METHODS OF EVALUATING THICKNESS AND TEXTURE OF GLACIAL TILL IN STUDIES OF GROUND-WATER RECHARGE

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ABSTRACT.—The thickness and vertical 'meability of the till that overlies the cial drift and shallow bedrock aquifers northeastern Illinois were measured to :ermine their relation to the recharge e of ground water. The till impedes :tical movement of the water. The erage thickness of the till at main pump- ; centers was determined from maps d from cumulative thickness curves. e saturated thickness of the confining d was estimated by subtracting depth the assumed water table from the erage thickness of the confining bed. rtical permeability at the pumping ıters was not measured directly but s calculated on the assumption that kage and pumpage are approximately ıal at the pumping centers.

Relative permeability was inferred m textural data obtained from hy- ɔmeter analyses of subsurface samples m 52 test holes that penetrated the full ckness of the glacial drift. Textural ferences of the confining bed varied ;ionally. Sand is more plentiful than y roughly west of the Fox River, in- :ating relatively high permeabilities, ıereas the reverse is true east of the er. The findings, supported by data rived from hydrologic analyses at the mping centers, indicated thickness and rtical permeability of the till do affect ɔund-water recharge.

Glacial drift and shallow bedrock uifers are a major source of ground ıter in the area of northeastern inois that includes Cook, DuPage, ane, Lake McHenry, and Will ɔunties. Where glacial drift aq- fers (sand and gravel) and shal- w bedrock aquifers (principally lurian dolomite) are overlain by nfining beds of glacial till, leaky tesian conditions exist. The till ds impede the vertical movement ground water to the aquifer.

The withdrawal of ground water ɔm these aquifers has produced a ımber of cones of depression. The rtical permeability of the confining beds as well as the hydrogeologic character of the aquifer are two of the factors that control the depth and shape of the cone of depression. In this report, the cone of depression is simply called the pumping center.

Several pumping centers were described and studied by Zeizel et al. (1962) and Prickett et al. (1964). The area of a pumping center is measured by drawing flow lines at right angles to the piezometric surface contours. It is rarely symmetrically shaped because production wells are usually unevenly distributed and are pumped at the same rates.

Figure 1 shows the areal distribution of the confining beds and possible sand and gravel deposits of the glacial drift (Piskin, 1963) in seven of these pumping centers. Working in northeastern Illinois, Walton (1960) calculated the quantity of leakage through a confining bed (the Maquoketa Group of Ordovician age) into an aquifer by employing the equation:

$$Q_c = \frac{P'}{m'} \triangle hA_c$$

where Q_c = leakage through the confining bed (gpd)
P' = vertical permeability of the confining bed (gpd/ft^2)
m' = thickness of the confining bed through which leakage occurs (ft)
A_c = area of the confining bed through which leakage occurs (ft^2)

