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Feasibility of Subsurface Disposal of Industrial Wastes in Illinois

Robert E. Bergstrom

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FEASIBILITY OF SUBSURFACE DISPOSAL OF INDUSTRIAL WASTES IN ILLINOIS

Robert E. Bergstrom

ABSTRACT

Deep-well disposal of industrial liquid wastes in Illinois is subject to pollution-control regulations and to hydrogeologic conditions. These conditions range from favorable for deep-well disposal in the Illinois Basin, where the geologic section is thick and partly impermeable and ground water is highly mineralized below shallow depth, to unfavorable or questionable in northern Illinois where the geologic section is thin and mainly permeable, the ground water is fresh to great depth, and the deep aquifers are heavily pumped.

The most promising disposal reservoirs in the southern part of the state are the Ordovician St. Peter Sandstone and the Cambrian Ironton-Galesville and Mt. Simon Sandstones. These are important aquifers in northern Illinois. Other possible disposal zones include sandstones of Pennsylvanian age, Chesterian sandstones and Valmeyeran limestones of Mississippian age, limestones and dolomites of Devonian and Silurian age, and dolomites of Ordovician and Cambrian age. Of the three disposal wells in Illinois, one is designed to inject wastes into the Mt. Simon Sandstone, one into Devonian age limestone, and one into Cambrian age dolomite.

INTRODUCTION

The recent increased interest in the subsurface disposal of industrial wastes in Illinois is a result of new industrial developments and greater public concern for the quality of water in streams. It is likely that in the future more industries will consider the possibility of discharging liquid wastes into specially constructed deep wells.

This report describes the factors that bear on the feasibility of industrial waste disposal wells in Illinois, with main emphasis on geologic conditions and natural resources.

FACTORS BEARING ON FEASIBILITY

The feasibility of disposal wells is governed by the nature and volume of the wastes to be discharged, the presence of suitably permeable and porous formations to receive the wastes, and the presence of confining formations to prevent other resources—mainly potable ground water—from being damaged by the wastes or by displaced formation water. A further consideration is that the waste disposal system must be in accordance with the Illinois regulatory controls.

Regulatory Controls

The Illinois Sanitary Water Board (Ill. Revised Statutes, 1965, chapt. 19, sec. 145.1 to 145.18) is charged with the control of pollution in the waters of the state, and among other duties, issues permits for the installation and operation of industrial waste disposal well systems. Issuance of a permit is contingent upon the applicant's submission of an acceptable engineering report on the project and the demonstration that "fresh" water will not be adversely affected. "Fresh" water has been defined by Illinois agencies that have responsibilities for protection of water resources from pollution as water containing less than 5000 milligrams per liter (mg/l) total dissolved minerals; consideration is now being given to revising this figure to 10,000 mg/l (Klassen, 1968).

The Sanitary Water Board states the following policy relative to their review of disposal well projects: "It is the intention of this office that the review of a proposed project be rigorous, with the exercise of conservative technical and administrative judgment. This attitude is taken with the thought that pollution of underground potable and fresh waters will undoubtedly represent a long-term damage to a critical natural resource. An industry that plans to utilize the deep-well injection of wastes should expect that the procedures to be followed to obtain the required Sanitary Water Board permit will be more rigorous than for a surface waste treatment works where the necessity of corrective measures are more easily observed and accomplished" (Klassen, 1968). The Illinois State Geological Survey assists the Sanitary Water Board in evaluating hydrogeologic conditions at proposed sites.

The disposal of oil-field brines in wells, which is a special type of industrial waste disposal, comes under the jurisdiction of the Illinois State Mining Board in the Department of Mines and Minerals (Ill. Revised Statutes, 1965, chapt. 104, sec. 67). Oil-field brine disposal is not specifically considered in this report.

Permits for drilling wells into formations below the glacial drift must be obtained from the State Mining Board in the Department of Mines and Minerals (Ill. Revised Statutes, 1965, chapt. 104, sec. 67). Wells drilled for waste disposal are included in this statute, but a permit for the installation and operation of a waste disposal well must be obtained from the Sanitary Water Board.

The State Mining Board also requires the plugging of abandoned wells in accordance with its published regulations (Ill. Revised Statutes, 1965, chapt. 104, sec. 67 and 80).

Engineering Aspects

A disposal well system is designed on the basis of the nature and volume of wastes to be injected and the geologic and hydrologic conditions at the site. The well must be cased and cemented to protect fresh-water zones, oil, gas, coal, or other resources, and to prevent caving of loose formations. The piping and fittings must be protected from the corrosive effects of the waste and must be of suitable strength to withstand operating pressures. Injection tubing of noncorrosive material and a packer at the bottom of the casing to prevent rise of wastes into the casing are commonly installed. Frequently, the annulus between tubing and casing is filled with a pressurized inert fluid for monitoring pressure conditions around the tubing and for providing a fail-safe mechanism in case the tubing or packer fail.

Where practicable, uncased hole is desirable in the disposal formation for ease of treatment of the formation face, freedom from corrosion, and economy.

The waste usually must be treated before injection so that the reservoir formation is not clogged by sediment, chemical precipitation, gases, or bacterial growths. In some cases of limited permeability of the disposal formation, the volume of wastes may have to be reduced before injection. Storage or standby disposal facilities may be necessary where interruptions in operation cannot be tolerated.

For details on the engineering aspects of disposal wells, the reader is referred to summaries of current disposal well technology by Donaldson (1964) and Warner (1965).

Geologic and Hydrologic Conditions

The disposal zone for liquid wastes should have sufficient porosity, permeability, and areal extent to serve as an adequate reservoir at acceptable injection pressures. Sandstones and creviced or vuggy limestones are the usual disposal reservoirs. The disposal reservoir should not contain useable water or, ordinarily, other mineral resources such as oil, gas, or coal. It should be confined either by relatively impermeable rocks, such as shales that limit the upward movement of wastes and saline waters, or by thick, porous, formations with saline water that can accommodate any upward encroachment of the waste.

The deep, extensive, confined formations that serve as aquifers or disposal reservoirs behave elastically rather than as rigid systems when water is pumped from them or injected into them. In the case of injection, space for the injected fluid is made by increase in the porosity of the formation and by compression of the fluid in the formation. Hydrogeologists attribute the increase in porosity to expansion of the aquifer's granular skeleton, chiefly in the vertical direction. Petroleum engineers consider compression of the rock or mineral grains in the aquifer to be a factor in the increase in porosity.

