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GROUND-WATER STUDIES IN WISCONSIN, A PROGRESS REPORT

by

F. C. Foley, W. J. Drescher, and G. E. Hendrickson

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Ground-Water Studies in Wisconsin

A Progress Report

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HISTORY OF GROUND-WATER STUDIES IN WISCONSIN

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F. C. Foley, W. J. Drescher and C. E. Hendrickson

Ground-water investigations have been carried on in Wisconsin for many years by several State agencies. The Wisconsin Geological Survey, under the direction of E. F. Bean, State Geologist, has collected well samples and has prepared well logs since 1912, with F. T. Thwaites in charge of well samples and logs. During the past two years Mr. Thwaites has examined over 7500 well samples from 109 wells. There are approximately 61,000 individual samples on file in the Wisconsin Geological Survey from many hundreds of wells. The samples have been furnished by well drillers throughout the state. The geologic information and water-level and pumpage data on file have been and will be of very great value to the current detailed ground-water studies. /

/ Chamberlin, T. C., Geology of Wisconsin: Vol. II, Geological Survey of Wisconsin, pp. 128 - 175, 1877.

Regional studies of water resources were made by the Wisconsin Geological Survey and the United States Geological Survey during the early years of the century. /

/ Weidman, S. and Schultz, A. R., The Underground and Surface Water Supplies of Wisconsin: Wis. Geol. and Nat. History Survey, Bull. 35, 1915.

The Wisconsin State Board of Health, Bureau of Sanitary Engineering, has been interested in ground-water supplies, not only in connection with sanitation and chemical problems but also in problems of supply and conservation of ground water. Their records are excellent and will be very valuable in current and future investigations.

An investigation of the ground-water resources of Milwaukee County has been made by the Milwaukee County Regional Planning Commission. A report on that investigation is now being prepared.

The Soil Conservation Service of the United States Department of Agriculture has done some investigation of ground water in connection with soil-erosion studies. A number of observation wells were established in 1934, in 8 of which water-level measurements are still being made by the U. S. Geological Survey.

The Wisconsin State Conservation Commission has done considerable exploration of shallow ground-water supplies as sources of water for fire fighting and in connection with drainage areas. Water levels in 5 wells are still being measured by the State Conservation Commission.

In 1944, 10 observation wells were established by the U. S. Geological Survey in the northern Wisconsin River Valley. Measurements of water levels in that area are being tabulated by the Wisconsin Valley Improvement Company, as well as by the U. S. Geological Survey.

Initiation of Current Investigations

For many years artesian wells have supplied water for municipalities, industries and domestic use in Wisconsin. A few of these wells were drilled prior to 1875. By 1900 most of the larger industries of the eastern part of the state were using artesian well water, and municipal supplies in the east and south of the state were obtained principally from artesian wells. The greatest concentration of artesian wells and the heaviest pumpage are in the eastern part of the state, particularly in the Milwaukee-Waukesha area. There are other local areas of heavy pumpage in the larger municipalities. Water levels had been declining for many years in the heavily-pumped artesian areas prior to 1942. Increased use of water during the war years accelerated the rate of decline and it became necessary to lower pump settings in many wells. The increasing demand and accelerated decline caused concern among ground-water users in the state and it became apparent that more should be known about Wisconsin's ground-water resources.

As a result, a bill was introduced in the 1945 legislature by the Joint Committee on Finance, by request of Mr. Ludvigsen, making an appropriation to the Board of Regents of the University of Wisconsin, "- - for the purpose of investigating the underground water resources of the state, determining the present use and depletion thereof and recommending to the legislature such action as may be deemed necessary to conserve these underground water supplies as a public resource". The bill authorized the

University, "- - to cooperate with the appropriate agencies of the federal government in conducting such study". A Cooperative Agreement was signed on January 15, 1946, with the Geological Survey, United States Department of Interior, to conduct ground-water studies in Wisconsin. Frank C. Foley, of the United States Geological Survey, Water Resources Branch, Division of Ground Water, was placed in charge of the federal part of the investigation. The University is represented by a committee consisting of E. F. Bean, State Geologist, Chairman, and Professors Noble Clark and Arno T. Lenz.

Mr. Foley arrived in Madison on February 16, 1946, to start the investigations. The delay in starting was due in a large part to non-availability of qualified personnel. Many technical men of the U. S. Geological Survey were still on active duty with the armed forces. An office was set up adjacent to the office of the State Geologist, in Science Hall, at the University at Madison.

Personnel, in addition to Mr. Foley, now consists of Gerth E. Hendrickson, Geologist, who reported for duty at the same time as Mr. Foley; Wm. J. Drescher, Engineer, who reported April 30; and a clerk-stenographer. During the summer months, E. F. Spitzer, E. N. Rein and H. V. Skatrud, University of Wisconsin civil engineering students, worked full time and Spitzer is continuing on a part time basis during the school year.

Procurement of necessary equipment has been difficult. Delivery has been very slow on almost everything that has been ordered, but most basic equipment is now on hand and in use. Transportation was a bottleneck for a time but one Ford Panel truck has been loaned by the Topographic Branch of the U. S. Geological Survey and two half-ton pickup trucks have been procured from Army Surplus.

Sufficient steel tapes for basic needs have been procured and more are on order. Water-stage recorders ordered last spring have recently been received and ten have been installed. A great deal of difficulty has been encountered in obtaining the small amount of materials necessary for construction of shelters for the recorders where installations must be in the open.