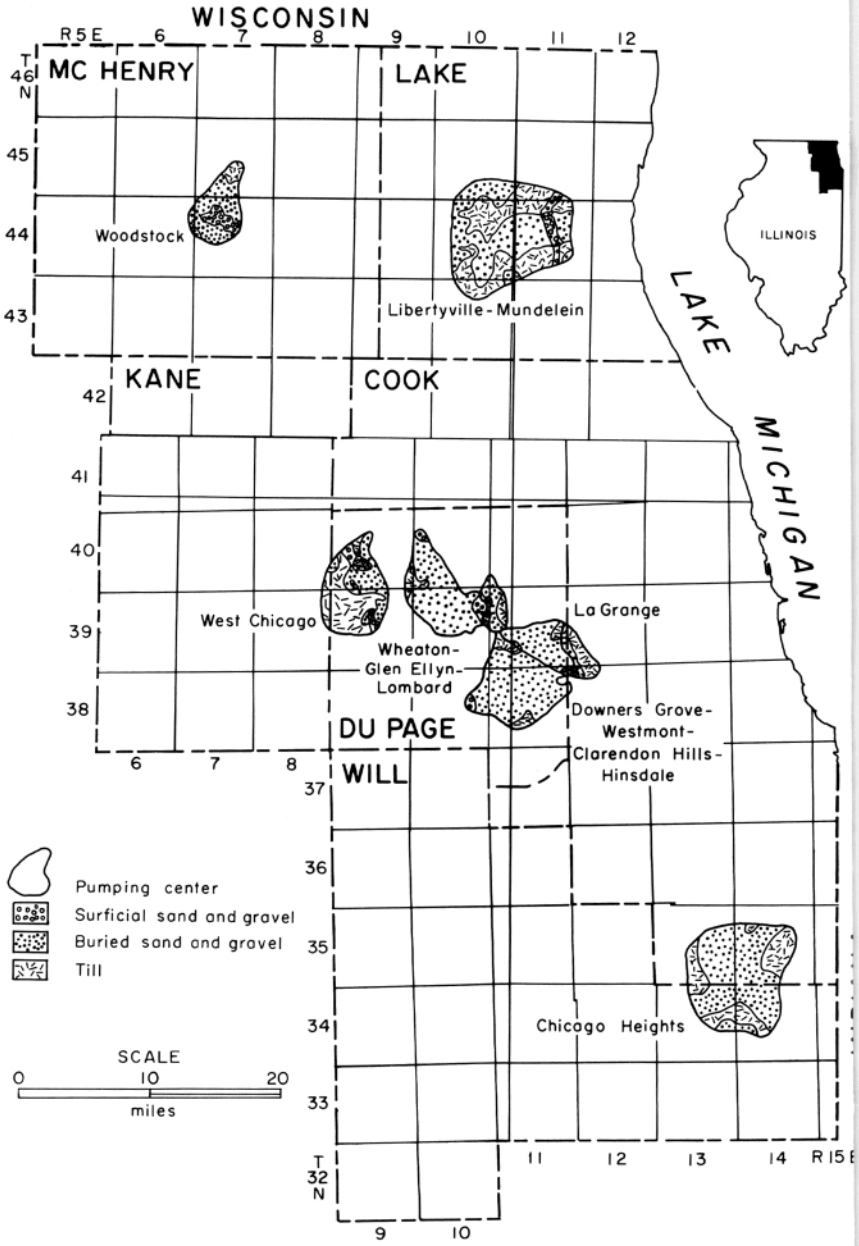

FIGURE 1. Distribution of glacial drift deposits in pumping centers in nort eastern Illinois.

$\triangle h$ = difference between the head of the aquifer and the source bed above the confining bed (ft)

; can be applied to leakage through confining layer of glacial till to valuate quantitatively the effect : such a layer on ground-water reharge to underlying aquifers.

GEOLOGY

The shallow bedrock in northastern Illinois consists mainly of ocks of the Maquoketa Group (Orovician) and the Alexandrian and iagaran Series (Silurian). Quaterary deposits, principally glacial rift, blanket the bedrock.

The Maquoketa Group underlies ne glacial drift along the western argin of the study area. It consts of three formations, two shale ormations and a middle formation hat is argillaceous dolomite or limeone interbedded with shale. Doloite is also present in the upper and ower shale formations, both of hich are commonly fossiliferous nd fine grained. The dolomitic midle formation is part of the shallow edrock aquifer system.

Silurian deposits directly undere the glacial drift in, approxiately, the eastern three-fourths of ne study region, which is where ne seven pumping centers used in ne tests are located. The Alexanrian Series (lower part of Silurian) onsists of argillaceous to finely andy, cherty, gray to light brown, nely crystalline dolomite; the overing Niagaran Series consists of hite to light gray, cherty, silty, nely crystalline to medium-crycalline dolomite. The total thickess of the Silurian deposits ranges om 0 to 465 feet, increasing toard the southeast. The Silurian is ne principal water-yielding unit of ne shallow aquifer system in northastern Illinois.

The unconsolidated Quaternary deposits, overlying the Silurian and Maquoketa, resulted principally from the extensive continental glaciers and subsequent action by wind and running water; thus, most of the region is covered with thick drift. The drift varies in thickness from 0 to about 500 feet, depending on bedrock topography as well as the present land surface (Piskin and Bergstrom, 1967). In general, the drift thickens from south to north and from east to west; the thickest deposits, exceeding 250 feet, are restricted to the northern part of the study area.

The glacial drift consists principally of unsorted ice-laid rock debris (till), sorted meltwater deposits (glaciofluvial), and ancient lake-bed sediments (glaciolacustrine). The till found throughout the region is dense clayey silt to gravelly sand; it is most commonly fine grained. The till deposits are the principal confining layer for both the shallow bedrock and glacial drift aquifers. Glaciofluvial deposits of the area, in the form of terraces, outwash plains, and valley trains, are characteristically coarser in texture (sand and gravel) than the till and commonly exhibit cross-bedding. These sand and gravel deposits are the second major source of shallow ground water in the region. Glaciolacustrine deposits, generally the finest grained sediments, are found along Lake Michigan and in western Will County, and, like the till, serve as a confining layer.

