

J. E. Hackett

STATE OF ILLINOIS
ADLAI E. STEVENSON
Governor

OFFICE COPY



GEOLOGIC CORRELATION AND HYDROLOGIC INTERPRETATION OF WATER ANALYSES

BY
T. E. LARSON

ISSUED BY
DEPARTMENT OF REGISTRATION AND EDUCATION
NOBLE J. PUFFER, Director
STATE WATER SURVEY DIVISION
A. M. BUSWELL, Chief
URBANA, ILLINOIS

GEOLOGIC CORRELATION AND HYDROLOGIC INTERPRETATION OF WATER ANALYSES*

by

T. E. LARSON

Head, Chem. Subdivision
ILLINOIS STATE WATER SURVEY
URBANA, ILL.

WHEN the water users of Peoria, Ill., realized that a receding water table in wells of limited depth was critically affecting the water supply for the many industries and for the municipality, they asked the Illinois State Water Survey to collect data and to conduct studies to determine the source and amount of available water in the vicinity. In view of the fact that Peoria is a highly industrial city located on the Illinois River and centrally situated in the Illinois corn and grain belt, serving as a center for processing some \$40,000,000 worth of farm products annually, the problem was considered of first importance.

Preliminary calculations⁽¹⁾ showed that the limited storage in the area of heavy withdrawal could not provide the amount of water needed for industrial and municipal purposes without recharge from external sources. It was also observed that the quality of the ground water was not constant either throughout the area or at any particular well. As a part of the investigation, water samples were collected for partial analysis to determine the extent of variation in quality and to determine the actual character of the waters from the various sources.

Since it was found, by correlation, that the water from a particular source is of generally constant character, it became possible to interpret the analytical data to show the origin of the waters obtained in each well field. Changes in character that occurred at any particular well were accompanied by relative changes in hydrostatic pressure in the immediate vicinity as a result of both extraction and recharge. It was therefore necessary to consider rainfall, river elevations and such pumpage records and water level data as were available.

The study considered the water quality of the Illinois River and the industrial and municipal well fields of Peoria, as well as those of Peoria



The Author

Heights, East Peoria and Pekin. All available records on farm and community wells in the surrounding area roughly within a 25-mile radius were also included. With few exceptions, only drift wells above the bedrock were examined in the study, these ranging in depth from about 50 to 300 ft. Water from the bedrock is not considered in this discussion, as it is highly mineralized and is not a major water supply factor in the area.

Glacial Deposits

The immediate Peoria-Pekin area offered no fixed reference values for the quality of water to be expected from any particular glacial deposit, because extraction and recharge during the history of well water use in the area have altered the composition of the available water in the formations and continue to do so. To establish a working basis for comparison, however, well water samples were obtained from the geologic formations in the region surrounding the area under study.

In a recent unpublished report⁽²⁾ on ground water geology of the Peoria Region, it has been shown that a broad buried valley connected with the Mississippi River existed at one time about 20 miles east of Peoria. Bedrock elevations vary from 300 to 750 ft. msl. (mean sea level datum), and the ground surface varies from 440 to 850 ft. msl. This buried rock valley is now filled with a pre-glacial or early glacial sand deposit (called Sankoty sand) to an elevation of about 500 ft. msl. This sand is also found in places along and under the present Illinois

River and at the base of another buried valley north and west of Peoria (Figs. 1.2).

The Sankoty sand is covered almost uniformly by the Illinoian glacial till. This was extensively cut by streams and does not constitute a major source of water. For the most part the Sankoty and Illinoian formations are overlain by the deposits from the Wisconsin glacial period. These Wisconsin moraines and till sheets are extensive and cover almost the whole area. There has been considerable erosion along the present Illinois River, outwash deposits being found there and also as narrow fringes bordering the moraines. The deposits are thickest in these areas. For the most part, water is found only in discontinuous and lenticular deposits in the Wisconsin drift, but the outwash deposits below the lower terrace along the Illinois River are generally well stratified and are therefore favorable areas for ground water development.

Water Quality Distinctions

Water from the Sankoty formation was invariably found to be characterized by a low sulfate content and by the presence of appreciable concentrations of ammonia and iron. Examination of 66 samples showed these waters to have a sulfate content below 7 ppm. The iron content found was invariably greater than 1.0 ppm., and there was up to 10 ppm. of ammonia.

Waters from the Wisconsin drift and the glacial outwash deposits are characterized by the presence of appreciable sulfate concentrations. A further distinction was apparent in the nitrate content. Waters from glacial outwash deposits and from outwash valleys cut in any of the lower formations almost always contained large amounts of nitrates. Twenty-one samples from wells penetrating glacial outwash were found to contain 12 to 425 ppm. of nitrates. The ion content of these samples was frequently, but not always, low, and the sulfate content ranged from 40 to 207 ppm. Some wells in the Wisconsin formation, near the areas where the bedrock

*Presented before the Water, Sewage and Sanitation Chemistry Division of the A. C. S. and published here by permission of the Amer. Chem. Soc.

outcrops, yield water of from 600 to 1,000 ppm. of sulphates.

Nineteen water samples from lenticular sand deposits in the Wisconsin drift areas contained 0 to 1 ppm. ammonia, 1 to 15 ppm. of nitrates and 15 to 102 ppm. of sulfate. The iron content varied from 0.2 to 6 ppm.

The hardness and alkalinity of the samples from each formation were far from distinctive, varying from 200 to 400 ppm. and 300 to 450 ppm., respectively, for Sankoty water. For the Wisconsin and outwash waters, the hardness varied from 300 to 600 ppm. and the alkalinity from 200 to 500 ppm. Neither the hardness-alkalinity nor the calcium-magnesium ratio was consistently distinctive for waters from any formation.

