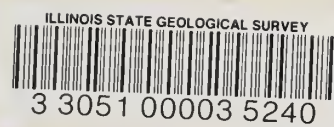
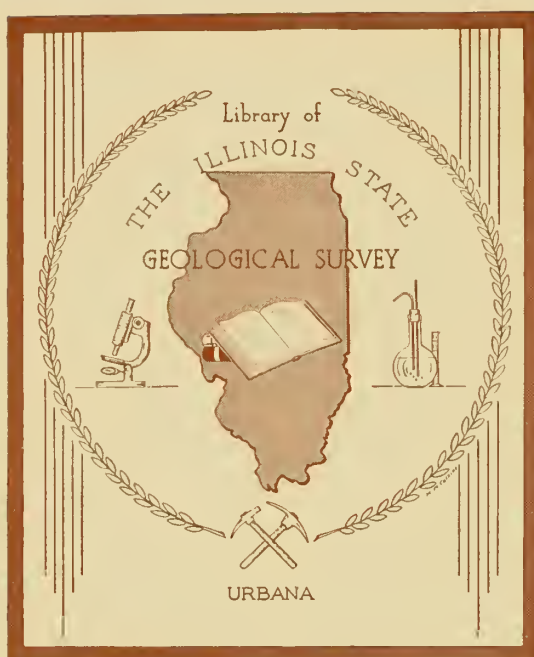



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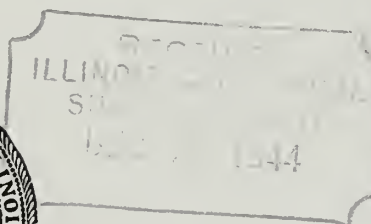
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GEOPHYSICAL LOGGING OF WATER WELLS
IN NORTHEASTERN ILLINOIS

By

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Geophysical Logging of Water Wells in Northeastern Illinois

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Presented November 4, 1943

FOREWORD

Because of the many problems of groundwater supply in northeastern Illinois, and particularly those occasioned by the great increase in industrial and municipal demands due to the war, a special geological and geophysical study of the groundwater resources of the region was undertaken. Although a great amount of data was available on the deep wells in this region, it was believed that many of the basic factors controlling the production of water in any well and the conditions that are regionally important were not known. Geophysical and geological methods for obtaining similar pertinent information in the oil industry had already been developed but had not been generally applied to the water well industry and practically no applications had been made in Illinois.

A program of experimental studies was set up to try the applications and modifications of these oil-well methods to water wells and to obtain as much information as possible on the producing zones and production conditions of deep wells in northeastern Illinois. A number of different tools and instruments were run in wells to obtain different types of data on the wall rock and fluids. As the investigations progressed there were developed a number of modifications of the usual techniques, measurements, scales and interpretative practices. In addition, tools

and techniques were developed for particular water well problems. To records obtained by these methods of logging the term "geophysical log" has been applied.

Geophysical logs have been made of more than 20 wells in northeastern Illinois, and from them many concepts that are essential to the understanding of water production have been worked out. The geophysical data have been closely integrated with geological and production data to give a sound basis for principles that have wide application and for specific recommendations on individual wells.

GEOPHYSICAL LOGGING METHODS

Logging Truck and Equipment

Geophysical well surveys are made from special trucks which are completely equipped for this work. They have special mono-conductor or multi-conductor cables for running the instruments into the well, a winch to spool the cable, and accurate measuring devices to obtain correct measurements of depth. All measurements of different conditions within wells are made electrically and are recorded photoelectrically with galvanometers as continuous curves on sensitized film or paper. The trucks carry their own power supply, usually both batteries and generator. All of the tools run into the hole are constructed for electrical measurement of various parameters to considerable depths under the hydrostatic pressure of the fluid column in a well.

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Measuring Devices

In many wells no correct or accurate measurements of the casing, liners, producing zones, or even of the total depth are available. Correct measurements play an important role in obtaining well data, and the measuring devices are a basic part of geophysical logging equipment. There are two types. Both are counter devices which are motivated by the sheave or sheaves over which the conductor lowering a surveying device into a well is run. In one type, the measuring device is mechanically connected to the camera in the logging truck and drives the film so that the correct depths are recorded photoelectrically. In the other type a self-synchronizing electric motor unit is used to operate the camera in coordination with the measuring sheave.

Electric Logs

Curves which record the electric potentials and the electric resistivities as measured in a well-bore together constitute the "electric log." In most cases a potential curve and a resistivity curve are recorded simultaneously by means of a traveling electrode assembly that consists of several electrodes spaced differently. Usually they are drawn on the electric log so that the potential log is at the left and the resistivity curve is at the right. The "higher" or negative potentials are at the left side of the potential log and the positive are at the right; resistivity values increase to the right. Measurements indicative of the formations are obtained only in open hole. No record other than the presence of casing and liners is obtained inside of pipe.

Potential Logs

Measurements of potentials are made with a single pick-up on the traveling electrode. The curves indicate the various conditions which create potentials and may usually be attributed to any of several causes, chief of which seem to be electrofiltration and several different types of electrochemical phenomena. The principal use of potential logs is to determine the relative effective permeability of the different zones within wells,

although in some wells the measurements yield considerable data on stray electrical earth currents which are important in the study of corrosion problems.

On potential logs the permeable zones, usually sandstones, creviced limestones or dolomites, have negative potentials which are relatively "higher" than those of many fresh water wells where there is little circulation and no difference in composition between the water in the well-bore and the water in the porous zones penetrated by the well. In some of these wells the addition of salt to the water in the well-bore will increase the potential relief so that the relative permeability may be recognized and the curve used. In other wells where a sufficient water volume is available at the well, a potential log made while keeping the hole filled with water has been the only usable curve by which to distinguish permeable zones. It is therefore desirable to run a "hole-filled" potential log wherever water connections, fire-hydrants and hoses, or other supplies are readily available.

Resistivity Logs

There are several methods of measuring the apparent electric resistivity or impedance of the formations in a well. That most commonly used employs two potential electrodes and one current electrode, all combined in a traveling assembly which is lowered into the well, and another current electrode which is grounded at the surface. The potential or measuring electrodes are spaced from a few inches apart (for detailed logging of thin-bedded zones) to six feet or more apart for deeper penetration of the well rock in order to investigate the character of the fluids in the porous formations beyond the zone invaded by fluid from the well bore. Measurements made with closely spaced electrodes sometimes do not penetrate deeply enough into the formations to reveal their true character, and the measurements made with widely spaced electrodes fail to show thin beds. Another method, and one which obtains extremely detailed logs of thin-bedded zones, employs a single traveling

electrode and one electrode grounded at the surface. In all methods the resistivity measurements are affected by the character of the fluid in the well-bore and by the hole diameter, as well as by the character of the wall rocks and the fluids in them.

On most well surveys two or more electric resistivity logs are run, usually a so-called "normal" curve made with the potential electrodes closely spaced (ordinarily 18 inches apart) or with the single traveling electrode to obtain a detailed log, and a so-called "third" curve with the potential electrodes from four to six feet apart to obtain information concerning the fluids in the formations. Where further information is needed, additional logs can be run with the potential electrodes only a few inches apart (the "auxiliary" curve) or with them more than six feet apart (the "lateral" or "fourth" curve).

The resistivity curves are used primarily to log the lithology of the wall rock in wells, but from them the character of the fluids (fresh water, salt water, oil, gas) can be surmised, and the exact location of casing and liner in the hole can be determined. Non-porous non-argillaceous materials, such as most limestones and dolomites, have high resistivity values; shales and other argillaceous materials have low resistivity values; the resistivity values of porous rocks such as most sandstones and some dolomites and limestones depend largely upon the amount and character of the contained fluids, and generally are intermediate between the typically high values of limestone and the low values of shale. The resistivity of metallic objects such as casing is extremely low. Close correlation of well-cuttings and resistivity curves through any or all zones in a number of wells gives a sound basis for interpretation of the curves alone through equivalent zones in wells where samples are not available.