In the seven pumping centers tested, till deposits occur at various levels within the outwash and valley train deposits. Locally, they rest on the underlying Silurian dolomite, where basal sand and gravel are absent. The areal relations of sand and gravel and till deposits for the seven pumping centers are shown in Figure 1. More detailed

geologic information on bedrock formations is given by Suter et al. (1959), Zeizel et al. (1962), and Hughes, Kraatz, and Landon (1966).

Method of Evaluation

The equation was used to determine vertical permeability of the confining beds at the seven pumping centers. In this report, the West Chicago pumping center, located in T. 39 and 40 N., R. 9 E., DuPage County, Illinois, is taken as an example. The area of influence of production wells was about 28.0 square miles in 1960 (Zeizel et al., 1962). The main aquifer at this center is the Silurian dolomite, which is recharged by vertical leakage through the overlying glacial drift. The drift itself is recharged by precipitation. Because water levels suggest that recharge from leakage increases with pumpage, recharge to the Silurian dolomite aquifer in the West Chicago pumping center was assumed to be equal to the pumpage, which was estimated to be 1.8 million gallons per day (mgd). Zeizel et al. (1962) estimated the rate of recharge to the Silurian dolomite in 1960 to be 64,000 gpd per squa mile.

The map in Figure 2 shows th sand and gravel at the West Ch cago site is at least 15 feet thic (Piskin, 1963). These deposits a divided into two groups, surfici deposits with less than 10 feet fine-grained overburden, and burie deposits with more than 10 feet fine-grained overburden, mainly ti Surficial and buried sand and grav are assumed to be separated by ti at least 10 feet thick. Surficial d posits, which attain a maximu thickness of 50 feet, cover an are of approximately 4 square mile buried deposits, ranging from 15 100 feet thick occupy an area about 10 square miles. Cross se tions (Fig. 2) show that the prese land surface approximates the t pography of the bedrock surfac except in the north where a sma valley in the Silurian dolomite h no present topographic expression

At the West Chicago pumpin center, confining beds of glacial ti which range in composition fro yellow-gray-brown sandy si through clayey silt and sand

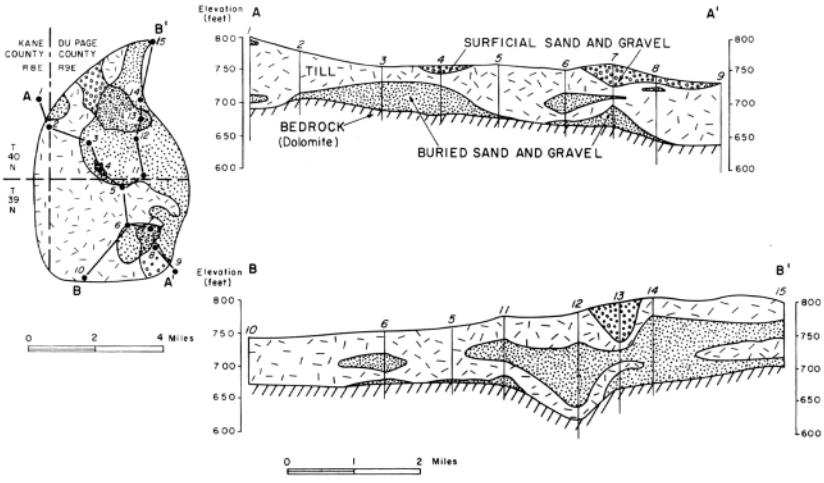

FIGURE 2. Geology of West Chicago pumping center.

ightly silty clayey sand, directly verlie the sand and gravel or, in ome cases, Silurian dolomite (Fig.). The confining beds range from ess than 25 to more than 75 feet hick (Fig. 3A), the thicker beds eing located in the northeastern art of the pumping center. To rep- esent the average thickness of the onfining bed at this pumping cen- er, the ratio of the area between he various isopachs to the total rea was plotted against the thick- ess of the confining bed. The 50th ercentile point of area (Fig. 3B) as then taken as the average hickness of the confining bed in he pumping center. The depth of he water table was assumed to be 0 feet (T. A. Prickett, personal ommunication, 1969). The satura- ed thickness of this bed may be oughly determined by subtracting he depth to the water table from the average thickness of the confining bed.