Illinois River

Another factor considered was the quality of the Illinois River water.

There is a dam across the narrow channel of the river south of the industrial district, which maintains a minimum level of 440 ft. msl. in the river and in Lake Peoria. The quality of the river water (minimum flow 4,000 cfs.) is influenced not by the pool level but by the total flow and by the proportion of the total flow which originated as diversion from Lake Michigan and sewage from Chicago (average 3,000 cfs.).

The mineral quality of the Illinois River water is characterized by its hardness-sulfate ratio. In general, the hardness (as CaCO_3) varies linearly with the sulfate concentration (SO_4^{--}). The total hardness varies from 182 to 352 ppm., the total mineral content from 196 to 443 ppm., and the chlorides from 7 to 30 ppm. The nitrate content is less than 15 ppm. The sulfate-hardness char-

acteristic of the Illinois River water is distinctively different from that of Farm Creek water (Fig. 1) and from any of the ground waters in the area.

Method of Approach

It became evident early in the investigation that each well or group of wells in a particular field required a study separate from the others. Each was influenced by local geological conditions and pumpage.

The greatest variations in analyses of samples from individual wells were in the sulfate and hardness concentrations. It was found that the relative concentrations of these two constituents served as excellent bases for interpretation. Variations were also noted in the temperature and in the alkalinity of the water from some wells. The alkalinity variations support the conclusion that there is some infiltration of river water into the

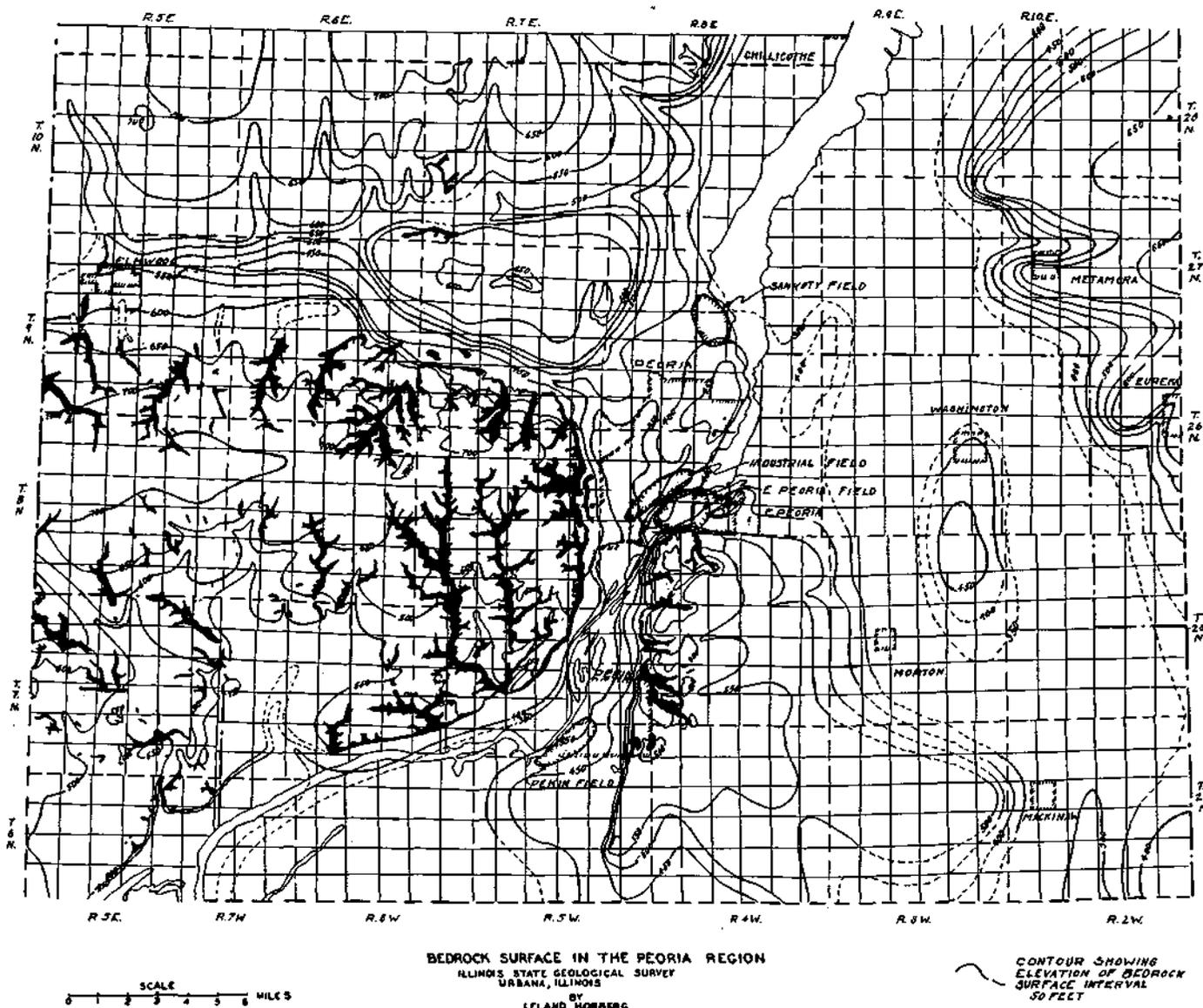


Fig. 1. Bedrock Contours in the Peoria-Pekin Area*

*Data obtained from Reference (2) and from an Ill. State Geological Survey Bulletin and an Ill. State Water Survey Bulletin, both of which were issued in 1948.

water-bearing gravel. Estimates of the sources of the water at any well are based on the general character of the waters, as exemplified graphically by patterns showing the hardness-sulfate relationships, rather than on the month-to-month variations. This procedure is necessary because of the rapid changes that have been found to take place from day to day and even from hour to hour.