The significance of the elastic method of accommodation of injected wastes is that there is no pistonlike displacement of formation water. The distance from the injection well at which pressure is appreciably affected and the amount of flow depend on the injection rate, the permeability of the rocks, the compressibility of the fluids and rocks, and other factors. In general, pressure effects extend outward from the injection well more widely in permeable rocks than in "tight" rocks.

CONDITIONS IN ILLINOIS

Conditions for the disposal of liquid wastes in wells in Illinois range from excellent to unfavorable. In much of the southern half of the state (areas I and II, fig. 1), there is a variety of permeable formations that contain brackish to saline water below a fairly shallow depth (table 1). Waste disposal wells would be feasible at many locations, especially in area I, which contains the deep part of the Illinois Basin, a saucerlike structure toward which the geologic formations of the northern, western, and southern parts of Illinois thicken and deepen (fig. 2).

In much of the northern third of the state (areas IV and V), the permeable rocks commonly contain potable water to depths of more than 1500 feet, and there is moderate to high development of ground-water resources. The Sanitary Water Board considers deep-well disposal in area V to be infeasible and in area IV to be very questionable.

In the large area III, between the northern and southern regions of Illinois, waste disposal is most likely feasible only in Cambrian formations because there is useable water in the Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician rocks. The southern boundary of this area is drawn along the edge of a tongue of fresher water in the St. Peter rocks, which extends beneath more highly mineralized water that occurs in the lower part of the Pennsylvanian and in the Mississippian rocks (fig. 2).

In general, water in the various formations becomes more highly mineralized as the formations deepen into the Illinois Basin (Meents et al., 1952; Graf et al., 1966). Formations such as the St. Peter, Ironton-Galesville, and Mt. Simon Sandstones (table 1) that are important aquifers in the north contain brine in area I (figs. 1 and 2). For example, the Mt. Simon Sandstone contains water with approximately 600 parts per million (ppm) total dissolved minerals (tdm) at a depth of about 2200 feet in DuPage County, 85,000 ppm at a depth of about 4000 feet in Champaign County, and 263,000 ppm at a depth of about 8900 feet in Marion County.

Because the factors of high permeability and high porosity, which characterize the sandstone aquifers, are also desirable for liquid waste disposal zones, the St. Peter, Ironton-Galesville, and Mt. Simon Sandstones, hereafter called the deep sandstones, are possible injection zones in the Illinois Basin where they contain highly mineralized water. The approximate boundaries between the areas where the Ironton-Galesville and Mt. Simon Sandstones are used as aquifers and where they might be considered for use as disposal zones are shown in figure 1.

The most critical area for consideration of the Mt. Simon as a possible disposal reservoir is south of Chicago, where mineralization of water in the Mt. Simon and Ironton-Galesville increases to the east and south with increasing depth of the formations and where there will be the greatest interest in developing industrial waste disposal facilities. However, water in the Ironton-Galesville contains less than 1500 ppm tdm in most of the Chicago and Joliet area, and water in the upper few hundred feet of the Mt. Simon exceeds 1500 ppm only in extreme eastern Cook and Will Counties (fig. 3). The locations of the 1500 ppm isocon lines southeast of Joliet are somewhat speculative because few wells have been drilled to the Ironton-Galesville and Mt. Simon in this area.

North of Chicago Heights, water in wells penetrating the Ironton-Galesville attains a maximum mineralization of about 2000 ppm, whereas water in wells penetrating the upper few hundred feet of the Mt. Simon attains a maximum mineralization of about 2500 ppm (data provided by the Illinois State Water Survey). Mineral-