Cooperation

The current ground-water investigations are based on cooperation between federal, state, local and private personnel. It holds true from the formal cooperative agreement between the University and the U. S. Geological Survey, to the collection of data from owners of private wells. The cooperation in Wisconsin has been splendid and complete. The State Board of Health is making its extensive records available and is actively cooperating in collecting basic data. The Milwaukee County Regional Planning Commission has made available data collected during its study of ground-water conditions in Milwaukee County - data very valuable in connection with the current investigations. All municipal officials as well as private corporations and individuals have readily assisted in the collection of data and have allowed access to wells and well records. The cooperation is particularly appreciated in connection with pumping tests where disruption of normal operating schedules has been necessary.

Geology of Wisconsin

A brief review of the geology of Wisconsin _/ is presented

_/ Hotchkiss, W. D. and Bean, E. F., A brief outline of the geology, physical geography, and industries of Wisconsin: Wis. Geol. and Nat. History Survey, Bull. 67, 1925

here, for the occurrence of ground water and studies relating to it are basically geologic.

The rock formations of Wisconsin include pre-Cambrian igneous and metamorphic rocks, Paleozoic sandstones, limestones and shales, and Pleistocene deposits of sand, gravel, and bowlder clay of glacial origin.

The pre-Cambrian rocks are at the surface or are covered only by glacial drift in a large area in the north and north-central parts of the state. To the east, south, and west of this area they are covered by Paleozoic strata which dip generally away from the area. The pre-Cambrian formations are of low permeability and do not yield large quantities of water, but in some places furnish enough for domestic use.

Cambrian sandstones crop out to the east, south, and west of the exposed pre-Cambrian. The outcrop area is greatest in the south and west sections of the state. The Cambrian sandstones are the most important artesian aquifers in the state, and in the outcrop area they are also an important source of ground water under water-table conditions.

The Lower Magnesian limestone overlies the Cambrian sandstones and occurs at the surface or directly under the glacial drift in a nearly continuous, concentric band around the east, south, and west of the exposed Cambrian sandstones. Over a large area in the western part of the state, the Lower Magnesian limestone caps the hills with the underlying Cambrian sandstones exposed in the stream valleys. The Lower Magnesian furnishes water to shallow wells over part of its outcrop area. Where it occurs as a thin capping on high hills, it generally lies above the water table.

Between the Lower Magnesian limestone and the overlying St. Peter sandstone is an erosional unconformity. Accordingly, both the Lower Magnesian and the St. Peter range considerably in thickness, and in some places the Lower Magnesian is entirely absent.

The area in which the St. Peter sandstone lies at the surface, or directly under the drift, is relatively small. It occurs as small patches overlying the Lower Magnesian uplands in the west and crops out in valleys in the south and southwest. It also forms a very narrow band from a point west of Marinette southward to the state line just east of Beloit. It is an important water-table aquifer where it crops out in the valleys, and in the eastern part of the state it is a source of artesian water.

The Galena-Platteville limestones overlie the St. Peter sandstone and are exposed at the surface, or under the drift, as a continuous broad belt from Marinette County southward to the state line, and form the upland surface in the south and southwest parts of the state. Relatively small patches occur capping the St. Peter sandstone in the northwest and west. The Galena-Platteville limestones form an important source of ground water in the outcrop area in the southwest part of the state. In some areas, the water table in the Galena-Platteville is perched.

The Richmond shale crops out as a narrow continuous band southwestward from Green Bay, along the east shore of Lake Winnebago, and southward to the Illinois state line near Walworth. It also occurs as minor patches capping the Galena-Platteville uplands in the south and southwest. The shale is important as a confining formation between the overlying Niagaran limestone and all aquifers