Pekin Field

The Pekin Field is located on the east side of the Illinois River, south of Peoria and downstream from the dam. It includes the Pekin city wells and the industrial wells southwest of Pekin. The water quality patterns of several of these wells and the three possible sources are shown in Fig. 2. It is apparent that the quality from each well varies considerably. In

view of the character identifications discussed so far, two interpretations are possible. First, it may be reasoned that the patterns represent mixtures of Wisconsin drift water and Sankoty water with a small quantity of Illinois River water. If this explanation were correct, however, each pattern should be confined within a narrow band limited by the hypothetical mixtures of these two waters. Actually, the hard-

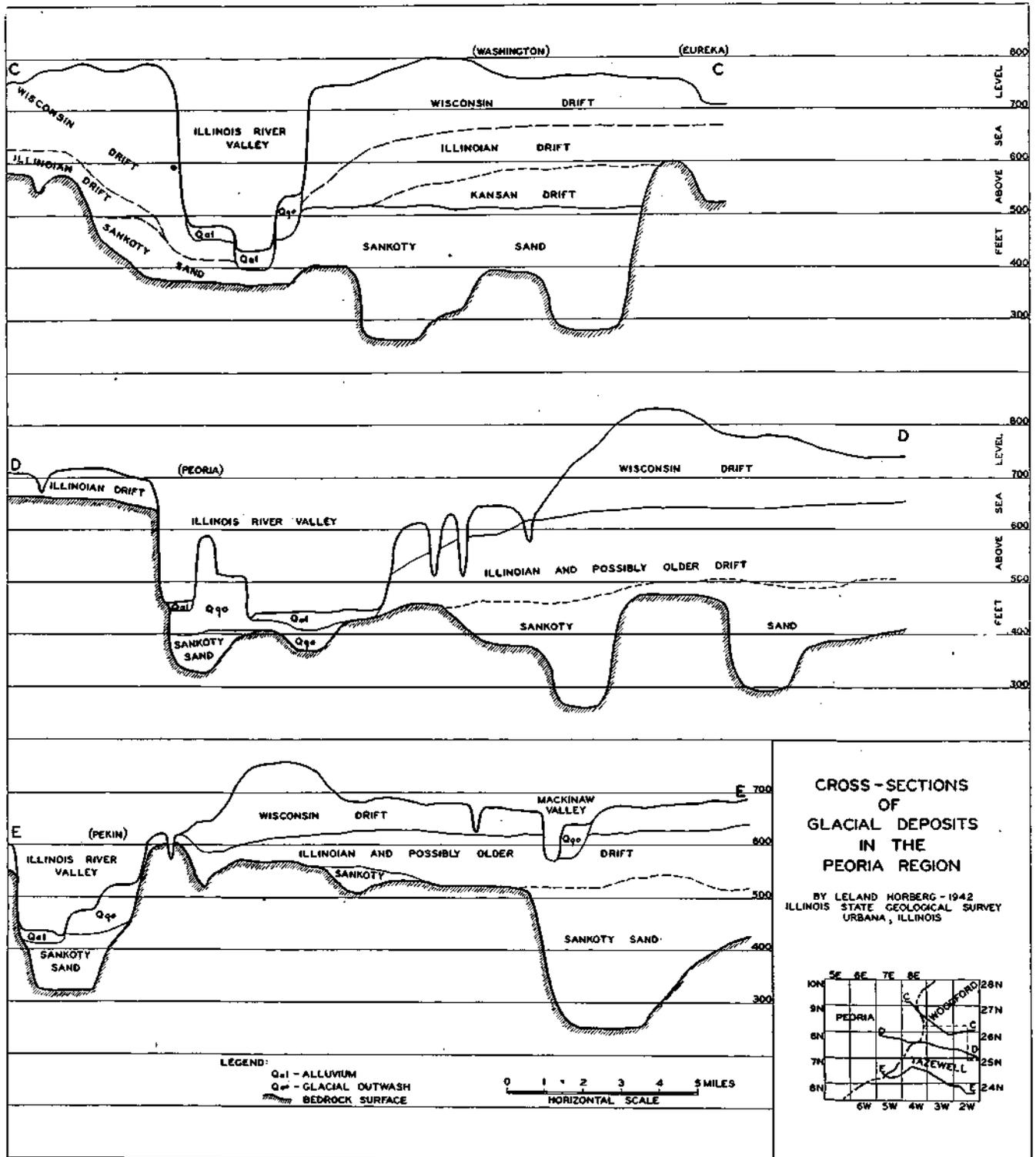


Fig. 2. Cross-sections of Glacial Deposits in the Peoria-Pekin Area*

*Data obtained from Reference (2) and from an Ill. State Geological Survey Bulletin and an Ill. State Water Survey Bulletin, both of which were issued in 1948.

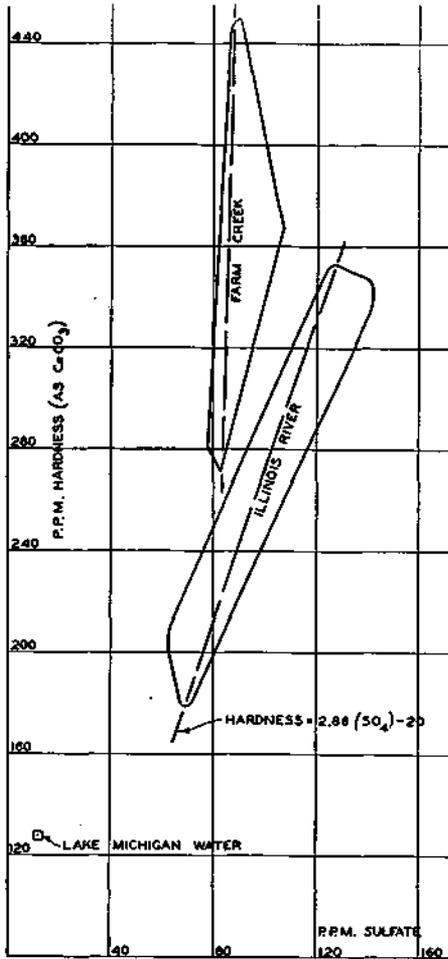


Fig. 3. Relative Character of Illinois River and Farm Creek Waters

(Straight lines represent the general character as given by mass of specific points.)

