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## Water Reuse Through Groundwater Recharge in Northeastern Illinois

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WATER REUSE THROUGH GROUNDWATER  
RECHARGE IN NORTHEASTERN ILLINOIS

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## ABSTRACT

This study was designed to examine the advantages, disadvantages, and effects of artificial recharge, using sanitary plant effluent as recharge water. A numerical groundwater model was constructed for a site near Aurora, Illinois, and validated by simulating an aquifer test at a proposed pit location. Model simulations were also conducted to calculate the flow capacity of the system, the flow capacity of a pilot recharge pit, and the solute transport through and away from the pit. Based on the study's findings, a pilot pit should be constructed at the Aurora Site, and the chemical quality of the water withdrawn from the operation would be the research aspect of a pilot pit. There may be some characteristics of the effluent, such as the total dissolved solids (TDS), that exceeds the background counts of the aquifer. A TDS of 100 mg/l, which is considered excessive for many water supply uses but neither is toxic nor creates a health hazard in the effluent, could be reduced through demineralization, but this is an additional cost. Furthermore, the sole purpose of this study was to evaluate the movement and changing characteristics of the high quality effluent from tertiary-treated wastewater which is primarily domestic in nature as this effluent moves through from a pit into the aquifer. Artificial recharge is a viable concept as shown by the calculations and model simulations of the Aurora site.

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KEYWORDS--Artificial Recharge, Sanitary Plant Effluent, Effluent Characteristics, Effluent Movement, Recharge Pit, Aquifer, Filter Media, Wastewater Treatment, Model Simulation



## INTRODUCTION

At the onset of this project in 1977 the diversion of water from Lake Michigan to meet rapidly rising water requirements in northeastern Illinois was limited by the Maris report in the U.S. Supreme Court. This decree stated, in part, that the State of Illinois may make application for the diversion of additional water from Lake Michigan for domestic use when and if the reasonable water needs of the Northeastern Illinois Metropolitan Region cannot be met from the water resources available to the region and the uses of water therein are conserved and managed in accordance with the best modern scientific knowledge and engineering practice.

Recharge of the shallow and deep aquifers was identified as a potential means of extending the regional water resources. Therefore, recharge either needed to be fully employed or shown to be infeasible before a new approach could have been made to obtain additional Lake Michigan water via the U.S. Supreme Court.

On December 1, 1980 the U.S. Supreme Court amended their early decree and thereby effectively allowed an increase in the diversion of Lake Michigan water to northeastern Illinois. This amendment has resulted in plans to construct pipelines to communities in the region. These pipelines, as yet, have not been built. The overall impact of the diverted water will be to alleviate some of the stress on the aquifers in northeastern Illinois. However, because of expense and local issues several communities have chosen not to participate in the pipeline.

The following excerpt is from Visocky (1982). "The Illinois Department of Transportation, Division of Water Resources, determined the available lake-water allocation for each applicant by considering current and



projected population, current and projected per capita income, nature and extent of industrial uses, municipal and hydrant uses, implementation of conservation practices, and reduction in unaccounted-for flows. Fifty-seven communities currently pumping from the deep aquifer have been granted allocations. However, more than 40 other communities expect to continue pumping from deep wells, including Joliet (Will County) and several other large public systems along the Fox River in Kane County." In part, he summarizes, "Allocations of Lake Michigan water will relieve many of the deep pumping lifts in the major pumping centers of northern and western Cook County and northeastern DuPage County. As communities allocated lake water shut off their deep wells, recovery of water levels will occur. However, the regional cone of depression will continue to spread outward, especially to the west and south. Major cones of depression will shift to Joliet and to the Fox River Valley." The site selected to demonstrate artificial recharge by the pit method is in the Fox River Valley at Aurora, Illinois.

#### Scope

The extent of the study area covered seven counties of northeastern Illinois (Cook, DuPage, Kane, Kendall, Lake, McHenry and Will). The final site for the proposed recharge pit is just south of the Kane County line in Kendall County. Currently the study area is more local (approx. 0.4 mi<sup>2</sup>).

In terms of project duration, four years were needed to locate a suitable site and obtain permission to conduct exploratory drilling. The last two years involved data collection (both existing and new), exploratory drilling, sampling, aquifer testing, analysis, etc.



### Project Objectives

In conjunction with a research-demonstration project that was planned for northeastern Illinois, three separate research endeavors were proposed.

First, the chemical and bacterial characteristics of the effluent were to be measured as it entered the recharge pit and then monitored as it moved through the aquifer. Special attention was to be given to the fate of any toxic heavy metals, nitrates, trace organics, and virus that might still be present in the effluent.

Second, various types of filter media and operating procedures were to be used to determine the most effective means of removing any of the above potentially harmful substances.

Third, a reexamination of the geological and hydrological data in northeastern Illinois was to be made after the preliminary results were known in order to map more accurately the potential for groundwater recharge of effluents from highly treated wastewater.

### Project Accomplishments

Finding a suitable site for the recharge project proved to be a major obstacle to accomplishing the original objectives of this project. Three sites were carefully evaluated (see pages 33-44) and each in turn was found to be unsuitable. A suitable site has, however, been found south of Aurora, Illinois.

A resistivity study was performed at the Aurora site, as well as gamma-ray logs at two stratigraphic test holes. An aquifer test was conducted at the proposed pit location for the purpose of determining the hydraulic conductivities of the saturated deposits underlying the site. A numerical groundwater model was then constructed for the Aurora site

because of the complex geometries and boundary conditions that existed there. The numerical model was validated by simulating the aquifer test conducted at the proposed pit location.

Model simulations were also conducted to calculate the flow capacity of the system, the flow capacity of a pilot recharge pit, and the solute transport through and away from the pit.

### Summary and Conclusions

Artificial recharge to surficial deposits is a viable concept as shown by the calculations and model simulations of the Aurora site. It could quickly gain acceptance as an alternate water source in Chicago's outlying communities with the advent of proposed pipelines for Lake Michigan water. With pipelines, water bills may triple.

Using sanitary plant effluent as recharge water severely limits the sites available for recharge because of lack of available land near plants and/or lack of a host aquifer within a reasonable distance from plants. Because of discontinuity of surficial deposits in northeastern Illinois, artificial recharge can occur only in carefully selected locations. River water is recommended as a potential optional water source for recharge pits.

Based on findings to date, a pilot pit should be constructed at the Aurora site. The chemical quality of water withdrawn from the operation would be the research aspect of a pilot pit. The aquifer at the site is adequate and the possibility of degrading any existing water supplies is very limited. The aquifer at the site and probably just to the north of the site is capable of supporting a million gallons per day plus recharge operation.



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## USE OF RECLAIMED WATER FOR AQUIFER RECHARGE

Artificial recharge is the replenishment of a groundwater reservoir brought about as a result of man's activities. It can be accomplished through three main methods: spreading-basins, injection wells, and pits. Case histories and descriptions of these methods can be found in two very good reports (United Nations, Department of Economic and Social Affairs, 1975; and Asano and Roberts, 1980). In this project, the pit method will be employed. One of the best references on the use of the pit method is Suter and Harmeson, 1960. In their report they describe the pits which operated at Peoria, Illinois.

Just as there are several methods for applying artificial recharge, there are also different types of source water which can be utilized. Most commonly, water for recharge is obtained by diverting water from a surface stream, such as was done at Peoria. Alternatively, effluent from wastewater treatment plants, or reclaimed water, has also been used to supply artificial recharge basins (Bouwer, 1970; Laverty, 1961; and Merrell and Ward, 1968). In this project, reclaimed water will be the source for artificial recharge.

### Reclaimed Water Characteristics

Some characteristics of reclaimed water may limit its acceptability for artificial recharge, apart from any changes which might result from recharge. In particular, the level of pretreatment received, the concentration of toxic waste, the salinity and suspended solids, Biological Oxygen Demand, and temperature will affect the use of reclaimed water.

Secondary treated wastewater could generally be acceptable for recharge by infiltration. Normally in such effluents BOD and suspended



solids have been reduced to a low enough level to maintain infiltration rates. Contaminants have also been reduced to an acceptable level. Primary treated effluent (with higher BOD and suspended solids) may be used for recharge in some cases assuming that infiltration rates can be maintained and provided that odors are controlled. Tertiary treated wastewater may be used, but the cost of tertiary treatment is high and in many cases such treatment would duplicate the beneficial effects of recharge infiltration.

Reclaimed water can be categorized in two ways: effluents which are predominantly domestic in origin and effluents which include substantial industrial waste. When assessing the various hazardous contaminants in reclaimed waters, all possible constituents of the water should be identified and a median value and range of concentrations established within close confidence limits. An effluent permitted to be discharged to a water course will probably be suitable for recharge to an aquifer.

In general, waters with a salinity in excess of 1000 mg/l are unsuitable for domestic, irrigation, or industrial use. Waters with a salinity in the range of 1000-140,000 mg/l are suitable for some stock uses. In arid areas the salinity of waters must be particularly examined because of concentration from evaporation during ponding.

Concentrations of suspended solids in the range of 1-20 mg/l can reduce infiltration rates in some situations. Generally, however, water with suspended solids up to 30 mg/l will be suitable for recharge, and under some circumstances effluents with as much as 50 mg/l or even higher may be used. However, in such a situation special provisions may be needed for the removal of solids from the infiltration pit surface.

Levels of BOD normally found in secondary treated wastewater will be suitable for recharge by infiltration and, if managed correctly, will not

clog the soil by excessive growth of the biological mat at the infiltration surface.

The temperature of the recharge water has a marked effect on recharge rates through its effect on viscosity. Also, higher temperatures are more favorable to nitrifying bacteria.

### Aquifer Characteristics

There are six general aquifer characteristics affecting recharge (as pointed out in Australian Water Resources Council, 1982): 1) aquifer thickness and extent, 2) aquifer mineralogy, 3) hydraulic parameters, 4) aquifer water chemistry, 5) natural hydrologic environment, and 6) predictability.

#### **Aquifer thickness and extent**

Aquifer thickness, porosity, and areal extent determine the size of the storage available. The available storage, together with extraction rates and other hydraulic aspects, will determine retention time, management of flow path, and mixing operations possible in the aquifer. The geometry of the aquifer can also be a major factor affecting the selection of an infiltration site.

#### **Aquifer mineralogy**

Certain minerals are known to have high adsorptive capacities while others may be leached or dissolved or exhibit ion exchange capacity. The mineralogy of an aquifer is probably the most significant factor affecting treatment capacity. The minerals of unconsolidated sediments can be separated into two main categories on the basis of particle size. The first category is comprised of silt, sand and gravel minerals or mineral



assemblages which consist of a major light fraction ( $\text{SiO}_2$  and Na, K, Ca aluminosilicates) and a minor heavy fraction (Fe, Mg, Ca silicates, Fe oxides and calcium carbonates). The second category is composed of the clay minerals. For practical purposes clay minerals can be seen as mineral colloids with physical and chemical properties such as shrinkage, swelling and flocculation, dispersion, plasticity, and cohesion. These properties can be related to two general characteristics of clay minerals: high specific surface area and an electrochemically negative charge usually dominating on clay mineral surfaces.

As a result of these properties, clay minerals that are well distributed within an aquifer mass and will come into contact with the infiltrating waters can have a major impact in both the fixation of heavy metals and the precipitation of radicals such as phosphates, as well as in the adsorption of ammonia before nitrification. In addition, they may be involved in complex ion exchange and precipitation reactions as well as in the dissolving - pH adjustment - re-precipitation series which further assists in removing contaminants. Adverse effects on infiltration rate may occur as a result of the swelling property. Also, the clay fraction can be a problem if the infiltration waters have a sodium adsorption ratio out of balance with the exchange sodium percentage of the formation prior to recharge. Many of these reactions do not lead to permanent fixation of contaminants during the wet operating phase but fixations will become permanent upon oxygenation during the drying phase. Because many highly porous materials such as clays, while having a very high treatment capacity, have a low infiltration capacity, the aquifer mineralogy must be

selected such that the degree of treatment is optimum relative to the infiltration rate.

### Hydraulic parameters

For a particular infiltration rate, the given combination of hydraulic factors of an aquifer will influence the rate of movement of recharge water through the aquifer, retention time, and the extent of dispersion and dilution. These factors will significantly affect the quality of water at the point of extraction and so influence suitability of waters for recharge. The parameters of significance are: porosity, hydraulic conductivity, transmissivity, storage coefficient, and dispersivity. There are detailed discussions of these parameters in all groundwater textbooks (e.g. Freeze and Cherry, 1979; and Davis and DeWiest, 1966). Dispersivity, the most difficult parameter to determine, is a measure of the heterogeneity of the aquifer and relates to both small scale (intergranular) and large scale (stratification) variations. It is a parameter which describes the amount of mixing between the natural and recharged waters.

### Aquifer water chemistry

While aquifer water chemistry places the least restraint when using infiltration for artificial recharge, it is the base against which contaminant levels in the aquifer will be measured and must be closely established and monitored. It is possible that some reactions between infiltrating waters and aquifer waters may occur causing precipitation and clogging of the aquifer. In particular the precipitation of iron compounds, siliceous cements, or calcium carbonate are problems which need to be considered.



### Natural hydrologic environment

An assessment of the natural hydrologic environment is essential in isolating the effects of artificial stresses. Depending on topography and geology, regional flow systems are composed of recharge areas, discharge areas, and transitional areas. The system designer must be cognizant of the position of a proposed recharge pit within the regional flow system, as this will affect flow rate and direction.

### Predictability

Aquifers vary in the degree to which flow paths through them can be predicted. Even-grained homogeneous granular aquifers allow much more confident predictions of flow paths than do heterogeneous or fractured aquifers. An aquifer in which flow paths can be predicted with reasonable confidence is clearly preferred because there is less likelihood of undiluted escape and/or short circuiting along unexpected flow paths. This factor is important in the context of pilot studies, during which management procedures are being studied relative to treatment efficiency and operation techniques.

### Infiltration and Wastewater Polishing

A common problem experienced with artificial recharge is a decrease of infiltration rate through time. The use of reclaimed water, with its relatively high BOD, further exacerbates this difficulty. Several remedial methods have been proposed to optimize the long term infiltration rate. On the other hand, the filtering action of the recharge bed tends to improve, or renovate, the quality of secondary treated wastewater. This phenomenon, known as polishing, is seen as a potential alternative to conventional



tertiary treatment. A balance between maximum polishing and high infiltration rates must be obtained when using reclaimed water.

A wide range of infiltration rates for recharge basins has been reported. According to American Water Works Association Task Group 2440R, basin infiltration rates of 0.09 to 200 ft/day have been reported in the United States (Task Group Report, 1963). Wastewater effluent has been recharged at rates of 1 to 3 ft/day at Phoenix (Bouwer, 1970) and at average rates of 1 ft/day at Hyperion (Lavery, 1961) and Santee (Merrell and Ward, 1968; and Merrell and Katko, 1966). River water is recharged at rates of 3 to 15 ft/day in Sweden (Winqvist and Marcelius, 1970), 0.5 to 1.5 ft/day in Holland (Haasnoot and Leeftang, 1970), at a design rate of 8 ft/day in Germany (Matlock, 1966), and at Peoria, Illinois, rates as great as 200 ft/day have been observed (Suter, 1956), although annual recharge was about 20 to 100 ft/day.

The initial infiltration rate of a recharge basin is a function of the intrinsic permeability of the bed material, moisture content of the underlying beds, water temperature, amount of suspended solids, and other related factors. Although it can be modified somewhat in basin design, it is essentially a fixed property of local geologic conditions.

The infiltration rate can be decreased for several reasons. If the groundwater mound beneath the basin rises to the bottom of the basin the infiltration rate could be reduced. This might occur when the initial water table is close to the surface and the amount of infiltration is great. The height of the groundwater mound can be computed from theoretical considerations and this should be done if such a problem is anticipated (Hantush, 1967; and Bianchi and Haskell, 1968).



Physical clogging of the surface layers in the recharge basin can reduce the infiltration rate. Behnke (1969) investigated the clogging of recharge basins by mechanical particles. Turbid waters were applied to sand columns. Within 8 hours observable clogging occurred at turbidities as low as 50 mg/l. The clogging was observed to be essentially a surface sealing phenomenon. The more important variables included the size distribution of the particles in the water relative to the pore size of the sand and the concentration of the material in suspension.

Physical clogging of a pit bed has been observed in Peoria, Illinois recharge pits (Suter, 1956; Smith, 1967; and Harmeson, 1968). Although the pit liner material has been renewed periodically, penetration of the sediment into the aquifer pores has reduced the permeability of the aquifer and permanently lowered the infiltration rate of the pits. Although the surface layers of recharge basins can be replaced or renewed, they should be sized so that physical particles (silt and clay) cannot enter the aquifer material.

Biological growth can also reduce the infiltration rate of recharge basins. Algae may grow in a recharge basin. Dead organisms can accumulate on the bottom, causing the surface to clog in much the same manner as particles of mineral matter (Frank, 1970; Baffa and Bartilucci, 1967; Moravcoua, 1968; and Berend, 1970). In some water algae growths can precipitate calcium carbonate and bacteria can precipitate iron salts, which can effectively seal the bottom.

Algae control through the use of an algacide, CA-350, which contains 300  $\mu\text{g/l}$  Cu and 50  $\mu\text{g/l}$  Ag, was studied at Sojovice, Czechoslovakia (Moravcoua, 1968). Algae growth was controlled with dosage at the aforementioned levels, although copper eluted from the test filters at a rate of



up to 0.17 mg/l. There were no observed harmful effects on the bacteria, and aerobic decomposition of the organic matter occurred.

Algae can also be controlled by intermittent drying of the basin surface (Ineson, 1970). Because this is one of the commonly accepted methods of restoring infiltration capacity, the required frequency might also meet the requirements for algae control. Bouwer (1970a and 1970b) investigated the effects on infiltration rates of various basin bottom materials, including bare soil, gravel, and grass. He found the lowest infiltration rates to be in the gravel bottom basins and the highest in the basins with grass in the bottom. The high infiltration rates of the grass-bottom basins were attributed to a reduced algae growth caused by shading of the bottom by the grass. The intermittent application of water also helps to control the growth of mosquitoes and midges, which may occur in standing water.

Studies by Nevo and Mitchell (1967) using artificial wastewater showed that biological clogging during recharge was caused by the accumulation of microbial polysaccharides (complex sugars). This was accompanied by a reduction in the measured oxidation potential in the sand. Periodic resting of recharge beds was found to restore aerobic conditions and renew the infiltration rate of the recharge bed. Paddy rice, which releases oxygen from its roots, was found to be effective in keeping the sand oxygenated. It was also found that soils with large pore spaces recovered their infiltration capacity more slowly than those with small pore spaces. This indicates that fine sand might be better for recharge than coarse sand. Amramy (1964 and 1968) noted that organic matter accumulated in the top 4 in. of soils receiving wastewater effluent. There was no progressive buildup of organic matter beyond this depth, even with the passage of time.



He determined that, under the conditions in Israel, a cycle of 2 or 3 days of wetting and 7 to 8 days of drying produced the best infiltration results. It was found that by passage through 262 ft of the aquifer BOD was reduced by 90 percent and organic nitrogen by 63 percent; total nitrogen decreased by 64 to 80 percent. Nitrate at the sampling point averaged 16.2 mg/l while the average total nitrogen was 34.2 mg/l in the basin.

Bouwer (1970a and 1970b) also found a very significant reduction in total nitrogen. This reduction is apparently related to the length of the wetting cycle. With a short cycle (2 days wet, 3 days dry), all of the nitrogen was oxidized to nitrate in the renovated water. However, a long cycle (14 days wet, 7 days dry) yielded about a 90 percent removal of total nitrogen.

Nitrogen removal by soil mechanisms was discussed by Lance (1972). Physical removal occurs through adsorption by clay and organic matter as well as cation exchange with clay minerals. Volatilization of ammonia may release a small amount of gaseous ammonia. Biological denitrification producing nitrogen gas may also occur. This is the system with the greatest potential for effectively removing nitrogen during a long term artificial recharge project.

At Santee, California, total nitrogen in the treatment plant effluent was 310 lb/day; in the oxidation pond effluent it was 160 lb/day; and in the renovated water after percolation, 7 lb/day. Removal of phosphorus was from 62 lb/day in the plant effluent to 1.4 lb/day in the renovated water (Merrell and Katko, 1966). No mechanisms for removal were suggested. It was found that the removal of virus was 100 percent effective with the passage of the water through 400 ft of aquifer (Merrell and Ward, 1968).



Percolation was also effective in removing bacteria at Santee (Merrell and Katko, 1966) and Phoenix (Bouwer, 1970a).

The ability of viruses to travel through soil strata is a subject that has not been thoroughly researched to date. The following excerpt is from a more recent study (Vaughn and Landry, 1980):

In general, the 12-Pines tertiary-treatment facility was effective in removing viruses from sewage. Occasionally, human enteroviruses were found in sewage effluents being used to recharge the aquifer. Viruses were subsequently isolated from the groundwaters beneath the test site recharge basin receiving effluent, indicating migration of the viruses through the soil profile.

The presence of coliform bacteria in the sewage effluent and the renovated waters could not always be correlated with the presence of viruses in the same samples. Viruses were generally isolated from samples with few coliforms, but not isolated from samples containing high concentrations of bacteria.

The removal of viruses during basin seeding experiments was clearly dependent on the infiltration rate of the virus-containing effluent. At high infiltration rates (75-100 cm/hr), considerable concentrations of viruses were seen at all depths, including groundwater samples. Greatly reduced infiltration rates (0.5-1 cm/hr) showed substantially better virus removal with few detected in the aquifer located 7.6 m below the floor of the recharge basin.