The vertical permeabilities of the confining beds in the West Chicago, Wheaton-Lombard-Glen Ellyn, and Downers Grove-Westmont-Hinsdale-Clarendon Hills pumping centers were calculated by using the equation with the values for saturated thickness inserted. Head loss ($\triangle h$) was estimated by computing the difference in elevation between the head of the aquifer and that of the source bed above the confining bed. The other hydrogeologic data for these centers were taken from Zeizel et al. (1962). Vertical permeabilities of the confining beds at the remaining four pumping centers (La Grange, Chicago Heights, Woodstock, and Libertyville-Mundelein) were determined from data taken from Prickett et al. (1964). These results were compared

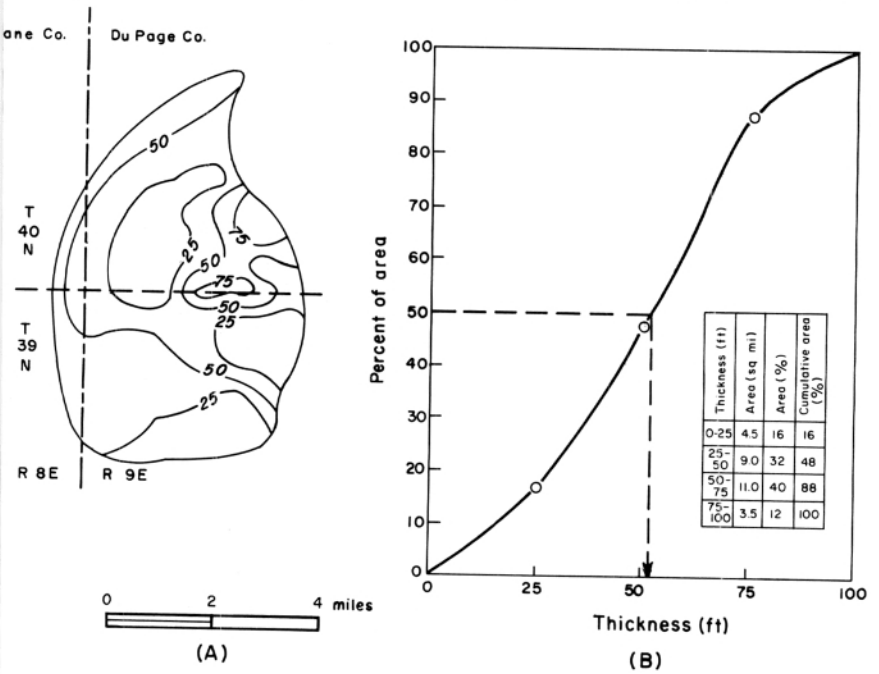

FIGURE 3. Thickness map (A) and graphical representation of average thickness B) of confining beds in West Chicago pumping center.

to the vertical permeabilities for the four pumping centers obtained by Prickett from analysis of pump tests; the two set of data compare favorably.

To evaluate the effect of texture upon vertical permeability, grain-size distributions of the confining beds were obtained by hydrometer analyses of subsurface samples from 52 precisely-planned test holes drilled in the six-county area. These test holes, penetrating the entir thickness of glacial drift, were par of a study on water managemer coordinated by the Northeaster Illinois Metropolitan Area Plar ning Commission (Hackett an Hughes, 1965). Textural analyse of the confining beds were average and plotted in a triangular diagrar (Fig. 4) to show the distribution c the sand-silt-clay ratios. Result were then compared with the ve