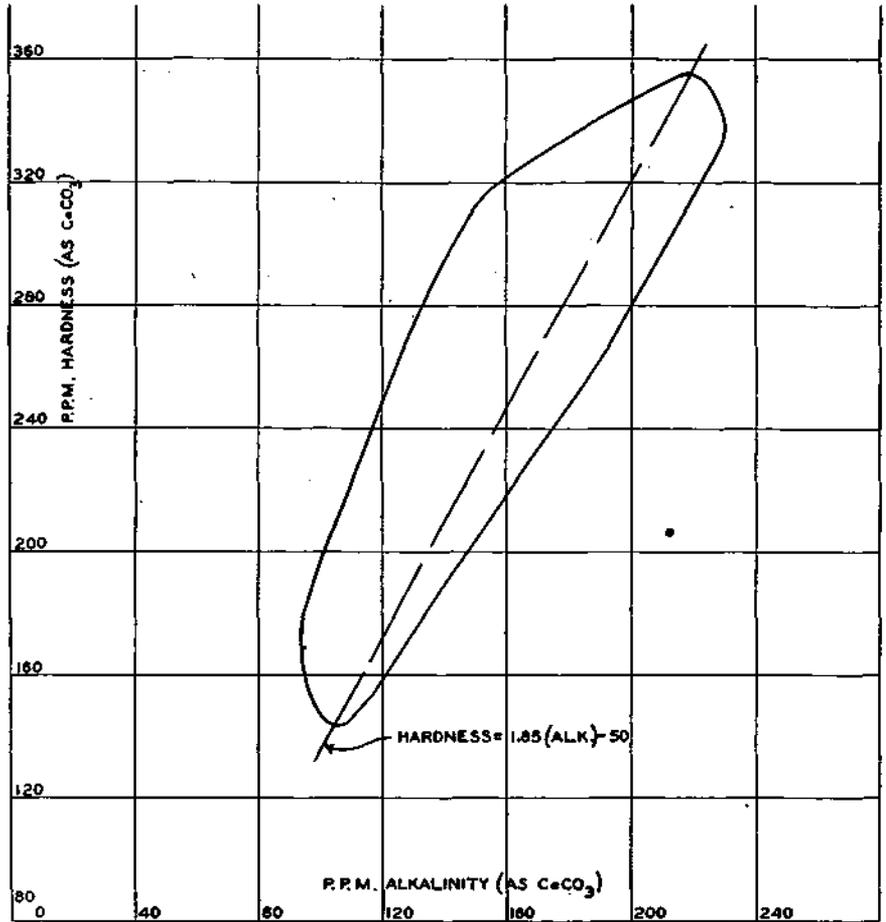


Fig. 4. Character of Illinois River Water

(Straight line represents the general character as given by mass of specific points.)

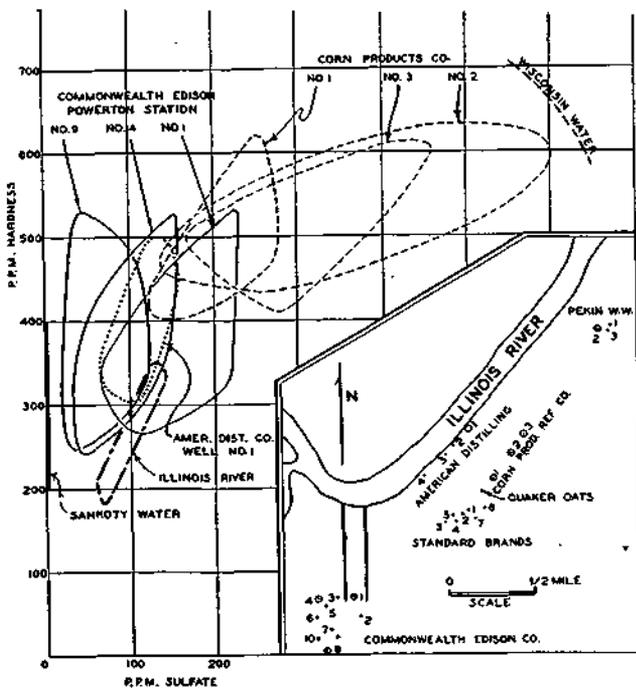


Fig. 5. Character Patterns of Waters from Industrial Wells South of Pekin

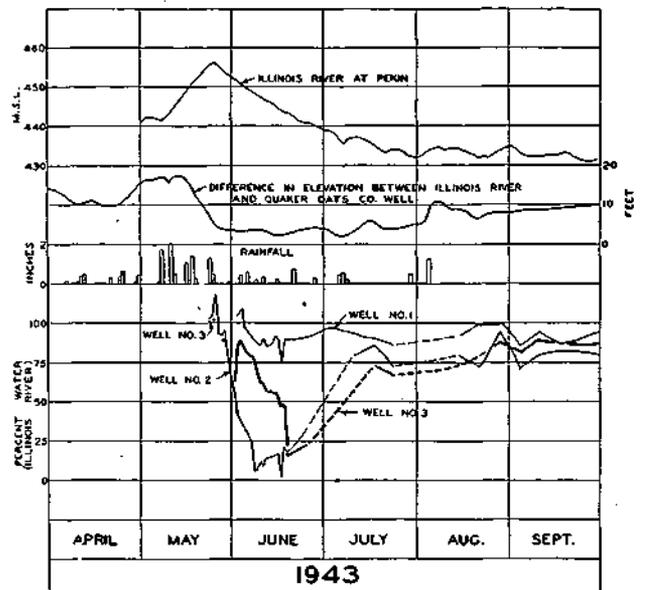


Fig. 6. Calculated Per Cent of Illinois River Water Entering Corn Products Co. Wells No. 1, 2, and 3

