark floating around in the tank. Alma takes water from a mill race 300 feet above a sewer. There is no protection to the banks of the stream above. Both of these places, however, use almost exclusively for drinking purposes water from deep wells which comes under clay and is therefore safe. In Saginaw it is said that the salt water from the deeper wells has found its way into some of the shallower rock wells and contaminated them, and the waste bitterns go into the river. But individual wells, however numerous, are not an ideal supply for a large town, with the running here and there to neighbors, the possibility of some wells being too shallow to be safe, and the liability to contamination from dug wells. The Saginaw is so sluggish a stream that it is practically a pond. A plant situated as far up as the East Saginaw plant, therefore, if the banks were bought for a "riverside park" and protected for a few miles, and if the reflux of water from the lower river were prevented, especially if there were a gravel bed instead of decaying planks between the settling tank and the river, might furnish a fairly satisfactory water supply; but one would probably not have to go far—not beyond Vassar—to secure an ample and pure supply in sandstone. Analyses of these waters will be given in a later paper. Most of the other large cities are supplied from the Great Lakes, and seem to find no objection to that source, though Chicago's experience shows that there is a possibility of danger to be guarded against.

Many towns, however, like Rochester, Birmingham, Hunt, Petoskey, Charlevoix, Harbor Springs, Bay View, and Cheboygan have found a sufficient supply in deep wells, and most towns of the State could be thus supplied if they were willing to give up the use for garden hose, motors, etc. The construction of a large reservoir to meet the extra heavy demand of summer might be feasible. One practicable way would be to limit the use of garden hose to a short time each day, during which time the reservoir or some inferior filtered source of supply could be drawn upon. It is an advantage of this plan that the efficacy of a gravel filter bed is immensely increased if it is not continuously in use.

The use of water in our Michigan towns is extravagant, and the difficulty of securing a proper quality is correspondingly increased. For example, Bay City, with a population of about 33,000, besides the supply from wells, in 1896 used 197 gallons a day, about 5 per cent of which was through manufacturing meters, 5 per cent through domestic meters, and the rest at fixed rates. The special water supply committee of the city council of Traverse City, 1897, George W.


TOPOGRAPHIC MAP
OF THE
LOWER PENINSULA OF MICHIGAN
PREPARED BY
ALFRED C. LANE ASSISTANT STATE GEOLOGIST
FROM RAILROAD PROFILES AND BAROMETRIC DATA
Scale of miles
0 10 20 30 40 50
1898.
No 1 EMMET
" 2 CHEBOYGAN
" 3 PRESQUE ISLE
" 4 ALPENA
" 5 MONTMORENCY
" 6 OTSEGO
" 7 CHARLEVOIX
" 8 ANTRIM
" 9 LEELANAW
" 10 BENZIE
" 11 GRANDTRAVERSE
" 12 KALKASKA
" 13 CRAWFORD
" 14 OSCODA
" 15 ALCONA
" 16 IOSCO
" 17 OGEMAW
" 18 ROSCOMMON
" 19 MISSAUKEE
" 20 WEXFORD
" 21 MANISTEE
" 22 MASON
" 23 LAKE
" 24 OSCEOLA
" 25 CLARE
" 26 GLADWIN
" 27 ARENAC
" 28 BAY
" 29 MIDLAND
" 30 ISABELLA
" 31 MECOSTA
" 32 NEWAYGO
" 33 OCEANA
" 34 MUSKEGON
No.35 MONTCALM
" 36 GRATIOT
" 37 SAGINAW
" 38 TUSCOLA
" 39 HURON
" 40 SANILAC
" 41 ST. CLAIR
" 42 LAPEER
" 43 GENESEE
" 44 SHIAWASSEE
" 45 CLINTON
" 46 IONIA
" 47 KENT
" 48 OTTAWA
" 49 ALLEGAN
" 50 BARRY
" 51 EATON
" 52 INGHAM
" 53 LIVINGSTON
" 54 OAKLAND
" 55 MACOMB
" 56 WAYNE
" 57 WASHTENAW
" 58 JACKSON
" 59 CALHOUN
" 60 KALAMAZOO
" 61 VAN BUREN
" 62 BERRIEN
" 63 CASS
" 64 ST. JOSEPH
" 65 BRANCH
" 66 HILLSDALE
" 67 LENAWEE
" 68 MONROE
LAKE MICHIGAN
MANITOU IS.
STRAITS OF MACKINAC
SAGINAW BAY
LAKE ST CLAIR
LAKE ERIE
MICHIGAN MERIDIAN
BASE LINE

Rafter, consulting engineer, figured upon supplying 100 gallons a day to a population three times the present. This is one of the most carefully studied of recent propositions and the report compares a number of typical city sources of supply.

USES WHERE HEAD IS IMPORTANT.

The use of water for motive power depends not only on the quantity, but also on the head. The total energy is expressed by the product of these two. There are two widely different conditions under which water is thus used. The one is where the head is first artificially obtained and the water is raised by pumping. In such cases the water acts merely as a distributor of power. In this way water is used in many of the cities and towns, running motors for light machinery, especially for elevators. The chief advantages are that it is ready at hand, quiet, noiseless, odorless, not dangerous, and convenient in every way. There is, however, considerable loss of head in narrow and crooked pipes, and it is not the most economical method of transmitting power, while the extra quantity of water needed makes the attainment of desirable quality far more difficult. Electricity may be expected to relieve our water systems of much of this burden of power transmission. The other use is where natural water power is utilized. In respect to natural water power, Michigan is much better situated than many adjacent States, though there are no very large streams except the international Detroit and St. Clair rivers, which are not dammed.

A large area, both in the northern and southern part of the State, is more than 1,000 feet above tide, or say 400 feet above lake level. It will be noticed, too, from the contour map (Pl. I) and from fig. 10 that the descent from the 1,000 to the 700-foot contour line is frequently quite rapid, and here is a great belt of water powers.

In a few cases, as at Traverse City and around West Branch, flowing wells furnish such a volume of water as to be of considerable power. Around West Branch and Rose City such wells distribute water into the second stories of the houses, and at Traverse City, as at Harbor Springs, it has been proposed to use part of the water in a hydraulic ram to elevate the remainder.

But the head of flowing wells is of most importance in saving the power, windmill or steam, which would otherwise be required to elevate the water.

There are also many lakes—and these chiefly in the highest parts of the State—which help to steady the flow of the streams by acting as reservoirs, though many of them are quite variable in their water stage. For instance, Clam Lake, near Cadillac, is said to have varied more than 16 feet. Thus conditions are quite favorable to the development of water power in streams, and small water powers, suited for village waterworks, electric-light plants, country sawmills and gristmills, etc., are widely distributed along the edge of and in the morainal areas. Almost uniformly wherever, as explained later (p. 63), the earlier high-level Glacial drainage has been captured and diverted by streams which have worked back across the moraines, good sites for water powers may be found, though thus far the abundance of fuel and the relatively heavy first cost of waterworks improvements have retarded their development somewhat.

WATER POWERS IN MICHIGAN.

The following table of places where water powers have been observed or reported is doubtless very incomplete. More complete accounts are given of the two important regions which have been studied in greater detail. The southeastern part has been studied in connection with the Tenth Census, and Kalamazoo River has been studied by Mr. Robert E. Horton. It must not by any means be inferred that the Huron and the Kalamazoo are, from the importance given to them, the most important water-power streams of the State. They are merely those of which the most is known, and the study of the Grand River system, and others equally important in the northern part of the State, would require more time and money than have been allotted to this paper.

Water powers in Michigan.

Stream.	Location of power.	Remarks.
LAKE ERIE DRAINAGE.		
Raisin River	Few above Adrian	
Huron River	Dexter to Ypsilanti, mainly.	See Report on Water Powers, Tenth Census. See also Winchell, Geology of Washtenaw County, 1881, p. 19.
Do	Ypsilanti (5-foot fall)	Water power for waterworks pumping station.
Do		Grist mill. About 10-foot fall.
Do		Underwear factory.
Do	Pettibone mills, Milford	Paper mill.
Tiffin River	Below Hudson	Small.
DETROIT RIVER DRAINAGE.		
River Rouge (Ecorce River).	Northville	Above Plymouth; small flow, considerable fall.
LAKE ST. CLAIR DRAINAGE.		
Clinton River	Rochester	Above Utica are numerous small powers.

Water powers in Michigan—Continued.

ST. CLAIR RIVER DRAINAGE.

Stream.	Location of power.	Remarks.
Belle River		
Mill Creek	Below Yale	
Black River		Poor power; a stream of diminishing drainage area; swamps being cleared and summer drought becoming accentuated.

THUMB OF MICHIGAN.

Stream.	Location of power.	Remarks.
Allen Creek	Rock Falls	10-foot head; not much water; abandoned.
Willow River	Huron	Abandoned.
Pinnebog River	Near Popple	Not used; drainage area growing, but the swamps are being cleared.
Pigeon River	Above Wolfton	Not used.

SAGINAW RIVER DRAINAGE.

Stream.	Location of power.	Remarks.
Cass River		A stream of diminishing drainage and sandy course.
Do	Caro	Undeveloped.
Do	Vassar	4-foot fall.
Flint River	Flint to Columbiaville	Good power near Flint.
Shiawassee River	Owosso	
Do	Corunna	10-foot fall.
Pine River	St. Louis and Alma, up to Millbrook.	At St. Louis dam; at Alma a dam with 10-foot head helps run elevator and waterworks.
Chippewa River	Mount Pleasant	15-foot fall runs waterworks, electric-light plant, and elevator.
Do	Barryton	Dam; 8-foot fall.
Salt River		
Tobacco River	Farwell and Clare	
Tittabawassee River		Very sandy and sluggish, except at head waters.

Water powers in Michigan—Continued.

LAKE HURON DRAINAGE NORTH OF SAGINAW RIVER.

Stream.	Location of power.	Remarks.
Rifle River		Good mill stream.
Houghton Creek	Rose City	10-foot dam.
Au Gres River		Small stream, with considerable valleys and fall where crossing the 200-foot contour line.
Au Sable River	Especially through the stretch from Mio to T. 24 N., R. 6 E.	Splendid water powers; unused, largely fed by springs, with a comparatively small flood plain.
Do	Grayling	Dam.
Thunder Bay River	Alpena. Numerous	Brodwell's mills and Trowbridge's mills.
Cheboygan River	Long Rapids to Hillman.	Little fall.
Oqueoc River		
Sturgeon River	Sec. 3, T. 34 N., R. 1 E.	Mill.
Rainy River		Probably some powers; rock banks.
Pigeon River		
Mulletts River	Wolverine to Trowbridge.	

LAKE MICHIGAN DRAINAGE.

Stream.	Location of power.	Remarks.
Bear River	Petoskey	Ingalls mills.
Boyne River	Boyne Falls	Other similar small streams to southwest.
Elk River	Elk Rapids	Wing dam and undershot wheel; put in as early as 1850; note the very large lake drainage; steady power.
Duck Lake	Outlet	9-foot fall; 60–70 horsepower used.
Boardman River		Variable; near Traverse City 20-foot head; flow in drought about 100 cubic feet a second. See p. 31.
Carp River		Outlet of Carp Lake; 5 to 6 foot fall.
Betsie River	Weldon Township	
Do	Benzonia	

Water powers in Michigan—Continued.

LAKE MICHIGAN DRAINAGE—Continued.

Stream.	Location of power.	Remarks.
Crystal Creek	Outlet of Glen Lake	2 or 3 powers.
Manistee River	Lower part	Sandy valley; drainage area diminishing; numerous small mill sites; quite variable.
South Branch		Rapid fall below Tustin.
Little Manistee River		
Big Sable River		
Notepseakan River		
White River		
Muskegon River	Newaygo	
Do	Big Rapids	30-foot fall; large stream; steadied inflow by lakes and springs; furniture factories, etc.
Crockery Creek		
Rabbit River		
Kalamazoo River		See report by Robert E. Horton, pp. 22–38.
Coldwater River		
Hog Creek		
Fawn River	Near Burrows	
Grand River	Grand Rapids	Large manufacturing power.
Flat River	Fallassburg	35-foot fall between here and at Lowell.
Rouge River		
Bear Creek	Cannon, T. 8 N., R. 10 W	200-foot fall in 12 miles.
Apple Creek	Caledonia, T. 5 N., R. 10 W.	
Do	Alpine, T. 8 N., R. 12 W	Tributaries of Grand River; mill sites in eastern part.
Thornapple River	Cascade, T. 6 N., R. 10 W	Fine water power.
Do	Whitneyville	
Cedar Creek		Good mill stream.
Do	Ada	Two mills.
Buck Creek		Mill stream.
Grand River	Grand Ledge	Factories. There are numerous small powers among the headwaters of the Grand.
Do	North Lansing	9-foot fall. Also a dam at South Lansing.
Do	Eaton Rapids	

Water powers in Michigan—Continued.

LAKE MICHIGAN DRAINAGE—Continued.

Stream.	Location of power.	Remarks.
Grand River	Jackson	Dams; about 10-foot head.
Paw Paw River	Almena, T. 2 S., R 13 W	Spring Brook, one of the head-waters, has 18-foot head running a saw and feed mill, about 821 cubic feet a day; lowers 5 or 6 inches a day, but fills up over night. The brook starts in a big spring 1 mile away and passes through two lakes. Adjacent brooks furnish similar powers of local value.

REPORT ON THE RUN-OFF AND WATER POWER OF KALAMAZOO RIVER.

By ROBERT E. HORTON.

GEOLOGY AND TOPOGRAPHY.

The Kalamazoo River rises in the south central part of the Lower Peninsula of Michigan and flows in a northwesterly direction, debouching into Lake Michigan 3¼ miles below the village of Saugatuck. Its current is slow, averaging about 3 miles an hour, and its slope uniform, there being no waterfalls and no considerable rapids except at two points, at each of which there occurs a descent of 3 or 4 feet within a distance of a few rods. The river flows through a rich agricultural region, in a valley from one-fourth of a mile to 2 or 3 miles in width, backed by low hills or sloping gently to the upland. The flat lands in the valley are often flooded and serve largely as permanent meadows through which the river winds, often in a very tortuous manner. Two branches unite at Albion to form the main stream. The total length from the point of juncture to the outlet is 101 miles.

In respect to the climate, topography, and run-off of its watershed Kalamazoo River may be considered as typical of the larger streams of southern Michigan, including the Grand, the St. Joseph, and the Raisin, all of which find their sources within a few miles of each other and of the Kalamazoo. The drainage area covers 1,750 square miles overlaid with Pleistocene deposits. The surface formations are distributed about as follows: Morainal ridge and glacial drift covers between 25 and 45 per cent of the watershed; clay-loam till plains, 25 to 35 per cent; overwash valley train deposits of the ice drainage, 35 to 45 per cent. The latter lies chiefly in the middle and upper portions of the watershed, underlying short tributaries with swamp drainage. The clay-loam till plains form basins for lake storage, but give small flow from ground storage. The surface soil is diversified. Gravel, clay, and loam, mixed with sand, alternate in relatively small areas.[1]

Between Albion and Augusta, a distance of 34 miles, the main river channel lies between parallel morainal ridges deposited by the east wing of a reentrant cusp of the ice front which had at one time worked back step by step from the Indiana line. Between Kalamazoo and Plainwell the river channel cuts through the more northerly of these parallel ridges. The Valparaiso moraine and Covert ridge, running parallel to the above and to the lake front, are similarly crossed below Otsego.

The main river below Kalamazoo largely follows lines of pre-Glacial drainage. In the upper portion of the watershed the tributaries, which are numerous and ramify extensively, generally disregard the morainal contours in their courses, while the main stream follows them closely. There is a fall of from 12 to 20 feet, within a distance of about a mile, at the point of discharge of a number of tributaries, furnishing excellent water powers at points where the extent of the flats prevents dams being built on the main river.

The depths in feet, as determined from deep borings of the drift sand and shale deposits underlying the river channel at various points along its course, are as follows:[2]

Sections below channel of Kalamazoo River.

Place.	Distance from mouth of stream.	Depth of glacial drift.	Depth of sand rock.	Depth of blue shales below sand rock. *a*
	Miles.	*Feet.*	*Feet.*	*Feet.*
Albion	101	10	271	100
Marengo	93	60	200	200
Marshall	88.8	70	43	327
Battle Creek	75.5	70	43	320
Kalamazoo	52.1	130	(*b*)	(*b*)
Allegan	32.5	260	75	770

a As far as measured. *b* Together, 1,070 feet.

The line of the supposed outcrop of the bottom of the Marshall sandstone crosses the watershed in a northwesterly and southeasterly direction, intersecting the river channel below Battle Creek.

[1] See effect of drift upon topography and drainage, by Frank Leverett: Seventeenth Ann. Rept. U. S. Geol. Survey, Part II, pp. 706-711.

[2] The geology of Lower Michigan with reference to deep borings: Geol. Survey Michigan, Vol. V, Part II.

There are, within the catchment basin, a large number of small lakes and spring hollows, in which water stands part or all of the time. Many of these have no surface outlets and feed the stream only through seepage or ground flow, a large portion of their waters being consumed directly by evaporation. Each of these lakes drains an area varying generally from six to twelve times its own area, and their combined catchment reduces materially the area directly tributary to the river. The following table shows the relative number and area of tributary and nontributary lakes within the watershed in the four counties having the largest tributary drainage:[1]

Tributary and nontributary lakes in the watershed of Kalamazoo River.

County.	Drainage of river.	Number of tributary lakes over 1/16 mile in diameter.	Area of tributary lakes.	Number of nontributary lakes within drainage area.	Area of nontributary lakes.
	Sq. miles.		*Sq. miles.*		*Sq. miles.*
Calhoun	486.63	58	3.69	47	2.95
Jackson	148.5	21	1.29	38	0.32
Kalamazoo	273.5	39	5.29	31	2.25
Allegan	637.	65	6.59	25	.64

It will be seen that most of the lakes are tributary. About 1½ per cent of the drainage area is lake surface. Probably 5 or 6 per cent drains into nontributary lakes.

The surface of the watershed is rolling. Prairie, swamp, and hilly stretches alternate at short intervals. Many lakes and a considerable area of swamp lands have been made to yield their waters directly to the stream through drainage.[2] To what extent the diminution of lake and swamp storage and of forested areas for the purposes of agriculture has been detrimental to the flow of the stream and to its value for water power can only be inferred. The oldest mill owners and water-power users strongly maintain that the river yields less power than formerly, holding that the flow is less uniform and the volume appreciably smaller than in pioneer days.

[1] These data have been obtained chiefly from atlases of the various counties.

[2] The problem of swamp drainage has been carefully studied. Peppermint and celery are largely grown on drained areas. See Michigan Engineer's Annual; Drainage engineering, by R. C. Carpenter: Proc. Michigan Engineering Society, 1882, pp. 40-48; Drainage of large marshes, by C. E. Hamilton: Proc. Mich. Eng. Soc., 1884, pp. 15-19; Reclamation of swamp lands, by O. H. Todd: Proc. Mich. Eng. Soc., 1894, pp. 57-66.

The distribution of cultivated, forest, meadow, and swamp areas in the watershed is as follows:[1]

Character of watershed of Kalamazoo River.

	Per cent.
Improved tilled land, including meadow and grass in rotation	60
Permanent meadows, pastures, orchards, etc	7
Woodland and forest	11
Undetermined, including waste swamp, lakes, building plats, villages, etc	22
Total	100

The character of the vegetation is an important factor in determining the proportion of rainfall on a watershed which reaches the stream as run-off during the summer months. The distribution of the principal crops grown and the number of inches of water they will require on the entire watershed during the growing season, are shown in the following table:

Distribution of crops in the watershed of Kalamazoo River.

Crop.	Entire watershed covered in 1896. *a*	Water required during growing season. *b*	Water required on the entire watershed.
	Per cent.	*Inches.*	*Inches.*
Wheat	11.2	10.8	1.2
Corn	8.0	13.3	1.1
Oats	4.0	16.6	0.7
Rye	3.3	9.1	0.3
Potatoes	0.7	4.6	0.03
Beans	1.7	4.6	0.08
Hay	6.9	20.5	1.4
Gardens, barley, millet, mint, etc	10.0	*c*15.0	1.5

a From Farm Statistics of Michigan, 1896, issued by the secretary of state, Lansing, Michigan, 1896, may be taken as an ordinary year.

b After Risler's data. See Report of State Engineer and Surveyor of New York for 1894, pp. 373-377.

c Average.

The length of the growing season has been taken as one hundred days, including the months of June, July, and August, and part of September. The average date of the first heavy or killing frost varies in different localites of the watershed. The limiting dates will usually be between September 25 and October 10. The inches of water required on the entire watershed has been obtained by multiplying the depth required by each crop by the percentage of the whole area covered. Comparing these with the former data the following amounts are obtained as the water requirements of vegetation during the growing season of an ordinary year.

[1] Deduced from acreage data given in census of Michigan, 1894, Vol. II, Table I.

	Inches.
Leading crops on tilled area	6.6
Permanent meadows, etc	1.1
Woodland and forest, 11 per cent at 4 inches	0.4
Add for areas not otherwise included	3.0
Total depth required by vegetation	11.1

RAINFALL AND METEOROLOGY.

In order to obtain the true mean rainfall of the watershed it would be necessary to have long contemporaneous records at stations uniformly distributed throughout the region. Rainfall records have been maintained within the Kalamazoo watershed at the stations, and for periods shown in the following table. Column 5 gives the average yearly rainfall at the station multiplied by the percentage of the entire watershed, which it may be fairly said to represent. In this way the mean annual rainfall of the entire watershed is found to be 33.87 inches. Toward the mouth of the stream the depth of the annual rainfall increases several inches.

Rainfall on watershed of Kalamazoo River. (*a*)

1 Station (proceeding down-stream).	2 Years.	3 Mean annual rain and melted snow.	4 Proportion of watershed represented by each station.	5 Rainfall on entire watershed for each station.	6 Probable annual fluctuation. *b*
		Inches.	*Per cent.*	*Inches.*	*Inches.*
Hanover	1886–1896	32.89	3.33	1.10	±4.2
Pulaski	1888–1891	28.54	4.16	1.19	3.8
Concord	1888–1892	29.39	5.56	1.63	2.8
Olivet	1888–1892, 1896	33.16	12.22	4.00	4.5
Marshall	1881–1892	35.70	6.39	2.28	2.0
North Marshall	1889–1896	30.28	3.75	1.14	4.3
Battle Creek	1876–1880, 1885, 1895, 1896.	29.18	11.22	3.35	4.4
Kalamazoo	1876–1896	36.45	20.40	7.42	4.0
Allegan	1890–1896	35.75	32.97	11.76	4.2

a The meteorological data used in this report have been supplied by Mr. C. F. Schneider, director Michigan weather service.

b Deduced from the records in accordance with the theory of probabilities by Peters's formula.

Inasmuch as the rainfall at a station for any year can not be less than the mean by an amount exceeding 100 per cent, but may be more than 200 per cent of the mean, one would expect to find slightly more dry years than wet years in a long rainfall record. Out of eighty yearly records used in the table, thirty-nine were above the station means and forty-one were below. The twenty-one year record at Kalamazoo showed twelve years below and nine years above the mean The fluctuation from the mean for dry years, or, in other words, the severity of the drought, will be less than the average fluctuation from the mean for wet years, in proportion as the number of dry years is greater than the number of wet years. The variability or probable fluctuations of rainfall, in inches, for any single year above or below the mean is shown in column 6.

The best record of rainfall within the watershed is that at Kalamazoo, covering twenty-one years, from 1876 to 1896, inclusive. The distribution of the monthly rainfall and the temperature throughout the year at Kalamazoo are shown by the following table. The heaviest rainfall occurs in the months of May and June, but that in August is most variable. This is probably due to the prevalence of thunderstorms during that month, which is also a month of high mean temperature. January has the lowest mean temperature, the least precipitation, and the least variability.

Monthly rainfall and temperature at Kalamazoo.

Month.	1 Mean monthly rainfall and melted snow.	2 Proportion of the mean yearly rainfall.	3 Probable fluctuation above or below the mean for a single year.	4 Mean monthly temperature at Kalamazoo. *a*
	Inches.	*Per cent.*	*Inches.*	*° F.*
January	2.24	6.2	0.63	23.08
February	2.40	6.6	0.92	25.45
March	2.42	6.7	1.01	32.15
April	2.63	7.2	1.21	46.95
May	4.47	12.3	1.02	58.58
June	4.58	12.6	1.35	68.35
July	3.15	8.6	1.15	72.17
August	2.79	7.6	1.46	69.64
September	3.36	9.2	1.31	61.73
October	2.76	7.5	0.90	50.34
November	2.97	8.2	0.88	37.03
December	2.70	7.3	1.12	28.19
For the year	36.47		4.03	47.9

a 1876 to 1895.

The data in the above table accord well with the observed character of the stream, which is usually about as follows: A spring freshet in March or April is followed by medium water until June. High water often occurs for a few days after heavy rains in June, and sometimes also in August. Low water in later July, August, and September is accompanied by a depletion of stored ground water. Gradual increase in the flow occurs until the ground becomes frozen. Winter flow is uniform and moderate, unless the stream is swelled by sudden melting of snowfalls. This frequently occurs in January or February, and is followed by moderate high water until the spring thaws.

In so far as the meteorological records at the different stations within the watershed are contemporaneous, they show a tendency for like variations from the mean rainfall and temperature at all stations during the same year. The region may therefore be considered fairly isoclimatic, since changes affecting any large portion of the watershed will in general similarly affect the whole region.

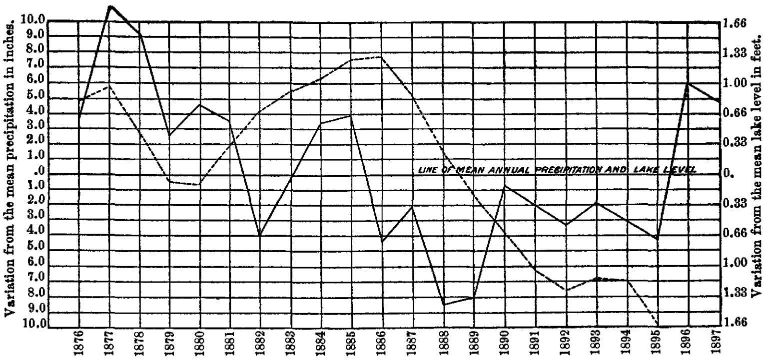


FIG. 1.—Fluctuations in the level of Lake Michigan and the annual precipitation at Kalamazoo, Michigan. (Prepared by R. E. Horton.)