Fluid Temperature

Temperature logs are made with continuously recording resistance thermometers which record the temperature of water in the well as a continuous curve.

From these logs the temperature of water from the different aquifers may be recognized. In most wells surveyed the temperature does not increase at a constant rate. Most temperature curves are interpreted as indicating circulation conditions or geological conditions in the well or producing conditions in adjacent wells at the time of logging.

In many of the wells some thermometers are affected by "noise" or stray earth currents so that many minor variations and irregularities not indicative of temperature changes in the fluid are recorded. These may mask irregularities which are related to actual minor temperature changes. Therefore, in drafting and interpreting temperature logs, particularly in the industrial sections in and near Chicago, such minor variations are eliminated or disregarded.

In one well surveyed recently a temperature log was run while water was flowed into the well from the surface. From the log, the zone where most of the added water was leaving the hole was recognized and was thus identified as the principal aquifer.

In oil wells the principal use of temperature logs has been to locate the approximate top of cement behind the casing. The method is based upon the fact that the heat generated during the setting of the cement produces a marked increase in temperature of the fluid within the casing at the top of the cement. Temperature logs have been used for the same purpose in a few water wells and undoubtedly will be so used to a greater extent in the future. The advantages of cemented casing are now recognized, and more and more casing strings are being cemented.

Hole Diameter

A continuous record of hole diameter is furnished by the hole caliper. The caliper tool consists essentially of four arms which are extended by springs, and an electric resistor which is motivated by the arms. The instrument is run into the hole with the arms closed, held to the frame by a small steel band. The arms are opened on bottom by breaking the band through detonation of a small shot.

Then the average hole diameter is logged as a continuous graph by recording the changes in resistance in the circuit due to the arms moving the resistor as the tool is drawn up the hole.

Caliper surveys of water wells in Illinois have been of value in analyzing the effect of shooting, in finding the actual diameter of wells about which there was no available information, and in locating caving zones. They have also furnished additional important information on the condition of casing and liners and the condition of the casing seat, and they have proved the existence of major crevice systems in some of the dolomite formations which, contrary to previous thought, play an important part in the groundwater supplies of northern Illinois.

Caliper records are also affected by stray direct currents in some urban areas, and because these currents cause many anomalies, some of the records are of greater relief than is explained by the variations in hole diameter, especially in lower shaly formations where such interference is at a maximum. Where stray earth currents exist, satisfactory caliper logs have been obtained only by cutting out the regular tool-opening and recording circuits and by using instead a rod affixed to the lower part of the tool which breaks the band and releases the arms when the tool is set on bottom, and an improvised alternating-current circuit to take a series of readings throughout the well; of course no continuous record is obtained but a log can be constructed from the spot readings.

Fluid-Resistivity Logs

The logs of the variations in resistivity of the fluid have furnished much corroborative evidence regarding circulation conditions within wells. Logs have been run with several different instruments with closely spaced electrodes inside an insulated tube, all measuring resistivity of the fluid in the well-bore.

In most of the geophysical surveys made, two fluid-resistivity logs have been run, one under natural conditions and the other after salt was added to the well. Originally it was planned to run a

fluid-resistivity survey to check the distribution of salt in the well, and it was decided that in order to do so it was essential to know what variations, if any, existed before salting. It was found after a few experimental runs that there frequently were major variations in fluid resistivity in wells and that some significance could be attached to them. It was also found that in static wells there was a tendency to spill salt on top of the fluid column while loading the salter so that the top few feet of water were very salty but that otherwise the salt was distributed fairly evenly. However, in most of the wells surveyed, the resistivity-meter surveys run after salting showed even greater variations in fluid resistivity than natural fluid-resistivity curves. Most of these variations correspond to anomalies on other logs and therefore corroborate postulated circulation conditions within wells.

Fluid Movement

The current meter, modified from the ordinary stream gauging meter, has long been used in water well work. For use with geophysical surveys an ordinary stream-type propeller meter was adapted to run in a vertical plane inside a protecting housing. Three contact pins on the gear driven by the propeller are spaced to create signals from which the direction of flow up or down through the instrument can be recognized. The rate of flow can be calculated from timing the period between signals. When direct current was used there was considerable electrolysis of working parts, but satisfactory results have been obtained by use of low amperage alternating current. The chief handicap of this instrument is that it becomes fouled in bacterial growths, debris, cavings, etc., which interfere with satisfactory operation.

Another type of current meter for use in wells has been developed but is still in the experimental stage. It consists of a counter-weighted vane which motivates a variable resistor. Moving fluids deflect the vane upward or downward changing the resistance in the circuit. The instrument is run into a well at a continuous rate of speed, giving a known

value of deflection, and deviations are interpreted to indicate fluid movement. Experimental calibration of the instrument and experimental use in several wells suggest that it may work satisfactorily under conditions where the propeller-type meter may prove to be unsatisfactory. A more sensitive and finished model as to shop work and mechanical details is being constructed and will be tested in the field soon.

Additional Geophysical Methods

The logs described above have provided much new information and increased our understanding of groundwater problems in Illinois. It is apparent that there are a number of improvements possible in the technique of operation and in the interpretation of results from the present methods. In addition it seems probable that a number of other geophysical methods or auxiliary instruments might have useful application in groundwater problems in Illinois and elsewhere.

The formation or drill-stem tester is widely used for testing the fluid content of individual formations in oil wells. To date no formation-tests have been run on water wells in Illinois but valuable information on the water resources has been obtained by the use of this tool in oil wells, and excellent results have been obtained in water wells in other sections of the country. Measurement of the static head or pressure in each aquifer and the sampling of its fluid content by use of the formation-tester would give worth while information about any well.

Various types of fluid samplers, which take samples at different depths, are in use in various industries and fields of investigations. Some samplers have been used in both oil and water wells in Illinois but there is no sampler at present available for use with a logging truck or measuring line which would prove satisfactory for obtaining samples large enough for chemical analysis. A fluid sampler has recently been designed, and it is planned to use it in detailed sampling of fluids in the well bore to obtain more detailed information than is now available and to furnish a check on fluid-resistivity logs.

The camera has been used successfully to inspect the lithology and physical characteristics of the wall rocks in water wells and is reported to have been used in oil wells. It is believed that use of a camera would be invaluable in fishing jobs and inspecting casing and liners.

Present methods of continuous recording of pH, or hydrogen-ion concentration, apparently do not lend themselves readily to measurements at depths such as would be necessary to obtain a pH log of the typical deep water well. However, a pH measuring device is under construction which it is hoped can be adapted to well work and modified to use through the recording panel of the regular logging truck.

Magnetic logging to determine the location of pipe and tools, etc., in wells has not been done on any water wells in Illinois as yet. It is expected that some situation will arise to permit the use of this method and a study of its application to the drilling, production, and completion problems of groundwater geology.

Radioactivity surveys (gamma ray and neutron) are used to log formations in cased and uncased portions of oil wells. It seems likely that these methods of investigation, particularly as applied to the formations behind the casing, should prove useful in some water-well problems. For instance, it may permit the identification of both glacial and bedrock aquifers which have been cased off, thereby giving new information from existing wells.