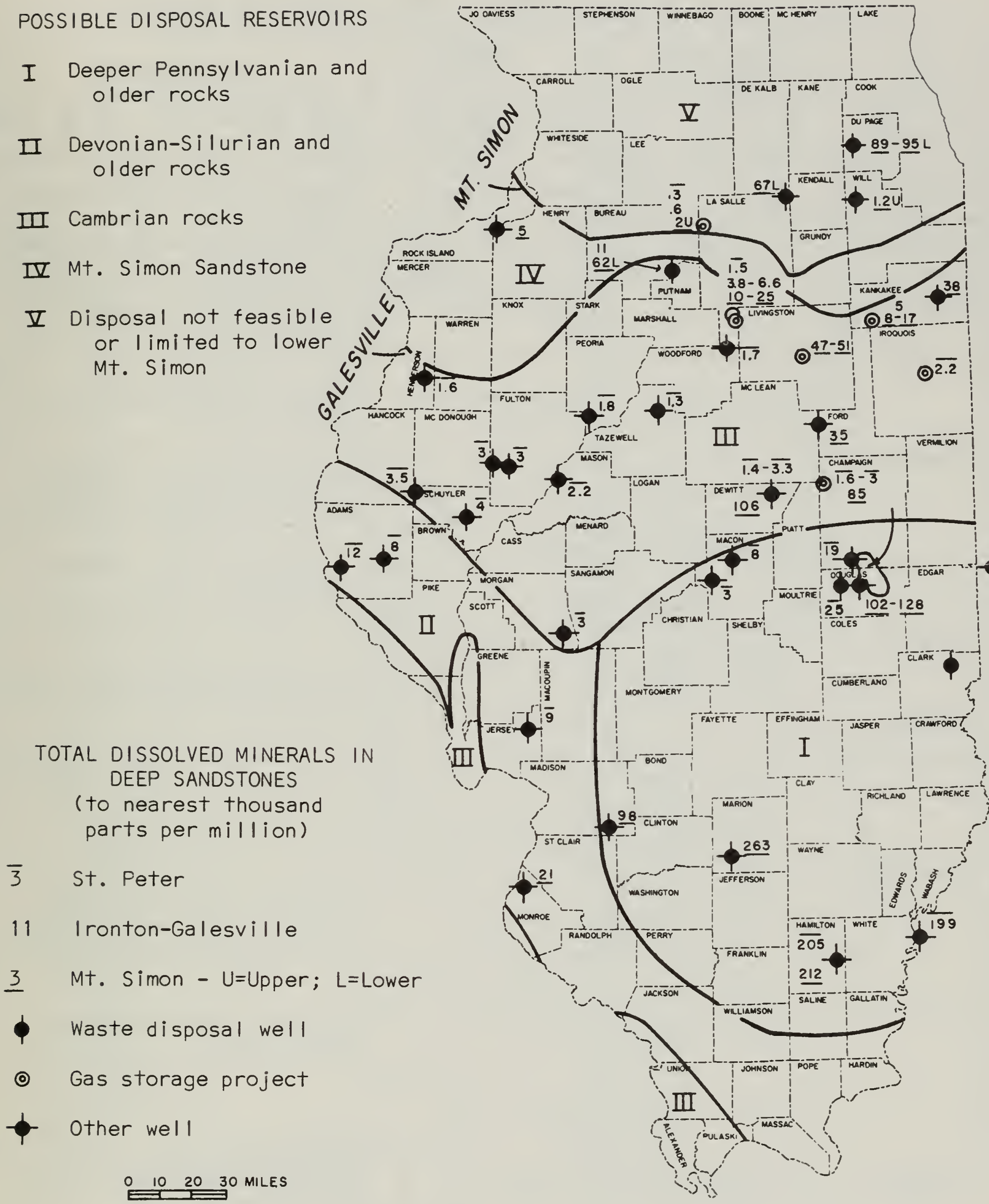


Figure 1 - Possible disposal reservoirs for liquid wastes, and water quality of deep sandstones. Additional quality data for the Illinois Basin are given by Meents et al. (1952) and Graf et al. (1966). The southern boundaries of areas V and IV are the approximate southern limits of use of the Mt. Simon and Ironton-Galesville Sandstones, respectively, as sources of potable water.

TABLE 1 - ROCKS OF ILLINOIS—PROPERTIES RELATING TO LIQUID WASTE DISPOSAL

SYSTEM	SERIES, GROUP, OR FORMATION	DOMINANT ROCK TYPES	DISTRIBUTION, USE
QUATERNARY	Pleistocene Series	Glacial till, sand and gravel, loess	Cover most of state; sand and gravel important aquifers
TERTIARY		Clay, silt, sand	Southern tip; sands local aquifer
CRETACEOUS		Sand, gravel, clay	Southern tip; sands local aquifer
PENNSYLVANIAN		Shale and sandstone; thin limestone and coal	Widespread; water mineralized with depth; some sandstones possible disposal zones in Illinois Basin
MISSISSIPPIAN	Chesterian Series	Shale, sandstone, limestone	Southern third; sandstones and limestones possible disposal zones in basin
	Valmeyeran Series	Limestone, siltstone	Southern two-thirds; limestones possible disposal zones in basin
	Kinderhookian Series	Shale	Southern two-thirds; relatively "tight" zone
DEVONIAN	Upper Devonian Series	Shale	
	Middle & Lower Devonian Series	Limestone	Widespread; aquifer in north, west, and south; possible disposal zone in basin
SILURIAN		Dolomite	
ORDOVICIAN	Maquoketa Group	Shale	Widespread; relatively "tight"
	Galena Group Platteville Group	Dolomite, limestone	Widespread; aquifer in north
	Ancell Group (St. Peter Sandstone)	Sandstone	Widespread; aquifer in north; possible disposal zone in basin
	Prairie du Chien Group	Dolomite	Widespread; possible disposal zone in basin
CAMBRIAN	Eminence Dolomite Potosi Dolomite	Dolomite	
	Franconia Formation	Dolomite, shale	
	Ironton-Galesville Sandstone	Sandstone	Widespread; aquifer in north; possible disposal zone in northern part of basin
	Eau Claire Formation	Shale, dolomite	Extensive; relatively "tight" zone
	Mt. Simon Sandstone	Sandstone	Extensive; aquifer in north; thick disposal zone in southern two-thirds

Precambrian crystalline rocks

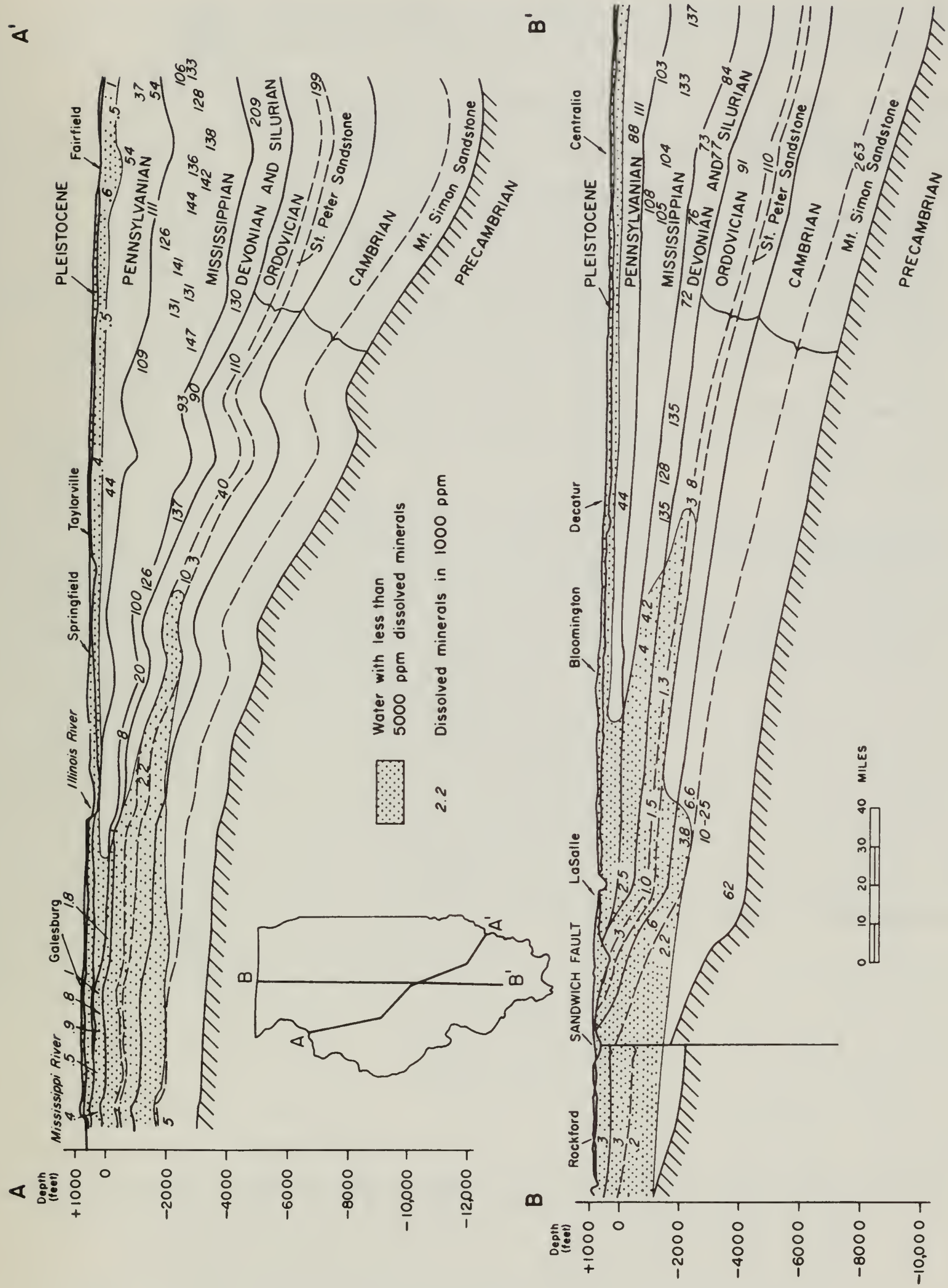


Figure 2 - Cross sections showing gross stratigraphy, structure, and ground-water quality.