The yearly rainfall record at Kalamazoo is shown by the solid line in the accompanying diagram (fig. 1). It will be seen that the yearly fluctuations from the mean annual rainfall are periodic in their occurrence. The ordinary cycle consists of a primary minimum followed by a period of increase for one to three years, and terminates in a primary maximum followed by a period of decrease for four or five years. This latter has a secondary superimposed cycle with its minimum and maximum usually one year apart. The times of recurrence of the different phases of the cycles thus far observed are shown in the following table:

Periodic rainfall at Kalamazoo.

Phase.	1	2	3	4
Primary minimum	----------	1882	1888	1895
Primary maximum	1877	1885	1890	1896
Secondary minimum	1879	1886	1892	----------
Secondary maximum	1888	1887	1893	----------
Whole period, years	6 or 7	6	7	----------

A fifth minimum may be expected about 1901.

Rainfall records at other stations within the watershed do not cover a sufficient number of years to determine whether there is a similar periodicity in the rainfall throughout the watershed, nor are there gaging data at hand to show whether a corresponding periodic decadence takes place in the stream flow. If such should prove to be the case, the fact should be of commercial value to farmers and water-power users. The existence of a short rainfall cycle following such a regular periodic law is worthy of remark. Periodic fluctuations in rainfall having cycles of greater length than the above have been observed at various places in this country and abroad. At Sacramento, California, a forty-year rainfall record exists showing a six or seven year cycle as at Kalamazoo.[1] Many long records show no regularly recurring cycles, but in all cases which the writer has observed two or more successive dry or wet years occur with much greater frequency than would be the case if the sequence of wet or dry years were purely a matter of mathematical calculation. As a safe conclusion it may be said that certain meteorological conditions underlying rainfall tend to recur in more or less obscure cycles. It seems not improbable that the causes of such cycles are general in their application; and their apparent effects in many instances are masked by local or secondary conditions. The final solution of the problem will have an important bearing on questions relating to the water resources of any region.

RELATION OF LAKE LEVEL TO RAINFALL.

Observations of the height of the water surface of Lake Michigan have been made since 1800. In the absence of longer rainfall records within the watershed any relation that may be found to exist between the rainfall and the lake levels will be helpful in studying the run-off. The different kinds of fluctuations to which the water level of the lake surface is subject may be classified in relation to the causes producing them, as follows:

(1) Small tides, which at Chicago the United States Lake Survey found to have an amplitude of 1½ inches for neap tide to 3 inches for spring tide.

(2) "Seiches," so called, similar to those observed on Swiss lakes, and not thus far satisfactorily explained. They consist of small waves or pulsations having an interval of about ten minutes from impulse to impulse and apparently recurring without cessation.

(3) Temporary fluctuations, due to the wind. Colonel Whittlesey states that on August 18, 1848, a gale from the northeast reduced the water level at Buffalo 15½ feet lower than on October 18, 1894, the time of a terrible gale from the southwest.

(4) Annual variations, caused chiefly by differences of temperature and evaporation and by the melting of snow and ice. On Lake Michigan low water usually occurs in November and March. The highest water occurs in June and July.

[1] See climate, soil, characteristics and irrigation methods in California, by Charles W. Irish: Yearbook U. S. Dept. Agric., 1895.

(5) Secular variations, covering periods of several years, dependent on rainfall and meteorological conditions. The length of the periods is irregular and the times of recurrence of maximum and minimum phases can not be predicted closely. Knowing the mean annual levels for a series of years we may expect a similar series in the future, but with the times of the different phases very different. The number of maxima and minima within a given interval of years will, however, be nearly uniform for long series.[1]

On the accompanying diagram (fig. 1) the height, in feet, of the water surface of Lake Michigan, above or below the mean level (viz, 581 feet above tide) is shown, by a broken line, for a period of twenty-one years, 1876 to 1896, inclusive. It will be noticed that the lake levels are subject to a much greater relative fluctuation than is the rainfall. The two curves follow each other somewhat closely, although the periods are longer and more continuous for the lake levels. The year 1896 is exceptional in that it shows the lowest lake level recorded, while it was the year having the highest recorded rainfall at all stations within the watershed except Kalamazoo, where it was third in rank for twenty-one years. There is reason to believe that the level of Lake Michigan and the rainfall and the run-off of the watershed are covariants. Exceptional years can be ascribed to high summer temperature, producing luxuriant vegetation and excessive evaporation, so that little rainfall appears as run-off, or else the distribution of the rainfall through the year may be unfavorable to its reaching the streams and lake as run-off. The former was apparently the case in 1896. Careful inquiry from power users showed that within the Kalamazoo watershed there was a much greater shortage of water in the river in 1896 than in 1897, a year of considerably lower rainfall and mean temperature during the summer months. The mean rainfall at six stations in the watershed in 1896 was 41.9 inches, or 8 inches above the average.

RUN-OFF, RAINFALL, AND WATER POWER.

In studying stream flow it should be borne in mind that the amount of rainfall appearing as run-off in a given year is the resultant of a large number of more or less independent influences. Conditions may so combine that those factors which would ordinarily be in the background will in some instances become the controlling elements. Few, if any, rules without exceptions can be laid down, and each stream must be studied separately in all its relations.

[1] The following references have been consulted in relation to lake levels:

(*a*) Chart of Fluctuations in the Level of the Great Lakes, by Charles Crosman, Milwaukee, Wisconsin.

(*b*) Climate of the Lake region, by Bela Hubbard: Pop. Sci. Monthly, January, 1888.

(*c*) Water-supply of western division of Erie Canal, by George W. Rafter: Report State Engineer and Surveyor of New York, 1896.

(*d*) Report United States Deep Waterways Commission: Washington, 1896.

(*e*) Reports of Chief of Engineers, U. S. Army.

The following table shows the discharge of the Kalamazoo watershed corresponding to different percentages of the mean annual rainfall appearing as run-off in the stream:

Relation between run-off and discharge of Kalamazoo River.

Proportion of mean annual rainfall appearing as run-off.	Depth of run-off on entire watershed.	Mean discharge of the stream.
Per cent.	*Inches.*	*Second-feet.*
110	37.26	4,803.2
100	33.87	4,366.5
90	30.48	3,929.8
80	27.09	3,493.1
70	23.7	3,056.5
60	20.31	2,619.9
50	16.92	2,183.3
40	12.53	1,646.7

The discharge of the Kalamazoo River was measured at a number of points along the stream during the spring high water of March, 1898.

Discharge of the Kalamazoo River at the Marengo dam, March 23, 1898.

Flow over dam and wasteweir	second-feet	456.8
Diverted for power purposes	do	113.
Total discharge	do	569.8
Drainage area above dam	square miles	261.
Discharge per square mile	second-feet	2.18

The depth of water flowing over the crest of the dam on March 23 was 15 inches. The height for maximum flow, which occurred on March 22 and lasted only a few hours, was 24 inches. This would have corresponded to a total discharge of about 930 cubic feet per second, or 3.5 cubic feet per second per square mile of drainage. We may compare this flow with that of Boardman River at Traverse City, a stream having a drainage area of 295 square miles. The river was measured on April 10, 1897, by Mr. George W. Rafter, and was at that time carrying about 300 cubic feet per second, or slightly over 1 cubic foot per second per square mile. Mr. Rafter shows that the flow of Boardman River undoubtedly may be as low as 100 cubic feet per second for two successive months, and that it may not yield more than 75 cubic feet per second, or about one-fourth of a cubic foot per second per square mile, for a period of a few days.[1]

[1] Water Supply of Traverse City, Michigan, by George W. Rafter and F. H. Northrup, city engineer, 1897.

Discharge of Rice Creek at Marshall, Michigan, March 23, 1898, 1 mile above point of confluence with Kalamazoo River.

Discharge over dam	second-feet	25.
Diverted for water power	do	125.
Tributary drainage	square miles	99.
Discharge per square mile	second-feet	1.5

Discharge of Battle Creek at Battle Creek, Michigan, March 24, 1898.

Discharge over dam	second-feet	253.3
Diverted for water power	do	75.4
Total discharge	do	328.7
Tributary drainage	square miles	180.
Discharge per square mile	second-feet	1.8

The discharge a day or two previous was somewhat greater, although at that time there was an extensive flood on the flats between the point of measurement and the confluence of Battle Creek with Kalamazoo River.

Discharge of Kalamazoo River at Battle Creek dam March 24, 1898.

Discharge over dam	second-feet	648.6
Diverted for water power	do	459.3
Total discharge	do	1,107.9
Tributary drainage area	square miles	510.1
Discharge per square mile	second-feet	2.17

Combining the two preceding measurements we get 1,436.6 cubic feet per second for the discharge of Battle Creek and Kalamazoo River at Battle Creek. This, with a total tributary drainage area of 690.1 square miles, gives 2.08 cubic feet per second as the discharge per square mile of drainage area.

Discharge of Kalamazoo River at Otsego, March 26, 1898.

Discharge over dam	second-feet	234.8
Diverted for water power	do	1,669.1
Total discharge	do	1,903.9
Tributary drainage area	square miles	1,600.0
Discharge per square mile	second-feet	1.2

For purposes of comparison a measurement of Grand River was made at the North Lansing dam.

Discharge of Grand River at North Lansing dam April 9, 1898.[1]

Discharge over dam	second-feet	642.
Diverted for water-power purposes	do	560.
Total discharge	do	1,202.
Approximate tributary drainage area	square miles	1,168.
Discharge per square mile	second-feet	1.02

This was at a time of medium water when the depth of water on the crest of the dam was but 14½ inches. At the time of maximum high

[1] Probably too small, owing to impossibility of getting precise data regarding capacity of all water wheels in use.

water in later March the depth of water on the crest of the dam was shown by the water marks to have been 29 inches. This would correspond to a total discharge of about 2,365 cubic feet per second, or 2.0 cubic feet per second per square mile of drainage area.

The preceding measurements, made at different points along the stream at nearly the same time, show about the flow that may be expected in Kalamazoo River at ordinary high water. The flow per square mile apparently gradually decreases as the tributary area increases. The low flow of Battle Creek may be due to a large proportionate area of lake storage, gathering the flood waters to be yielded as run-off at a later period.

The high-water flow exhibited by the gagings was preceded by heavy rainfalls and high temperature, as shown at several stations, within the watershed, in the accompanying table:

Meteorological conditions at stations on Kalamazoo River, March, 1898.

Station.	Precipitation.						Temperature.		
	March 10 to 13.	March 18 to 21.	March 24 to 28.	Total for month.	Greatest rainfall in 24 hours.	Day of heaviest rainfall.	Maximum daily.	Minimum daily.	Mean daily.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*		°*F.*	°*F.*	°*F.*
Olivet	3.38	1.61	0.48	6.16	2.02	10	67	10	38.8
Hanover	1.07	.55	1.10	3.57	1.	28	70	1	38.2
North Marshall	.91	1.94	.78	3.83	1.44	20	69	1	36.5
Battle Creek	1.35	1.50	......	4.21	1.50	18	69	10	38.9
Kalamazoo	1.01	.47	.51	2.32	.51	26	69	8	39.
Hastings	1.27	1.12	.52	3.21	.80	19	69	1	37.2

No snow fell during the month. On March 1 the ground was covered with about 9 inches of packed snow. This melted rapidly, and, as the ground was frozen, appeared almost entirely as run-off during the month.

Depth of snow on ground at stations on Kalamazoo River, March, 1898. (a)

Station.	Mar. 1.	Mar. 2.	Mar. 3.	Mar. 4.	Mar. 5.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Somerset	9.0	8.0	7.0	6.0	5.0
Olivet	11.0	10.0	8.0	7.0	6.0
Battle Creek	5.0	5.0	4.0	3.0	3.0
Kalamazoo	12.0	12.0	12.0	10.0	10.0
Hastings	8.0	8.0	7.0	6.0	5.0
Average depth	9.0	8.6	7.6	6.4	5.6
Average daily melting	......	0.4	1.0	1.2	0.8

Station.	Mar. 6.	Mar. 7.	Mar. 8.	Mar. 9.	Mar. 10.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Somerset	4.0	3.0	1.0	......	....
Olivet	5.0	4.0	3.0	1.0	0.0
Battle Creek	0.5	0.0	......	......	....
Kalamazoo	8.0	0.5	None	......	....
Hastings	4.0	2.5	1.0	Trace	......
Average depth	4.3	2.0	0.8	......	....
Average daily melting	1.3	2.3	1.2	......	....

a At sunset of each day.

There are no precise data at hand relative to the low-water flow of the river. By careful inquiry from power users it was found that in nearly all cases a shortage of water occurs for from two to six weeks in the months of July, August, and September. At such times the flow is insufficient to supply the water wheels now in use to their full capacity, and is less than the amount of water shown as being diverted for power purposes at the time the measurements were made. This would be expected from the rainfall records. The following table shows the lowest recorded yearly rainfall at stations in the watershed. As the minimum observed rainfall at a station decreases as the length of the record is extended, years may be expected to occur in which the rainfall will not exceed that at Kalamazoo in 1894, or 71.5 per cent of the mean, as shown in the table. This would be 25.43 inches for the entire watershed, using our previously derived mean of 33.87 inches. For the years 1888 and 1889 the total rainfall at Kalamazoo was but 56.53 inches. The rainfall for August frequently falls below 0.1 inch, and in 1889 the combined rainfall for July, August, and September was but 3.89 inches. If the flow from full ground water were 2 inches a month it would undoubtedly have been depleted in such a drought so as not to exceed three-fourths of an inch in a month. As little or no rainfall reached the stream directly, the run-off in the summer of 1889 must have fallen as low at least as 0.7 cubic foot per second per square mile.

Years of least recorded rainfall at stations on Kalamazoo River.

Station.	Number of years' record.	Year of least rainfall.	Rainfall in lowest years.	Per cent of mean annual rainfall at station.
			Inches.	
Pulaski	4	1889	24.20	85.0
Concord	5	1888	24.17	81.8
Allegan	7	1895	26.95	75.3
Battle Creek	8	1879	20.20	74.8
North Marshall	8	1894	22.73	75.0
Hanover	9	1888	25.30	76.9
Marshall	11	1889	28.1	78.7
Kalamazoo	21	1894	26.07	71.5

HIGH WATER AT KALAMAZOO.

The extent and duration of high water at Kalamazoo is shown by the following data relative to the height of the river surface during floods at that place. At the township line, 2 miles below the city of Kalamazoo, the elevation of the bottom of the river bed is the same as at the Gull street bridge within the city, there being practically no fall in the river in that distance. As a result, the current is extremely sluggish, and a portion of the city is subject to frequent floods. The muck-covered river flats within the city are extensively devoted to the cultivation of celery. The annual spring flood is productive of little damage, but when floods occur during the summer months they result in a heavy loss to the celery growers and also tend to produce a bad sanitary condition, lasting for some time.

The following table gives the elevation of the river surface in feet above the city datum plane. The elevation of the water surface at its mean stage is 67 feet. The measurements at East avenue bridge are at the point of confluence of Portage Creek with Kalamazoo River. Those at Gull street bridge are below that point.

Observations of high water at Kalamazoo. (*a*)

Year.	Date.	Elevation.	Place of measurement.
		Feet.	
1883	June 28, 5 p. m	71.66	At East avenue bridge.
	June 29, 7.30 a. m	72.25	
	June 29, 1 p. m	72.42	
	June 29, 6 p. m	72.50	
	June 30, 7 a. m	72.74	
	June 30, 1 p. m	72.90	
	June 30, 6.30 p. m	73.03	
	July 1, 9 a. m	73.36	
	July 1, 6 p. m	73.59	
	July 2, 7 a. m	73.71	
	July 2, 1 p. m	73.71	
	July 2, 6 p. m	73.63	
	July 3, 7 a. m	73.40	
	July 18	67.88	
	August 17	68.55	
1887	February	*b* 74.77	
1888	July	67.55	Do.
1896	July 16	69.10	At Gull street bridge.
	July 19	68.74	
	July 31	70.69	
	August 1	70.99	
	August 3	70.49	
	August 5	69.20	
	August 8	68.99	
	August 19	69.50	
1897	March 12, 1.20 p. m	71.34	At East avenue bridge.
	March 12, 6 p. m	71.48	
	March 13, 7 a. m	71.84	
	March 13, 1.20 p. m	72.01	
	March 13, 6 p. m	72.34	
	March 14, 4 p. m	72.04	
	March 15, 7 a. m	71.54	
1898	March 14	71.35	At East avenue bridge during spring flood.
	March 15	71.80	

a These data were obtained from records furnished by Myron C. Taft, city engineer of Kalamazoo. Data for 1883 are not strictly comparable with those since that year, as an old dam has been removed and a shorter channel cut, allowing flood waters to pass off more quickly.

b Highest water recorded.

WATER POWER.

The fall and slope of the river is shown by the accompanying table. In comparison with this the next table (on page 38) shows the number of feet of fall used for water power at dams on the main river. Out of a total fall of 338 feet from Albion to Saugatuck, 76 feet is now used for the production of power. The aggregate rated power of the water wheels in use on the main river is between 4,000 and 5,000 horsepower. This includes 18 flouring and 5 paper mills, besides planing mills, machine shops, municipal waterworks, etc. There are also 20 dams on tributaries with a developed water power, so far as it could be ascertained, of 1,500 horsepower.

Fall and slope of Kalamazoo River.[1]

Portion of river.	Distance along river.	Total fall.	Mean slope per mile.
	Miles.	*Feet.*	*Feet.*
Albion to Marshall	12.25	52	4.22
Marshall to Battle Creek	13.25	70	5.26
Battle Creek to Kalamazoo	23.37	43	1.84
Kalamazoo to Allegan	19.73	57	3.00
Allegan to Saugatuck	32.50	116	3.55
Albion to Saugatuck	101.10	338	3.34

As has been shown, the capacity of water wheels now in use is fully as great as the flow of the stream will warrant without the construction of new dams. Viewed from an economic standpoint the water power of the stream can not be greatly increased over the present development unless some method of flow regulation and conservation of the flood waters be put in operation.

[1] The fall has been deduced from railroad profiles. See topography and climate of Lower Michigan, Report Michigan State Board of Health, 1878.

Water power developed on Kalamazoo River.

Location of dam.	Head or fall.	Net horse-power developed.
	Feet.	
North Branch at Horton	10	55
North Branch at Concord	9	118
North Branch at Bath Mills	8	33
South Branch at Mosherville	14	80
South Branch at Homer	8	214
South Branch at North Homer	7	69
Main River at Albion	13	298
Main River at Marengo	7	118
Main River at Marshall	6	----------
Main River at Ceresco	8	289
Main River at Battle Creek	12	469
Main River at Plainwell	19	786
Main River at Otsego	12	1,725
Main River at Allegan	8	----------

WATER POWER OF HURON RIVER.[1]

Huron River rises in the town of Clarkston, Oakland County, Michigan, and runs southwest into Livingston County, draining many lakes in Oakland County. The chief of these are White, Union, Upper Straits, Lower Straits, Pine, and Spring lakes, averaging one-half to 1 square mile in area. In the southeast part of Livingston County it takes the waters of four lakes, viz, First Base Lake, Second Base Lake, Strawberry Lake, and Portage Lake, varying from 1 to 2 square miles in area. Portage Lake is the largest and also the lowest down the valley. It is 3 or 4 miles long and averages about half a mile in width. It is fed by Portage River, which itself drains ten lakes of small size. From there the Huron flows northeast, then southeast again, and enters Lake Erie just below the mouth of Detroit River. The total drainage area is 950 square miles.

The country is flat or rolling, with a glacial drift of clay, sand, and gravel, well adapted to the raising of wheat, which is the staple and which gives work to many flouring mills. The river was declared navigable by Congress. Once a flatboat for freighting ran from Ypsilanti 30 miles to the mouth, but its use was discontinued on the advent of railroads. There was too little water for navigation, and the dams interfered. Boats run up to Rockwood, 4 or 5 miles up, on the line of the Lake Shore and Michigan Southern Railroad.

No lumbering is done, and the stream is devoted to manufacturing,

[1] From the report by James L. Greenleaf, special agent of the Tenth Census of the United States, Vol. XVI, p. 493 et seq.

for which it is peculiarly suited. It has a fall averaging 5 feet a mile, and this near its mouth. It is on the line of several railroads, and, owing to adjacent lakes, the storage capacity is large and its flow more regular than that of various other rivers in the country. The banks of the river are usually from 9 to 12 feet high, and hence ponds do not spread. The bed and banks are usually hard clay, or a sort of conglomerate of clay, gravel, and stone (till). There is no rock bed except at Flat Rock, the first fall above the mouth.

The course is extremely winding. The Michigan Central Railroad runs along the river 17 miles from Ypsilanti to Dexter, and in that distance crosses it sixteen times. The bulk of the manufacturing is between Dexter and Ypsilanti, on the line of the Michigan Central Railroad.

At Ypsilanti the average breadth is 100 feet, the average depth 1½ feet, and the maximum depth about 5 feet. The ordinary low-water flow, calculated from the estimated horsepower, is 220 cubic feet per second, or 0.23 cubic foot per second per square mile of drainage area. The available power under 10 feet head at ordinary low water is from 225 to 250 horsepower. There is no difficulty from floating ice. A mill using the full average power of the stream can run at full capacity ten months of the year, and during August and September at half capacity. The river has no large tributaries below the lakes, and hence the power for a given fall is nearly the same in the upper and in the lower part.

DEVELOPED POWER.

Most of the mills are between Dexter and Ypsilanti, a distance of 17 miles. Above Dexter and below Portage Lake are the Hudson and the Dover mills. Below Ypsilanti are mills at Rawsonville, Belleville, etc.

Three forms of dam are in use: (1) The pile dam, a common form. A typical specimen is one belonging to the Ypsilanti Paper Company. Piles were driven 6 feet between centers, both across and down the stream, covering a strip 50 feet wide across the channel. The ends were then cut, so that taken together their surface formed two planes, meeting at the center line of the dam, like a roof. The space between the piles was filled in with stone and the top planked over. A plank apron was built on the lower side. (2) The crib-work dam—ordinary timber cribs, filled with stone and planked over. (3) The frame dam, used at the Dover mills. A triangular frame was built and planked over and stone thrown under; a plank apron was built on the lower side, and gravel thrown in on the upper side. So far as ascertained, there have been no instances of the breaking away of dams.

At Flat Rock, 7 or 8 miles above the mouth of the river, is the first power. There is about 100 horsepower available.

At New Boston and at Belleville powers are being developed. There are two flouring mills at Belleville. The banks are high and well adapted to ponding.

At Rawsonville is a flouring mill with 7 feet head. There is 150 to 175 horsepower available.

Ypsilanti is the chief manufacturing center on the river. There are three paper mills, two flouring mills, a woolen mill, and a small custom sawmill, also a low dam in connection with the city waterworks. The banks are from 9 to 12 feet high, and ponds do not spread. There are three dams, about one-half to three-fourths of a mile apart, and no fall is wasted. The bed is hard clay. The Michigan Central Railroad runs up the valley from this point, and freight facilities are good.

The lower pond has 7 feet available fall and 175 available horsepower. There is a pile dam 190 feet long. The average breadth of the pond is about 150 feet and the length half a mile. The power is utilized by the Ypsilanti Paper Company's mill. The middle pond has 5 feet available head and 125 available horsepower. The only mill at the power is the Huron flouring mill, which uses on the average 75 horsepower. There is a pile dam 5 to 6 feet high and 100 feet long. The pond is from 150 to 200 feet broad and half a mile long. The upper pond is owned by the City flouring mill and the woolen mill, and feeds them and also a small sawmill fed from the race of the flouring mill. The fall at the dam is 8 feet and the available power is 225 horsepower. The dam is from 120 to 130 feet long, the area of the pond 35 acres, and the depth 5 or 6 feet; the dam does not spread much. The woolen mill uses 42 horsepower. The flouring mill, situated on a race, has 1 foot additional fall, making the total fall 9 feet; it uses 100 horsepower. The sawmill, when running, uses about 10 horsepower.

The mills of the Peninsula Paper Company are situated at a pond a short distance above Ypsilanti, and have 300 available horsepower.

The largest power on the river is at Lowell, and it is used by the Ypsilanti Paper Company. The available head is 16 feet, and 400 horsepower is available. The pile dam has been described; its length is 166 feet. The area of the pond is 30 or 35 acres.

At Ann Arbor, 7 or 8 miles above Ypsilanti, there is a level with a head of 10 feet and 250 available horsepower. The dam is a pile dam 200 feet long, which is utilized by the Ypsilanti Paper Company's mill. Above it is another level with the same head and power. A woolen mill, a flouring mill, and a sawmill are fed from this pond, using altogether 100 horsepower. The dam is 140 feet long.

At Foster's station, 3 miles from Ann Arbor, there is a fall of 9 feet, all of which is utilized by a paper mill taking 100 horsepower and a woolen mill taking 58 horsepower. The power is estimated at 300 horsepower for six months of the year.

At Delhi there are two flouring mills, a woolen mill, and a sawmill, all using water from the same level. There is 7 feet head and 140 available horsepower. Usually all the mills can run at once. The dam is of crib work, 150 feet long. The Scio flouring mills are above Delhi, and have 8 feet fall, with 140 available horsepower. The dam is of crib work, 100 feet long.

Dexter has a flouring mill, a woolen mill, and a sawmill, all run from the same level. The available head is 5 feet. The dam is of crib work, 75 feet long.

Above Dexter are the Hudson mills, with 5 feet head and 75 horsepower—a crib-work dam 100 feet long,—and the Dover mills, with 7 feet head and 100 horsepower—a frame dam 100 feet long. The ponds above Ann Arbor average from 120 to 180 feet wide and one-half mile to 2 miles long. There are no important powers above.