The prevalent conclusion is that viruses can travel only limited distances in sand or silt soil strata. This is based to a great extent on the inability of easily monitored bacteria of the coliform group to travel. Robeck et al. (1962) reported on experiments approximating groundwater flows that showed effective virus removal as a result of filtration at natural groundwater movement rates. They further concluded that removal resulted from contact with the sand particles and not from die-off.

Investigative work undertaken in connection with recharge of reclaimed secondary effluent at the Hyperion Plant in Los Angeles County (Evans, 1964) included monitoring for the presence of enteric viruses in the treated wastewater during the period when the county was embarked on a



large scale mass poliomyelities immunization program using live attenuated virus. The results obtained during this severe test led the investigators to conclude that there would be little if any probability of human enteric viruses penetrating beyond the recharge water.

Clark and Chang (1959) and others have listed a number of outbreaks of infectious hepatitis that involved groundwater supplies. These studies indicate that the virus-contaminated water traveled anywhere from several to a few hundred feet through fissured or fractured substrata rather than through the soil itself.

Drewry et al. (1968) conducted a series of laboratory experiments using bacterial viruses. From these experiments they concluded that virus movement through a few centimeters of a continuous stratum of soil containing a fairly high percentage of silty or clayey material should present no more, and possibly less, of a public health hazard than movement of pathogenic bacteria. They cautioned, however, that there were definite limitations on using bacterial viruses to serve as models for animal viruses. This study further concluded that virus retention by soils is an adsorption process that is highly effective at pH values below 7.0 to 7.5, but with rapidly decreasing effectiveness at higher pH values. Adsorption was also found to increase with increasing clay and silt content, ion exchange capacity, and glycerol retention capacity. Virus movement through saturated soils apparently was no greater than through unsaturated soils.

#### Evaluation of a Recharge Scheme

Before a final decision can be made on proceeding with a full scale scheme to recharge an aquifer with reclaimed water, it is essential that as many aspects as possible associated with the economic and physical facets



of the scheme and all suitable alternative schemes be considered. While a detailed examination might not be possible or even warranted at this stage, a genuine attempt should be made to determine whether recharge with reclaimed water is a viable option, bearing in mind relative cost and the ultimate use of the aquifer water.

It cannot be assumed that recharge with reclaimed water is a good proposition merely because reclaimed water is available. Cost effectiveness of alternatives for providing the required water supply should be examined. Limiting factors of long term yield, security of supply, initial capital expenditure, and operation and maintenance costs should be established.

Recharge with reclaimed water also may be only one of a number of alternatives for recharge which may include diversion of stream flows, stormwater, etc. The economics of sources of recharge, including durability of supply, should be assessed for the alternatives as well as for the reclaimed water. Finally, the costs and benefits of not using the reclaimed water for recharge should be assessed before final decisions are made on 1) aquifer recharge or not and 2) recharge with reclaimed water or not.

In some circumstances the intended use of the recharged water may not be entirely compatible with current or potential use of the groundwater. If, for example, the existing groundwater is potentially potable but the need in the area is for irrigation supplies, then the recharge process with appropriate pretreatment of the reclaimed water should be designed to at least maintain the potable standard of water in the aquifer. If necessary only a portion of an aquifer need be used for renovation of reclaimed water. It may be necessary to keep the rest of the groundwater in the



aquifer separate from the renovated water, which can be achieved by zone management using wells or drains to control movement and distribution of the renovated water. If the quality of the groundwater is less than that required for intended or potential use, then the effect of mixing the recharged and natural waters must be carefully examined to ensure that an acceptable quality can be achieved. Rather than deliberately lowering the quality of the reclaimed water by recharging, the question of direct reuse should be considered in such cases. The capacity of the aquifer to significantly reduce pollutants can only be firmly established by long term pilot studies, but laboratory column studies may indicate orders of removal achievable and give early indications of the necessity for pretreatment or post-treatment to achieve end use quality requirements. The costs of these processes should be included in the economic analysis.

#### The Pilot Study

This pilot scheme follows the general recommendations outlined in Australian Water Resources Council, 1982 and has been modified for north eastern Illinois conditions, and in particular, near the Aurora Sanitary District plant.

The pilot study should continue for a minimum period of 4 to 5 years. The pilot study can be split into 3 main phases according to the following suggested procedure:

1. Phase 1: This phase would last for about 1 year, during pit construction. It should involve drilling more observation wells and test production well(s). This phase should involve continued

allowed unless monitoring is taking place concurrently. It is also important to allow the program to be flexible so that modifications can be made in the light of significant findings.

Characteristics that should be monitored fall into four main groups, as shown in Table 1. Group 1 characteristics which should receive the most detailed monitoring are those which are necessary for the control of the basic operational techniques and may be used as tracers for the reclaimed water progress (e.g. nitrates, sulphates, potassium, chlorides). Group 2 characteristics, being the dominant variables of both groundwater and effluent, should receive evaluation at regular intervals, although not at the same intensity as Group 1. Group 3 characteristics, the heavy metals, should be evaluated at infrequent intervals, and any constituent found in a significant concentration should be upgraded to the monitoring frequency of Group 2. Group 4 characteristics, trace organics, may be determined occasionally to establish whether more frequent analysis and specific monitoring in the produce water is required.

To avoid unnecessary analytical costs, markers should be identified and sampled routinely, with other constituents less frequently monitored. More complete analysis is then necessary only if a marker shows fluctuation or where some change or breakthrough in water quality is indicated. The markers selected should be detectable in very small concentrations so that the arrival time of the infiltrated water can be identified. Desirably they should be those constituents which are not attenuated by the infiltration process or passage through the aquifer. Their chemical nature should be such that their proportion in extracted waters is indicative of the proportion of artificially introduced waters present in the aquifer at the site of sampling.



Table 1. Groups of chemical constituents to be monitored

GROUP 1	GROUP 2	GROUP 3	GROUP 4
Electrical Conductivity	Total dissolved solids	Arsenic	Organo-chlorine
pH	Sodium	Barium	Organo-phosphorous
Dissolved Oxygen	Magnesium	Cadmium	Pesticides
BOD <sub>5</sub>	Silica	Chromium	Cyanides
COD	Potassium	Copper	Phenols
Dissolved Organic Carbon	Calcium	Mercury	Chlorinated hydrocarbons
Organic Nitrogen	Manganese	Nickel	Aromatic hydrocarbons
Chloride	Iron	Selenium	Total Radio-activity
Ammonia	Sulphate	Tin	
Nitrate	Bicarbonate	Zinc	
Nitrite	Carbonate		
Phosphorus	Boron		
Total Coliform	Lead		
E. Coliform	Fluoride		
Grease	Non-ionic detergent		
Suspended Solids			

It is advisable to select an indicator to monitor for breakthrough of particular groups of ions. Experience has shown that of the heavy metals cadmium is the least retarded while selenium, though delayed in transport time, is not reduced at all. Cadmium, if present, may be used as an indicator of the breakthrough of heavy metals, and the monitoring of other heavy metals need not be undertaken until cadmium is detected.

#### Hydraulic performance

Hydraulic monitoring should be aimed at evaluating the following: recharge rates, variations in the groundwater mound in response to periods of recharge, difference between the actual mound and predictions made from analytical or numerical models, effect of low vertical permeability strata on the height and configuration of the mound, and flow patterns through the aquifer as a whole and within individual horizons. Water level monitoring throughout the study area is essential, particularly where the mound is expected to be the highest. At least two automatic water level recorders should be installed on observation wells to provide a continuous record of water level fluctuation.

The hydraulic performance of the recharge pit should be established including the variation in infiltration rate with differing basin water depths, varying types of floor covering (e.g. sand, gravel, etc.), different periods of flooding and drying, and different seasons of the year. Of major importance is a study of the movement of recharge water through particular horizons. This will necessarily involve well logging. The most suitable methods to do this include flow metering equipment (current and heat pulse meters), temperature and differential temperature logs, conductivity logs, natural and induced tracers, and neutron and gamma ray logs.



It is recommended that logging, using temperature probes, be carried out in the first phase of the study, as this will help to establish patterns of initial movement of recharge in the aquifer.

#### Aquifer materials

Some changes in the characteristics of the aquifer material will result from the application of reclaimed water. Consequently, a monitoring program for this will be necessary with at least annual sampling. Characteristics that are of importance include grain size distribution, soil stratigraphy, level of various elements (e.g., the sodium adsorption ratio), cation exchange capacity, and degree of clogging.

In summary, the interpretation of results from the pilot study should be aimed at establishing whether or not:

1. The combination of pit design and aquifer characteristics is capable of handling the expected discharge.
2. There are any adverse hydraulic effects, e.g., extremely high mounding under the basin or leakage paths.
3. The recharged water is flowing in the desired direction.
4. There are any chemical reactions producing undesirable or toxic material. (A study of redox - pH levels and mineralogy of the aquifer would help to establish this). Precipitation at depth could be a long term problem.
5. Purification is occurring prior to re-use.
6. Additional treatment will be necessary prior to re-use.
7. Clogging by residue is causing irreversible deterioration of recharge rates.

Caution must be exercised in scaling up results and extrapolating from the pilot scheme to the full size recharge situation. Each parameter's role needs to be studied separately. In particular, mounding of the water table must be examined with extreme care. On the small scale mounding is local, but on the larger scale the mounding is more extensive and will generally be higher. In some instances, the water table for the full scale pit could rise above the pit floor, thereby causing a loss of the unsaturated zone resulting in lower infiltration rates and less effective treatment than those of the pilot scheme. It also should be kept in mind that dilution in the case of the pilot scheme water is large because of the relatively small discharge. For the full size pit, dilution will be far less and the results must be viewed and interpreted in this light.



## SITE DEVELOPMENT

The location and development of a specific artificial recharge project must apply the previously established principles to the local hydrogeologic and social conditions. It must be understood that previous solutions may not be directly transferable to a new location. The degree of urbanization combined with widely variable zoning restrictions can have a great influence on the eventual outcome of the project. In highly developed areas, land acquisition becomes difficult and may be the limiting factor in eventual site location. In some states or localities artificial recharge is encouraged through zoning regulations; however, in those areas without such regulations, economic factors will become more important in the final plan.

Ultimately, a specific plan must be based on the local hydrogeologic environment. Since much of the early studies were done in an arid region, with a deep water table, their results must be carefully examined before being applied to the humid Midwest. The local flow system, stratigraphy and groundwater composition must all be considered.

Two strategies can be used to locate a suitable location for the development of a recharge operation. In the first strategy, sources of input water are first located, and then each site is reviewed on the basis of local hydrogeology. This strategy is favorable in urban areas which have many water reclamation plants which can be used to supply the system or in less developed areas which may have only a few suitable sources of water. This is also useful when the surficial earth materials are fairly uniform and predictable across the region. In the second strategy, the first step is to outline possible recharge materials, then locate a source



of water. This method is useful in regions where hydrogeologic conditions are variable, but where ample water sources are available.

In our study in northeastern Illinois, it was initially assumed that the limitations of dense urbanization would be the key factor in site location. However, it was found that most government officials, who were faced with the costly alternative of constructing pipelines from Lake Michigan, were quite receptive of our project and gave us considerable cooperation. On the other hand, the shallow hydrogeologic conditions in the region are quite complex. Three promising sites were abandoned because of unfavorable hydrogeologic conditions after land-use permits had been resolved. The fourth, and final, site was chosen only after an analysis was made of the regional shallow aquifer system. A wastewater treatment plant was found which was located within a potentially favorable area. As in other places, our proposed project was met with enthusiastic cooperation by both the Aurora Sanitary District that operates the treatment plant and the Caterpillar Tractor Company that owns a large tract of land adjacent to the treatment plant. Consequently, site work progressed easily through the subsequent stages of the project.

### Geology

The geology of northeastern Illinois has been intensively studied and is summarized by Willman (1971). The surface and near surface geology (Figure 1), which may affect a recharge program, will be briefly described in this report. The shallow materials can easily be divided into two types, the unconsolidated glacial deposits and the underlying Paleozoic carbonates (Willman and Lineback, 1970).



SYSTEM	SERIES (Stage)	GROUP FORMATION MEMBER	GRAPHIC LOG	THICKNESS	DESCRIPTION	HYDROGEOLOGIC PROPERTIES
QUATERNARY	PLEISTOCENE	HOLOCENE				
		WISCONSINAN				
		ILLINOIAN				
PENN.	DESM.					
MISS.	VAL.					
	KIND.					
DEV.	UP.					
SILURIAN	NIAGARAN					
	ALEX.					
ORDOVICIAN	CIN.					
	TRENT.					
CHAMPLAINIAN	BLACKRIVERAN					
	ANCELL					
CANADIAN						

Figure 1. Geologic column of northeastern Illinois.



### Unconsolidated deposits

The unconsolidated deposits above the bedrock consist primarily of glacial deposits of Wisconsinan age. Some remnants of the Illinoian age Glasford Formation may exist in the region and alluvium of modern streams is assigned to the Cahokia Formation. The Wisconsinan deposits range in thickness from zero in some of the river valleys to over 300 feet in some morainal areas. Stratigraphically these deposits are differentiated into three formations. The Wedron Formation averages 100 feet thick throughout the area and it is as much as 300 feet thick in some buried valleys and in the higher moraines. It is dominantly till that occurs in sheet-like deposits separated by beds of water-laid sand, gravel, or silt (Willman, 1971). It is differentiated into five members based on distinctiveness of the tills (Figure 1).

The Henry Formation is glacial outwash that directly underlies the modern soil. Outwash that underlies or is interbedded with till is included in the Wedron Formation (Willman, 1971). In some areas, especially along the Fox River Valley, surface tills have been eroded exposing the underlying sand and gravel beds. It is often difficult, on a regional scale, to trace the actual extent of these surficial deposits. Therefore, careful study of the local stratigraphy is necessary to determine the continuity of these sands beneath the till sheets.

Glaciolacustrine deposits are assigned to the Equality Formation. Silt and clay resulting from quiet-water deposition predominate. However, several extensive beach and near-shore sand and gravel deposits have remained from previous high stages of Lake Michigan. These deposits are local and of little significance to this study.



### Shallow bedrock

The geologic map of Illinois (Willman and others, 1967) depicts the shallow bedrock in Illinois. In northeastern Illinois the dominant rock types are carbonates of Silurian and Ordovician age. Rocks of Pennsylvanian age occur in the extreme southwest corner of the area on the northern tip of the Illinois Basin. The Silurian Niagaran and Alexandrian rocks which occur at the surface in the eastern half of the region are primarily dolomite. In the western half of the region, where the Silurian is eroded, Ordovician age rocks occur at the surface. In this area, the Maquoketa Group, which consists of dolomitic shale and dolomite, is predominant. Dolomites of the Galena and Platteville Groups can be found at the surface in western Kendall County, and in extreme western Kendall County these are eroded so that sandstones of the Ancell and Prairie du Chien Groups are at the bedrock surface.

### Regional hydrogeology

For the purposes of this report, the regional hydrogeologic system can be considered to contain three major water-yielding components - sand and gravel, shallow bedrock, and deep sandstones (Bergstrom et al., 1955). These are described in detail by Suter et al. (1959), and Zeizel et al. (1962), and will only be discussed briefly in this report.

The most important regional aquifer system (Suter et al., 1959) has been the sandstones of the Ancell Group and within a thick sequence of rocks below the Ancell not included in Figure 1. These deposits occur at depth throughout the region and have yielded large amounts of fresh water. This regional aquifer has now been over-used, prompting the study of alternate water supplies. Direct recharge of the sandstones by injection



wells has been recently suggested (Bennett, 1982), but the problems associated with such a proposal are beyond the scope of this project and will not be addressed in this report. The deep sandstone aquifers should not be directly affected by any shallow recharge efforts and, therefore, will not be considered further.

The shallow bedrock in this area is predominantly dolomite which, where creviced, yields large amounts of water. In DuPage County especially it is the primary aquifer (Zeizel et al., 1962). Where the upper bedrock is shale or shaley dolomite of the Maquoketa Group, the water is diminished in both quality and quantity. Generally, the Maquoketa is considered an aquitard; however, at the surface it is often fractured and will yield small amounts of water. Because primary flow paths in the dolomite are along crevices and not through the rock matrix, this aquifer is quite susceptible to contamination. Very little attenuation of contaminants will occur, consequently it is not a recommended host for artificial recharge of reclaimed water. In fact, care must be taken to insure that it is not adversely affected by recharge operations in other units.

The unconsolidated sand and gravel is the least utilized aquifer system in the region (Zeizel et al., 1962). Compared to the nearly ubiquitous bedrock aquifers with their predictably high yields, the distribution of the sand and gravel is discontinuous across the region with variable yield. Because it is so complex, it has been somewhat ignored in the past. Most often it has been considered a supplement to the dolomite aquifer (Zeizel et al., 1962) in areas where basal sand and gravel is directly overlying the dolomite. The Henry Formation offers the most potential for the development of an artificial recharge system in this region. Where it occurs, it is often coarse-grained with high transmissivity. Locally, sand



and gravel of the Wedron Formation may be considered for a recharge system. Because it is interbedded with till it is likely to be discontinuous with a lower transmissivity. On the other hand, till offers a natural barrier to contaminant migration away from the site. Each potential site must be carefully evaluated. Coarse-grained alluvium within the Cahokia Formation is not abundant in this region and is generally not considered to be a potential host to a recharge system.

The hydrologic conditions of northeastern Illinois are not ideal for the development of artificial recharge systems although individual sites may be adequate or special engineering designs might be employed to make other sites usable. The humid climate combined with a generally fine-grained soil matrix and poorly developed topographic relief results in a high water table throughout most of the region. The remedial action of a recharging sand bed is diminished under these conditions and problems with groundwater mounds are pronounced. The coarse-grained deposits of the Henry Formation generally occur in low-lying areas which are most often zones of natural discharge. These conditions require special engineering designs to reverse the hydraulic gradient and, in Illinois, may require zoning variances when the site is located on a natural floodplain. Upland areas which are areas of natural recharge are composed of tills of the Wedron Formation. In some areas, especially near river valleys, Henry Formation sand and gravel are locally extensive or the surface tills are partially eroded leaving sand and gravel outwash deposits at or near the surface. These sites provide the greatest potential for recharge systems in this region. The feasibility of establishing a recharge system at any site can only be determined after careful study of that site.



## Site Investigations

### **Schaumburg site**

The Egan Water Reclamation Plant in the Schaumburg Township of Cook County (Figure 2) was the site of initial efforts of establishing a demonstration pit. The Egan plant is a member of the Metropolitan Sanitary District of Greater Chicago and is located across Interstate 90 from the Ned Brown Forest Preserve (Figure 3), a property owned by the Cook County Forest Preserve District. The initial concept was to pump effluent from the Egan plant to a proposed pit on the Forest Preserve property. Permits were obtained; however, exploratory investigations demonstrated that the proposed site was not adequate.

The Schaumburg site is located in the drainage basin of Salt Creek in a lowland between the Palatine Moraine to the west and the younger Tinley Moraine to the east. The natural surface drainage within Ned Brown Preserve has been altered by construction of three small flood control dams on Salt Creek (Figure 3). The resulting ponds have flooded much of the surface area within the lowland, restricting the space available for a possible recharge pit.

The surface drift, part of the Wadsworth Member of the Wedron Formation has been partially eroded by the action of the West Branch exposing sand and gravel (Willman and Lineback, 1970). Several local pits (see Figure 3) have exploited this unit which was also the potential recharge aquifer for this study. Initial investigations by the Illinois State Geological and Water Surveys were undertaken to determine the character, thickness and extent of the outwash, its hydraulic conductivity, and the quality of the groundwater.



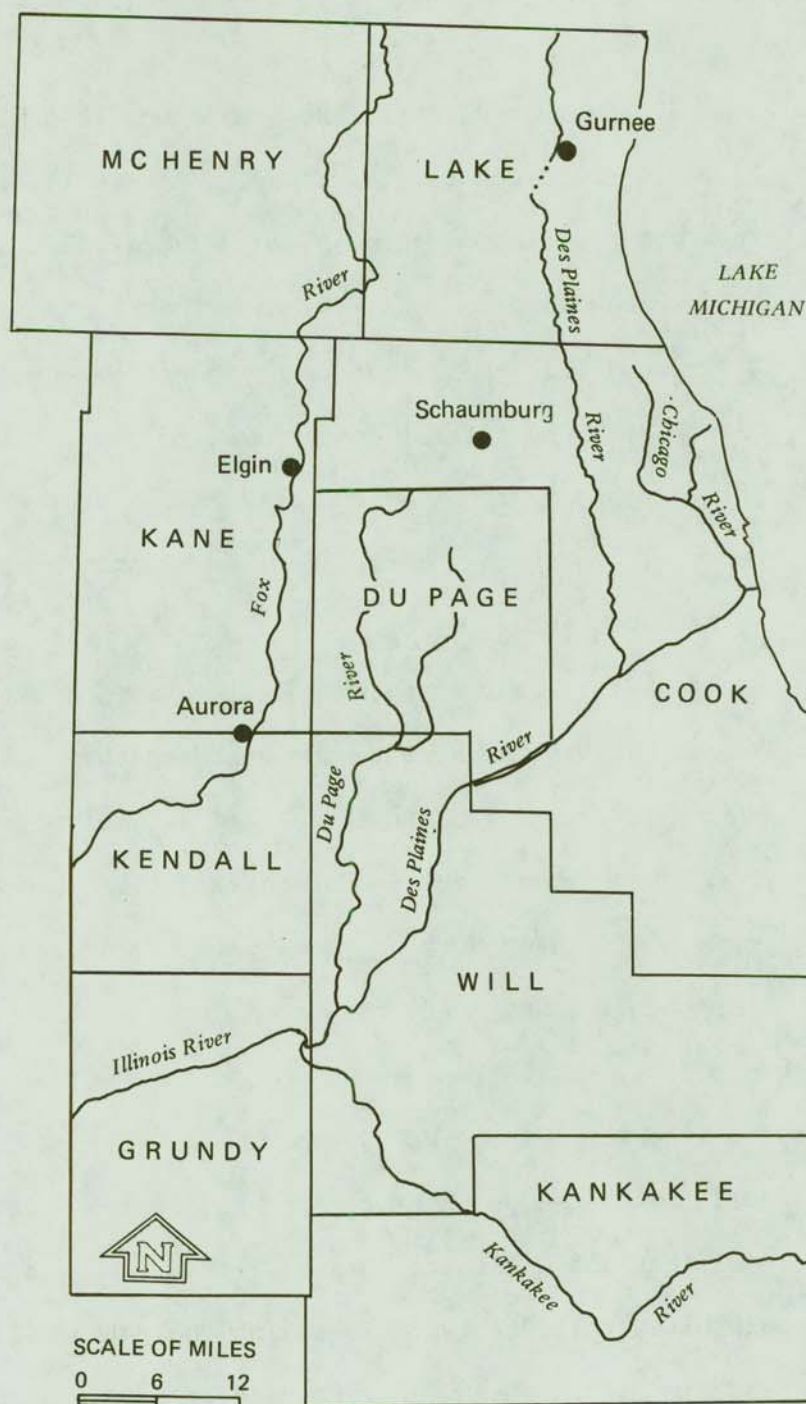


Figure 2. Locations of study areas.