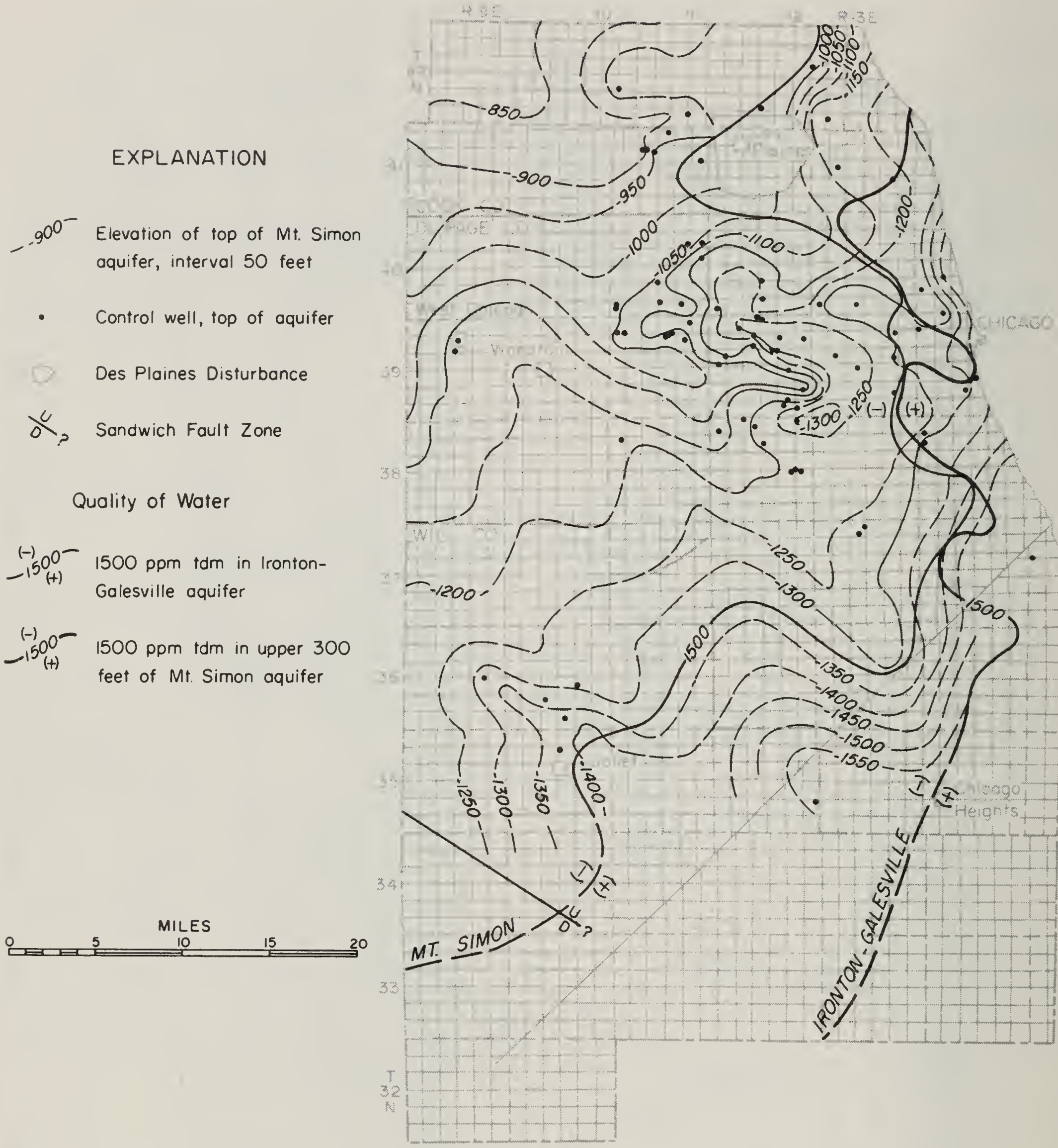


Figure 3 - Elevation of the top of the Mt. Simon aquifer and isocon lines of 1500 parts per million (ppm) total dissolved minerals (tdm) for the Ironton-Galesville and the upper part of the Mt. Simon aquifers. Mineralization of water in the aquifers is greater than 1500 ppm east of the isocon lines. Elevation contours are from Hughes, Kraatz, and Landon (1966). Water quality data for the isocon lines were provided by the Illinois State Water Survey.

ization of water increases fairly rapidly with depth below the upper part of the Mt. Simon, as shown by quality data from a deep test well at West Chicago, DuPage County (fig. 4).

Another area in which there are marked changes in the quality of water in the deep sandstones is along the Illinois River Valley from Hennepin eastward to Ottawa, which includes northern Putnam, east-central Bureau, and west-central LaSalle Counties (fig. 1). These changes affect the usefulness of the St. Peter and the Ironton-Galesville as aquifers. For example, wells about 2700 feet deep, penetrating the Ironton-Galesville, yield water containing 600 to 800 ppm tdm at Spring Valley and Peru (data from Illinois State Water Survey), whereas at Hennepin, Putnam County, 8 miles southwest of Spring Valley, a waste disposal well (fig. 4) encountered water containing 11,000 ppm tdm in the Ironton-Galesville. Marked variations in water quality also occur in the St. Peter, particularly in LaSalle County.

The variability in water quality is probably a result of irregularities in ground-water circulation that are related to folds and faults connected with the LaSalle Anticlinal Belt.