UNDEVELOPED POWER.

There are a few undeveloped powers. Three miles below Ypsilanti is one of 300 horsepower, which has not been used, because the pond would spread over valuable farming lands and because the location is not near the railroad. One mile below Ann Arbor is a power with 4 or 5 feet fall, unimproved, giving from 100 to 125 horsepower. It is on the line of the railroad. The small power, compared with the cost of improvement and lack of demand for it, is the apparent reason it has not been improved. One and one-half miles above Ann Arbor is a fall of 10 feet, unimproved. Nearly 300 horsepower is wasted. It was used formerly by a sawmill, now burned down. It is on the line of railroad and awaits improvement.

WATER POWER OF RAISIN RIVER.

The North Branch rises in Jackson County, and the South Branch in the northwestern corner of Ohio. They unite east of the center of Lenawee County and flow into Lake Erie. The drainage area is 1,162 square miles. Near the mouth it is 200 or 300 feet wide, but in ordinary water it is only from 6 to 12 inches deep, with a sluggish current. At Adrian it is a small stream, 25 or 30 feet wide, with a moderate current, about 1 foot deep. There are several small mills on the river, but no power of importance.

USES WHERE QUALITY IS IMPORTANT.

USE FOR DRINKING.

INORGANIC IMPURITIES.

The uses of water where the quantity required is not excessive and is usually readily obtained, but where the proper quality is important and is not so easily maintained, will now be considered. Impurities are of two kinds, organic and inorganic. Under the first head are classed sewage, swamp contaminations, ammonia, and bacteria. Salt, though inorganic, has often been considered an indication of the presence of organic contamination. But in the district under consideration it is not true, and a knowledge of the normal chlorine percentage of the same class of water in the same neighborhood is a prerequisite to the application of the chlorine test as indicative of sewage. Investigation of this normal percentage has been undertaken for the State board of health by Prof. D. Fall. Salt is one of the commonest inorganic constituents, only less common than the acid carbonates of lime and magnesia, which are always present except in some sandstone wells and in cistern waters. Iron in some shape, and sulphates of lime, etc., are also not uncommon in wells.

The quantity of mineral matter in the lakes or rivers is not sufficient to affect the water appreciably as a supply for healthy people, while for cases of uric acid diathesis, where lime should be avoided, many sandstone wells and shallow surface wells in sand seem specially suited, since their water contains less than the usual amount of lime. Occasionally the water from deeper wells is softer. Filtered rain water is used and is not at all unpalatable when one is accustomed to it. Distilled water is also manufactured and sold.

More detailed conclusions as to the connection between the chemical character and the suitability of a water for drinking will be found in a subsequent paper.

Dr. W. H. Deadman, veterinary surgeon at Alpena, asserts that 80 per cent of all the horse disease in northern Michigan is due to hard water. The hardness of water varies in the lakes and rivers, and probably varies with the season of the year and with the depth at which the samples are taken.

Some of the shallower rock wells, almost all those over 500 feet, and a few of the wells in drift are so highly charged with mineral matter (over ½ oz. per cubic foot) as to be cathartic or otherwise unpleasant and unfit for domestic use. It is important to note, however, that in many cases the mineral matter comes from beds of salt or gypsum, or from even less continuously porous beds, and that therefore fresh water may at times be obtained by proper casing, even under beds of salt. There are a number of cases on record in which fresh water has been obtained under salt. A notable case is that of Mr. Leipprandt, near Caseville (sec. 13, T. 17 N., R. 10 E.), who has a well 100 feet deep that is very salt, and another well 280 feet deep (cased to 228 feet) which yields good fresh water.

ORGANIC IMPURITIES.

Organic impurities are most prevalent when inorganic are least so, in the shallow wells, rivers, and ponds, and even in cisterns and standpipes. Yet even deep artesian wells are not by any means free from organic matter—for example, the Bad Axe supply. Such matter is, however, probably harmless. Organic impurities may be divided into two kinds—mere vegetable growths of algæ, etc., and the more dangerous bacteria of typhoid. The former are not wholesome, though not so dangerous as the latter, and may form in cisterns and standpipes in very pure water, as, for example, at Bad Axe and at Leaton, and are especially abundant in artesian water. The exclusion of light tends to check their growth in cisterns. A few cases are reported where malaria was cured by a change to drinking artesian water, seeming to show that bad water, and not bad air, was the cause of the disease. But it is of course possible that it was not the previous presence of vegetable matter in the water that caused the disease, but rather the curative properties of some mineral ingredient in the artesian water that effected the cure. Wooden or plank casing, which is much too common, soon gives a foul taste to water, and any dug well with a basin is liable to have foreign matter get into it that does not improve its quality—angleworms, frogs, mice, moles, rats, and snakes, which well drillers find on cleaning the wells.

Wells dug or driven in sand only, without a clay capping, are liable to surface and sewage contamination, though of course when they are put down 100 or 200 feet the danger is greatly reduced by the sand filtration. Even then it would be well to have the point and strainer considerably below the top of the water line. It would save trouble in an exceptionally dry year, and would give additional protection.

The practice of having any dug or shallow surface water well in a barnyard or near a privy is uncivilized and is only the temporary expedient of uneducated immigrants who have recently arrived, and one is glad to see that among the intelligent and more prosperous farmers deep driven or drilled wells are becoming the rule and not the exception. Too commonly, however, the well water of the deep driven well is allowed to flow into the old dug basin, a practice which has many objections (considered on page 73). The casing should extend from the pump to the water-bearing stratum. The well should be removed from the barnyard, to which the water may be conducted by a long launder. If a surface or dug well is the best that is available, it should be out in the orchard, and removed from sources of contamination.

Digging is sometimes the best way of sinking through a bowldery formation. A good practice, prevalent in Emmet County, is to cement the wall as the well is sunk, using a 3-foot boiler tube as a shield. Mr. E. R. Phillips, of Bay City, uses such a cemented well in the city, but he has a depth of sand and charcoal at the bottom which acts as a huge filter—an excellent palliative expedient.

Rivers and lakes are the great sources of supply for village and city waterworks, being but rarely used by individual farmers, except as some dry season forces them to haul water. Unfortunately, as we have already remarked, too often an ample supply has been considered the prime requisite for city plants.

DAIRY USE.

One great advantage of flowing wells is in keeping milk cool. The temperature of such wells approaches the mean annual temperature of the place at which they are, plus a certain small amount, dependent on the depth below the surface from which they draw their water, about 1 degree for 60 feet. The annual fluctuations of temperature hardly affect them, though in fact if from 30 to 60 feet deep they are colder in summer than in winter. This is not only to be expected theoretically, but has been verified in practice. Professor Davis found, in studying some of the Alma flowing wells, that the water of one about 55 feet deep stood at 52° F. in winter and at 48° F. in summer.

Since the mean annual temperature of Michigan, as is shown in fig. 4, varies between 39° F. and 49° F., the temperature of flowing wells or springs should have about the same range, and the recorded observations of the shallow flowing wells are but 4° or 5° higher. This is precisely the range of temperature best adapted to keep milk. Such flowing wells may be obtained all over the Saginaw Valley, and, as the map (Pl. VII) shows, such wells, drawing water either from the rock or from gravel beds under clay, occur throughout the State. These wells yield a water very favorable to the growth of algæ, and the vegetable matter must be frequently cleaned from the tanks. Darkness checks its growth.

For use in refrigeration or for general dairy use the same purity is not requisite as in drinking water. While of course water brought in contact with butter should be free from dangerous organic impurities, inorganic mineral constituents, like salt and sulphates, are reported to be some advantage and help in hardening the butter. Much of the water of the Saginaw Valley, which is rather too salt for domestic use, is excellent for dairy purposes.

COOKING, LAUNDRY, BOILERS.

Next to the use for drinking naturally comes cooking, laundry, and boiler use. As organic impurities are rendered harmless when boiled, this factor is eliminated, except when, as is occasionally the case, "foaming" is produced in the boiler. The deposit of mineral matter in the teakettle is usually either carbonate or sulphate of lime, magnesia, or iron. If the former, a little acid quickly removes it. Iron is betrayed by its color. Only occasionally is water found with so much mineral matter as to be unfit for cooking. In such cases iron is usually the offending element, turning tea black and discoloring potatoes. Water, if allowed to stand, will precipitate most of the iron. It forms a scum which is at times mistaken for oil.

Impurities of another class, i. e., hydrogen sulphide and other gases, as well as traces of oil, occur more or less in various parts of the State. Hydrogen sulphide occurs in various places, and is characteristically common just beneath the Devonian black shales. A moderate amount does not seem to be injurious, and users soon get used to its peculiar odor; but in the deeper salt wells in the southeastern part of the State it is disagreeable, in some cases seriously affecting the eyes.

Another important consideration in regard to water is its effect on boilers. The impurities which deposit scale are the sulphates and carbonates of lime and magnesia, and many railroads have spent considerable money to obtain purer boiler water. Water with 8 to 10 grains of carbonate of lime to the gallon is considered hard, and when there are over 40 grains to the gallon—and there are large districts where this amount is present—the water has been condemned by railroad authorities. Mount Pleasant water is typical as a bad water for use in boilers.

The sulphate of lime is worse than the carbonate. The carbonates of lime, magnesia, and iron are somewhat precipitated by exposure to the air, and further by boiling or by the addition of quicklime. In every district it will be found that the water of certain wells is considered good for threshing machines, both in quantity and in quality.

In the steam plant of the University of Michigan, which furnishes steam heat and also drives a couple of engines, the condensed water is returned to the boilers. In addition, the engineer informs me that a supply of about 400 gallons plus about 10 per cent is used daily. This is nearly all derived from cisterns, representing about eleven months' supply. I obtained, through the kindness of Professor Cooley, a blue print showing the exact roofage used in supplying the cisterns. From this I estimate that 19,493 square feet of catchment area furnishes 17,600+ cubic feet of water. This is not far from 1 cubic foot per square foot of catchment surface, or 38 per cent of the Ann Arbor rainfall (32 inches). It is impossible to estimate the amount of leakage, as there are five cisterns, scattered at considerable intervals over the grounds, and part of the rainfall of exceptionally wet seasons may overflow the cisterns. It seems as though a larger percentage of the rainfall might be saved, although the percentage of run-off to rainfall is apparently higher than in the Kalamazoo Basin. Much of the winter snow will of course slide off, and in each rain a certain percentage must be allowed for wetting the roof and for evaporation. It will be safe, however, to estimate that 10 feet square of roof surface will yield 100 cubic feet, or about 25 barrels, of water per annum.

At the Agricultural College the custom is to heat the water to boiling and then allow it to aerate, cool, and settle. At the Midland Chemical Works they propose to remove the hardness first with lime and then with soda ash.

In any case it is well to get the water as pure as possible before introducing it into the boiler; and heating the feed water with the exhaust steam and allowing it to settle will certainly help. The growth of the soda-ash industry in Michigan will doubtless permit the economical use of that chemical.

Cistern or rain water and condensed boiler water are of course free from these impurities, and it might be well to plan an agricultural engine for use in the Saginaw Valley with a condenser arranged to use its water over again and again. The soda salts, common salt, and sulphate of soda are not objectionable, but rather help to clean out scale, and in the Saginaw Valley are often present in the water. The chlorides of lime and magnesia and the heavily carbonated waters are corrosive.

Generally speaking, the softest waters are either rainfall waters from sands so near the surface that the lime has been leached out, or waters from wells in the Napoleon and certain other sandstones, which, even when salt, run much lower in sulphates than do the waters of the higher beds.

What has been said concerning cooking and boiler feed water applies also to that for laundry use. The prevailing hardness of the water has led to the extended use of cistern water for washing. If one-third the rainfall can be saved, a roof 10 feet square will yield about 600 gallons a year. It is only in part of the sandstone district that the wells are so soft that there is no object in saving rain water. To supplement rain water very shallow wells are sometimes used, when only 2 or 3 feet of sand is underlain by clay and has been washed free from lime, so that one can get practically surface rain water. In a fresh cut in a gravel bank (e. g., at Mecosta), the leaching out of the lime and iron from the first 2 feet or so is well marked by a dark line at the bottom where the lime and iron are concentrated, which have often cemented the pebbles together into one form of "hardpan," a term also applied to till.

The same remedies for hardness mentioned above, viz, exposure to air, boiling, and the addition of quicklime or sal soda, are also available in laundry use, and are known as "breaking" the water.

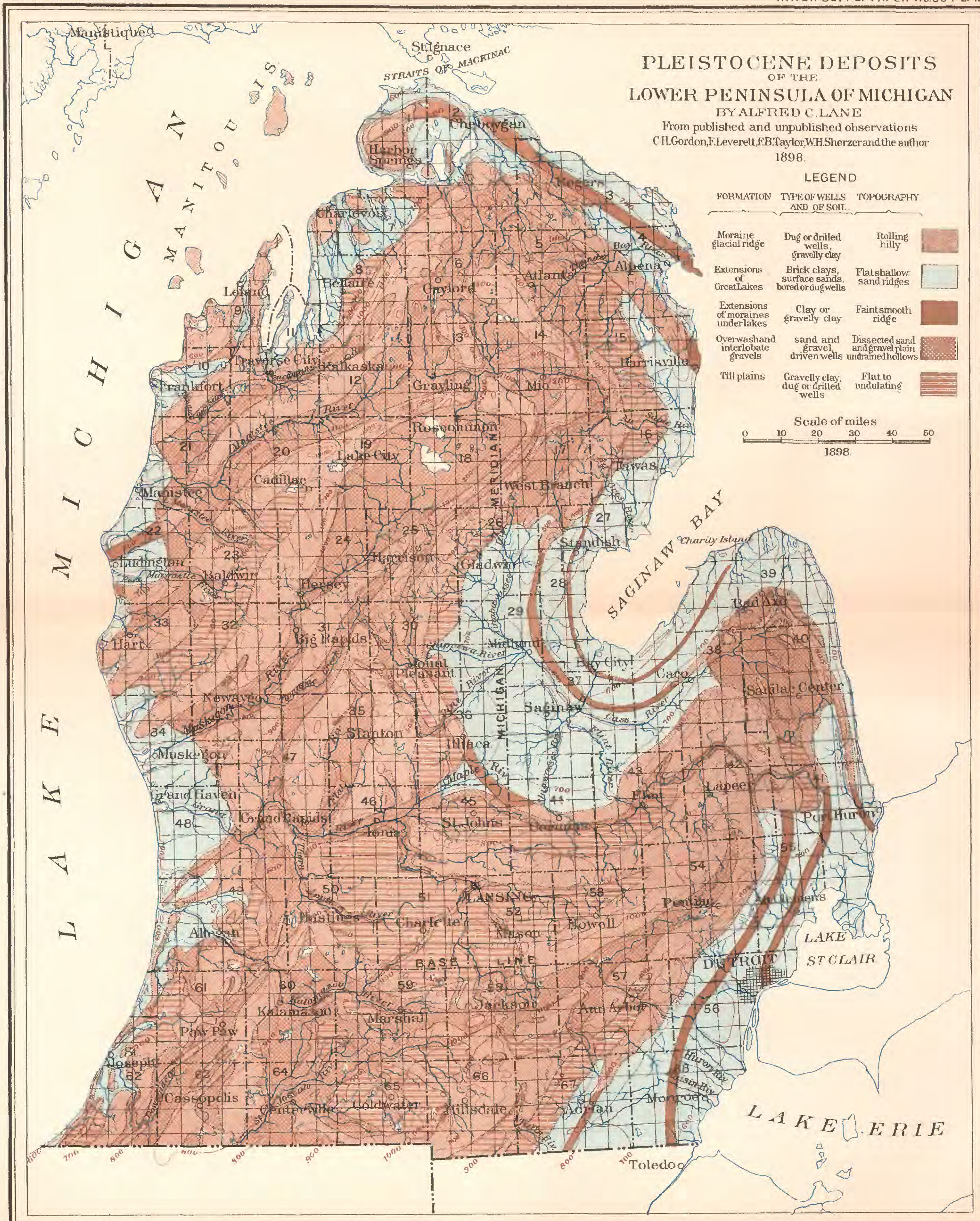
It is advisable to get the water as pure as possible before its injection into the boiler, rather than to rely entirely on "dosing" the boiler.

SUGAR-BEET INDUSTRY.

In the manufacture of beet sugar it is important to have a water as free as possible from salts, for every molecule of chlorine salt is said to invert about five molecules of sugar into glucose. Organic matter is said to work in like fashion. None of the surface waters, and but few of the deeper drift wells, are really disqualified, although there is considerable difference between them. Most of the deeper rock wells, however, over 300 feet in the rock, except those in the northern part of the State and, relatively speaking, the waters of the coal basin, would be unsuited for such use. A great deal depends on prompt handling and skill.

PHOTOGRAPHY AND OTHER USES.

For photography, paper making, wool scouring, and manufacturing industries generally it is important to have as little mineral matter as possible. For photography rain water can be used only if fairly free from organic matter. Photographers frequently use the common hard water. One possible exception to the general rule that sulphates


PLEISTOCENE DEPOSITS
OF THE
LOWER PENINSULA OF MICHIGAN
BY ALFRED C. LANE
From published and unpublished observations
C.H. Gordon, F. Leverett, F.B. Taylor, W.H. Sherzer and the author
1898.
LEGEND
FORMATION
TYPE OF WELLS AND OF SOIL.
TOPOGRAPHY
Moraine glacial ridge
Dug or drilled wells, gravelly clay
Rolling hilly
Extensions of Great Lakes
Brick clays, surface sands, bored or dug wells
Flat shallow sand ridges
Extensions of moraines under lakes
Clay or gravelly clay
Faint smooth ridge
Overwash and interlobate gravels
sand and gravel, driven wells
Dissected sand and gravel plain undrained hollows
Till plains
Gravelly clay, dug or drilled wells
Flat to undulating
Scale of miles
0 10 20 30 40 50
1898.
LAKE MICHIGAN
MANITOU IS.
STRAITS OF MACKINAC
SAGINAW BAY
LAKE ST CLAIR
LAKE ERIE
MICHIGAN MERIDIAN
BASE LINE
Manistique
St Ignace
Cheboygan
Harbor Springs
Rogers
Charlevoix
Alpena
Atlanta
Gaylord
Bellaire
Leland
Traverse City
Kalkaska
Frankfort
Grayling
Mio
Harrisville
Roscommon
Lake City
Tawas
Cadillac
Manistee
West Branch
Standish
Charity Island
Ludington
Baldwin
Harrison
Gladwin
Hersey
Bad Axe
Hart
Big Rapids
Midland
Mount Pleasant
Bay City
Caro
Sanilac Center
Newaygo
Saginaw
Stanton
Ithaca
Muskegon
Lapeer
Grand Haven
Flint
Grand Rapids
Ionia
St. Johns
Port Huron
Lansing
Pontiac
Mt. Clemens
Hastings
Charlotte
Howell
Allegan
Mason
Detroit
Kalamazoo
Marshall
Jackson
Ann Arbor
Paw Paw
St. Joseph
Cassopolis
Centerville
Coldwater
Hillsdale
Adrian
Monroe
Toledo

are deleterious in manufactures is ale, in which, it has been said,[1] a certain amount of calcium sulphate is an improvement. Generally speaking, however, the breweries take great pains to get as pure water as possible. In compounding medicines also a pure water is of importance. The industries (salt, potash, bromine, and mineral water) dependent on minerals in the water are not here treated.

The industries requiring pure water are well worth consideration in reenforcing the demand for pure water and in estimating the availability of several possible supplies. Of course pure water is important to those seeking the most favorable location for such industries.

QUALITY AND QUANTITY COMPARED.

It may be said in general that while for uses which look first to quantity the lakes and rivers are the natural source, for freedom from organic impurity the deeper wells have the preference. Water from both these sources, except from some sandstone and coal measure wells, is rather hard, so that for washing cistern water is preferred. The deeper the well the greater the inorganic impurity, with some noticeable exceptions, chiefly in that the waters from the Napoleon sandstone and the Dundee limestone, down to the Sylvania sandstone, may be less charged than the waters from beds above.

The Great Lakes, with properly located and guarded intake pipes, furnish a good city water supply. The supply from all rivers, even the Detroit and St. Clair, should be filtered. Many towns fortunately possess an ample supply from deep wells. Only in that territory which lies at the same time in the region of the old lake bottoms, colored blue on the map (Pl. II), and that of the Coldwater shales (see Pl. VI) is the outlook for deep-well supply entirely unpromising, so that carefully filtered river water or aqueducts from springs near the flank of the nearest moraine seem the most hopeful sources of large supply for towns.

Statistics show that city use is generally extravagant, rarely less than 100 and rising to 200 and 300 gallons per capita a day. This is much more than domestic use requires, and is due partly to uses where quality is comparatively no object, such as street sprinkling and fire protection, the use of lawn hose and of water for elevators and light machinery, etc., but largely to sheer waste. It is not for the public welfare to stint the use of water to the detriment of cleanliness, but it is advisable to stop waste, and the effect of meters in this respect is wonderful. It would be well to have a minimum price for a certain quantity, say 30 gallons a day for each room served, to prevent undue economy, and after that charge in proportion to the amount of water used. It is a question, also, whether the more wealthy residents who use the lawn sprinklers freely pay more or less than their fair share of the water rates at the present schedules.

[1] See Ency. Brit., article Burton.

Some few towns, like Rochester, possess an ample supply of unexceptionable water, though even in such cases a prudent provision for the interests of posterity would guard against the waste which has already lowered the head in some communities to a dangerous extent. A flowing well is valuable, and the head needful to produce one should not be recklessly wasted.

Most of the smaller towns, however, stand on a border line. They can get a supply of well water which will suffice for ordinary and economical use but not for emergencies. This is a field for reservoirs and for filters. It should be remembered that the efficacy of a filter depends very largely on its not being used constantly, but allowed, as it were, to rest from time to time. Filtration of a lower grade supply is especially adapted for extraordinary demands. The ordinary supply of such towns as Alma and Mount Pleasant should be from deep wells, but in case of fire filtered river water might be turned in. To use unfiltered river water without notice to consumers ought to be out of the question. Accustomed as people may be to the better supply they will not use the same precautions as if they had the poor supply regularly. In the Manual of American Waterworks it appears that there are many towns which, in case of fire, pump directly from the river.

Lower Michigan is so situated with respect to the Great Lakes that most of the larger towns can derive from them a satisfactory supply by using proper precautions. Many others can derive a domestic supply from the Marshall sandstone. Only along the Saginaw River is the question of water supply at all serious. Saginaw Bay is exceedingly shoal, and for East and West Saginaw and Bay City the supply can not be regarded as at all satisfactory.

It seems, however, that there is destined to be a city of the first rank along Saginaw River. Even if from the sandstones (not merely the drift which has been tested unsuccessfully by the waterworks experimental wells) a sufficient supply of water relatively free from mineral can not be obtained,[1] it seems certain that to the west and southwest, in Tuscola County, less than 25 miles away, the water resources can be utilized for a metropolitan water supply.

CLIMATE.

The most detailed account of the climate of the State is by the former State geologist, A. Winchell.[2]

[1] The recent explorations for coal and city wells show that here and there in channels there are within the first 200 feet beneath Saginaw areas of water-bearing sandstones.

[2] Tackabury's Atlas of the State of Michigan, edited by H. F. Walling. First edition, 1873; second edition, 1884.

Proc. Am. Assoc. Adv. Sci. (Troy meeting), August, 1870.

Harper's Magazine, Vol. XLIII, July, 1871, p. 275.

Wegweiser der Michigan, Hamburg.

Oesterreich. Ges. für Meteorologie, Wien. Zeitsch., Bd. VIII, February 1, 1873, p. 40.

From Winchell's work much of the material in this chapter is abstracted. It is, of course, not wholly up to date, but Prof. E. A. Strong, of Ypsilanti, director of the State weather service, who has studied and compiled the later data, informs me that they are substantially correct, and I am indebted to Mr. C. F. Schneider, director of the State weather service, for additional figures.

The most notable features of the climate of the Lower Peninsula may be summed up in a few words by saying that it is what its name implies, pene-insular, modified by the fact that it has greater relief than the neighboring States to the west. The mean temperature for the year is higher on the east shore of Lake Michigan than on the west shore, as is also vividly shown by Winchell's isothermals of the extreme minima, and in this respect, owing to air drainage, the highlands have an advantage over the lowlands, the central part of Michigan being better off than St. Louis, so far as the extreme cold of winter is concerned. In fact, the mean of January temperature is higher and of July heat lower than farther west.

It is obvious that these facts have a bearing on the run-off of the streams. The amount and distribution of the rain or snow must also be taken into consideration. This has been carefully studied for the Kalamazoo River by Mr. Horton in a previous section, page 26. The average precipitation for the Lower Peninsula is some 32 inches. The heavy dews which occur in some parts of the State need not be taken into consideration as run-off, however important they may be for the farmer, because they are largely evaporated or absorbed by plants and do not become a part of the water resources. Some idea of this factor might be obtained from the relative humidity of the air, but as to actual rainfall the Lower Peninsula is in about the condition of Wisconsin. The distribution of this precipitation is also of interest. The contrast in the winter between the upper and lower parts of Michigan has frequently been observed. The region of Lake Superior will be buried in snow 2 or 3 feet deep when through the lower part snow is found only in scattered patches. Winchell gives the following table:

Distribution of precipitation in Michigan by seasons.

Season.	Upper Peninsula.	Lower Peninsula.	The State.
	Per cent.	*Per cent.*	*Per cent.*
Spring	19.	25.8	23.8
Summer	27.	28.7	28.3
Autumn	28.8	27.3	27.7
Winter	22.	19.1	20.
Total	96.8	100.9	99.8

Taking into consideration both the milder climate and the marked diminution of precipitation in winter, the table above indicates less accumulation of snow during the winter. Thus the spring freshets are much less decided than in many other States, while the temporary winter snows largely sink into the ground. From this results a steadier flow and less erosion and fewer flood plains in the streams than would otherwise be the case. The many lakes without outlets would fluctuate even more violently were this not the case, and doubtless be more likely to cut channels for themselves. The abundance of lakes also helps to keep more uniform the flow of the streams. The effect of cultivation, on the other hand, is to make the spring freshet sharper and earlier, for the snow disappears first from plowed fields and cleared lands.