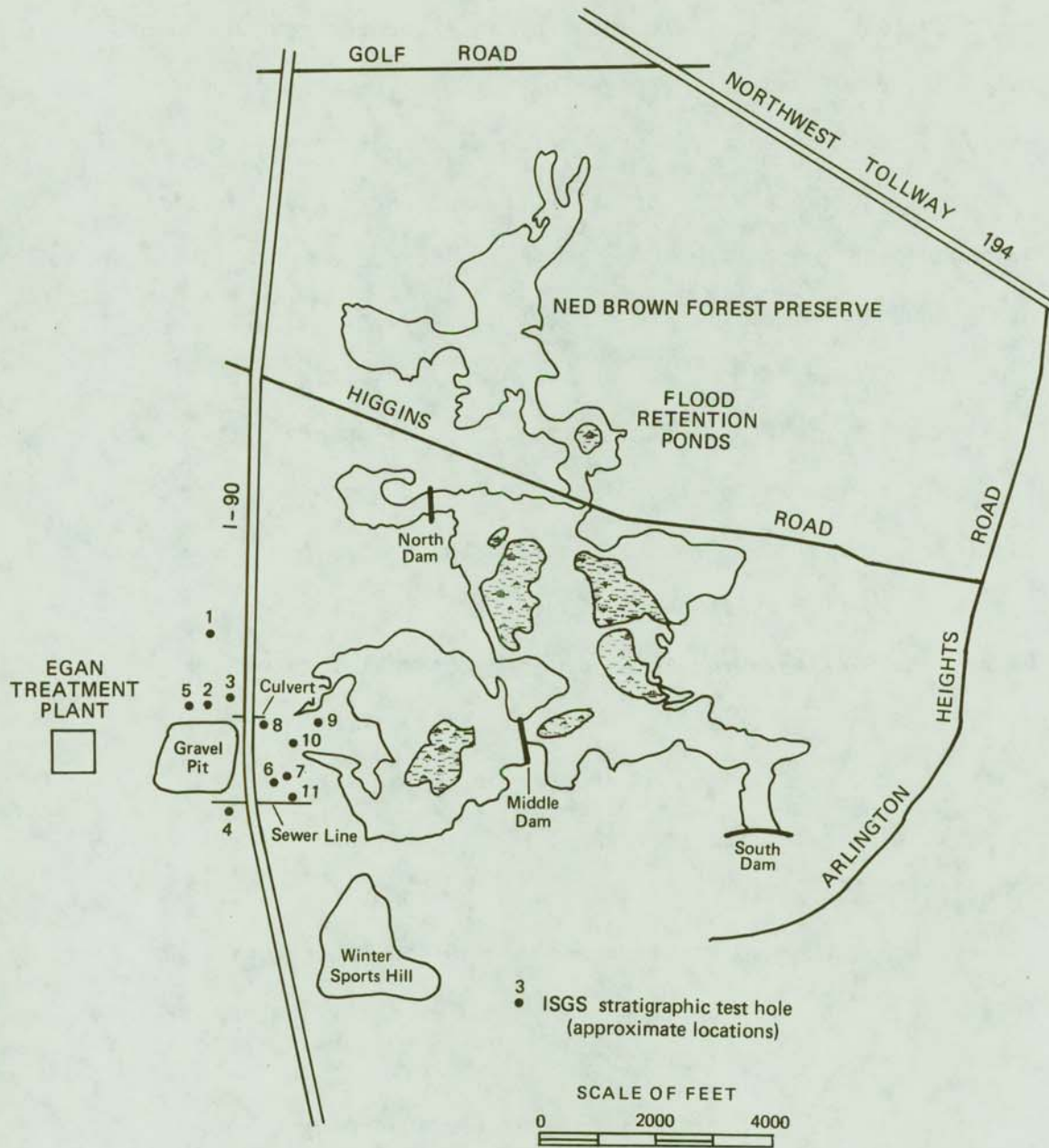


Figure 3. Locations of stratigraphic test borings at the Egan site.



Initial site investigations included eleven stratigraphic test borings (average depth 30 feet (9 m)) supplemented by an electrical earth resistivity survey (Figures 3 and 4). The geologic investigations revealed a typical outwash deposit of unsorted stratified sand and gravel with interbedded silt and till (Figure 5). The thickest sand and gravel deposits are probably 30 to 40 feet (9 to 12 m) thick with the coarsest material in the vicinity of the abandoned gravel pit. Laterally, the entire outwash deposit grades into fine-grained outwash materials and till. Laboratory tests indicate that significant amounts of silt (5-10%) present throughout the deposit result in fairly low calculated hydraulic conductivities.

A preliminary aquifer test was conducted using a 6-inch diameter test well pumping at about 11.5 gallons per minute (gpm) for five hours. The water level response was measured in an observation well located about 50 feet from the pumped well. Based on the analysis of this test, the transmissivity and the coefficient of storage of the aquifer were estimated to be 10,000 gallons per day per foot (gpd/ft) and 0.1, respectively. The aquifer hydraulic conductivity was estimated to be about 320 gpd/ft<sup>2</sup> ( $1.51 \times 10^{-2}$  cm/sec) which was within the range of the laboratory tests. The aquifer was judged to have adequate (although certainly not exceptional) size and conductivity to merit more extensive testing.

The mineral analysis on a water sample collected during the aquifer test (Table 2) indicates that the groundwater in the vicinity of the test well is highly mineralized. This condition, especially the high sulfate content, is atypical of groundwater normally encountered in the glacial drift of northeastern Illinois and indicates that the aquifer is probably contaminated. Therefore, any changes in groundwater quality resulting from artificial recharge of this aquifer could not be considered representative

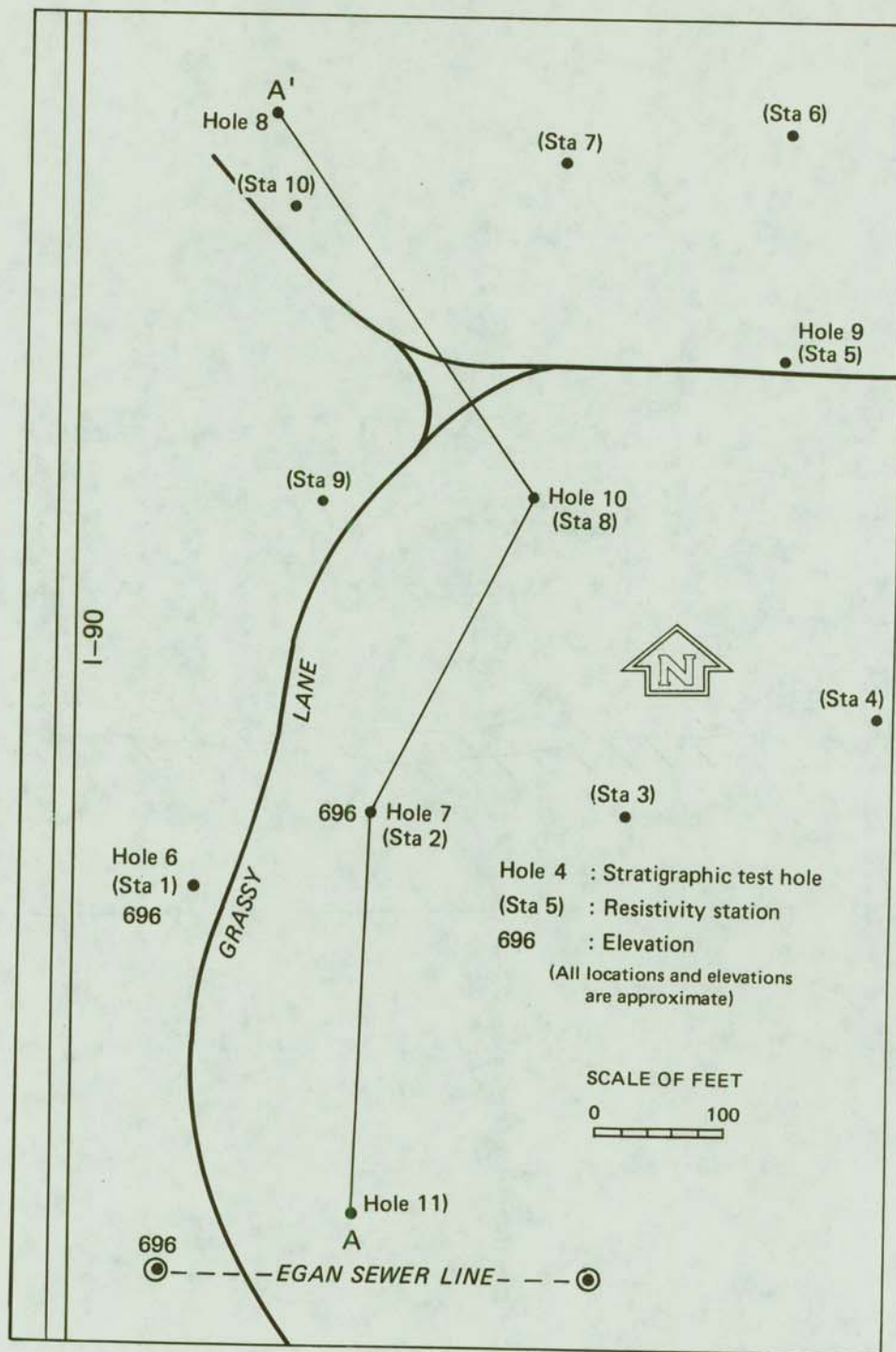


Figure 4. Locations of earth resistivity stations in the western portion of the Ned Brown Forest Preserve.



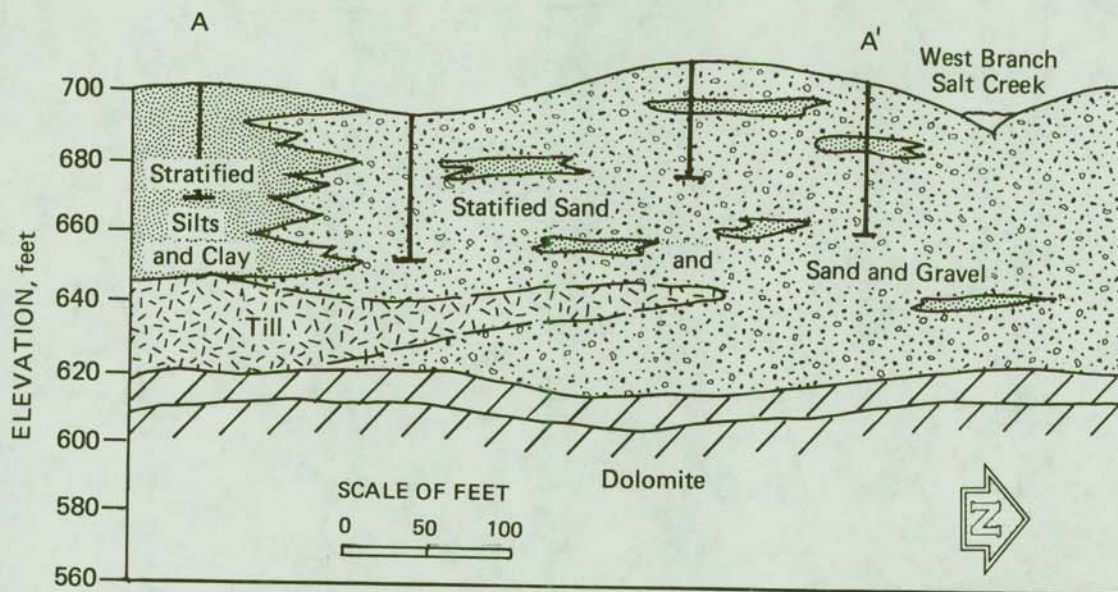


Figure 5. Generalized north-south cross section of the Ned Brown Forest Preserve.

Table 2. Partial Chemical Analysis of Groundwater Sampled  
from the Ned Brown Forest Preserve

		<u>mg/l</u>	<u>me/l</u>
Iron (total)	Fe	10	
Manganese	Mn	.54	
Calcium	Ca	435	21.71
Magnesium	Mg	200	16.45
Strontium	Sr	1.65	.04
Sodium	Na	19.3	.84
Potassium	K	12.0	.31
Ammonium	NH <sub>4</sub>	0.7	.04
Barium	Ba	<0.1	
Cadmium	Cd	.01	
Chromium	Cr	.00	
Copper	Cu	.00	
Lead	Pb	<.05	
Lithium	Li	.05	
Nickel	Ni	<.05	
Zinc	Zn	.03	
Silver	Ag	.00	
Phosphate (filt)	P	0.0	
(unfilt)	P	0.0	
Silica	SiO <sub>2</sub>	15.8	
Fluoride	F	0.1	
Boron	B	0.2	
Nitrate	NO <sub>3</sub>	0.5	.01
Nitrite	NO <sub>2</sub>	.01	
Chloride	Cl	24	.68
Sulfate	SO <sub>4</sub>	1396.3	29.04
Alkalinity (as CaCO <sub>3</sub> )		484	9.68
Hardness (as CaCO <sub>3</sub> )		1908	38.16
Total Dissolved Minerals		2540	

mg/l = milligrams per liter  
me/l = milliequivalents per liter  
mg/l x .0583 = grains per gallon



of northeastern Illinois. In addition, it is doubtful that changes in the quality of the injected water could be reasonably determined within this highly mineralized aquifer. Therefore, it was decided to abandon the Schaumburg site from further consideration as a location for an artificial recharge installation.

#### Gurnee site

The second site considered is in Lake County one half mile south of the city of Gurnee. The Gurnee Sewage Treatment Plant is located on the floodplain of the Des Plaines River adjacent to property owned by the Lake County Forest Preserve. The surficial materials at the site are glacial valley train and alluvial deposits of the Henry Formation (Willman and Lineback, 1970). These coarse-grained deposits cut into and overlie till of the Deerfield Moraine, part of the Wadsworth Member of the Wedron Formation. Two stratigraphic test borings in the forest preserve south of the site were used to supplement geologic information available from the construction of the sewage treatment plant. The modern river alluvium is 20 to 30 feet thick consisting of clayey silt, silt, and fine silty sand. The valley train deposits which have been mined extensively in the area consist of up to 50 feet of cross-bedded sand and gravel. The coarse-grained deposits overlie approximately 100 to 150 feet of till. The bedrock beneath the till is dolomite of Silurian age. Based on the preliminary geologic investigation, this site was judged to be unsuitable for construction of an artificial recharge pit due to the fine-grained nature of the surficial materials.



## Elgin site

The South Elgin Water Reclamation Plant was the last site to be considered in the initial series of potential project sites. The plant is owned by the Sanitary District of Elgin and is located on the west bank of the Fox River, south of Elgin in Kane County. After lengthy negotiations with nearby landowners, permission was obtained to conduct exploratory investigations on property owned by the Kane County Park District and located approximately 1500 feet to the north of the plant (Figure 6).

The surficial deposits in this area are less than 50 feet thick in the river valley, in fact the Silurian-age bedrock is exposed in the river bed about one mile downstream from the site. The glacial geology is complicated by the presence of the Minooka Moraine which is composed primarily of till from the Yorkville Member of the Wedron Formation. The erosive action of the Fox River and its tributaries has removed much of the soft till leaving localized remnants of the moraine, some of which are blanketed by coarse-grained outwash and valley train deposits. Willman and Lineback (1970) mapped the region as Cahokia Formation alluvium overlying valley train and outwash deposits of the Henry Formation. Three-dimensional mapping completed for the Northeastern Illinois Planning Commission (Kempton, Bogner, and Cartwright, 1977) reveals more extensive Yorkville deposits beneath a covering of outwash, especially east of the river. Site investigations were necessary to determine the exact nature and extent of the coarse-grained materials at the site.

Exploratory investigations consisted of a preliminary electrical earth resistivity survey followed by two stratigraphic test borings (Figures 6 and 7). The borings were continued to bedrock which was encountered at a depth of about 50 feet. Both borings encountered two layers of sand and



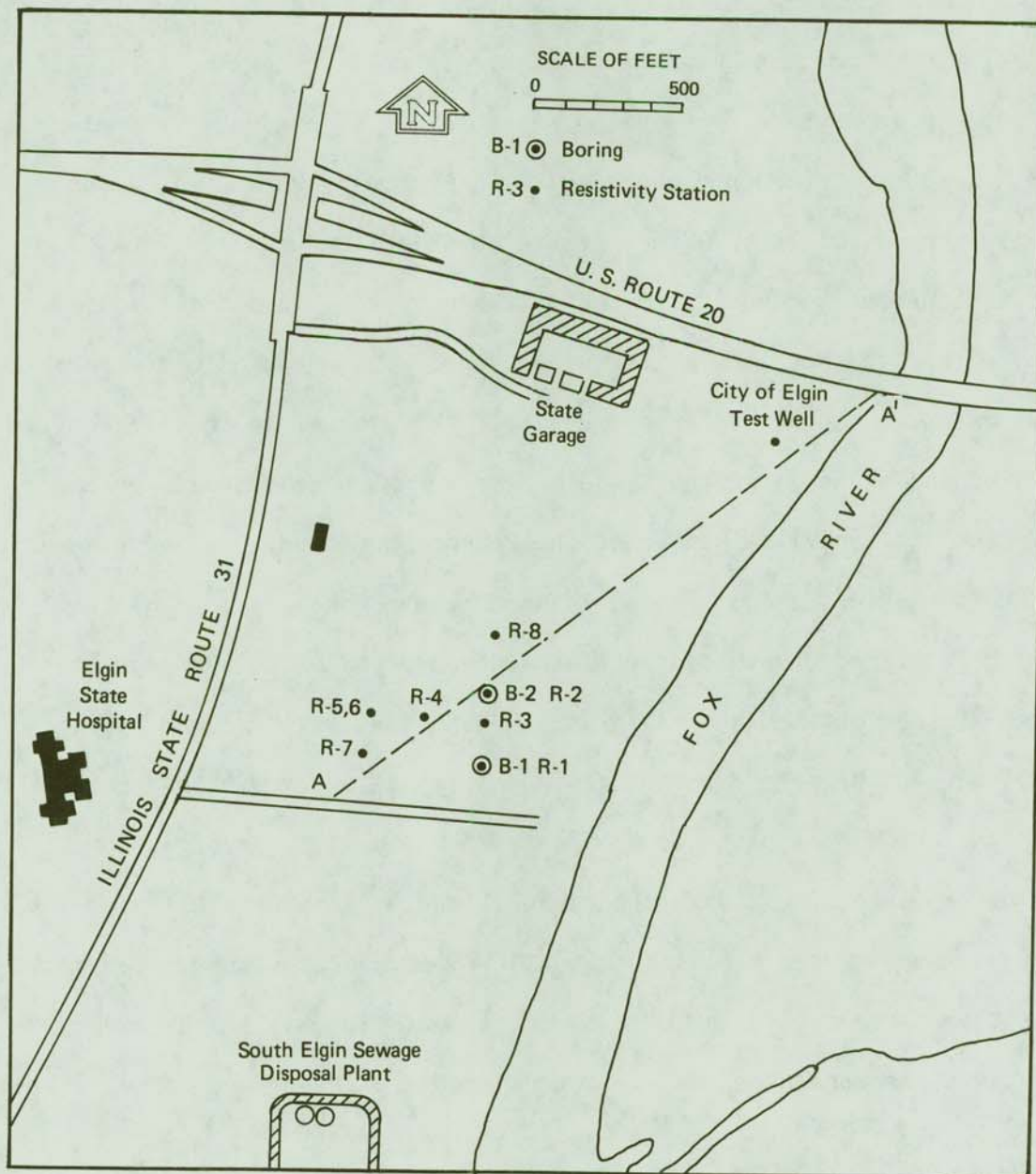


Figure 6. Elgin site showing locations of exploratory borings and resistivity stations.

