Illinois Oil Field Brine Disposal Assessment

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
WATER QUALITY MANAGEMENT PLANNING

Staff Report

ILLINOIS OIL FIELD BRINE DISPOSAL ASSESSMENT

STAFF REPORT

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY
208 WATER QUALITY MANAGEMENT PLANNING PROGRAM

PLANNING AND STANDARDS SECTION
DIVISION OF WATER POLLUTION CONTROL
2200 CHURCHILL ROAD
SPRINGFIELD, ILLINOIS 62706
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FOREWORD

The study described within was initiated January, 1978 as part of the statewide 208 Water Quality Management Planning Program. Funding was provided in part by the U.S. Environmental Protection Agency under provisions of Section 208 of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), as amended.

Contractual assistance was provided by the Illinois State Geological Survey (I.S.G.S.). Particular recognition should be given to Mr. George Lane of the Department of Mines and Minerals for his substantial cooperation and assistance in this effort, to Mr. Philip Reed of the I.S.G.S. for assisting in the acquisition, compilation and interpretation of field data, and also to Mr. Craig Murphy of Northern Illinois University for technical assistance and his many hours of fieldwork expended throughout the summer.

INTRODUCTION

This study of environmental problems related to oil field brine disposal in Illinois began in January 1978, as part of the Illinois statewide 208 water quality management planning program, and is scheduled to be completed by the end of 1979. The preliminary findings and recommendations contained herein are based on information collected and analyzed through August 1978. The format reflects the approach taken in gaining an understanding of brine related problems and in developing recommendations for their abatement. A glossary of terms appearing in this report is provided at the end of the text.

Initial Inquiries and Study Objectives

The oil field brine disposal study was initiated by the Illinois Environmental Protection Agency (Agency) after receiving several complaints from affected landowners concerning contaminated water supplies and damaged land. The majority of complaints initially received were channeled through the public participation Regional Advisory Committee serving the southeast central portion of the state. To obtain further information on brine disposal, "Problem Report Forms" were made available to interested citizens. These forms were designed to provide preliminary estimates of the areal extent and nature of problems commonly associated with brine disposal operations. Subsequent press releases soliciting the help of concerned citizens generated considerable interest, resulting in the submission to the Agency of 16 completed forms. An example of the circulated form appears in Appendix A. The information thus collected helped provide the basis for initial investigations described in this report.

Major objectives outlined for the study included:

1. Providing an assessment of the nature and extent of environmental problems emanating from oil field brine disposal practices in Illinois.

2. Conducting a detailed field study of more specific problems related to brine disposal, in particular the subsurface migration of chloride bearing waters.

3. Providing an assessment of the efficacy of the rules and regulations governing the disposal of oil field brines in Illinois.

Information on regional geology, soil types and hydrogeology of the affected areas, as well as information on contaminant characteristics were obtained by researching previous work. It was found that a great amount of information on Illinois oil field brine and brine disposal had been compiled by the Illinois State Geological Survey (ISGS).

To employ this expertise, the Agency entered into a contract with the ISGS for a detailed field investigation of four typical brine disposal sites in south central and southeast central Illinois. The primary purpose of the field study was to develop a reliable and convenient methodology for identification of chloride concentrations in water-bearing earth materials.

Twenty-three piezometers were installed during the months of June and July 1978 to facilitate development of a relationship between ground water quality (chloride concentration) and apparent resistivity. Geologic descriptions of the sites, cross sections with gamma logs, and water level maps from piezometer observations were also developed to aid in the assessment of oil field brine disposal pollution problems.

Origin of Oil Field Brine

Identifying the origin of brine in the Illinois Basin is a complex problem. Researchers have yet to agree upon a solution. Details of the more widely accepted hypotheses are technically far beyond the scope of this report. However, for descriptive purposes, the most simplistic hypothesis will be presented here. It proposes a derivation from original sea water with a minor contribution of fresh water (Graf et al. 1966). Even though the brines originated from sea water initially incorporated in the sediment, subsequent compaction and chemical alteration resulted in concentration of the constituents. For comparative purposes, the surface water closest in composition to these subsurface brines is that of the present day Dead Sea.

Table I provides a comparison of the common constituents and typical concentrations of sea water and oil field brine (Reid et al., 1974).

Table I. Comparison of Sea Water and Oil Field Brine

	Sea Water (mg/l)	Oil Field Brine (mg/l)
Na^{+1}	10,600	12,000-150,000
K^{+1}	400	30 - 4,000
Ca^{+2}	400	1,000-120,000
Mg^{+2}	1,300	500- 25,000
Cl^{-1}	19,000	20,000-250,000
Br^{-1}	65	50 - 5,000
I^{-1}	0.05	1 - 300
HCO_3^{-1}	--	0 - 1,200
SO_4^{-2}	2,700	0 - 3,600

As indicated in Table I, brine salinity is primarily a function of the sulfates (SO_4^{-2}), bicarbonates (HCO_3^{-1}), and chlorides (Cl^{-1}) of the cations sodium (Na^+), calcium (Ca^{+2}) and magnesium (Mg^{+2}) (Reid et al., 1974). As a point of reference, the maximum allowable concentration for both chloride and sulfate in ground water, as set by the Illinois Pollution Control Board (IPCB, 1977), is 250 milligrams per liter (mg/l).

A feature of the underlying geology known as the Illinois Basin covers approximately 135,000 square miles of the south central and southeastern portions of the state and extends into southwestern Indiana and western Kentucky (Figure 1). Most of Illinois oil and brine production is concentrated along structural features within the basin

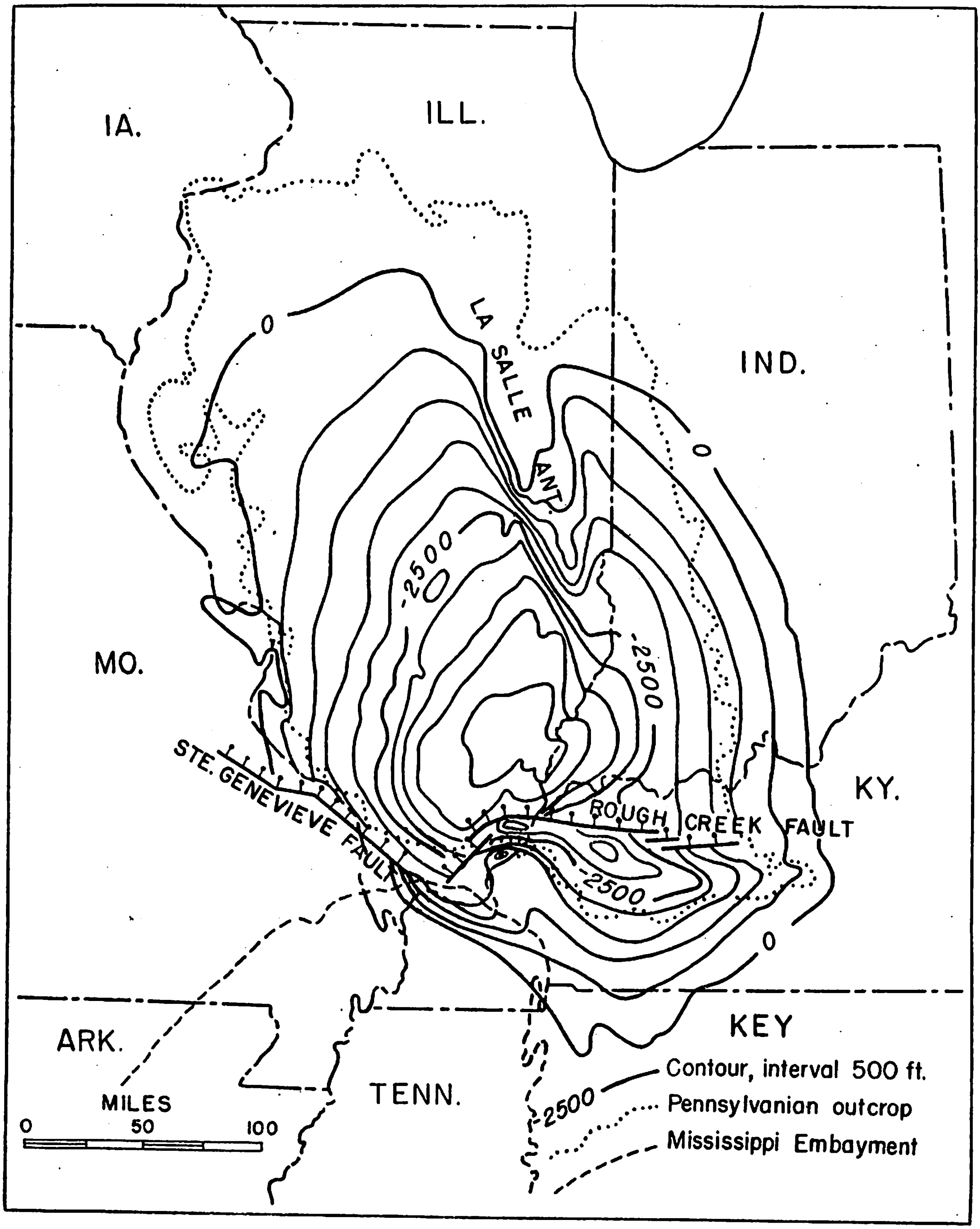

Figure 1.--Geologic structure of Illinois basin drawn on base of New Albany black shale (from Meents et al., 1952)

(Figure 2), although reef deposits also act as reservoirs for hydrocarbons.

Studies on the concentrations of total solids present in Illinois Basin brine reveal that the greatest concentrations are centrally located within the Basin. As reported by Meents and others (1952), concentrations diminish radially outward and seem to conform to the contours of the Basin. Figure 3 displays the distribution of concentrations found in samples retrieved from the Ste. Genevieve formation. Total solids in other basin formations vary slightly but all seem to exhibit similar structural dependencies.

Oil Production

The first oil fields of Illinois were discovered around 1903 in Lawrence and Crawford Counties along the La Salle Anticlinal Belt. Since the period of peak production from these oil fields in 1910, annual production has fluctuated drastically with changes in economy and technology. A peak in annual oil production of 146.8 million barrels resulted from the post-1937 Mississippian discoveries (Mast, 1970). Since then, rates have decreased to 26.3 million barrels according to 1976 statistics of Van Den Berg and Lawry (1976).

Fluid Injection

In an attempt to increase crude oil yield, numerous secondary recovery operations have been employed in the Illinois fields with

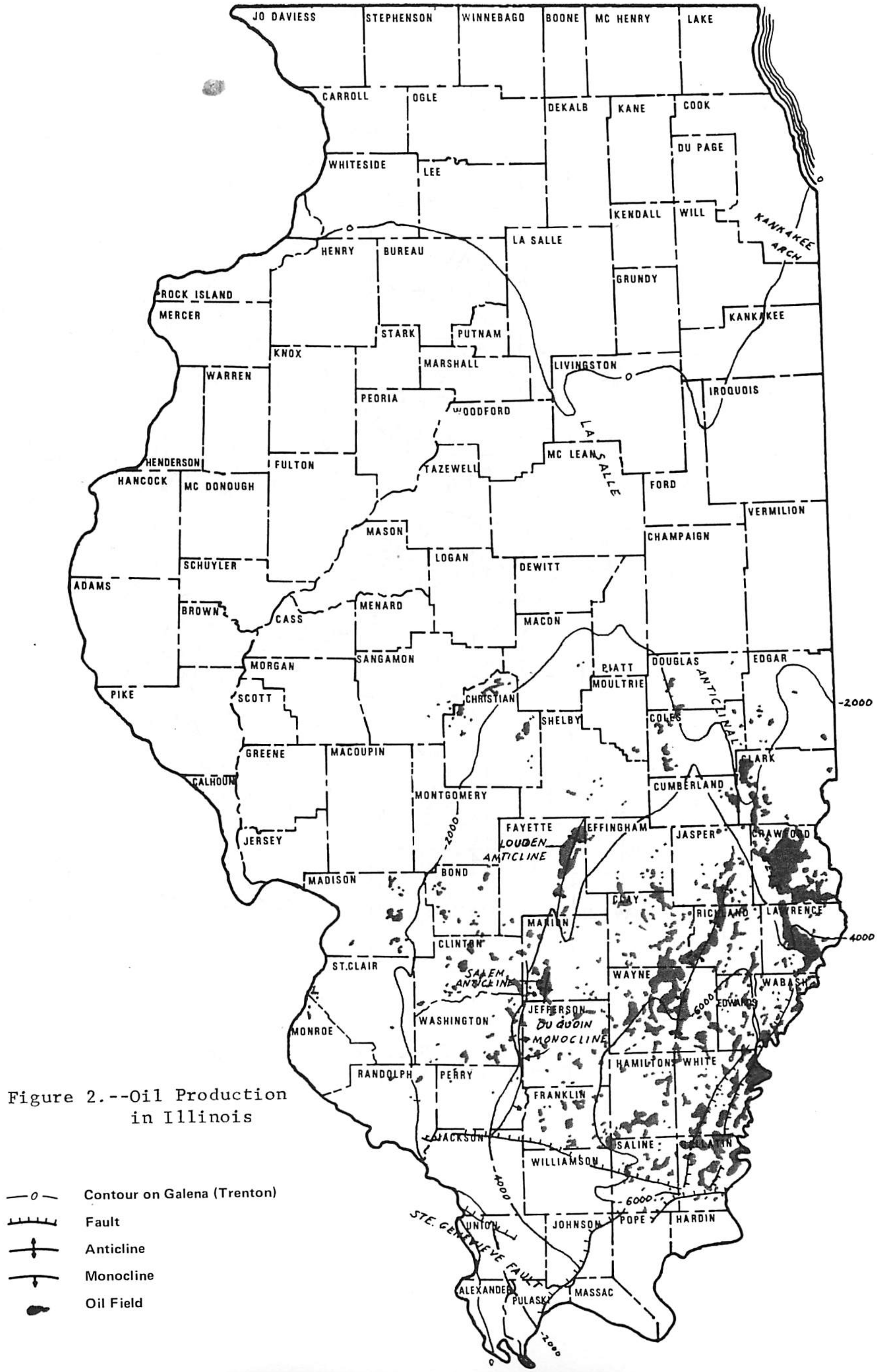

Figure 2.--Oil Production in Illinois

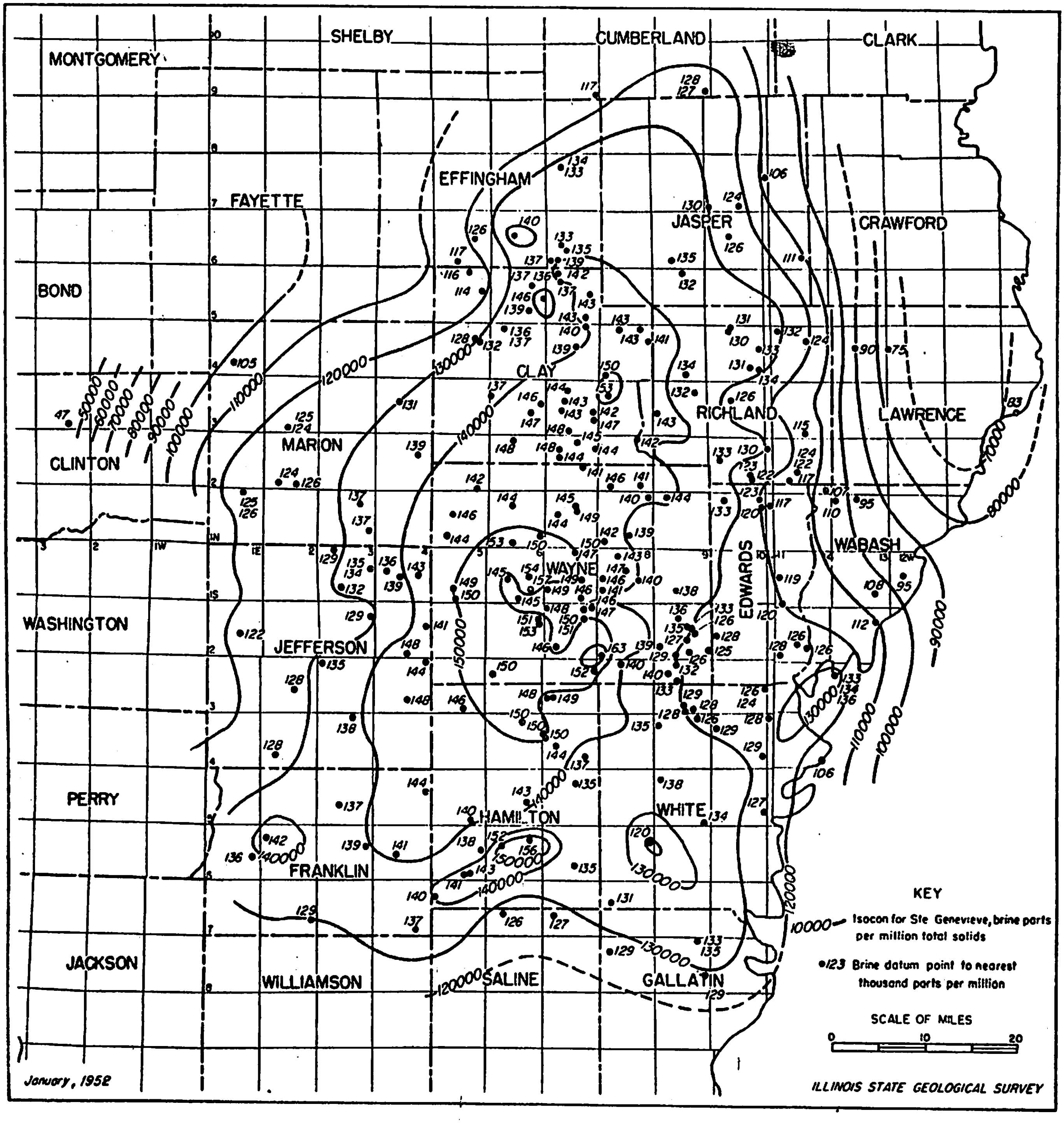

Figure 3.—Isocon map of Ste. Genevieve brines (from Meents et al., 1952).

varying degrees of success. These installations facilitate the injection of water into oil-bearing strata via input wells and are termed waterfloods. In this method, surface and subsurface waters are utilized to repressurize and flush-out oil-bearing formations. Little effect was made on the annual oil production by the early waterfloods of the 1930's. However, in the early 1950's, the combined effects of modern waterflood and hydrofracing techniques increased the total annual oil production by approximately 35 percent over production yields obtained prior to the use of these techniques.

Quite similar to waterflood installations are salt water disposal (SWD) wells. In the field, it is difficult to distinguish between the two operations. As both are injection operations, the difference lies in the final destination of the injected fluid. Unlike the fluids of a waterflood operation, the saline waters injected into an SWD well do not stimulate oil production. Rather than being reinjected into the producing formation, the brine is injected into a porous non-oil-bearing formation. To facilitate reinjection, wells drilled specifically for SWD or wells which have been converted from other functions are utilized.

Detailed information on waterflood and SWD operations may be obtained from the Illinois State Geological Survey's annual publication (Van Den Berg and Lawry, 1976).

It has been reported (Bell, 1957) that, with early oil field brine disposal practices, brine was often siphoned from an earthen holding pond directly into a cased well. Since gravity was the only injection force utilized, this type of facility was usually abandoned as the permeability of the receiving formation diminished to a point where free flow was restricted. This posed no particular problem in that another well in the proximate area could generally be found and readily converted to meet the disposal needs. In subsequent years, technology progressed as did the amount of brine produced. With the development of the more modern secondary recovery techniques, injection pressures on the order of several hundred pounds per square inch were commonly applied, thus dramatically increasing the ultimate capacity of a typical injection well.

Some of the more serious problems involved in these disposal operations are due to the relatively high density and corrosiveness of oil field brines and their damaging effects upon land and water quality. These problems can be compounded by the fact that as an oil field matures the ratio of brine to oil may increase substantially. In fact, it is not uncommon for brine to oil production ratios to exceed 80:1. The effects of this amount of brine production can be very destructive unless oil well operators are equipped to safely dispose of or reinject these large quantities of caustic waste.

As calculated from 1976 statistics, Illinois oil fields subject to waterflooding produce an approximate average of 19 barrels of brine per barrel of oil recovered. The annual disposal rate for waterflood operations in Illinois during 1976 was 355,059,000 barrels, a 3.5 percent increase over the 1975 rate. This amounts to an average daily brine injection rate of nearly one million barrels of brine. In addition to reinjection for waterflooding, substantial quantities of brine are injected into salt water disposal wells, which in 1976 accounted for approximately 20 percent of the new injection wells. However, there are no records available indicating the amount of brine disposed of by this method.

Brine Pollution

The highly saline waters associated with oil production pose a threat to water and land. The daily disposal of approximately 973,000 barrels of brine in Illinois has been responsible for the sterilization of thousands of acres of productive land, 3,000 recorded acres in White County alone (Fasig, personal communication). Reports from individuals indicate that oil field brine has also been responsible for the sickness or loss of numerous animals.

The Illinois Pollution Control Board (IPCB) Regulations, Chapter 3, Part II, Section 207, prescribe quality standards for underground waters of the state. Table II lists these maximum allowable contaminant levels.

Table II. IPCB Water Quality Standards

	Ground Water	General Use Surface Water
Chloride	250 mg/l	500 mg/l
Sulfate	250 mg/l	500 mg/l
Total Dissolved Solids	500 mg/l	1,000 mg/l

By comparing the constituent concentrations found in brine pits at the four study sites with the maximum allowable chloride levels set by the IPCB, it is apparent that one barrel of brine possessing a chloride concentration of 40,000 mg/l would be theoretically capable of elevating the chloride concentration of over 160 barrels of fresh water above the maximum allowable contaminant level.

Since the discovery of large commercial supplies of oil in southern Illinois in the 1930's, brines from oil fields have been disposed of in various ways. Initially, direct discharge into streams was the most common method of disposal (Reed, 1978). Later, in the 1940's, the development of injection wells allowed the oil field brine to be reinjected into compatible underground reservoirs. Perhaps the most common practice was to pump the brine into a holding pond, as this was believed to allow the brine to evaporate into the atmosphere. However, in Illinois where permeable materials are often near the surface, many brine holding ponds actually became infiltration ponds (Roberts and Stall, 1967). Consequently, although the surface water pollution problem was greatly improved through the use of holding ponds, a problem of ground water pollution is now present in many Illinois oil fields (Reed, 1978). However, this is not to imply that streams in the oil production areas have been completely unaffected since the 1940's. Oil field brines slightly diluted by precipitation, after entering the ground water system (Figure 4), can eventually be discharged into nearby streams. Flemal (1978) has reported that Illinois surface waters in areas of petroleum production may be receiving significant amounts of ground water brines.