For the four figures (figs. 2 to 5) illustrating Michigan climatology I am indebted to the director of the Michigan weather service, Mr. C. F.

FIG. 2.—Distribution of average minimum temperature in Michigan.

Schneider. They are compiled from the records of the various stations (about 108 in all), and are the result of averaging all the data on file in the office, in general covering a period of about ten years, except for the precipitation chart (fig. 5), which covers a much longer period. The period of observation is not the same for all stations. The temperature observations at Lansing go back to 1873.

Fig. 2 shows the average of the average diurnal minimum temperature for each year.

The mollifying effect of the westerly winds blowing off Lake Michigan and Saginaw Bay is very apparent. The highlands northwest of Saginaw Bay have extremely low minima, as might be expected, while those southeast, on the contrary, have not so low minima as the Saginaw Valley, and it appears that the valleys draining thither have, on the whole, lower minima than those draining southeast.

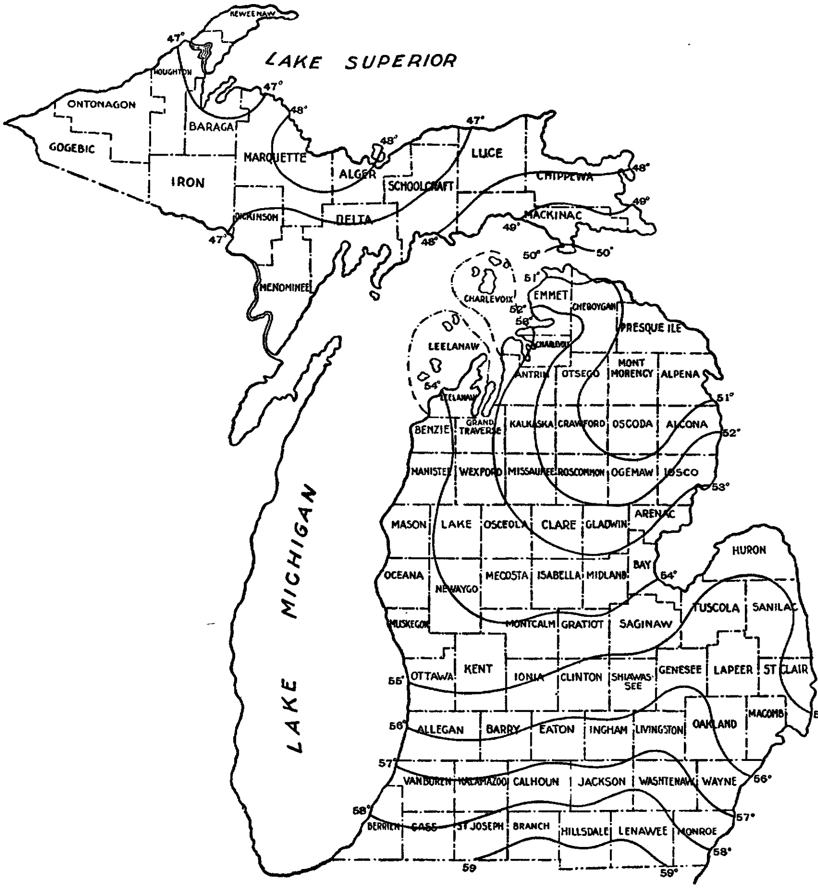


FIG. 3.—Distribution of average maximum temperature in Michigan.

Fig. 3 similarly gives the average of the average maximum temperature during each year. At the northern end of Lake Michigan the maximum as well as the minimum temperature is raised, and the general average is abnormally high (fig. 4). At the lower end, however, the maximum and the mean temperatures are but little raised, so that the lake serves only to mollify the frosts of this fruit belt, changing the climate, as a whole, only as it becomes more equable. The two highlands have opposite relations to the maxima; the one northwest of Saginaw Bay has specially low maxima, while the one southeast is distinctly higher. The former is sandy and largely covered with barren, denuded jack-pine plains; the latter is lower, more clayey, more cultivated, and probably retains its moisture—the great regulator of climate—better.

Fig. 4, showing the mean temperature, indicates that warmth enters from the southwest corner of the Lower Peninsula and extends up Grand River Valley, while the temperature at Saginaw is rather

FIG. 4.—Distribution of average mean temperature in Michigan.

colder than it is immediately east or west. The mollifying effects of Lake Erie and Lake St. Clair are also shown in figs. 3 and 4. It is generally supposed that, as stated below, the temperatures of flowing wells are those of the localities given in fig. 4, plus a certain amount, this amount depending on the depth of the well—about 1 degree in 60 feet, but observations give rather higher temperatures in wells less than 200 feet deep. The summer rains may penetrate farther and more rapidly than do the winter snows.

Fig. 5 shows the average rainfall. In the southern part of the peninsula precipitation and temperature seem to increase together, while in the northern part of the peninsula a line of low precipitation seems to extend from Saginaw Bay to Grand Traverse Bay. It is a fortunate coincidence that the flat, low, clayey, easily flooded Saginaw Valley has a relatively low record in precipitation as well as in temperature, while the sandier western shore has more rain.

The wind has some influence on problems of water supply. Many wells are said to change their level with the wind. This is probably

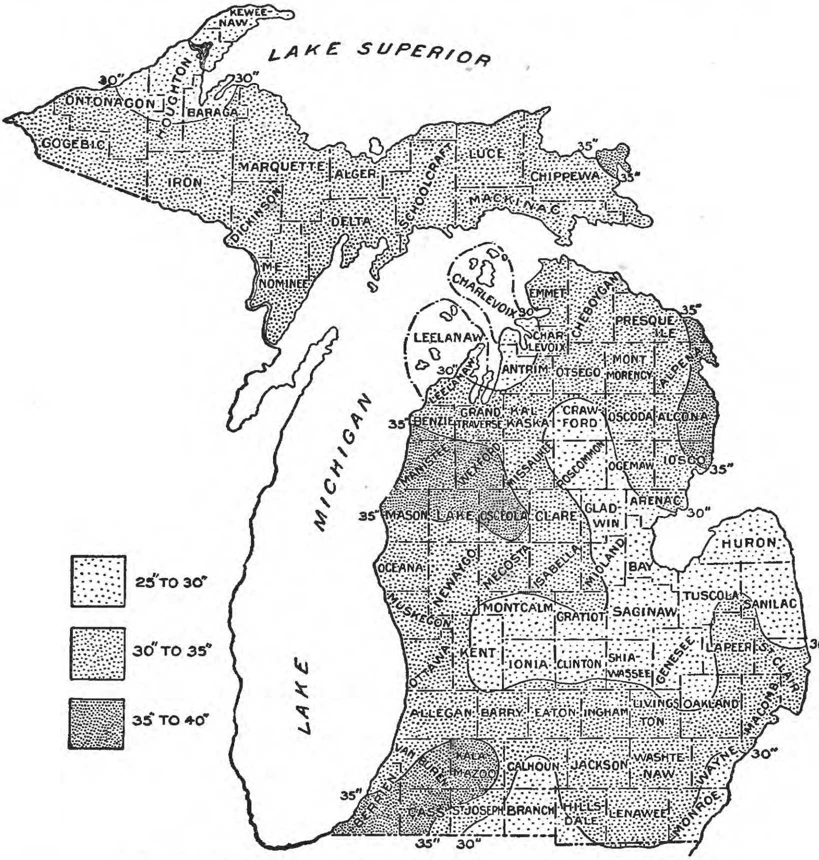


FIG. 5.—Distribution of average annual precipitation in Michigan

in many cases not directly due to the wind but to fluctuations in barometric pressure. The prevailing winds have another very important effect. Where the prevailing wind is on shore, the shore is more apt to be sandy than where the wind is offshore. A large part of the peninsula has been covered by lakes and the sandy character of the shores and old shore lines that face the west, which is the direction of the prevailing wind, is pronounced. It should be remarked, in addition, that during the hot days of summer a marked afternoon breeze from the lake is a prevailing feature.

LONG-PERIOD VARIATIONS IN RAINFALL.

There is one important feature of the climate, however, on which no light can be gained from Winchell—the variations of the annual rainfall from year to year. This may be learned from the fluctuation of the ground-water level, or the level of the Great Lakes, which observation has shown (see fig. 1) rise and fall according as the general rainfall of the previous years has been more or less than the average. When the rainfall for several years has been below the average there is also a fall in the level of underground water and in the level of the lakes, especially those that have no outlets. Clam Lake, near Cadillac, has varied 16 feet within memory, and Houghton Lake and Higgins Lake are lower than they have been. One will everywhere find reports that the lakes, streams, and wells are lower than they were formerly, and muck plains (Pl. III, *B*) underlain by shells, marking former lake bottoms may be seen. This lowering of lakes and ground water is ascribed to various causes, all of which may perhaps be at work.

In the first place, it is argued that cultivation tends to accelerate the run-off so that water does not have time to soak into the earth. This is doubtless true. On preliminary railroad profiles, for instance, areas are marked "swamp" or even "all water" which are now fertile fields by no means damp. The original Government field notes of the United States Land Office also show areas marked "swamp" which are far from such to-day. Much discussion and many charges of fraud concerning these "State swamp lands" have arisen, but not all such descriptions were by any means fraudulent. Many of these swamps are explicitly described as beaver meadows or as due to beaver dams. The beavers have gone, their dams have been broken, and the swamp has become dryer. Again, loggers' operations are active in clearing out the streams and in cutting out the dams, though they erect dams and obstructions of their own. On the whole, however, the floods, aided by the loggers, have cleared the streams and made them more efficient drainage channels. The more irregular the flow of a given quantity of water the greater its efficiency as an erosive agent.

The next cause to be considered is devastation by fire. Logging operations leave the forest a forest still, but the black scourge of fire which follows strips the ground of leaves, and, worst of all, frequently consumes the vegetable mold that absorbs water like a sponge. The amount of water actually evaporated by a fire is insignificant in proportion to the permanent damage. Most of this fire waste is accidental, but some of it is the result of gross carelessness. I have seen a meadow with the mold of generations burned clean in clearing, leaving only a bare subsoil of sand fertilized with ashes that will yield good crops for a few seasons only and then be leached out. Then comes the plow. Sandy soils still absorb water, some of them having 36 per cent water capacity, but some of the bare, plowed,

A. CLINTON BORING APPARATUS.

B. FIELD OF ONIONS IN DRAINED LAKE BOTTOM: 1,350 BUSHELS TO 1⅛ ACRES. MUCK PRACTICALLY BOTTOMLESS.

sun-baked slopes of the clay hills are almost impervious to water. Finally, in the extreme lowlands drains of every size and variety, from the farmer's tile drains to the roadside, the township, and the large county drains, accelerate the departure of undesired water.

The time may come when drainage, instead of being down the slopes, will be along them, transferring the water from the hollows to the lower uplands and thus promoting irrigation. But that time has not yet come.

In the second place, there is often supposed to be a general desiccation of the climate, a steady decrease in precipitation. Of this there is no definite historic evidence, though of course in the ice age and immediately subsequent there was certainly more water in all lakes and rivers, though possibly no greater precipitation. Frozen water once covered the country. Legends of what the Indians used to do in the way of canoeing can be easily interpreted, partly by the desiccation due to settlement (which has already been mentioned) and partly by the fluctuations of precipitation and water stage from decade to decade. But as research shows, the general water level has been fairly constant during the century. A period (1886–1896) of decreasing rainfall, however, which has just been passed, has lowered the lakes and caused the wells to fail in a way that has surprised the oldest inhabitants of many of the new towns. It is necessary to go back many years for a similar fall.

SHORT-PERIOD FLUCTUATIONS IN WATER LEVEL.

Sudden fluctuations occur in the Great Lakes and in the ground water which are not regular annual and seasonal fluctuations like those before described, but are more like waves of great breadth, the whole water of the lake basin washing from side to side. An instance may be recorded in which the surface of a channel connecting a small lake with Lake Superior rose and fell about a foot in an interval of twenty minutes. Similar fluctuations occur everywhere in the lake and completely disguise, except to most careful and systematic observation, the minute lunar tides. Sometimes these variations can be distinctly traced to the wind. A strong north wind will pile the water up in Saginaw Bay, and a strong southwest wind will drive it out. A variation of 400 feet in the position of the shore line has thus been caused in one night. Another cause of these variations, often cooperant with the one just mentioned, is a variation of atmospheric pressure over different parts of the lake basin, the water tending to rise when the pressure is least.

Analogous phenomena, probably due to analogous causes, are reported from numerous wells, but as yet have not been subjected to careful investigation. When the wind is in a certain quarter long enough or strong enough, or just before a storm (i. e., at a time of low atmospheric pressure), the water is reported to come more freely, to have greater head, or to be roily. These phenomena are naturally most conspicuous in wells which flow with no great head, and are analogous apparently to those long noted on Stromboli and Vesuvius, which are said to discharge their lurid contents more freely before a storm. Sometimes these phenomena are attributed to direct connection with the lake. This theory, of course, ought not to be rejected in all cases; but similar phenomena occur so far from the lake that it is safe to assume that in most cases the well fluctuations are due to the same cause as the fluctuations in the lake rather than to the fluctuations themselves. An interesting "breathing" dry well is noted in sec. 7, T. 35 N., R. 5 E., a phenomenon which has been noticed in caves elsewhere in the world.

WELL TEMPERATURES.

Special attention is due to the effect of mean annual temperature on the temperature of wells and springs. It is true in general that the temperature of the water in flowing wells or springs represents the mean temperature of the locality, but there are some qualifications; something must be allowed for the increase of temperature which we find everywhere in going toward the center of the earth.

If the rate of increase shown by the Alma Sanitarium deep and shallow wells gives a true average, we get an increase of temperature of about $(98°-48°=50°)\div(2863-157=2706)$ or 1° in 54 feet, which is very nearly the normal rate of increase of the world, which may be assumed in preliminary reductions. Other wells at Midland, Saginaw, Frankfort, etc., would give other rates down to 1° in 100 feet, but they are for less depths. Water flowing from a driven well 56 feet deep, therefore, might have its temperature raised about 1° above the average for the place, provided it had been flowing so long or in so strong a stream that the temperature of the ground traversed on the way up did not affect it. The effect of the summer's heat and the winter's cold is felt in the ground (as Lisbon and Edinburgh observations have shown) to a considerable depth, the annual variation growing less with increased depth and the time of greatest cold becoming later, so that if the flow is from 30 to 60 feet down the temperature should be actually slightly lower in summer than in winter. Observations by Prof. C. A. Davis, of Alma (T. 11 N., R. 3 W.), show this to be the case in some of the wells there, the water of a well 55 feet deep standing at 52° F. in winter and at 48° F. in summer. Other observations of the temperature of wells require modification to allow for the above factors. But it is certain that the temperature of water from a well 100 feet deep ought not to vary more than 2° F. from the mean annual temperature of the place, and probably in summer, when observations are usually taken, is very near it, the effect of the last winter's cold balancing that of the earth's thermal gradient.

The temperature of deep-flowing wells of small bore is somewhat affected by the earth's heat, e. g., the deeper Bay Port (T. 17 N., R. 9 E.) wells; but it would certainly be incorrect to take anything near ($338 \div 56 =$) 6° from their temperature (of 47° F.) to obtain the mean temperature of the place. Again, as the winter temperature is felt to a depth at which no effect of a particular cold day or week can be detected, so a series of extra cold or extra hot years will modify the temperature to a depth where no trace of annual fluctuation can be observed. In a similar way any permanent factor, like the presence of a boiler house or a cellar furnace, may modify the temperature of a flowing well to a considerable depth. A good illustration tion is afforded in a flowing well at the sawmill in Rose City (fig. 8), which is deeper and on ground 25 feet lower than the wells of the town; but this is not sufficient to account for nearly 7° greater warmth over the hotel well.

SUPERFICIAL GEOLOGY AND TOPOGRAPHY.

GENERAL DESCRIPTION.

The contour map of the State (Pl. I) shows two high areas, to the southeast and northwest of Saginaw Bay, respectively, which are also brought out in fig. 6. Winchell has laid down the following proposition (Tackabury's Atlas of Michigan, p. 14): "The actual topographical and hydrographical axes of Michigan and the whole lake region are the resultant of two forces—a glacial, acting from the northeast, and a stratigraphical, acting along the lines of strike of the rock formations." This is what he calls the diagonal system in the physical features of the State. While this statement may be true in a broad way, it must be seriously modified to express the facts of the case. It ignores the shore lines of the old lakes, elsewhere recognized by Winchell as an important factor, and it is really as approximately true that the various positions in Michigan where the glacial front halted, i. e., the moraines, and more or less at right angles to the direction of its motion, are the dominant features, and that next to them come the lines of halt of the lakes succeeding. The old stratigraphic lines of rock outcrops are very obscure.

In a broad way, as described by Winchell, the consolidated rocks are arranged in concentric circles, surrounding the coal measures which occupy the center of the State. (See map, Pl. VI.) During Mesozoic and Cenozoic time these were eroded, but two sets of strata proved to be sufficiently resistant to become topographic features of the first class. The Marshall sandstones (Logan conglomerate), the Helderberg in the southern part of the State, and the Traverse limestones in the northern part of the State, tended to make ridges, as may be seen in the cross section (fig. 10). Inasmuch as the softer coal basin rocks were thus surrounded by harder strata this harder rim would be cut across in some way. The evidence seems strongly to indicate that the channel draining the central basin went off, not as Spencer has suggested, through the Saginaw Valley, but past Manistee toward the great valley, now occupied by Lake Michigan, which was excavated in the softer shales, gypsum, and salt, and marks the Salina (Lower Helderberg). The circumvallation was probably somewhat broken in the region of Saginaw; at any rate, the outer circle made by the Helderberg (Traverse, Dundee, and Monroe limestones) was passed. Thus the ice flood, advancing from the Laurentian highlands, was deflected by this circular double rampart and passed in two great lobes—the Michigan and the Huron-Erie respectively—west and east of it. As the ice reached its maximum, however, it broke over the outer rampart and passed down the present valley of the Saginaw. At the greatest extent of the ice Michigan was completely and undoubtedly smoothly covered with it. Of inter-Glacial periods, with accompanying forest beds and other deposits interstratified with the till, the evidence is not very clear in Michigan. This is a point of importance, as such inter-Glacial beds might be water-bearers. The red clay described by Rominger may be such an inter-Glacial formation. Wood, however, is not uncommonly found in boring wells, as at Vassar, at Paw Paw, in Huron County, and elsewhere.

A bed of gravel or bowlders, which is porous compared with the overlying till, generally comes just above the bed rock, and the till itself is sometimes composed of alternations of gravelly clay and sand or quicksand. Such alternations and buried wood might be explained by the oscillations in the advance and retreat of the ice front and by the shifting of the ice streams from season to season, decade to decade, or century to century. It should be remembered, too, that caution must be used in interpreting the results of mere borings. For instance, a 3-foot seam of sand, reported in a 2-inch boring near Saginaw, when a shaft was sunk proved to be merely an irregular, nearly vertical seam.

It can not be said that below the present surface of the drift such an oxidized and eroded surface has been detected as would plainly imply an inter-Glacial period of considerable duration. Such a surface, especially near the center of motion, would often be swept away and obliterated by the readvance of the ice, and I have seen few exposures which indicated it, for erosion has not gone very deep since the last disappearance of the ice. The cliffs north of Frankfort, and particularly the valley of the Au Sable, would seem most hopeful places for the search. I should be puzzled to know how to make sure of its existence from a mere well record, unless, perhaps, such a zone being reached might be recognized by the yielding of softer water than that of the strata above.

The comparative lack of evidence of inter-Glacial epochs in Michigan, compared with States farther south, can not, however, be wholly accidental, and the advance of the ice may be likened to the tides rising and falling on the shore. The highest tides of spring extend farther than the others, and the intervals between such extreme tides are at least half a year. Lesser high tides occur twice a month, and the common tides ebb and flow every day. So, down the beach, areas but rarely reached by the waters and uncovered most of the time, adjoin those generally covered by the waters. Thus, along the Ohio River—the line of the greatest extension of the ice—its presence must have been comparatively brief and its visits few, while in Michigan, nearer the source of the ice, the inter-Glacial periods may have been partly or wholly absent and certainly must have been shorter. When the ice finally retired, a lobed arrangement of the ice front—two large lobes on each side of the Marshall circumvallation and a smaller one, the Saginaw lobe, passing directly over it—were conspicuous and remained the most important features in determining the topography of the State. (See map of the Pleistocene deposits, Pl. II.)

The general theory is that the ice retired first from the higher lands; the Saginaw ice lobe, therefore, retired first, and bounding it on each side were two deeply reentrant cusps, which may be said to be the topographic axes of the State. Naturally, streams issued from such cusps, draining away the water from the wasting glacier, so that the typical form in which cusps appear is that of a stream valley, much wider than the present stream, charged with gravel and bowlders—valley trains—and heavily belted with moraines. This concentration of till and detritus on the highest parts of the rock floor naturally forms the highest parts of the State (see fig. 10).

The eastern cusp follows fairly closely the dividing line between the drainage into Lake Erie, Lake St. Clair, and Lake Huron (direct), and the drainage into Saginaw Bay and Lake Michigan. It, and also the other cusp, is marked by a belt of country crowded with lakes. Of the western cusp, Mr. Leverett thinks that he can determine the moraines on the Michigan side from those on the Saginaw or east side, by the fact that the latter contain many more pebbles of a bright red jasper conglomerate.[1]

Thus, at the extreme southwest of the State, where the cusp first entered, Mr. Leverett refers to the Saginaw lobe, because it bears many red jasper-conglomerate pebbles, the morainic belt (see Pl. II) which passes northeast from Niles and goes through Kendall, in the northeast corner of Van Buren County. Therefore the first position of the cusp would lie between it and the stronger ridge just west, which undoubtedly belongs to the Michigan lobe and is known as the Valparaiso. In confirmation, Mr. Bate, a surveyor of much experi-

[1] My own observations agree so far as they go, but the fact is singular. The conglomerate and jasper in question appear to come from the original Huronian area on Thessalon River in Canada, and one would think that they would find their way rather into the Michigan than into the Huron-Saginaw lobe.

ence in the region, states that the red jasper-conglomerate is abundant in Montmorency County, but scarce or absent in Otsego County, except near the eastern line. It is to be noticed that on the map (Pl. II) these moraine belts have their separate color, and the more important areas of sand and gravel deposited by streams draining the ice front are also delineated, although many smaller areas of gravel and sand and stream channels are, for the sake of clearness, omitted. A different color is devoted to those areas over which the ice front retreated more rapidly, making less conspicuous ridges.

Both cusps were evidently guided by the higher land of the Marshall sandstone outcrop. As the eastern cusp worked northeast the upper valleys of the two St. Joseph rivers, the Tiffin (whose drainage area has been preyed on by the Raisin), and the upper Huron River above Dexter, which probably drained off at one time past Adrian and possibly earlier found its way into the Ohio, were successive outlets of discharge. Farther northeast the drainage has been largely rearranged, though the upper parts of the Clinton River, and later the northern forks of the Flint River, the Cass River on the Saginaw Valley side, and the Black and its branches on the other, served for a time. The old summit swamp referred to by Taylor[1] may also be mentioned, and in Huron and Tuscola counties a number of channels are known which evidently drained the ice front but are too numerous to be indicated in a general map. High deposits near the angle are found at Metamora, between Deanville and Brown City, and near Verona Mills.

For the other cusp Dowagiac Creek served at first and, with St. Joseph River, poured into the Keokuk that vast expanse of gravel which is found in its upper reaches in Indiana. Then passing north, through a belt full of lakes, down the valley of the Thornapple, it may be followed up the valley of Flat River, and past Mecosta into the Muskegon Valley. In the Muskegon Valley there is a stream which, first by way of Mecosta and Barryton and then by the main stream, received the cusp drainage for a considerable time. Thus the cusp may be followed into Oscoda County. From this point on the original cusp-drainage lines have again been so disturbed and reversed that it is hard to trace them. Probably the high points near Otsego Lake were at one angle. An old channel seems to pass near Valentine Lake. But the ice soon retired and allowed the water to flow freely all around the peninsula.

The lines of retreat of these cusps are bordered with moraine hills, composed of the débris left by the ice front where it tarried long or readvanced. Moreover, the ranges of moraine hills are crowded together and are higher toward the lines of cusp retreat, for, these hills being nearly parallel to the direction of ice advance and retreat, a general advance or retreat in the ice front made only a slight differ-

[1] Geol. Soc. Am., Vol. VIII, 1896, p. 31.

ence in their position. Of course such moraine belts are studded with small tarns—deep lakes of water caught between the various rows. Some of the moraines, especially the higher ones, which do not mark readvances so much as the edge of the cusp dump grounds, are exceedingly sandy, with hardly any clay, and in such cases the lakes fre-

FIG. 6.—Sketch map of the drainage of Lower Michigan.

quently have no outlets. Lakes of another variety are formed in the following way. The moraine belts are frequently cut through by channels which served as vents for streams coming forth from the moraine. Only a few of these channels are indicated on Pl. II. One, well marked, is formed by the upper valley of Willow Creek in T. 16 N., R. 13 E., Huron County, which also has branches. Near Harrison, in Clare County, are others, some of the finest that I have seen. Entering the valley of the South Branch of Muskegon River there are others, in T. 14 N., R. 8 W. But many that I have noticed I have not yet been able to connect into significant channels. Now, while sometimes the old channels abandoned by the streams from the melting ice sheet stand perfectly empty, more often they are occupied by marshes at least, and not infrequently by lakes, the hollows occupied by the lakes having been made by the melting of a lump of ice (kettle-holes), by irregular settling of the sand, by an original sand bar in the stream, or by delta sand washed in by some tributary Glacial or post-Glacial stream. Many of the long, winding, and generally shallow "crooked" lakes, are thus located.