Attempts have been made with one of the available side-wall samplers or coring devices to obtain samples of the wallrock from an Illinois water well for core analysis and examination. It is believed that valuable information on wells already drilled and on formations which do not crop out close to the producing areas may be obtained from such side-wall samples, but most of the formations in the deep wells of Illinois are too hard for satisfactory use of methods of side-wall sampling hitherto available. Recently developed side-wall sampling devices designed to overcome these conditions may prove successful.

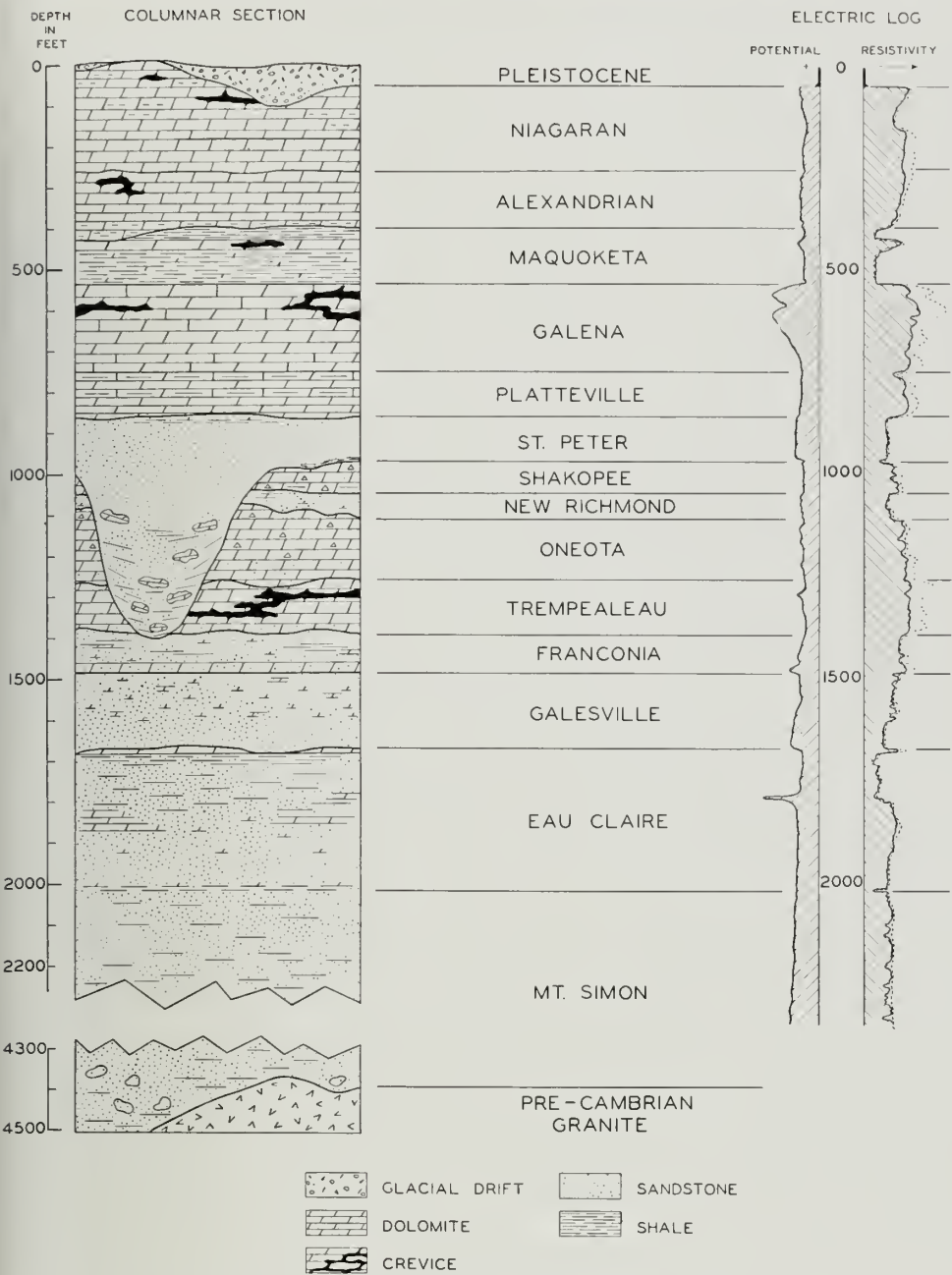


FIG. 1
Diagrammatic Columnar Section and Composite Electric Log
for Northeastern Illinois

UTILITY OF GEOPHYSICAL LOGS

In the course of the Illinois Geological Survey's geophysical well logging program during 1942-43, geophysical logs were made of wells that ranged in age from some which had been drilled nearly half a century ago to some in which drilling was still in progress. Available records for the older wells were incomplete, unreliable, or lacking altogether, but for most of the newer wells there were carefully kept records and sets of cuttings that were studied in the Geological Survey laboratories.

The geophysical logs have afforded valuable information about all of them. In the newer wells they supplement the drillers' logs, geological studies, and engineering data in accurately determining the numerous subsurface conditions and phenomena that affect drilling and operation. By comparison and correlation of geophysical logs of wells for which there are poor or no records with geophysical logs which have been successfully interpreted through integration with drilling, geological data and production data on their respective wells, the formations present in the "unknown" wells can be identified, the producing zones located, and other features determined. Geophysical logs are therefore particularly helpful in guiding the rehabilitation of old wells which is especially important at the present time because of the shortage of manpower and materials for new construction.

In addition to their practical value to the men who are responsible for the drilling, maintenance, and operation of water wells, and consequently to the many individuals and industries dependent upon the water from these wells, geophysical logs furnish a wealth of data that are of scientific value today and that may prove to be of practical value tomorrow. This discussion, however, is limited to the results that repay the cost of geophysical surveys in dollars and cents to the well owner and his engineer or to the drilling contractor.

Identification of Producing Zones

That the Pleistocene sands and gravels, Niagaran and Galena limestones and dolomites, St. Peter, New Richmond, Galesville, and Mt. Simon sandstones are important aquifers in various parts of northern Illinois has been well known for many years. Fig. 1 shows a diagrammatic columnar section and composite electric log. But geophysical logging has revealed that in some wells there are other important aquifers, such as the middle limestone member of the Maquoketa formation, creviced portions of the Trempealeau dolomite, some parts of the Franconia formation, and some sandstones in the Eau Claire formation.

It has not been definitely known heretofore what particular zones furnish water in any one well, and of course each well is an individual unit, differing in some respects from all others. With geophysical logs the depths, thicknesses, and characters of the important producing zones and the principal factors influencing their respective yields in different wells have been determined. For example, geophysical logs have demonstrated that most of the water produced from the Galesville (formerly "Dresbach") formation comes from the lower 40 to 60 feet, the upper 100 or so feet of the formation being dolomitic and relatively impermeable. It had been supposed that the whole section was about equally productive. This and other productive zones in old wells for which there are no records can be located with geophysical logs through correlation with wells for which records and cuttings are available. Fig. 2 illustrates the correlation of two such wells.