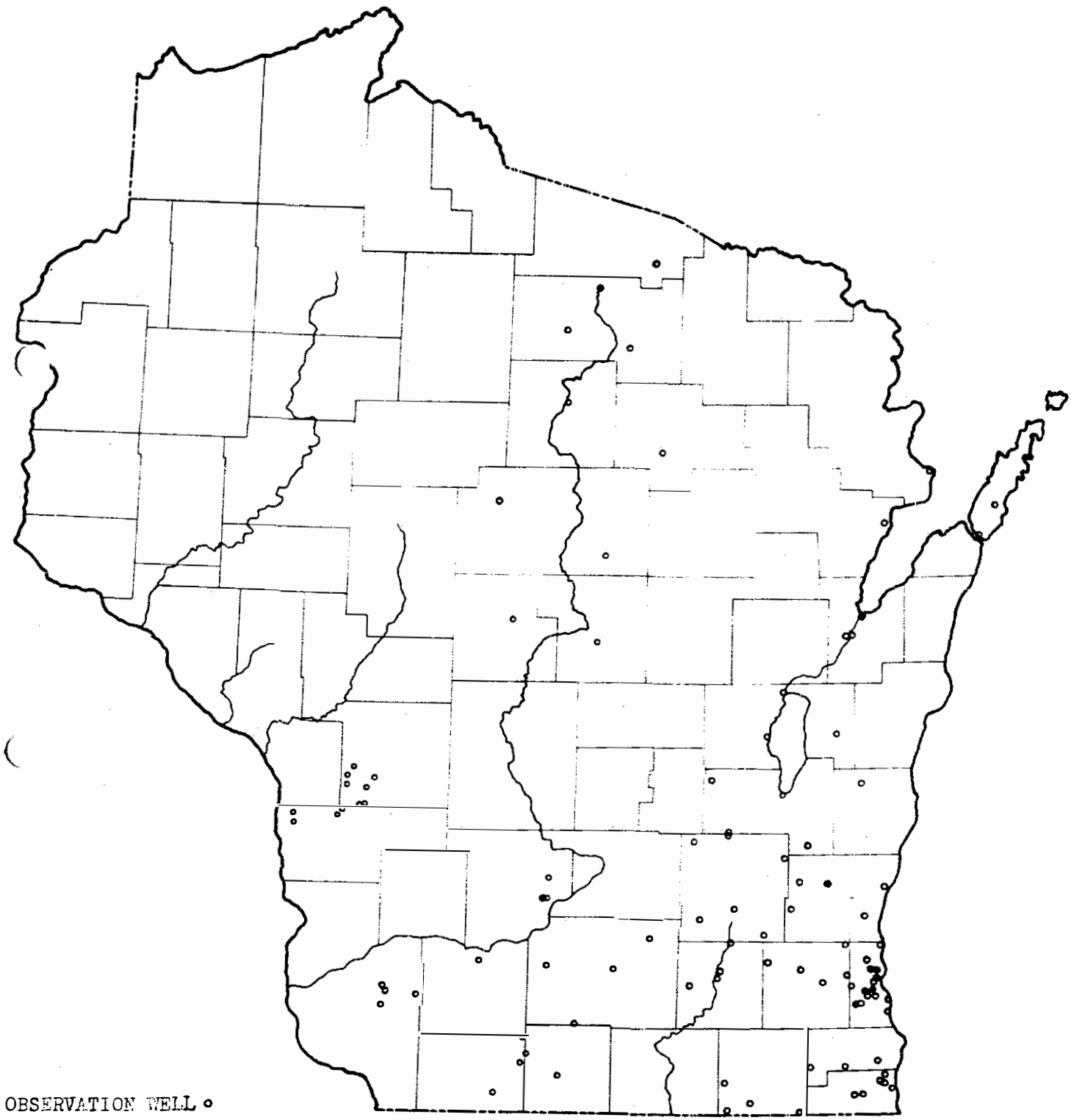

FIGURE 1. WISCONSIN OBSERVATION WELLS

below it, but in itself it is of no importance as an aquifer.

The Niagara limestone overlies the Richmond shale in the area adjacent to Lake Michigan. It extends from Door County southward to the state line in Kenosha County. It is important as a souce of both water-table and artesian ground water. Most of the few present-day flowing wells in eastern Wisconsin derive their water from the Niagara. In the heavily-pumped sections of the Milwaukee area, where deep wells are open in both the Niagara and in the underlying sandstones, the Niagara is losing water to the sandstone formations.

The Milwaukee formation occurs as a narrow band along the Lake Michigan shore from Sheboygan to Milwaukee. It is composed of limestone and interbedded shale. It is of minor importance as a source of ground water.

The sand and gravel of the glacial drift is an important source of ground water over most of the glaciated area. With the recent decline in water level in deep wells in certain areas, the possibility of developing supplies from the glacial drift is receiving increasing attention. Because of the considerable variation in character of the glacial drift, even in small areas, it is generally necessary to drill test wells prior to the drilling of a producing well. In the area of pre-Cambrian outcrop the mantle of glacial drift is, with few exceptions, the only possible source of ground water.

Investigations in Progress

General Observation Well Program

A series of observation wells is being established in Wisconsin which will eventually cover the entire state. Measurements of water

levels are made in the observation wells at intervals, usually once a week, or once a month. Wells are selected so that, as far as possible, each type of ground-water occurrence is represented. Water-level data obtained in order to show fluctuations as a result of climatic conditions, water use, and drainage are valuable in obtaining an overall picture of ground-water resources. In detailed studies water-level data are essential in determining the effects of pumping and seasonal trends, and for determining drawdown and recovery during pumping tests.

Wherever possible unused existing wells are set up as observation wells but some of the shallow wells have been driven by hand using well drive points for specific use as observation wells.

As of October 15, 1946, 108 observation wells had been established in Wisconsin. Location of the observation wells is shown in figure 1. Not all individual wells are shown in the Milwaukee area as they are too closely spaced to show satisfactorily. The group of 11 wells in the Coon Creek area in Vernon and Monroe counties was established in 1934 by the Soil Conservation Service of the United States Department of Agriculture and was later taken over by the U. S. Geological Survey. Records of water levels in the wells have been published in U. S. Geological Survey Water Supply Papers 777, 817, 840, 845, 886, 908, 938, 946 and 988. Water levels in 1943 are the latest to be published but those for later years will appear in due course, both for the Coor Creek area wells and for more recently-established wells.

The wells in the northern Wisconsin River Valley were established in 1944. All others have been established since the current investigations were started. Five wells being measured

by the Wisconsin State Conservation Commission are not shown on the map. They are all in northern Wisconsin.

Measurements of water levels are made by members of the U. S. Geological Survey staff, state employees, local observers, usually a person on whose land the well is located, or someone living nearby, and by municipal water departments. Measurements are made with a steel tape from a fixed measuring point and are taken to hundredths of a foot.