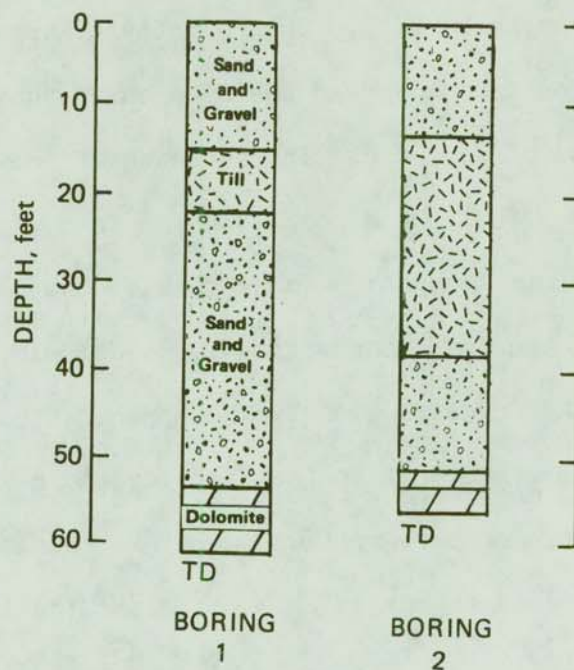


Figure 7. Stratigraphic logs of the borings at the Elgin Site.

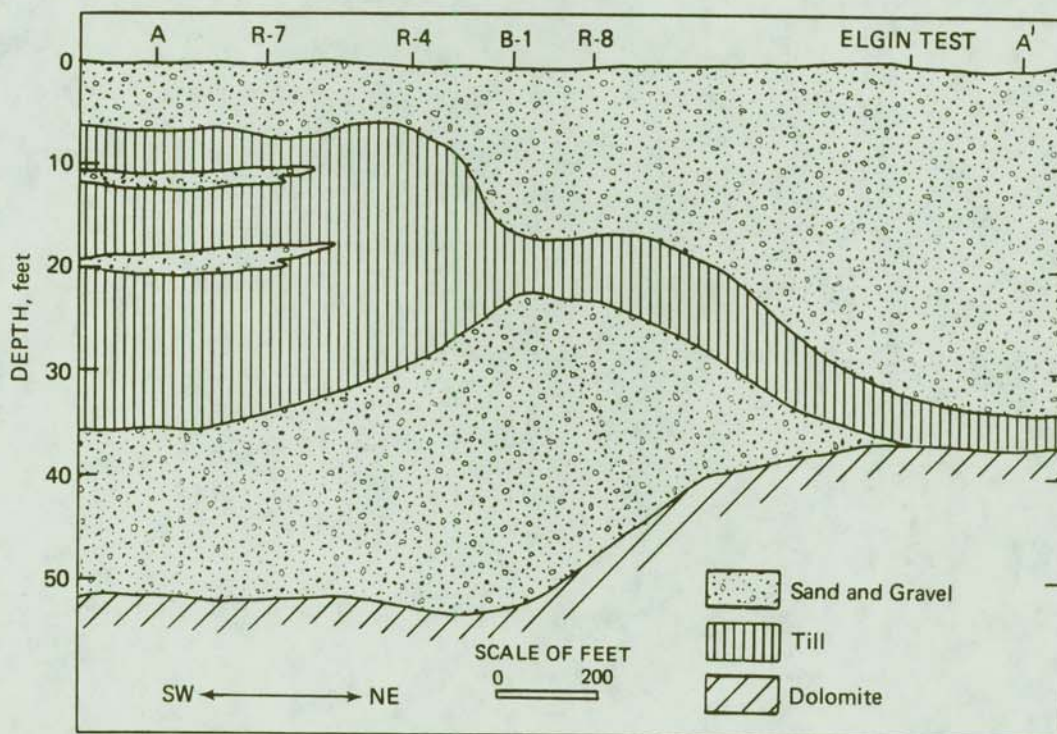


Figure 8. Generalized cross section through the Elgin recharge site.



gravel separated by a layer of till. The resistivity survey indicated that the till is probably continuous across the site as is shown in the schematic cross section of Figure 8. The presence of the till was unexpected and indicates that the Minooka Moraine is not as deeply eroded at this site as previously thought. A more detailed analysis would be necessary to determine the exact stratigraphic relationships. However, based on the preliminary investigation it was apparent that the till layer would probably diminish the overall transmissivity of the surficial materials to the point that a recharge pit would not be feasible. Consequently, the Elgin site was abandoned as a potential location for an artificial recharge pit.

## THE AURORA SITE

The first three sites investigated were selected from a list of wastewater treatment plants in the area. Since this method of site selection was not succeeding, we decided to change strategy. A large deposit of surficial sand and gravel borders the Fox River in southeastern Kane and northern Kendall Counties. Concentrating on this region, we found a suitable site south of Aurora in Kendall County. At this location reclaimed water from the Aurora Sanitary District's south plant could easily supply a recharge pit on adjacent land owned by the Caterpillar Tractor Company (Figure 9).

The roughly triangular region is well suited to artificial recharge operations. Bordered by three prominent glacial moraines, the Minooka to the east, the Marseilles to the south, and the St. Charles to the west and north, the area has been a trap for large amounts of outwash which varies in thickness between 30 and 45 feet in the region. Much of the fine-grained materials, including large portions of the Yorkville Till Member, have been removed by the Fox River and its tributaries. The Fox River has also cut a channel into the outwash exposing the bedrock in some places. The upper bedrock unit throughout much of this region is shale or shaly dolomite of the Ordovician-age Maquoketa Group which is capped by Silurian-age dolomite in the eastern portions.

The Caterpillar Tractor site is located on the edge of the upland overlooking the wastewater treatment plant in the valley below. Site investigations were undertaken to determine the nature of the local materials. Following a study of regional well data and foundation boring



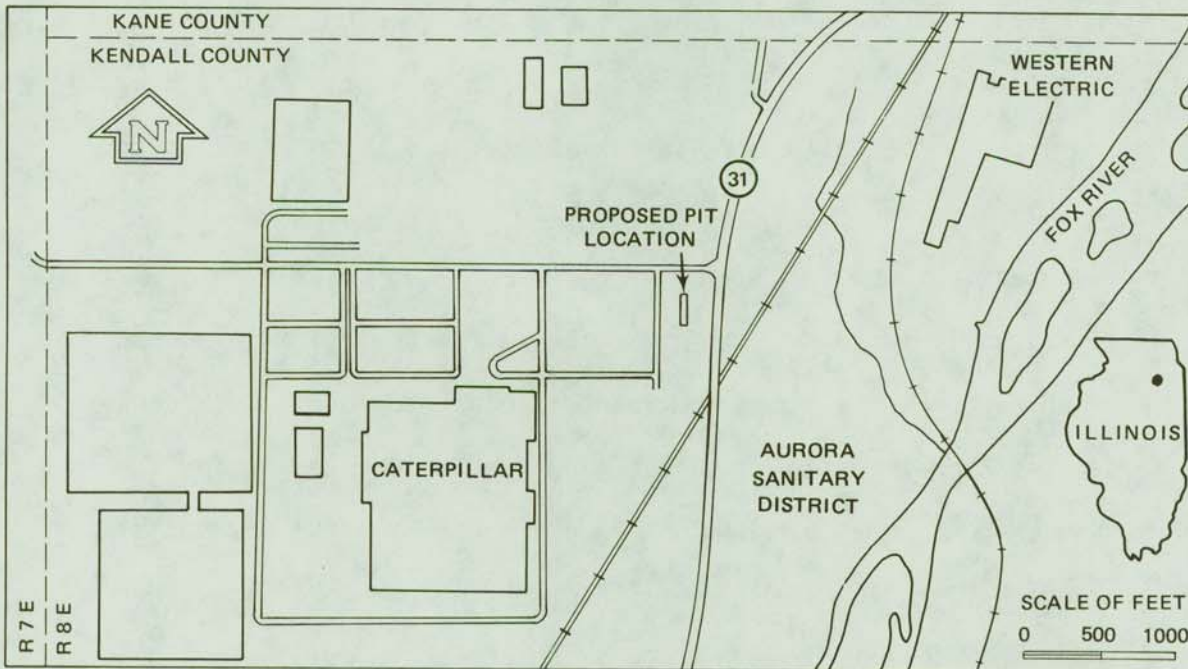


Figure 9. Location of the proposed recharge pit

records from the Caterpillar plant, an electrical earth resistivity survey was conducted on the site (Figure 10).

### Resistivity Survey

Ten resistivity stations were occupied using the Schlumberger electrode configuration. The resulting geoelectric sections, shown as Figures 11 and 12, represent the electrical properties of the earth materials. Five separate units can be distinguished in these sections and are listed below with an interpretation.

<u>Electrical unit</u>	<u>Range of resistivities</u>	<u>Average thickness</u>	<u>Interpretation</u>
1	79 - 888	1 m	variable surface materials
2	564 - 1485	4 m	coarse sand and gravel
3	244 - 778	4.6 m	coarse sand and gravel
4	2 - 136	6 m	till or shale
5	273 - 930	?	limestone or dolomite

Unit 1 may include discontinuous till and sand lenses as well as soil. Units 2 and 3 may be the same materials with unit 3 being completely saturated and unit 2 unsaturated. In this case, the interface between these two units represents the water table. Regardless, the resistivity values obtained for both units indicate very coarse-grained materials. The low resistivity values associated with unit 4 indicate the presence of a fine-grained material at depth. This may be either a till or silt layer or a thin shale above the dolomite. Unit 5 was not detected at every station, although it is probably continuous throughout the site.

The resistivity study indicated the presence of a thick, coarse-grained deposit of sand and gravel below this site. This coarse-grained deposit is separated from underlying dolomite by a layer of fine-grained shale or till. Two stratigraphic test holes were drilled to confirm these



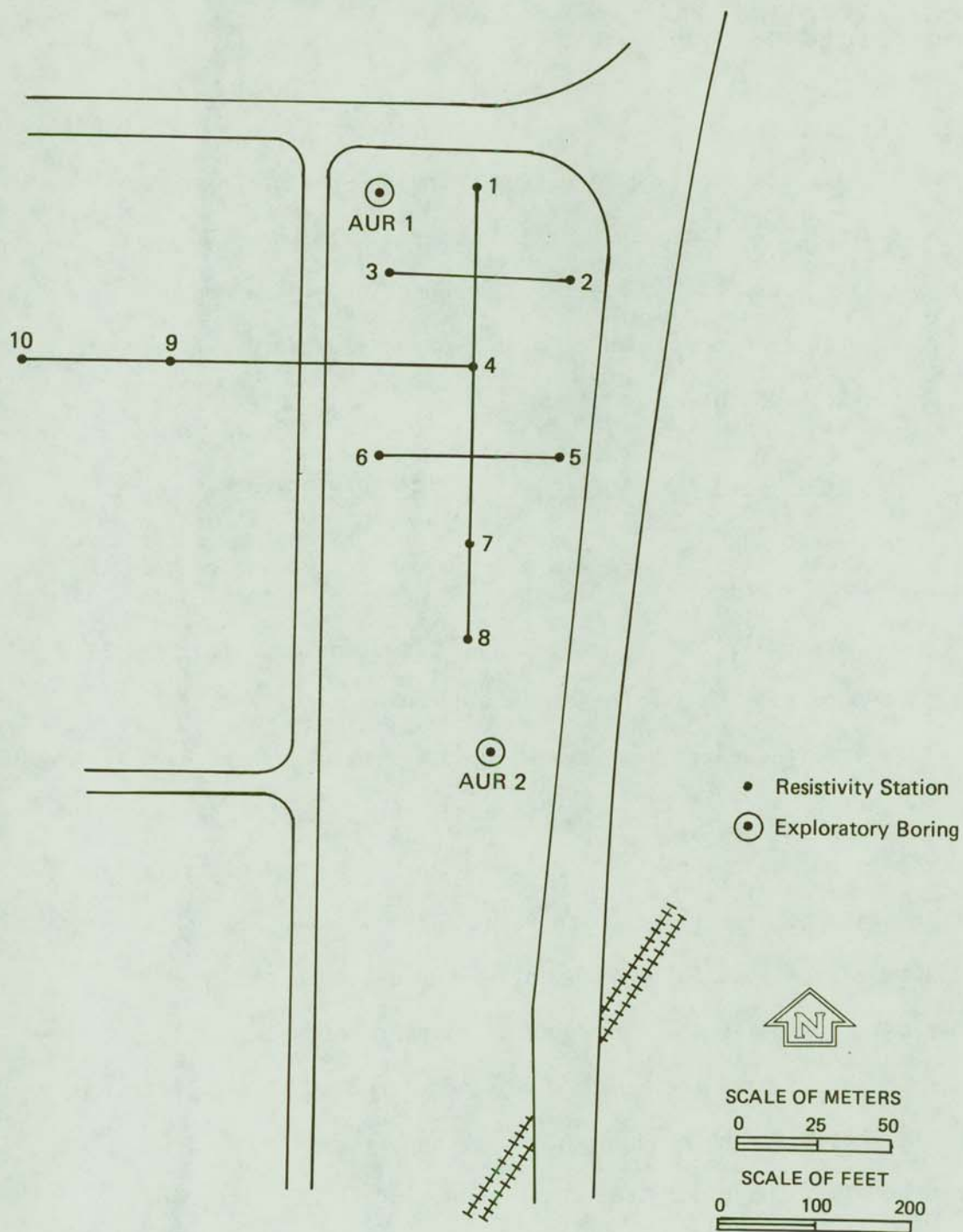


Figure 10. Locations of electrical earth resistivity stations and stratigraphic test borings in the area of the proposed pit.

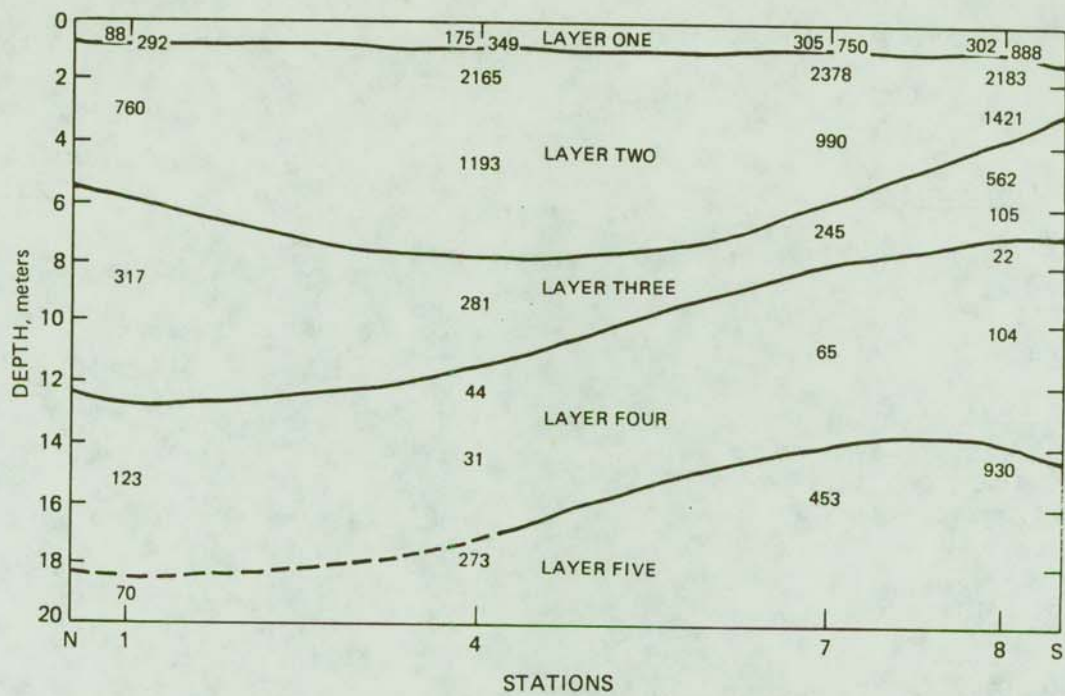


Figure 11. North-south profile of resistivity values in ohm-meters.

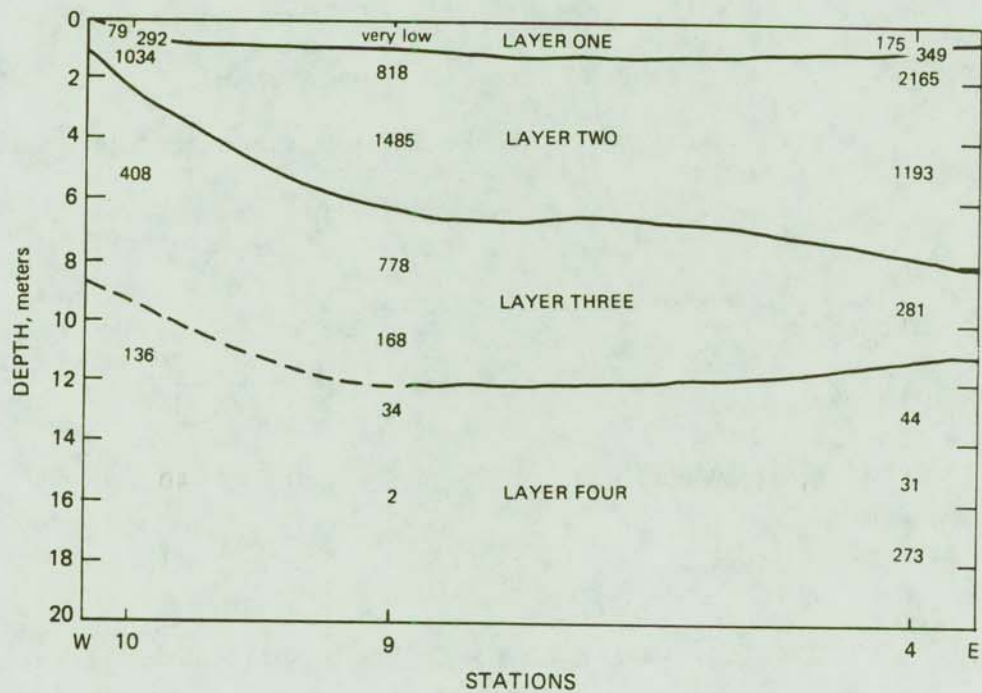


Figure 12. East-west profile of resistivity values in ohm-meters.



findings and to determine the nature of the fine-grained material beneath the sand and gravel.

### Exploratory Borings

The log of the first test hole, AUR-1, is summarized as follows:

<u>Strata</u>	<u>Thickness</u>		<u>Bottom</u>	
	<u>ft.</u>	<u>m</u>	<u>ft.</u>	<u>m</u>
Fill and soil; silty, gravelly sand	10.5	3.2	10.5	3.2
Silty, gravelly sand	8.5	2.5	19	5.7
Gravelly loam till	2	0.6	21	6.3
Silty sandy gravel	5	1.5	33	9.9
Sand	8	2.4	41	12.3
Loam till	1	0.3	42	12.6
Sand and gravel	11	3.3	53	15.9
Maquoketa Group				
Dolomite, fractured, argillaceous	3	0.9	56	16.8
Dolomite, argillaceous	11	3.3	67	20.1 T.D.

A gamma-ray log was run in hole AUR-1 before it was cased as an observation well. The well is cased from 2 feet (0.6 m) above ground surface to a depth of 67 feet (20.4 m) with 2-inch diameter PVC pipe and is slotted at one foot intervals between 53 and 67 feet (16.2 and 20.4 m).

The log of the second test hole, AUR-2, is summarized as follows:

<u>Strata</u>	<u>Thickness</u>		<u>Bottom</u>	
	<u>ft.</u>	<u>m</u>	<u>ft.</u>	<u>m</u>
Fill and soil; sand and gravel	5.5	1.7	5.5	1.7
Sand, med/coarse	8.5	2.6	14	4.2
Till	2	0.6	16	4.8
Sand, medium	17.5	5.3	33.5	10.1
Alexandrian Series				
Dolomite, cherty, fractured	6.5	2.0	40	12.1
Maquoketa Group				
Dolomite, fractured	3	0.9	43	12.9
Dolomite	10	3.0	53	15.9

Gamma-ray and electrical resistivity logs were run in hole AUR-2 before it was finished as an observation well. The well was plugged back to 33 feet

(10.1 m) and the 2-inch diameter PVC casing was slotted at one foot intervals between 13 and 33 feet (4.0 and 10.1 m) below ground surface.

West-east and north-south profiles were derived from these two logs, regional data, and the resistivity survey. They illustrate the probable relationship of the earth materials (Figures 13 and 14). The unconsolidated material consists of 3 units of sand and gravel outwash separated by two thin, discontinuous layers of till. Laboratory analyses determined that the tills are remnants of the Malden Member of the Wedron Formation; all traces of the younger Yorkville Till have been eroded at this site. The bedrock consists of silty or shaley dolomite of the Maquoketa Group with a cap of Silurian dolomite in the south. There is sharp relief on the bedrock surface with the Silurian cap forming a small knob.

The thickest sand unit lies between the two thin till layers and ranges in thickness from between 17.5 feet (5.3 m) in the south to 20 feet (6.0 m) in the north. In the south where this sand occurs at a slightly higher elevation, it consists of a very well sorted fine sand, but in the north, where it is lower in elevation, a high energy environment resulted in the deposition of sand, gravelly sand, and gravel.

The two till layers are very thin and, from all available data, appear to be local in distribution. There is, therefore, reason to believe that the three sand layers are at least partially connected. However, resistivity data suggest that the lower till unit extends southward where it abuts the bedrock knob, in which case the lower sand unit does not have southern connection to the middle sand unit.