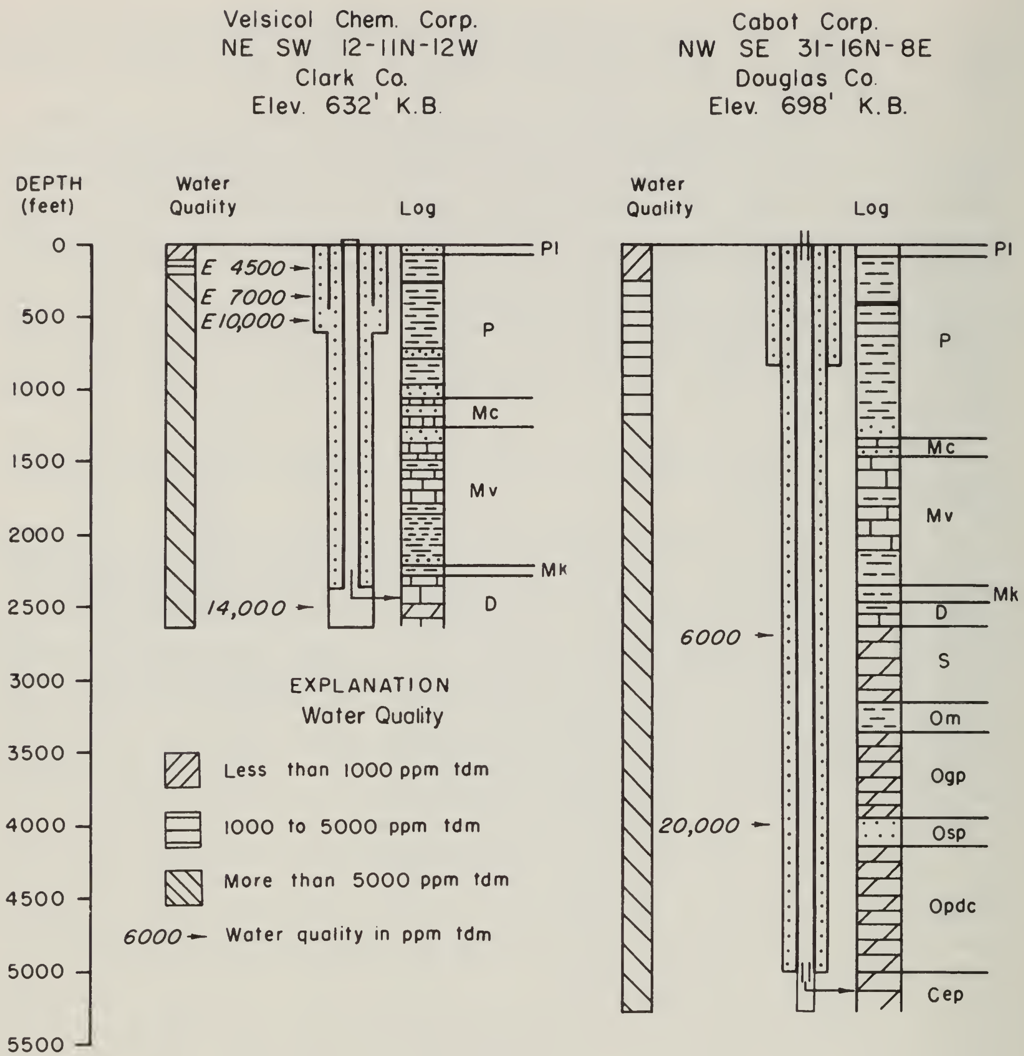
Other possible disposal zones that are not quite as obvious as the deeper sandstones are suggested in table 1. In descending order, these include sandstones of Pennsylvanian age, Chesterian sandstones and Valmeyeran limestones of Mississippian age, limestones and dolomites of Devonian and Silurian age, and dolomites of Ordovician and Cambrian age. These rocks, like the deep sandstones contain highly mineralized water in much of the southern part of the state, and all are possible disposal zones in area I. Two of the three disposal wells in Illinois are designed to inject into Devonian age limestone and Cambrian age dolomites, respectively. As a general rule, the permeabilities and porosities of the sandstone, dolomite, and limestone formations in the deep part of the Illinois Basin are much lower than of the same formations in northern Illinois (Bell et al., 1964, p. 33).

Selection of sites for waste disposal should take into account that coal is mined from the Pennsylvanian rocks and that oil and gas is obtained from the Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician rocks in some area in the southern two-thirds of the state. Oil and gas might be present in rocks at depths considered for waste disposal.

Rocks of low permeability—most commonly shale—that constitute probable barriers to the vertical migration of liquid wastes are well distributed throughout the geologic column (table 1) in the southern part of the state. However, in much of the northern part (most of area V), only Silurian and older rocks are present, and in these rocks, fairly thick extensive shales occur only in the Maquoketa Group, Franconia Formation, and Eau Claire Formation. Because potable water commonly extends below the Franconia in this area, the demonstration of an adequate confining bed above a suitable disposal zone might be a major problem. The upward leakage of gas from considerable depth that occurred in two gas storage projects in Illinois indicates that the determination of the "adequacy" of confining conditions is not always absolute.

Variations in conditions in Illinois are illustrated by cases of three disposal wells (fig. 4) that have been authorized by the Sanitary Water Board.