(After heavy rains and floods in 1943)

nes's variations overhang the band on both sides, indicating the presence of a considerable proportion of water from other sources. In addition, several tests have shown that the saturation index of Sankoty water is positive, indicating calcium carbonate saturation. These considerations indicate that the Pekin Field derives water from a third source. Again, waters from the Sankoty formation invariably contain more than 1 pph. of iron, whereas no indication of iron has been given in the analyses of the water from these wells. Only 4 of 72 samples from the American Distilling Co. well contained more than 0.1 ppm. of iron.

The Illinois River is a third possible source of water. Since this water has a negative saturation index, it could readily dissolve additional calcium and magnesium.

Compared to the solubility of dolomite, all other salts of calcium and

magnesium, as well as all sodium and potassium salts, are very soluble. It was therefore assumed that over a long period of time practically all of the soluble salts in the ground formation under and near the river were leached out, whereas much of the relatively insoluble dolomite still remains. It was then postulated that, if Illinois River water entered the ground, its chemical character would be altered only by the solution of dolomite, thereby increasing the hardness and alkalinity by equal but unpredictable amounts.

For this reason, the pattern for the Commonwealth Edison Powerton Station Well No. 9 (Fig. 5) is interpreted to represent mixtures of Sankoty water (containing no sulfate) with Illinois River water (altered by an increase in hardness) and possibly some Wisconsin or outwash water.

The patterns for the Powerton Station Wells No. 4 and 1, and the Corn

Products Co. Wells No. 1, 3 and 2 are interpreted to show these waters to be predominantly mixtures, containing progressively greater proportions of Wisconsin or outwash waters with water of Illinois River origin. Further consideration of the relative location of these wells with respect to the Illinois River and to the channels to the Powerton Station, and of the relative pumpage from these wells and other wells in the immediate district, confirms and explains the interpretation of the analytical data.

In 1943, during and after a severe flood, the Corn Products Co. made frequent analyses of samples of water from their wells. At no time were analyses found to be identical in quality or character to Illinois River water, but with the aid of the assumptions concerning the possible alteration of river water quality, an equation was developed to indicate the proportion of water coming from the river in each sample (Fig. 6).

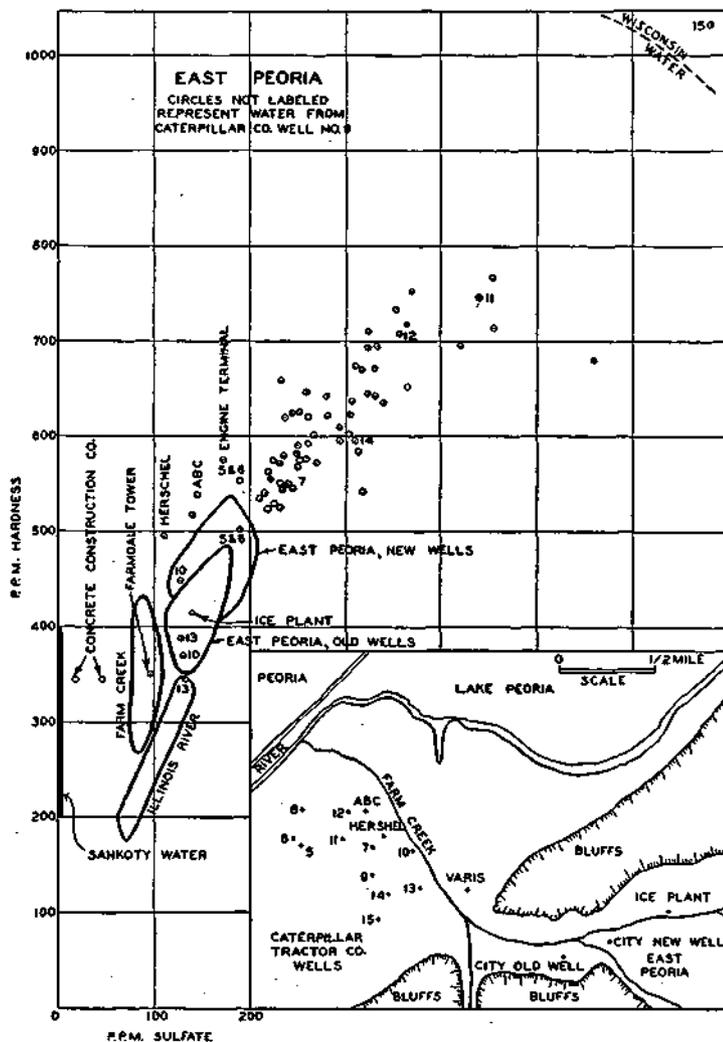


Fig. 7. Character Pattern of Wells in East Peoria

(Circles not labeled represent water from Caterpillar Co. Well No. 9)