Water level measurements in one key well, on which data are available since 1934, refute the belief held by some people that water levels generally have declined drastically in Wisconsin during the past several years. The well is a water-table well 44 feet deep, located 2½ miles southwest of Cashton in Monroe County. Measurements were started on June 29, 1934, at which time the water level was 17.76 feet below land-surface datum. The water level was at its lowest point during the more than 12 years of record on February 28, 1935, at which time the water level was 18.71 feet below land surface datum. The well started to recover in 1935 and reached the highest level during the period of record on March 29, 1946, when the water level was only 6.10 feet below land-surface datum.

Pumpage Data and Water Levels in Municipalities

The Bureau of Sanitary Engineering of the Wisconsin State Board of Health, has started a very worth-while project to obtain records of quantity of water pumped and static and pumping water levels in municipal wells in Wisconsin. Basic data and monthly report forms have been printed by the Bureau of Sanitary Engineering.

The basic data sheets are for record of basic information on each well in a municipality, used or unused. The report forms, submitted monthly, are for a daily report of quantity of water pumped in each well and for a report of static and pumping water levels at intervals, preferably at least once a week. The forms are submitted in duplicate by municipal water superintendents with one copy retained by the Bureau of Sanitary Engineering and one copy going to the U. S. Geological Survey. Report forms have been sent to 141 municipalities in Wisconsin and it is planned to complete the coverage of the state. Data compiled from the reports will furnish a very valuable record of water used in Wisconsin and a continuing check on trends of water levels. Many municipalities have kept records of pumpage and water levels for years but many more have started keeping records as a result of the project. The records are of value to the municipalities as well as to the understanding and solution of ground-water problems in Wisconsin. The information will be of increasing value as the period of record becomes longer. Reports are being returned, though not all the municipalities have reported as yet.

Eastern Wisconsin Area

Work is being concentrated at present in eastern Wisconsin where the decline in water levels in deep artesian wells has caused greatest concern. The investigation is a detailed study of the water resources of the area, not only of the deep artesian aquifers but also of shallow sources. Measurements of water levels, both static and pumping, are being made to determine trends and to map the piezometric surfaces. Pumping tests have been made and others will be made to determine the hydraulic characteristics of the various aquifers.