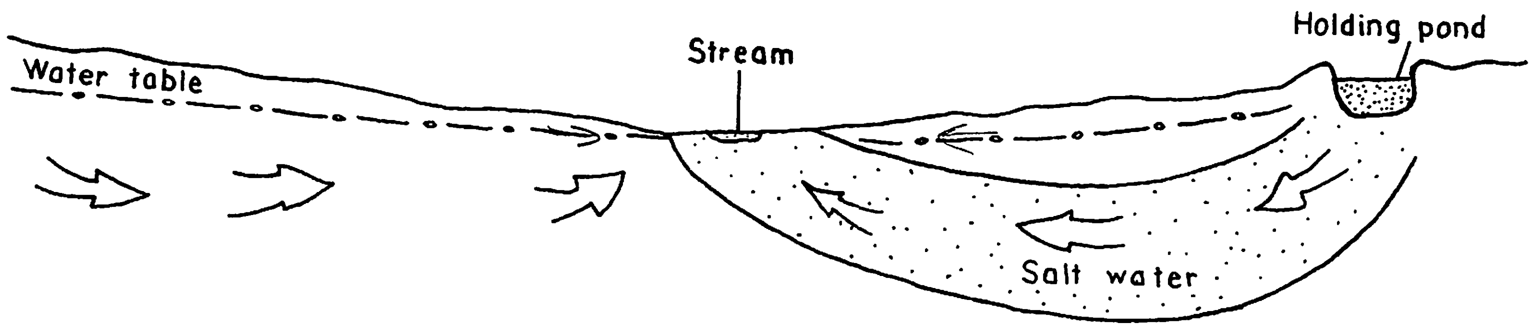

Figure 4.--Generalized movement of water in the vicinity of holding ponds (from Reed, 1978).

In addition to raising the concentrations of many chemical constituents of local ground water far above the maximum contaminant levels set by the IPCB, many of the brine holding ponds in central and southern Illinois are responsible for vegetation kills covering a limited area generally of a few acres or less. These vegetative kills are discernable from the ground and from aerial photographs, as can be seen in Plates 1 through 5 of the four study sites, shown on the following pages.

Brine-polluted ground water may eventually infiltrate public or private water supplies, or percolate to the surface. Water supplies for farms and dairy operations can become saline, leaving cattle and a family without potable water. This was the case for a Clinton County dairy farmer and his family in 1976, when highly mineralized waters infiltrated his local ground water supply (Case I - Appendix B).

Productive farm land can be left completely unvegetated as can be seen at a site in south central Bond County. In this case a field adjacent to a brine pit was left void of vegetation after saline ground water percolated to the surface (Case II, Appendix B).

Property values can drop as a result of threatened ground water contamination. This occurred in 1977 at a housing development located near a brine pit in Rochester, Illinois, after elevated chloride concentrations were found in the surrounding ground water (Case III, Appendix B). These are just a few examples of environmental degradation through brine pollution that have occurred in Illinois over recent years.

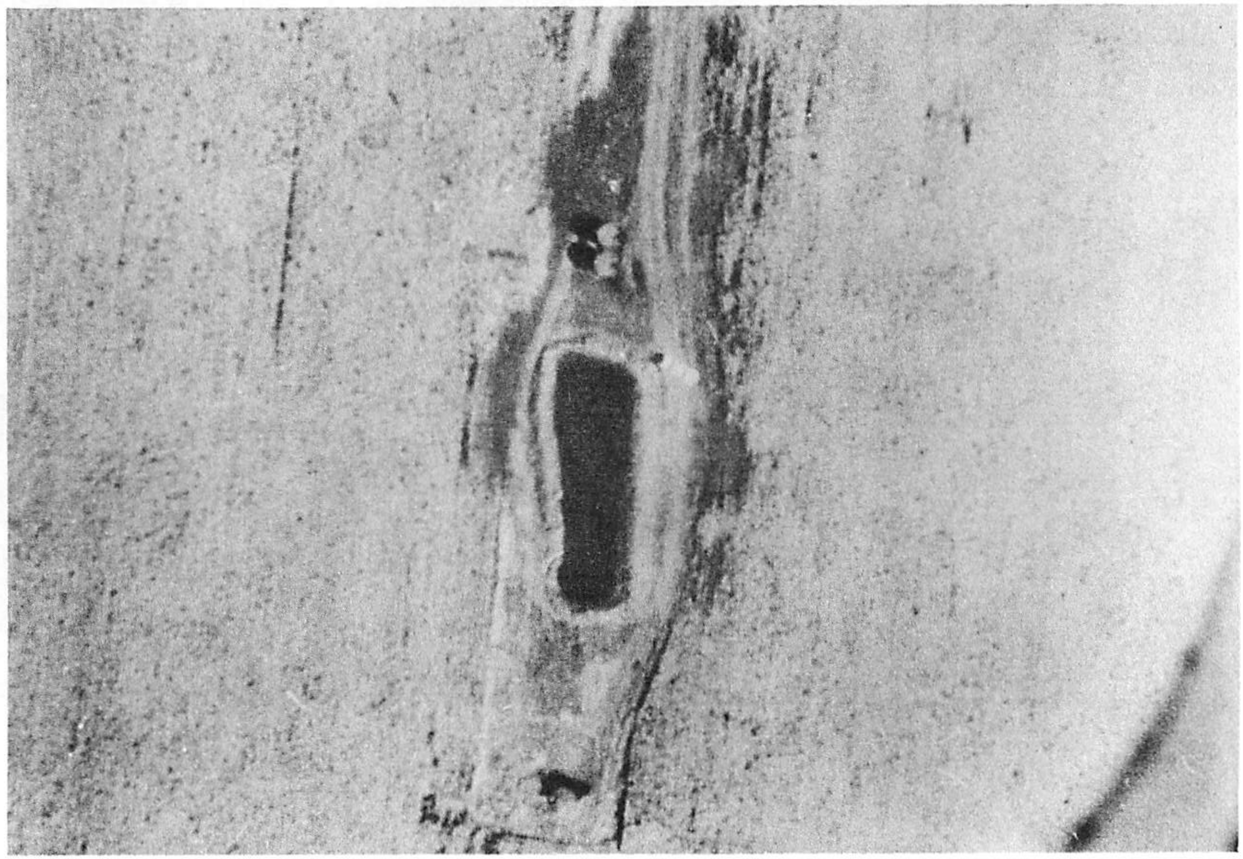

Plate 1.--Christian County Study Site

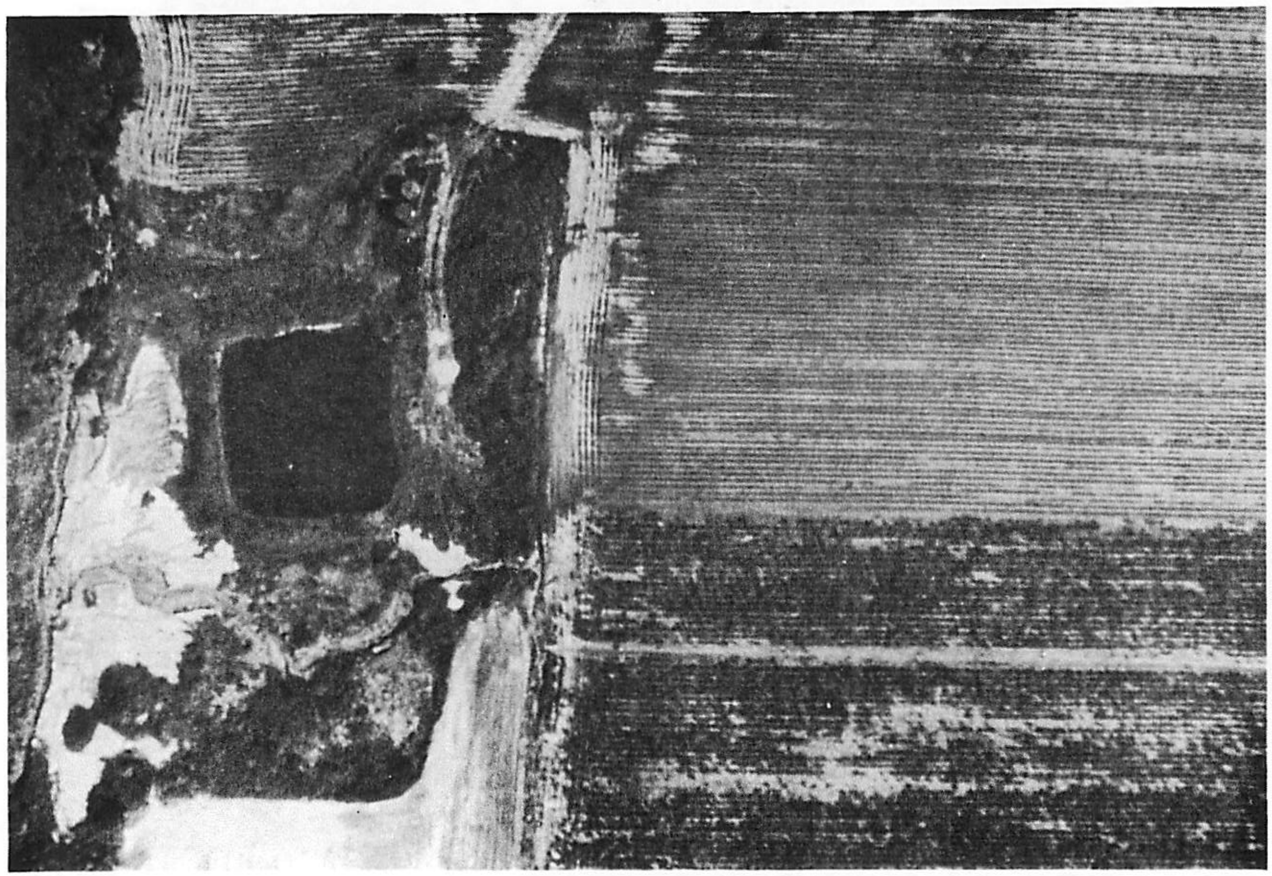

Plate 2.--Bond County Study Site

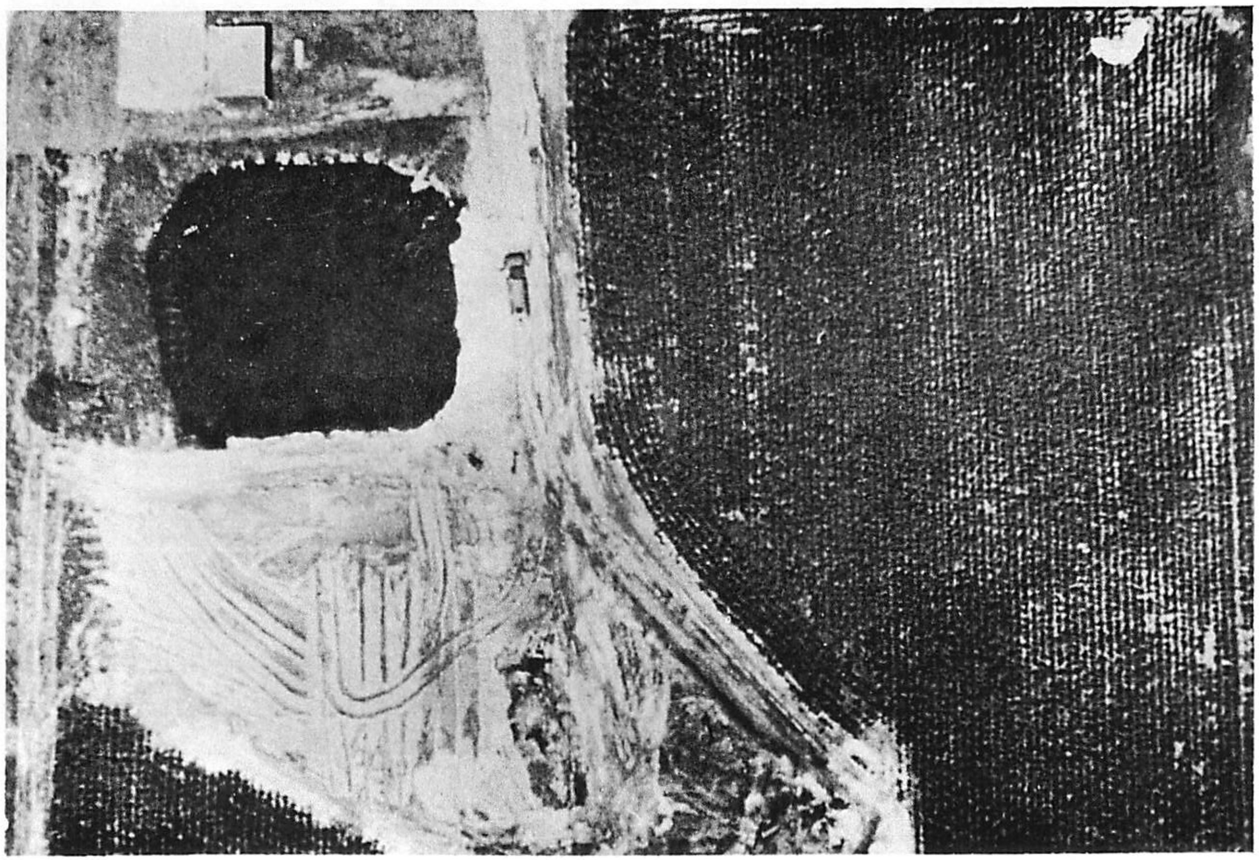

Plate 3.--Effingham-Fayette County Study Site

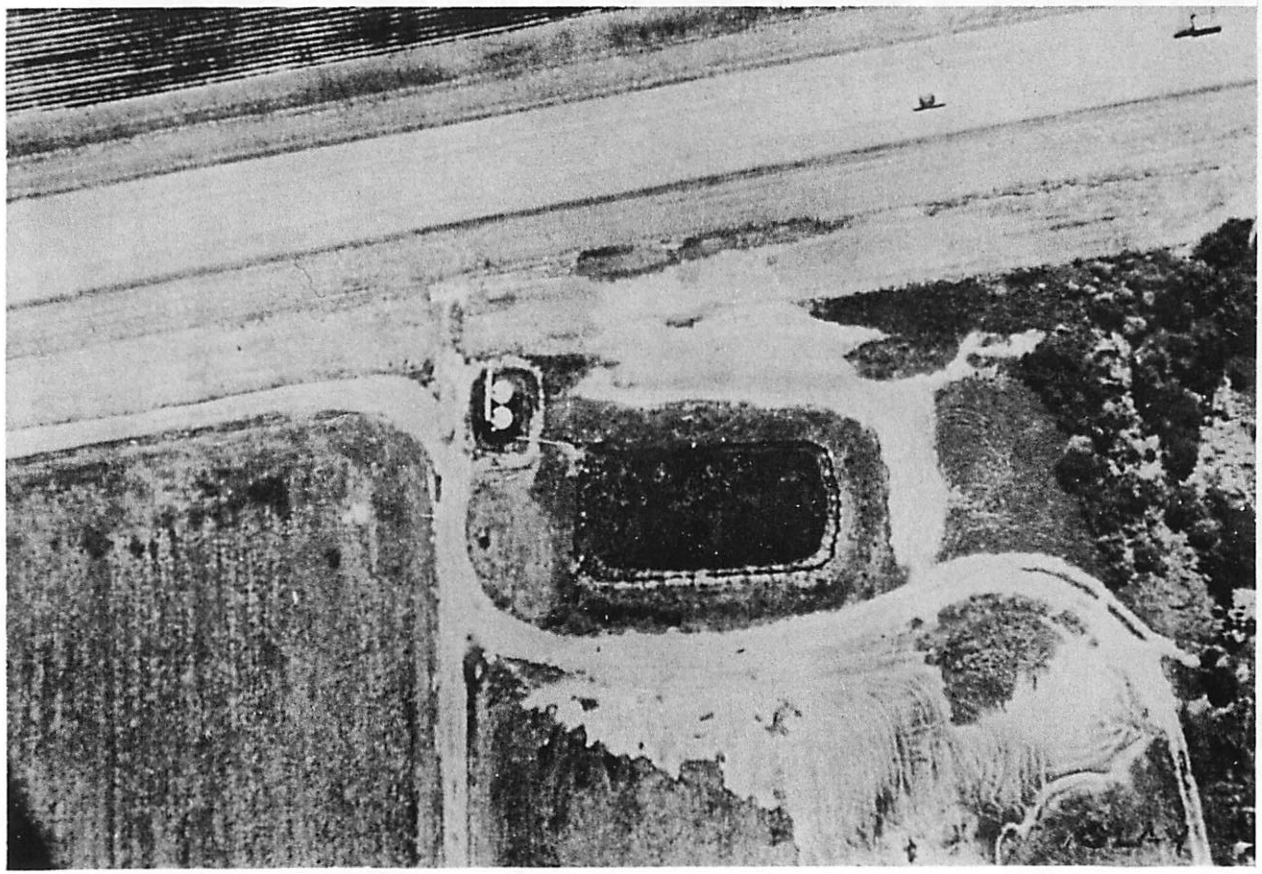

Plate 4.--Clay County Study Site

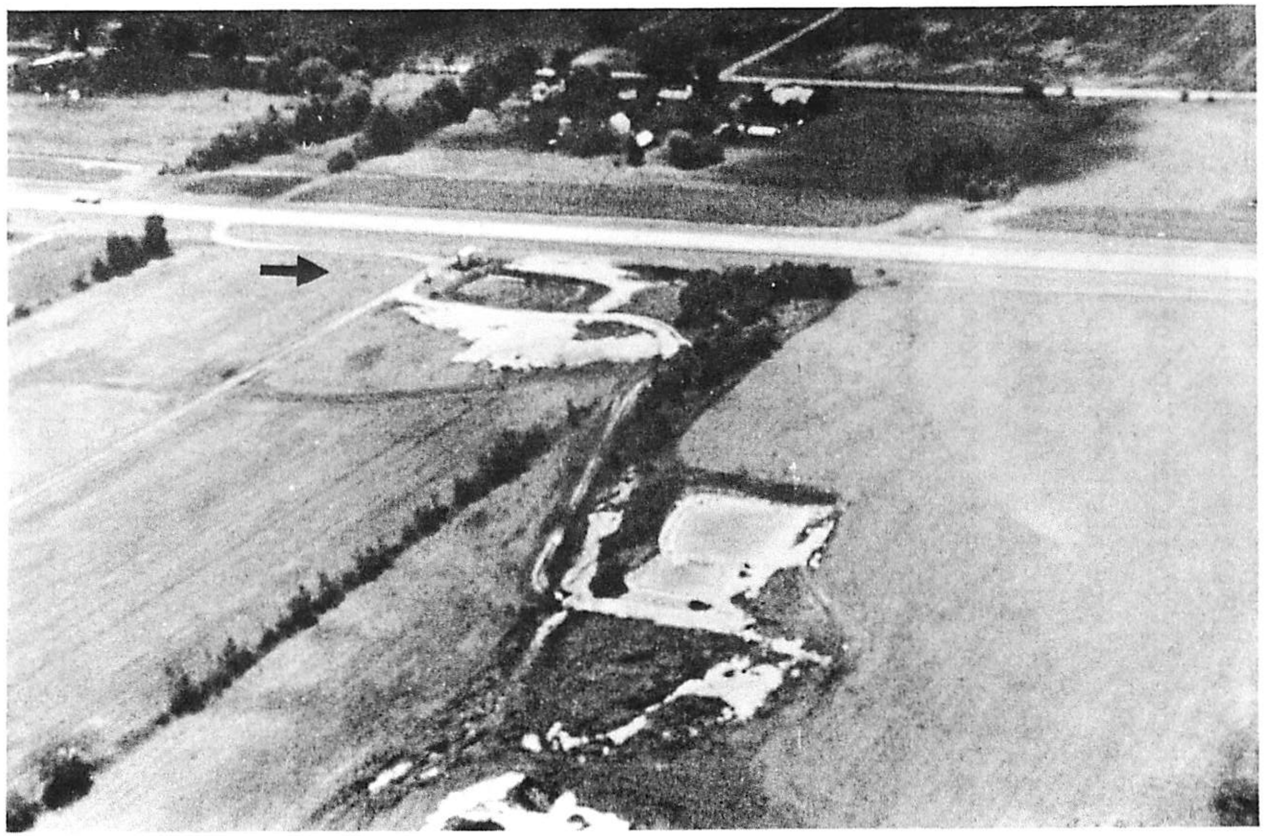

Plate 5.--Clay County Study Site (indicated by arrow)

However, even though these cases have occurred in close proximity to active oil field brine disposal operations, lack of acceptable legal evidence has left land owners without means to secure compensation for damages incurred.

One of the important characteristics of brine pollution often overlooked until the damage has been done, is that the pollution cannot be readily reversed by merely eliminating the existing source. In ground water, brine pollution may persist for decades and travel several miles from its point of origin before it is appreciably diluted.

FIELD INVESTIGATIONS

During the course of this study, considerable time was spent in the field by Agency and ISGS personnel. This section outlines the field studies and observations completed to date.

Criteria

During initial reconnaissance trips completed in May of 1978, the following criteria for selection of sites for studying environmental problems associated with oil field brine disposal, particularly unlined pits, were developed.

1. The sites should be geographically distributed across the oil producing region of the state and be in "representative" geologic environments.

2. The site should have relatively uniform geology which can be readily determined.

3. The site should have simple hydrogeology, preferably with one main water transmission zone.

4. The site should be sufficiently isolated from other sources of chloride contamination, including other brine ponds.

5. Brine disposal facilities at the site should have been in operation for a sufficient length of time (at least 10 years) so that salt water has had a chance to migrate away from the site.

6. The site and observation wells should be accessible for a period of one year, if possible, to provide a sufficient number of samples on which to base the final conclusions.

7. The layout of the site should be such that the observation wells can be located with a minimum of interference with existing property uses.

8. The site should have as few pipes and other metallic objects as possible, to preclude possible interference with resistivity measurements.

9. The land owner, tenant, and lessee of the site should be cooperative with project staff.

10. There should be no litigation or regulatory action ongoing or pending at the sites proposed for study.

Location and Study of Sites

Based on the criteria above and on the field reconnaissance work, four sites were selected for resistivity surveys, test drilling, piezometer construction, and earth material and water sampling. The sites are located at active oil fields in Bond, Christian, Clay, and Effingham-Fayette Counties, as illustrated in Figure 5.

Lithologies encountered at the four study sites were quite similar. Three of the sites, Christian, Bond, and Effingham-Fayette Counties, possessed relatively thin deposits (1-6 ft.) of Wisconsinan loess immediately underlain by deposits of Illinoisan till, primarily of the Hagarstown member of the Glasford formation. The Hagarstown is basically comprised of four types of compact to noncompact sediments -- gravelly till, poorly sorted gravel, well sorted gravel, and sand and silt often intermixed with blocks of underlying till (Jacobs and Lineback, 1969). In most cases, the holding ponds constructed over the Hagarstown till, which covers a large portion of the oil producing area of the state (Figure 6), are excavated within 5 to 20 feet of aquifer materials consisting chiefly of sand and silt with minor amounts of gravel (Reed, 1978). Since the study sites are fairly uniform lithologically, the principal control mechanisms for chloride migration appear to be dilution from rainfall and ground water and the gradient and direction of ground water flow (Reed, 1978), as well as the static pressure differential between water table level and pit level.