It is obvious that thus to uncover and drain the higher lands must produce, first of all, a peculiarly unnatural form of drainage. A marked type of river valley is thus produced. (See fig. 6.) All the larger streams begin to flow to the south, starting from some of the lines of drainage from the ice. They run along the ice front opposite a moraine, which, as a comparison of fig. 6 and Pl. II shows, is often a divide, and receive, of course, some tributaries from the north, which usually flow in valleys of ice outlets, but also receive a great many streams, perhaps smaller individually, which flow down the back of the moraine last deserted. At some point in their flow they reach the old lake shores, unless they are first diverted by some stream which has cut back through the moraine, and thence flow more directly down to the present lake. This accounts for two of the most striking facts in studying the drainage of the Michigan streams, namely: (1) The principal stream valleys curve so as to be concave northward; (2) the principal streams receive more numerous tributaries from the south. The Manistee is a most striking illustration of this tendency, while the Bear and the Betsie (Aux Becs Scies), near by, are similar. But so far as the curve is concerned, hardly anything can be more striking than the way in which the Tittabawassee on the one side and the Cass on the other curve around Saginaw Bay to me in Saginaw River.

The simplest and most natural form of drainage occurs where a smooth, tilted plain is lifted above water level. There all the rain water can run straight to the lake, or allowing for minute undulations, gather into small streams which run parallel to each other down the slope. This simple type of drainage is almost perfectly and typically illustrated along the east side of the Thumb in Huron and Sanilac counties, and it may be seen in small areas elsewhere. I have noted in one section of Elmwood Township (T. 14 N., R. 10 E.) four distinct parallel water courses traversing diagonally a section of land a mile square.

It is obvious that the type of drainage produced by first opening the higher lands to drainage is just the reverse. Hence it is subject to rearrangement. The Lower Peninsula of Michigan might, were it closely and accurately contoured, become a classical land for the study of the phenomena of stream capture. One can see it taking place even now. Ditches are found of which one end drains into one river valley, and the other end into another river valley (e. g., south of Bad Axe, T. 16 N., R. 12 E.), but little by little one stream will come to drain the ditch more than the other.

Instances of reversed drainage are therefore not uncommon. One instance, previously cited by students, is that the lower part of Dowagiac Creek has been reversed so that the St. Joseph now flows up it and to the lake that way, instead of south to Keokuk, as formerly. Another clear case is in Huron County, where the upper Willow occupies a valley once a Glacial outlet by way of the Cass to the south. In fact Shebeon, Pinnebog, and Pigeon rivers, especially the last, are encroaching on the Cass and will probably deprive it of the North Fork that comes down from Huron County. The Pigeon, using a Glacial channel to the Cass that it has reversed, has already effected an entrance into the main valley of the North Fork of the Cass. Man is assisting in this readjustment, for it is obviously to his interest to reclaim the rich lands of the swamps and the drained lakes along the shortest possible lines.

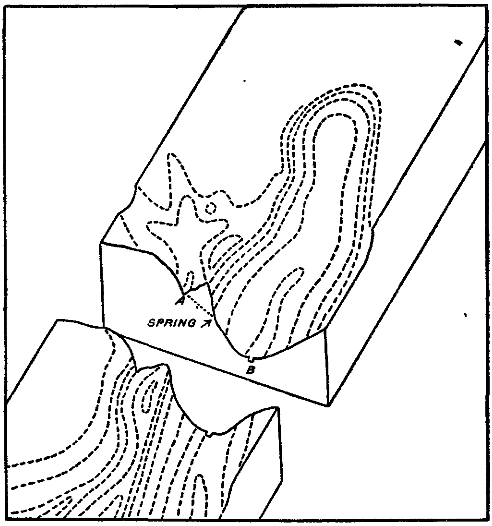


FIG. 7.—Diagram illustrating method of stream capture. A, dry channel; B, deeper encroaching channel with springs on its sides.

The streams which drained the ice front have many features that make them an easy prey to pirate streams. In the first place, flowing along the higher lands, with a circuitous course, they have easy grades, which weaken their power of erosion. In the second place, the ice streams, of which they are now deprived, carved valleys much too large for them and brought down much débris—more than the present streams can handle; and much of the débris was so coarse that there is a constant tendency for the water to percolate through the sand and gravel and do no erosive work whatever, except some little chemical erosion, which leaves the beds even more permeable than before. This is quite noticeable in the North Fork of the Cass, the bed of which shows that its erosive work is nearly at an end, for vegetation is pressing hard upon it. Now, as the vigorous headwaters of the pirate streams push into the plain of sand and gravel of such an old valley they naturally lower the water level, and the water of the valley is drained away by seepage through the sand and gravel. The annexed figure (fig. 7) is an ideal illustration of lateral seepage from an actual case; fig. 8 is also instructive. In fig. 7 the valleys are nearly parallel. In fig. 8 the attacking stream is working in at right angles to the ancient valley course. In many parts of the State one will come across valleys where, judging from the vegetation, there is now rarely any surface-water erosion, as the water sinks in and is absorbed by the sands and gravels (e. g., sec. 34, T. 24 N., R. 2 E.).

In some parts of the region of overwash sand and gravel kame plains (e. g., around Harrison, T. 19 N., R. 4 W., and Grayling, T. 26 N., R. 4 W.) one may have to sink 100 feet or more in surficial deposits before reaching water, and may then reach a real surface seepage water, while even the deep valleys are dry most of the year, so perfect is the subsurface drainage.

LAKES OF LOWER MICHIGAN.

The lakes of Michigan are numerous. Estimates of their number vary from five to fifteen thousand. There are twenty-five in the township of Grattan (T. 8 N., R. 9 W.) alone. They are of great importance as direct sources of water supply, as reservoirs which tend to steady the stream flow, and, finally, when they disappear, as furnishing the black muck soil, with a shell-marl subsoil, that has proved wonderfully adapted to celery and other culture. The accompanying illustration, Pl. III, *B*, shows a field of onions on such land. It is the second type of lake—the shallow lake of the interlobate drainage—which is especially likely to be thus filled. The remarks concerning the lakes of the Kalamazoo River Basin, page 24, apply very nearly to any other part of the Lower Peninsula above the line of the old lake extensions, colored blue on Pl. II.

The following description has been taken from an unprinted paper, by Prof. C. A. Davis, read before the botanical section, Michigan Academy of Sciences, giving a graphic description of these pools:

"The lakes of the State, exclusive of the Great Lakes, cover an area of 1,225 square miles, or more than 784,000 acres, or about $\frac{1}{150}$ of the total area of the State, and they are so distributed that there is hardly a botanist in Michigan who can not readily reach one or more of them.

"The small lakes, particularly those of the Lower Peninsula, are commonly depressions in the drift, shallow and not of large extent, frequently partially filled in around the margin with the remains of former generations of plants, so that many of the typical features of lakes of hilly or mountainous regions are partly suppressed or entirely wanting. These lakes belong to recent geological time, and this undoubtedly accounts for some of their peculiarities. By far the larger number of them exhibit the following features. A small sheet of water, roughly elliptical in shape, bordered by a marshy area of varying width, or on two or more sides by low, abruptly sloping, sandy, or gravelly hills. The marshy tract is frequently wider on the south than on the north side, and its character varies from a quaking bog at the inner margin through a sphagnous zone into a swamp, in which the prevailing trees may be tamarack, cedar, or spruce. The plants of the sphagnum zone are characteristically those of the boreal-life zone, and in such lake margins we find northern plants reaching their southern limits. The quaking bog is usually a lakeward extension of the shore plants and is a closely woven turf of the roots and rootstocks of various species of *Carex*, *Cyperus*, grasses, and at its outer margin consists sometimes of *Typha latifolium* and *Sparganium eurycarpum*. In the larger lakes the marshy border may not extend entirely around the margin, but it is usually noticeable along the southern shore, where it may be of considerable extent, while the rest of the shore is entirely without it."

Most of the lakes of Michigan belong, in origin, to the two classes already described, i. e., they are either inclosed between moraine ridges or are left as pools in the kame plains of sand and gravel. Lakes of these two classes are usually more than 750 feet above tide. In general, the regions of numerous lakes are the regions of crowded moraine belts, and they may be approximately traced in this way. But there are two or three other classes of lakes that deserve mention.

First, there is a class of lakes which arise from the erosion of limestone into caves that finally tumble in and produce sink holes. Though there are some indications of sink holes in the Carboniferous limestones, lakes of the sink-hole class are, so far as known, practically confined to the lower Devonian limestones (Traverse and Dundee) and occur only in the extreme southeast (Ottawa Lake, T. 8 S., R. 6 E.) and northeast (e. g., sec. 32, T. 33 N., R. 6 E.) of the State.

Second, there is a class of lakes which may be in part in rock or moraine basins, but which owe their distinct existence to the fact that the Great Lakes now, or at a higher stage of water, have built sand bars across the mouth of long bays and have thus cut them off from the main body of water. Such lakes are frequently less than 25 feet above the water level. A good illustration is the lake to the right in the view of Sleeping Bear Point (Pl. V), or Pine Lake, near Charlevoix, which is now reconnected by an artificial channel with Lake Michigan (T. 34 N., R. 8 W.), and it is easy to see, from the map or from Pl. IV, that Grand Traverse Bay might be converted into such a lake.

Some of the lakes are nothing more than old river valleys flooded by the tilting of the earth's crust and the consequent encroachment of the lake on the land. This is a class not clearly separate from the others. Such lakes occur by the score along the west coast of Michigan from Kalamazoo River to Frankfort, and seem to be submerged river valleys,[1] but the bars built across their mouths, are as in the second class.

If, as Professor Gilbert has said, the land is rising to the northeast at the rate of 5 inches a century for each 100 miles, it is easy to see that such a stream as Saginaw River will also tend to be ponded back; and, in fact, so far as current is concerned, Saginaw River is now but a long, narrow lake.

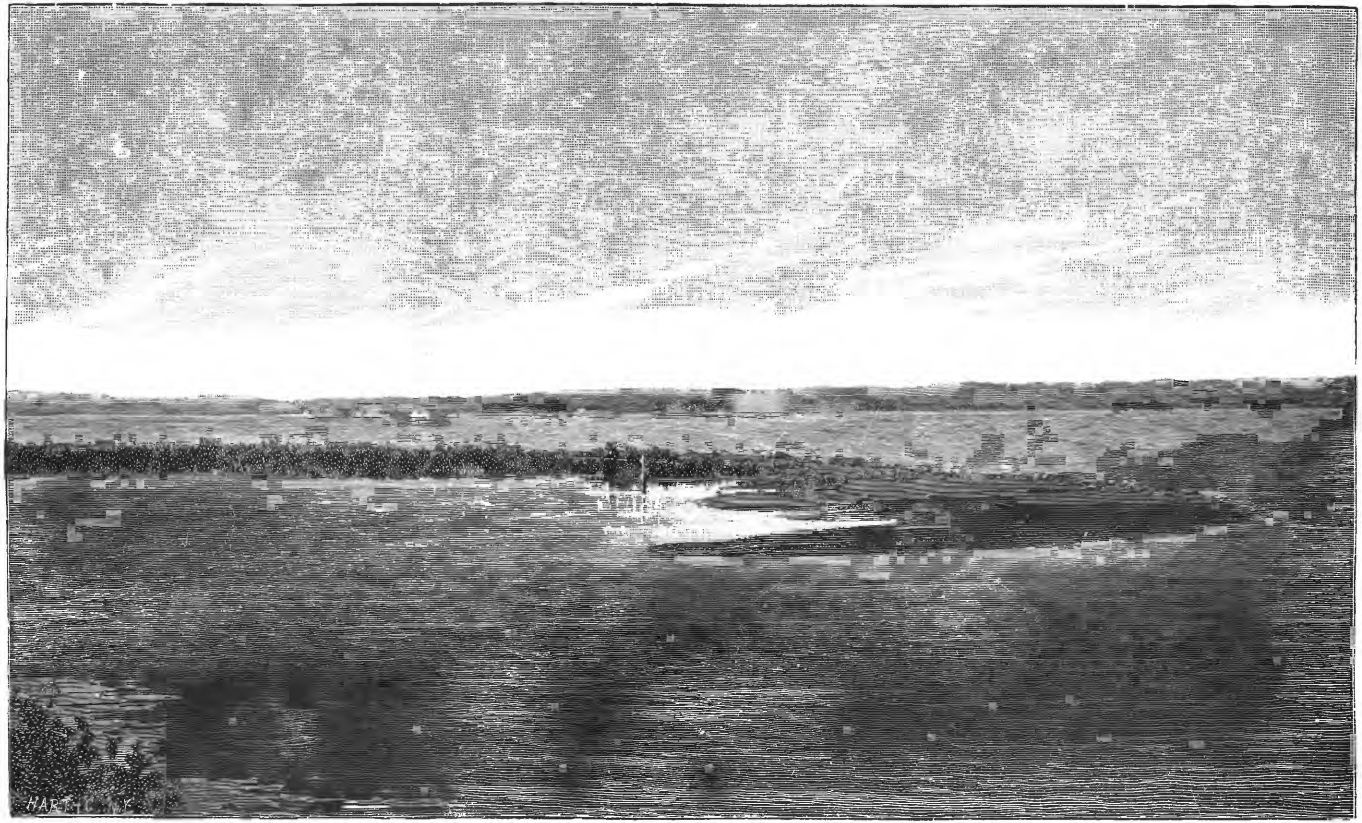
When the ice lobes retired so that the heights of the rock surface lay in front of them, crowned by a heavy moraine, the water gathered in front of them in great lakes. The débris brought by streams in the ice was, in this case, laid down more smoothly and stratified with the clay that accompanied it. Thus the topography of these moraines laid down under water is far more gentle than that of the earlier ridges. On the east side the lake in front of the Huron-Erie lobe, as shown by Gilbert in the Ohio reports, drained off past Fort Wayne into the Maumee, and the waters of this lake level were about 220 feet above Lake Erie or 785 feet above tide level. Toward the north the beach lines are at a somewhat higher level, the change to water-laid topography occurring somewhere about 800 feet above tide.

In the center of the State a lake was penned up in the Saginaw Valley, as recognized by Winchell and Mudge, and flowed down Grand River. The highest water of this lake, as seen in the sandy gravels around Alma and Pompeii, seems to have been about 760 feet above tide, so that, as the swamps south of Ashley are about 85 feet above Lakes Michigan and Huron (i. e., 667 above tide), the water would have stood about 100 feet deep in the channel, unless it has gradually scoured it down to present level. It is no wonder, then, that the drift was scoured down to the rock at Grand Rapids and Ionia. It flowed into the lake which had been similarly formed in the lower end of Lake Michigan and was draining over into the Mississippi by the recently reopened Chicago outlet. This lake was at first at least 90 to 100 feet above the present lake level, or 680 feet above tide, and probably more.

As the ice retired the lake east found a number of drainage channels across the Thumb through Sanilac and Huron counties, as indicated in Pl. II.[2] Finally free communication was opened around the Thumb in Huron County. This produced a slight but preceptible drop in the water level of the eastern lake, but thereafter it remained relatively permanent, and is marked by a well-defined gravel line, not perfectly horizontal but rising a little to the north. This may be explained by the removal of the attraction of the ice mass to the north, or by a subsequent tilting. Around Ypsilanti (T. 3 S., R. 7 E.) it is 750 feet above tide, while in Iosco County (sec. 30, T. 22 N., R. 6 E.) it is about 775 feet above tide, and in Huron County, north of Verona (T. 16 N., R. 13 E.), it is about 774 feet above tide.

[1] See article by Winchell in Harper's Magazine, Vol. XLIII, July, 1871, pp. 284 and 285.

[2] See also article by F. B. Taylor, Bull. Geol. Soc. Am., Vol. VIII, 1896, p. 31.



DUTCH POINT SAND SPIT, GRAND TRAVERSE BAY.

The fall from this level, whether due to the opening of a new outlet in New York, or, as is possible, to freer communication into Lake Michigan, was rather sudden for the first 50 to 75 feet, for we find that there are but few, and these local, traces of sand ridges in this interval, that the soil is clayey, and that the general course of the streams is directly down the slopes toward the lakes. The drop of the next 25 feet was comparatively slow and marked by a broad sand belt, and at a slightly lower level (650 feet in Huron County) was another marked halt. Then still lower, about 25 feet above present lake level in Huron County and about 17 feet in Iosco County, was a long stay, during which many bays were filled in or bridged by sand spits, so as to form lakes.

The history of the western side of the peninsula is perhaps not so eventful as that of the eastern side, given above, and is not so familiar to me. The belt of lacustrine deposits belonging to the Great Lakes is naturally narrower, being only from 60 to 125 feet above the present lake level, but there were many large lakes. Kalamazoo County, for example, has been divided into eight "prairies," viz, Prairie Ronde, Ground Neck, Genesee, Grand, Tollands, Gull, Dry, and Climax. These prairies, with their black loam soil, are probably old lakes. (See p. 64.) The marked change of grade in Kalamazoo River near Kalamazoo, brought out by Mr. Horton's table (p. 37), is probably due to the river crossing such an old lake bottom, where the grade is barely enough to keep the water moving.

Similarly, Higgins and Houghton lakes seem to be but shrunken remnants of a large lake drained by the Muskegon, which covered a large part of Roscommon County when the ice lay on both sides of it.

There are high terraces around Traverse City and in similar situations, which show that the ice front once dammed up a lake at a much higher level in that region, a lake whose water level was as high and at first higher than that on the east side of the peninsula, and which probably drained off southwest. The study of this lake in all its stages would make a very interesting problem for the glacialist. The map (Pl. II) without doubt needs much correction in Leelanaw County. It is obvious that the ice projected in a long tongue into Lake Michigan and retired very slowly, much more slowly than from the highlands. From the retreating cusp sprang large rivers, draining into Lake Michigan, whose channels were heavily lined with coarse sand, gravel, and bowlders—the so-called valley trains. From Cadillac to Elmira the line of the Grand Rapids and Indiana Railway is mainly through sand.

WELLS IN THE PLEISTOCENE.

Before taking up in detail the application of the facts noted above to the study of the water supply of the various districts it may be well to call attention to certain general statements:

1. Clayey regions do not yield water freely. This applies first to

lake clays, and in slightly less degree to bowlder clays or till, known among drillers as "hardpan." Regions of this type are mainly included in the sections colored blue and light buff on the map (Pl. II).

2. Sandy regions will at some depth yield a supply of water. But a distinction must be made between the sandy belts of the lake-washed region, in which the sand and gravel are a very dry, superficial coating to the clay beneath, liable to contamination and likely to fail altogether in dry seasons like 1895, and the heavier sand and gravel regions, which represent drainage from the ice sheet, such as the great gravel plains of the Muskegon, the Manistee, and the well-named Au Sable. In such plains water is found at considerable, often at great, depths, but the supply once reached is abundant. The heavy sand regions are mainly colored brown and crosshatched on the map (Pl. II).

3. The alternate advances and retreats, whether of ice or of lake, have tended to produce an alternation of deposits more or less clayey.

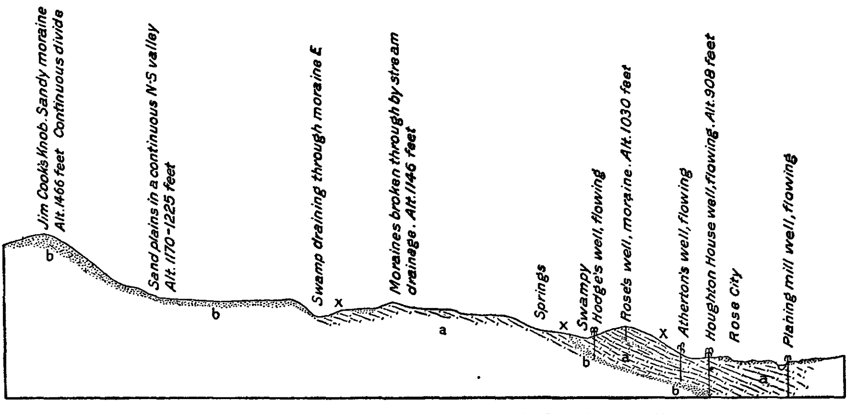


FIG. 8.—Profile near Rose City, Michigan. a, impervious beds—clayey till; b, pervious beds—sand and gravel; x, springs. Horizontal scale, 1 mile=1 inch; vertical scale, 400 feet=1 inch.

It is easy to see that in the case of a lake such deposits will dip slightly from the lake margin toward the lower, deeper parts of the lake bottom. But the same thing is true also of ice. The ice front would retire from the highlands, leaving an apron of gravel in front, and then a little change of climate would produce a readvance, in which it would roll up the apron ahead of it or roll over it and deposit a gravel clay (ground moraine) upon it. Or, if it retired so far as to leave a lake between it and its past position, it might push the lake clays on top of the shore gravels of this lake. That is in many cases what has occurred. In some cases, of course, the pervious bed is entirely destroyed; but often the pervious bed remains as a good source of water, and has head enough to produce a flow. Close to the lakeward side of prominent moraines, shown upon the map (Pl. II), flows from the drift may be expected. The cross section near Rose City (fig. 8) illustrates this principle. In the midst of moraine regions there is confused and broken topography, springs are common, and there are often small groups of flowing wells in the low grounds.

4. The ice was very likely to leave some gravel in all sheltered, i. e., southern sloping, parts of the rock surface or the valleys therein. If the rock itself was not impervious there was some circulation of water along it which leached out channels. Thus it is the rule, though not without exceptions, that just above the rock surface there is a water-bearing stratum.

METHODS OF SINKING WELLS.

While the wells in the rock have been almost invariably drilled, there has been considerable variety in the method of putting down wells in the drift, and a brief recapitulation may be suggestive.

First, of course, are the dug wells. Where experience has shown that many bowlders and stones are likely to be encountered, digging will probably prove the most economical method. Wells are dug 2 feet or more in diameter, and are variously cased. From all parts of the State come complaints that wooden casing soon rots and makes the water foul, and is almost always used longer than it ought to be.

Another form of casing is stoning, where stones are plenty. The disadvantage of stoning is, however, that it does not keep out the surface waters.

Where stone is scarce brick casing is often used, also large crocks, or sewer pipe about 2 feet in diameter. Properly sealed against surface water, these make excellent casings, though fragile and likely to be cracked by uneven settling of the earth.

A plan followed in some extra deep drift wells and worthy of wider adoption, is the use of a boiler plate shield and the cementing of the well as it is dug. Mr. E. R. Phillips has his well in Bay City cemented down to its bottom and a bed of charcoal and clean sand therein—an excellent plan for those who must use wells in unsatisfactory localities.

The disadvantage of combining a dug basin with some other form of well, and the various disadvantages of a lack of thorough casing are described on page 72.

Another kind of well is the driven well. This is a great favorite in the sandy and gravelly districts of the areas covered by Glacial drainage deposits (colored brown and crosshatched on the map, Pl. II). In the heavy clays of the lake clay areas (colored blue on the same map) it is quite common to use an earth auger and bore down, and this may be combined with driving where necessary.

The chief difficulties encountered are stones too large to be pushed aside, which have to be dynamited, quicksand, and fine sand, like that of an hourglass, which runs in faster than it can be pumped out. In going through strata carrying quicksand, work should be continued night and day without interruption. I do not know that artificially freezing or cementing the quicksand bed has ever been tried in the State, though it would be effective. It would seem that especially in case of quicksand, a mode of sinking wells illustrated by Pl. III, *A*, might prove very effective. This method consists of forcing down, in a smaller pipe within the casing, a current of water, under a very strong head (sometimes steam is also used), which scours out the soils and lets the casing drop as it is tapped. There is thus no opportunity for the sand beyond the reach of the very strong current to pile in. These quicksand beds sometimes contain water, but the well becomes easily clogged if its point is near quicksand.

EASTERN SHORE DISTRICT.

For the purpose of detailed description the State may be divided into seven sections.[1]

In the eastern shore district is included nearly all the country which slopes off to the east from the land water-laid moraines along the eastern part of Huron County down to Monroe. The surface soil is predominantly clay. This is varied by strips of sand along the streams, composed of successive deltas and old shore lines more or less parallel to the lake,[2] along which the ridge roads often run. On the clay no surface wells can be obtained and deep wells prevail. On the sand ridges shallow surface wells can be obtained, but are likely to fail in dry times and are, besides, at all times liable to pollution. In boring down an impervious lake clay or a gravelly clay, generally known as hardpan, is found. Interlaminated streaks of gravel are few and not uniform, except that generally just above bed rock there is a porous water-bearing seam. In the extreme south of this district through Monroe County, from Ottawa Lake to Sibleys (an area colored red on the map, Pl. VI), limestone outcrops are found, and the drift is accordingly shallow, but in passing to the northwest there is very soon encountered about 80 feet or so of the blue and gravelly clay. Where this clay overlies the limestone sulphureted hydrogen, which may also spring from the decomposition of the sulphide of iron in the drift, is generally accumulated, and the deeper wells—the so-called sulphur springs—are heavily charged with it. Where black shale underlies—and there is black shale both above and below the Berea grit—burning gas is very likely to accumulate, and often excites surprising hopes. Most of the deeper wells in Wayne are charged with one or the other of these two gases, but no large permanent supply can be expected from them, though in many cases they might for a time furnish a house or two with a convenient fuel. Flows of water from gravel beds are not uncommon throughout this region, and the number and strength of flows increase from the shore back toward the moraine.

[1] After making these sections I noted that there was a striking parallelism between the regions into which I had divided the State and those into which Professor Wheeler had divided it for study of floral distribution.

[2] In Huron County the markedly sandy strips are 20 to 25, 68, 98 to 118, and 163 to 193 feet above the lake.

There, too, the section of the drift becomes less monotonous, and there are more interlaminated gravels. At about 750 feet above tide, on the border of the moraine, on a line along through Britton, York, Milan, Ypsilanti, Northville, Birmingham, and Rochester to North Street, back of Port Huron, one may be reasonably sure of striking water which will rise nearly if not quite to the surface of the ground and frequently overflow. The water of these wells—e. g., that of the Ypsilanti waterworks—is of excellent quality. Farther down the slope the drift beds are less porous and the water, if obtained, is likely to be too highly charged with gas and mineral for comfort.

Through this district, therefore, the sources of water supply may be summarized as follows:

(1) Lakes. Only the Great Lakes are of practical importance and are the only satisfactory supply for large towns.