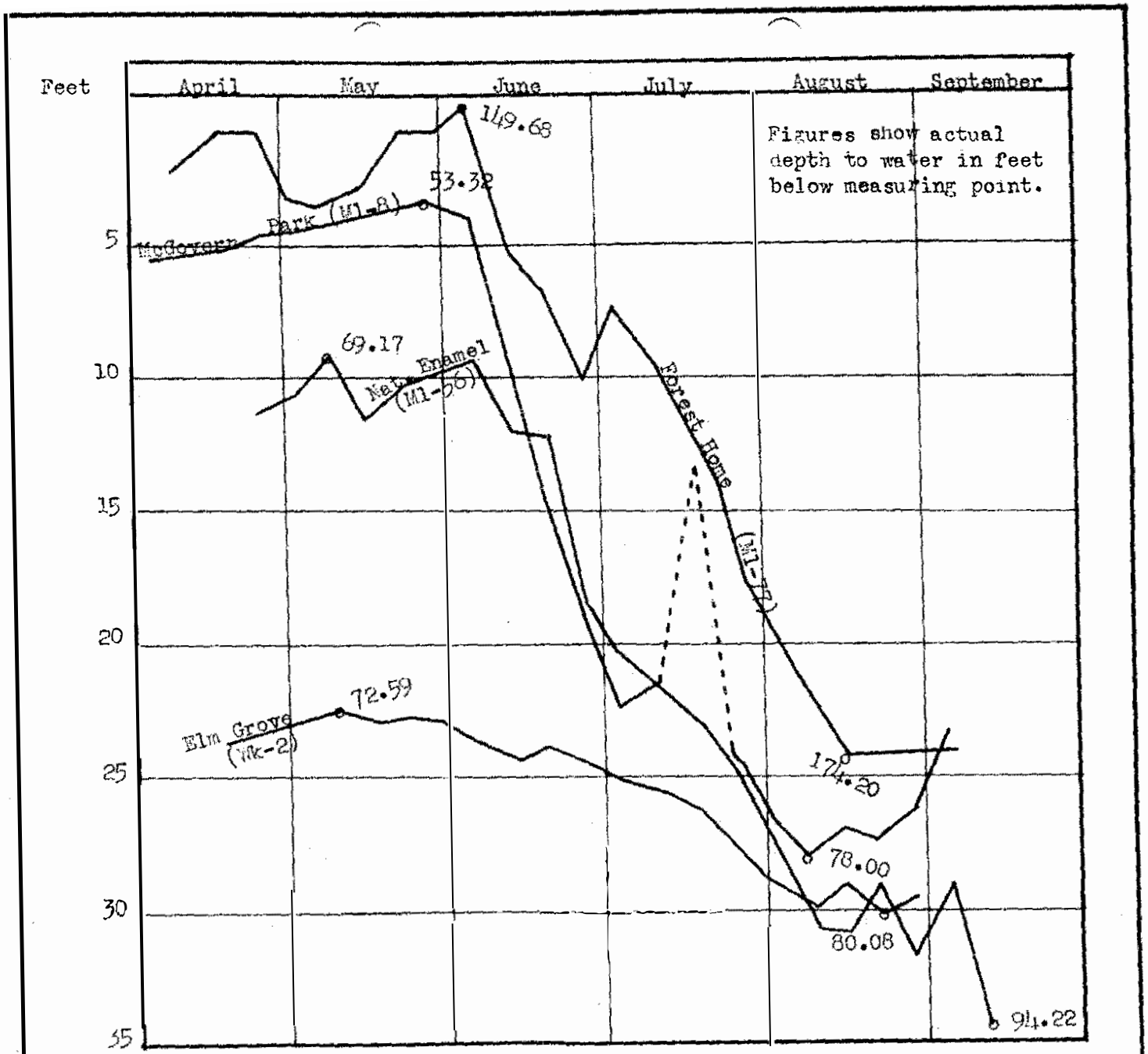

FIGURE 2. HYDROGRAPHS SHOWING DECLINE IN WATER LEVEL IN FOUR MILWAUKEE WELLS THROUGH THE SUMMER OF 1946

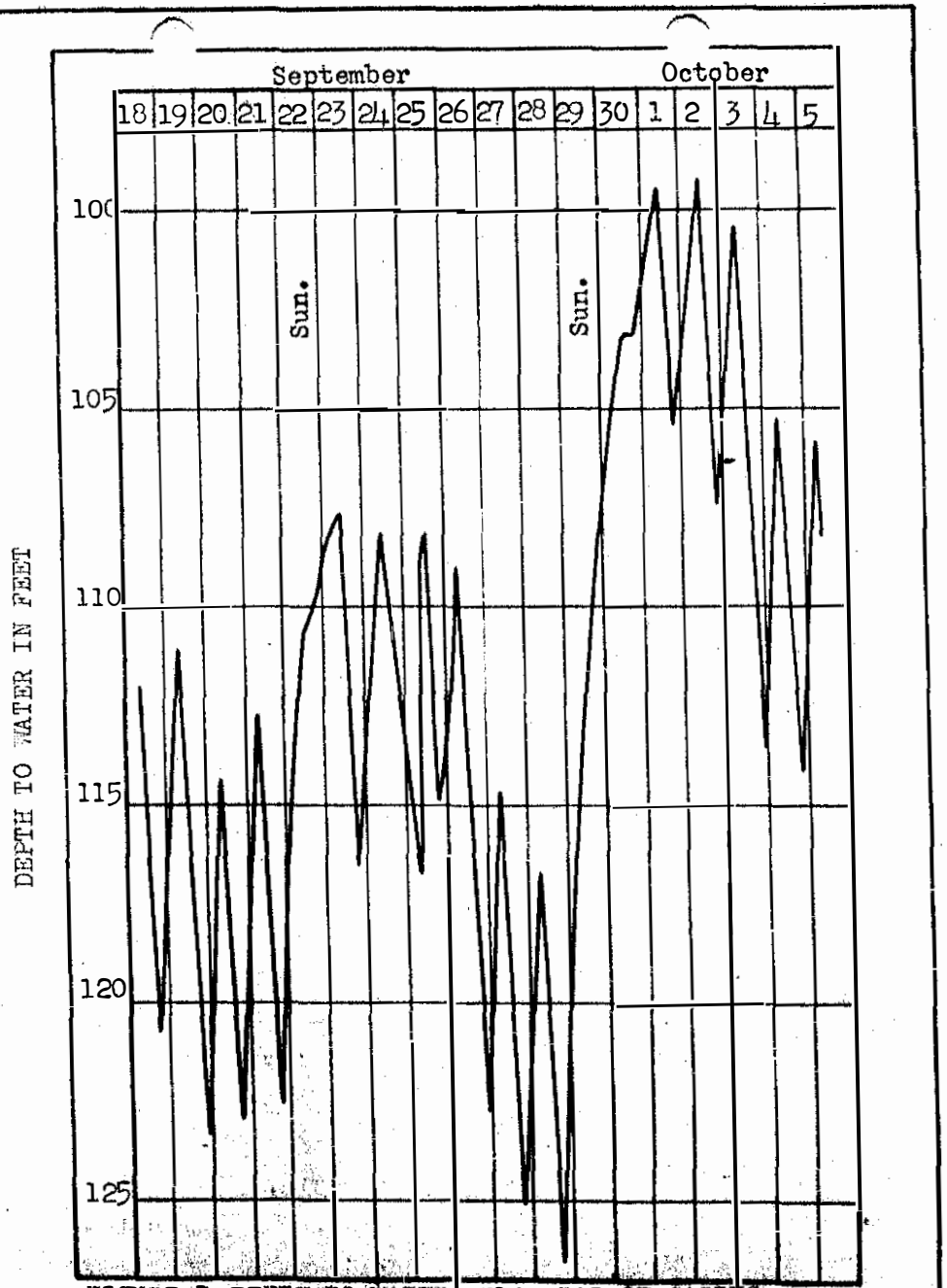

FIGURE 3. DEPTH TO WATER BELOW TOP OF CASING, SEPT. 18 to OCT. 5, 1946, FROM RECORDER CHARTS in the MILWAUKEE JOURNAL WELL, MILWAUKEE, WISCONSIN

Studies of past and present quantities of water pumped and the uses to which the water is put are in progress but are not yet far enough advanced to give total quantities of ground water being withdrawn. Recharge areas and rates of recharge will be investigated. It is planned that the completed study will show present and future effects of withdrawal of ground water on water levels, the interference that can be expected between wells, and the quantities of water that can be withdrawn to develop the ground-water resources to their fullest extent for perennial use.