With the geological and geophysical data now available, the depths and thicknesses and the relative yields of all the aquifers in the uncased portions of a well and any appreciable flow from behind the casing can be determined by making a geophysical survey of that well. Two cases will illustrate the economic importance of this information. In one city in northern Illinois the question arose as to whether or not enough water was produced from the Eau Claire formation to justify drilling the wells deep enough to

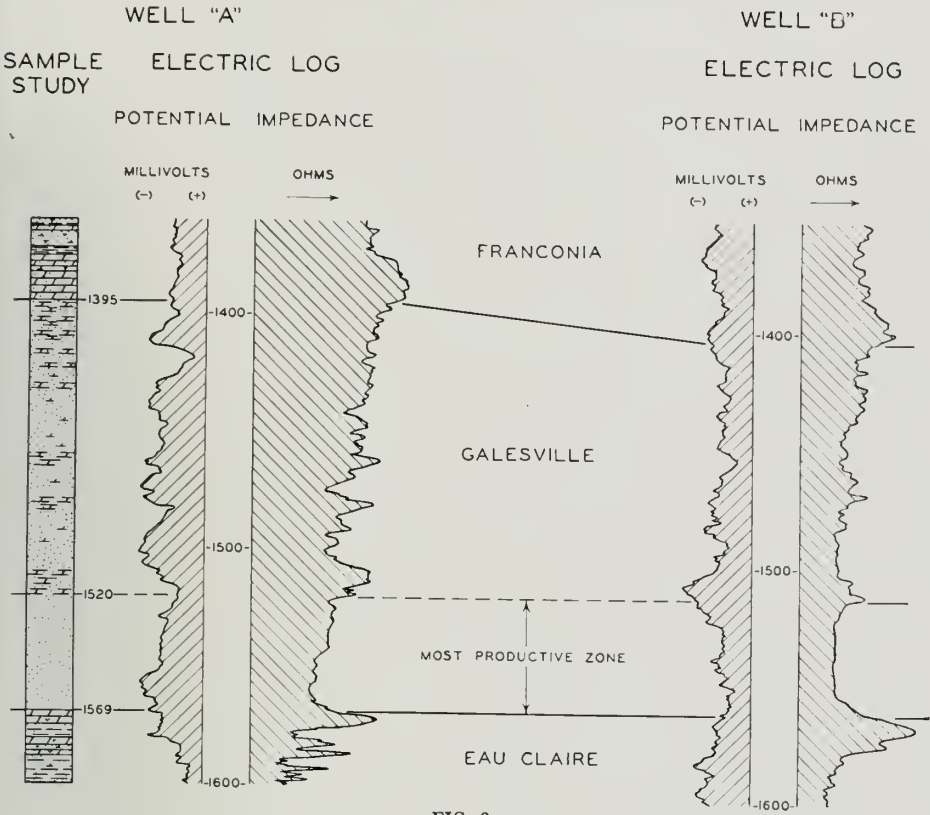


FIG. 2
Location of Productive Zone by Correlation of Electric Logs

penetrate it. From a geophysical survey it was determined that a sandstone in the lower part of the Eau Claire in that area is both porous and permeable and is capable of furnishing large volumes of water. In another municipality a well that supposedly had been drilled through the Galesville, but for which the bottom-hole cuttings were not delivered to the Geological Survey, had a surprisingly low yield, too low in fact to fulfill the local requirements. On correlation of the electric log of this well with that of a well a few miles away (see Fig. 3) it is evident that the well in question does not penetrate the lower part of the Galesville, which is by far the most productive part of the formation, and that

a large increase in production may result by deepening the well by only 50 feet.

Sources of Contamination and Pollution

The widespread occurrence of pollution and contamination of wells by surface or near-surface fluids that enter through holes in casing, through crevices below the casing, or by way of imperfect casing seats constitutes a menace to public health and increases the treatment costs of water for both public and industrial use. The place of entrance of such waters can be detected and the conditions that permit their entrance be determined by the use of geophysical surveys, including temperature, current meter, and fluid-resistivity measurements in

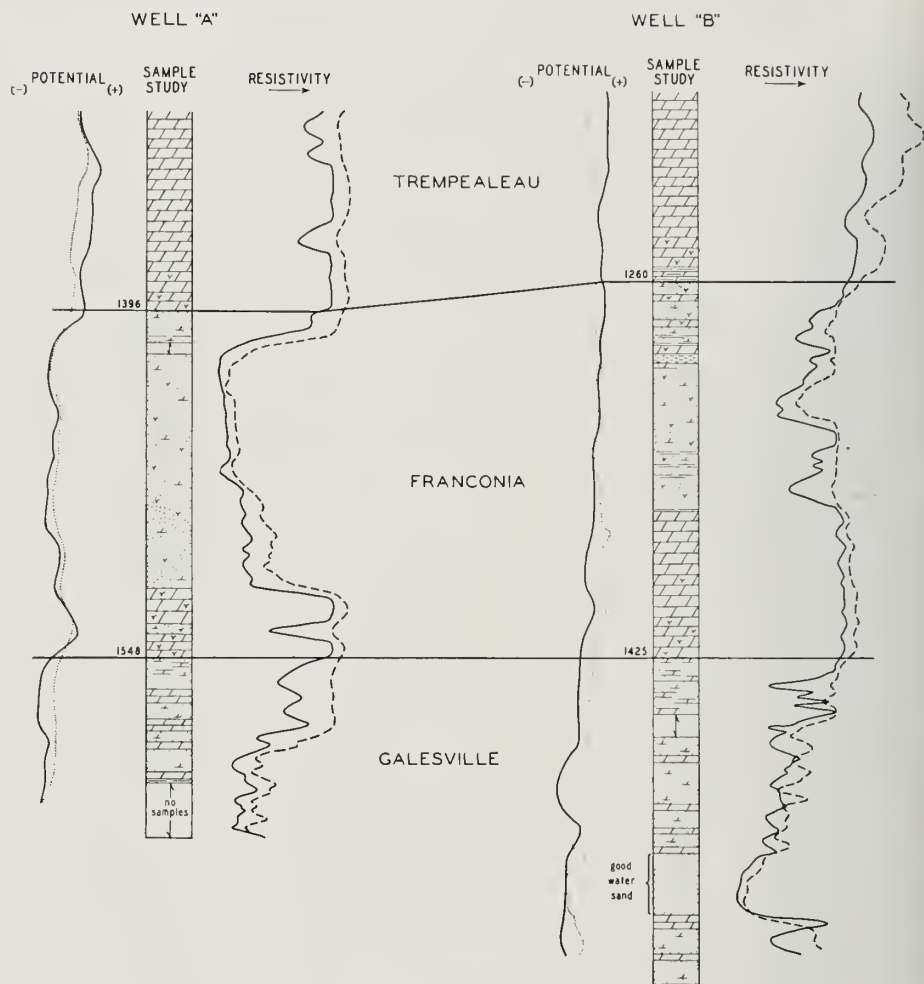


FIG. 3

Correlation of Portions of Electric Logs of Two Wells

conjunction with electric logs and caliper logs. With that information available it is possible to determine what remedial measures—such as replacing the defective casing, reaming the hole to improve the casing seat or extending the casing below the creviced zone, and/or cementing—should be taken to eliminate the contamination or pollution.

Water from the well illustrated in Fig. 4 was unfit for use as either drinking water or boiler water in the ordnance plant by which it was urgently needed. The casing seat was located by the electric log and the caliper log. A 120-foot section of the dolomite under the casing was shown to be creviced, but the high negative potentials indicated that