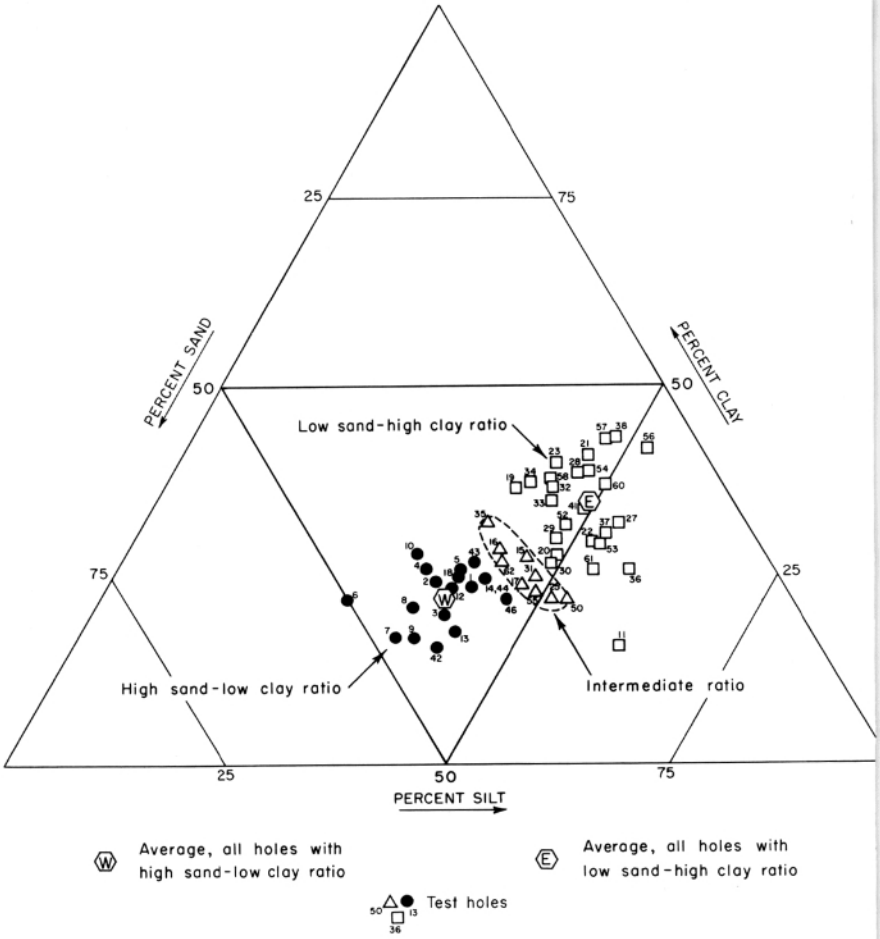

FIGURE 4. Average composition of confining beds penetrated in test holes.

ical permeabilities of the various confining beds in the seven pumping centers.

Results and Discussion

Table 1 shows the thickness and characteristics of the confining beds in the seven pumping centers; at these sites, total drift thickness ranges from 10 feet in the La Grange area to approximately 300 feet in the Woodstock and Libertyville-Mundelein areas. The table indicates that the average saturated thickness of the confining bed is higher in the Woodstock and Libertyville-Mundelein centers where the drift is thickest. Because the areas of thicker drift generally contain thicker deposits of confining till as well as sand and gravel, drift thickness directly influences the saturated thickness of the confining bed. These results are in agreement with previously published data on the saturated thickness of the confining bed in the Chicago Heights, La Grange, Libertyville-Mundelein, and Woodstock pumping centers (Prickett et al., 1964). The saturated thickness of the confining bed at the other three pumping centers (Table 1) was found to be reasonable (T. A. Prickett, personal communication, 1970).

Results of hydrometer analyses of the confining beds in the 52 test holes previously mentioned were obtained from standard grain-size ratios for sand (2.0 mm and 0.062 mm) silt (0.062 and 0.004 mm), and clay (< 0.004 mm). These figures indicate that, although the percentage of sand ranges from 6 to 50

Table 1. Thickness and Characteristics of Confining Beds in Pumping Centers

Pumping Center	Average Thickness (ft)	Assumed Saturated Thickness (ft)	Characteristics
Chicago Heights	44	34	Till, brown silty clay, clayey silt, and occasional gray silty clay with gravel and trace sand.
Downers Grove-Westmont-Hinsdale-Clarendon Hills	58	48	Till, gray silty clay with trace of sandy silt and brown gravel.
La Grange	45	35	Till, brown to gray silty clay and gray clayey sand with silt.
Libertyville-Mundelein	150	140	Till, gray clayey silt, silty clay with trace of sand and gravel; occasional gray clay and pebbles.
West Chicago	52	42	Till, yellow-gray-brown sandy silt, clayey silt, and sand to clayey sand with trace of silt.
Wheaton-Lombard-Glen Ellyn	45	35	Till, gray sandy silt, gray to brown clayey silt, and silty clay with occasional sand and gravel.
Woodstock	119	109	Till, gray to brown clayey sand with medium to coarse sandy gravel, and pinkish brown sandy silt with clayey gravel.

percent and that of clay from 16 to 49 percent, the amount of silt is more or less consistent, averaging 45 percent. These ratios are dependent on the character of local tills within the glacial drift.