Twenty observation wells have been established in Milwaukee County where decline in water levels is most widespread. In each case the observation well is an existing well. Most of them are unused but a few that are being pumped intermittently are being measured. Observation wells have been established also at many points outside Milwaukee County as shown in figure 1.

Automatic water-stage recorders have been placed on eight wells in eastern Wisconsin. More will be set up as soon as recorder shelters have been constructed. All those now in operation are in pump houses or buildings where individual shelters are not necessary. As an illustration of the record provided by an automatic recorder, that of the Milwaukee Journal well, located at 333 West State Street, Milwaukee, for the period September 18 to October 5, is shown in figure 3. Daily fluctuations of from about 7 to 12 feet are shown. The well is in an area of heavy pumpage where nearby wells are used largely for air conditioning. Note the recovery in static water level on Sunday, September 29, when pumpage was reduced.

It is apparent that spot measurements of water levels weekly or even daily do not give a real picture of conditions in a well where fluctuations are large and rapid.

Observation wells were first set up by the Geological Survey in eastern Wisconsin in April 1946 and additional wells have been established during succeeding months. The period of record is very short and little can be determined yet as to the present trend in water levels. Static levels in four of the Milwaukee area wells for which the period of record by the Geological Survey is longest are shown in figure 2. Water levels in three of the wells reached highest points in May while the Forest Home Cemetery well reached its peak in early June. Lowest points were reached in August and September.

The greatest range in water levels measured in 1946 was in the Milwaukee Journal well for which only 18 days of record is shown in figure 3. Weekly measurements with a tape were started on April 23, 1946, before a water-stage recorder was available. The highest water level measured was on May 9, when it was 74.02 feet below the top of the casing, and the lowest was on August 22, when it was 121.29 feet, a range of 47.27 feet. On October 2, the high point shown in figure 3 was 99.23 feet below the top of the casing.

It is expected that water levels will rise during the winter months due to normal decrease in quantities of water pumped. It is probable that the highest levels in 1946 were reached in May or June, shortly after measurements were started. It is evident that measurements must be continued indefinitely to show long-term trends.

PUMPING TESTS

Coefficients of Transmissibility and Storage

The amount of water that can be withdrawn from an artesian aquifer depends upon the amount of water which is absorbed by that aquifer in the area of outcrop, upon the ability of the aquifer to transmit water to the wells, and upon the amount of water that is released from storage in the aquifer with a reduction in artesian head. The rate and amount of decline of water levels due to pumping from an aquifer depend upon the transmissibility and storage capacity of the aquifer.

The ability of an aquifer to transmit water is expressed as a coefficient of transmissibility, which is defined [1] as the number of

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[1] Theis, C. V., The significance and nature of the cone of depression in ground-water bodies: Econ. Geol., vol. 33, pp. 889-902, 1938.

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gallons of water that will move in one day through a vertical section of the aquifer one foot wide, with a height equal to the full thickness of the aquifer, with a hydraulic gradient of 100 percent.

The storage capacity of an artesian aquifer is expressed by a coefficient of storage, which is defined [1] as the volume of water,

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[1] Theis, C. V., Idem., 1938

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measured in cubic feet, released from storage in each column of the aquifer having a base of one square foot and a height equal to the thickness of aquifer, when the artesian head is lowered one foot.