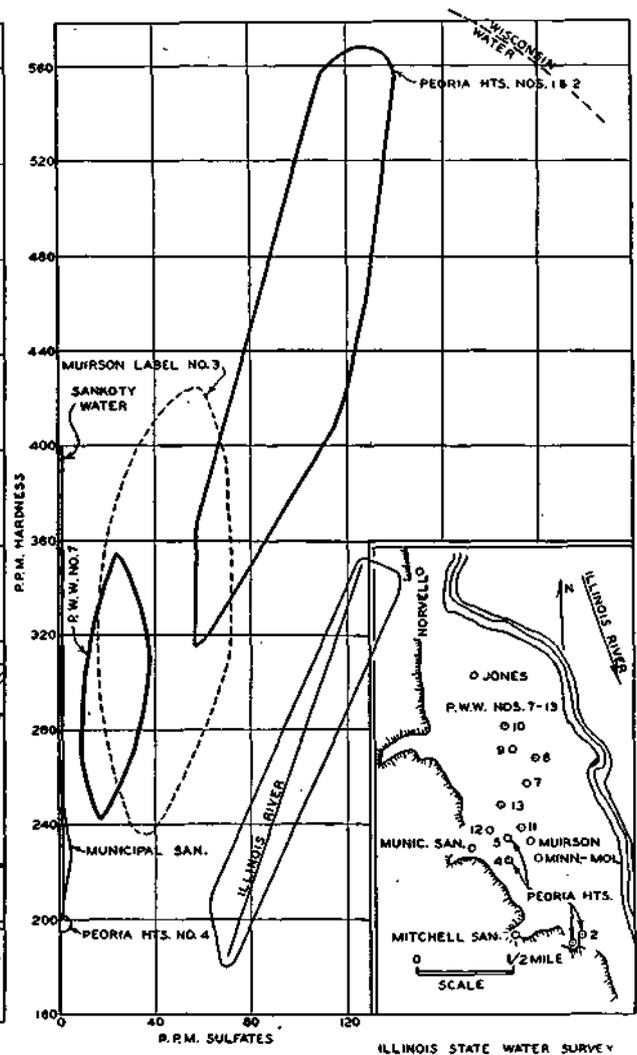


Fig. 8. Character Patterns of Wells in Sankoty Field.

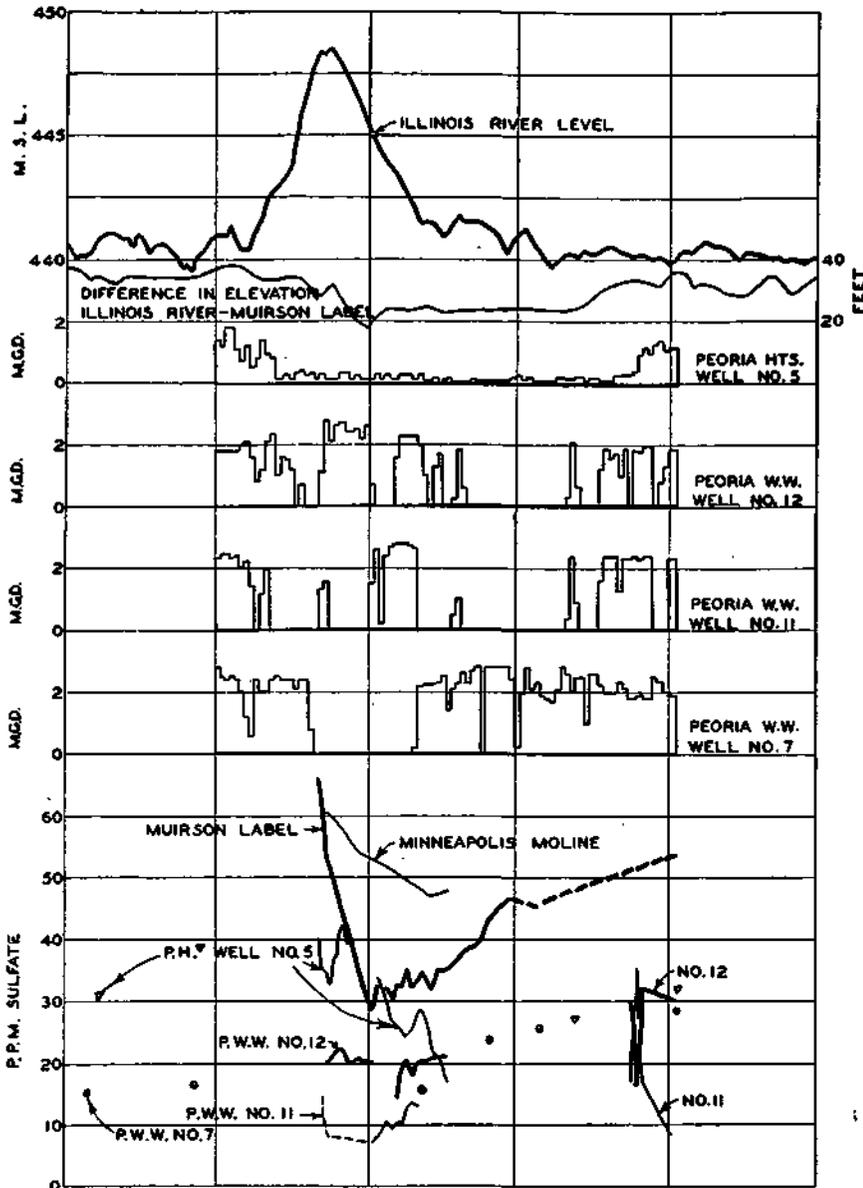


Fig. 9. Sampling Data from Sankoty Field

The character of Illinois River water was defined by the general relationship between the hardness and sulfate content and the hardness and alkalinity (Fig. 3, 4).

$$\begin{aligned} \text{Hardness} &= 2.86(\text{SO}_4) - 20 \\ \text{Hardness} &= 1.85(\text{Alky.}) - 50 \\ \text{Alkalinity} &= 1.55(\text{SO}_4) + 16 \end{aligned}$$