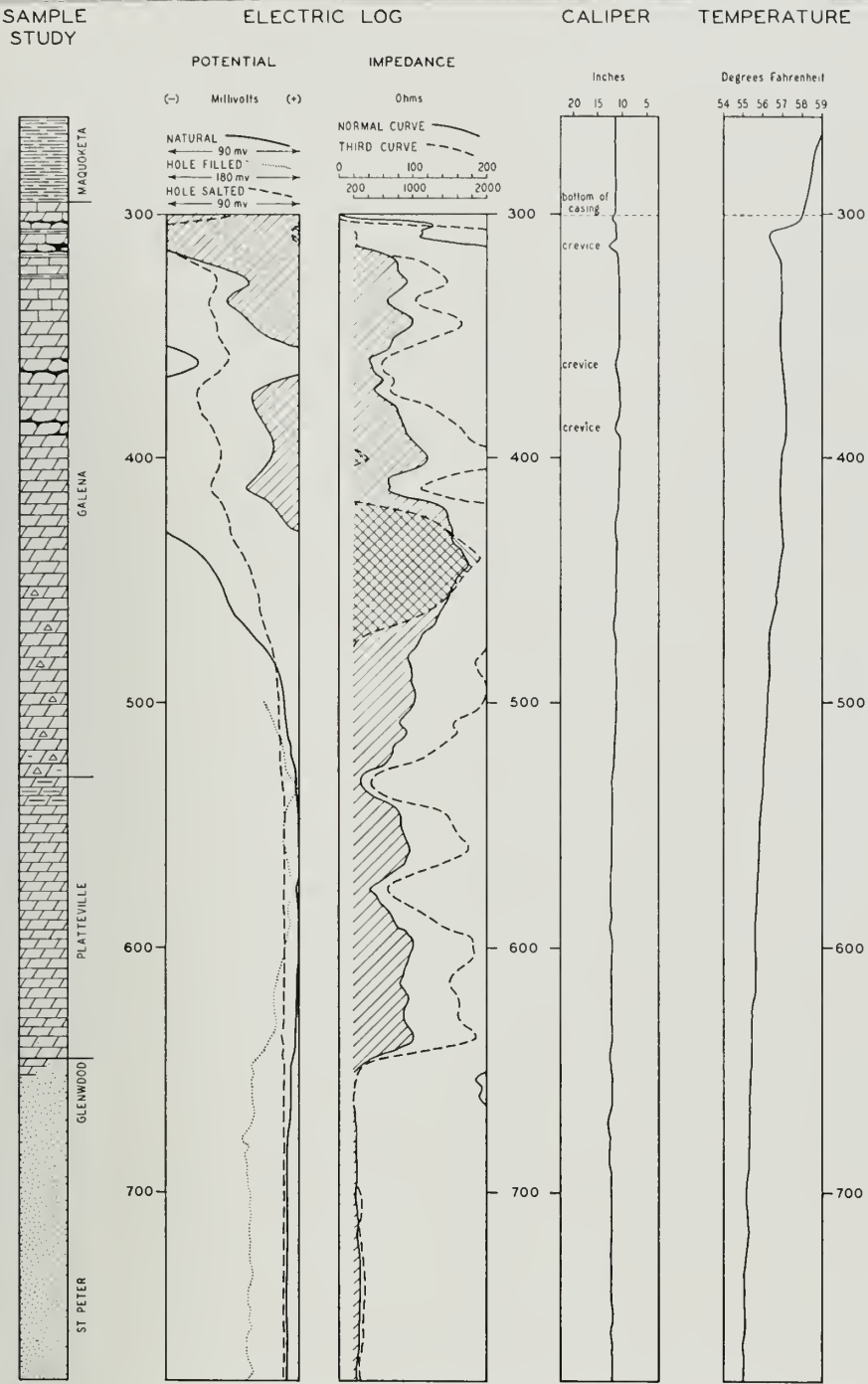


FIG. 4

Portion of Composite Geophysical Log Used to Locate Source of Contamination

water was leaving the hole through the crevices. A distinct "cold" anomaly was recorded on the temperature log just under the casing seat, and inasmuch as the well was surveyed in warm weather and the fluid column in the casing was warm, this anomaly was interpreted as indicative of cold water from behind the pipe entering the well around the casing seat. When the current meter was placed just below the pipe it indicated water moving downward at such a velocity that the flow was about 200 gallons per minute. On the basis of the geophysical survey it was recommended that the hole be reamed down and the casing be set on a firm seat below the upper crevice zones and cemented to the top. All of the pollution and contamination was shut off by this working-over. The water from the well had been extremely variable in composition and had necessitated considerable expense in treatment. By shutting off harder waters from the glacial drift and the surface waters, a water of constant composition was obtained and treatment costs were greatly reduced.

Thieving Zones

Where considerable differences in hydrostatic head exist in the various aquifers of multi-zone wells, some zones may take or "thieve" water from the wells. By use of temperature logs, fluid-resistivity logs, and current-meter logs in conjunction with the electric log such thieving zones can be recognized. If the thieving zone is a creviced dolomite, as is frequently the case in Illinois wells, the caliper log also is helpful in locating it.

In the well illustrated in Fig. 5 large changes in fluid resistivity and temperature at the creviced zone indicated on the caliper log coincide with a major disturbance of the potential curve of such magnitude that it was necessary to introduce a manual shift to keep the record on scale in spite of the fact that full scale is 900 millivolts. The relations of the curves suggest that large volumes of water were leaving the hole through these crevices at the time of logging. When the head on such thieving zones is lower than the operating levels in the well it is desirable to shut off the zones and thus increase the yield of the well.

Location of Casing and Liners

The location of casing and liners in a well and the determination of their condition is an important problem. In Fig. 5 the impedance curve showed a liner from 938 to 997 feet and the irregularities in diameter measured by the caliper indicated it to be in very poor condition. For another well there was an old set of samples but no reliable record of the pipe, or hole diameter below the top. The length of casing and position of the top of a liner were determined from the impedance log, and the diameters of the casing and of the open hole were measured with the caliper. The hole was bridged across the liner at 740 feet so the log could not be run deeper. This well was being used as an observation well, supposedly to record the fluctuations in water levels as indicative of the water resources of the important sandstone aquifer at about 1600 feet through which the well was reported to have been drilled. The geophysical survey, by indicating that the hole was bridged, showed that the water levels could reflect hydrologic conditions only in formations above 740 feet. In addition a hole in the surface string of casing was located by the caliper at a depth between 250 and 260 feet. As the well was logged in the middle of the winter during its period of highest water-level, and the top of the fluid, as indicated by the temperature and fluid-resistivity curves, so closely coincides with the hole in the casing, it appears that the water levels are controlled by the rate at which water can leave the well through the hole. It became apparent that this well was valueless as an observation well for the water-level data.

Effects of Shooting

For better drilling and completion practice it has been worth while to analyze the effect of shooting sandstone zones in wells. A number of 150-pound shots were used in different spots in a northern Illinois well (see Fig. 6) without knowing exactly where the producing water sands were. In the good water sands the diameter of the hole was enlarged from 12 inches to 32 inches but in