Investigative Procedures

Investigative procedures at each site began with an electrical earth resistivity (EER) survey of the entire study area. With the EER method,

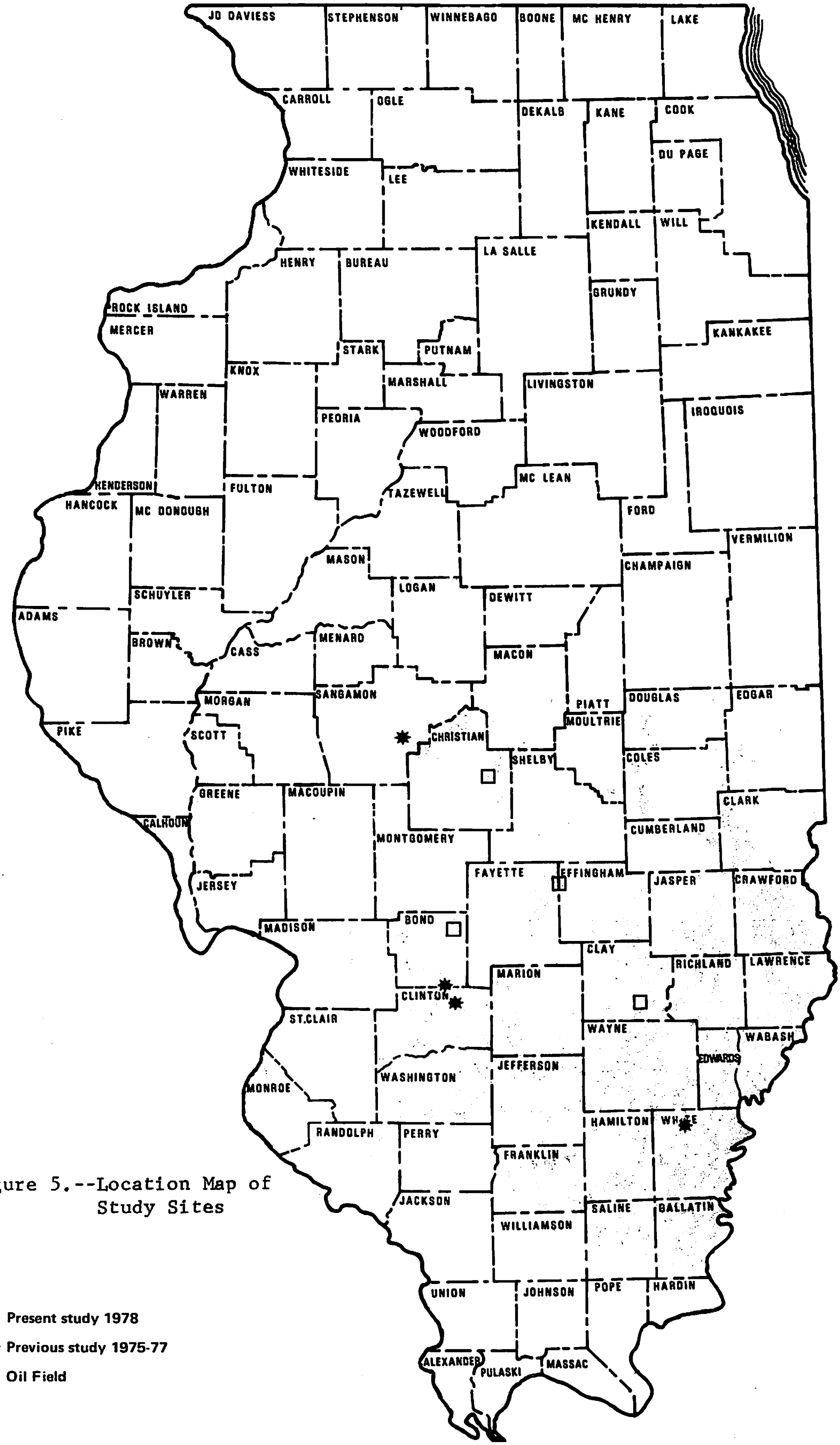

Figure 5.--Location Map of Study Sites

□ Present study 1978

✱ Previous study 1975-77

Oil Field

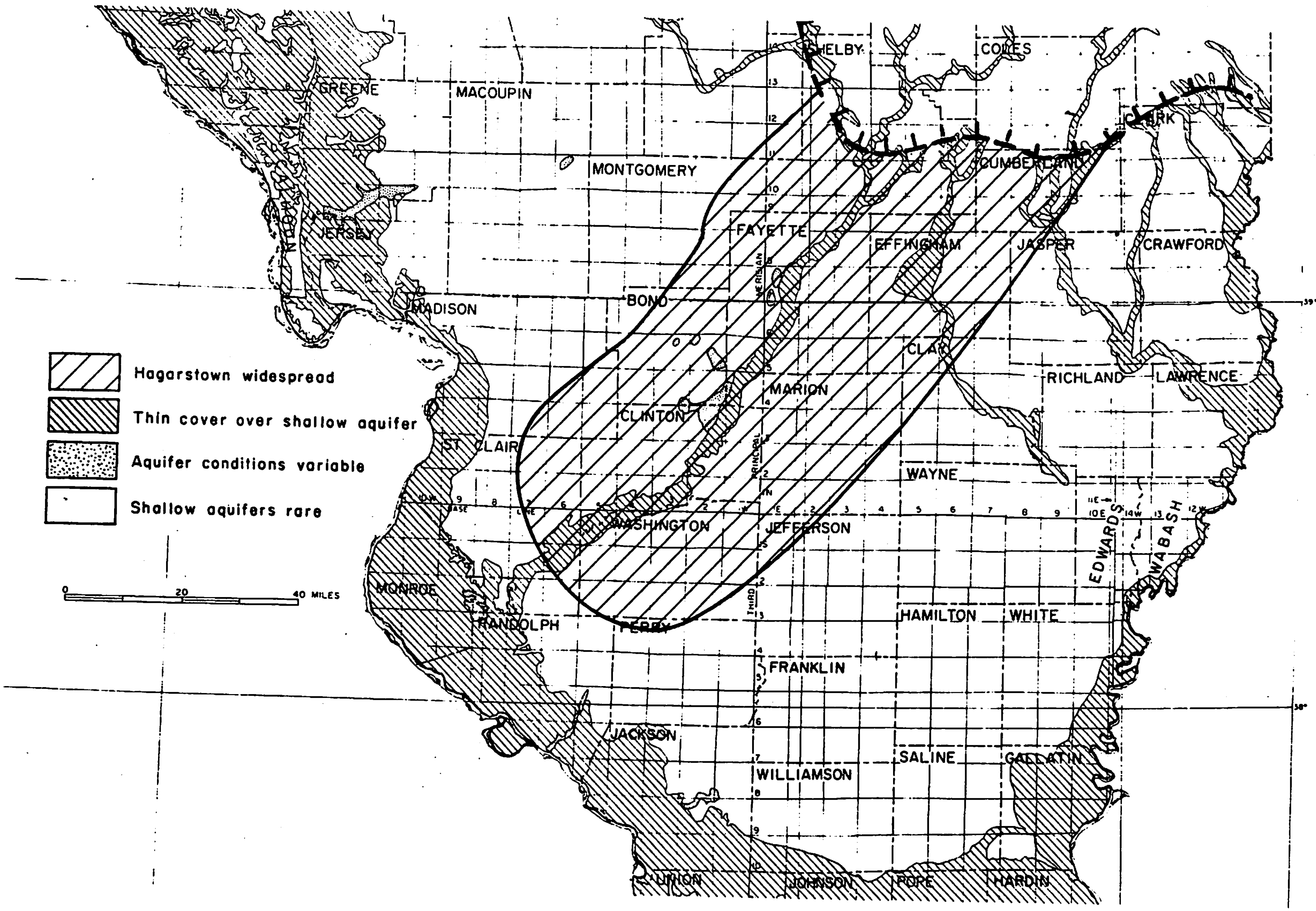

Figure 6.--Generalized Location of the Hagarstown Member of the Glasford Formation

a direct, commutated or low frequency alternating current is introduced into the ground by means of two source electrodes (metal stakes) connected to a portable power source. By mapping the resulting potential distribution created on the ground surface using two potential probes (non-polarizable electrodes), the electrical resistivity below the surface may be ascertained. By using the Wenner electrode configuration (Figure 7), in which the four electrodes are spaced equally along a straight line, the apparent resistivity can be calculated as 2π (π = 3.14) times the electrodes spacing times the recorded resistance.

This method has been used primarily in searching for water-bearing formations and in prospecting for conductive ore-bodies. EER studies have also been used to monitor the deterioration of water quality and the extent of leachate migration near landfills (Cartwright and Sherman, 1972). Success of the EER method in the applications mentioned above is due to the fact that apparent resistivity is partially controlled by the presence and quality of subsurface water. This same technique can be applied to the migration of oil field brine. The presence of highly conductive brine in the ground water is readily apparent as a depression of the normal resistivity values. The decrease in resistivity with increasing water salinity is shown in Figure 8, adopted from Guyod (1952). The greatest change in resistance occurs at the lower salinity end of the curve from 15,000 parts per million (ppm) downward. Although previous electrical earth resistivity studies conducted by the Illinois State Geological Survey have clearly related differences in subsurface resistivity measurements to the migration of oil field brine, no detailed

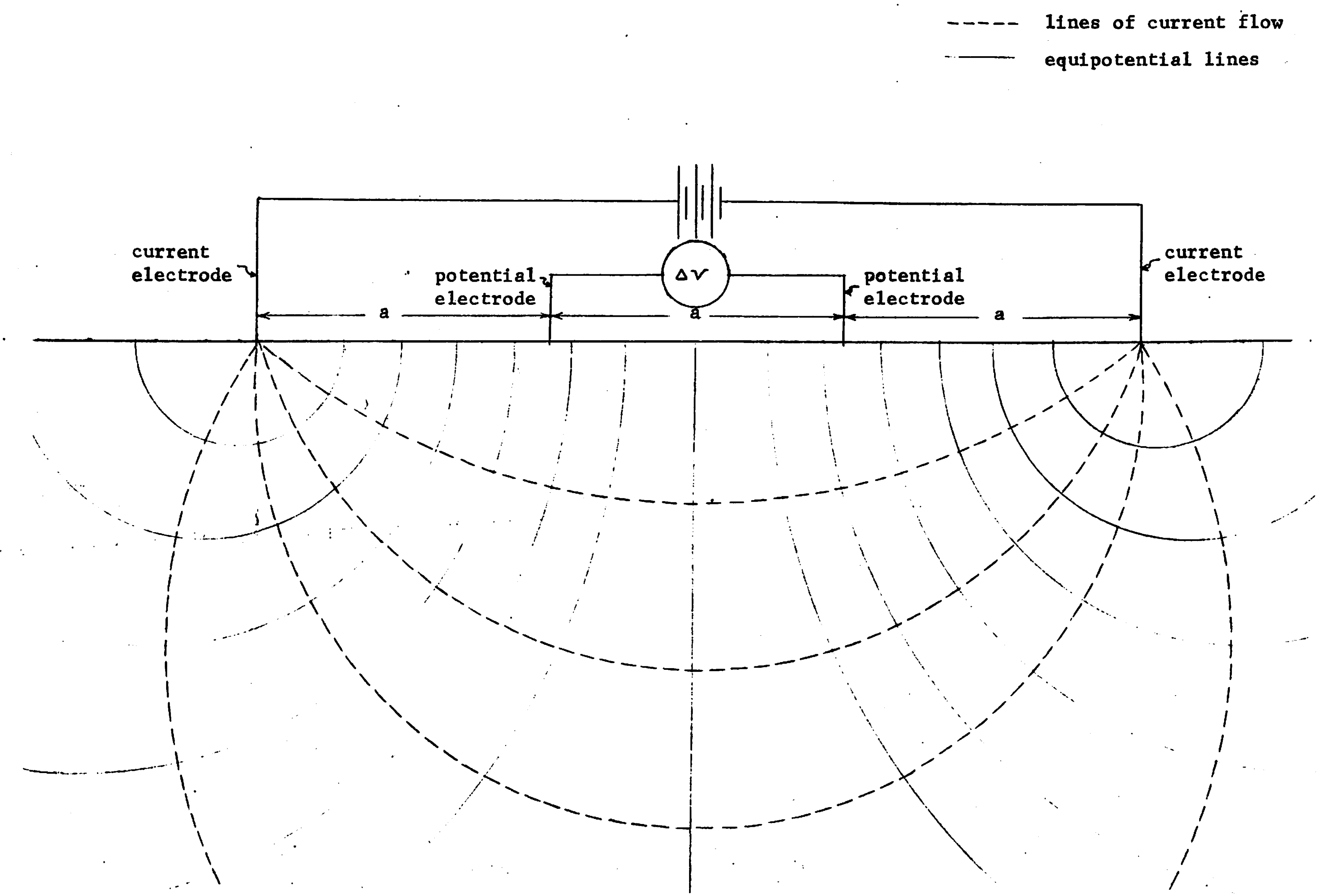

Figure 7.--Electrode Spacing for Measuring Electrical Earth Resistivity Using a Wenner Configuration.

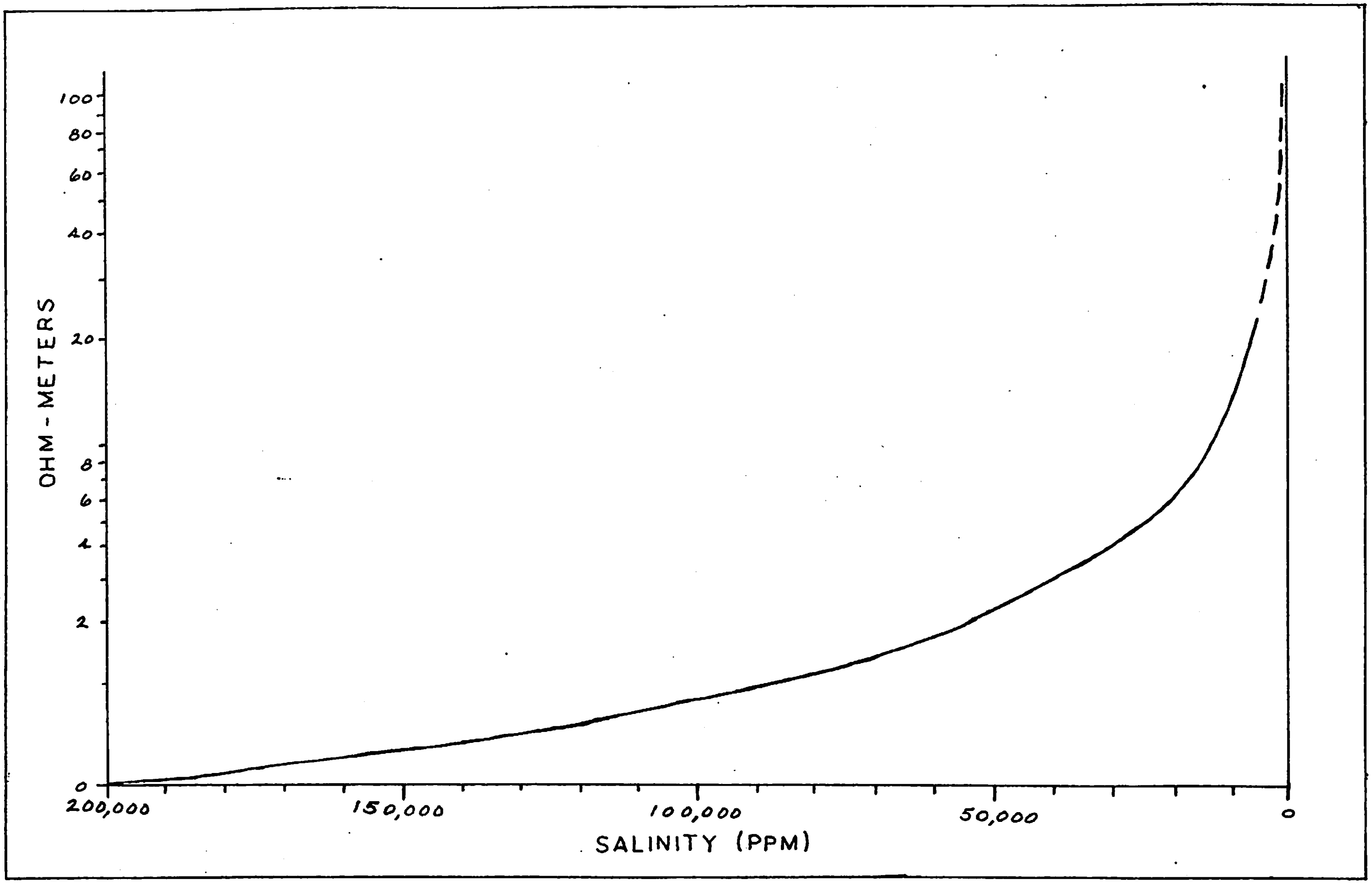

Figure 8.--Relationship of resistance and connate water salinity (from Guyod, 1952).

investigation of subsurface water quality, lithology, and surface electrical measurements had been made in the state prior to this study. Case histories of four sites previously studied in Clinton, Sangamon and White Counties are included in Appendix B. The exact locations of these sites in relationship to the current study sites are illustrated in Figure 5.

Apparent resistivity values obtained from the EER surveys were plotted and contoured for various electrode spacings. This spatial variation provides control over the depth of observation. In general, an apparent resistivity value obtained from an electrode spacing of X feet can be thought of as the apparent resistivity of the subsurface materials to a depth of X feet. However, the actual apparent resistivities of materials beneath a highly conductive layer may be masked. A comparison of surface resistivities and resistivity measurements made on drill core samples indicates this is clearly the case at the four study sites. At these sites, surface resistivity surveys suggest the presence of enlarged areas of reduced resistivity in a compact gracial till below a depth of approximately 20 feet. Low resistivities in this zone was not expected due to the impermeable nature of the material, and was discounted, after looking at core resistivities, as being caused by a masking effect of the overlying contaminated aquifer material. Contour maps for each site of the apparent resistivities obtained from electrode spacings of 5, 10, 15, and 20 feet are included in Appendices C through F.

The next step in the investigation was to locate and emplace a piezometer network. This was done by using the EER contour maps. Piezometers at each site were located so as to provide a spatial as well as an electrical resistance dispersion across the study areas.

Once located, the bore holes were augered with a portable drill rig provided by the ISGS, and split spoon samples of the earth materials were taken generally every five feet. To provide additional information on the permeability of the material and the degree of contamination of the interstitial fluids, both the number of blows required to obtain the sample and its apparent resistivity were recorded. After penetrating to an impermeable zone, usually a cobbly till, a gamma ray probe was lowered through the augers to verify the position of water-bearing earth materials. After making this determination, a plastic casing slotted opposite the most permeable zone was lowered into the bore hole. Upon retraction of the augers, the bore hole was gravel-packed, bentonite sealed and back-filled.

The measurement of static water levels and water sampling began after emplacement of the 23 piezometers at the four sites. Initially two sets of water samples were taken at semimonthly intervals to provide the data for this report. Sampling is now scheduled to continue at monthly intervals through July 1, 1979. From the laboratory analyses, average concentrations of the major constituents of water samples from each piezometer and study pit are reported in Table III.

Table III. Average Concentrations of the Major Chemical Constituents From Each Piezometer and Pit.

	Chloride ppm	Sodium ppm	Calcium ppm	Sulfate ppm	Potassium ppm	Magnesium ppm
R-Pit	14,500	11,000	370	103	25	310
R-1A	76.5	200	150	104	3.0	57
R-3B	19,750	1,250	1,000	91	7.4	585
R-16	3,900	1,900	645	65	6.6	280
R-26	95	190	50	1.5	.9	20
R-28A	22,000	14,500	800	97	11.7	505
R-32	75	100	133	53	1.2	45
R-43	27	78	303	29	.6	134
R-US	290	170	50	43	7.0	17
R-DS	14,500	10,000	510	82	8.8	310
M-PIT	10,812	7,200	540	121	22	212
M-1B	30,500	15,000	3,500	355	45	760
M-22	83	40	50	56	.6	42
M-31	2,650	1,850	265	72	2.2	105
M-33	335	372	145	73	1.2	46
M-35	35	43	82	63	1.8	37
H-PIT	24,000	16,000	1,400	725	52	470
H-3	10,000	350	550	67	2.3	250
H-11	2,850	925	1,320	29	4.5	605
H-21	20	53	93	27	1.0	38
G5A	1,400	895	525	32	4.3	230
G19A	188	162	186	54	2.6	71
G25A	126	230	94	29	13.3	45
G32	26,250	14,250	2,550	60	3.0	1,200
G32A	4,850	1,950	1,550	13	12.0	830

By applying a least squares line fit to the chloride concentration and apparent resistivity data plotted on coordinate semi-log graph paper, correlation coefficients (r) of -.76 (Figure 9) for filtered samples and -.72 (Figure 10) for unfiltered samples were obtained (Reed, 1978). This result is in general agreement with Cartwright and Sherman (1972), and signifies that EER surveys can provide a reliable, convenient technique

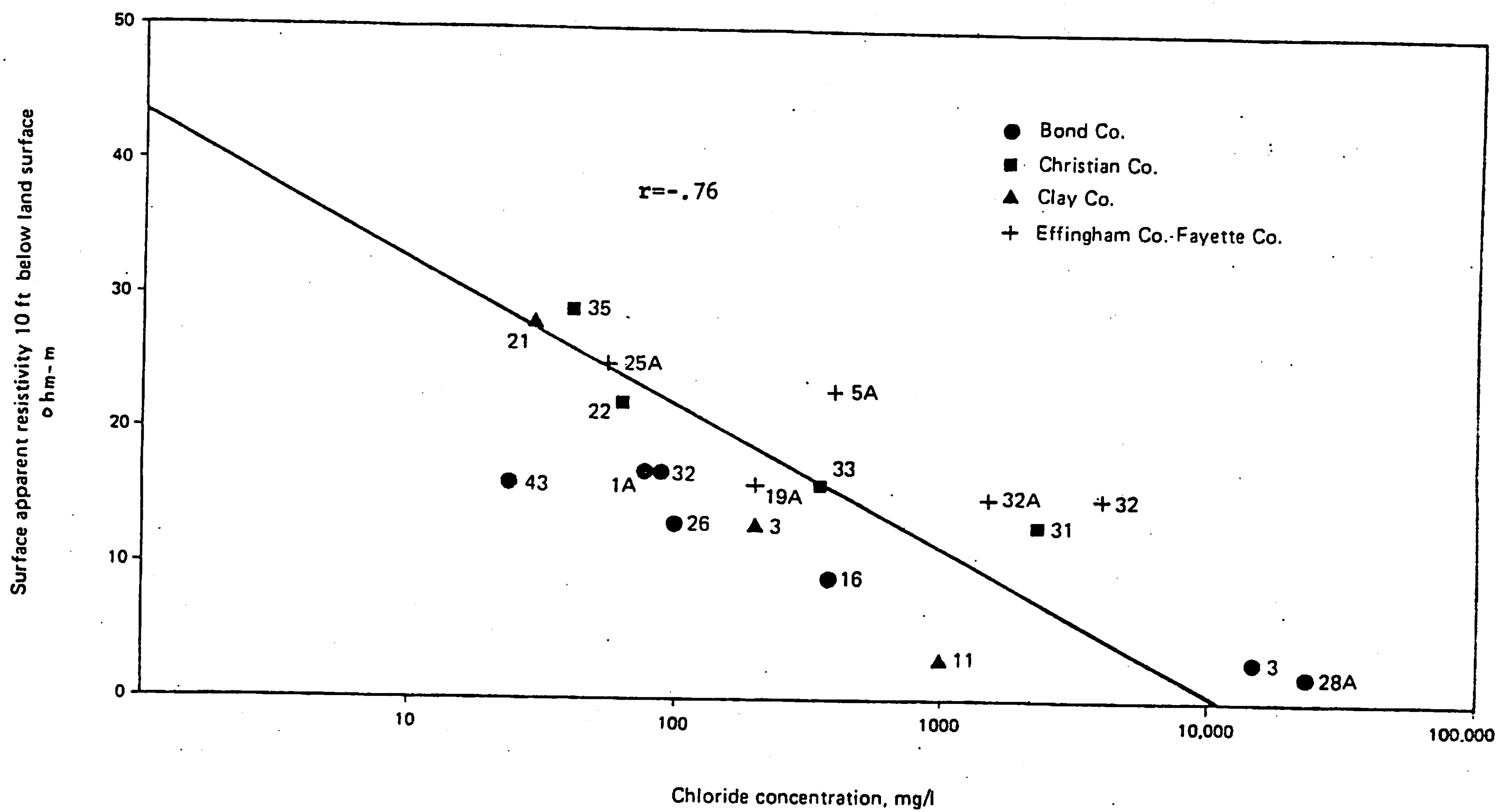

Figure 9.--Relationship of apparent resistivity and filtered chloride concentration (from Reed, 1978).