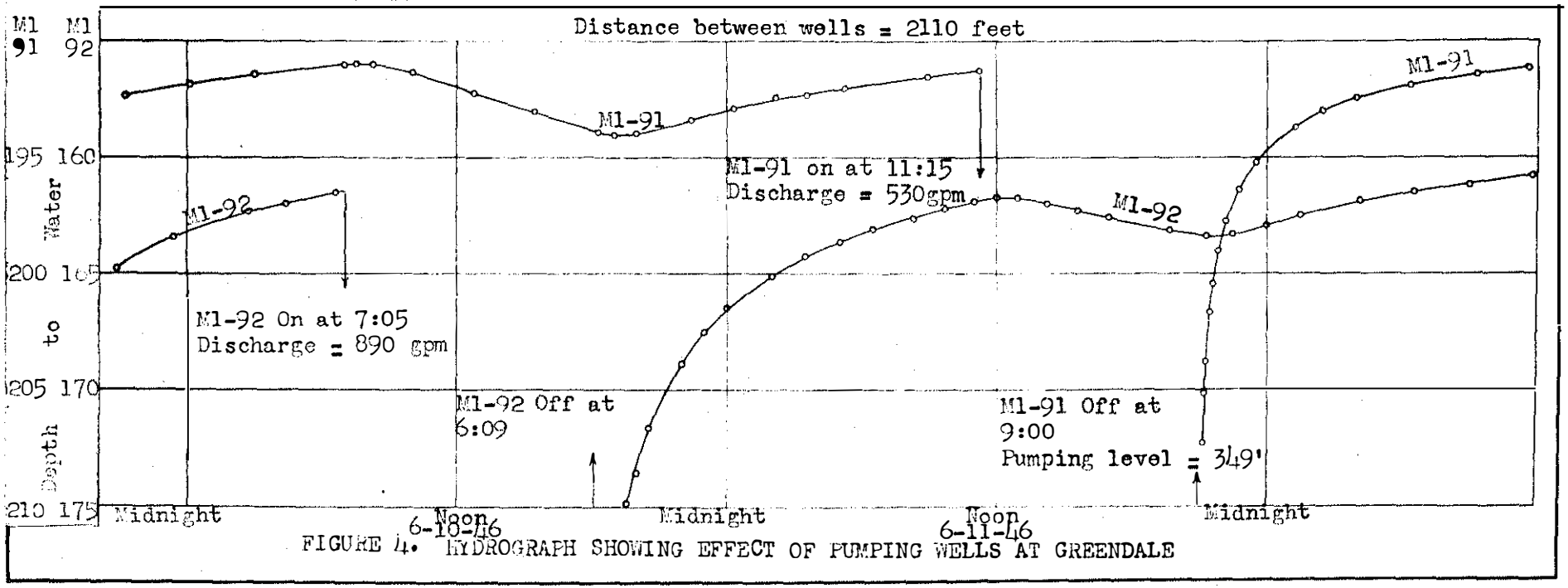

FIGURE 4. HYDROGRAPH SHOWING EFFECT OF PUMPING WELLS AT GREENDALE

In order to determine the coefficients of transmissibility and storage of the artesian aquifers that underlie most of eastern Wisconsin, pumping tests have been made at Greendale, Town of Lake, McGovern Park in Milwaukee County, Badger Ordnance Works, and at Waukesha. The Waukesha test was the most extensive but was made too recently for results to be included in this report. Other tests will be made throughout the State.

Greendale Tests

A typical series of pumping tests was made of the St. Peter and Cambrian sandstones in June of 1946 at Greendale in Milwaukee County. Both of the municipal wells that were used in the test are cased through the Richmond shale thus shutting off all water except that which comes from the sandstones. Each well in turn was pumped at a constant rate and the fluctuation of the water level in the idle well was measured. The pump was then turned off and the amount and rate of recovery of the water level in each well was measured. Measurements to the nearest hundredth of a foot were made by means of a steel tape. Airline measurements of pumping levels were made in the north well but could not be made in the south well due to mechanical difficulties. Figure 4 shows hydrographs of the recovery of each well after pumping and the effect of each well on the other. The distance between the two wells is 2110 feet.

Certain features of this test should be pointed out as differing from the ideal test. Wherever possible water levels should be measured in at least two observation wells other than the pumped well; at Greendale only one observation well was available. Before a well is turned on or off during a test it is desirable that the water levels be at equilibrium, ie., the water level in all wells should be

rising or falling at the same rate. It was impossible, at Greendale, except on the last day of the test, to allow the water levels to reach equilibrium because of the necessity of meeting the municipal demand for water.

The non-equilibrium formula__/ which was developed under

__/Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Trans. Amer. Geophys. Union, pp. 519-524, 1935.

Theis, C. V., Op. Cit., Econ. Geol., vol. 33, pp. 889-902, 1938.

Jacob, C. E., On the flow of water in an elastic artesian aquifer; Trans. Amer. Geophys, Union, pp. 574-586, 1940.

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the direction of Charles V. Theis of the U. S. Geological Survey, was used to determine the coefficients of transmissibility and storage. The formula is

$$s = \frac{114.6\,Q}{T} \int_{\frac{1.87\,r^2\,S}{Tt}}^{\infty} \frac{e^{-u}du}{u}$$

in which s is the drawdown, in feet, at any point in the vicinity of a well pumped at a uniform rate; Q is the discharge of the well in gallons a minute; T is the coefficient of transmissibility, in gallons a day per foot; r is the distance, in feet, from the pumped well to the point of observation; S is the coefficient of storage of the aquifer; and t is the time, in days, that the well has been pumped.

In using the formula it is assumed that the aquifer is infinite in extent, that its transmissibility is the same at all places, that it is confined between impermeable beds above and below, that the coefficient of storage is constant, and that water is released from storage instantaneously with a decrease in artesian head. In determining coefficients the non-equilibrium formula may be applied in three ways: (1) to the drawdown or recovery of at least two observation wells at any time; (2) to the amount and rate of drawdown or recovery of a single observation well; or (3) to the rate of recovery of a pumped well after pumping ceases.

Methods (2) and (3) were used in applying the formula to the Greendale tests. The following table gives the coefficients of transmissibility and storage obtained from the Greendale tests.

RESULTS OF GREENDALE PUMPING TESTS

June 9-12, 1946

Recovery Tests

Well	Duration (hrs)	T gpd/ft
M1-91	9 (Dd)	21,600
	14½	14,100
M1-92	17	16,400
	17	16,100

Interference Tests

Obs. Well	Pumped Well		Duration (Hrs)	T gpd/ft	S
M1-91	M1-92	on	11	35,100	.00047
		off	17	32,300	.00042
M1-92	M1-91	on	10	21,800	.00031
		off	14½	20,700	.00027

Average Coefficients

Recovery and Drawdown Tests

No. of Wells	No. of Tests	Average Duration (Hrs)	T gpd/ft Max.	T gpd/ft Min.	T gpd/ft Aver.	S Max.	S Min.	S Aver.
2	4	14½	21,600	14,100	17,000			
			Interference					
2	4	13	35,100	20,700	28,000	.00047	.00027	.00037
			All Tests					
2	8	13-3/4	35,100	14,100	22,300			
2	4	13				.00047	.00027	.00037