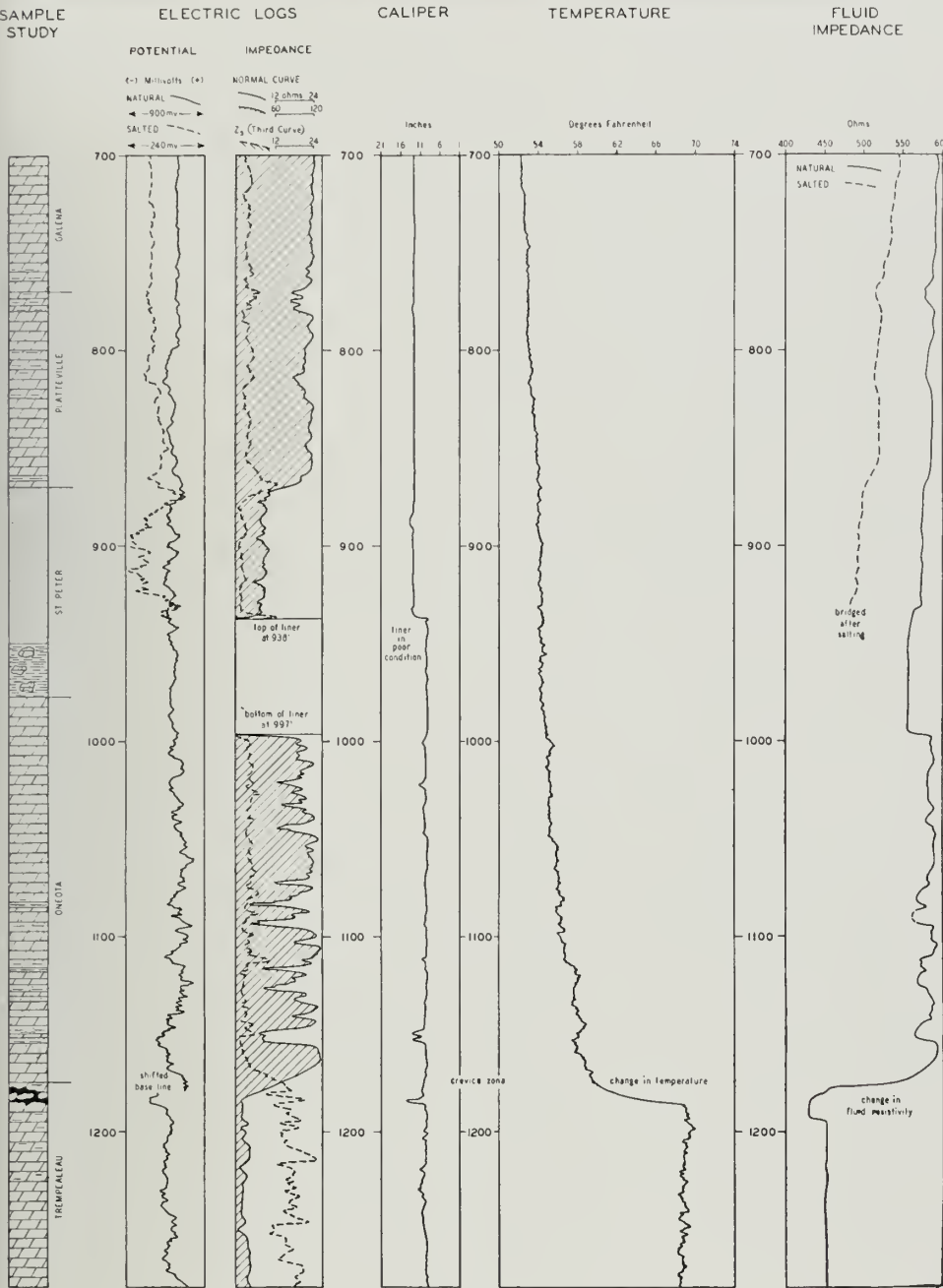


FIG. 5
Log Showing Influence at Crevice Zone

the tight sands the maximum diameter obtained was 20 inches.

Caliper logs are valuable aids to re-working old wells because they locate tight spots and zones of caving shales, conglomerate, or soft sandstones in the wells. The caving shale and conglomerate at a depth of about 460 feet in the well shown, probably should have been cased off during drilling. The tight spot, or place that was not drilled to gauge between 980 and 990 feet, should be reamed out to prevent the tools from sticking while working on the well, or to prevent subsequent bridging by the caving of materials which would shut off the water sand below.

Location of "Fish"

In addition to the location of casing and liners, it may be important to know the location of lost tools or junk in the hole. As has been shown, the electric log gives good measurements of the casing and liners and in some wells locates

the position of drilling tools, joints of old air-lift pipe, and other steel or iron articles that might have been dropped in the hole. In the bottom of the well illustrated in Fig. 7 the portion of a string of tools lost while cleaning out after shooting was located by both the electric log and the caliper log. Inasmuch as they were below the shot-hole in the main producing water sand and it is unlikely that the well will ever be deepened, they were not fished out. The shot-holes in this well are also of interest in that they illustrate clearly the differences in the effect of shooting on the loose water sand and the tight dolomitic sand.

Stray Earth Currents

A byproduct of the geophysical well surveys is the location of areas and sub-surface zones in which stray electric currents are most intense. These stray currents probably account for much of the corrosion of liners, casing, pumps, and