The relief on the bedrock surface is probably a result of pre-glacial erosion. The weathered zone at the surface of the dolomite is much thicker (10 ft (3.0 m)) on the bedrock knob than in the adjacent valley (3 ft



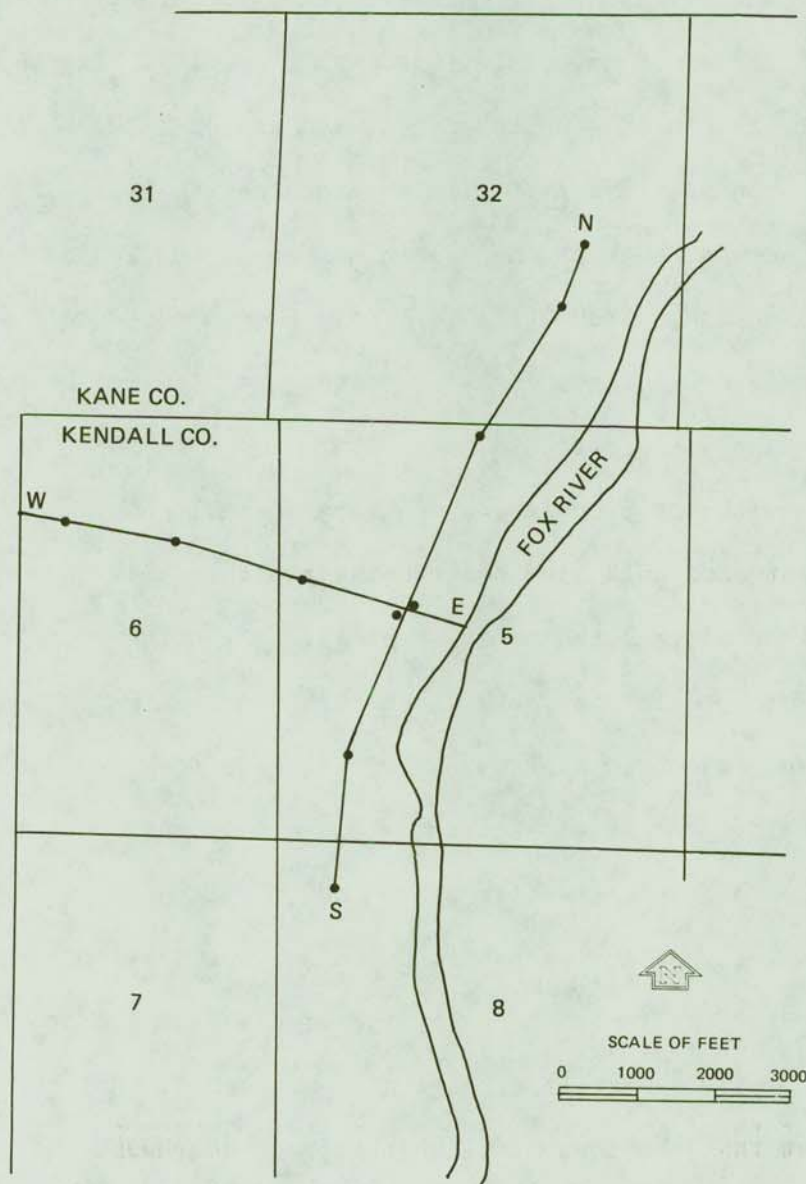


Figure 13. Locations of west-east and north-south profiles.

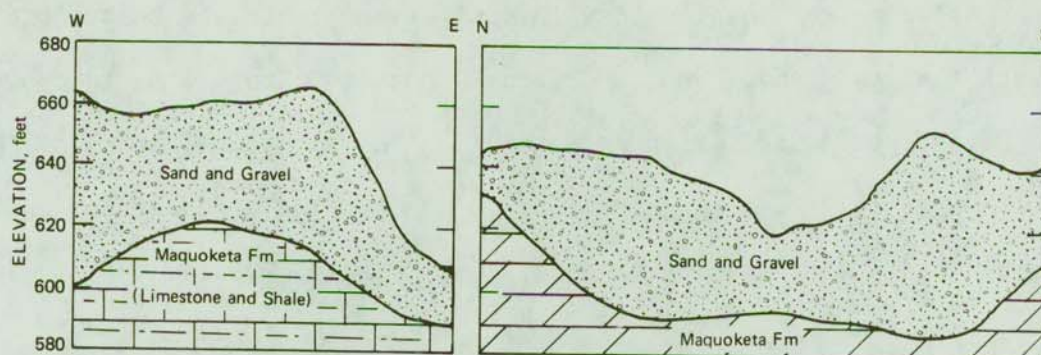


Figure 14. West-east and north-south profiles.

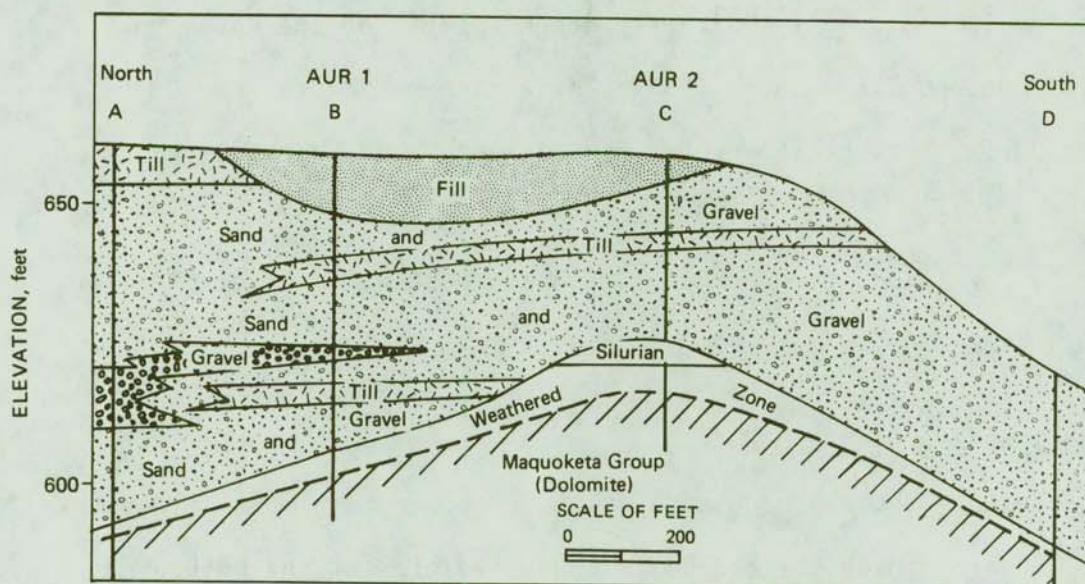


Figure 15. Cross section through the Aurora Caterpillar Tractor Co. site.



(0.9 m)). This weathered zone consists of highly fractured dolomite with clay and silt (possibly till) filling many of the fractures.

In conclusion, the exploratory investigations indicated that a clean, continuous sand and gravel aquifer 15 to 20 feet (4.6 to 6.0 m) thick is present beneath this site (Figure 15) and can be reached at depths of 15 to 21 feet (4.6 to 6.3 m). The probability of developing a successful artificial recharge pit at this site is good, justifying more extensive studies.

#### Water Table Trends

The depth to the water table is important when considering artificial recharge because of flooding at the land surface, causing seeps or springs to appear and compromising the integrity of subsurface structures and foundations. The water table level was monitored continuously at the site between May 1982 and July 1983. The deepest level of the water table, 24.66 ft, occurred in January 1983. The shallowest depth, 21.40 ft, occurred during spring recharge in April, 1983. The seasonal variation in water table level that can be expected at the site is therefore on the order of 3 ft. Short term recharge events caused water level rises of about 0.5 ft.

#### Multi-well Aquifer Test

An aquifer test was conducted at the proposed pit location for the purpose of determining the hydraulic conductivities of the saturated deposits underlying the site. Five wells were installed in an east-west and north-south cross over the site (Figure 16). These wells are CAT1 through CAT5. Wells AUR1 and AUR2 are the exploratory borings. The 5 CAT wells were used in a 24-hour continuous pumping aquifer test. The completion features of the 7 wells and a log of the deposits encountered while

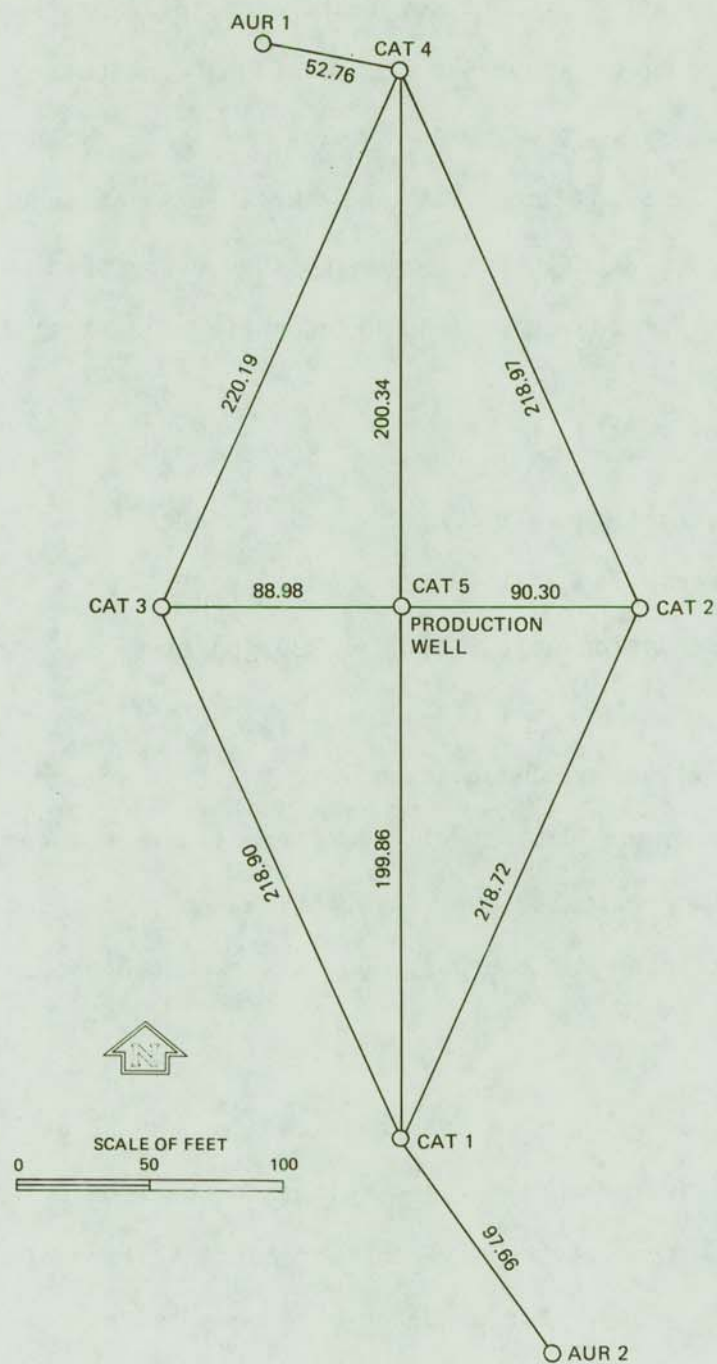


Figure 16. Existing wells at the proposed pit location.



drilling each well are presented in Figures 17 through 23. The stratigraphic logs were pulled together to construct two cross sections of the deposits (Figures 24 and 25). The key feature of the cross sections is the till layer which occurs at about 640 ft elevation. The bottom of the recharge pit should be constructed just below the till. This implies excavating through and removing the till and backfilling with sand and gravel.

The data from the aquifer test were analyzed using traditional curve matching techniques. These data yielded hydraulic conductivities as follows:

Production well (PW)	=	860 gpd/ft <sup>2</sup>
North observation well (CAT4)	=	100 gpd/ft <sup>2</sup>
East observation well (CAT2)	=	7090 gpd/ft <sup>2</sup>
South observation well (CAT1)	=	320 gpd/ft <sup>2</sup>
West observation well (CAT3)	=	690 gpd/ft <sup>2</sup>

These are the values needed to calculate the flow volume from the proposed pit to nearby production wells. A numerical model was designed to aid in the flow volume calculations. A numerical model is needed because of the complex geometries and boundary conditions of the problem.

#### The Aurora Model

A numerical groundwater model was designed for the Aurora site. The model was built for two reasons: 1) to calculate the flow of water through the system and 2) to predict the movement and concentration of dissolved constituents in the system. The computer code used is described in Prickett, Naymik, and Lonnquist (1981). The code is two-dimensional in the horizontal plane and calculates the distribution of a dissolved constituent

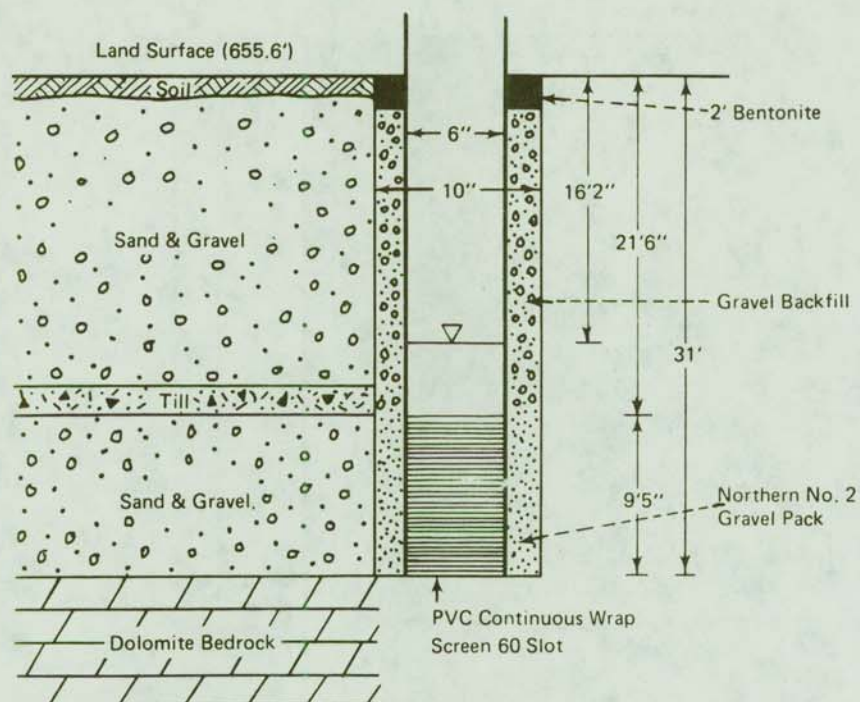


Figure 17. Completion features of the south observation well (CAT1).

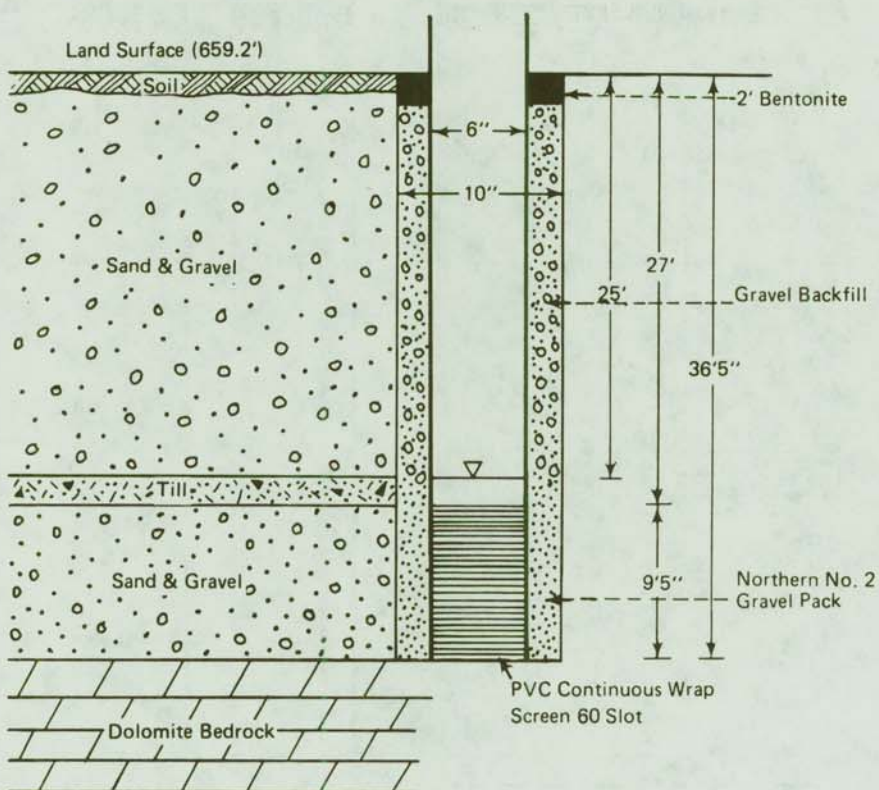
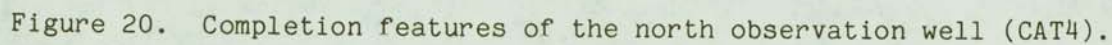
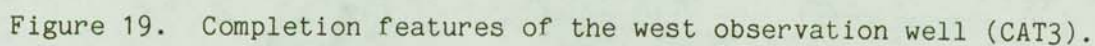


Figure 18. Completion features of the east observation well (CAT2).





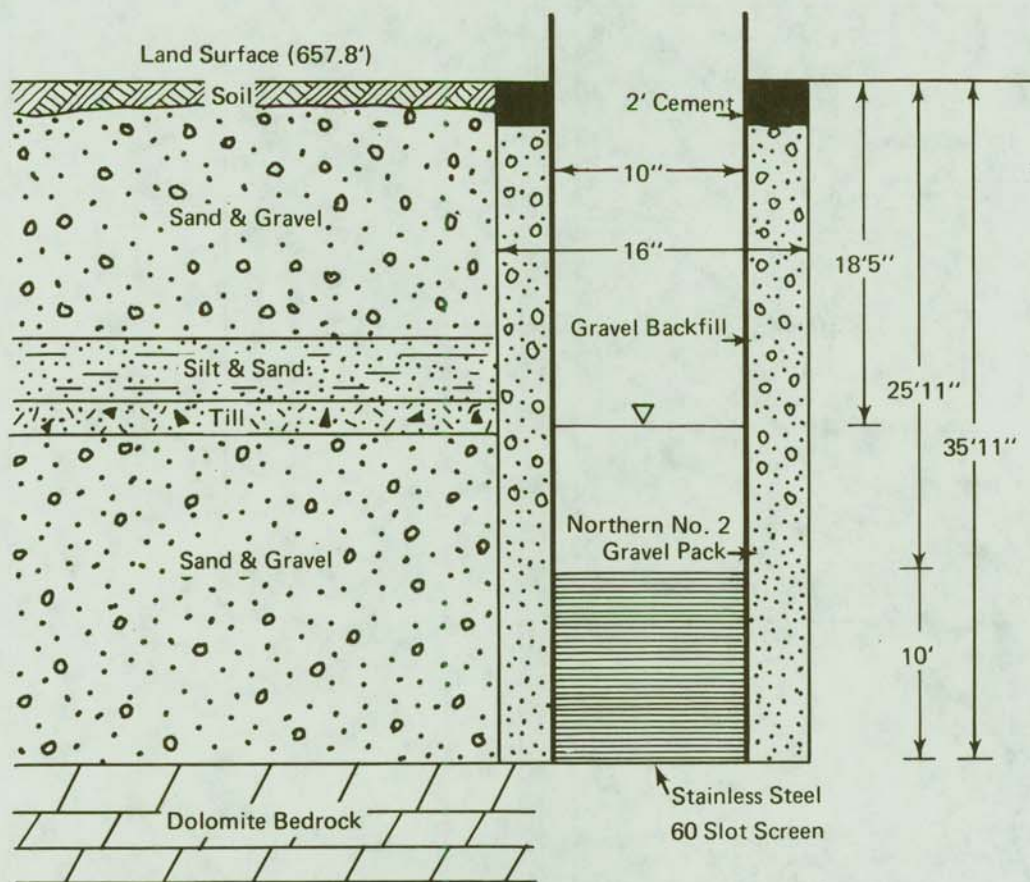


Figure 21. Completion features of the production well (CAT5).