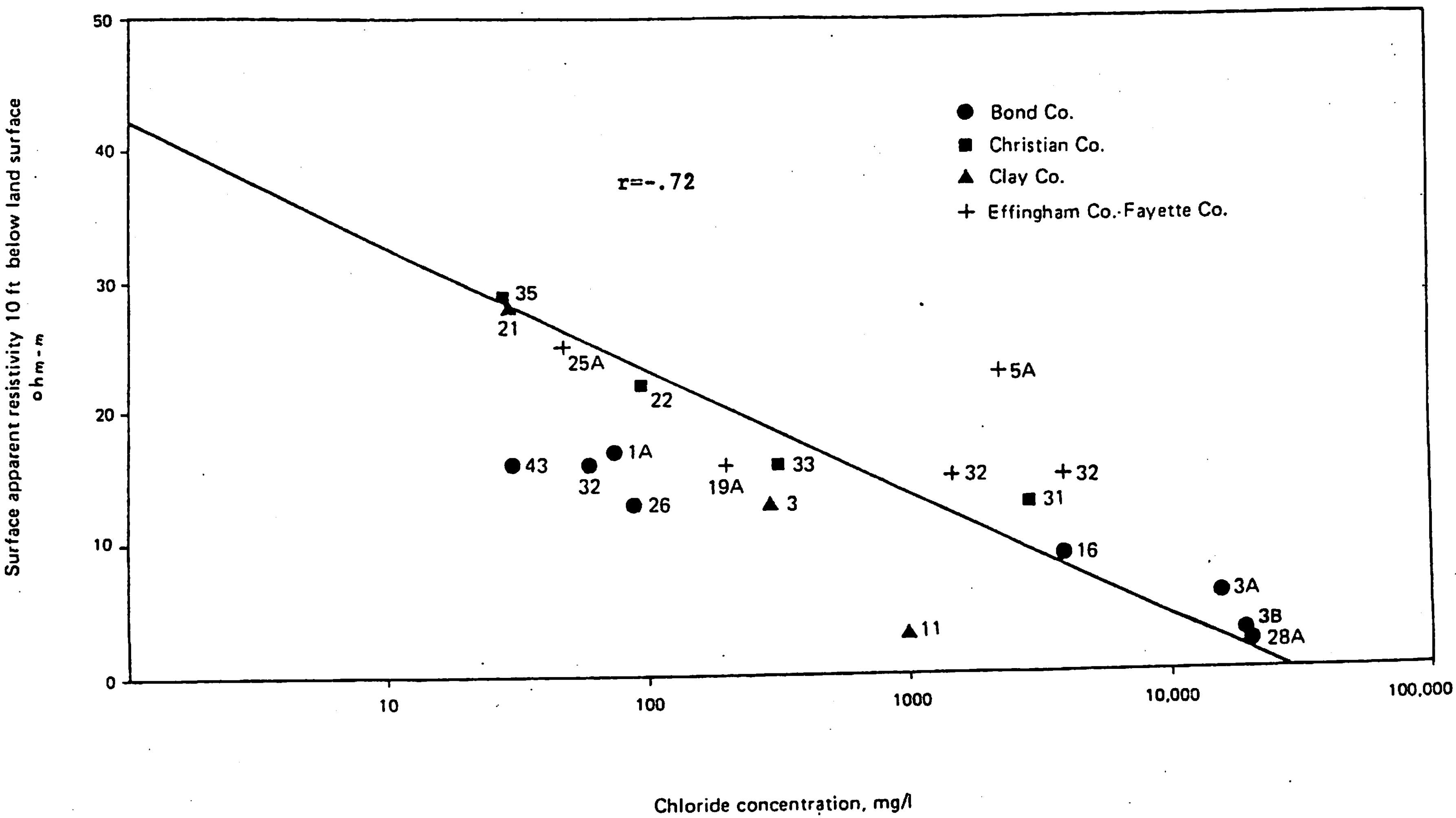

Figure 10 -- Relationship of apparent resistivity and unfiltered chloride concentrations (from Reed, 1978).

for determining the extent of subsurface oil field brine migration. Approximate chloride concentrations can also be estimated from the graphed relationship (Figures 9 and 10), given EER readings at other locations. However, since the sites in this study were confined to areas covered by the Hagarstown or similar till, additional research should be completed before making estimates of chloride concentrations in dissimilar lithologies. It is expected that further refinement of this relationship will allow chloride concentrations to be approximated with an even greater degree of accuracy and confidence in all lithologies across the state.

Field Conditions

Following is an assessment of the field conditions observed by project staff during the course of the study and a description of the three major sources of brine pollution in Illinois oil fields.

Evaporation/Seepage Pits

Evaporation pits were introduced in Illinois from the southwestern oil producing states, and rely solely or in part on evaporation for the removal of water vapor. These pits are used as ultimate disposal facilities or storage facilities pending underground injection. However, the relatively humid climate of Illinois allows little or no net evaporation throughout the year. Evaporation rates for fresh water illustrated in Figure 11 would be significantly lower for brines due to the presence of dissolved solids and oil film (Reid et al., 1974). This suggests that evaporation pits in Illinois are capable of disposing of only small volumes of brine and are totally inadequate to handle the brine disposal requirements of a producing well.

The Department of Mines and Minerals is currently in the process of phasing out the old unlined evaporation pits. Also, new evaporation pits are currently required to be lined with impervious material (for example, plastic, concrete or fiberglass) to guard against subsurface seepage of brine, whereas clay was prescribed as the lining material prior to 1973. The fact that these liners are not indestructable and do have a limited life expectancy indicates that, although the possibility of seepage may be reduced by the use of liners it is by no means eliminated.

During the initial field investigations, it was noted that the fluid levels in at least 80 percent of the estimated 200 pits inspected were being maintained above surrounding ground level. Pits displaying breached walls were also noted. In a few instances, even though the pit was perilously close to overflowing or was in fact flowing over its banks, brine input continued at a substantial rate, i.e., 5-15 gallons per minute (Plate 6).

Other brine related problems noted in the field included remnant scars from pits which had drained into nearby streams or across open land rendering it void of vegetation (Plates 7 and 8). A few of the pits exhibit darkened halos around their peripheries indicating seepage from within. These improperly constructed or maintained pits allow brines to

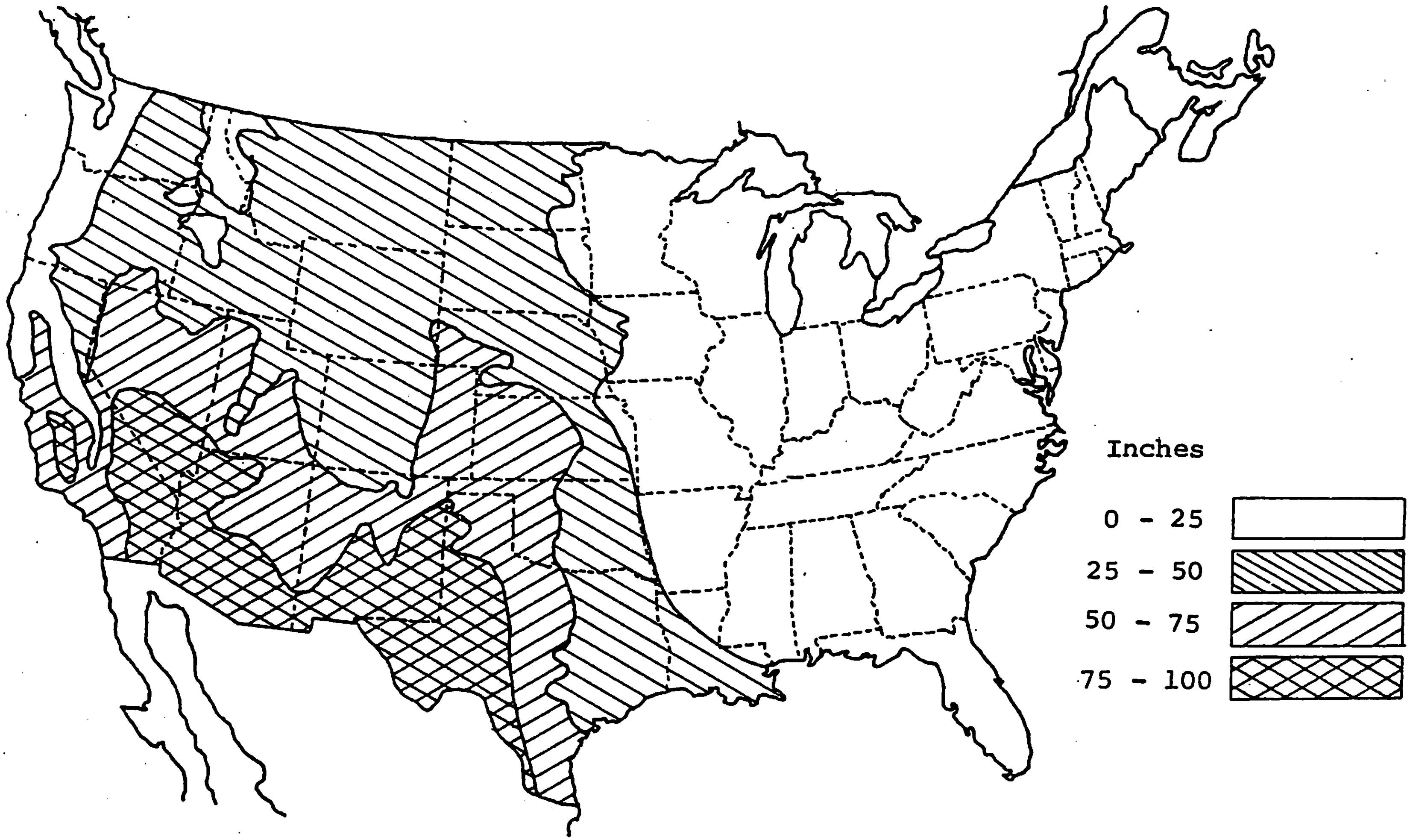

Figure11.--Map of Annual Net Evaporation in Inches (from Reed, 1978).
(pan evaporation minus precipitation)

Plate 6.--Brine Pit Overflow

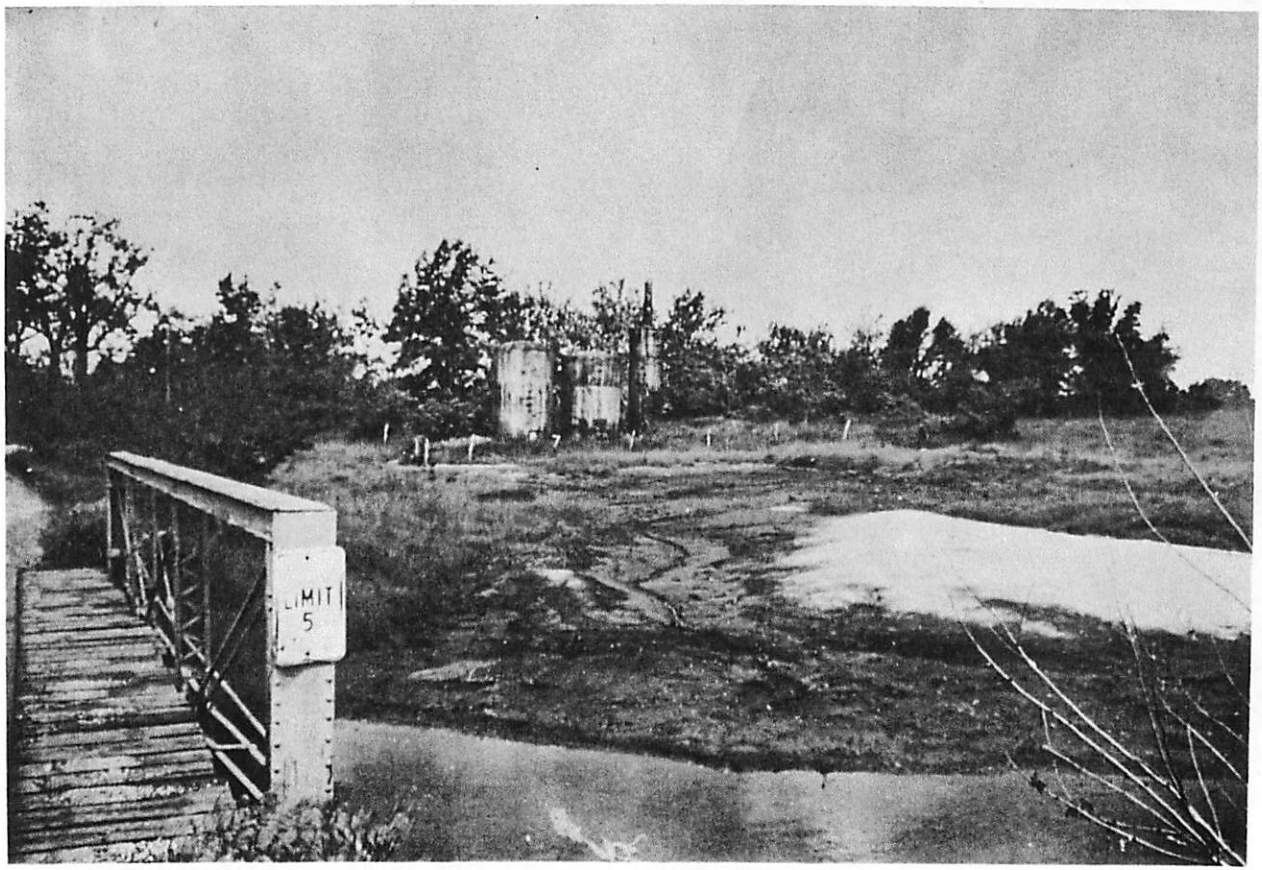

Plate 7.--Stream Pollution from Brine Runoff

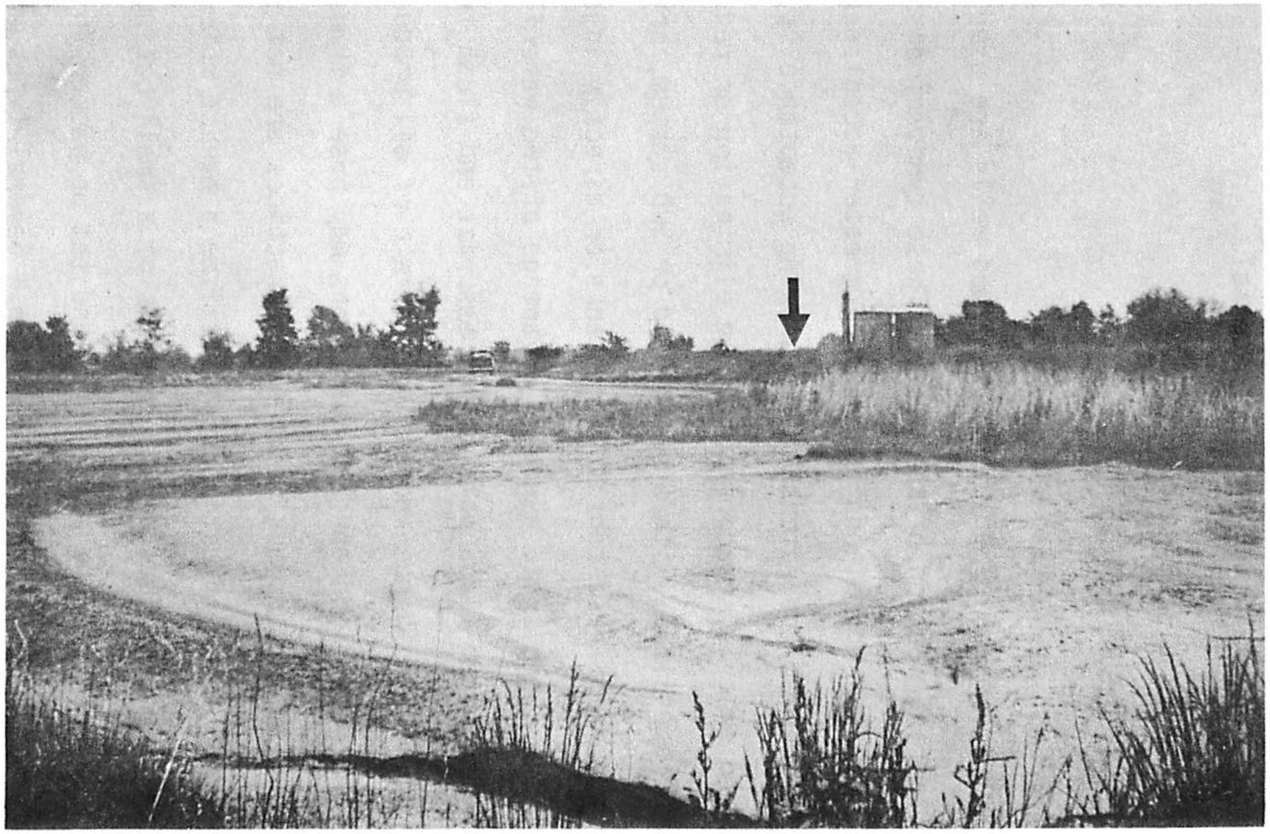

Plate 8.--Vegetation Kill from Brine Runoff
(arrow indicates location of pit)

seep into underlying soils and eventually migrate into ground water reservoirs. Once absorbed into the ground water system, the brines (particularly chlorides) can travel several miles due to their resistance against absorption into the aquifer material.

Injection Operations

Salt water disposal (SWD) and waterflood wells are used throughout the oil producing portion of the state. These types of disposal and secondary recovery operations are gaining greater acceptance from both land owners and well operators. This growing acceptance is greatly due, from the land owner's standpoint, to the elimination or reduction in the need for surface pits. With a waterflood or SWD system, brines can be stored in corrosion-resistant holding tanks or directly injected from the brine/oil separating unit. Another advantage of the waterflood operation is that the injected fluid acts to repressurize and flush through the producing formation, hence increasing the rate of oil production. However, both waterflood and SWD operations may pose a threat to ground water supplies if meticulous maintenance practices are not followed.

Many of the newer injection wells utilize a device referred to as a "tubing and packer." This device consists of a small casing or tubing which is inserted into the main casing and set or packed in place immediately above the injection formation. Several types of injection installations are illustrated in Figure 12. In addition to providing the advantage of allowing replacement of the tubing in case of failure,

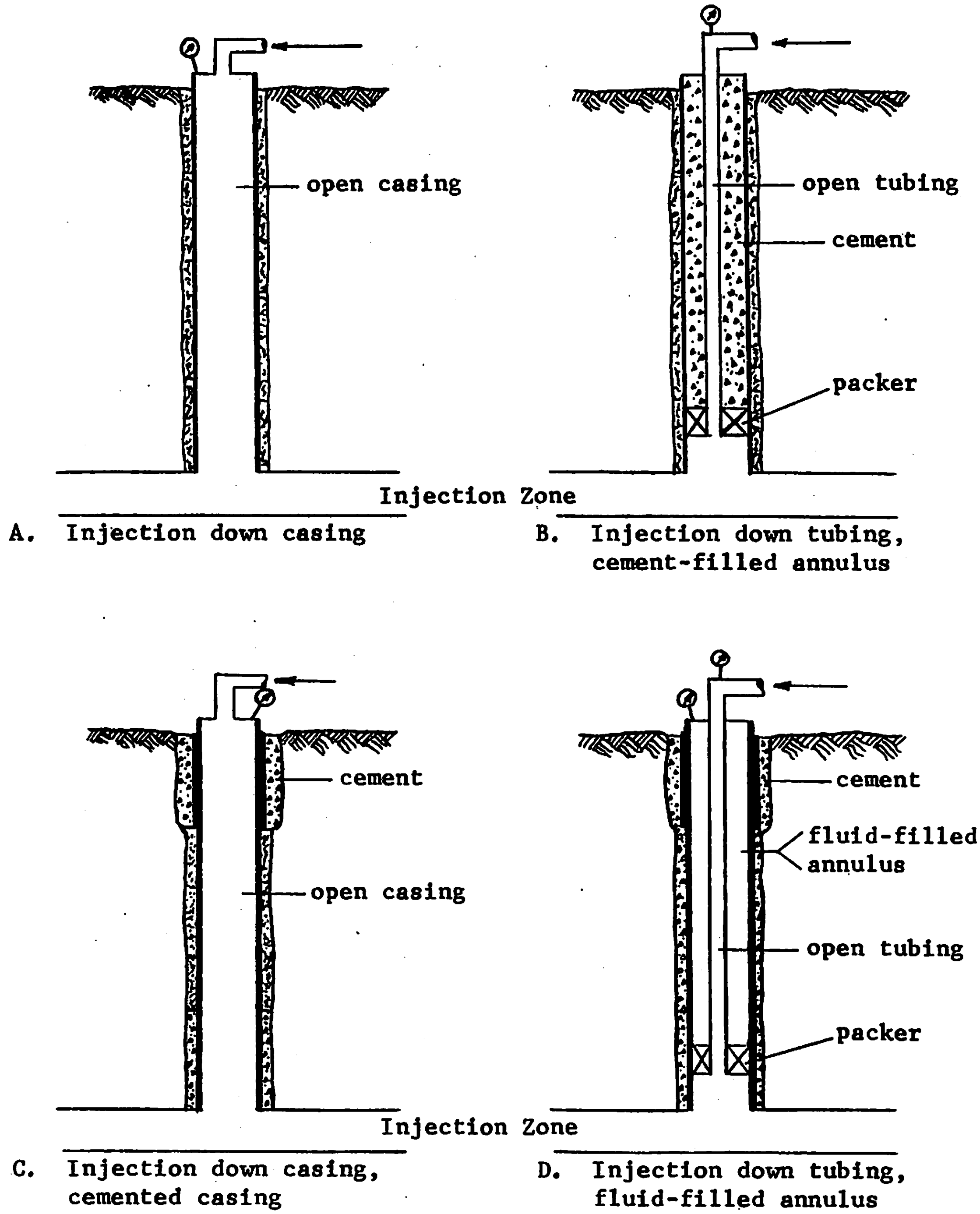

Figure 12.--Tubing and Packer Injection Installations

Injection through tubing also provides added protection to resources outside the borehole (Warner, 1977). Although all of the tubing and packer installations provide this protection initially, continued use over long periods of time may result in corrosion and eventual casing failure which can contaminate surrounding ground water. Only an injection system which allows annulus pressure monitoring, such as one with a fluid-filled annulus (Figure 12-D) provides the capability of detecting such a failure by indicating change in annulus fluid pressure. With this type of system, continued weekly monitoring of the annulus fluid pressure would reveal a failed system before a substantial volume of ground water could be contaminated.