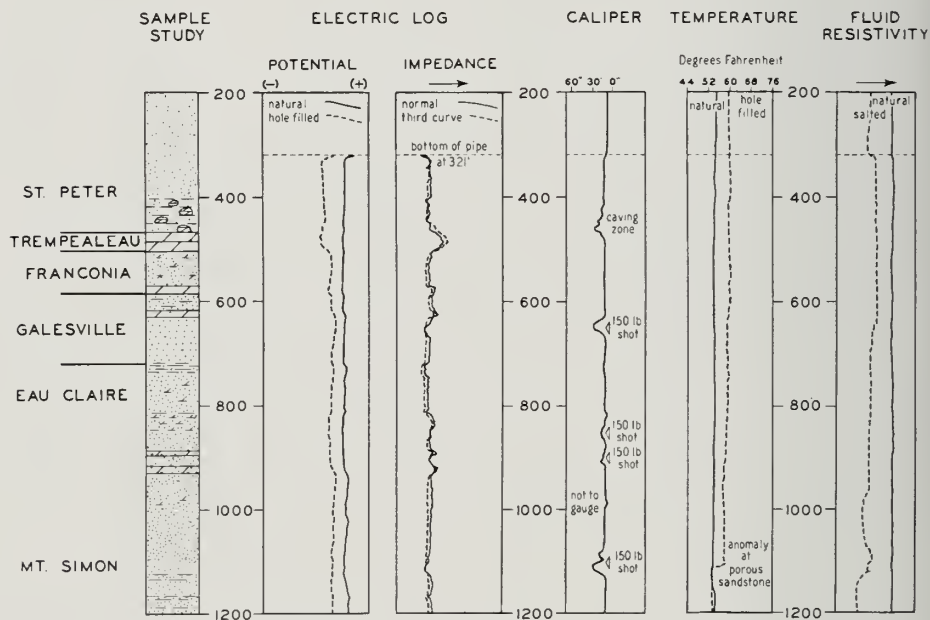


FIG. 6

Portion of Log Showing Effect of Shooting

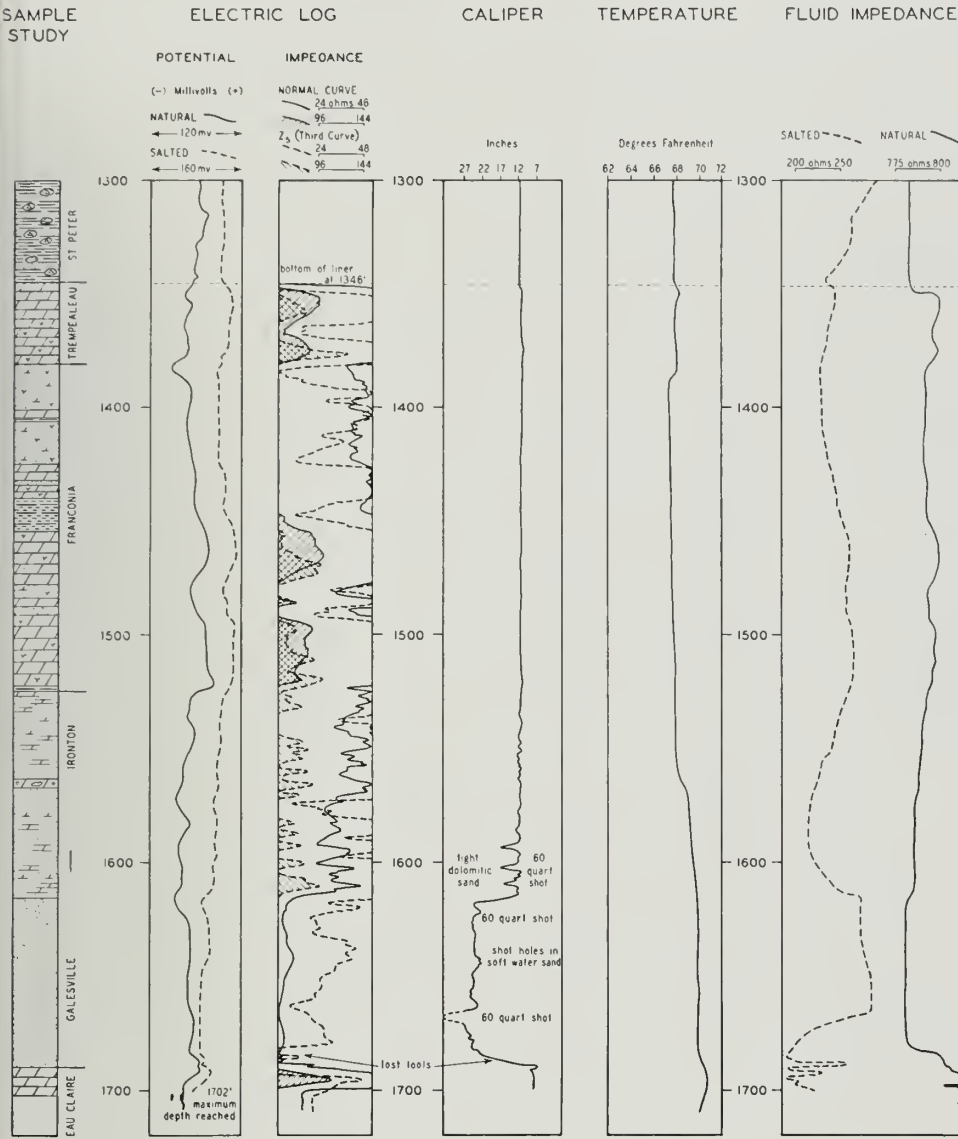


FIG 7
Portion of Composite Geophysical Log of an Ordinance Plant Well

column pipe in wells, especially in industrial districts. Geophysical methods have long been used in the study and remedy of electrolysis and corrosion of pipelines, underground telephone and telegraph cables, and other buried metal objects. It is hoped that as additional data on stray electric currents and their relation to corrosion are collected by geophysical surveys and other methods some practical suggestions can be made toward the solution of these problems in water wells.

INTEGRATION OF GEOPHYSICAL AND GEOLOGICAL DATA

Through compilation and comparison of geophysical data derived from a number of methods of investigation, supplemented with all available geological and production data from a specific well and nearby wells, a reasonably good picture of subsurface conditions can be obtained and many of the problems of ground-water production can be solved. To integrate all such information, a composite log of each well is prepared, on which is displayed all the phases that have been investigated. The composite logs now made by the Illinois Geological Survey present the following:

1. A detailed log of the lithology of the uncased portions of the well based on microscopic study of cuttings from the well or nearby wells and the electric log and a sample study of the cased portions of the well.
2. Exact measurements of the casing and liners, both as to depths and inside diameters, and some knowledge of their condition.
3. Location, thickness, and relative importance of the water-producing zones.
4. Location of "thieving" zones.
5. Approximate salinity of the water in the well-bore, and probable zones of production of waters of different salinities.
6. Temperature of the water in the well-bore and the approximate temperature of water from different zones.

7. Caving zones that have not been cased off.
8. Circulation conditions under non-operating conditions.
9. Critical production or well conditions such as collapsed or corroded liners, poor casing seats, location of iron or steel "fish," etc.
10. Effects of shooting, acidizing, caving, and other special conditions within the well.

CONCEPTS BASED ON GEOPHYSICAL SURVEYS PERTINENT TO WATER RESOURCE DEVELOPMENT

From the geophysical logs made in Illinois, and correlation of the data therefrom with all the available geological, engineering, and production records, it has been possible to formulate a number of concepts that are believed to be widely applicable in development and production of the water resources of deep wells in northern Illinois. These concepts merit consideration in laying plans for the rehabilitation of old wells and for drilling new wells.

Conservation of Drilling

Examination of the zones producing large quantities of water in the deep wells has shown that in addition to the main sandstone zones, there are numerous crevice systems with high specific capacities. In many wells sandstones and crevices act as thieving zones which take considerable volumes of water from the wells under both producing and static conditions. Because the role of the crevice systems was not understood, many wells have been drilled through several zones, each of which was capable of producing the needed water supply. Usually the specifications for a well require drilling to a specified depth or producing zone because it is generally understood that most of the water in the area is produced from a certain aquifer or above the specified depth.

Drilling costs and time could be reduced if well drilling could be done with the geological conditions in mind. In many areas, crevice systems in the Niagara or Galena-Platteville formations

are quite capable of producing as much water as would be obtained from wells drilled to the Galesville or Mt. Simon zones where under typical producing conditions one or two zones will produce considerable water but where losses are high in the thieving zones. In many areas careful testing of each possible producing zone during drilling will lead to considerable saving if drilling is stopped where adequate water is obtained. Wherever there is evidence that a crevice system is intersected by a hole, investigations should be made to see whether the crevices are capable of supplying the required demand. Several wells nearly 2000 feet deep which have been surveyed obtained most of their production from the first few hundred feet and have serious losses of water into some of the lower zones. In the Chicago-Joliet area there is evidence to suggest that wells drilled to crevices in the Trempealeau formation might yield as much water as deeper wells drilled through the Galesville.

Running a pumping test on each individual zone is not usually considered a feasible means for testing because of the high cost involved. However, another rather simple method may be used in water wells. The technique is a result of observations by the writers when running water into wells to obtain hole-filled potential and temperature logs. It was noted that wells of high capacity took large volumes of water readily and that high inputs were necessary to keep the wells filled while logging, whereas wells with smaller capacity took proportionately smaller volumes. Wells capable of making 1200 gallons per minute (gpm) took as much as 600 gpm to keep them full, and smaller-capacity wells took much less. While no directly proportional or mathematical relationships have as yet been worked out, it is safe to conclude that a well that requires comparatively large volumes of water to stay filled will also produce large volumes. If a nearby water supply, such as a fire-hydrant, is available, it will provide a ready and inexpensive "rule-of-thumb" method of testing the capacity of a well during drilling.

Cementing of Casing

In most wells in northeastern Illinois a string of pipe is set through the glacial drift into bedrock. Another string of casing is usually set inside this "surface" string running from the surface through the Silurian limestone and dolomites, through the Maquoketa shale and for some short distance into the underlying Galena dolomite. This may be referred to as the "long" string. Usually no other casing, except liners to case-out caving shale, is set in these wells.

The surface string is either driven through the glacial drift, with a forged-steel or similar shoe on the bottom of the pipe, or it is set on bedrock after the hole is made. The long string is usually set on a shoulder in the dolomite near the top of the Galena formation. In nearly all of the wells surveyed ineffective casing seats were found. Most dolomites, particularly where they are creviced and fractured, do not permit a satisfactory shut-off without special means of sealing being used. A nearly standard recommendation following a geophysical survey is for the long string to be cemented or pressure-grouted from bottom to top. The best known method of cementing pipe is to bridge or plug the well immediately under the casing, pump a cement slurry of proper weight and composition down the casing and up around the outside until the pipe is completely enveloped in cement. Such cementing practice is standard in oil wells.

Proper cementing effectively seals the casing seats of wells and thereby prevents pollution and contamination of the well by surface or near-surface waters, and also may be expected to reduce pipe corrosion by the protection of the casing and to prevent circulation of water behind the casing between cased-off aquifers, thus protecting important gravels and shallow crevice systems from contamination.