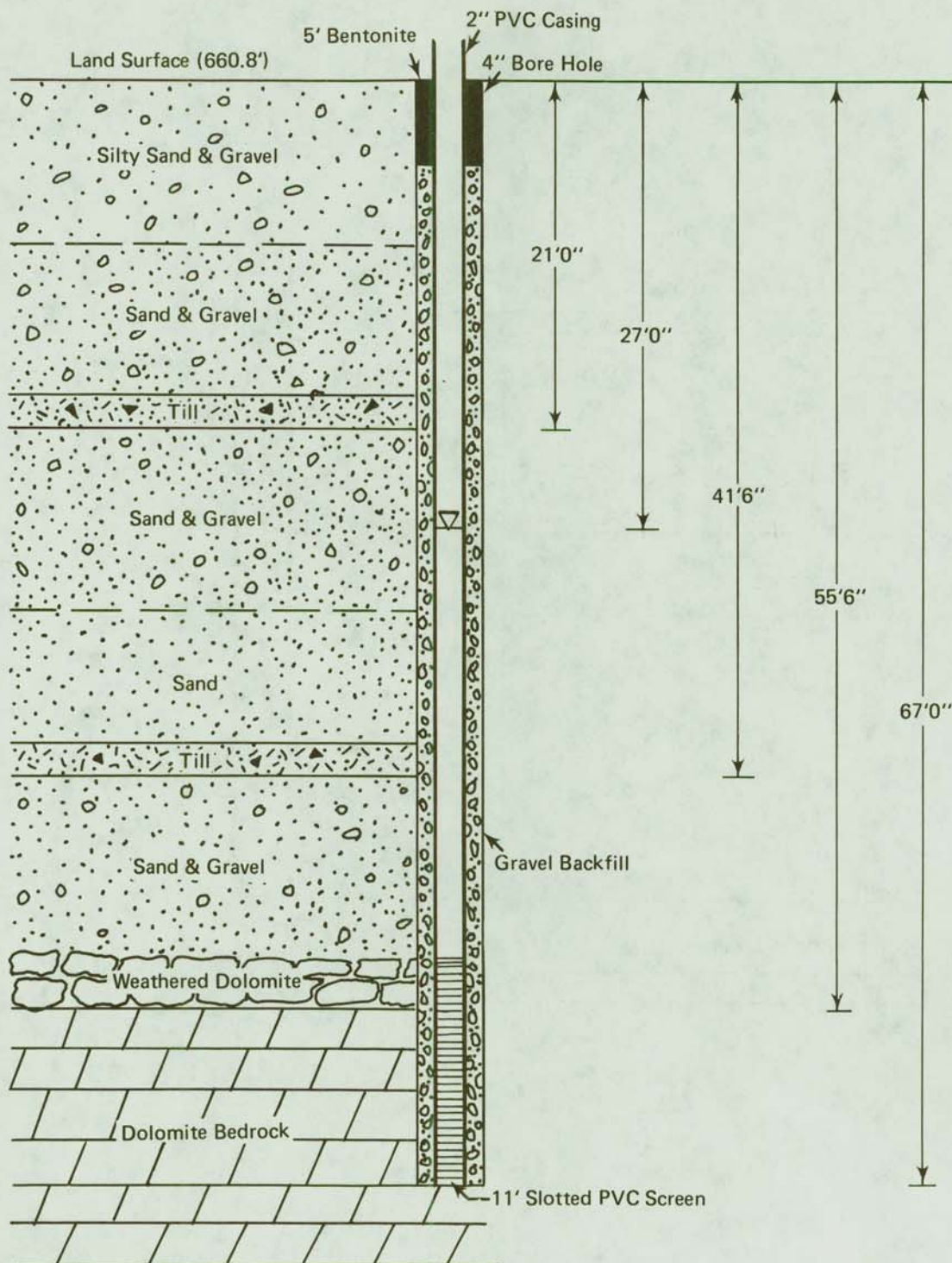


Figure 22. Completion features of the north exploratory well (AUR1).

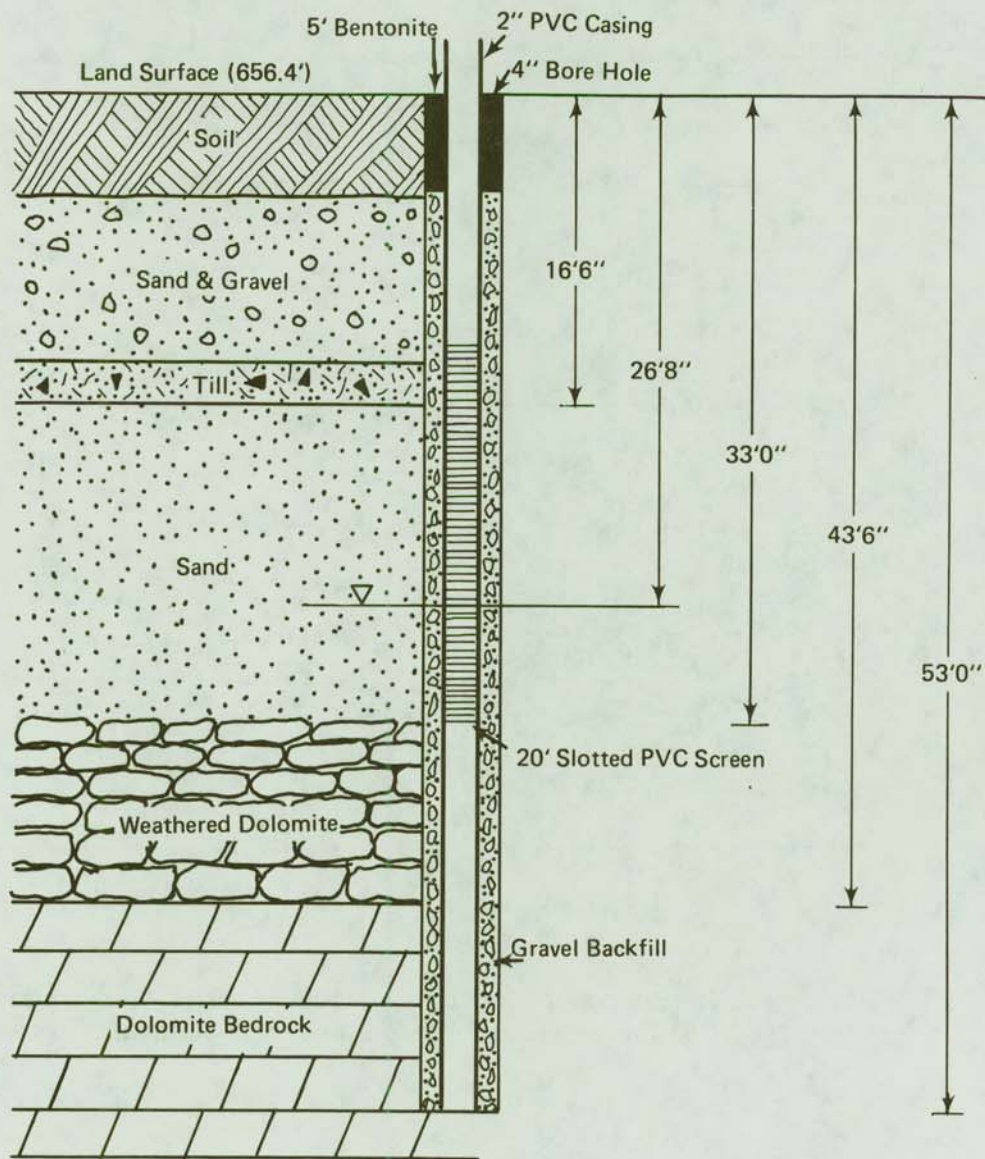


Figure 23. Completion features of the south exploratory well (AUR2).



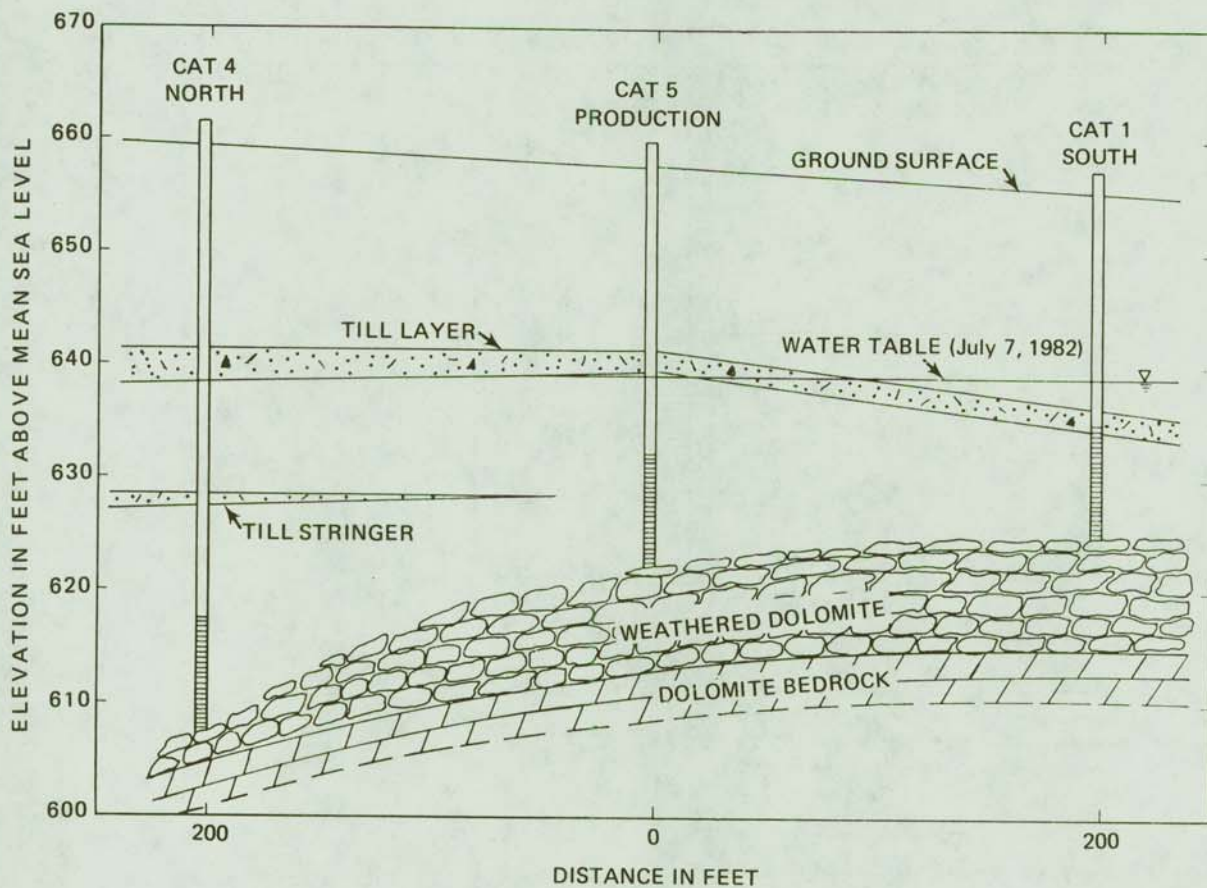


Figure 24. North-south cross section of the deposits at the proposed pit-site. Blank areas on the figure are sand and gravel.

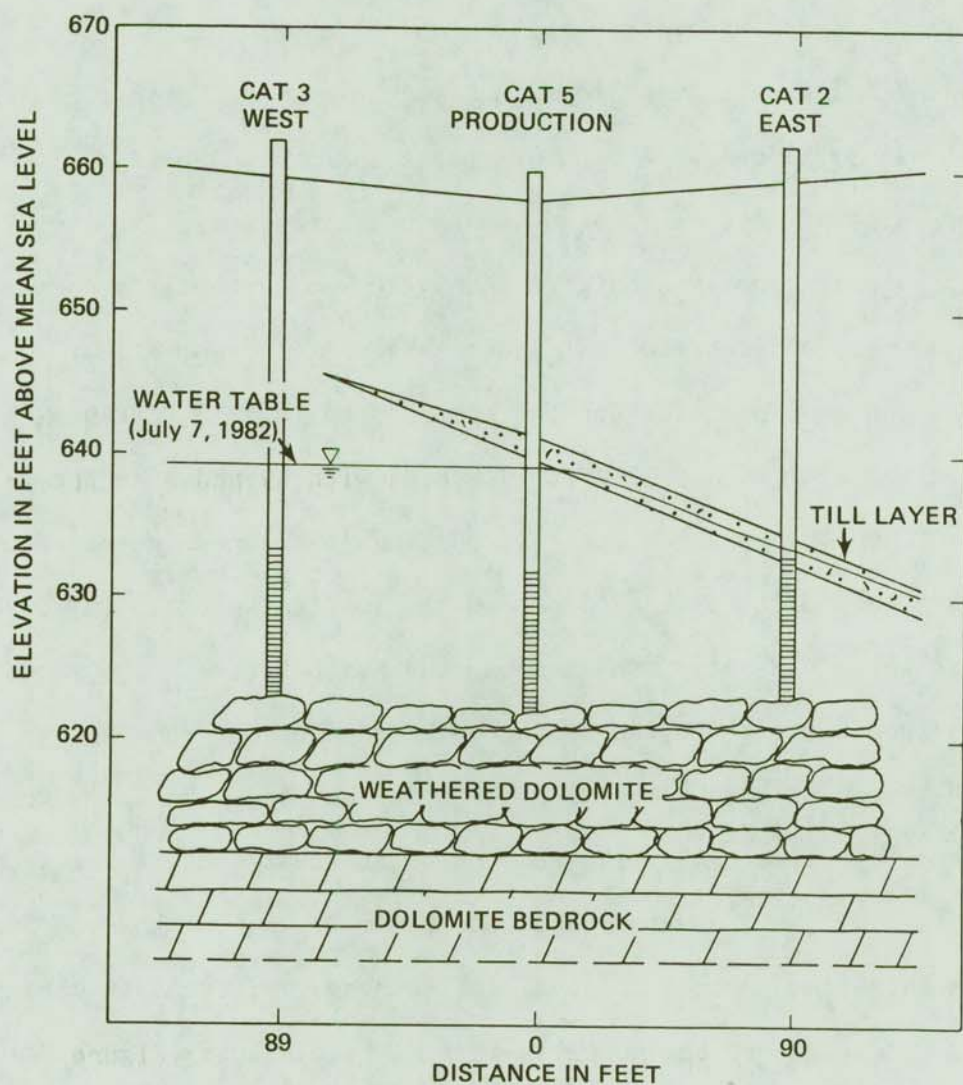


Figure 25. East-west cross section of the deposits at the proposed pit-site. Blank areas on the figure are sand and gravel.



in groundwater. In the code, the premise for dissolved constituent migration is that a solute in an aquifer can be simulated by the distribution of a finite number of discrete particles. Each particle is assigned a mass that represents a fraction of the total mass of the chemical constituent involved. As the number of particles grows extremely large and the molecular level is approached, the exact solution is obtained.

The "random walk" technique is based on dispersion in porous media being a random process. A particle moves through an aquifer with two primary types of motion: one motion in the direction of the mean flow, and the other in a random motion governed by scaled probability curves related to flow length and longitudinal and transverse dispersivities.

The model constructed for the Aurora site is 3270 ft (996.9 m) with 43 nodes on the x-axis, and 3250 ft (990.8 m) with 39 nodes on the y-axis (Figure 26). The grid has variable spacing, with the highest resolution occurring around the pit. The pit itself is treated as an influx boundary for both water and mass. The stream, the Fox River, and the production wells around the pit are the sinks for both water and mass.

The types of data needed for the model and the data entry format are described in Prickett, Naymik, and Lonquist (1981) and in Prickett and Lonquist (1971). The water table for the model was contoured from 123 measurements taken from individual soil borings. These data were zoned and entered directly into the model as initial head values (Figure 27). The completed data file contains the known hydrogeological information for the site, including top and bottom of the unconsolidated aquifer, water table, land surface, and transmissivity. The area of the aquifer used in the continuous pumping aquifer test has been zoned in the model according to

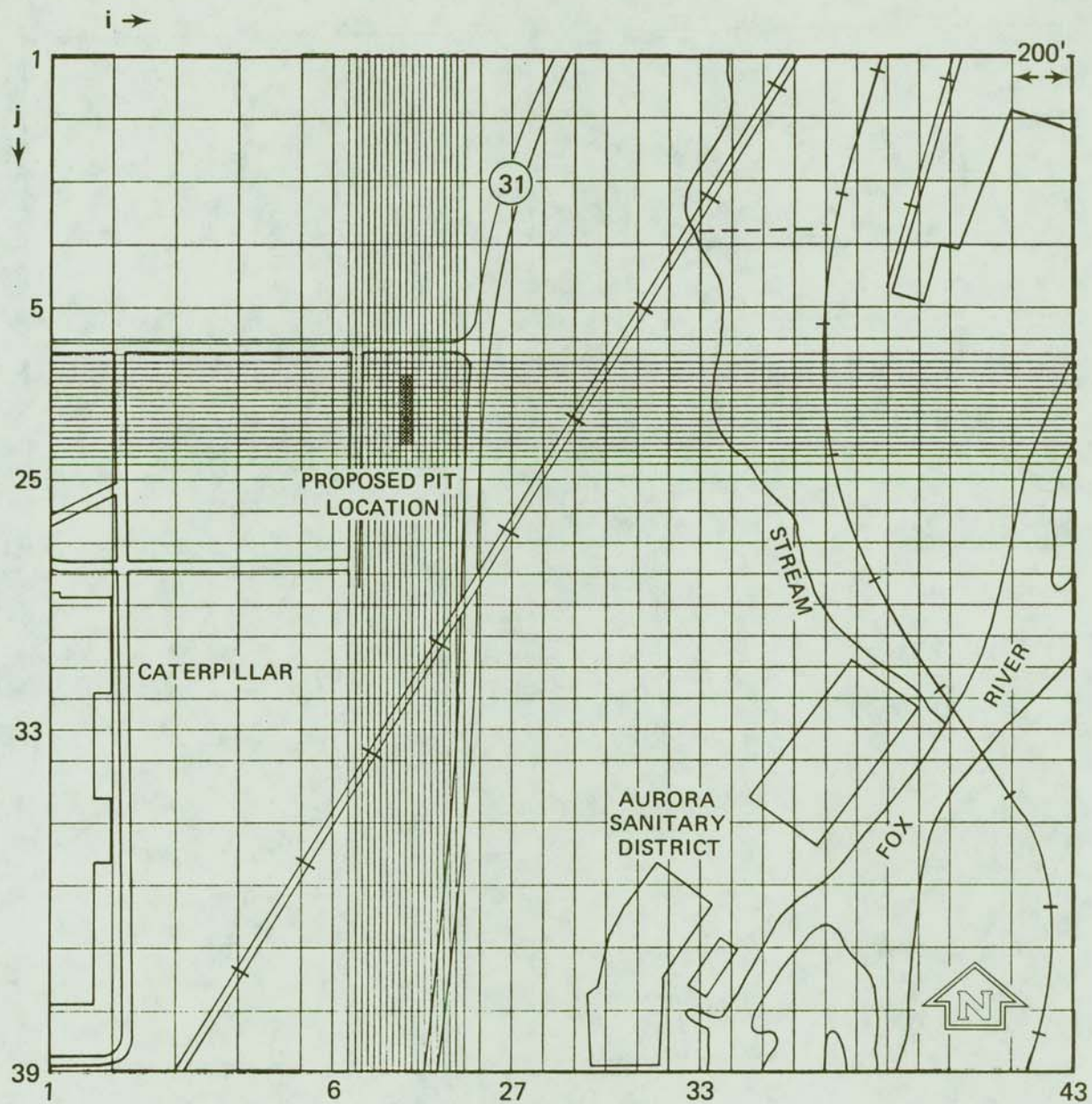


Figure 26. Finite difference grid for the Aurora model.



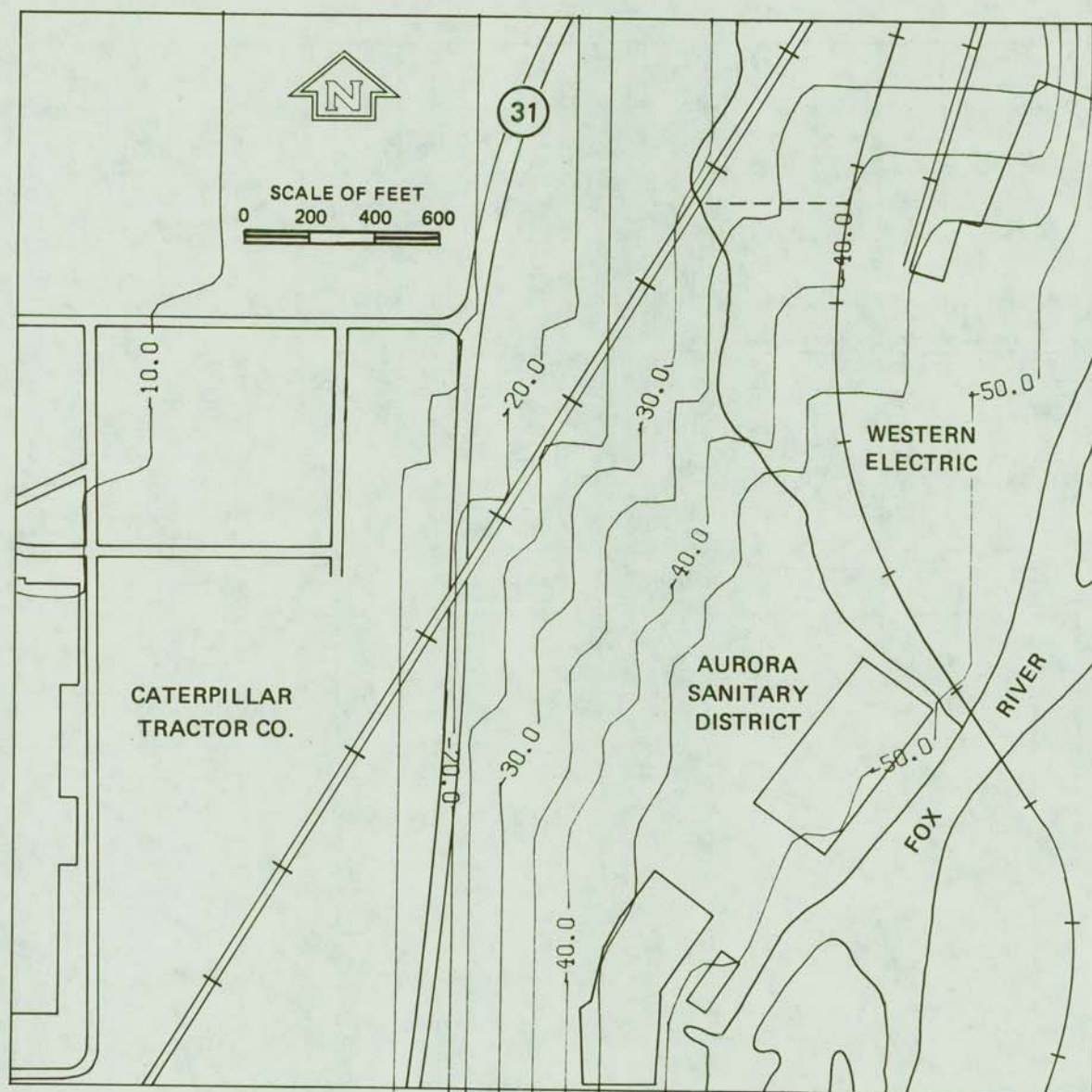


Figure 27. Computer-generated contour map of the water table at the Aurora site.

the hydraulic conductivity values (Figure 28). This is a common modeling technique used to increase the validity of the model.