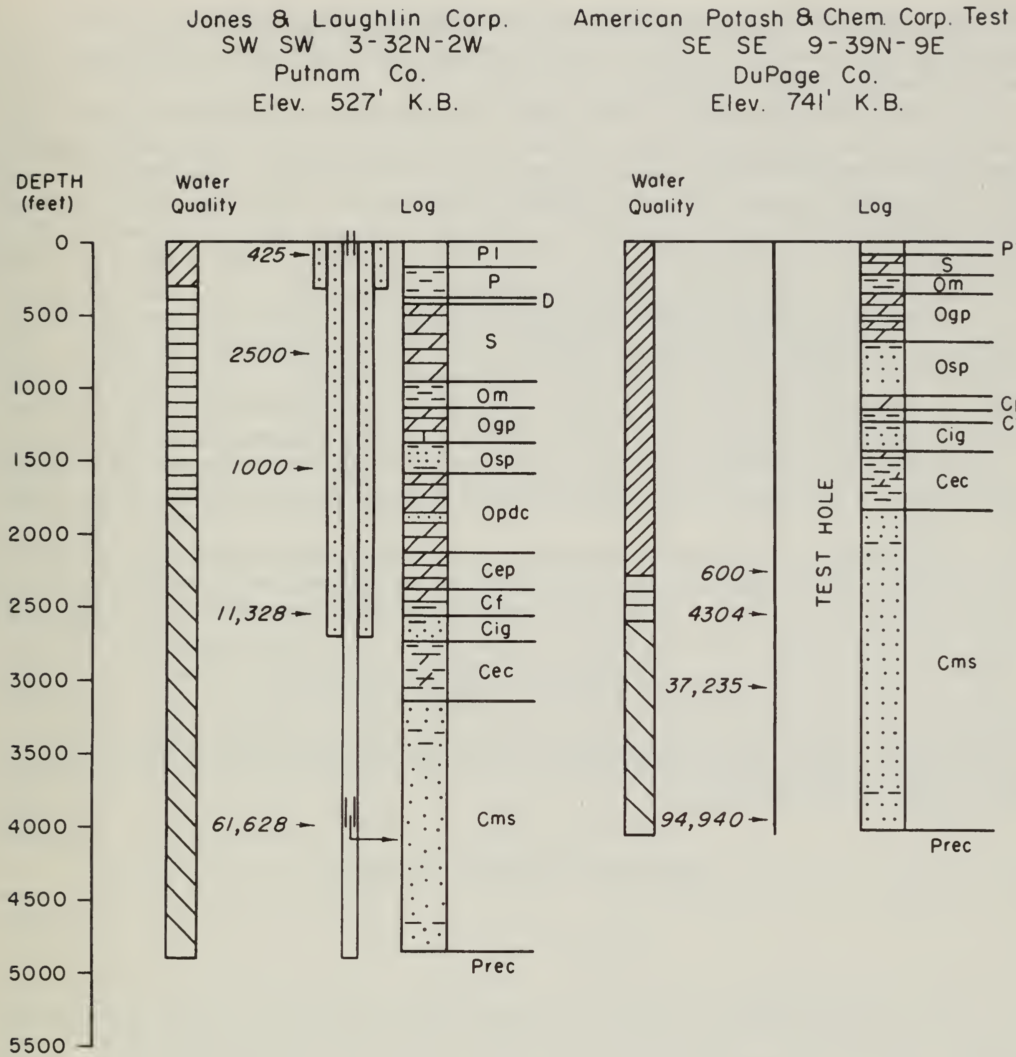
The well in Clark County disposes 55 to 65 gallons per minute (gpm) of alkaline solution with about 65,000 to 100,000 ppm dissolved minerals into creviced Devonian age limestone at a depth of about 2500 feet. Potable water occurs in the glacial drift and the upper part of the Pennsylvanian rocks, but below a depth of a



K.B. = Kelly Bushing
E = estimated
ppm tdm = parts per million total dissolved minerals
Pl = Pleistocene
P = Pennsylvanian

M = Mississippian
Mc = Chesterian
Mv = Valmeyeran
Mk = Kinderhookian
D = Devonian
S = Silurian

Figure 4 - Geologic and water quality conditions



O = Ordovician
Om = Maquoketa
Ogp = Galena-Platteville
Osp = St. Peter
Opdc = Prairie du Chien
C = Cambrian

Cep = Eminence-Potosi
Cf = Franconia
Cig = Ironton-Galesville
Cec = Eau Claire
Cms = Mt. Simon
Prec = Precambrian

at industrial waste disposal wells and test hole.

few hundred feet, mineralization of water increases rather sharply with depth. Upward migration of alkaline waste water would probably be prevented by shales in the Mississippian and Pennsylvanian rocks.

A somewhat deeper disposal well in Douglas County has been designed for injection of about 35,000 gallons per day (gpd) of hydrochloric acid into creviced Potosi Dolomite of Cambrian age at a depth of about 5000 feet. Originally designed for injection of wastes into the St. Peter Sandstone, the well was drilled deeper when the permeability of the St. Peter was found to be too low. Substantial shale sections occur above the disposal zone, and the more permeable formations contain water with more than 5000 ppm dissolved minerals below the lower Pennsylvanian.

The well in Putnam County is for the disposal of about 100,000 gpd of hydrochloric and chromic acid from a steel mill. It is in the area where the St. Peter Sandstone contains useable water but the Ironton-Galesville and Mt. Simon Sandstones contain brackish to saline water. Injection of wastes will be into a zone of the Mt. Simon at a depth of about 4000 feet. The low permeability of shaly beds in the Eau Claire Formation and the large reservoir capacity of the Mt. Simon Sandstone will tend to prevent the acid waste from moving upward into the zone of potable water.

Conditions in the extreme northern part of Illinois where potable ground water extends into the upper part of the Mt. Simon Sandstone are illustrated by a well recently drilled in DuPage County. The well penetrated the entire Mt. Simon Sandstone (2200 feet thick) and reached the Precambrian crystalline basement rocks at a depth of about 4000 feet. Potable water extended to a depth of about 2300 feet, or 500 feet into the Mt. Simon. Below this depth the mineralization of the water increased to more than 90,000 ppm at the base of the Mt. Simon. The 1700 feet of Mt. Simon that contains nonpotable water consists mainly of sandstone, with only a few thin shaly zones.

POSSIBLE DISPOSAL HORIZONS

Pennsylvanian System

The Pennsylvanian rocks attain a maximum thickness of about 2500 feet (in Edwards County) and consist mainly of shale, siltstone, and sandstone, with subordinate amounts of limestone and coal. Sandstones are the most promising rocks for disposal of liquid wastes. They are most abundant in the lower part of the Pennsylvanian System and are of two types—channel sandstones that are thick, commonly lenticular, and sometimes discontinuous, and sheet sandstones that are thin and relatively widespread. Individual channel sandstone bodies range from less than 100 feet to 35 miles wide and from 20 to several hundred feet thick. The sands are variable in texture. Sheet sandstones are rarely more than 20 feet thick and are usually fine grained.

Limited information on the permeability and porosity of Pennsylvanian sandstones is available from municipal water-well and oil-field waterflood data and from oil-well core analyses.

Municipal water wells are completed in Pennsylvanian sandstone aquifers that consist of single or multiple beds of sandstone, with aggregate thicknesses of about 20 to 175 feet. Most of these wells are 60 to 550 feet deep but these depths do not necessarily indicate the maximum depth of fresh water occurrence in the Pennsylvanian rocks. Pumpage of water from individual municipal wells in the sandstone aquifers ranges from about 6 to 147 gpm (Hanson, 1950, 1958, 1961). Specific capacities of these wells range from .06 to 3.3 gallons per minute per foot of drawdown (gpm/ft). The median specific capacity of all wells tested is 0.32 gpm/ft (Csallany, 1966, p. 26).