On passing through the ground toward the well, this water would dissolve some dolomite and thereby increase in hardness and alkalinity by Z pprn., but the sulfate content would be unaltered. If the sulfate, alkalinity and hardness of the transferred and altered river water are called A, B and C respectively, then:

$$\begin{aligned} A &= \text{SO}_4 \\ B &= \text{Alkalinity} + Z \\ C &= \text{Hardness} + Z \end{aligned}$$

and:

$$B = 1.55A + 16 + [C - (2.86A - 20)] = 36 + C - 1.31A$$

If the ground water quality is arbitrarily exemplified by the analysis showing the greatest hardness and sulfate content, then the per cent x of river water in any sample can be calculated from the sulfate, alkalinity and hardness of any particular sample. The ground water is characterized by a hardness of 610 ppm., an alkalinity of 325 ppm. and a sulfate content of 600 ppm.

$$\begin{aligned} 100 \text{ SO}_4 &= xA + (100-x)600 \\ 100 \text{ Alky} &= xB + (100-x)325 \\ 100 \text{ Hdns} &= xC + (100-x)610 \\ B &= 36 + C - 1.31A \\ x &= \frac{500 + \text{Hdns} - \text{Alky} - 1.31 \text{ SO}_4}{464} \end{aligned}$$

For the purposes of illustration, Table I has been prepared to show the data used for the calculation of the per cent of river water obtained from

the Corn Products Refining Co. wells on June 10, 1943.

The assumption of a definite point value for ground water and of a straight-line relationship for hardness-sulfate and hardness-alkalinity for river water are actually rough approximations and involve a maximum possible error of about 50 per cent, but it was found that reasonable deviations from these ground water

Table I

Well	Sulfate	Alkalinity	Hardness	River Water
	ppm.	ppm.	ppm.	per cent
1	213	281	465	87
2	551	336	585	6
3	348	292	525	60

values and river character relationships did not alter the trend of the results shown in Fig. 6.

The data show that the heavy rain accompanying the flood period recharged the ground water supply and permitted a high percentage of ground water to be pumped from the wells for about a month after the flood period. This was followed by a return to character indicative of river water origin. This set of interpretations is typical of the approach at the other well fields.

East Peoria

In East Peoria, the city wells are located between Farm Creek and a small branch tributary. It is evident from Fig. 7 that a large percentage of the water obtained from these wells is indirectly from Farm Creek. The old wells appear to contain a greater concentration of water from Farm Creek than the new wells. The temperature of the water from these city wells of 25-ft. depth varies seasonally from 46° to 63°F.

At the Caterpillar Tractor Co., considerable variation in quality occurs from one well to another. Figure 7 shows the general character of the water obtained from Well No. 9 over a period of five years and from each of the other wells on two specific dates. It appears that exceptionally high sulfate water is obtained from the Wisconsin drift at the bluffs to the south, as exemplified by the character of the water at the Caterpillar Well No. 15.

Sankoty Field

In the Sankoty field located north of Peoria Heights about three miles north of the Main Pumping Station of the Peoria Water Works Co., the quantity of water extracted for the city supply is such that approximately three months' pumping would completely dewater the formation in the

immediate area of the wells in this field, if there were no water entering from surrounding areas and no recharge.

The Muirson Label Co. Well No. 3 (Fig. 8) shows a considerable variation in quality because of its proximity to all three of the recharge or inflow sources. The pumpage from this well (0.1 mgd.) and from the Minneapolis-Moline Co. well (0.001 mgd.) is low, but the quality is greatly influenced by the pumpage in the nearby heavy producing area.

Peoria Water Works Well No. 7, which is perhaps at the center of the greatest amount of extraction (Fig. 6), also appears to be centered in the ranges of quality obtained from the three sources. The quality appears to be predominantly on the side of typical Sankoty water (zero sulfate) rather than on the side of Wisconsin drift or the Illinois River water. The temperature is predominantly about 54°F., but occasionally varies to 53° and 58°F.

The quality of the water from each of the wells varies considerably and at this field no clear interpretation could be made. Here again, however, the variations in quality for each particular well are limited to a specific or characteristic pattern of sulfate and hardness concentrations. Typical patterns for the waters obtained in the field are compared with possible recharge waters.

The qualities of these waters vary from that of typical original Sankoty formation water, such as that found in Peoria Heights Well No. 4 and in the Peoria Municipal Sanitarium well (located near the buried valley northwest of Peoria), to that of the Illinois River, which is shown to have an appreciable sulfate concentration. In general, the hardness and the sulfate concentrations are not as great as those found in certain samples from Peoria Heights Wells No. 1 and 2 at the bluffs on the south side of the heavy producing area. These wells, by virtue of their proximity to the bluffs, often appear to obtain a considerable proportion of Wisconsin drift water of relatively high hardness and sulfate.

It appears that water enters the heavy producing area of the Sankoty Field (Peoria Heights Well No. 5. Peoria Water Works Wells No. 7, 9, 10, 11, 12 and 13) from the Wisconsin drift, the underlying Sankoty sand and possibly the Illinois River.

An attempt was made to obtain further information by daily sampling of wells in this field in June 1945. The data collected are shown in Fig. 9. Unfortunately, the operation of the

wells at this time did not permit sufficient sampling to establish any definite conclusions other than that considerable variation in quality occurs from day to day.

Industrial Field

In the industrial field, the records of analyses determined by Hiram Walker & Sons, are interpreted to show that much of the water obtained from the No. 2 Well, which is closest to the river (Fig. 10) was derived indirectly from the river (solid-line pattern) and that only after the high rainfall periods in 1942 and 1943 was an appreciable amount of ground water (high sulfate) obtained (extended broken-line pattern) at this well.