The percentage of coarse materials is generally higher in the western than the eastern part of the area, and the reverse is true for the fine materials. This relation is apparent in Figure 4, which was compiled by plotting the average percentage composition of the confining bed at each test hole. Because of its relative consistency, the percentage of silt was not considered. On the basis these percentages, three main groups were identified. The first, which falls at the left side of the diagram (the western part of the study area), is characterized by high sand (32 to 50 percent) and low clay (16 to 28 percent) ratios; a second group at the far right (the eastern part of the area) is characterized by low sand (6 to 24 percent) and high clay (16 to 43 percent) ratios (Fig. 4). These two divisions are separated by a third group, which is characterized by intermediate ratios of sand (25 to 30 percent) and clay (22 to 32 percent). In addition, the average composition of all holes with high sand and low clay and low sand and high clay percentages within the two groups were averaged. These total averages are shown in Figure 4 by hexagons *W* and *E*, which represent the average sand-silt-clay ratios as 39:39:22 and 17:49:34, in west and east groupings, respectively.

Figure 5 illustrates the regional distribution of the 52 test holes where subsurface data were obtained for the confining beds. The holes with high sand and low clay ratios generally occupy the area west of the Fox River, while the the reverse is true east of the river. Holes with intermediate ratios are about equally distributed within the two groups. To compare variations in vertical permeability with textural distribution, the vertical permeability of the confining bed at each of the seven pumping centers was also included in Figure 5.

The vertical permeabilities obtained for the confining beds in the latter four pumping centers compares favorably with previously published data by Prickett et al (1964). The vertical permeabilities in the various centers ranges from 0.3×10^{-2} gpd/ft^2 to 1.3×10^{-2} gpd/ft^2. The Woodstock pumping center, which is the only one located west of the Fox River, had the highest vertical permeability in the region. The rest of the pumping centers, located east of the Fox River have comparatively low vertical permeabilities. These results appear to correspond with the regional distribution of sand-clay ratios within the confining beds at the various pumping centers. The vertical permeabilities and clay ratios of the confining beds in the seven pumping centers are plotted in Figure 6 with a linear regression line drawn through these points. This relationship suggests that the high sand and low clay percentages coincide with the area of high vertical permeability (west of the Fox River), while low sand and high clay percentages can be observed in the area with low vertical permeabilities (east of the Fox River).

Summary

The saturated thickness and vertical permeability of a glacial till overlying an aquifer has, under leaky artesian conditions, an effect on the recharge rate of the aquifer. Although this relation has long been inferred in this region, no previous experimental data have been obtained to support it. Data from subsurface sampling programs and from