Plugging of Abandoned Wells

With one exception, all of the geophysical surveys have been run in wells under so called static or non-pumping conditions. In only rare instances have

such wells been actually static; generally water is moving from one zone to another because of the differential hydrostatic pressures in the different aquifers. In some cases this circulation is at rates of more than 100 gpm. There must be several hundred deep wells in northeastern Illinois which are not in use or for which no further use is planned. A number of these probably could be reconditioned as useful water producers with proper engineering practice.

It is probable that the majority of such wells are acting as channels for thieving between formations and are effectively reducing the water levels in wells in their vicinity inasmuch as the levels in such wells are controlled by the head in the formation which has the lowest pressure. In addition, many such wells have poor casing seats and so receive polluted or contaminated water from the surface. In many areas wells have been abandoned because they were drilled into zones which produce water too hard, too salty, or for other reasons undesirable. Thus every abandoned well is a possible channel for loss of large quantities of water from aquifers productive in other wells, a possible cause of part of the local reduction in water levels in some areas, a possible source for introduction of contamination and pollution into widely used aquifers, and a possible cause for high chloride content, hardness, or other undesirable features of the water in nearby producing wells. All such abandoned wells not in use that do not readily lend themselves to rehabilitation should be plugged from top to bottom in order to eliminate the hazards they create.

Well Spacing

From geophysical surveys and allied geological investigations some picture of the effective permeability of the producing formations in the deep wells has been obtained. The magnitude of the crevice systems which provide rapid water transfer between closely spaced wells which intersect them has been recognized. From these data it has become evident that in many areas there are too many wells for stable water production under existing

conditions of permeability. For example, in one urban section where calculations based on permeability studies suggest an optimum spacing of one deep well per 900 acres, there is an area where wells are spaced one to approximately 60 acres. Rapid recession of water levels is reported during the periods of high production.

Inasmuch as the intersection of a crevice system by a well is largely fortuitous, determination of well spacing should be largely on the basis of the permeability of the sandstone aquifers which are everywhere present and have fairly uniform characteristics. Wells should be spaced on the basis of obtaining stabilized water levels within a few feet—both static and operating, a minimum of lift for producing the water, and a minimum of interference between producing wells. The demand, probable pumping periods, recovery periods, and much fundamental geological data form the basis for calculation of the best spacing in any area. Also there are many other factors of ownership and engineering which necessitate compromise in determining the actual spacing of wells. However, it is now possible to make recommendations of suitable spacing for new developments on a sound basis. Generally the tendency has been to put wells too close together, and thereby to overtax the local water resources, create a large local cone of depression, create irregular non-operating and operating water levels because of competitive interference with nearby wells, and thus require continuous lowering of pump settings, giving no permanence to water-supply installations. Wider spacing will eliminate these difficulties and obtain much more permanent development of deep well water resources.

In one area, where about half-mile spacing for several wells in a war industry was used, a study of the data suggested a spacing of 6800 feet as optimum for the area. Later wells drilled at a spacing of nearly a mile gave higher yields and much more satisfactory operation during the heavy pumping season. Similar calculations can be made for other areas, and in cases where new developments are planned or reconditioning

of old wells is considered, spacing merits consideration as a basis for such planning.

Operating Level

Analyses of the geological and production conditions in wells in northeastern Illinois show that where there are several producing zones in a well the specific capacity is increased as the operating level is lowered. Thus during the first part of the drawdown from non-operating to operating level in any well, a comparatively low specific capacity is to be expected. As the operating level is progressively lowered, different zones with successively lower hydrostatic heads begin to contribute to the well's yield. If the head, or the critical operating level for any zone can be determined in any well, then this zone's contribution can be controlled by controlling the operating level. This concept has two major important applications for planning of water wells.

1. If allowance is made for an increase in specific capacity with lower drawdown levels, pump settings can be planned at levels that are safe for operation under all conditions, and yet pumps do not have to operate against such great heads as might be necessary if the specific capacity for only the upper part of the drawdown were used. Setting pumps on this basis instead of that normally used will give savings in installation materials and costs of operation.

2. Certain of the sandstone zones in northeastern Illinois in the Franconia and Eau Claire formations are highly glauconitic. Glauconite is a complex hydrous ferric-aluminum-potassium-magnesium silicate with high base-exchange properties which make it ideally suited for a natural water-softener. Water from the glauconitic sandstones consequently is not as hard as that from other formations. A few establishments in northern Illinois take advantage of these underground water-softeners by casing off the overlying formations and producing water only from the glauconite-bearing zones. Unfortunately the yield of these zones is low, but it might be possible to utilize their water-softening

properties and still obtain large well yields by proper well construction and production practice.

In one well in northern Illinois, it was noted that hard water was pumped all the time when the well was pumped continuously, but that much softer water was obtained when the well was pumped on alternate days. The geological explanation that can be offered is that when the well was pumped continuously it produced hard water from the Galesville sandstone, but when pumped intermittently the water levels during the rest periods were about the head of water in the Franconia sandstone so that water from the Galesville was fed into that zone and softened, and then when pumped the soft water was produced as the level was lowered below the head of the water in the Franconia. When the pressures of water in sandstones of the Franconia and Eau Claire formations in other areas can be determined, it is possible that by control of operating levels much softer water can be secured by use of the natural water softeners of these formations.

Temperature Gradients

It is well known that in most areas, except for a relatively shallow zone of annual temperature variation, the earth's temperature remains essentially constant at any given depth at any one locality and that the temperature increases with depth. In northeastern Illinois, according to the best available measurements, the earth's temperature the year around at a depth of about 100 feet remains close to 50 degrees Fahrenheit. Below that depth the temperature increases at approximately one degree for each 125 feet, which accordingly is considered the normal temperature gradient for the region. It is unusual, however, for the temperature log of a well to be a straight line having that gradient, for in most wells circulation and other conditions produce anomalies in the temperature logs. Nevertheless the bottom-hole temperature of most wells is that which would be expected for the depth on the basis of the normal temperature gradient, and the temperature of the water produced from

each aquifer is close to that expected for the depth from which it comes. The normal temperature gradient can be used as a "rule-of-thumb" method for determining the greatest possible depths at which water of any desired temperature can be obtained.

Water for Cooling Purposes

Although it is evident that water from the shallowest aquifers will usually provide the most desirable water for cooling purposes, it is not uncommon to drill to increasingly greater depths to obtain large supplies of water for air-conditioning and similar uses. Where cooling water is desired, glacial sands and gravels, which are widespread in buried valleys above the bedrock, should be sought as the best possible source. Next the crevice systems in the shallow bedrock formations should be tested, and only finally a deep well considered as a possible source of cooling water.

Where large quantities of cooling water are needed and inadequate sources are found in creviced or porous shallow limestones or dolomites, the probable increases in production from acidizing these zones should be considered. Recently in Kansas it was found that a shallow well in dolomites and limestone had its capacity increased four times by acidizing. Some water wells in Illinois

have been treated with acid, but wider application of this method of increasing yields seems merited. Commercial acidizing services use non-toxic inhibitors particularly adapted to use in water wells, so that they will not react unfavorably on any of the well casing, liners, or equipment.

SUMMARY

Geophysical methods have proved successful in solving many of the problems that arise in drilling, completing, and producing water wells. The geophysical surveys made of Illinois water wells and research in groundwater geology have furnished much factual material that, when properly integrated, permits sound interpretation of groundwater phenomena and subsurface conditions. Such knowledge can be used to correct many of the defects in old wells and to plan more intelligent development and conservation of groundwater resources in the future.

As the investigations are continued it is expected that many of the questions in geophysical surveys and interpretations will be answered, and that new techniques and instruments can be developed for solving other problems in groundwater work, not only in Illinois but in many other areas where the same or similar problems are encountered.