Many of the disposal wells presently in use may be inadequately designed or constructed to facilitate the safe injection of saline waters. In the past, abandoned production wells, subject to pressure check, could be converted to SWD or waterflood wells without installing tubing and packers. Often the casing in an old well has deteriorated from years of exposure to corrosive formation fluids. Although such a casing may withstand an initial pressure check, its subsequent life expectancy could be substantially shortened. When failure does occur, chloride solutions can be expelled at injection pressure into the adjacent strata, as illustrated in Figure 13. Due to the relatively slow rate of migration and to the fact that salt water injection wells are not frequently monitored for unexpected injection pressure changes, large volumes of ground water can be polluted before casing breaks are discovered.

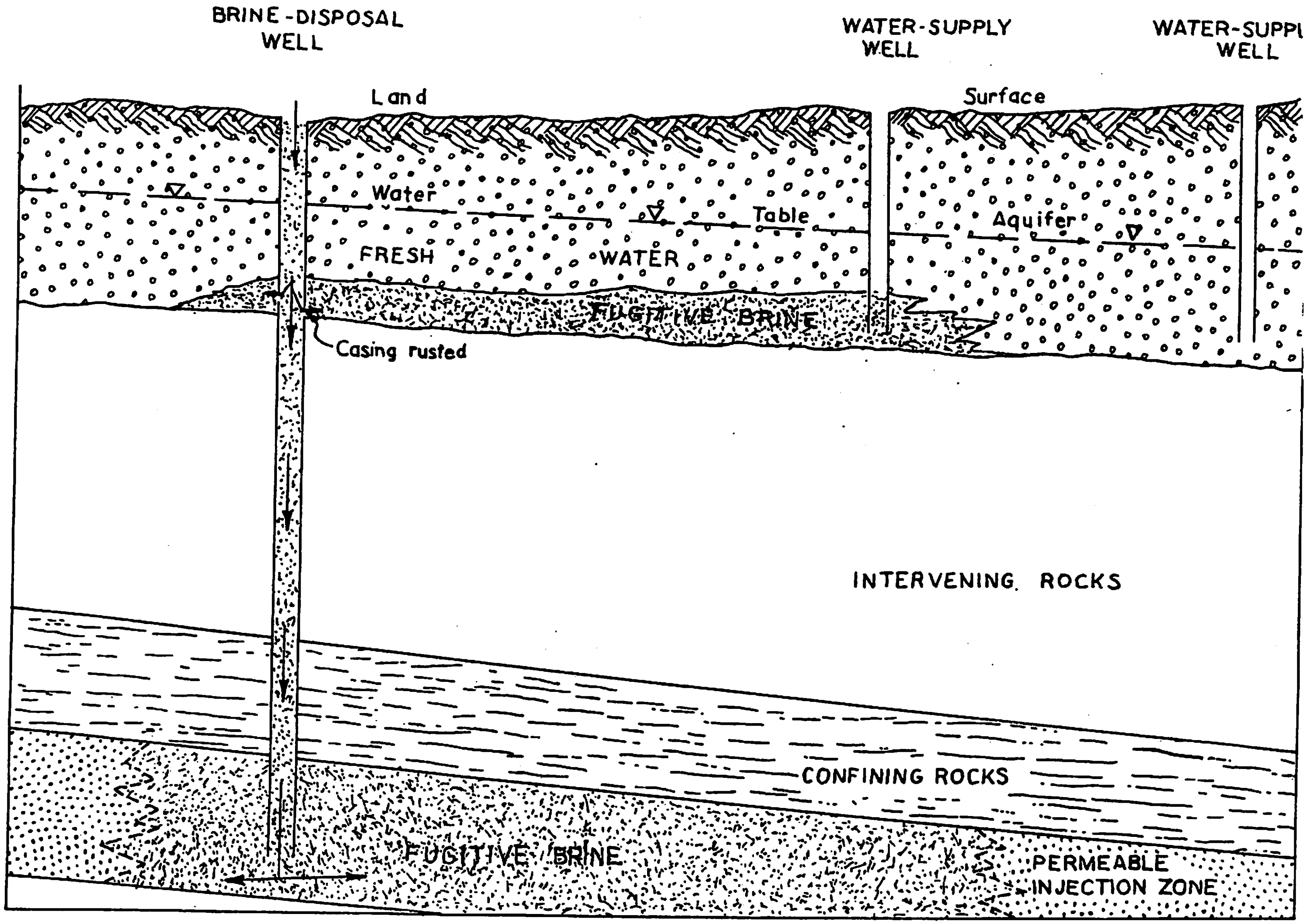

Figure 13.--Pollution of a Fresh Water Aquifer Through a Failed Injection Casing

Abandoned Wells

In old production areas, abandoned wells may pose a serious threat to ground water quality. Unplugged or improperly plugged wells provide possible vertical communication between saline and fresh water aquifers. An increase in formation pressure due to secondary recovery operations can supply the hydraulic pressure required to transfer the saline fluids from depth to an elevation adjacent to a fresh water aquifer, via an abandoned casing (Figure 14). Once this situation is established, the corrosion process and the failure of the casing are hastened.

During the relatively limited field reconnaissance, a few unplugged, uncapped and improperly plugged wells were noted. In addition to these, the records of the Illinois Department of Mines and Minerals indicate that there are thousands of plugged wells within the state. Many of these wells were plugged prior to the 1940's before plugging records and specifications were developed, and may not have retained the integrity necessary to restrict vertical migration of highly saline waters. Ultimately, the migration of saline waters through these casings could lead to the degradation of otherwise potable ground water resources.

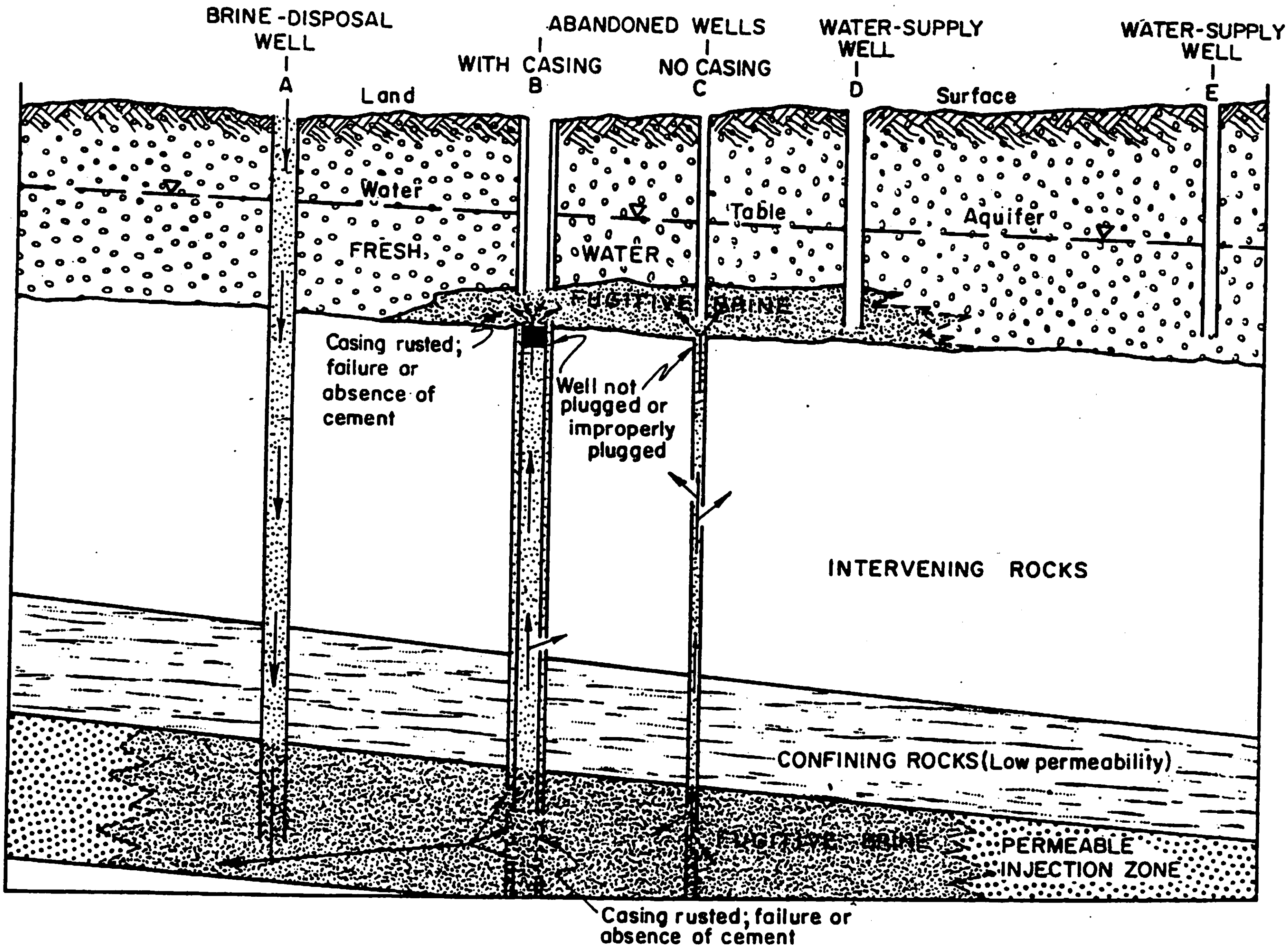

Figure 14.--Pollution of a Fresh Water Aquifer Through Abandoned Wells (from Newport, 1977)

PRELIMINARY FINDINGS

1. During field investigations, ground water contamination at four study sites was found to be more extensive than the damage visible at the surface. This indicated substantial seepage from beneath the four brine holding ponds.

2. Analysis of stream samples obtained at a study site in Bond County exhibited high chloride concentrations. This was most likely due to highly saline waters seeping from beneath a nearby brine holding pond, into the aquifer which serves as a recharge source for the stream. Chloride concentrations recorded 200 feet downstream from the pond (i.e, 14,500 ppm, a value far greater than the maximum contaminant level of 500 ppm set by the Illinois Pollution Control Board) were equivalent to those recorded within the pond. This situation indicates the impact of improperly handled brines on water quality.

3. A correlation coefficient (r) of -.76 was found between ground water quality data (chloride concentrations) and surface electrical earth resistivity measurements obtained at each site. This degree of correlation suggests that EER surveys can be used as a valid method in studying subsurface migration of oil field brines.

4. From field observations, it was noted that a larger incidence of brine related pollution appeared to emanate from older facilities. This is probably due in part to advanced stages of corrosion of well casings, and increased brine/oil ratios.

5. Taking into account the damaging effects of brine pollution and the volume of salt water disposed of daily, it is evident that strict enforcement of existing regulatory guidelines for the disposal of oil field brines is essential for the protection of currently utilized and potential ground water sources.

PRELIMINARY RECOMMENDATIONS

1. The Department of Mines and Minerals and the Illinois EPA should investigate a means to accelerate the program, initiated in 1973, for eliminating unlined brine pits. A target date with annual goals should be established for phasing out the estimated 4,000 remaining brine pits in Illinois.

2. All injection wells should be constructed with an annulus that can be pressure-monitored. The pressure on such an annulus should be monitored weekly to insure early detection of any failures in the system. This construction and recording requirement should be considered by the Illinois EPA in its review of the pending federal underground injection control program developed under provisions of the Safe Drinking Water Act.

3. Illinois EPA should continue geophysical and water quality testing to better assess the surface and subsurface impacts of brine pollution across the state. In addition to assessing the extent of pollution, investigations into feasible means of rehabilitating chloride contaminated aquifers and soils should be made through proposals for federal funding from the USEPA.

4. A detailed professional legal assessment should be made by the Illinois EPA of all current and proposed regulatory programs pertaining to the disposal of oil field brine.

GLOSSARY

Annulus: The space between the tubing casing and the long string or outside casing.

Anticlinal Belt: A series of folds in the underlying geology that are convex upward or had such an attitude at some stage of development.

Apparent Resistivity: The resistance of rock or sediment to an electrical current per unit volume as measured by a series of current and voltage electrodes on the surface of the earth. It is equivalent to the actual resistivity if the material is truly uniform.

Aquifer: A porous, permeable, water-bearing geologic body of rock or sediment, generally restricted to materials capable of yielding an appreciable amount of water.

Back-filled: The refilling of an augered hole with earth material after emplacement of the casing.

Bentonite Sealed: The sealing of the permeable reservoir from the back-fill material by covering the reservoir with a water absorbing clay material, bentonite.

Cations: An ion that bears a positive charge.

Correlation Coefficient: A dependency or association factor between two parameters. Coefficients range from -1 to 1 with the mid-point 0 indicating a total lack of correlation.

Corrositivity: The ability to deteriorate or destruct substance or material by chemical action.

Formation: A uniform body of rock; it is most often tabular and is mappable on the earth's surface or traceable in the subsurface.

Gamma Log: A graph of the natural radioactivity of rocks obtained by lowering a gamma ray probe into a bore hole.

Gamma Ray Probe: (Geiger-Mueller) A probe or counter capable of measuring the intensity of radioactivity in the surrounding rock.

Gradient: (Hydrological) Slope of the regional water table.

Gravel-Packed: Placement of gravel around the open portion of a casing to provide a permeable reservoir for inflowing waters.

Ground Water Pollution: (As defined for this report.) The elevation of chemical constituent concentrations (primarily chlorides) above those existing naturally in the regional ground water.

Hydrofracing: Process of increasing the permeability of rock near a well by pumping in water and sand under high pressure.

Hydrogeology: The study of ground water movements in the underlying geology.

Illinois Basin: The structural basin in southeast central Illinois in which the rocks dip generally toward a central point.

Interstitial: That which exists within an opening of space in a rock or soil that is not occupied by solid matter.

Leachate: A solution obtained by leaching, as in the extraction of soluble substances by the downward percolation of rain water through soil or solid waste.

Lithologies: The physical characteristics of rocks such as color, structures, mineralogic composition, and grain size.

Loess: A uniform, nonlayered deposit of silt, fine sand and/or clay.

Permeable: Having a texture that permits water to move through it.

Piezometer: A casing providing access to the static water level in an aquifer, and through which ground water samples may be extraced.

Potential Distribution: The resulting dispersion of an electrical current artifically introduced into the ground.

Reef Deposits: A mound-like or layered rock structure initially built by organisms such as corals and subsequently buried by sediment.

Till: Nonsorted, nonlayered sediment carried or deposited by a glacier.

Water Transmission Zone: A zone of material below the surface of the earth capable of transmitting water.

Waterfloods: The secondary recovery operation in which water is injected into a petroleum reservoir for the purpose of increasing oil production.

REFERENCES

1. Bell, A. H., 1957, Brine Disposal in Illinois Oil Fields: Illinois State Geological Survey, Circular 244.

2. Cartwright, K., Sherman, F. B., Jr., 1972, Electrical Earth Resistivity Surveying in Landfill Investigations: Illinois State Geological Survey Reprint Series 1972 U, Reprinted from Proceedings of the 10th Annual Engineering and Soils Engineering Symposium, Moscow, Idaho, 16 p.

3. Department of Mines and Minerals, Division of Oil and Gas, 1977, An Act in Relation to Oil, Gas, Coal and Other Suirface and Underground Resources, Revised Edition.

4. Department of Mines and Minerals, 1976, Annual Coal, Oil, and Gas Report.

5. Flemal, R. C., 1978, Preliminary Evaluation of the Impact of Saline Groundwater Brines on the Quality of Illinois Surface Waters, Illinois Water Information System Group.

6. Graf, D. L., Meents, W. F. Friedman, I., Shimp, N. F., 1966, The Origin of Saline Formation Waters, III: Calcium Chloride Waters: Illinois Geological Survey Circular 397.

7. Guyod, H., 1952, Electrical Well Logging Fundamentals: Houston, Texas, Reprinted from Oil Weekly and other magazines, 164 p.

8. Illinois Pollution Control Board Rules and Regulations, 1977, Chapter 3: Water Pollution.

9. Jacobs, A. M., Linebach, J. A., 1969, Glacial Geology of the Vandalia Region: Illinois Geological Survey, Circular 442, 23 p.

10. Mast, R. F., 1970, Size, Development, and Properties of Illinois Oil Fields: Illinois Petroleum 93, Illinois State Geological Survey, Urbana, Illinois 61801.

11. Meents, W. F., Bell, A. H., Rees, O. W., Tilbury, W. G., 1952, Illinois Oil-Field Brines Their Geologic Occurrence and Chemical Composition: Illinois Petroleum 66 Illinois State Geological Survey, Urbana, Illinois.

12. Newport, B. D., 1977, Salt Water Intrusion in the United States: Environmental Protection Agency Research Paper, EPA-600/8-77-011.

13. Parasnis, D. S., 1972, Principles of Applied Geophysics, Chapman and Hall, London.

14. Reed, P. C., 1978, Results of Electrical Resistivity Surveys Near Brine Holding Ponds in Illinois: Unpublished.

15. Reid, G. W., Streebin, L. E., Canter, L. W. Smith, J. R., 1974, Brine Disposal Treatment Practices Relating to the Oil Production Industry: Environmental Protection Technology Series EPA-660/2-74-037, May, 1974.

16. Roberts, W. J., Stall, J. B., 1967, Lake Evaporation in Illinois: Illinois State Water Survey Report of Investigations 57, 44 p.

17. Van Den Berg, J., Lawry, T. F., 1977, Petroleum Industry in Illinois, 1976: Illinois Petroleum 112, Illinois State Geological Survey, Urbana, Illinois 61801.

18. Warner, D. L., 1977, An Introduction to the Technology of Subsurface Wastewater Injection: Environmental Protection Technology Series EPA-600/2-77-240.

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APPENDIX A

Problem Report Form

Illinois Environmental Protection Agency

"208" CLEAN WATER MANAGEMENT PLANNING PROGRAM
OIL FIELD BRINE DISPOSAL PROBLEM REPORT

PLEASE READ

Because of reports from concerned citizens like yourself, the Illinois Environmental Protection Agency is conducting a detailed study of water pollution problems associated with oil field brine disposal in your area of the state.

The purposes of this study are to determine how existing brine disposal problems can be solved most effectively, and how we can better ensure that no additional problems are created in the future.

In order to help us, please take a minute or two and fill out the attached Problem Report. It asks only for basic information to assist us in becoming familiar with problems you may know about.

If you wish to be kept informed of the progress of this study or would like to talk with us directly, please fill in your name and address. THIS PROBLEM REPORT IS NOT AN OFFICIAL COMPLAINT OR OTHER LEGAL DOCUMENT AND CANNOT BE USED IN ENFORCEMENT PROCEEDINGS.

The ILLINOIS DEPARTMENT OF MINES AND MINERALS, Oil and Gas Division, is responsible for investigating public complaints concerning oil field brine disposal. If you wish to file an official complaint, you should contact: Mr. George Lane; Oil and Gas Division, Illinois Department of Mines and Minerals, 704 Stratton State Office Building, 400 South Spring Street, Springfield, Illinois 62706, Phone (217) 782-7756.

Please return the completed form to the person named below. Feel free to contact him if you have any questions about this study:

Donald R. Osby
Illinois Environmental Protection Agency
Planning and Standards Section
Division of Water Pollution Control
2200 Churchill Road
Springfield, Illinois 62706
Phone (217)782-3362

You may tear off this sheet and keep if for reference.
Thank you for your participation.

DO:bl/2111/8

2200 Churchill Road, Springfield, Illinois 62706

"208" CLEAN WATER MANAGEMENT PLANNING PROGRAM

OIL FIELD BRINE DISPOSAL PROBLEM REPORT

Date: Meeting Place (Town):

I. GENERAL INFORMATION

Citizen Name and Address:

Well Operator or Lessee Name and Address, if known:

This individual is: ____ well operator ____ lessee (check one).

Well Location:

County:____________________ Township____________________ (if known)

Range ____________________ (if known)

Section ____________________ (if known)

(If possible, locate well on the county map.)

II. BRINE PROBLEM INFORMATION

Well Operation:

Is the well presently producing oil? ___Yes ___No

If not, how long has the well been out of production?

Disposal System:

What type of brine disposal system if being used?

____Evaporation ponds ___Injection wells ___Other ______

(specify)____

Pollution Affects:

What are the affects of the brine pollution?

_____ Damage to vegetation _____ Contamination of water supply

_____ Other (specify)____

____

Problem:

What is the nature of the problem:

______ Leaking pond _____ Broken pipe ______ Faulty firewall

____ Other (specify)____

When was the problem first noted?

____

Has anyone been notified of the problem? _____Yes _____No

If so, whom and when?____

____

Have any actions been taken? _____Yes _____No

If so, by whom and what actions? ______________________________

____

APPENDIX B

Selected Samples of
Previously Completed E.E.R. Studies

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
JOAN G. ANDERSON
DIRECTOR, SPRINGFIELD

ILLINOIS STATE GEOLOGICAL SURVEY
NATURAL RESOURCES BUILDING, URBANA, ILLINOIS 61801 TELEPHONE 217 344-1481
Jack A. Simon, CHIEF

September 2, 1977

A RECONNAISSANCE ELECTRICAL EARTH RESISTIVITY SURVEY AT A BRINE DISPOSAL PIT IN SECTION 31, T. 4 N., R. 2 W., BOND COUNTY, ILLINOIS

By

Keros Cartwright, Geologist and Head
Philip C. Reed, Assistant Geologist
Hydrogeology and Geophysics Section

Introduction

At the request of Mr. George R. Lane, Department of Mines and Minerals, State Office Building, Springfield, Illinois, 62706, a reconnaissance electrical earth resistivity survey was made on August 16, 1977, within and adjoining the Dwight Follett lease, Beaver Creek Field, in the NW¼ Section 31, T. 4 N., R. 2 W., Bond County. We were assisted in the fieldy by Mr. Leonard Strum from the Department of Mines and Minerals. The purpose of the study is to determine if the brine in the pit on the lease is leaking to the ground-water reservoir and, if it is leaking, to determine the distribution of the salt water wedge.