(2) Surface wells. The wells are generally very shallow and exhaustible. Wells from gravel or sand "pockets" in the clay are very uncertain, but are likely to flow for a time. The Pagoda spring of Mount Clemens appears to belong to this class, but yields more freely than is usually the case. Toward the upper margin of the district the supply is more abundant.

(3) Wells from base of drift. These are almost always present; the supply is ample and the flow probable. They are free from contamination, and are somewhat highly mineralized, but probably not to a degree to render them useless.

SAGINAW VALLEY DISTRICT.

In this district is included the drainage of Saginaw River and part of the surface drainage—about to the 750-foot line and including the part once covered by Lake Saginaw. The rock surface is exceedingly variable. The old coal measure plateau was cut up by gorges 100 to over 200 feet deep, which are more extensive than can be shown on the map (Pl. VI). But the present surface is flat and is varied only by the valleys which the larger streams have cut from 10 to 30 feet below the plain. First with moraine till, and then with the lake clays, the rough rock surface has been plastered nearly smooth. Thus the depth of surface deposits is not uniform, varying from even 0 to 500 feet, but being generally about 80 to 100 feet. Finally, sand ridges frequently occur about 25 feet above the lake, then again, as near Hemlock City, about 70 feet above the lake (655 above tide), and again about 160 feet above the lake (742 to 766 feet above tide), as at Alma, Ithaca, Gagetown, and Cass City.

These sand ridges yield surface water, easily exhausted and liable to contamination. On the clay lands between them the farmers have to go deeper for water, and rarely fail to find it. In most places there are beds of quicksand, which yield water under the clay and very often gravel. Waters from these horizons always rise well, and in many places flow, especially near the 700-foot contour. The quicksand wells, however, easily clog up and are short lived. The quality of the water is not so unexceptionable as the quantity. It is generally hard and not infrequently somewhat mineralized. But throughout all this region as good water, with as good or better head, can usually be obtained from underlying sandstones.

To the southeast in this district the drift coating is very thin, from 0 to 40 feet, and outcrops in the streams occur; but toward the west the coating becomes thicker. Thus, at St. Johns it is 141 feet deep; at Midland, 198 to 300 feet; at Mount Pleasant, 250 to 350; at Coleman, 300; and the greatest known depth of drift in this district lies at Alma, 495 feet. To the northwest in this region it will be exceptional cases and exploration for other things than water which will lead wells to rock. Especially is this true since ample supplies of flowing water can generally be obtained from the quicksands, which are very difficult to drill through. It will be noted, moreover, that this part of the region lies in a southwest direction from the gypsum quarries of Alabaster. This is the direction of Glacial motion. Hence it is not surprising to find gypsum disseminated through the drift. Prof. C. A. Davis has called attention to a bowlder of gypsum as large as two fists, which he discovered near Alma. This is certainly exceptional, and is of interest as showing the recent date of ice movement. A certain amount of gypsum is disseminated through the drift in this region and gets into the water. This is most marked at Mount Pleasant and in the region immediately around, as at Leaton. Here the wells in the drift, whether deep or shallow, are, without exception, permanently hard and highly impregnated with sulphate of lime. These mineral waters, though free from bacterial contamination and not likely to produce typhoid and diphtheria, are said to be injurious to the bowels and bladder of certain constitutions, while they might be what others need. Persons in this region who tend to a uric acid diathesis might find filtered rain water better than patent medicines. A trace of common salt, or lithium carbonate or sodic sulphate, might be added to remove the flat taste of the water.

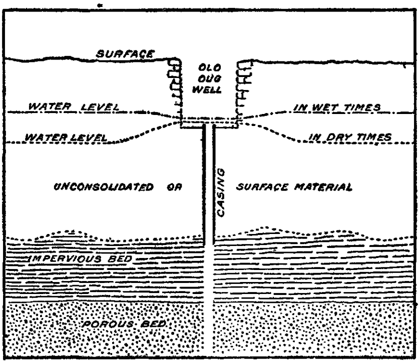


FIG. 9.—Diagram illustrating evils of insufficient casing.

This district is much like the first except that gas is not common in the wells. The wells in surface sands are usually shallow and easily exhausted in dry times. Deeper wells in quicksand or gravel in or under the clay can generally be obtained, but the water is often very hard. The thickness of drift—i. e., depth to bed rock—is quite irregular, but is much greater to the northwest.

One practice common in this district but not confined to it, which can not be too strongly deprecated, is drilling from a basin or dug well and letting the water resulting flow directly into the basin, the upper basin remaining as pervious as ever. The way in which this practice arises is simple and natural. A farmer begins by a dug well, perhaps 16 feet down in the surface sands, as in fig. 9. In a dry season like that of 1895 his well goes dry. He borrows an augur and bores down through sand and then through the clay, say 20 feet more, and strikes another porous bed full of water under a good head, which rises and fills his well up far enough, and he stops satisfied. But in the first place the impervious clays through which he has bored will probably creep in and fill the hole, and in a few years the work will have to be repeated. In the second place, suppose that the well is cased from the bottom, or that the flow from the lower pervious beds is so strong as to keep the hole open; in dry times the water from the lower bed will still work out sidewise through the stone curbing into the upper beds that have gone dry. Thus the head of the lower beds will be wasted, and some neighbor who has had a flowing well from that bed may suddenly find his flow stopped, while he himself will have to exert himself more than should be necessary in operating the pump. Again, if there is a strong flow upward from the lower beds, sand may be carried up in sufficient quantities to fill the upper well and leave a cavity around the bottom of the hole through the impervious beds, into which they will finally fall and seal the well, even though the beds themselves are cased. Finally, there is nothing to prevent a rainy season from reversing the process—raising the water level in the upper beds, changing the current, and contaminating the supply with rain water and surface drainage, so that the certainty of purity, which might easily be obtained, is lost.

If, however, as shown by the dotted lines, the hole is cased and the casing continued to the surface, the head of the lower bed will be preserved, risk of contamination removed, and the life of the well lengthened.

NORTHEASTERN SHORE DISTRICT.

This district is occupied mainly by the drainage valley of Thunder Bay River, with the lower reaches of the streams which drain into Huron Bay between it and the Tittabawassee, and the streams, mostly small and insignificant, which lie to the north of Thunder Bay River.

To the southwest of this district lies the high interior moraine which surrounds the Muskegon, marks most sharply the outline of the Michigan-Saginaw cusp, and probably includes the highest points of the peninsula (e. g., 1,465 feet, at Jim Cook's knob, on the north line of sec. 34, T. 24 N., R. 2 E., and, it is said, 1,682 feet near Otsego). Near West Branch the district approaches nearest the waters of the lake, and there and at Wolverine the descent, from over 1,200 feet to less than 700 feet, is very abrupt, especially in the stream valleys. This region is but newly settled and is still in large part wilderness.

The general character of the district is somewhat as follows: Around the nucleus (the central district) of sand plains, about 1,180 feet above tide, except as cut by river valleys, runs a moraine, which is mainly or at times entirely covered with sand and frequently rises over 1,400 feet above tide. (See fig. 8.) There is also another sand plain, about as high as the inner sand plain but narrower, and then a moraine, only about 1,200 feet above tide, which is clayey and clothed with hard wood, especially on its northerly or easterly side. Then the moraine is deeply gullied, and there is a rapid drop to about 960 feet above tide, where there are again extensive sand plains. Inclosing these is another broken clayey morainal belt frequently 1,000 feet above tide, and then another drop brings us to about 800 feet above tide. Below this the moraines are less marked, and gravel ridges, produced as shore beaches, replace the extensive overwash sand plains of the higher regions, studded with jack pine. The soil becomes clay with streaks of sand, rather than sand interrupted by lines of clay hills. In other words, there is a series of encircling moraines as shown on Pl. II, and between each moraine and the one next within the valley the space has been filled with sand, shown in brown and crosshatched, nearly to the level of the outer moraine, and often covering it heavily. In the sandy regions water may be obtained from surface sand, though it may be quite deep. Whenever streams like the Au Sable or Au Gres have cut down through the sands to underlying clays springs occur, and they are abundant in this region.

The drift through all this region is probably deep, and the clay moraines probably mark epochs of readvance of the ice, when it was likely to override the sand deposits formed in front of it in its retreat. In the few deep wells already sunk deposits of sand and gravel are found under the clay and till. Wells sunk into them, especially near the moraine belts on the north and east sides, may be expected to find plenty of water with considerable head. Fig. 8, from conditions at Rose City, will show how favorable are the conditions for artesian wells. There are high, sandy gathering grounds on the side south or west of the moraine, and higher semi-impervious ground with higher water level between the gathering ground and the discharge.[1] Flowing wells may be expected, therefore, all along from West Branch past Rose City to Indian River.

On the moraine belts the same sheets of water-bearing gravel may be struck, but the height to which the water will rise in the well depends on the altitude.

On the sand plains to the southwest of a moraine belt it will be necessary, except in low spots, to go deep for even surface water. There

[1] Requisite and qualifying conditions of artesian wells, by T. C. Chamberlin: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 131 to 172.

are a great many fine, undeveloped water powers in this region, and lakes are quite numerous. The quality of the water is generally excellent. It is, of course, hard, and it has been stated that 80 per cent of horse diseases are due to hard water. The water is not suited to boiler use. But the hard water of this region probably differs from that of Saginaw Valley and around Mount Pleasant, in that its hardness is largely temporary, as letting the water stand removes some, and boiling or breaking with quicklime all, of the hardness, which consists of lime and iron.

On the other side of Thunder Bay River a smooth moraine, which covers an underlying limestone ridge, gently rises. The coating of drift is shallow, the underlying limestones are pervious, and it is often necessary to go down into rock to obtain a permanent water supply.

Throughout this district there are many ponds. In some the water is said to be quite soft. The ponds are either clay moraine tarns, crooked lakes left in abandoned channels of the old ice drainage, or sometimes sink holes and valleys in the limestone. At present their main worth is to the hunter, the fisherman, and the lumberman, but the time may come when they will be useful as reservoirs for mill streams or as town water supplies. In most of this district good water supplies can also be obtained from the rock, though at considerable depths.

WESTERN SHORE DISTRICT.

There is much greater difficulty in defining, by natural characteristics, this district than some of the previous ones. There is a series of moraines which come diagonally down toward Lake Michigan (see Pl. V), becoming gradually lower, more extended, and more undulating in contour. The moraines are heavily swathed in gravels, sands, and clays of the valley trains which lie between them. At the extreme north of this district, from Bay View and Petoskey southwest, there is a rock ridge, and there is probably also a rock ridge from Grand Rapids northwest into Oceana County, where the drift covering is comparatively thin. Between these ridges the drift is very thick, so that only the deep salt or mineral wells strike rock, which is encountered 500 or 600 feet down. Probably the relief of the rock surface is considerable. This thick layer of drift is generally varied in section, as the wells at Big Rapids, Traverse City, etc., show, and various sands and gravels yield water; and on lower grounds, as at Traverse City, at the Nochemo springs (really wells), near Reed City, around Empire and White Cloud, and at Mecosta, flows are likely to occur. The level of the flows at these places is below that in the adjacent country, but on the higher grounds, as about Walton, especially on the great sand and gravel plains which are so pronounced a feature, it is often necessary to go 100 feet or more to reach water. Usually, however, water can be reached by a drive well, and of course water at such depths is steadier in supply and freer from some forms of contamination.

The deeper a surface-water well is the farther it should be away from any privy.

At the extreme north, north of Harbor Springs, there is a singular district, which seems to have an exceedingly heavy coating of drift and overwash gravel and which is so porous that wells must be sunk 300 or 400 feet to water.

Toward the south in this district there is a region of shallower wells and drift, but the varied character of the drift continues. Occasionally a section will be found which shows no pervious bed; this may be expected mainly along the moraines, indicated in Pl. II. Usually, however, even in the belts marked as moraine ridges, sufficient minor alternations in the drift exist.

The relatively greater thickness of drift, and the ample supply of water which may be obtained from the Glacial drainage gravel deposits, account for the relative scarcity of strongly mineralized waters in the area of the coal measures and Michigan series compared with those in Saginaw Valley.

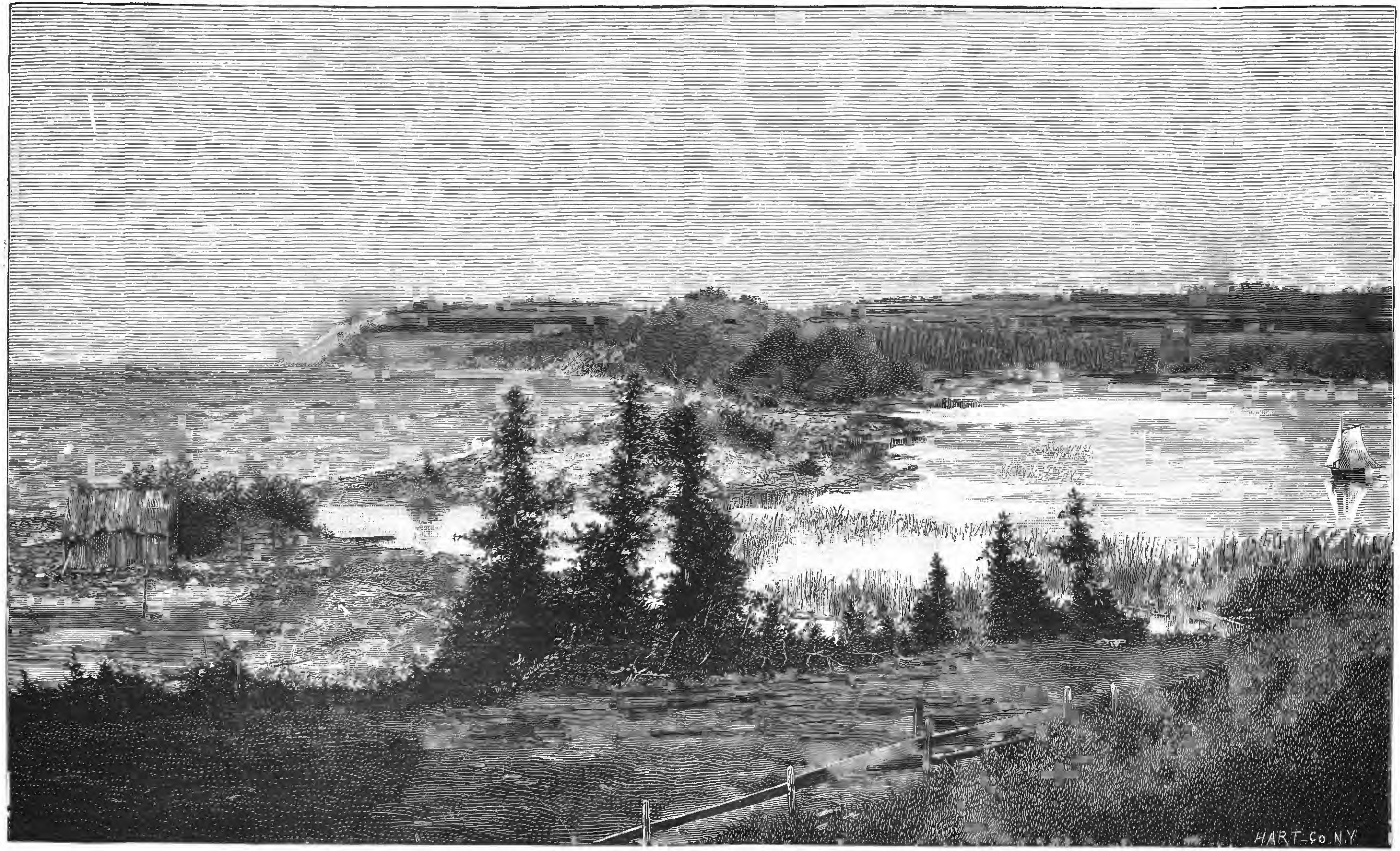
NORTH CENTRAL DISTRICT.

This district includes the upper valleys of Manistee, Muskegon, and Au Sable rivers, and is bounded by the northeast district and the west district, previously described, or, in a general way, by the second of the series of ascending moraines, which passes through Lewiston. On the south it may conveniently be brought down to the second correction line of the Land Office, or about to the Ann Arbor Railroad. As thus defined, the district is characteristically sandy. The depth of drift is probably often very great, how great is not known, as no wells have reached rock.

Wells are generally driven, not drilled, and water may be from 17 to 60, 80, or even 180 feet through the sand, depending on the altitude. The first encircling moraine appears to be as sandy as the intervening plains, though the sand may mask clay. On the lower parts of the plains, as at Roscommon, there is but 12 to 14 feet of sand above clay, and below this clay are sheets of water which flow, or at least have good heads. The water is said to be comparatively soft, but it is by no means equal to rain water.

SAGINAW MORAINE DISTRICT.

This central part of the State lies higher than the old lake bottoms of Saginaw Valley and the eastern shore, and is more varied in its topography. It is generally undulating, with 20 to 30 foot rolls, and occasionally rises to hills 100 to 200 feet high. While, as a whole, it lies on a rock ridge—largely the Marshall sandstones—the rock surface does not at all conform to the minor undulations of the present surface. Consequently the depth of the drift varies, occasionally exceeding 200 feet but being more usually 30 to 50 feet. Over these areas there is a great variety in the drift deposits.



BARRIER BEACH CONNECTING EMPIRE BLUFFS AND SLEEPING BEAR POINT, LAKE MICHIGAN.

While in the eastern shore district the drift is almost uniformly clay or bowlder clay, here there are alternations of sand and gravel with till (hardpan), sometimes many of them, indicating retreats and readvances of the ice. The axis of the Thumb lies in this district, and it is traversed by many Glacial drainage channels with heavy valley trains, which yield abundant surface water.

Consequently, much less can be said about this district as a whole than about some others. Usually water is found above the rock, but as the rock waters are good and ample there are also numerous deep rock wells. Frequently the streams have cut down through the overlying sand or gravel to clay beneath, and in these cases springs are certain to appear. Occasionally erosion has reached bed rock. Not infrequently on the lower lands flowing wells, as well as springs, may be obtained, and they are found scattered all over the area; but on the higher lands and moraine ridges it is necessary to bore deep for water. Along the margin of this district, however, there is a sudden drop of the country, and along this belt wells are very likely to occur with flow ample enough in many cases, as at Rochester, for town supply. The quality of the water is almost invariably good—hard but not otherwise strongly mineralized.

SOUTH CENTRAL DISTRICT.

The conditions here are practically as in the Saginaw moraine district. The coating of drift over the sandstones in the valleys is usually thin, while beneath the hills it is 100 feet or more thick. Between the hills are usually swamps and Glacial drainage deposits or valley trains. In some places in Hillsdale County the drift is found to fill and obliterate pre-Glacial channels. One of these lies about 5 miles northwest of Jonesville; and another, which traverses the county from east to west, passing near Osseo, has been described by Mr. H. P. Parmelee in a paper read before the American Association for the Advancement of Science, but not published.

DEEPER WELLS AND PALEOZOIC STRATIGRAPHY.

Below the mantle of sands, gravels, clays, and till which we have considered in the last section, the drill encounters the consolidated rocks of the Paleozoic series. Among the rocks the drillers readily distinguish the black, white, blue, red, and sandy shales, the white or brown sandstones, and the harder limestones. Soap rock or soapstone is usually very clayey, and is often a calcareous shale. Between limestone and dolomite no distinction is made, although the latter is sometimes mistaken for sandstone. The last two, especially when full of chert nodules, "flint" layers, etc., are usually much more difficult to drill than sandstones and shales. Sometimes a ball of pyrite or a nodule of sideritic iron ore will resist the drill as effectually as flint, and may pass for such. The variation in hardness naturally makes a great difference in the cost of drilling. While for 2-inch holes in the softer strata (the coal measures or Coldwater shales) 50 cents a foot has been a standard rate and will yield good wages if there is no special difficulty encountered, some specially hard layer of a foot may take more time than all the rest of the well; and in general through the State wells have cost about $1 a foot. Usually half the time at least in drilling a well is consumed in overcoming exceptional difficulties and in making repairs.

In mere churn drillings coal is difficult to distinguish from black shale, at least to determine its exact thickness; though an expert, by turning the drill 90 degrees each time and thus getting larger pieces, and by noting especially the peculiar crunch under the drill, which may be felt if the hand is on the rope, may ascertain approximately the nature and thickness of a deposit. Gypsum or plaster is another substance which is often not recognized, and which it is highly important to avoid if good drinking water is desired.

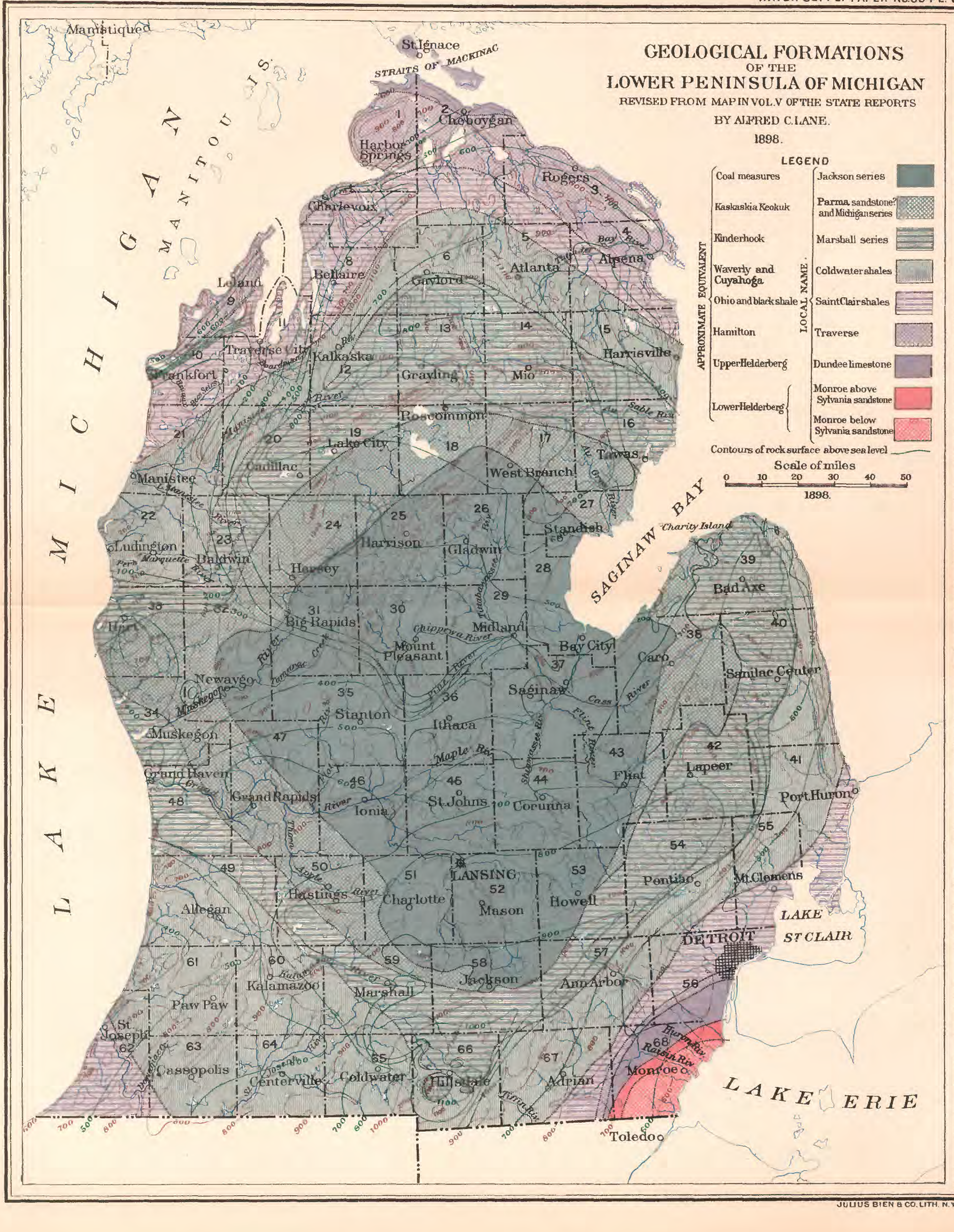
Usually, just before striking through shale into a strong stream of water with a good head, a certain springiness of the churn drill is noticed by the driller, which warns him that some new development may soon be expected, and it is common to find a red layer or a hard cap (specially charged with pyrite) or crust just before piercing a stratum containing salt water. Is not the sulphur of the ferrous sulphide of the hard cap, or the ferric oxide of the red shales derived from the sulphates of the brine?

A description of the rock series, not primarily from the view of the paleontologist or general geologist but from that of the seeker after water—fresh, medicinal, or salt—follows.

CARBONIFEROUS FORMATION.

JACKSON COAL MEASURES TO MARSHALL SANDSTONE.