The Pennsylvanian sandstones are sources of a large volume of water for injection in the oil fields. Specific capacities for 17 water wells, mainly brine wells, in 10 oil fields range from 0.02 to 1.2 gpm/ft and average 0.43 (Pryor, Maxey, and Parizek, 1957, p. 73).

The specific capacities are an approximate measure of the capacity of the sandstones to accept fluids in gpm per foot of head in excess of hydrostatic head.

Data on Pennsylvanian oil "pay" sandstones (Piersol, Workman, and Watson, 1940; Bell et al., 1963; and Whiting et al., 1964) show that the porosities are relatively uniform and low, averaging 17 to 20 percent. Permeabilities exhibit a wider range, but average from 122 to 430 millidarcys for individual "pay" sandstones. The thicknesses of these sandstones are approximately 20 to 30 feet. Mast (1967) reports that permeabilities of Pennsylvanian sandstones decline with increasing depth.

Any proposal for injecting liquid wastes into the Pennsylvanian rocks must take into account the occurrence of potable water in the upper part, which ranges from as little as 100 to as much as 900 feet in depth.

Chesterian Series (Mississippian)

The Chesterian Series, consisting of about 50 percent shale, 25 percent sandstone, and 25 percent limestone, is limited roughly to the southern half of the state, and in most of this region is overlain by Pennsylvanian rocks. The maximum thickness of the Chesterian Series is about 1400 feet.

Potable water occurs in the Chesterian rocks only in and near the outcrop area along the Mississippi and Ohio Rivers. The sandstones are the principal aquifers and, where suitable conditions prevail, would be the most promising disposal zones.

Like the Pennsylvanian sandstones, the Chesterian sandstones have channel and sheet phases, with maximum thicknesses of about 140 and 20 feet, respectively. The most important aquifers are the Palestine, Waltersburg, Tar Springs, Cypress, and Bethel Sandstones, and, a short distance below the Chesterian Series, the Aux Vases Sandstone. The Tar Springs and Cypress Sandstones, both of which attain a maximum thickness of more than 100 feet, as well as the Pennsylvanian sandstones, are the main sources of brine for waterflooding of oil fields in the Illinois Basin.

Pumping tests of water wells completed in Chesterian sandstones give specific capacities ranging from 0.08 to 1.1 gpm/ft and a median of 0.3 gpm/ft, which are similar to values for the Pennsylvanian sandstones (Csallany, 1966, p. 28). Well yields of 12 to 52 gpm with large drawdowns are reported for brine wells in the Tar Springs and Bethel Sandstones (Pryor, Maxey, and Parizek, 1957, p. 75).

Data from Chesterian sandstone oil "pays" (Piersol, Workman, and Watson, 1940; Bell et al., 1963; and Whiting et al., 1964) show that porosities are relatively low, averaging 16 to 18 percent. Permeabilities are also low, and average from 68 to 231 millidarcys for individual "pay" sandstones. The thicknesses of these sandstones are approximately 10 to 20 feet. The more permeable Chesterian sandstones are generally less permeable than the Pennsylvanian sandstones.

Water injection rates in Chesterian, Valmeyeran, and Pennsylvanian sandstones in oil-field waterflood projects usually range from 2 to 20 barrels (84 to 840 gallons) per day per foot of sandstone, and average about 10 barrels (420 gallons) per day per foot (Van Den Berg, Lawry, and Mast, 1966). Somewhat higher rates are achieved in the limestone reservoirs. These rates are at injection pressures that are probably substantially greater than those that would be employed in industrial disposal wells.

Valmeyeran Series (Mississippian)

The Valmeyeran Series, chiefly limestones and siltstones with a combined thickness of 1000 to 2000 feet, is present in the southern two-thirds of the state. In the deep part of the Illinois Basin, the Valmeyeran rocks are reached at a depth of about 3500 feet and contain water with more than 100,000 ppm dissolved solids (Meents et al., 1952, p. 16).

Valmeyeran rocks yield potable water in western Illinois and in a narrow band along the Mississippi and Ohio Rivers. The principal aquifers include the Ste. Genevieve, St. Louis, Salem, Keokuk, and Burlington Limestones, which yield water from joints and solution channels. Within the Illinois Basin, the limestones contain brine and, in some places, oil.

Porosity and permeabilities determined from cores give an incomplete picture of the reservoir properties of limestones, for some fluid movement is through joints and solution passages, which are irregularly distributed and are not sampled in coring.

Pumping tests of wells completed in Valmeyeran limestones in western Illinois and along the Mississippi and Ohio Rivers suggest that the Keokuk-Burlington rocks are more permeable than the Ste. Genevieve, St. Louis, and Salem rocks. The median specific capacity of wells in the Keokuk-Burlington rocks is 1.02 gpm/ft and in the Ste. Genevieve, St. Louis, and Salem rocks is 0.12 gpm/ft (Csallany, 1966, p. 1).

Mast (1967) reports that the mean porosity and permeability of Mississippian limestones (excluding the Ste. Genevieve) and the Ste. Genevieve Limestone alone in oil reservoirs are 17 percent and 206 millidarcys and 16 percent and 168 millidarcys, respectively.

Devonian-Silurian Systems

The Devonian-Silurian limestones and dolomites are possible disposal reservoirs in areas I and II where they contain very saline water (Meents et al., 1952, p. 18). They are more than 1000 feet thick in most of the Illinois Basin and are reached at a maximum depth of about 5000 feet. In much of the southern part of area III, the Devonian-Silurian rocks contain water with 2000 to 5000 ppm and locally higher concentrations of dissolved minerals, but fresher waters occur in the underlying St. Peter Sandstone (fig. 2), thus restricting waste disposal to rocks below the St. Peter.

Water pumpage data from the northern part of the state show that the median specific capacity of wells penetrating Devonian-Silurian rocks below other bedrock formations is about 0.015 gpm/ft per foot of penetration of the rocks. Where both the Devonian and Silurian rocks are open to the well, the Devonian rocks contribute little water compared to the Silurian (Csallany and Walton, 1963, p. 18). However, the Devonian System contains units that are known to be permeable and porous within the Illinois Basin.

Mast (1967) reports that Devonian-Silurian-Trenton carbonate reservoirs in Illinois oil fields have a mean porosity and permeability of 13 percent and 40 millidarcys, respectively.

Deep Sandstones

The St. Peter Sandstone is a relatively permeable formation more than 100 feet thick in most of Illinois. It contains mainly fine-grained sandstone, some coarse-grained sandstone, and some clay or shale with chert. In northern Illinois, where it is an important aquifer, it is 200 to 400 feet thick.