Hydrogeologic Setting

The brine pit is located in a region of gently sloping terrain of the Illinois till plain between Greenville and Carlyle, Illinois. There are a number of oil well logs from the immediate area in the Geological Survey files, including two on the Follett lease. Copies of the first page of these logs are attached. Unfortunately, the description of the surficial material is very poor and often contradictory. The logs do suggest the presence of a sandy or gravelly zone at 10 to 15 feet below land surface. This interpretation is consistent with our regional stratigraphic information.

The site is similar to two sites studied in detail about 10 miles to the south. There are four glacial tills in this region. The uppermost till is the Hagerstown, which is the sandy, gravelly till forming the prominent ridges in the region. The hills being quarried for sand and gravel just south of the brine pit consist of a thick Hagerstown sequence. On lower flat ground such as that found around the brine pit, the Hagerstown is quite thin and found at depths of 10 to 20 feet. The clayey Vandalia till underlies the Hagerstown; overlying the Hagerstown is a sequence of gleys and silts (loesses). Generally, the Hagerstown and overlying sediments have undergone several episodes of soil genesis, beginning with the formation of the Sangamon soil, continuing through two or more periods of soil genesis during the Wisconsinan and culminating with the modern soil formation. The Hagerstown beds and some sandy zones associated with the overlying loesses are relatively permeable.

A generalized observation of the hydrogeology can be made from analysis of the topography of the area near the brine pit. Our observations of the topography indicate that if any brine is entering the ground water it would flow north or north-northwest to the small, unnamed stream (a tributary to Beaver Creek) which flows across the northwest corner of Section 31. Discharge of ground water would occur along the creek and possibly in the small drainage swale which transverses, in a northeasterly direction, the property just north of the pit.

Resistivity Survey

The electrical earth resistivity survey is based on the principle that uncontaminated, compact glacial till, clay-alluvium and shale present more resistance to the passage of an electrical current than do sand and gravel, or sandstone and limestone of the bedrock. However, resistance to the passage of electricity through earth materials is a property of both the rock type and the water contained in its pores. Electrical current introduced in earth material containing water with high concentration of soluble salts will have a greatly reduced electrical resistance. This relationship has been demonstrated in numerous published papers; it has also been demonstrated that electrical earth resistivity surveying can be used to map contaminated ground water (see enclosure).

Results

During the survey of the pit area, we made 23 electrical depth sounding profiles. The accompanying map, modified from the one made by Clifford H. Simonson for Mr. Arnold R. Edwards, shows the approximate location of the resistivity soundings. Also enclosed are copies of all the depth soundings; no profile could be obtained at station no. 14 because surface conductance prevented penetration of the electrical field into the ground. In normal, uncontaminated, uniform materials the "a" spacing (taken from the geometry of the Wenner electrode configuration we used) is approximately equal to the depth of penetration of the electrical field. However, a very conductive layer (very low resistivity) such as a salt water zone, will disturbe the electrical field, reducing the depth of penetration.

We drew slice maps for all "a" spacing from 10 to 50 feet. All show the same relationship; a region of greatly depressed apparent resistivity extending northwestward from the pit to the stream. This region of depressed resistivity is shown on the accompanying map. Resistivity stations showing normal profiles are numbers 1, 10, 11, 12, 13, 17, 19 and 23. Station numbers 3, 4, 5, 6, 14, 15, 20 and 21 are strongly effected by highly conductive material. Station numbers 2, 7, 8, 9, 16, 18 and 22 are intermediate.

Two characteristics of the depth sounding profile taken in the strongly effected area are apparent. The first type, best shown at station no. 15, shows a decline in resistivity values from the initial reading at a = 10 feet. This suggests that the surface soils do not have significant accumulations of electrolites. Stations showing this characteristic, numbers 3, 4, 5, 6, 9 and 15, are all in soil with good crop vegetative cover (except number 15 which is a grassy part of the fallow field).

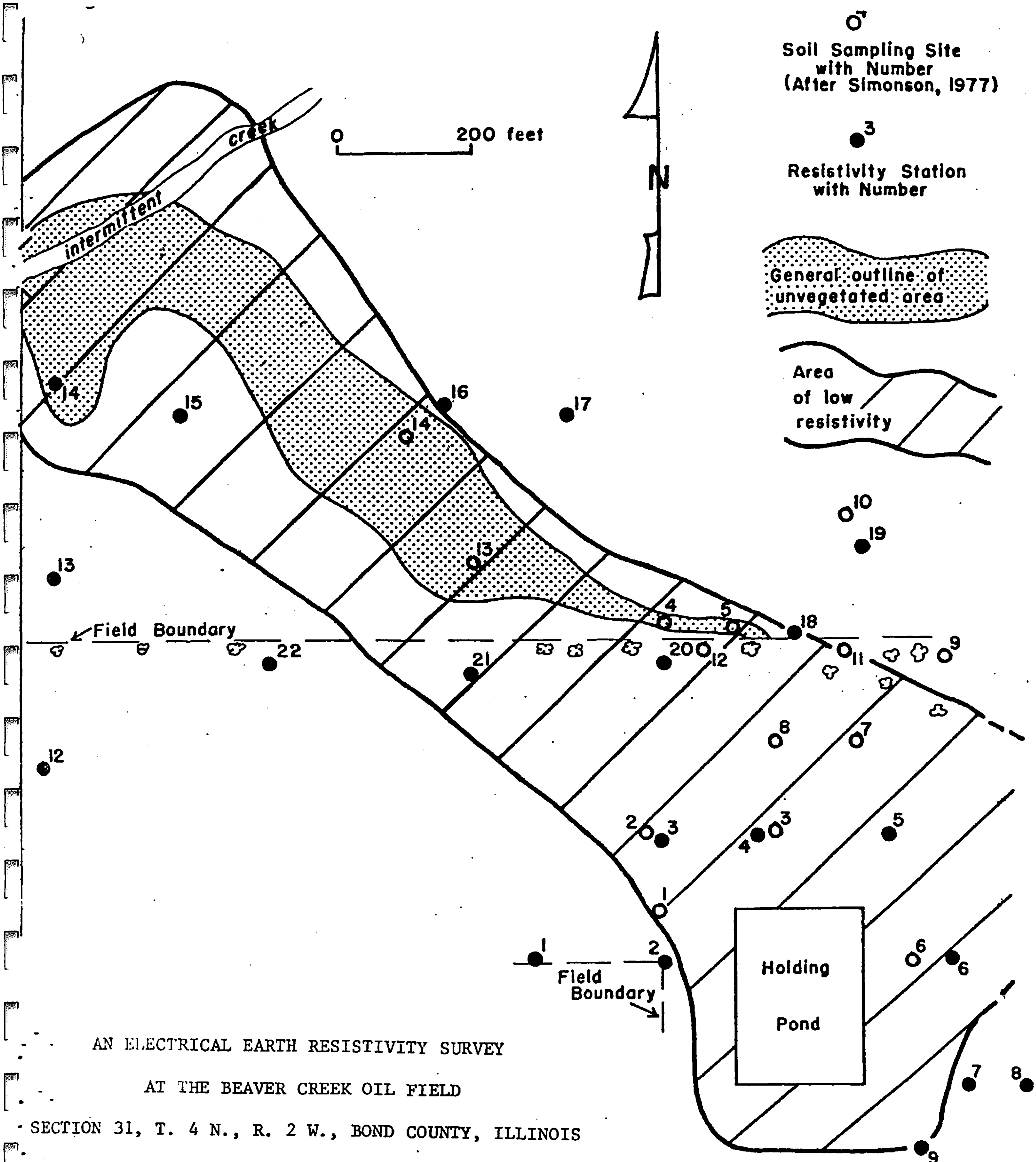
The second type of depth sounding profile is illustrated at station no. 14 where no reading could be obtained because of the accumulation of electrolites at the surface. Several attempts were made to obtain depth sounding in the unvegetated area between stations 14 and 16, but none could be obtained. Station no. 16 shows a similar low surface resistivity but the decrease is much less severe.

Discussion

The electrical earth resistivity data appears to verify the hydrogeologic evaluation based on topographic analysis and the regional geologic interpretations. This data shows that an electrolite, almost certainly salt water brine from the pit, is entering the ground-water system and moving northwestward toward the small creek. The brine would move downward from the pit and then laterally in the permeable Hagerstown beds. This is consistent with our interpretation of the resistivity data illustrated by the type of depth sounding profile at station no. 15, etc. In the lower unvegetated areas along the drainage swale and at the creek there would be an upward ground-water gradient bringing salts to the surface. This interpretation is supported by the electrical earth resistivity data around stations 14 to 16.

To travel from the pit to the creek, a distance of approximately 1500 feet, in 35 years, the water would have to be moving in a zone more permeable than normal clayey till. The sandy Hagerstown beds could provide such a zone of ground-water movement.

In summary, the electrical earth resistivity survey strongly suggests the presence of a wedge of salt water extending from the brine pit on the Follett lease northwest to the creek where the vegetation kill has occurred. This is consistent with the geology of the area and the generalized interpretation of the hydrogeology based on observations of the topographic relationships.



AN ELECTRICAL EARTH RESISTIVITY SURVEY

AT THE BEAVER CREEK OIL FIELD

SECTION 31, T. 4 N., R. 2 W., BOND COUNTY, ILLINOIS

August 1977 Cartwright, Reed

Hydrogeology and Geophysics Section

Illinois State Geological Survey, Urbana, IL

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION
JOAN G. ANDERSON
DIRECTOR, SPRINGFIELD
BOARD OF NATURAL RESOURCES AND CONSERVATION

ILLINOIS STATE GEOLOGICAL SURVEY
NATURAL RESOURCES BUILDING, URBANA, ILLINOIS 61801 TELEPHONE 217 344-1481
Jack A. Simon, CHIEF

December 14, 1977

A RECONNAISSANCE ELECTRICAL EARTH RESISTIVITY SURVEY ON THE CHARLES VONDER HAAR FARM, SECTIONS 8 AND 17, T. 3 N., R. 2 W., CLINTON COUNTY, ILLINOIS

By

Philip C. Reed, Assistant Geologist
Keros Cartwright, Geologist and Head
Hydrogeology and Geophysics Section

At the request of Mr. George R. Lane, Department of Mines and Minerals, State Office Building, Springfield, Illinois, 62706, a reconnaissance electrical earth resistivity survey was made on November 3, 1977, on the Charles Vonder Haar Dairy Farm situated near the Keyesport Oil Field in the SW¼ Section 8 and the NE¼ Section 17, T. 3 N., R. 2 W., Clinton County, Illinois. Assisting in the field work were Mr. Leonard Sturm, 312 West Commerce, Grayville, Illinois, 62844, from the Department of Mines and Minerals and Mr. Charles Vonder Haar, R. R. #1, Carlyle, Illinois, 62231. A separate request by Mr. Charles E. Fisher, Jr., Oil Producer, Box 369, Mt. Carmel, Illinois, 62836, was received on November 14, 1977. Information on the location of abandoned oil wells and oil tests, producing and injection wells, and cultural features at and near the farm was furnished by Mr. Fisher. The purpose of the study was to determine the distribution of the salt water within the ground-water reservoir or aquifer utilized at the farm for water supply and if possible, to determine the origin of the salty water so that the water quality in the aquifer can be restored to the original condition. During the study, particular emphasis was made to resolve the question of whether the presence of salty water in the Vonder Haar farm well is related to disposal of brines by reinjection into the oil producing horizon.

Hydrogeologic Setting

The Vonder Haar farm is located at the northernmost part of the Keyesport Oil Field in a region of kame and esker-like hills on the Illinoian till plain west of the Carlyle Reservoir. A hill immediately south of the farm residence has about 20 feet of relief, while one mile to the north another hill rises about 50 feet above the till plain. Well logs from the Geological Survey files in the study area attached with this report give data on the earth materials in Sections 7, 8, 16, 17 and 18, T. 3 N., R. 2 W. The logs indicate that 20 to 60 feet of unconsolidated materials, primarily of glacial origin, overlie the Pennsylvanian-age bedrock. The bedrock consists of relatively impermeable shale and limestone with minor beds of sandstone and coal.

At the Vonder Haar farm, driller's logs and natural gamma logs (enclosed) run by the Geological Survey indicate that the glacial drift thickness is about 28 feet, consisting of about 6 to 18 feet of silty sandy clay which in turn is underlain by as much as 14 feet of gravelly sand lying directly on the bedrock. Two large diameter water wells tapping the gravelly sand are utilized for supply on the farm. Well no. 1, completed in 1969, is situated about 400 feet north of the residence and well no. 2, completed in 1976, is located about 300 feet east of the residence. A large diameter well reported to be 14 feet deep is immediately west of well no. 1. On the hill immediately south of the farm in the Keyesport Oil Field in Section 17, T. 3 N., R. 2 W., the drift section reportedly consists of about 55 feet of clay and gravel. Regional stratigraphic studies by the Survey in the Carlyle area indicate that these glacial materials are associated with the Hagerstown Member of the Glasford Formation of Illinoian age. Hills mined for sand and gravel two miles north of the Vonder Haar farm are part of the Hagerstown Member.

The deposits of significance in this study are the permeable sand and gravel beds above the bedrock which form the ground-water reservoir at relatively shallow depths. These beds are subject to contamination while sources of pollution are available. Water entering the ground-water reservoir from rainfall will move from higher to lower elevations and eventually discharge into Allen Branch to the east or move westward toward the unnamed drainageway in Section 8. Similarly, oil field brines entering the ground-water reservoir from holding ponds would move outward from the upland areas into the lowland in the vicinity of the farm.

Resistivity Survey

The electrical earth resistivity survey is based on the principle that uncontaminated, compact glacial till, alluvial clay and shale present more resistance to the passage of electrical current than do sand and gravel, or sandstone and limestone of the bedrock. The passage of electrical current through earth materials is a property of the rock type and the water contained in rocks. Electric current introduced in earth materials containing water with a high concentration of soluble salts will have greatly reduced electrical resistance. This relationship has appeared in many published studies and has been used in electrical earth resistivity surveying to map contaminated ground water (see Illinois State Geological Survey Reprint 1972-U entitled Electrical Earth Resistivity Surveying in Landfill Investigations).

Collection of Field Data

During the study on the Vonder Haar farm, electrical depth sounding profiles were made at 29 resistivity stations using the Wenner electrode configuration. The locations of the resistivity stations are shown on an enlarged section of the Keyesport Quadrangle Topographic Map 7.5-minute series modified in part to conform to information supplied by Mr. Charles E. Fisher, Jr. Profiles of the depth soundings of each resistivity station are attached with this report. In normal uncontaminated, uniform materials the "a" spacing of the Wenner configuration is approximately equal to the depth of penetration of the electrical field. However, if a very conductive (low resistance) layer such as a salt water zone is present, the electrical field will be somewhat distorted reducing the depth of penetration.

Iso-resistivity contour maps showing apparent resistivity, were constructed for "a" spacing depths of 5, 10, 20 and 30 feet. These maps indicate a region of greatly depressed apparent resistivity surrounding the north part of the Keyesport Oil Field extending outward into the Vonder Haar farm. The contour map for the

20-foot "a" spacing is included with the modified quadrangle map of this report. Station nos. 1, 2, 3, 10, 14, 15, 16, 18, 19, 26 and 27 are affected by highly conductive materials, presumably saltier water. These stations are in contrast to station nos. 7, 17, 21, 22 and 23 where readings are near normal due to little or no accumulation of electrolites in the earth materials. The relationship between the apparent resistance of the aquifer materials and their contained water near the pumped wells on the Vonder Haar farm is given below using Illinois State Water Survey water analyses (enclosed) from wells 1 and 2 and a well of similar depth on the Olsen farm (obtained in 1970) about one mile north from the contaminated area.

	Apparent Resistivity (ohm meters) 20-foot "a" spacing	Chloride Concentration (Cl)
Well #1	15	1060
Well #2	20	150
Olsen Well	25 (estimated)	64

These data demonstrate the relationship between the apparent resistivity and chloride ion concentrations present in the drift aquifer. As the chloride concentration diminishes the apparent resistivity increases due to the lower concentration of soluble salts.

Conclusion

The electrical earth resistivity survey data are in agreement with the hydrogeologic evaluation in the study area based on the topographic analysis of the regional and on site geologic interpretation. Information collected during the study shows the presence of a circular wedge of salt water around the abandoned brine holding ponds extending from the ponds along the north perimeter of the Keyesport Oil Field into the Charles Vonder Haar farm lot area. There are no data which show conclusively whether the reinjection of produced brine is or is not related to the water quality problem on the farm.

The presence of poor quality water on the Vonder Haar farm may have resulted for one or more of several possible explanations. They are listed below in the order from those we think most likely to those least likely:

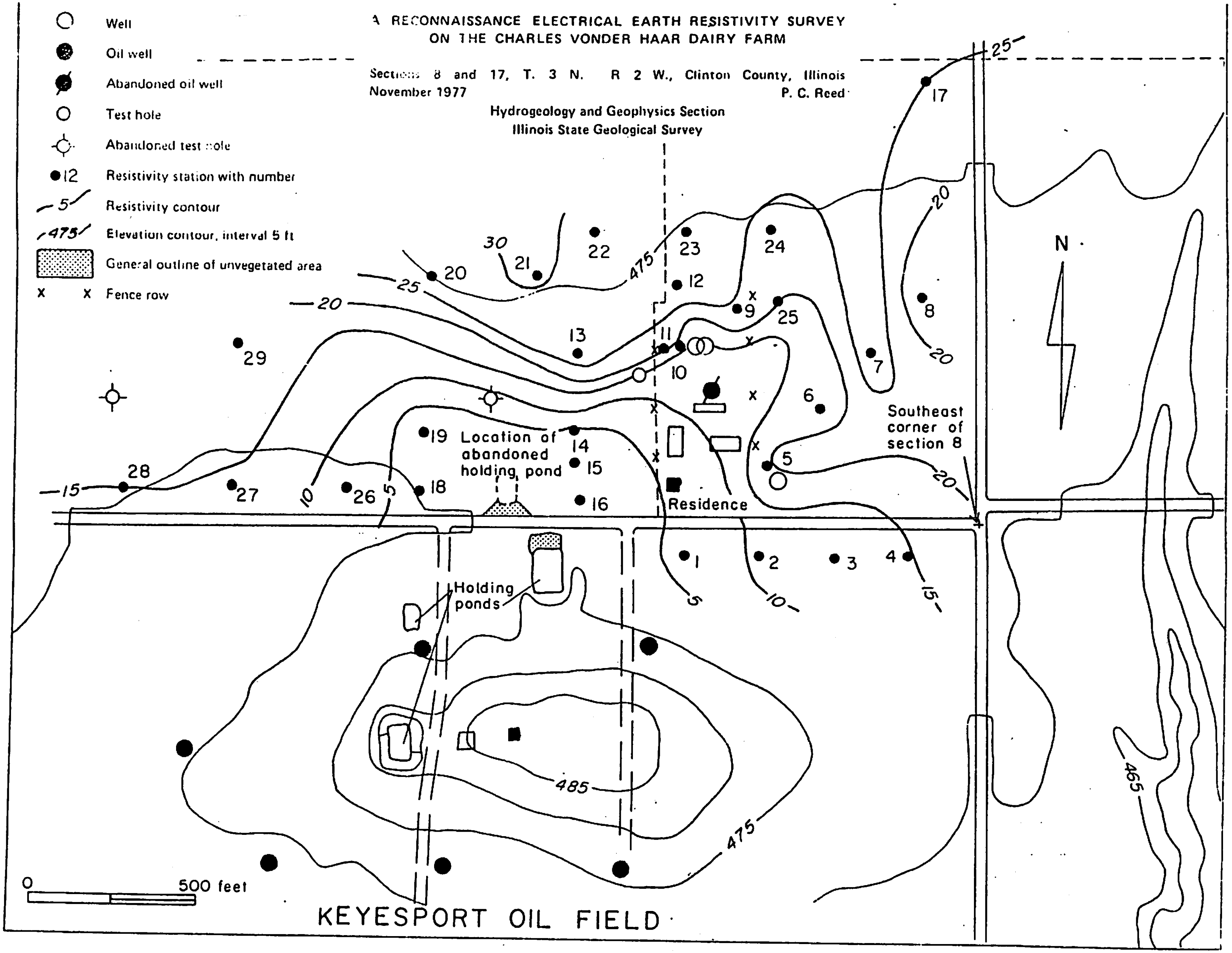
(1) The data from the resistivity survey clearly show that the abandoned brine holding ponds leaked salt water to the shallow aquifer and spread outward. The two wells on the Vonder Haar farm are within the region of depressed electrical earth resistivity values. There was sufficient time for the salt water to spread from the ponds to the Vonder Haar farm during their long period of use. Abandonment of the ponds will allow the quality of water in the aquifer to slowly recover; meanwhile, the salt water already in the aquifer will continue to spread and continue to be diluted by rainfall.

(2) The Vonder Haar wells are in or very near the animal lot. The presence of cattle is commonly associated with high chloride water which originates in the animal waste. The large diameter dug or bored wells are particularly vulnerable to nearby surface sources of pollution. These wells, especially the old dug ones, are difficult to seal. In addition, the thin, surficial loess affords only moderate protection of the aquifer. The shape of the 15 ohm-meter line is similar to the outline of the animal lot.

(3) Repressuring the production by reinjection of the produced brine may force salt water up an unplugged abandoned well. According to Mr. Fisher, three wells were originally drilled on the Vonder Haar farm; two were dry and plugged, a third located in or near the farm lot produced oil but was reported abandoned and plugged in October 1953. According to Mr. Fisher, the farmer on the property several years ago took out or broke off the surface casing. The Survey has no other records of deep wells drilled on the property. However, if there are unknown wells with broken seals, water could leak upward producing a low resistivity ring around the leaking well. No rings were observed with the station spacing that was used. A small bulge in the coutour interval is present northeast of the farm log and the abandoned well, but there is no indication that this bulge is the result of leakage from an abandoned oil well.

(4) The combination of leakage in one or more of the wells in the oil field to the south, and/or the pumpage of the farm wells may increase the rate of salt water migration, thus causing water quality in the farm wells to deteriorate more rapidly.

In summary, the most likely source of salt water in the well on the Vonder Haar farm is water migrating from the old brine holding ponds abandoned over two years ago. The problem may also be aggravated by waste products from animals on the property, possible leakage from abandoned wells with broken seals or unknown and unplugged wells, or by injection in and/or pumping of existing wells.