The central part of the State, as shown by the map, Pl. VI, and by the cross section, fig. 10, is occupied by a series of rocks belonging to the Carboniferous formation, in some respects not unlike the coal measures of Ohio and Indiana, with some beds that can be closely paralleled with those coal measures and yet with such marked points of difference as to render it probable that for most of the time, at any rate, there was little or no continuous connection with any other State, but that the rocks were laid down in an inland sea, between Canadian highlands on the north and flat reaches of the emerging continent on the south. At the base of the series is a heavy white sandstone—the Napoleon or Upper Marshall—which is very massive and thick to the east and southeast, as shown in fig. 12, but becomes somewhat thinner toward the north, although it is rarely less than 50 feet of well-defined water-bearing sandstone. It lies directly under the drift, as the map shows, through most of the broad belt of higher land that extends from the Thumb down to Hillsdale County. It is a



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prolific water bearer, yielding numerous flowing wells at a moderate depth (250 feet) throughout the west part of Huron County to Sebewaing. Under Tuscola county it continues, as at Fairgrove, though at Reese it is getting a little too salt, and so along past Flint, Vassar, and Birch Run, to Corunna, Lansing, and Mason. Along this line and south there is usually good water in this formation. There is frequently above this formation intensely salt or bitter waters, pierced on the way going down, which must be cased out. It seems that to the northwest an arm of the sea was cut off from the ocean, where evaporation exceeded precipitation, depositing the gypsum beds which extend from Alabaster and Soule, in Huron County, to Grand Rapids, and saturating the rocks with a very salt brine. This formation has no parallel in adjacent States, and hence is known as the Michigan series. It consists of light-

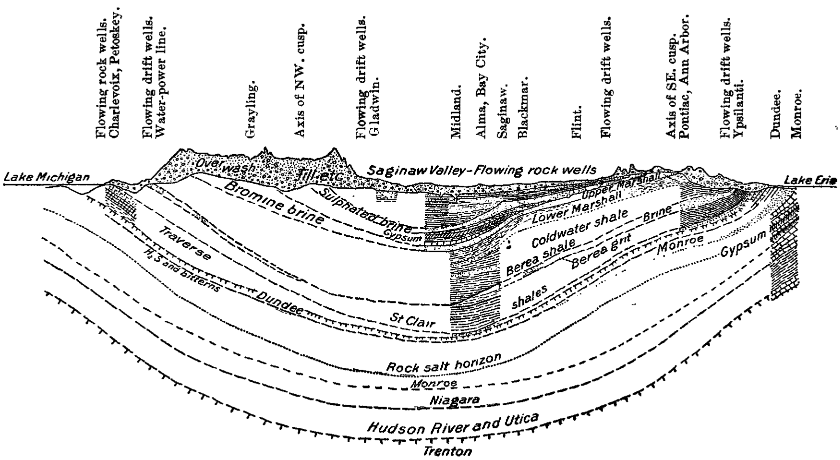

FIG. 10.—Cross section of the Lower Michigan Basin. Horizontal scale, 1 mile = .135 inch; vertical scale, 1,200 feet = .321 inch.

colored blue or gray shales, hydraulic limestones, and gypsum beds Its extent to the southeast seems to be somewhat irregular, as it lies in bays and synclinals in the Marshall sandstone. It can be followed, even where it does not outcrop, by its effect on the mineral waters.

In fact, in many parts of Lower Michigan, where outcrops of bed rock are scarce, important geologic data can thus be gathered. In much of our work in Huron County, Professor Davis and I discarded the familiar tools of the geologist, the hammer and the compass, and instead carried a urinometer and a small leather case containing barium chloride ($BaCl_2$), for sulphate test, silver nitrate ($AgNO_3$), for chlorine test, ammonium oxalate—$(NH_4)_2C_2O_4$—for lime, and sometimes tannic acid, for iron, and went from farm to farm inquiring the depth to rock, etc., and testing the waters. The line between the Upper Marshall or Napoleon and the Michigan series was traceable, sharply within a mile, by the reaction for sulphates which the latter series gave, and by a rapid increase in total mineral contents. This purely objective line agreed with reports as to the nature of the rocks and the rare outcrops. (Compare Pl. VI and fig. 12.) For further details reference may be made to the forthcoming report of the State geological survey on Huron County.

It is not uncommon, however, to find good fresh water in the Marshall sandstones directly beneath the Michigan series; there seem to be two reasons why the salt water has not worked down and charged the Marshall sandstone.

In the first place, as the Marshall sandstone outcrops all around under the high land, there is a strong pressure, nearly if not quite enough to make the water in the center of the basins rise to the surface. Thus the tendency is for the water to work up rather than down in the lower central parts of the Michigan Basin, which are overlain by the Michigan series and by the outcrops. This tendency has been shown in hundreds of wells for fresh water and in dozens of wells for brine, which have been put down in the Saginaw Valley. The Marshall, toward the center, becomes deeper and more salt. It is the source of the brines of Saginaw and Bay City, of the brominiferous brine of Midland, St. Louis, and Alma, and probably of that of Big Rapids; it is almost saturated with salt. The salt, however, is not derived from above, since it is comparatively free from gypsum. At one time the wells in the Saginaw Valley made a really noticeable reduction in the percentage of salt contained in the brine. They may have drawn in fresh water from the sides to replace the brine extracted at the middle of the basin. The Marshall sandstone is generally easy drilling.

The overlying Michigan series from Bay Port to Saginaw, Midland, Alma, and Grand Rapids is a trifle over 200 feet thick. The position and thickness of the gypsum and hydraulic limestone beds, which are intercalated in the prevalent series of gray or blue shales, are not constant. To a certain extent this appearance may be due merely to imperfect records. Some of the gypsum beds are quite extensive. To the southeast, even around Sebewaing, the gypsum feathers out. Of its character to the north little or nothing is known. Water from the Michigan series is generally scanty or strongly mineralized. Occasionally pyritiferous beds and cherty limestones make hard drilling.

A change of climate, or more likely a slight depression making an open sea, probably caused the deposition on top of the Michigan series of a series of cherty limestones and sandstones of an entirely different character from those of the Michigan series—almost exactly paralleled by the Maxville limestone of Ohio and rich in similar fossils. In this series I am now inclined to include not only the Grand Rapids limestone but Winchell's Parma sandstone. The sections and borings at Bay Port, at Charity Island, and elsewhere have convinced me that limestones and sandstones are intimately intercalated at this horizon. Many of the sandstones are highly cross bedded, and according to the observations of the writer are apparently mere sand bars. This is noted in the drill cores of the Bay Port quarry explorations by Rominger, who called it an unconformity, also on Charity Island, and by Winchell in his original description of the Parma around Jackson. The Bay Port limestone has the strongest possible resemblance to the Grand Rapids limestone in character and in fossils, and both are intimately associated with and underlain by sandstones.

The brines of this horizon, as pointed out by Garrigues, run higher in sulphates of lime, etc., and lower in earthy chlorides than do those of the Marshall; this is in harmony with the general theory of the upward pressure of the waters of the basin. The Parma sandstone is not always recognizable as distinct from the Marshall, although to the north from Bay Port it can be fairly well traced to Sebewaing, Bay City, Midland, Alma, and as far as Ithaca to the southeast toward Corunna and Flint. As the Michigan series feathers out this Parma sandstone either feathers out also or merges in the great shore development of the Marshall sandstone. (See fig. 10.) I now think that the record of the Jackson well is misinterpreted.[1] The Parma and Marshall are both probably merged in the great sandstone from 83 to 373 feet below the surface, the dividing line being perhaps near 200 feet, while the blue sandstones at 415 and 660 feet are probably merely minor beds of the Lower Marshall or Coldwater, respectively—Cuyahoga formations, especially as they are not free water bearers.

Returning once more to the Parma horizon—that of the Grand Rapids and Bay Port limestones—the water is usually hard, but at Bay Port it is quite pure, and no doubt is the water horizon of many wells besides those at Ithaca, especially in the region about Mason, Lansing, Owosso, and Birch Run, where thus far it can hardly be separated from the Marshall. It has been but little used for brine.

Above the Parma comes a varied series of black shales, fire clays, black band iron ores, and coals and sandstones. The sandstones usually yield water, but the water is generally quite mineralized (being occasionally prescribed for the sick) and is sometimes a brackish water which cattle drink greedily. Wells in the coal measures generally have a good head, and frequently flow. The sandstones are generally white, except well up in the series, while to the northwest, around Ionia, Ashley, St. Johns, St. Louis, and in Garfield Township (T. 16 N., R. 3 E.) there are records of a red sandstone, which Winchell called the Woodville sandstone. This red sandstone also yields water which is rather strongly mineralized, but it is yet little known, and it can not be said how far the red color is due to surface oxidation. In some cases it appears too thick for that and reminds one of the upper barren coal measures of Ohio and West Virginia, and, as at Saginaw, it appears to be quite unconformable on the coal measures proper.

[1] Geol. Survey Michigan, Vol. V, Part II, 1895, Pl. XXIII.

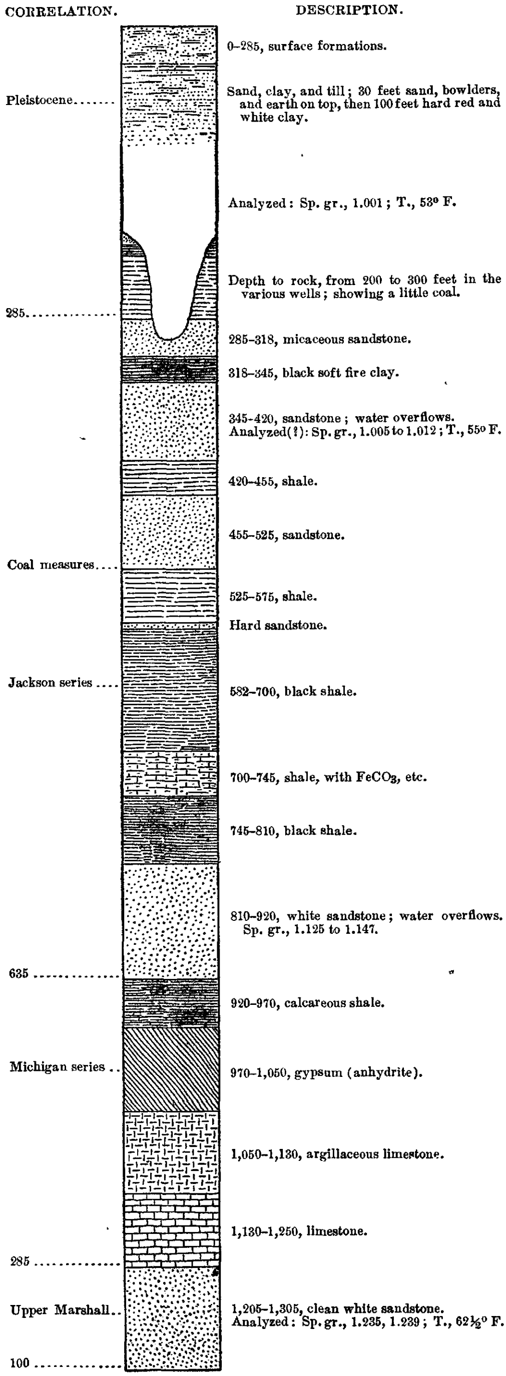

FIG. 11.—Section of well at Midland, Michigan. Altitude about 613 feet.

Above the Parma at Midland (see fig. 11), or combining the well records at St. Louis and Alma, there is a series of coal measures 400 to 600 feet thick, and sandstones are very abundant in the upper half, but are also very irregular—mere channels which will here cut entirely through a coal seam which a few feet away will be as strong as ever. One bore hole has found no coal, and 30 feet away one put down later for water passed through 3 feet of coal. These sandstone channels have been excellently exhibited in some of the Jackson coal mine plans by J. Holcroft.

This coal basin was deeply cut into by stream valleys before the ice swept over it and filled them. Hence the depth to rock is very uncertain and is more uncertain toward the northwest. The shore ridge of Marshall sandstone seems to have acted as a divide from which the streams flowed, gathering strength as they went. The abundance of deep wells in Huron County has rendered it possible to trace quite accurately in the rock contours of Pl. VI one valley which, coming down from Soule, is deflected by the Bay Port limestone and passes south through T. 16 N., R. 10 E., being about 140 feet deep, while on the general plateau around the valley the depth of drift is less than 50 feet. Thence it passes 3 miles southeast of Sebewaing, then close to Unionville, and on west. There are irregularities in the depth of wells around West Saginaw and Bay City that indicate spurs of this valley, and the next well-marked location is at Midland, where some wells, like those near Hubbard to the north, find only about 200 feet of drift, while others, at the east end of the town, find 300 feet of drift. Wells are said to have struck rock at 76 feet in Mount Pleasant, but on the other hand wells north of there have gone 160 feet, wells west 355 feet, and wells south 205 feet without striking rock. At Alma it is 495 feet to rock, and at St. Louis, 3 miles away, it is only 355 feet or less, and at Ithaca 330 feet. At Big Rapids it is 600 feet to rock, while at Ludington, Manistee, and Frankfort, although close to the lake, there is a great depth of drift. These facts indicate clearly enough an incised valley system of 100-foot ravines, and also seem to indicate, contrary to Spencer's very natural hypothesis, followed by Mudge,[1] that the drainage of the coal basin was toward the west and not by Saginaw Bay, both because the depth of the ravine steadily increases, and also because the limestone ridge seems to run continuously across the mouth of Saginaw Bay, from the islands off Bay Port, in continuous rock bottom to Charity Island, and outcrops again on the north shore. The limestone may be followed near Omer and Prescott at a higher level than the bottom of the valley just described. The rock contours of Pl. VI illustrate these facts.

The troughs which Mr. Mudge assumes represent troughs or valleys in the rock surface are sufficiently explained by the Glacial drainage, which, indeed, Mr. Mudge has pointed out for the Ionia channel; and the very fact that in the Ionia channel the Grand River has in two distinct places struck bed rock far above the lower rock surface of the Saginaw Valley makes the supposition that it follows a rock channel rather forced. There are two other arguments of a general nature for my interpretation of the rock surface. In the first place, the rock ridge seems much more broken, the depth of drift far more irregular, and the topographic relief greater in the Grand Traverse region than in the Thumb of Michigan, which indicates that the former region is farther downstream, or nearer the master valley, than the latter. In the second place, the generally accepted theory of a greater northern elevation of the land preceding glaciation disproves the supposition that the gradient from Alma northeast was reversed, and makes the course of the valley from Bad Axe to Ithaca even more natural. From that point on its course is much less certain. It seems to have been deflected when it met the northwest-striking sandstones and limestones beneath the softer coal measures, at the southwest side of the coal basin.

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[1] Am. Jour. Sci., 4th ser., Vol. IV, 1897, p. 384.

CARBONIFEROUS AND DEVONIAN SHALES.

LOWER MARSHALL SANDSTONE.

Beneath the heavy Upper Marshall sandstone which, as has already been mentioned, lines the shore of Huron County from Rush Lake to Hat Point, there are in Huron County (see fig. 12) about 260 feet of strata which are largely sandy flags and include three well-marked sandstones, one outcropping at Port Austin, another at Pointe Aux Barques, and another—the famous Huron blue stones, used for whetstones and grindstones throughout the United States. The series is very ferruginous, and beds often become red and friable as the iron oxidizes, although they are green or blue when fresh. These sandstones may be traced under cover by wells or by scattered outcrops through Huron County and into Sanilac County. Generally the supply of water is ample, the quality excellent (although occasionally salty streaks occur in the Lower Marshall), and occasionally, as near Bad Axe and Port Austin, in exceptionally low ground there are flows. As the sandstones are traced to the west under cover, they are soon lost, except when they merge into a belt of red rock, paint rock, red shale, sandy shale, etc., in which form they may be traced quite continuously as far at least as Saginaw River. They are evidently shore deposits of no wide range and have not yet been successfully followed individually to the southwest. They are transition beds from the Upper Marshall or Napoleon sandstone to the great shale formation below. They are easy to drill, and extend the width of the Marshall belt, from which good water can be obtained a rather indefinite distance to the southeast.

COLDWATER SHALES.

Farther down, in the Coldwater shales proper, the sandstone seams grow thinner and finer grained, and the water contained is more apt to be salty. Little sheets of sandstone cemented by carbonate of iron, as at Pointe Aux Barques light-house, at Sand Beach, and at Richmondville, are found at various levels in the Coldwater shales, but in general this formation is composed of fine-grained, micaceous, bluish shales, easily drilled and very dry. In Caseville, about 400 feet below the Upper Marshall, is a brine which seems to be fairly persistent and which is possibly even more marked to the northwest. In outcrop balls of carbonate of iron are frequent, and one wonders how often the bands of limestone recorded as encountered in drilling are nothing but such balls.

BEREA SHALE AND GRIT.

About 1,000 feet below the Upper Marshall the shales become blacker. The horizon of the Berea shale recognized in Ohio is reached, and then all along the southeastern part of the State the Berea grit is

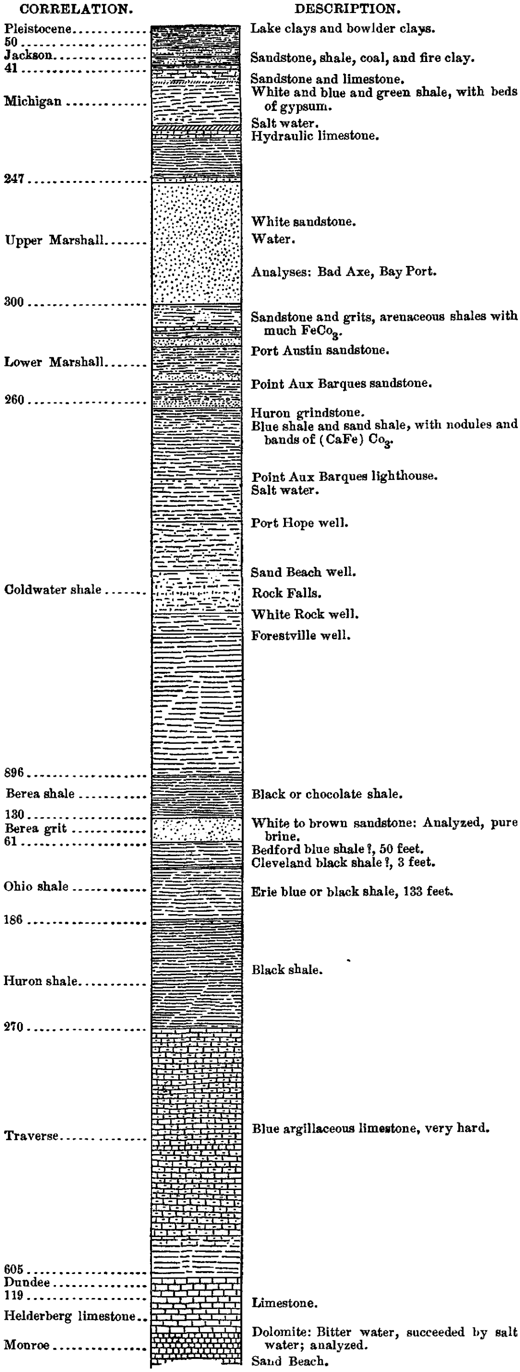

FIG. 12.—Geological column in Huron County, Michigan, adapted to the wells at Caseville and Sand Beach but illustrative also of those at Sebewaing, Bay Port, Port Crescent, Port Austin, Grindstone City, New River, Port Hope, White Rock, Forestville, etc.

well developed. It is a horizon well known for brine, and is followed to a depth of 1,650 to 1,750 feet at Caseville and at Blackmar, but is quite salt even when not very deep, as at Forestville, Ann Arbor, and Ypsilanti. At the latter place it seems to be more salt than underlying strata. It may be the source of some of the salt in wells about Ray (T. 4 N., R. 13 E.), Utica, Wales, and Rochester. With black shales above and below it is not surprising that the Berea grit frequently contains gas, and that many of the wells which strike gas immediately beneath the clays seem to be located over its beveled edge. It does not seem to be a marked topographic feature, nor does it break the general valley of the shales above and below. The Berea brines are of very good quality. Where recently struck in Bay City, at a depth of 2,200 feet, it actually flows, which, in a concentrated brine, indicates a considerable head.

ST. CLAIR BLACK SHALES.

Though the Bedford shales immediately below the Berea grit are often blue or red (oxidized blue), black soon becomes predominant, at first in streaks (Cleveland shale), but later in a solid mass of 100 to 300 feet or more of bituminous shale nearly equivalent to the Ohio shale, a horizon widely marked and in a general way recognizable all over the State. This shale is somewhat sticky, but on the whole is easily drilled and is of importance as lying just above the horizons which contain most of the more famous bath waters of the State. From the Marshall down to the base of these black shales, with the possible exception of the Berea grit, there is no horizon of much importance either for brine or as a source of water, and in regions where these formations underlie the drift the prospects for rock wells for drinking water are not generally encouraging. Of course, near the outside margin good water may be obtained by drilling through to lower beds.

In general this great series of shales probably makes valleys lying between the Marshall sandstone ridge on one side and the ridge of the Dundee limestones on the other, and this is exhibited in the rock contours of Pl. VI and in the rock profile of fig. 10.

Very remarkable is the occurrence of a 6-foot bed of rock salt in this formation at Bay City, with black shale immediately above and below. This occurrence seems to show that the black shale is not a deep sea sargasso-like deposit.

LOWER DEVONIAN AND UPPER SILURIAN LIMESTONES.

TRAVERSE SERIES (HAMILTON).

A transition series between the black shales above and the limestone series below is of slight importance in the south part of the State, where it is about 80 feet thick, but rapidly increases in thickness and in interest toward the north. Along the St. Clair River—at Port Huron, and elsewhere—it has thickened to over 300 feet and is subdivided as follows:

Typical section of series between St. Clair black shales and Dundee limestones.

	Feet.
Hard argillaceous limestone	2
Shale, argillaceous soapstone	12
Limestones, "top limestones," argillaceous, often containing gas	80
Shale, "top soapstone," argillaceous	150
Limestone, "middle limestone," argillaceous	4
Shale, "lower soapstone"	65

Beneath the last member are light-colored Dundee limestones, yielding gas and mineral water. The "middle limestone" is not always recognized, and the shales are calcareous, so that they may be considered alternations of calcareous shales and of argillaceous marls or limestones. The division into a top of limestone and a bottom of shale can be traced throughout the State. On the north side of the basin, from Alpena to Charlevoix and Frankfort, the formation is 500 or 600 feet thick, retaining its marked shale base, and also the tendency to bluish, richly fossiliferous layers; but the formation is quite varied and dolomitic, as is seen from the Charlevoix and Petoskey records. (See fig. 13.)

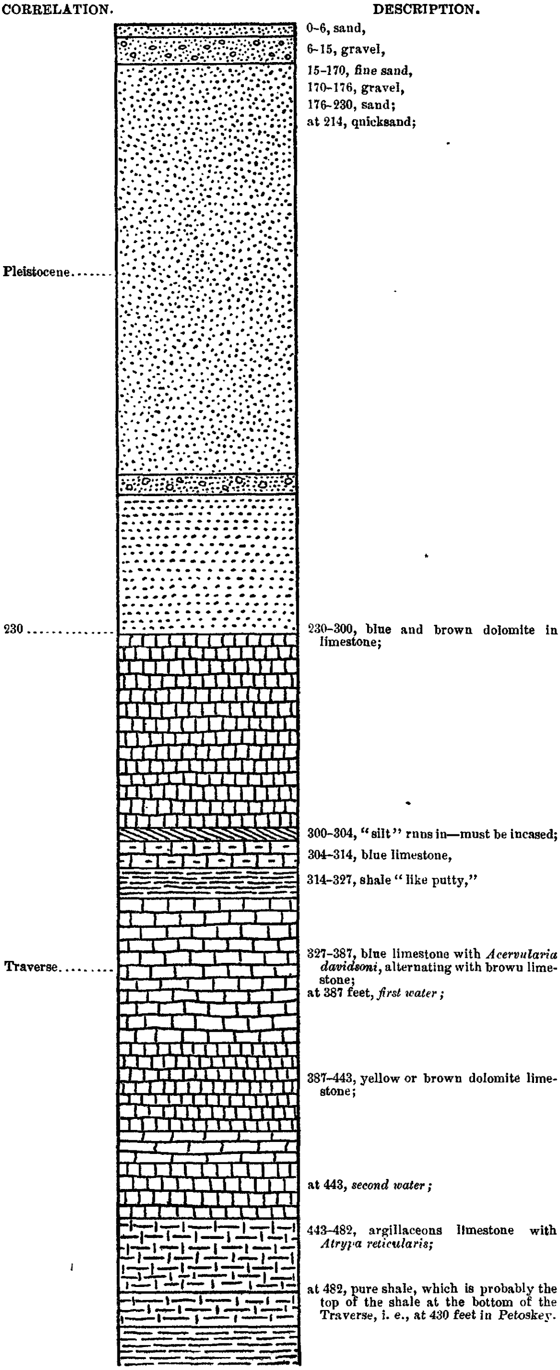

FIG. 13.—Section of well at Charlevoix, Michigan.

There are several streaks of limestone in this formation which yield more or less water, even in the southern part of the State, and to the north, as shown at Charlevoix, it is quite freely water bearing. There is some reason for thinking that the Alma well also is still in this formation, but the principal mineral-water horizon is just beneath.

DUNDEE LIMESTONE (UPPER HELDERBERG).

This formation has also been called the Corniferous or Mackinac limestone. Lithologically the upper limit of this formation is one of the best-marked lines that extends throughout the State. It separates a great series of bluish-gray or black clayey rocks from a great series of buff-yellow or almost white largely calcareous ones. It is generally very light yellow in color, is full of flint, and is very hard, so that the drilling is slow at times. It effervesces very freely with acid, and some of the layers rank as the purest limestone of the State, containing 98 per cent of calcium carbonate ($CaCO_3$).

It is almost always more or less permeated with water which is charged with hydrogen sulphide (H_2S) even at Petoskey. When under greater cover the water becomes more salty, but is also strongly charged with other ingredients than salt—real bittern, or mother liquor—and is the most valued mineral water in Michigan.

The deposit of celestite with native sulphur has been associated by Professor Sherzer with the occurrence of traces of strontia (SrO) in these sulphureted waters. Frequently, also, oil or gas is encountered. In spite of the strength of this brine at times (at Charlotte the specific weight is 1.198) it is too impure for salt manufacture, and is mainly important medicinally.

The line between this formation and the one below, being one chiefly between limestone and dolomite, can be surely ascertained only by the use of acid. Hence over most of the State the line is still very uncertain.

THE MONROE AND SALINA BEDS (LOWER HELDERBERG).

These are the oldest beds exposed at the surface in the Lower Peninsula. Not more than 100 or 200 feet of these beds are exposed at the surface, but borings reveal over 1,200 feet, if with Orton we include in the group the salt beds (Salina). The beds are mainly buff dolomites and calcareous and argillaceous marls, associated with anhydrite and rock salt. Near the top a bed of the purest white quartz sand (often recrystallized), the Sylvania sandstone, extends persistently across Monroe County and can be traced under cover at least as far as Mount Clemens and St. Clair River. This sandstone is, of course, a good water bearer. Near Detroit, while at about 200 feet the strongly sulphureted waters of the Dundee are reached, at about 400 feet comparatively fresh potable water is met, and it seems as if it might be worth while to develop further this horizon, which is probably also encountered in Ypsilanti and Alpena. Below this sandstone the salt beds and brines of the Salina are reached. Rock salt is here in single layers often over 100 and even 200 feet thick; its aggregate thickness can not be estimated. These rock-salt beds extend apparently beneath (or at any rate skirt) the whole of the peninsula, from Alpena and St. Ignace down to a line drawn from Trenton to Muskegon. South of this line there is gypsum (or anhydrite), but not salt. A group of six wells at Trenton shows, within a few hundred yards, the exact margin of the salt basin.