The model was calibrated to the known water table configuration by varying the natural recharge rate over the area. A recharge value of 50,000 gpd/mi<sup>2</sup> yielded a model response which was reasonable when compared to known conditions. This value is low when compared to Walton (1965) and Prickett et al. (1964) where natural recharge values are reported for areas near to Aurora. Nevertheless, 50,000 gpd/mi<sup>2</sup> was used in the model. If this value is truly on the low side, it will only serve to drive the system toward dependence on artificial recharge for flow through the aquifer thereby yielding conservative answers.

The calibrated model was then validated by simulating the multi-well aquifer test conducted at the proposed pit location. The total water level deviation was only 6 percent between simulated and actual values.

#### **Proposed pit recharge calculations**

A conceptual plan of the proposed pit is presented in Figure 29. The pit dimensions which will be used in the model are 200 ft by 60 ft (61.0 m by 18.3 m) (Figure 29a). Figure 29b is the present north-south cross section and Figure 29c is the cross section modified by the pit. In the model, the pit will be rated by an induced-infiltration function (Figure 30). This function is dependent mainly on the water level in the pit, the potentiometric head in the aquifer, and the pit bed properties.

To date, this model has been calibrated to all known geohydrological conditions at the site. At present, the model is being used to calculate the flux through the system.



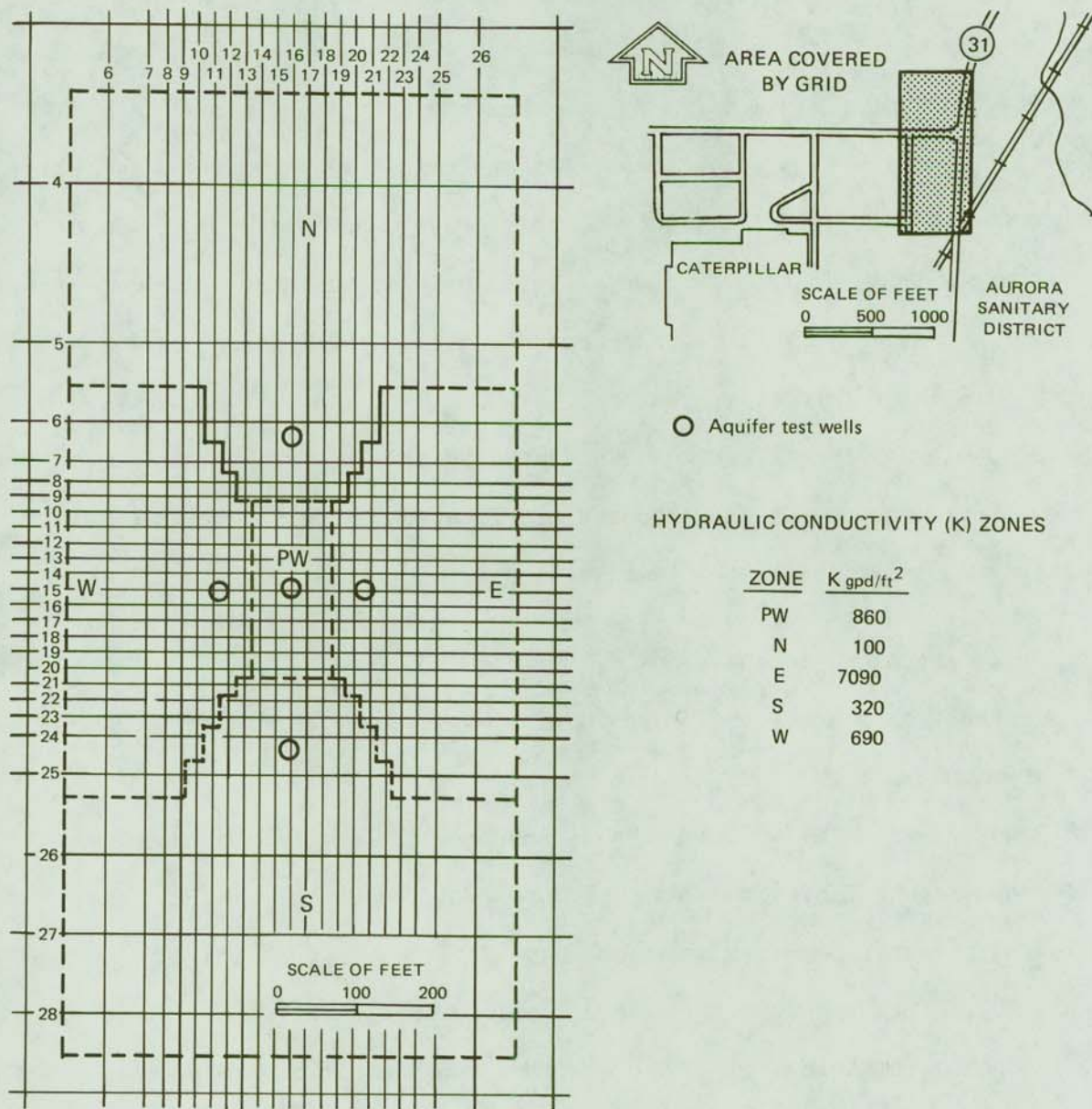


Figure 28. Zoned hydraulic conductivity values in the area of the proposed pit.

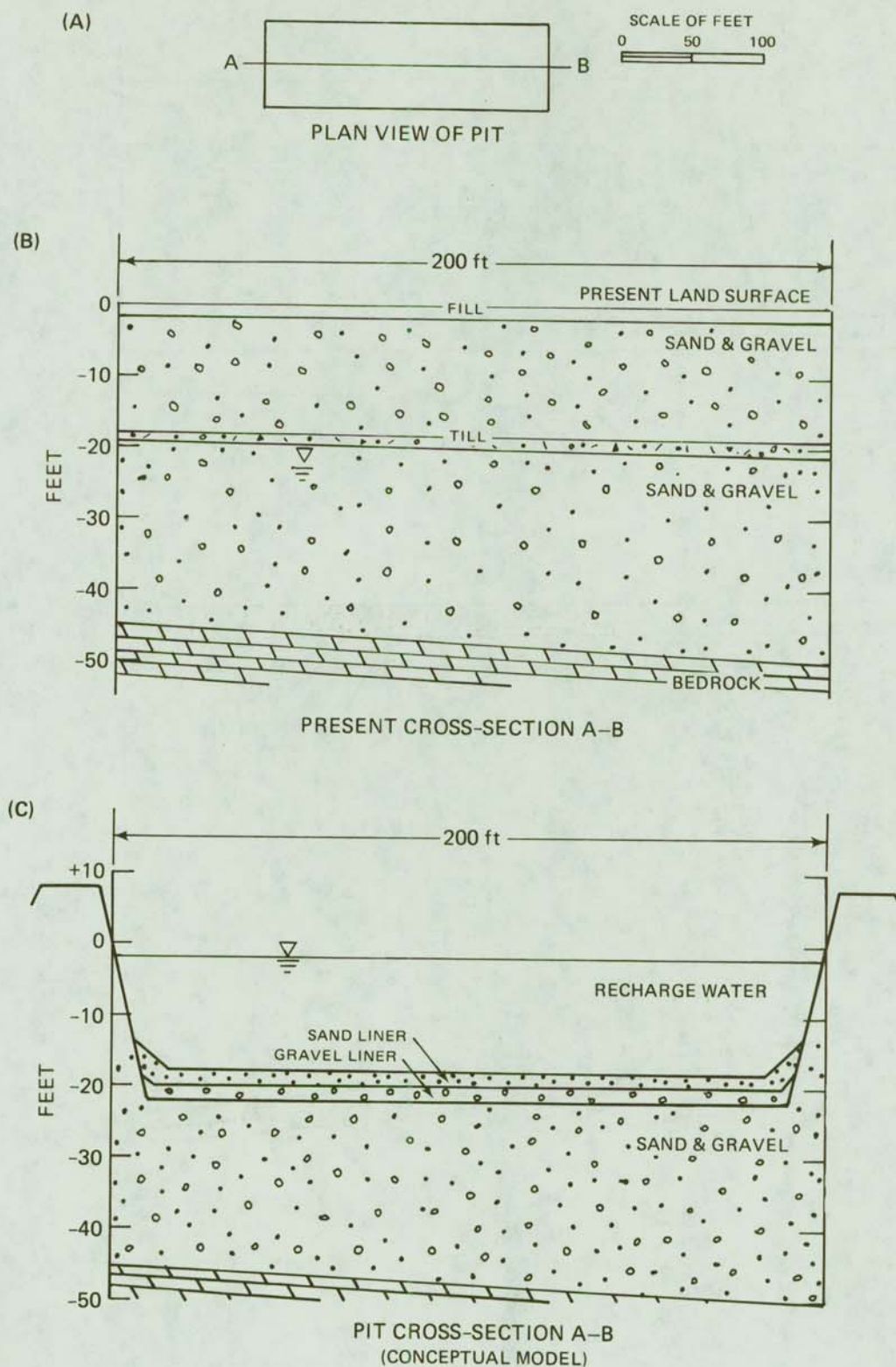


Figure 29. Conceptual plan for recharge pit: A. plan view; B. present north-south cross section; and C. cross section modified by pit.



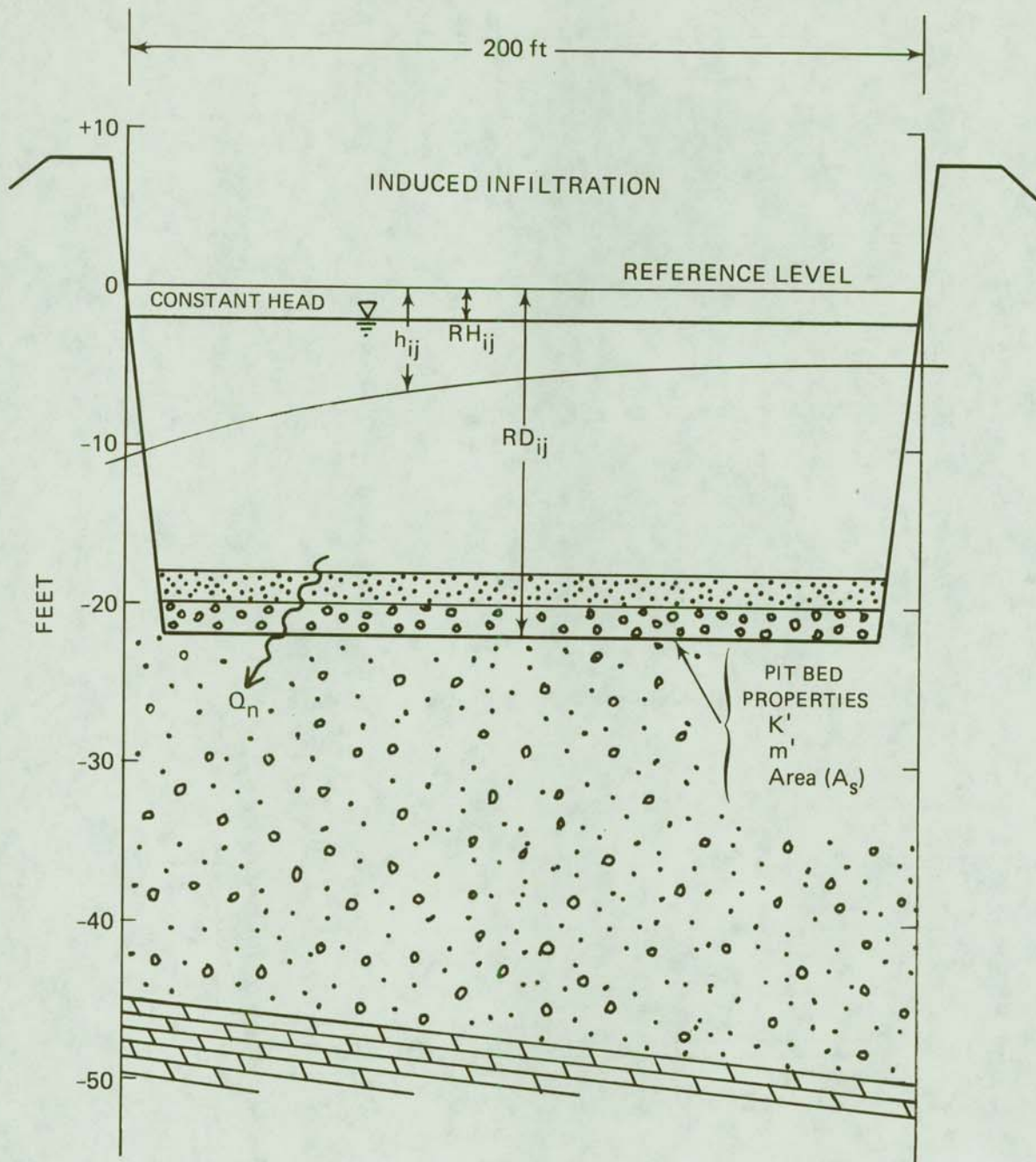


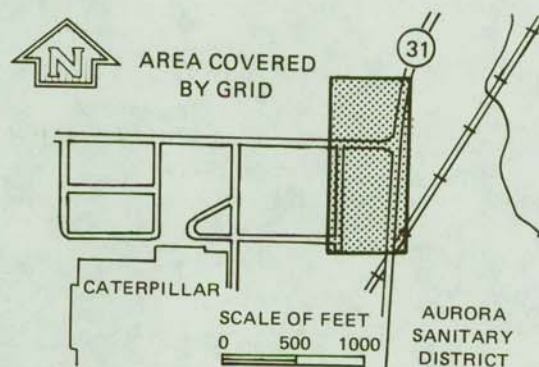
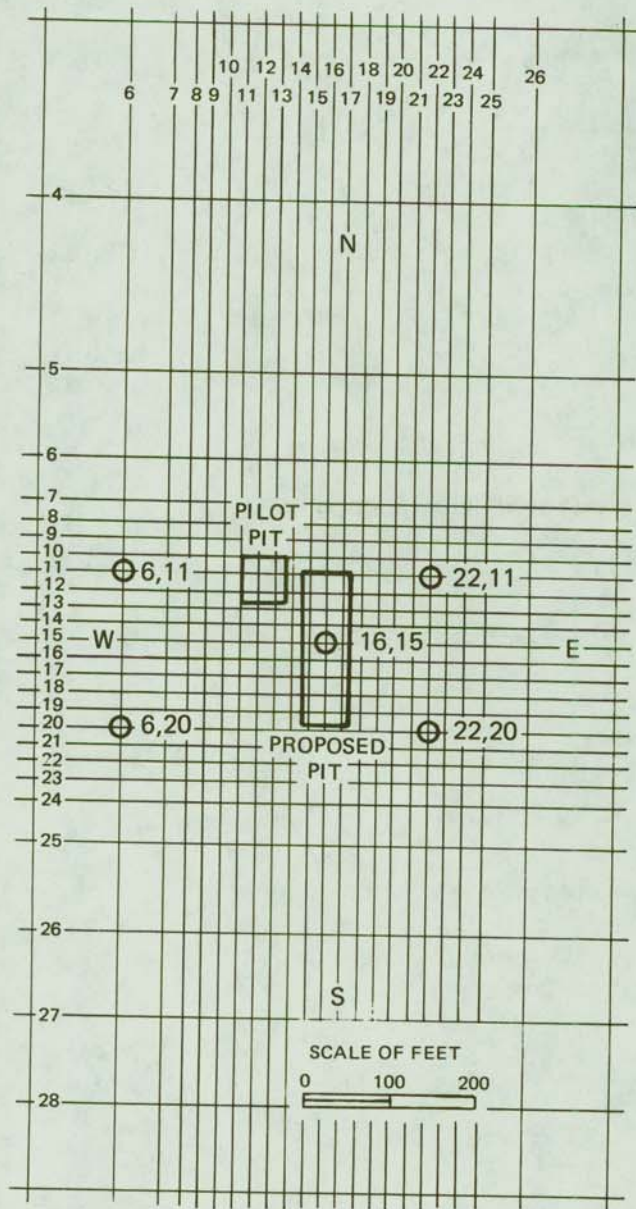
Figure 30. Induced infiltration method for calculating flow from the pit into the aquifer.

Model simulations were conducted to calculate the flow capacity of the system under different scenarios. The objectives were to check the sensitivity of the system to hydraulic conductivity, determine an upper limit on the capacity for artificial recharge, and predict water levels in the production wells.

Figure 31 shows the locations of both the proposed pit and the pilot pit with their associated production wells. In the scenario for the proposed pit, the wells are located at (6,11), (6,20), (22,11), and (22,20) on the finite difference grid and for the pilot pit at (6,11), (16,15), and (22,11). These are two separate scenarios which are never simulated simultaneously even though they are presented on the same figure. In this section only the proposed pit scenario will be discussed.

The potential artificial recharge rate of the proposed pit is great. Figure 32 shows that the recharge rate is not exceeded by the total well production rate at system flow rates of 1 million gallons per day and greater. For this calculation, 860 gpd/ft<sup>2</sup> was used as an aquifer hydraulic conductivity (K). This K value was determined from the multi-well aquifer test. By holding the total well production rate at 633,600 gpd and varying the hydraulic conductivity, the artificial recharge rate was plotted against K (Figure 33). Figures 34 through 37 show water levels in the four wells as a function of individual well production rate with the proposed pit operational. For comparison, Figures 38 through 41 show water levels in the four wells without an operating pit. The bottom of the sand and gravel aquifer is at 45 ft below land surface.





○ Production wells

Pilot pit wells (6,11), (16,15), (22,11)

Proposed pit wells (6,11), (6,20), (22,11), (22,20)

Figure 31. Location of both pits and corresponding production wells.

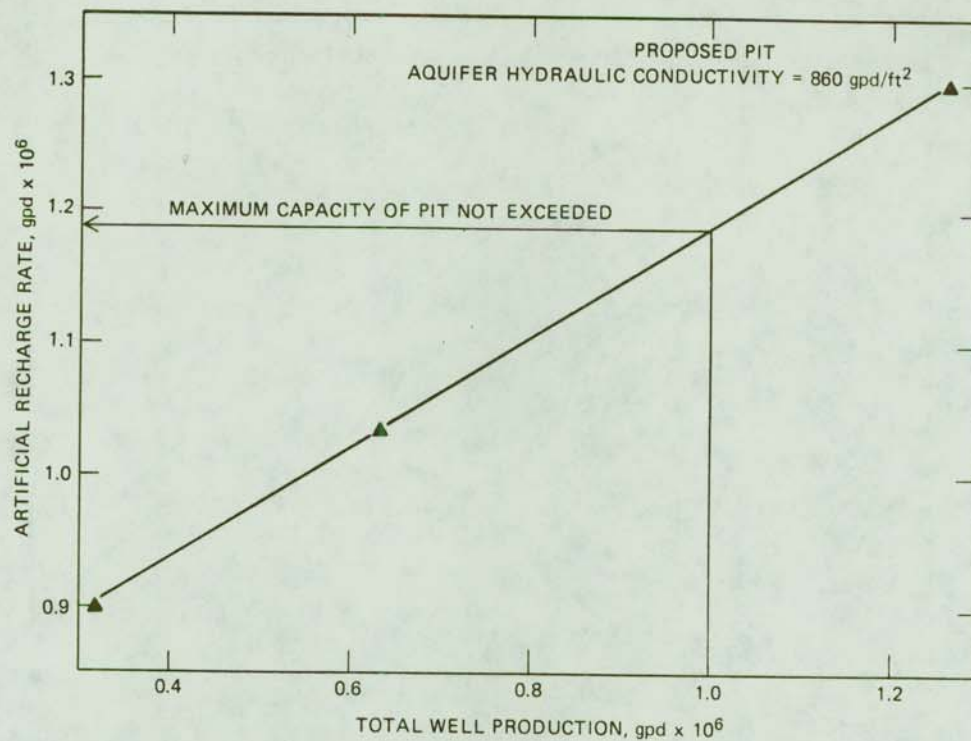


Figure 32. Artificial recharge rate of the proposed pit as a function of the summed withdrawal of the four production wells.

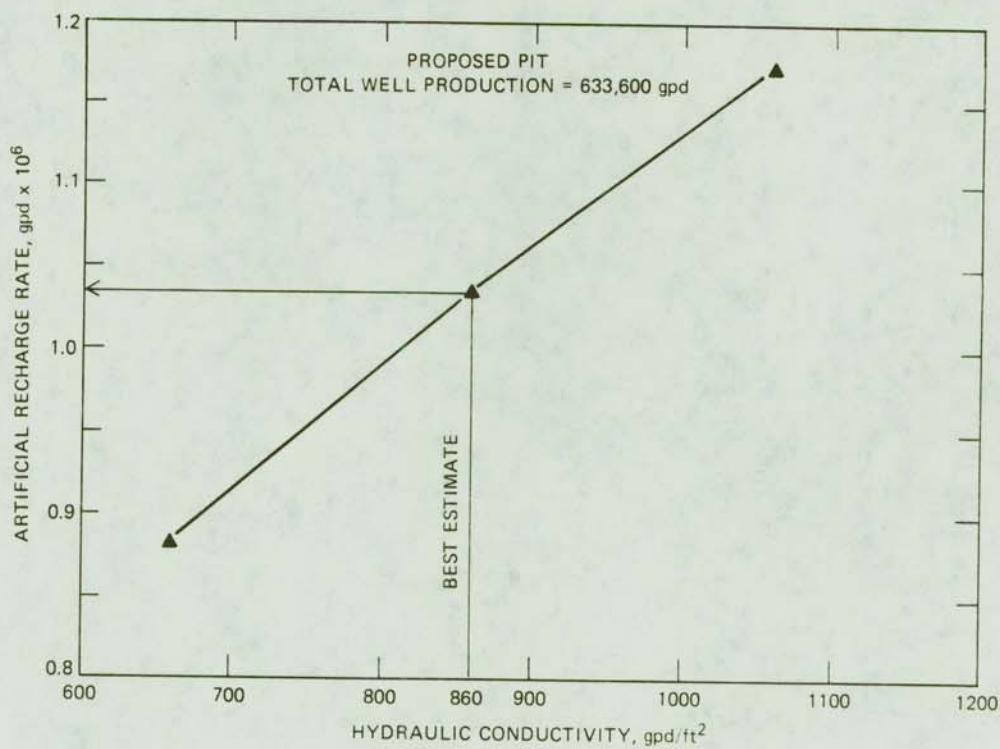


Figure 33. Artificial recharge rate of the proposed pit as a function of aquifer hydraulic conductivity around the proposed pit.