A RECONNAISSANCE ELECTRICAL EARTH RESISTIVITY SURVEY
ON THE CHARLES VONDER HAAR DAIRY FARM
Sections 8 and 17, T. 3 N. R 2 W., Clinton County, Illinois
November 1977
P. C. Reed
Hydrogeology and Geophysics Section
Illinois State Geological Survey
Well
Oil well
Abandoned oil well
Test hole
Abandoned test hole
Resistivity station with number
Resistivity contour
Elevation contour, interval 5 ft
General outline of unvegetated area
Fence row
Location of abandoned holding pond
Residence
Holding ponds
Southeast corner of section 8
N
0
500 feet
KEYESPORT OIL FIELD

	WELL #1 SECTION 8, T. 3 N., R. 2 W. 1977		WELL #2 SECTION 8, T. 3 N., R. 2 W. 1977		WELL SECTION 9, T. 3 N., R. 2 W.	
	NOV.	DEC.	NOV.	DEC.	1970	1977
NITRATE (NO_3)	0.4*	1.2	0.9	5.2	2.6	1.0
CHLORIDE (Cl)	1060	750	150	2100	64	40
ALKALINITY (HCO_3)	318	400	9.5	390	568	600
TOTAL HARDNESS ($CaCO_3$)	920	725	358	1500	662	250
TOTAL DISSOLVED SOLIDS	2105	1500	362	3700	906	610

* VALUES REPORTED IN MILLIGRAMS PER LITER (MG/L)

ILLINOIS STATE GEOLOGICAL SURVEY
NATURAL RESOURCES BUILDING, URBANA, ILLINOIS 61801 TELEPHONE 217 344-1481
Jack A. Simon, CHIEF

August 22, 1977

A RECONNAISSANCE ELECTRICAL EARTH RESISTIVITY SURVEY AT THE COUNTRY TRAILS SUBDIVISION #1, SECTION 34, T. 15 N., R. 4 W., SANGAMON COUNTY, ILLINOIS

By

Philip C. Reed, Assistant Geologist
Hydrogeology and Geophysics Section

Introduction

At the request of Mr. Murray Williams, Greene and Meador, 202 West Park Street, Taylorville, Illinois, 62568, a brief electrical earth resistivity survey was made at the Country Trails Subdivision owned by Mr. Bud Hunter on August 10, 1977. The purpose of the survey was to determine the distribution of a salt water wedge at the subdivision. An abandoned brine pit located adjacent to the eastern edge of the subdivision is no longer in use. Four large diameter water wells drilled on lots 7, 8, 10 and 11 were reported to have chloride concentrations ranging from 250 to over 33,000 mg/l (milligrams per liter).

Hydrogeologic Setting

The subdivision is situated in the upland and lowland areas of the Sangamon River Valley 540 to 585 feet above mean sea level near an active oil field. The ice deposited materials (glacial drift) of Illinoian age overlying the bedrock of Pennsylvanian age consist of a pebbly clay material, called till, with some thin, discontinuous beds of sand and gravel. Most of the wells in the area are large diameter bored wells open to the drift that produce only small and often seasonal amounts of water. The contact between the glacial drift and the underlying bedrock is marked by a line of glacial boulders along the road near the western margin of lot no. 1 at an elevation of approximately 545 feet above mean sea level. The bedrock consists primarily of shale with some thin, discontinuous beds of limestone and sandstone, not generally considered an aquifer in this area. Below a depth of 200 feet water from the bedrock may become too mineralized for most uses.

Resistivity Survey

The electrical earth resistivity survey is based on the principal that uncontaminated, compact glacial till, clay-alluvium and shale present less resistance to the passage of an electrical current than do sand and gravel or sandstone or limestone of the bedrock. Electrical current introduced in earth materials with high sodium chloride concentrations will have a greatly reduced resistance. The accompanying map shows the location of the 21 stations occupied during the course of the survey. All stations are marked with numbered wooden stakes driven in the ground.

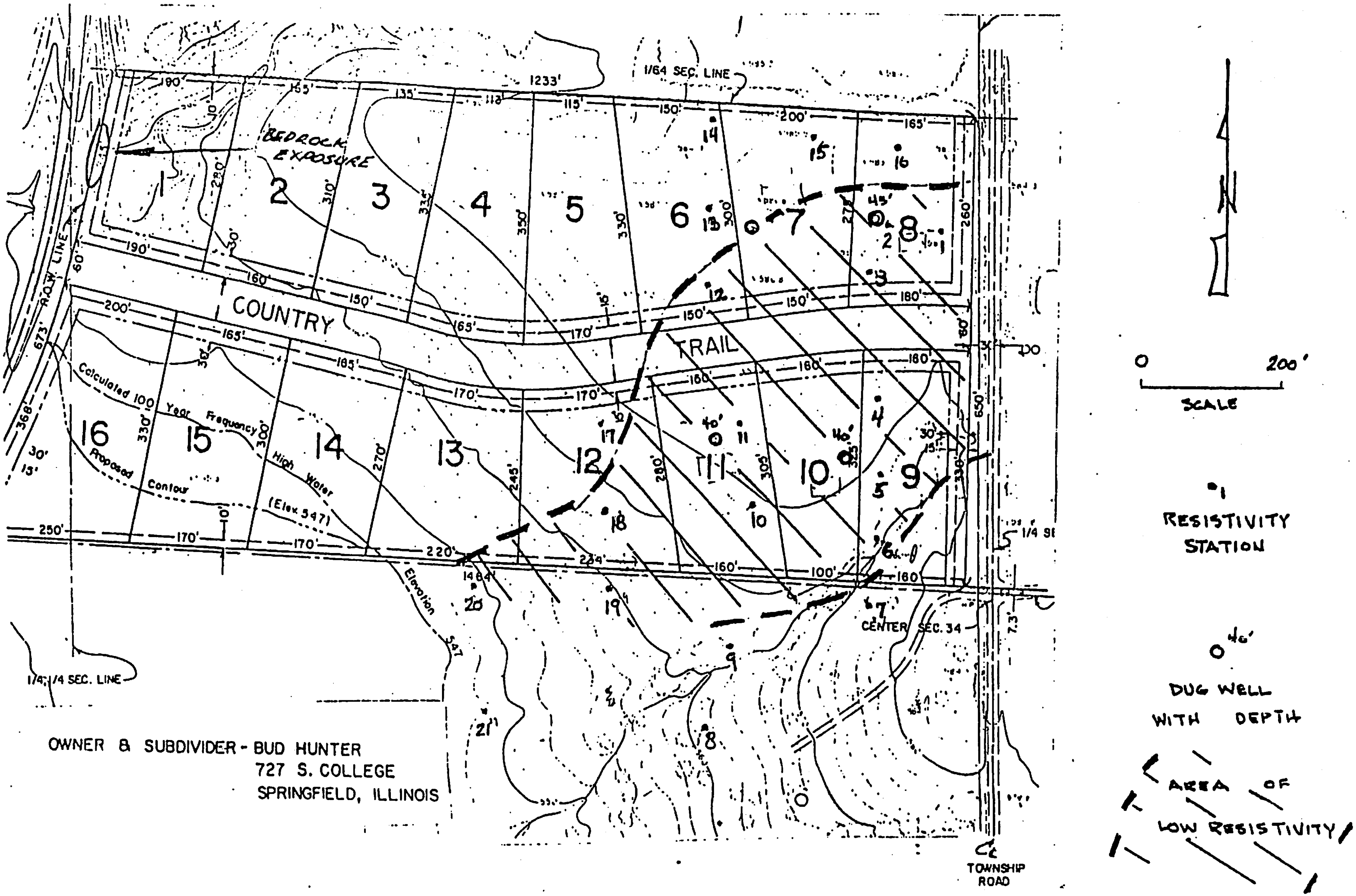
Conclusion

This study demonstrated the usefulness of an electrical earth resistivity survey in describing oil field contamination due to salty water. The outline of a low or reduced resistivity area is shown by the hachured pattern on the map. This area of low resistivity correlates well with the reported chloride concentrations from the large diameter wells in the study area and depicts the movement of the salty water above the bedrock toward the lowland.

Information from drillers' logs supplied by Reynold Well Drilling, Inc., in conjunction with the geologic setting, suggests that yields from individual large diameter wells constructed in the drift materials above the bedrock at the subdivision may fluctuate greatly seasonally and that wells of this type are only a short term solution to the water supply problem present at the subdivision. A more desirable and lasting source of ground water may be present in the alluvial materials of lowland of the Sangamon River Valley possibly within the limits of the subdivision.

Driller's logs of formation changes in color and texture and sample cuttings taken at regular five-foot intervals should be sent to the State Geological Survey for study and interpretation. Sample sacks and log books will be furnished free of charge upon request.

Any future correspondence referring to this report should be addressed to the State Geological Survey, Urbana, Illinois, 61801.



AN ELECTRICAL EARTH RESISTIVITY SURVEY AT COUNTRY TRAILS SUBDIVISION

SECTION 34, T.15N., R.4W., SANGAMON COUNTY, ILLINOIS

AUGUST 1977 P.C. REED

HYDROGEOLOGY AND GEOPHYSICS SECTION

ILLINOIS STATE GEOLOGICAL SURVEY, URBANA, ILLINOIS 61801

ILLINOIS STATE GEOLOGICAL SURVEY
NATURAL RESOURCES BUILDING, URBANA, ILLINOIS 61801 TELEPHONE 217 344-1481
Jack A. Simon, CHIEF

August 7, 1975

AN ELECTRICAL EARTH RESISTIVITY SURVEY ON AN OIL LEASE OF BERNARD PODOLSKY, WHITE COUNTY, ILLINOIS

By

Philip C. Reed, Assistant Geologist
Hydrogeology and Geophysics Section

At the request of Mr. Bernard Podolsky, P. O. Box 278, Fairfield, Illinois, 62837, an electrical earth resistivity survey was conducted on an oil lease located in the W½ of Section 27, T. 3 S., R. 9 E., White County, on June 18 and 26, 1975. The purpose of the survey was to better define the source and occurrence of the contamination of the earth materials by salt water at the lease so that the land could be returned to its original state.

The Problem

The problem that exists at the oil lease in Section 27, T. 3 S., R. 9 E., is the contamination of the earth materials by oil field brines associated with oil production. Injection of the brines in the vicinity of the abandoned oil well and the spilling of the brines in waterways near the abandoned oil well from pre-existing storage pits have contaminated the area around parts of the lease. The principal storage pit, which was filled in last fall, was located southwest of the abandoned well shown on the enclosed sketch map. Vegetation will not grow in areas around the pits and in drainageways where the salt concentration is too high.

Geological Situation

The oil lease is situated in the upland area eight miles northwest from the confluence of the Skillet Fork and the Little Wabash River within the Golden Gate Consolidated oil field. Wells in this part of the field generally produce from Mississippian sands and limestones in the depth range of 3000 to 3500 feet. The drift materials overlying bedrock of Pennsylvanian age range in thickness from about 10-25 feet and consist primarily of Illinoian-age till. The best exposures present in the request area are at the salt spring and pond. Here, rubble of siltstone and sandstone of Pennsylvanian bedrock, litter the pebbly clay walls of the pond. Silt pockets appear to be present within the pebbly clay glacial materials higher in the section, especially where a water line crosses the road and enters the pond from the tank battery. The pebbly clay till is overlain by as much as two feet of loessial silt in the upland of the study area.

The physical features, which are shown on the sketch map, of the study area are: 1) the abandoned McClosky oil well, Moses and Stewart #1 constructed with 45 feet of surface casing in 1952; 2) a salt water injection well completed to a depth of 950 feet; 3) a tank battery consisting of three 210 barrel tanks and an oil-water separation unit; 4) a house owned by George Lamont; and 5) a brine-evaporation pit recently filled and leveled to conform with the original land surface.

Hydrogeologic Features

The hydrogeologic features within the study area, which are shown on the sketch map, are: 1) a pond and a salt spring northwest of the Lamont house; 2) a pond east of the house; 3) a cistern about 8.5 feet deep on the north side of the house; 4) a network of ditches trending north, west and east, and generally away from the upland area where the abandoned oil well and injection well are situated; and 5) an area without vegetation covered in part with what appears to be white salt crystals.

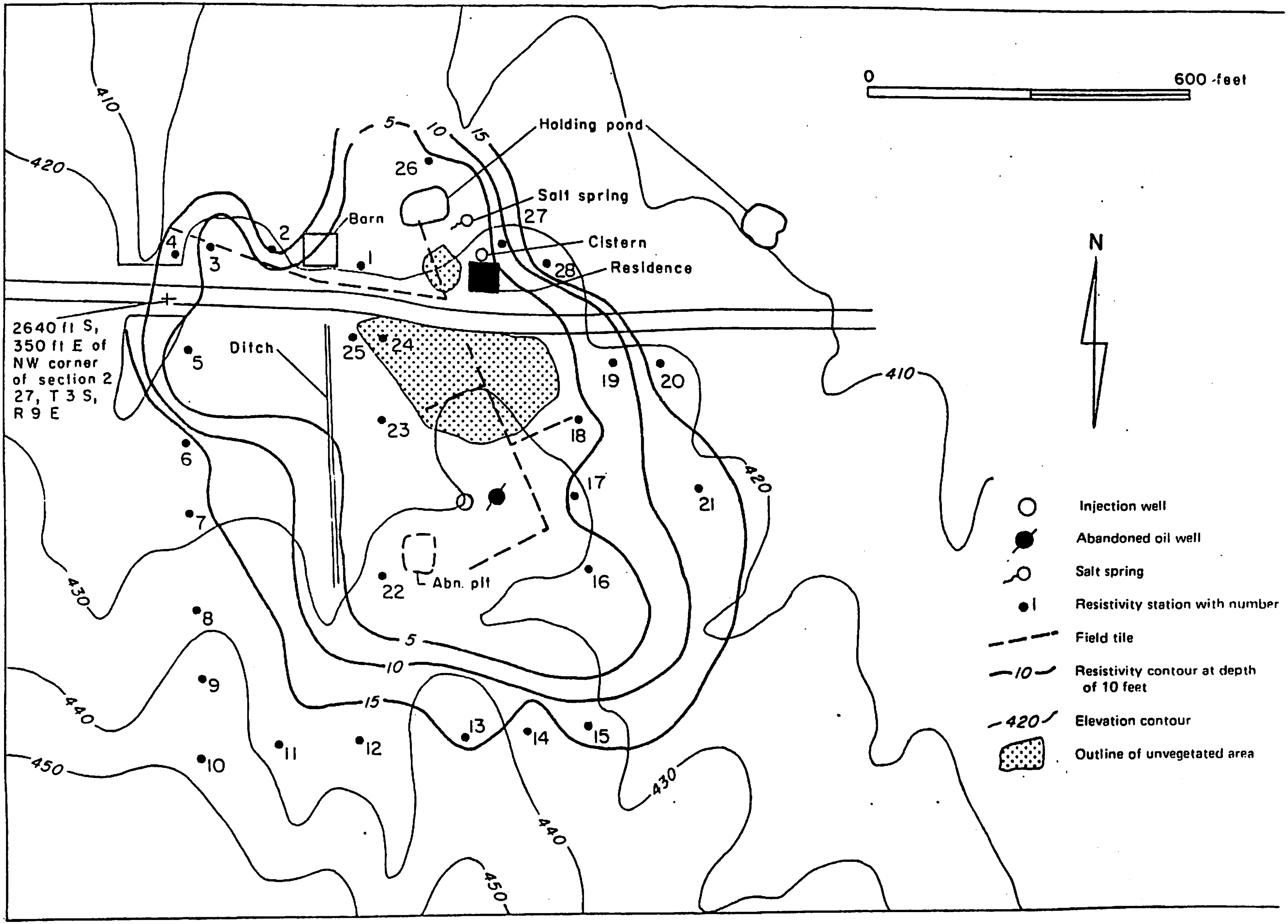
Resistivity Survey

The electrical earth resistivity survey is based on the principle that uncontaminated, compact glacial till, alluvium and shale present less resistance to the passage of an electric current than do uncontaminated sand and gravel or sandstone or limestone of the bedrock. Electrical current introduced in earth m materials with high chloride ion concentrations in the water will greatly reduce the resistance so that the instrumentation of a resistivity survey frequently will not detect any reading at all. As the chloride ion concentrations are reduced in the earth materials, the instrumentation becomes more sensitive, measuring progressively higher levels of resistance as the contamination or chloride ion concentration decreases. The accompanying sketch map shows the approximate location of the 28 stations occupied in the course of the survey. All stations are marked by numbered wooden stakes driven into the ground

Conclusion

The maps showing isoresistivity values of 15 and 20 ohm-meters at depths 10, 20 and 30 feet below land surface, depict the effect of the oil field wastes and their movement and dilution due to rainfall outward from the primary area of contamination near the covered disposal pit, the brine injection well, and abandoned oil well. The resistivity readings correlate with the enclosed water analyses made from water collected during the course of work at the request area.

This study demonstrated the usefulness of an electrical earth resistivity survey in describing oil field contamination due to salty water. No point source was found; however, the general outline of the contaminated area was established.


0
600 feet
N
Holding pond
Salt spring
Cistern
Residence
Barn
Ditch
Abn. pit
2640 ft S,
350 ft E of
NW corner
of section 2
27, T 3 S,
R 9 E
5
10
15
410
420
430
440
450
1
2
3
4
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25
26
27
28
Injection well
Abandoned oil well
Salt spring
Resistivity station with number
Field tile
Resistivity contour at depth of 10 feet
Elevation contour
Outline of unvegetated area

1975

	POND	SEEP	CISTERN SURFACE	CISTERN BOTTOM 8.5'	RUPTURED TANK
CHLORIDE (Cl)	16,800*	18,400	200	360	13,800
TOTAL DISSOLVED SOLIDS	30,800	34,200	400	780	24,100
pH	7.55	7.34	8.47	7.21	7.51

1977

	FIELD TILE				
CHLORIDE (Cl)	6,000	16,400		140	
TOTAL DISSOLVED SOLIDS	10,600	27,600		330	
pH	4.98	6.16		7.51	

* VALUES REPORTED IN MILLIGRAMS PER LITER (MG/L) SECTION 27, T. 3 S., R. 9 E.

APPENDIX C

Christian County
E.E.R. and Water Table Maps
Lithologic and Gamma Ray Logs

Christian County Holding Pond Study Site
Land Owner: Mr. J. David Myers
Operator: Mr. E. H. Kaufman
Pond Size: 30'x100'. Date Constructed: 1954?
Present Salt Water Input: None (Reportedly as much as 100 bbls/day prior to 1977)

Geologic Setting

The Christian County study site is located on an Illinoian till plain in Section 20, T. 13 N., R. 11 E., within the Assumption Consolidated Oil Field. The land elevation is estimated to be between 615-620 feet above mean sea level. Drainage is locally toward a swale north of the pit but generally southeastward toward a tributary of Oak Branch Creek. The unconsolidated Illinoian glacial drift and the more recent deposits of loess consist of sand, silt and glacial till about 80 feet thick and form a broad, flat plain in this area. Beneath these deposits is bedrock of Pennsylvanian age.

Hydrogeology

The surficial material at the site consists of about 5 feet of loessial silt and sand which forms part of the soil in this region. Bleached silt, sand and clay till form part of the surface spoil materials around the unvegetated areas of the pit. Beneath the loess is about 15 feet of silt and very fine to fine-grained sand of the Hagarstown Member of the Illinoian Glasford Formation. Below the Hagarstown, in decending order, are the Radnor and Smithboro Members of the Glasford Formation. The units consist of compacted sandy till and compacted clay till and probably extend to the underlying Bond Formation of Pennsylvanian age.

The silt and sand of the Hagarstown Member are the principal source of ground water in the area and are less compact than the underlying till of the Radnor Member (see compressive strength measurements).

Hydrology

Water level contours around the hold pond indicate a ground-water mound beneath the holding pond with the regional water level surface trending away from the upland toward the lowland areas.

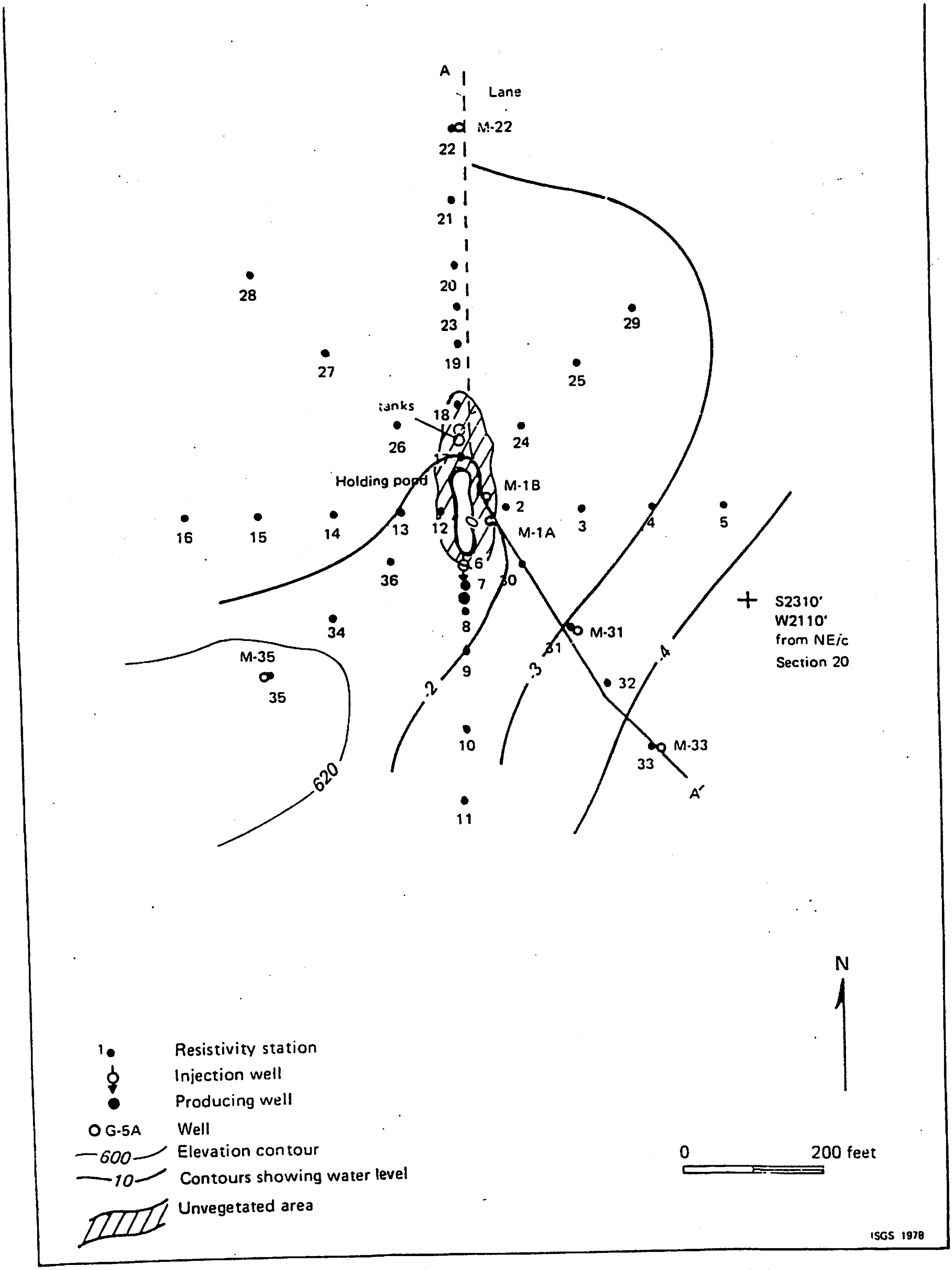
The isoresistivity contours also indicate the migration of chlorides to be greatest northward and southeastward.