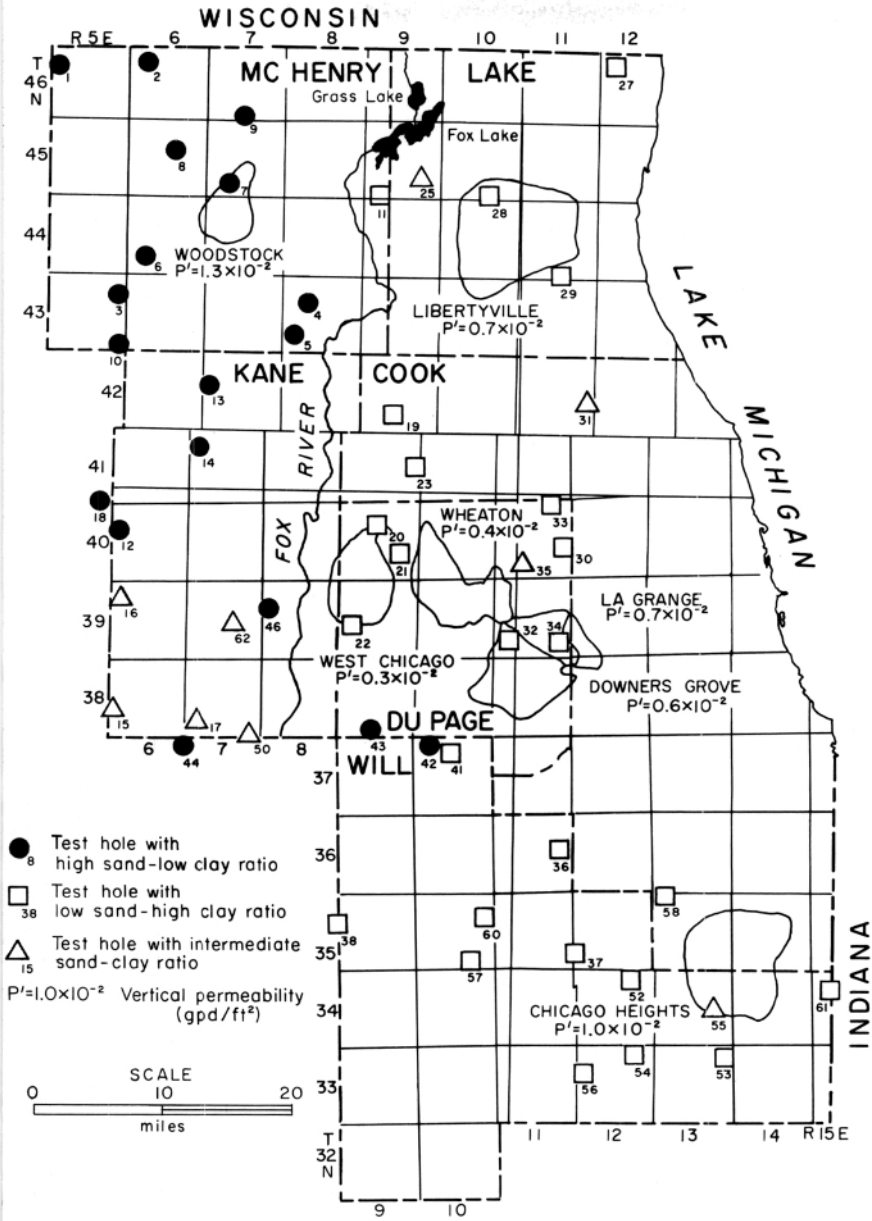

FIGURE 5. Distribution of test holes and pumping centers. Sand-silt-clay ratios for the test holes and vertical permeability of confining beds for the pumping centers.

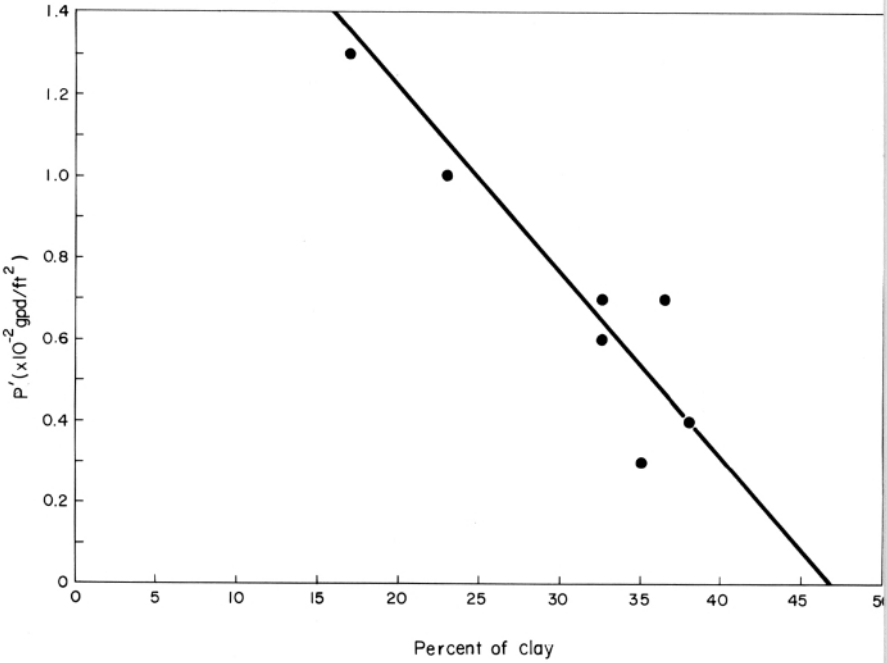

FIGURE 6. Comparison of vertical permeability with clay ratio of confining bed in 7 pumping centers.

cone analyses of selected pumping centers, both used in this study, are generally reliable. However, the vertical permeability differences among the seven pumping centers have a limited range, and greater variations might be expected in other areas. The relation between sand-clay ratios and vertical permeabilities can be better established when additional pumping centers, especially west of the Fox River, are considered. Supporting studies from other areas would prove helpful.

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