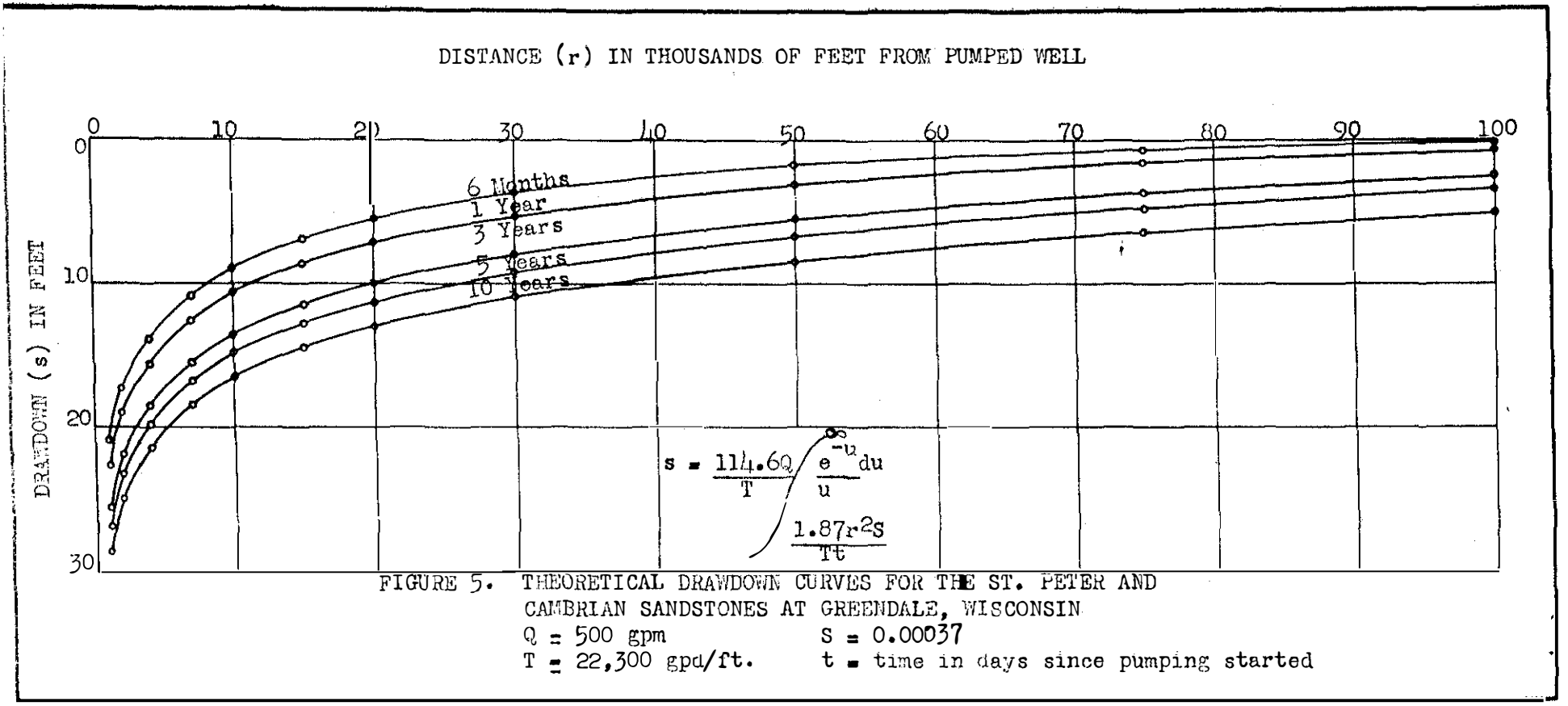

FIGURE 5. THEORETICAL DRAWDOWN CURVES FOR THE ST. PETER AND CAMBRIAN SANDSTONES AT GREENDALE, WISCONSIN

Q = 500 gpm S = 0.00037

T = 22,300 gpd/ft. t = time in days since pumping started

Application of Coefficients

The curves in figure 5 were computed by means of the non-equilibrium formula, using the average coefficients obtained from the Greendale tests. The curves represent the theoretical drawdowns in water levels at various distances from a pumped well at the end of 6 months, one year, 3 years, 5 years, and 10 years produced by continuous pumping from the well at the rate of 500 gallons a minute.

As stated, the non-equilibrium formula assumes an aquifer of infinite areal extent; therefore, the drawdown figures obtained from these curves must be corrected for the effects of lateral boundaries and changes in thickness and character of the aquifer before they are applicable to the sandstones at Greendale.

The lateral boundaries of the sandstones in the Milwaukee-Waukesha area are the outcrops of the sands and possibly pre-Cambrian highs to the northwest on a line between Waterloo and Fond du Lac. The effect of the outcrops of the aquifers after a long period of continuous pumping is to establish a new distribution of artesian head such that water withdrawn from the formations is replaced by recharge or by water drawn from storage in and near the outcrop area. Boundaries such as the pre-Cambrian highs within the formation which restrict the capacity of the formation as an aquifer, have the same effect as reduced permeability and cause an increased rate of decline of water levels. The magnitude of the effect of the pre-Cambrian highs is as yet unknown.

Conclusion

A good start has been made on the study of the ground-water resources of Wisconsin but very much remains to be done. The detailed investigation of the eastern artesian area alone, on which work is now being concentrated, will require at least two years. After a report has been made measurements and records should be maintained indefinitely. Water supply in the remainder of the state presents a series of interesting and important problems, the solution of which will require a great deal of work.