This great thickness of salt suggests that there should have been a concentration, as at Stassfurt, in Germany, of the rare potash and bromine salts in the upper layers. The earlier Sand Beach analyses indicated such concentration, but the water does not now give similar results. The Mount Clemens, Somerville Springs, and similar waters are clearly of the nature of mother liquors.

These salt beds, like all the beds, dip away from the St. Clair and Detroit rivers to the northwest, but after descending to depths of probably 3,000 to 4,000 feet, they rise again, and just north of the Straits of Mackinac gypsum beds outcrop. At St. Ignace a thin bed of salt is reported only 400 feet below the surface, while at Alpena rock salt is encountered within 1,000 or 1,200 feet. Though the Salina can not be sharply divided from the formation above or below, the following arrangement may be suggestive: at the top, dolomites and gypseous marl mark a time of desiccation; then comes an arenaceous dolomitic limestone passing into a glass sand—the Sylvania sandstone; then some more beds with gypsum and sometimes with rock salt; then 200 feet or more of somewhat gypsiferous dolomites; and beneath them a rapid succession of thick rock-salt beds, marking probably the first and greatest period of desiccation.

NIAGARA AND CLINTON FORMATIONS.

These formations have been struck only southeast in Monroe County, southwest from Kalamazoo, and north at Frankfort. The most characteristic part probably belongs to the Guelph formation—the churn-drill powder being almost white—a very fine-grained dolomitic limestone. It answers to Orton's description, and in accord with his remarks of the change from southern to northern Ohio, I recognize the Rochester[1] shale only at Wyandotte. Generally toward the bottom the limestone becomes more ferruginous and, as at Wyandotte and Dundee, a "red rock," and then the red shales of the Medina are reached. Concerning the water resources of this part of the column little is known. Water was noted at Dundee from these beds, but there is no report of its chemical character.

HUDSON RIVER AND UTICA SHALES.

There is next a great series of shales, struck only by a few wells in exploring to the Trenton, like those at Dundee, Monroe, and at South Bend, Indiana, viz: (1) The Medina red and green shales at Dundee, at a depth of 1,625 to 1,725 feet; (2) the Hudson River blue shales, about 300 or 400 feet thick; (3) the Utica brown or black bituminous shales, about 100 feet thick. This series is similar to the Lower Marshall, the Coldwater (Cuyahoga), and the St. Clair shale series.

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[1] The Director of the United States Geological Survey has decided that hereafter in the publications of the Survey the term *Lockport limestone* will be used in place of the term "Niagara limestone," and the term *Rochester shale* in place of the term "Niagara shale," the word *Niagara* being reserved for the designation of some higher classific unit.—EDITOR.

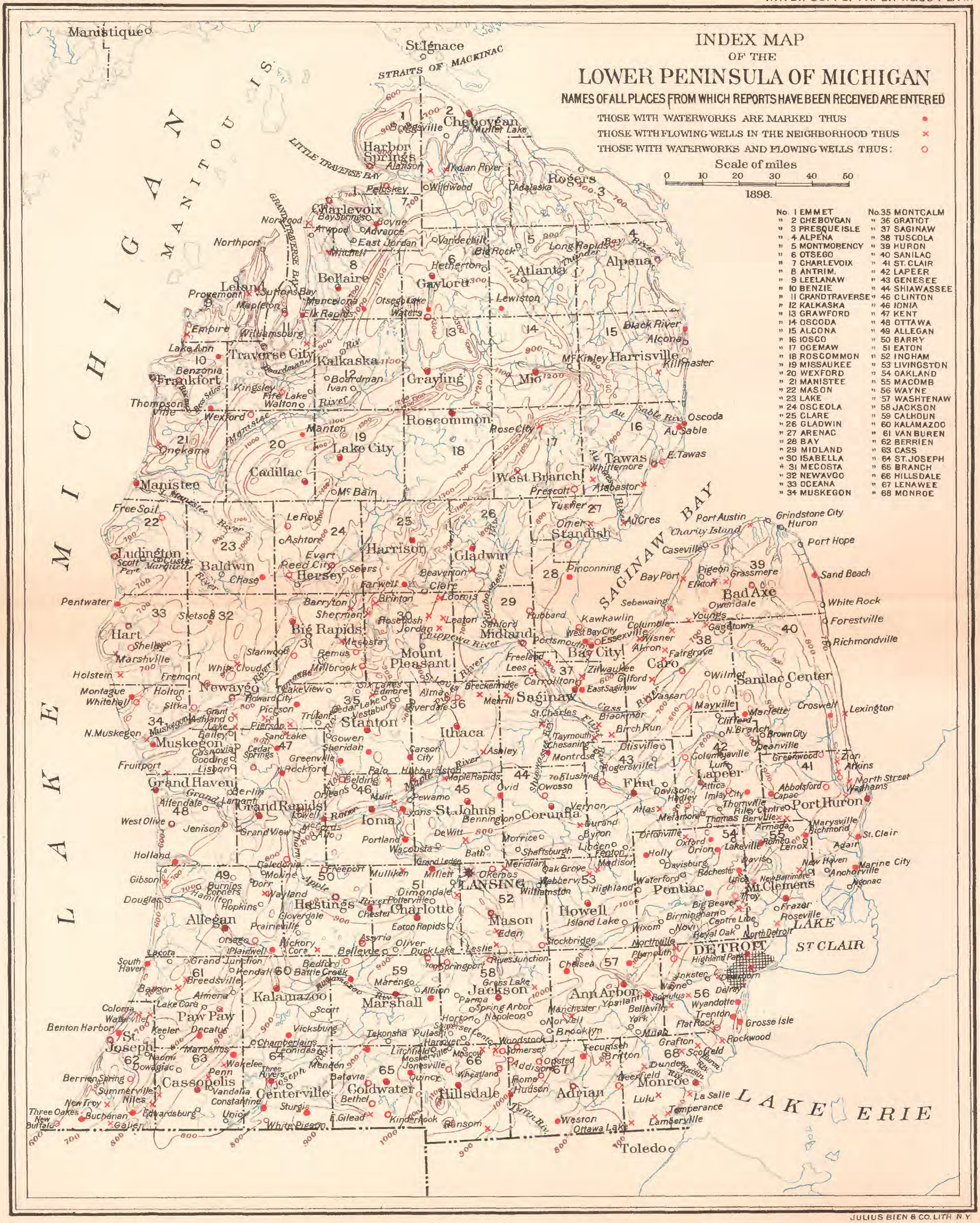
TRENTON LIMESTONE.

This formation has been penetrated a few feet at Monroe and at Wyandotte, somewhat further at Dundee, and again in the southwest part of the State, at Dowagiac. It is really a buff, granular, porous dolomite, with traces of gas and oil usually drowned out by a strong impure brine.

ROCK STRUCTURE AND TOPOGRAPHY.

The general structure of the rock basin, which has been described, is well shown by Pls. LXVII to LXX of Vol. V (1895), Pt. II, Michigan geological survey, which can, however, be improved by use of records since received; fig. 10 is a new section from Monroe to Charlevoix. The limestones and sandstones of the Traverse, Dundee, and Monroe make a rock ridge, which comes to the surface in Monroe County, can be distinctly traced as an escarpment, as Spencer has remarked, in the bottom of Lake Huron, and reaches land once more at Thunder Bay. From that point the ridge, though apparently broken beyond Cheboygan by cross valleys, continues nearly around to Frankfort, where the rock surface is slightly higher than at Manistee. The deep valley between this ridge and the Marshall sandstones is clearly defined in the well records in the southeastern part of the State, and seems to discharge near Algoma, where there is considerable thickness and where the depth to drift is irregular. This shale valley was overlooked on the northwest by an abrupt escarpment of Marshall sandstone, which is almost everywhere concealed, and yet within a mile the depth to rock may vary from less than 10 to 30, 40, or even 100 feet. This Marshall sandstone escarpment is more or less escalloped and ravined, as was indicated in Hillsdale County, and there are probably outlying areas or spurs of sandstone. On the main ridge of Marshall sandstone the rock floor is reported to be fairly level, and the irregularities in the drift are due to the irregularities of the moraine ridges, etc.; but in toward the coal basin, i. e., toward Mason County and around Pigeon, in Huron County, there is a system of valleys in the rock surface up to 100 feet deep. In the lower part of the Michigan series soft beds, easily cut, predominate, while the upper part, the Parma sandstone, the Bay Port limestone, etc., is more resistant, and shows an escarpment facing outward at least 10 or more feet vertically, and the valleys, as they traverse it, rapidly deepen to more than 100 feet. It is probable that some of the limestone masses which have so puzzled Winchell[1] and others have been outliers of this escarpment pushed or dragged off from the soft shales beneath and left stranded in the drift. They are particularly conspicuous, as Winchell remarks, in Oceana County, in the northwestward extension of the rock divide—which follows the Mar-

[1] Proc. Am. Assoc. Adv. Sci., 1875, p. 36.


INDEX MAP
OF THE
LOWER PENINSULA OF MICHIGAN
NAMES OF ALL PLACES FROM WHICH REPORTS HAVE BEEN RECEIVED ARE ENTERED
THOSE WITH WATERWORKS ARE MARKED THUS
THOSE WITH FLOWING WELLS IN THE NEIGHBORHOOD THUS
THOSE WITH WATERWORKS AND FLOWING WELLS THUS:
Scale of miles
0 10 20 30 40 50
1898.
No. 1 EMMET
2 CHEBOYGAN
3 PRESQUE ISLE
4 ALPENA
5 MONTMORENCY
6 OTSEGO
7 CHARLEVOIX
8 ANTRIM
9 LEELANAW
10 BENZIE
11 GRANDTRAVERSE
12 KALKASKA
13 GRAWFORD
14 OSCODA
15 ALCONA
16 IOSCO
17 OGEMAW
18 ROSCOMMON
19 MISSAUKEE
20 WEXFORD
21 MANISTEE
22 MASON
23 LAKE
24 OSCEOLA
25 CLARE
26 GLADWIN
27 ARENAC
28 BAY
29 MIDLAND
30 ISABELLA
31 MECOSTA
32 NEWAYGO
33 OCEANA
34 MUSKEGON
No.35 MONTCALM
36 GRATIOT
37 SAGINAW
38 TUSCOLA
39 HURON
40 SANILAC
41 ST.CLAIR
42 LAPEER
43 GENESEE
44 SHIAWASSEE
45 CLINTON
46 IONIA
47 KENT
48 OTTAWA
49 ALLEGAN
50 BARRY
51 EATON
52 INGHAM
53 LIVINGSTON
54 OAKLAND
55 MACOMB
56 WAYNE
57 WASHTENAW
58 JACKSON
59 CALHOUN
60 KALAMAZOO
61 VAN BUREN
62 BERRIEN
63 CASS
64 ST.JOSEPH
65 BRANCH
66 HILLSDALE
67 LENAWEE
68 MONROE
LAKE MICHIGAN
MANITOU IS.
STRAITS OF MACKINAC
LITTLE TRAVERSE BAY
GRAND TRAVERSE BAY
SAGINAW BAY
LAKE ST CLAIR
LAKE ERIE
Manistique
St.Ignace
Cheboygan
Harbor Springs
Petoskey
Charlevoix
Rogers
Alpena
Gaylord
Atlanta
Bellaire
Leland
Northport
Traverse City
Kalkaska
Grayling
Mio
Harrisville
Frankfort
Roscommon
Oscoda
Au Sable
Tawas
Lake City
Cadillac
Manistee
West Branch
Standish
Ludington
Baldwin
Harrison
Gladwin
Hersey
Big Rapids
Midland
Bay City
Mount Pleasant
Hart
Newaygo
Saginaw
Caro
Bad Axe
Sanilac Center
Stanton
Ithaca
Muskegon
Grand Haven
Grand Rapids
Ionia
St.Johns
Corunna
Flint
Lapeer
Port Huron
LANSING
Allegan
Hastings
Charlotte
Mason
Howell
Pontiac
Mt.Clemens
DETROIT
Kalamazoo
Marshall
Jackson
Ann Arbor
Paw Paw
St. Joseph
Cassopolis
Centerville
Coldwater
Hillsdale
Adrian
Monroe
Toledo

shall sandstone around to Holland—near which there are outcrops. To the southeast around Allegan, South Haven, and Bangor, the rock surface is considerably lower. How far the softer Michigan series make a trough separating the Marshall ridge from the limestone ridge is not yet clear from the well records. Rapid variations in the altitude of the rock surface around Grand Rapids make it evident that the limestone there is much eroded. Up Grand River, at Ionia, there are other outcrops of a sandstone which is probably high up in the coal series. The rock ridge can be followed, being occasionally struck by wells, to the southeast corner of Newaygo County. From this point north the rock surface evidently falls off, for it is so deep that no ordinary wells for water encounter it, and it is only from deep explorations for salt, oil, or gas that it has been found to fall below sea level at Manistee (30 to 40 feet below tide). It is near these low points in the rock surface that the large limestone masses are found in the drift in Oceana County, and it is not unnatural to suppose that this is in a region of strong relief, whose scenery was something like that of the driftless area of Wisconsin, full of pinnacles capped with limestone. It is here, therefore, that we have carried the stream valley described on page 83, which seems to drain the most of the coal basin surrounded by the Marshall rampart.

The great depth of drift at Traverse City, with the rock bottom not yet reached, compared with Provemont, where the limestone has been struck, shows that on the northwest side again the Coldwater and St. Clair shales make a valley, though outcrops are not far away, and other facts go to support the suggestion that the limestone escarpment on this side was in bold relief and probably severely cut up. In all probability Grand Traverse Bay marks some prominent cross valley. Beyond Cheboygan Lake the limestone ridge becomes more continuous. Throughout the north half of the State the well records of depth to rock are so few that the reconstruction of the rock topography is largely guesswork, and it is necessary to fall back on the analogies of the relations of moraines to rock ridge in the lower part of the State.

PROSPECTS OF ROCK WELLS.

NORTHERN LIMESTONE DISTRICT.

From what has been said in the previous part of this paper in connection with the well reports, it appears that there is a district, from Alpena and Long Rapids to Charlevoix and north of these places, through which it will frequently be necessary, in order to get a permanent supply of water, to drill down into the limestone (Traverse or Dundee), which is often close to the surface. At moderate depths, down to about 500 feet, the water, though hard and slightly charged with hydrogen sulphide (H_2S) will be suitable for drinking. At greater depths, however, within 1,500 feet, rock salt and brines will be encountered.

NORTHERN SHALE DISTRICT.

Toward the south there is a broad district heavily covered with drift, with the rock surface probably a valley in which it will very rarely be necessary to go to rock for drinking waters, and in fact the prospect for them is not very good. The underlying rocks belong to the Carboniferous and Devonian shale series. Only here and there will a deep well, drilled for gas, brine, mineral water, etc., penetrate to the rock and find mineral water beneath the shales.

Toward the south side of this district are the sandstones of the Lower Marshall; but little is yet known of their extent.

COAL BASIN.

The coal basin occupies the center of the State, including in it the Michigan and Upper Marshall series. The basin extends from Tawas Bay probably well up toward Otsego Lake, thence to Ludington and Hart, thence down to Hillsdale County (as shown on the map, Pl. VI). Throughout this district the structure of the rocks is favorable for artesian wells, and inside the belt of moraine that surrounds it there is a very fair chance of getting a flow of water, as at Birch Run, Midland, Bay Port, Sebewaing, and elsewhere. Near the margin of this basin the Upper Marshall sandstone furnishes an abundant supply of the purest water. Toward the center of the basin the overlying Michigan series, with their highly mineralized waters, must be cased off if drinking water is desired. Still nearer the center of the basin almost all the water is slightly saline, but is still quite potable. The limits of the saline waters are roughly shown in fig. 14 (e. g., deeper wells of Saginaw, Ithaca, etc.). The deepest waters now become strong brines, the Upper Marshall becoming remarkably charged with bromine, as at Alma, Midland, and Big Rapids.

SOUTHERN SHALE DISTRICT.

This district, being the southern counterpart of the northern shale district, is the only part of the State where there is any serious difficulty in getting a satisfactory supply of water. It is divided into two parts by the projection of the Marshall sandstone nearly to the Michigan-Ohio-Indiana State boundary. To the southwest there are usually, but not always, ponds and lakes enough for city supplies, and the heavy deposits of overwash valley drift give numerous chances for wells in surface deposits. To the southeast, however, there are practically no lakes below the 800-foot contour. The surface deposits are largely lake clays and clay till, and the underlying rocks shales with subordinate sandstone streaks. These sandstones are likely to be salty or unpleasantly charged with gases. In this region, if a permanent supply can be obtained from cisterns or from the surface gravel ridges, that is probably often the best obtainable, provided due precautions are taken against surface contamination. The Berea sandstone seems to be usually salty. It might be worth while to see how far the sulphureted waters of the Dundee could be cased out and a

FIG. 14.—Map showing areas of shallow saline waters in Michigan.

good supply obtained from the Sylvania sandstone. There is no difficulty in this region in getting mineral waters, especially sulphureted.

SOUTHEASTERN LIMESTONE DISTRICT.

There only remains to be considered the limestone district of Monroe and southeastern Wayne counties. Here wells just down to or a little way in the rock encounter plenty of water, generally flowing chalybeate, hard, and highly charged with hydrogen sulphide (H_2S). There are plentiful flows of fresh water all the way down, until at 800 feet or less the gypsum and salt layers begin. Naturally the wells draining from the Sylvania sandstone seem to have the best supply, and it might be worth while to go down to it a little farther under cover.

ACKNOWLEDGMENTS.

General acknowledgment is due to a large number of persons who have rendered assistance, mainly by replies to schedules. Thanks are particularly due to L. L. Hubbard, State geologist of Michigan, for free use of data accumulated by the survey and for assistance in many other ways; also to my colleagues on the survey; to Prof. C. A. Davis for information, especially as to Tuscola County, and for hints too numerous to mention; to Prof. W. H. Sherzer and Mr. Cramer for information, especially concerning the southeastern part of the State; and to Dr. C. H. Gordon for information relating to Sanilac County and for hints as to Pleistocene deposits. In this last matter Mr. F. B. Taylor and Mr. Frank Leverett have assisted not only by their publications but by their kindly criticism. Especially in Pl. II data for the southwest part of the State are derived almost wholly from unpublished notes which Mr. Leverett kindly furnished, for the form of which, however, I am entirely responsible. The map in Pl. VII gives the location of those places from which reports have been received, and also indicates the location of public waterworks so far as can be ascertained from these reports, from the Manual of American Waterworks (1897), and from the Michigan Gazetteer. It also indicates, by a special sign, those localities near which flowing wells are reported. It may thus serve to indicate how thoroughly the ground has been covered and in what parts of the State information is still scanty. Above Saginaw Bay the population is sparse.

The paper is least satisfactory in regard to the water powers of the region considered. Those who know the facts consider them too valuable to publish. In this connection the paper by Mr. Robert E. Horton is a welcome addition. The water powers northwest of Saginaw Bay seem especially worth exploiting.

Finally, to the State weather service, C. F. Schneider, director, I am indebted for meteorological data.

INDEX.

1895.

Sixteenth Annual Report of the United States Geological Survey, 1894–95, Part II, Papers of an economic character, 1895; octavo, 598 pp.

Contains a paper on the public lands and their water supply, by F. H. Newell, illustrated by a large map showing the relative extent and location of the vacant public lands; also a report on the water resources of a portion of the Great Plains, by Robert Hay.

A geological reconnoissance of northwestern Wyoming, by George H. Eldridge, 1894; octavo, 72 pp. Bulletin No. 119 of the United States Geological Survey; price, 10 cents.

Contains a description of the geologic structure of portions of the Bighorn Range and Bighorn Basin, especially with reference to the coal fields, and remarks upon the water supply and agricultural possibilities.

Report of progress of the division of hydrography for the calendar years 1893 and 1894, by F. H. Newell, 1895; octavo, 176 pp. Bulletin No. 131 of the United States Geological Survey; price, 15 cents.

Contains results of stream measurements at various points, mainly within the arid region, and records of wells in a number of counties in western Nebraska, western Kansas, and eastern Colorado.

1896.

Seventeenth Annual Report of the United States Geological Survey, 1895–96, Part II, Economic geology and hydrography, 1896; octavo, 864 pp.

Contains papers on "The underground water of the Arkansas Valley in eastern Colorado," by G. K. Gilbert; "The water resources of Illinois," by Frank Leverett; and "Preliminary report on the artesian areas of a portion of the Dakotas," by N. H. Darton.

Artesian-well prospects in the Atlantic Coastal Plain region, by N. H. Darton, 1896; octavo, 230 pp., 19 plates. Bulletin No. 138 of the United States Geological Survey; price, 20 cents.

Gives a description of the geologic conditions of the coastal region from Long Island, N. Y., to Georgia, and contains data relating to many of the deep wells.

Report of progress of the division of hydrography for the calendar year 1895, by F. H. Newell, hydrographer in charge, 1896; octavo, 356 pp. Bulletin No. 140 of the United States Geological Survey; price, 25 cents.

Contains a description of the instruments and methods employed in measuring streams and the results of hydrographic investigations in various parts of the United States.

1897.

Eighteenth Annual Report of the United States Geological Survey, 1896–97, Part IV, Hydrography, 1897; octavo, 756 pp.

Contains a "Report of progress of stream measurements for the year 1896," by Arthur P. Davis; "The water resources of Indiana and Ohio," by Frank Leverett; "New developments in well boring and irrigation in South Dakota," by N. H. Darton; and "Reservoirs for irrigation," by J. D. Schuyler.

1898.

Nineteenth Annual Report of the United States Geological Survey, 1897–98, Part IV, Hydrography, 1899; octavo, 814 pp.

Contains a "Report of progress of stream measurements for the calendar year 1897," by F. H. Newell and others; "The rock waters of Ohio," by Edward Orton; and "Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian," by N. H. Darton.

Water-Supply and Irrigation Papers, 1896–1899.

This series of papers is designed to present in pamphlet form the results of stream measurements and of special investigations. A list of these, with other information, is given on the outside (or fourth) page of this cover.

Survey bulletins can be obtained only by prepayment of cost, as noted above. Postage stamps, checks, and drafts can not be accepted. Money should be transmitted by postal money order or express order, made payable to the Director of the United States Geological Survey. Correspondence relating to the publications of the Survey should be addressed to **The Director, United States Geological Survey, Washington, D. C.**

WATER-SUPPLY AND IRRIGATION PAPERS.

1. Pumping water for irrigation, by Herbert M. Wilson, 1896.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis, 1897.
3. Sewage irrigation, by George W. Rafter, 1897.
4. A reconnoissance in southeastern Washington, by Israel C. Russell, 1897.
5. Irrigation practice on the Great Plains, by E. B. Cowgill, 1897.
6. Underground waters of southwestern Kansas, by Erasmus Haworth, 1897.
7. Seepage waters of northern Utah, by Samuel Fortier, 1897.
8. Windmills for irrigation, by E. C. Murphy, 1897.
9. Irrigation near Greeley, Colorado, by David Boyd, 1897.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker, 1898.
11. River heights for 1896, by Arthur P. Davis, 1897.
12. Water resources of southeastern Nebraska, by Nelson Horatio Darton, 1898.
13. Irrigation systems in Texas, by William Ferguson Hutson, 1898.
14. New tests of certain pumps and water lifts used in irrigation, by O. P. Hood, 1898.
15. Operations at river stations, 1897, Part I, 1898.
16. Operations at river stations, 1897, Part II, 1898.
17. Irrigation near Bakersfield, California, by C. E. Grunsky, 1898.
18. Irrigation near Fresno, California, by C. E. Grunsky, 1898.
19. Irrigation near Merced, California, by C. E. Grunsky, 1899.
20. Experiments with windmills, by Thomas O. Perry, 1899.
21. Wells of northern Indiana, by Frank Leverett, 1899.
22. Sewage irrigation, Part II, by George W. Rafter, 1899.
23. Water-right problems in the Bighorn Mountains, by Elwood Mead, 1899.
24. Water resources of the State of New York, Part I, by George W. Rafter, 1899.
25. Water resources of the State of New York, Part II, by George W. Rafter, 1899.
26. Wells of Southern Indiana, by Frank Leverett, 1899.
27. Operations at river stations, 1898, Part I, 1899.
28. Operations at river stations, 1898, Part II, 1899.
29. Wells and windmills in Nebraska, by Erwin Hinckley Barbour, 1899.
30. Water resources of the Lower Peninsula of Michigan, by Alfred C. Lane, 1899.

In addition to the above there are, in various stages of preparation, other papers, relating to the measurement of streams, the storage of water, the amount available from underground sources, the efficiency of windmills, the cost of pumping, and other details relating to the methods of utilizing the water resources of the country. Provision has been made for printing these by the following clause in the sundry civil act making appropriations for the year 1896–97:

Provided, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be printed in octavo form, not to exceed 100 pages in length and 5,000 copies in number; 1,000 copies of which shall be for the official use of the Geological Survey, 1,500 copies shall be delivered to the Senate, and 2,500 copies shall be delivered to the House of Representatives, for distribution. (Approved, June 11, 1896; Stat. L., vol. 29, p. 453.)

The maximum number of copies available for the use of the Geological Survey is 1,000. This number falls far short of the demand, so that it is impossible to meet all requests. Attempts are made to send these pamphlets to persons who have rendered assistance in their preparation through replies to schedules or donation of data. Requests specifying a certain paper and stating a reason for asking for it are attended to whenever practicable, but it is impossible to comply with general requests, such as to have all of the series sent indiscriminately.

Application for these papers should be made either to members of Congress or to

THE DIRECTOR,

UNITED STATES GEOLOGICAL SURVEY,

Washington, D. C.