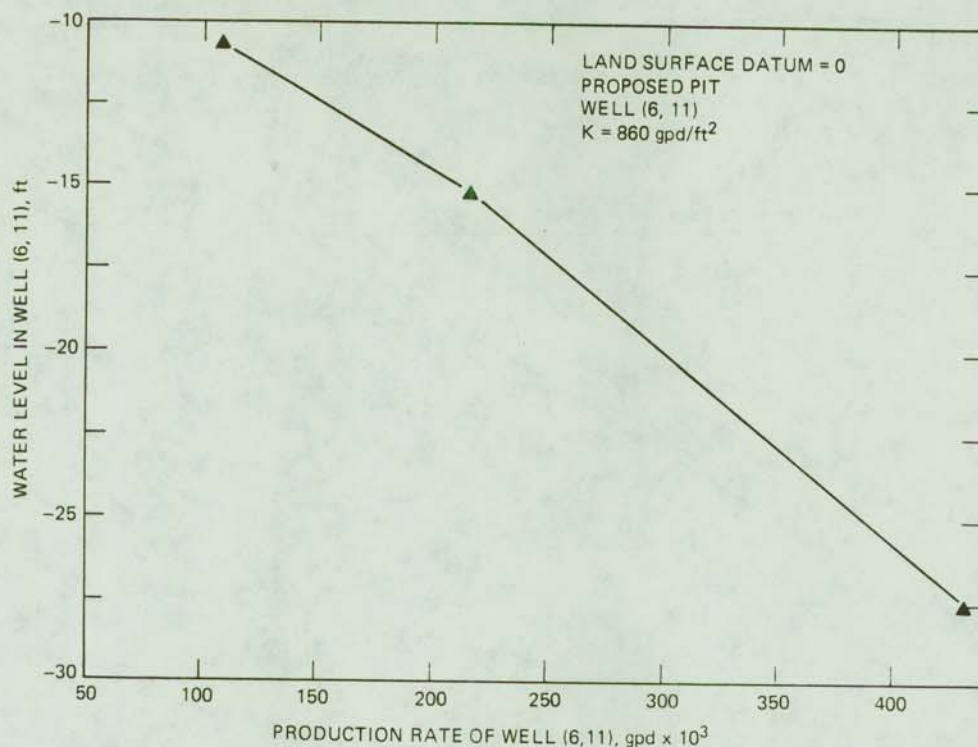


Figure 34. Water level in well (6,11) as a function of well production rate (proposed pit).

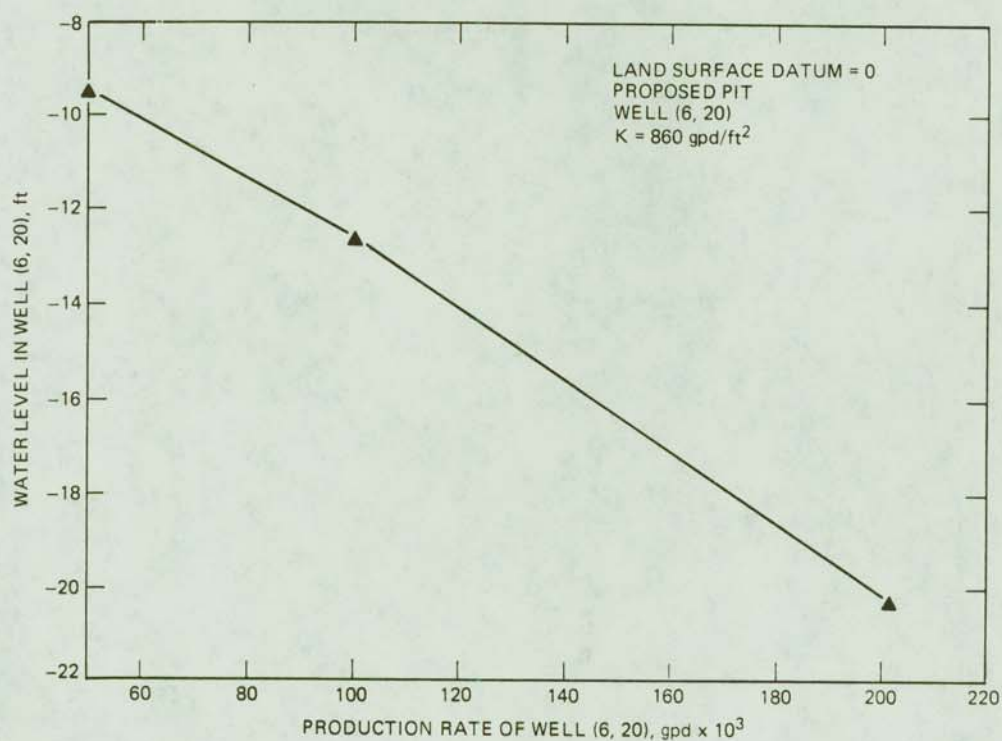


Figure 35. Water level in well (6,20) as a function of well production rate (proposed pit).

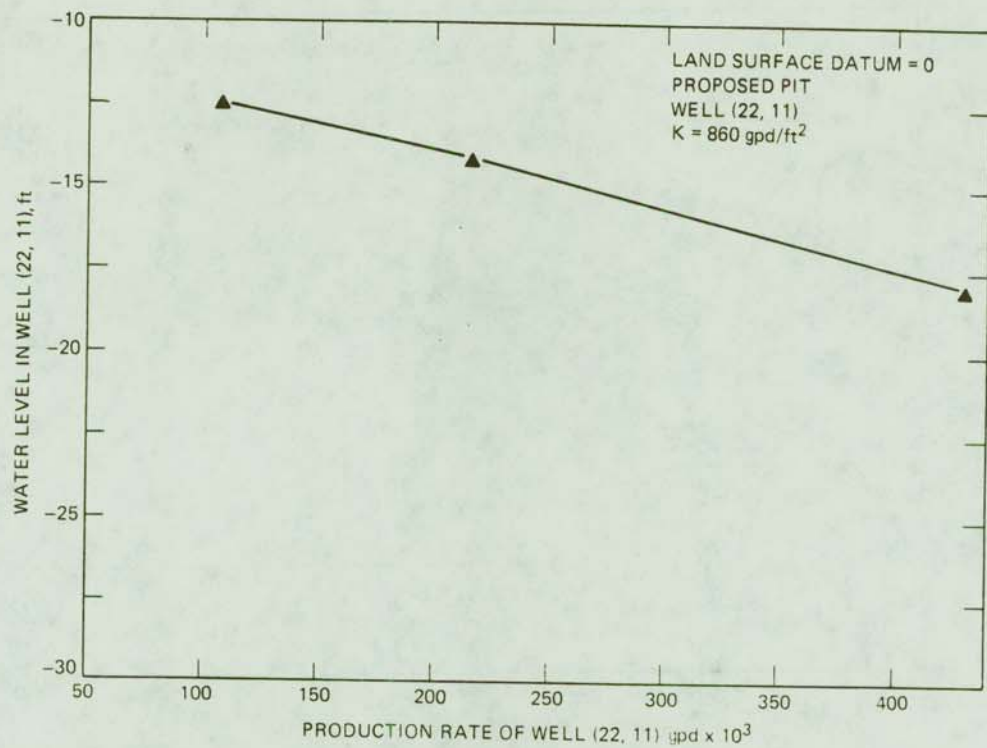


Figure 36. Water level in well (22,11) as a function of well production rate (proposed pit).

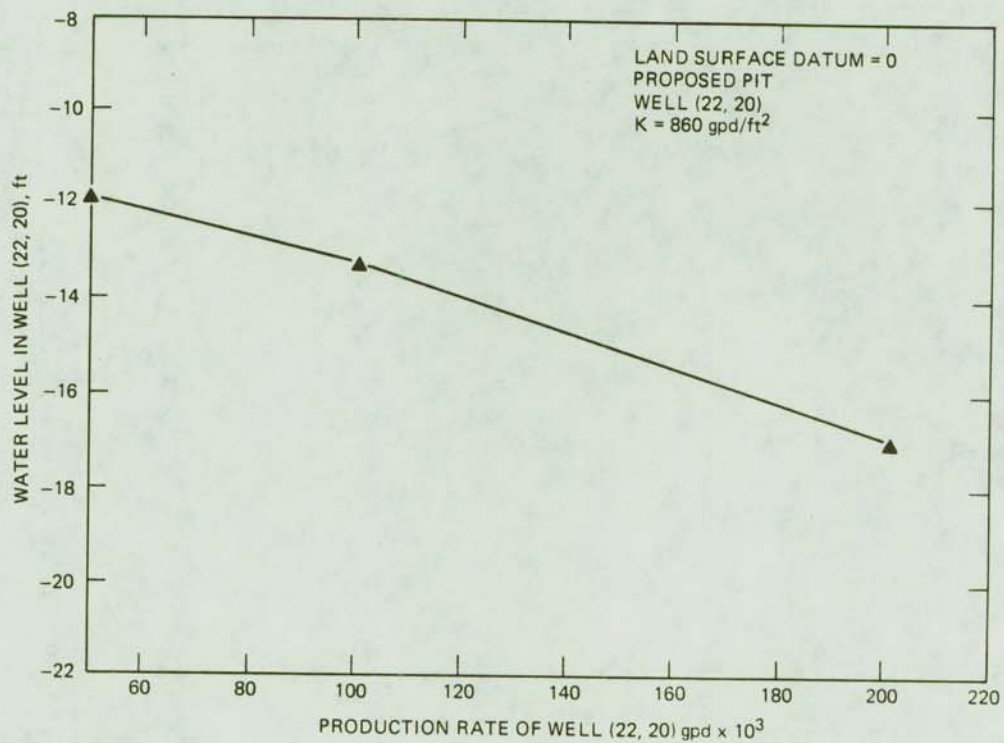


Figure 37. Water level in well (22,20) as a function of well production rate (proposed pit).



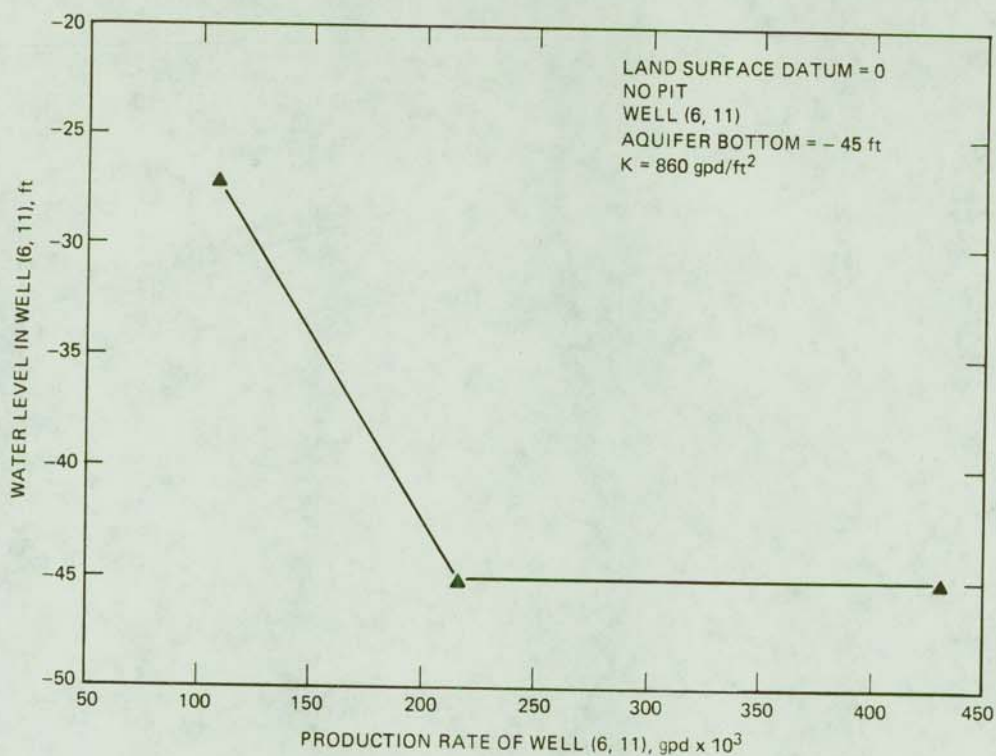


Figure 38. Water level in well (6,11) as a function of well production rate (no pit).

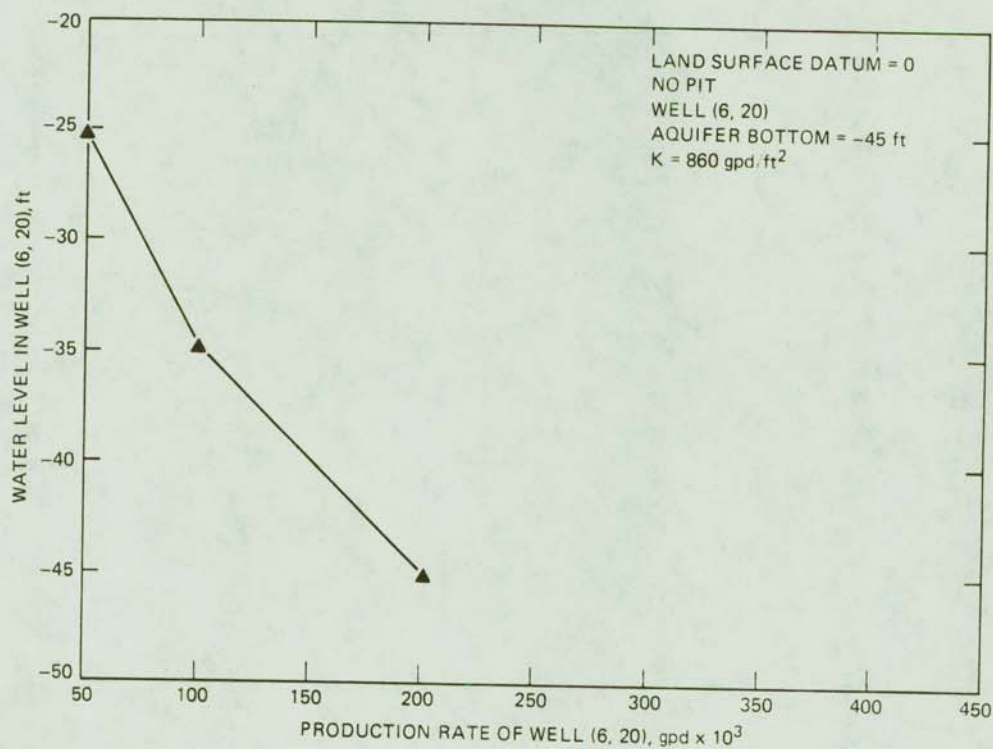


Figure 39. Water level in well (6,20) as a function of well production rate (no pit).

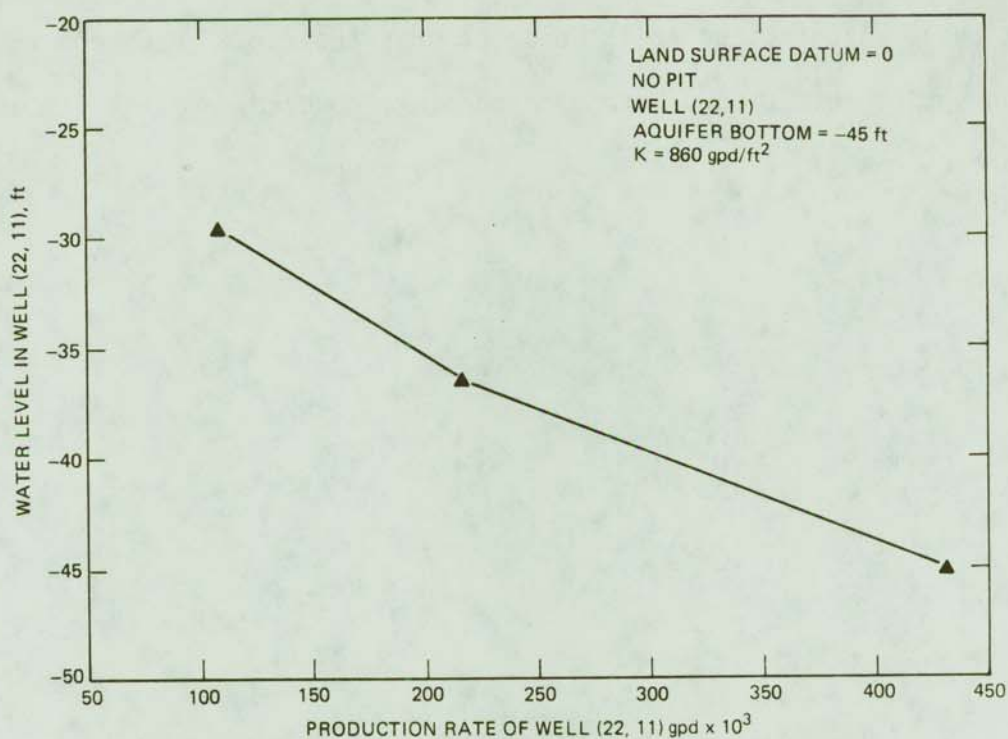


Figure 40. Water level in well (22,11) as a function of well production rate (no pit).

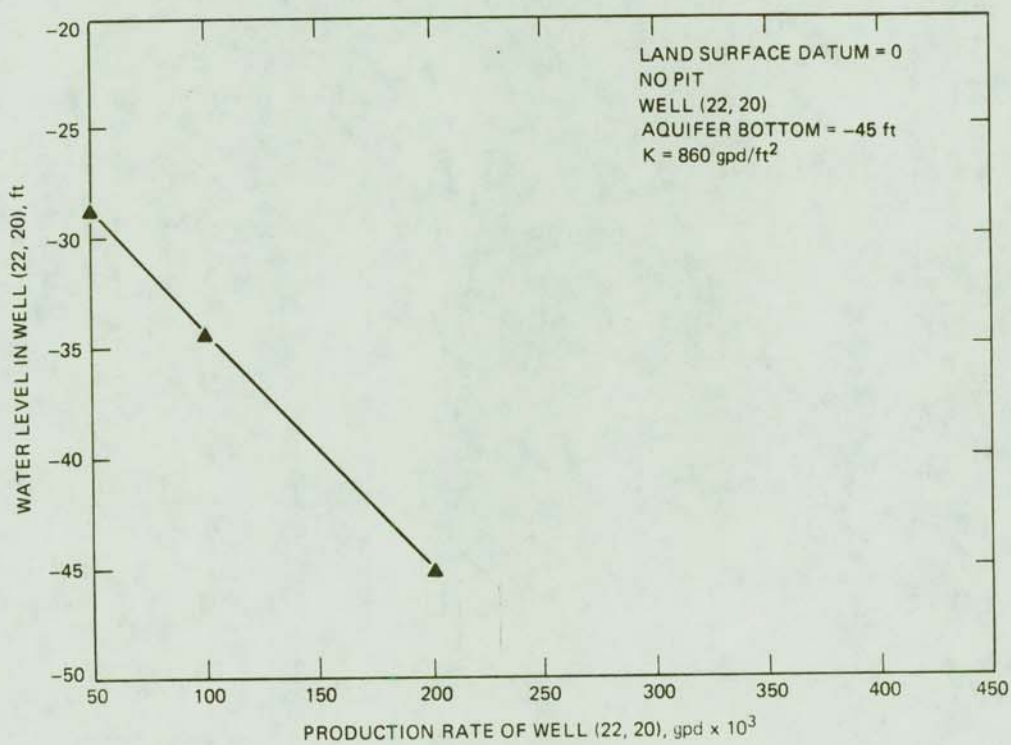


Figure 41. Water level in well (22,20) as a function of well production rate (no pit).



From these calculations it is apparent that artificial recharge is a viable concept at this site. Before proceeding, however, a pilot pit must be made operational in order to fully test the system.

## RECOMMENDATIONS

Artificial recharge to surficial deposits is a viable concept as shown by the calculations of the Aurora site. It could quickly gain acceptance as an alternate water source in outlying communities from Chicago with the advent of proposed pipelines for Lake Michigan water. With pipelines, water bills may triple.

Using sanitary plant effluent as recharge water severely limits the sites available for recharge because of lack of available land near to plants and/or lack of a host aquifer within a reasonable distance from plants. Because of discontinuity of surficial deposits in NE Illinois artificial recharge can occur only in carefully selected locations. River water is recommended as a potential optional water source for recharge pits.

Based on findings to date, a pilot pit should be constructed at the Aurora site. The aquifer at the site is adequate and the possibilities of degrading any existing water supplies are very limited. The aquifer at the site and probably just to the north of the site is capable of supporting a million gallon per day plus recharge operation. The chemical quality of water withdrawn from the operation is the research aspect of a pilot pit. Prior to an operational pit, water quality predictions are quite speculative.



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