Mineralization of water in the St. Peter increases only gradually in and immediately south of area IV in northern Illinois, as shown by the dissolved mineral values in figure 1. Injection of industrial waste into the St. Peter would be considered most feasible where the formation contains water with more than 5000 ppm dissolved minerals. This generally would be south of Champaign, Macon, and Sangamon Counties, where the salinity gradient is believed to increase rapidly (Meents et al., 1952, p. 20).

Porosity and permeability data are sparse for the St. Peter in the Illinois Basin. In gas storage projects, porosity and permeability at Pontiac (Livingston County) averaged 14.8 percent and 136 millidarcys, respectively, for 130 feet average thickness. At Crescent City (Iroquois County), the porosity and permeability averaged 14.6 percent and 139 millidarcys, respectively, for 165 feet average thickness. At Mahomet (Champaign County), the porosity and permeability averaged 18.4 percent and 404 millidarcys for 41 feet average thickness. These figures may represent a more permeable and porous part of the St. Peter, whose total thickness at the site exceeds 230 feet.

W. F. Meents (personal communication) reports that south of a line roughly between Edgar and Jackson Counties, the St. Peter becomes notably tighter, and other shallower horizons may be more suitable for waste disposal.

The Ironton-Galesville Sandstone is the most consistently permeable and productive aquifer in northern Illinois. The upper formation, the Ironton, is a poorly sorted sandstone that is somewhat dolomitic. The Galesville is better sorted, fine grained, nearly uncemented, and generally free of dolomite.

The two formations become more dolomitic and, consequently, less permeable and porous to the south. In the southern part of Champaign County, dolomite reaches a level of 50 percent of the rock (Emrich, 1966, p. 24). South of Shelby County, the rock becomes so dolomitic that it is indistinguishable from overlying and underlying formations. Thus, only in the southern part of area III (fig. 1), where the Ironton-Galesville is 125 to 250 feet thick and contains less than 50 percent dolomite, are conditions judged favorable for waste injection in the Ironton-Galesville.

Core analyses of formations at gas storage projects in northeastern Illinois show that: (1) wide variation in porosity and permeability occurs in the Ironton section between adjacent sandstone and dolomite beds, whereas most of the Galesville section is composed of thick, highly permeable (up to 8000 millidarcys) beds, with low permeabilities (less than 10 millidarcys) restricted to thin zones; (2) there is a general southerly or southeasterly decline in average permeability of Galesville

Sandstone cores, but fairly wide variation in average permeabilities are frequently present between wells in the same gas storage structure; and (3) the Galesville Sandstone is generally more porous and permeable than the St. Peter Sandstone and substantially more porous and permeable than the upper part of the Mt. Simon Sandstone.

At Pontiac (Livingston County), the porosity and permeability of a mean thickness of 59 feet of Galesville beds average 19.8 percent and 442 millidarcys, respectively. At Mahomet (Champaign County), 56 feet of the more permeable, basal Galesville Sandstone gave an average porosity of 17.8 percent and an average permeability of 777 millidarcys.

The Mt. Simon Sandstone is more than 1500 feet thick in most of the region in Illinois where it would be considered as a liquid waste injection zone (Bell et al., 1964, p. 16). However, a few wells in Illinois, one of them in Hamilton County, have shown the Mt. Simon Sandstone to be absent, apparently due to nondeposition on a Precambrian rock hill. The Mt. Simon is dominantly a fine- to coarse-grained sandstone, and contains beds or lenses of shale and siltstone that do not exceed 5 percent of the formation. The principal cementing material is quartz.

In the shallow regions north and west of the Illinois Basin, the Mt. Simon is moderately compact and friable. Deep in the basin and on the eastern margin, many beds are tightly cemented, even quartzitic, and have greatly reduced porosity.

Most water wells that enter the Mt. Simon in area V (fig. 1) penetrate it no more than 300 to 400 feet because of an increase of mineralization of water with depth. In the Chicago region, water below an elevation of about 1300 feet below sea level in the Mt. Simon is too salty for most purposes (fig. 3). Water samples from the lower few hundred feet of the 2000 feet of Mt. Simon in three wells in northeastern Illinois have from 60,000 to more than 90,000 ppm dissolved minerals. In northern Illinois, then, with potable water in the upper part of the Mt. Simon, highly mineralized water in the lower part, and no apparent thick shale beds between, the problem in liquid waste disposal is to demonstrate that potable water will not be degraded by upward movement of more saline water or wastes when present equilibrium conditions are changed by injection or pumping.

Within the Illinois Basin, most testing of the Mt. Simon—with regard to water quality and formation characteristics—has been in the upper 500 feet. The water generally contains more than 50,000 ppm dissolved minerals (figs. 1 and 2). Permeability and porosity are markedly lower than in the Galesville and St. Peter Sandstones, but this disadvantage is offset by the fact that there is a great thickness of Mt. Simon available for a disposal reservoir.

Core analyses in gas storage projects reflect a tightening of the Mt. Simon from north to south and west to east. At Herscher (Kankakee County), Crescent City (Iroquois County), and Mahomet (Champaign County), average porosities and permeabilities are 13 percent and 55 millidarcys, 10 percent and 10 millidarcys, and 12 percent and 36 millidarcys, respectively. The section also contains thin beds in which permeabilities are substantially higher than these averages.

Other Rocks

Dolomites between the Maquoketa and St. Peter and between the St. Peter and Ironton-Galesville represent a substantial thickness of rocks in the Illinois Basin. It is likely that disposal zones could be developed in these rocks in addition to those described above.

CONCLUSIONS

The disposal of liquid wastes in subsurface formations offers a promising means of alleviating a growing problem today, provided that the wastes remain isolated from man's environment and do not degrade needed resources. There is little likelihood that wastes once injected into a subsurface formation by a properly designed disposal well could return by natural routes to the surface, but the possibility that a potable ground-water reservoir could be polluted by saline water migration brought about by waste injection, by failure, or by improper plugging of an abandoned disposal well must be considered.

The greatest hazard exists in northern Illinois, especially in northeastern Illinois, where fresh water extends to great depth, barrier conditions between potable and saline waters are mainly unknown, the pumpage from deep aquifers is substantial, and the concentration of industry and need for waste disposal are great. Here, the most rigorous requirements are needed as to natural conditions, testing, engineering safeguards, monitoring, and well abandonments.

On the other hand, many places in the deeper part of the Illinois Basin (area I) offer optimum conditions for subsurface waste disposal.

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