In this well field, the relative patterns of water character from several wells indicate the sources of water ob-

tained from these wells. These patterns show that:

1. The Hiram Walker Well No. 2 obtains much of its water from the river, whereas No. 7, which is farther from the river, constantly yields water of a greater sulfate content.

2. The Schwab Dairy and the new Dodge Street Well waters are almost identical, and by virtue of a high nitrate content these, incidentally, appear largely typical in character of waters from the glacial outwash from the northwest.

3. The Sanitary District well, which is closer to the river, yields water of lower sulfates, indicating a large proportion of its source to be from the river.

4. Spot samples at other wells indicate that more river water is present, as the location of these wells is closer to the river. Of corresponding

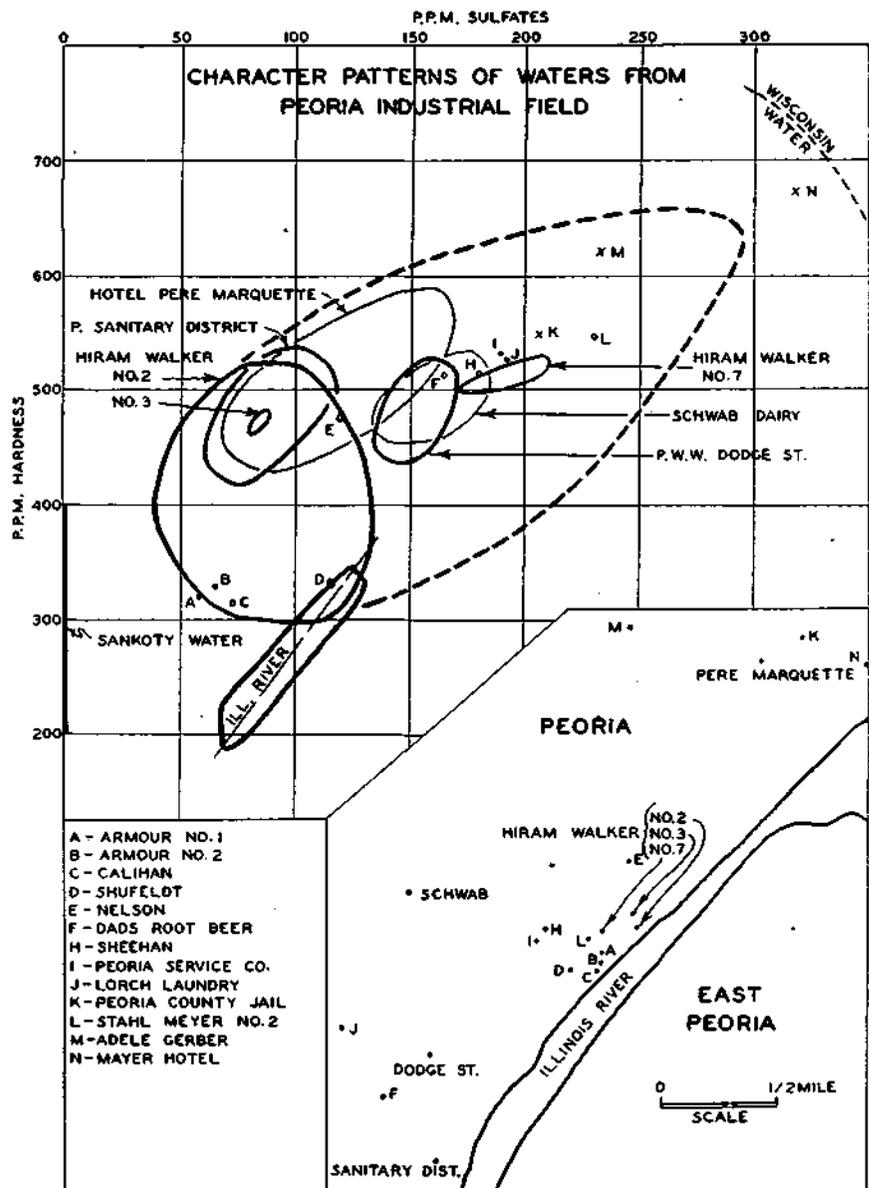


Fig. 10. Character Patterns of Wells in Peoria Industrial Field

interest is the fact that the wells showing a high percentage of river water are not the heavy producing wells in this field.

Some question has been raised concerning the extent to which river water may enter the ground water formations. This question is based on the fact that the river bottom above the dam is covered with a silt deposit estimated to average 10 ft. in thickness and found to have a maximum recorded thickness of 25 ft. It is conceivable that this silt deposit, having only about 12 per cent water content, may act as a relatively impervious barrier to the transfer of river water. The interpretations do not indicate

where or how river water enters the ground at each field, but do indicate that it does to a variable extent, depending on the location of the well.

It is estimated that 34 per cent of the over-all estimated pumpage of the area, exclusive of Sankoty Field, is of river origin. The 11 mgd. pumped in the Pekin Field below the dam derives some 73 per cent of its water from the river. Of the 37 mgd. pumped in the Peoria Industrial and the East Peoria fields, only 14 per cent is estimated to be of river origin, and 10 of the 14 per cent is estimated to come from Farm Creek. No estimate is made on the percentage at Sankoty Field.

As a whole, the study has been highly interesting. The data serve as additional bases for hydrologic interpretations and to supplement the hydrologic conclusions.

Acknowledgment

The author wishes to express his appreciation to the various members of the Illinois State Water Survey staff who have co-operated and contributed constructive criticisms during the preparation of this report.

References

1. Bulletin 33. State Water Survey Div., Urbana, Ill.
2. HORBERG, L. Groundwater Geology of the Peoria Region. Illinois State Geological Survey, Urbana, Ill. (1946).