The extent of the unvegetated area is depicted clearly on the photographs in the report. This area was often moist in many places, particularly after a rainfall event, suggesting that holding pond water is migrating laterally.

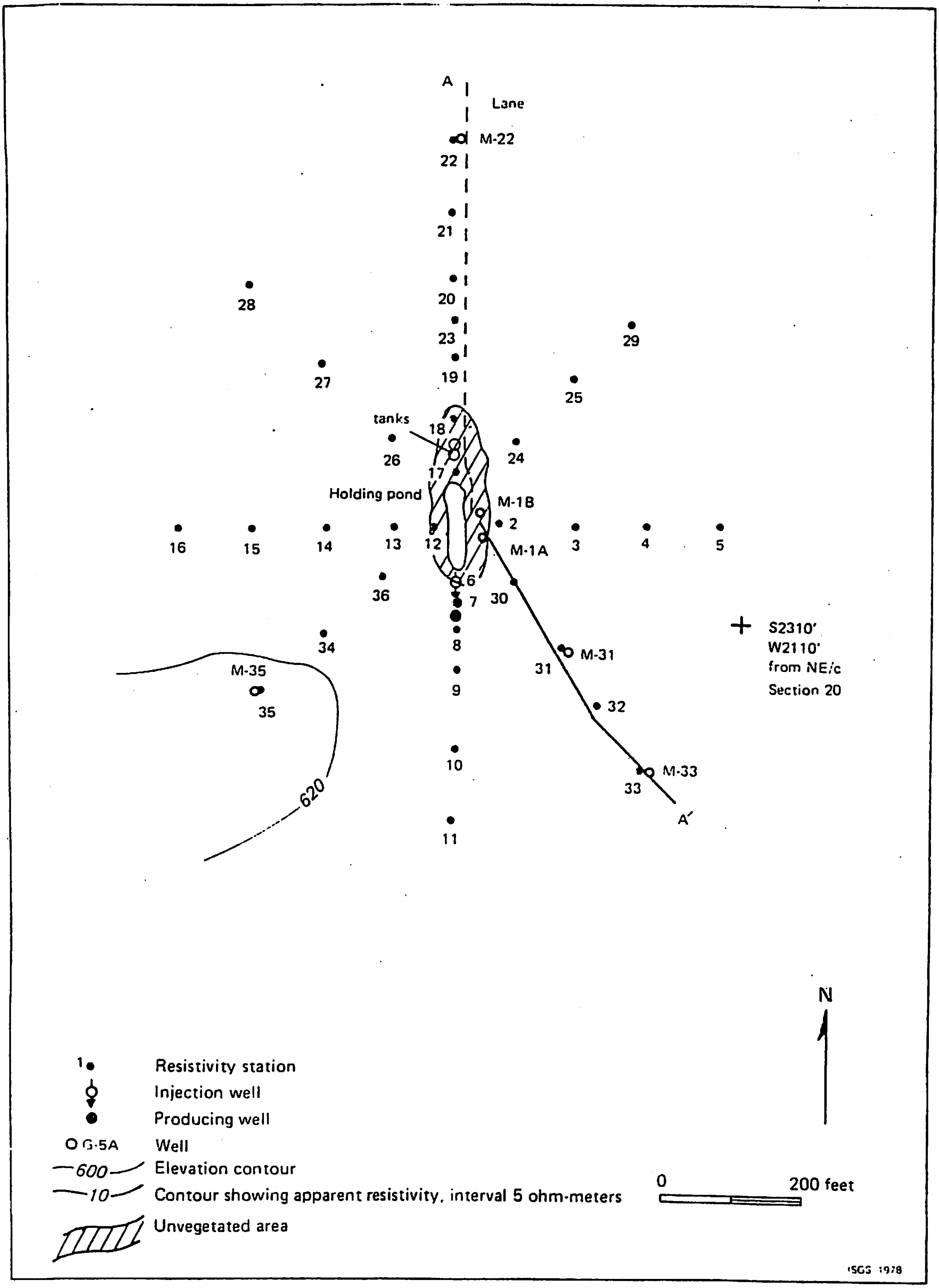
Apparent resistivity values from split spoon samples were much higher below the Hagarstown Member, probably indicating little downward movement of the highly mineralized water.

C H R I S T I A N   C O U N T Y

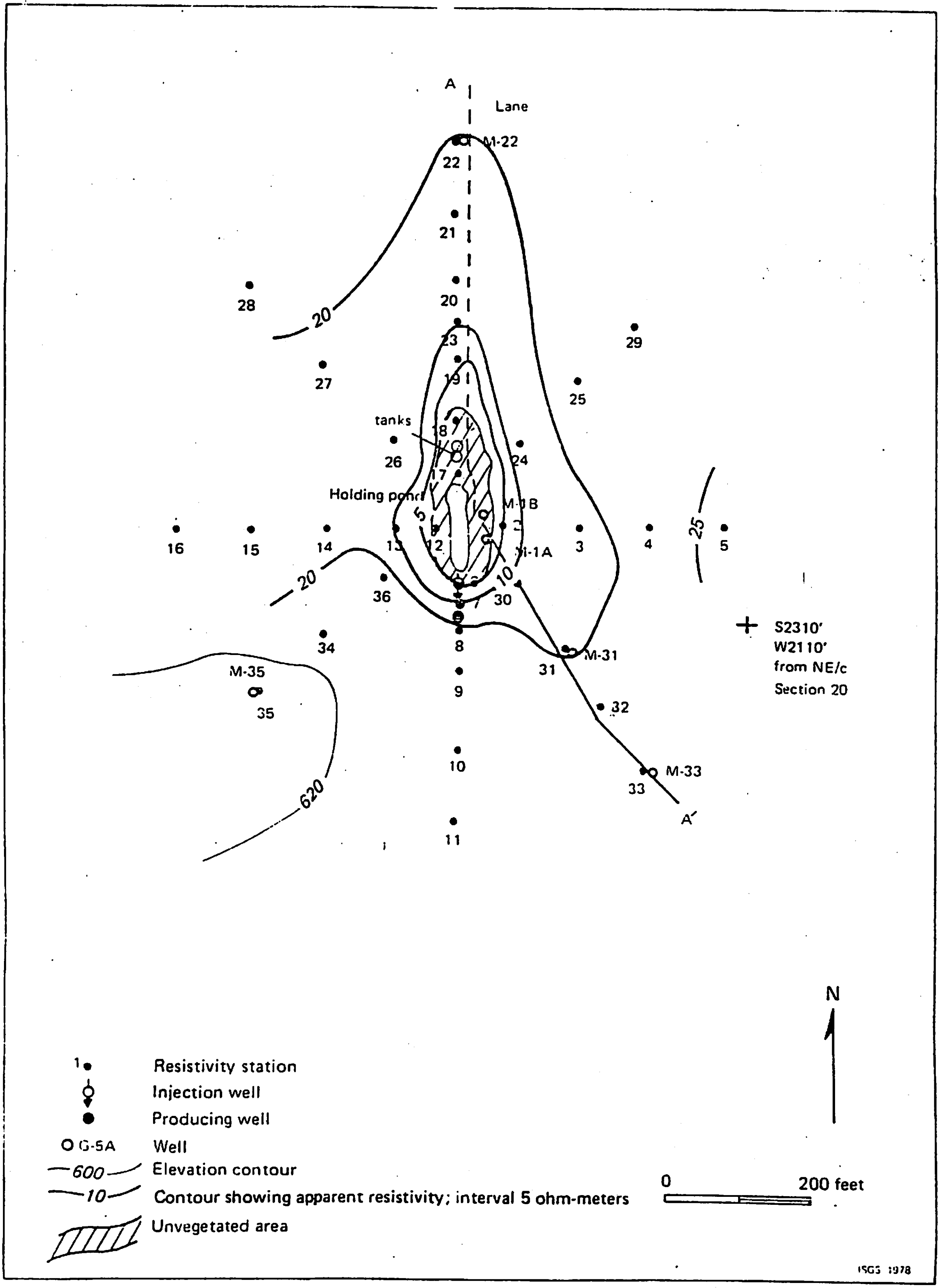
Well No.	Slot Interval	Relative Height Casing	Static Level Below Top Of Casing, July 20, 1978	Height Casing Above Ground	Relative Ground Level At Well	Static Level Below Ground	Ground Level Relative To Datum	Water Levels Relative To Ground Level Datum
M-1A	9-19	-	1,83	,10	5,08	-1,73	0,0	+(-1,73)=-1,73
M-1B	4-9	-	2,65	,35	5,15	-2,30	-0,07	+(-2,30)=-2,37
M-22	9-19	-	3,37	,11	4,91	-3,26	+0,17	+(-3,26)=-3,09
M-31	10-20	-	4,28	,32	4,28	-3,96	+0,80	+(-3,96)=-3,16
M-33	9-19	-	3,89	,60	6,18	-3,29	-1,10	+(-3,29)=-4,39
M-35	10-20	-	5.40	,70	1,49	-4,70	+3,59	+(-4,70)=-1,11
Fluid Level in Pit					5,18			-0,10



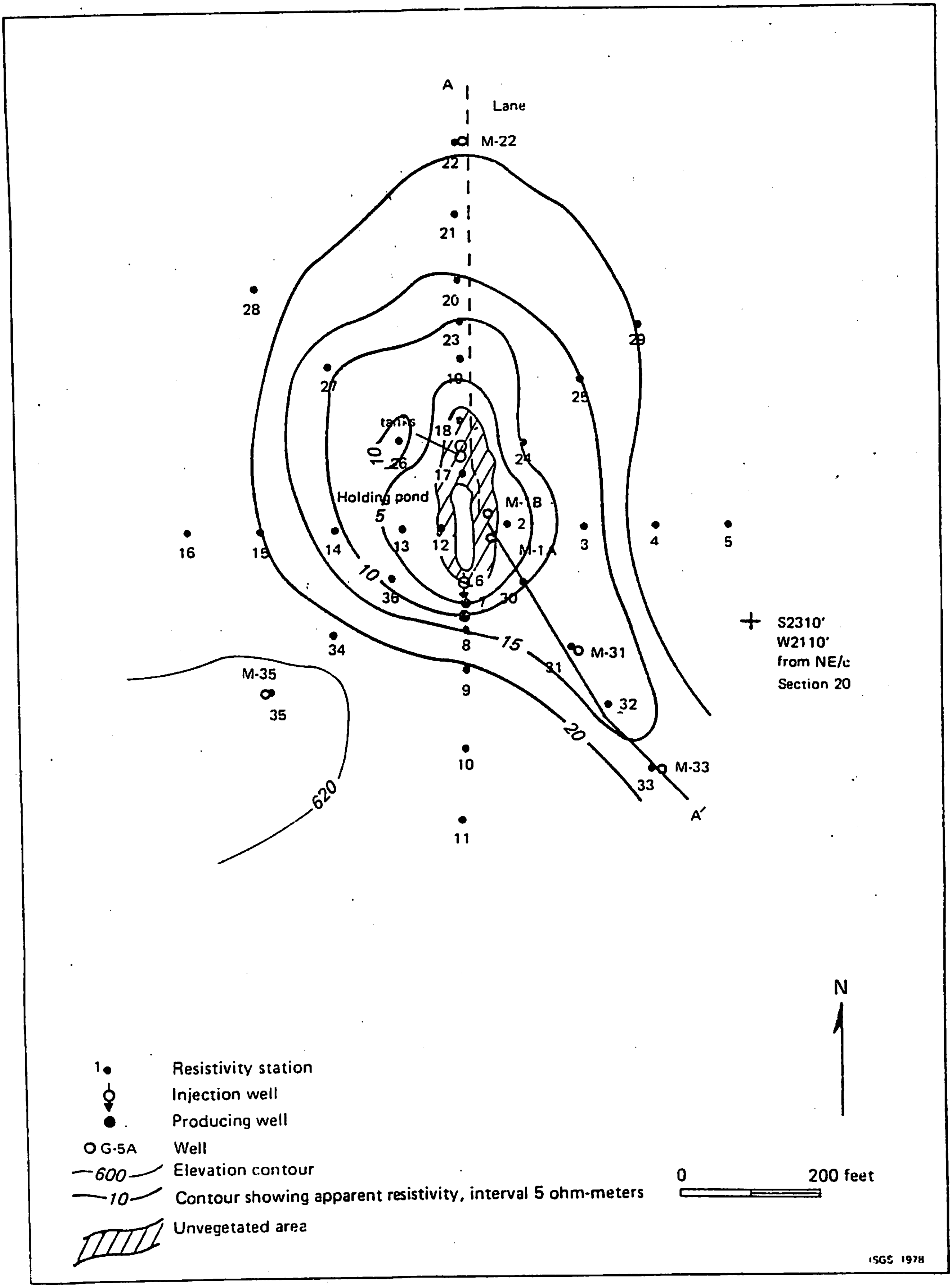
WATER LEVEL CONTOURS (DATUM GROUND LEVEL, M-1A)
AT THE ASSUMPTION CONSOLIDATED OIL FIELD
Section 20, T. 13 N., R. 1 E., Christian County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



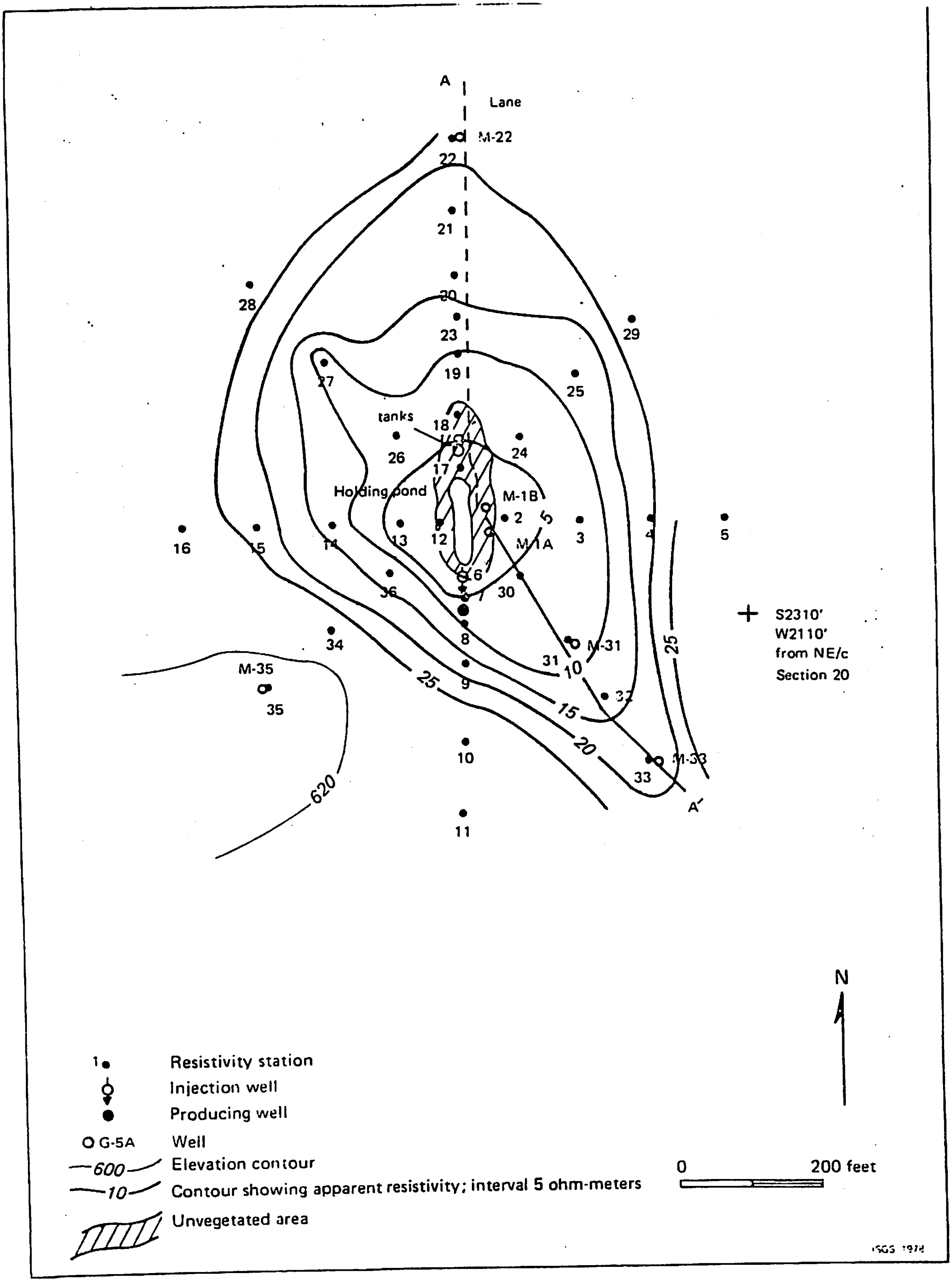
AN ELECTRICAL EARTH RESISTIVITY SURVEY
AT THE ASSUMPTION CONSOLIDATED OIL FIELD
Section 20, T. 13 N., R. 1 E., Christian County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



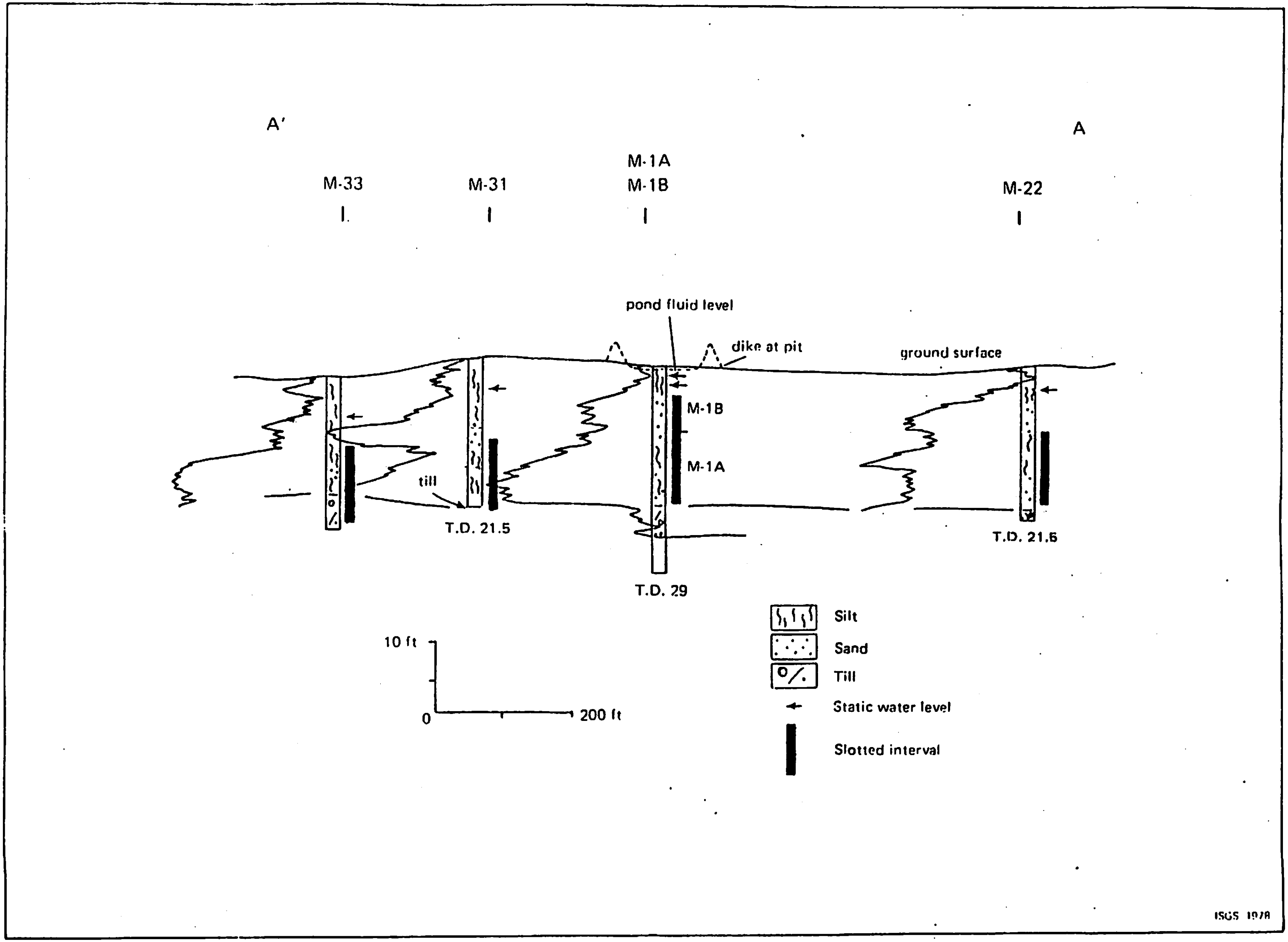
APPARENT RESISTIVITY (OHM-METERS) AT 5-FOOT DEPTH
AT THE ASSUMPTION CONSOLIDATED OIL FIELD
Section 20, T. 13 N., R. 1 E., Christian County, Illinois
July 1978–Murphy, Osby (IEPA); Reed (ISGS)



APPARENT RESISTIVITY (OHM-METERS) AT 10-FOOT DEPTH
AT THE ASSUMPTION CONSOLIDATED OIL FIELD
Section 20, T. 13 N., R. 1 E., Christian County, Illinois
July 1978–Murphy, Osby (IEPA); Reed (ISGS)



APPARENT RESISTIVITY (OHM-METERS) AT 20-FOOT DEPTH
AT THE ASSUMPTION CONSOLIDATED OIL FIELD
Section 20, T. 13 N., R. 1 E., Christian County, Illinois
July 1978–Murphy, Osby (IEPA); Reed (ISGS)



GEOLOGIC SECTION AT THE ASSUMPTION CONSOLIDATED OIL FIELD
Section 20, T. 13 N., R. 1 E., Christian County, Illinois
June 1978–Reed (ISGS)

APPENDIX D

Bond County
E.E.R. and Water Table Maps
Lithologic and Gamma Ray Logs

Bond County Holding Pond Study Site
Land Administrator: Roger Riedemann
Operator: Clyde Bassett
Pond Size: 100'x100'. Date Constructed: 1940?
Present Salt Water Input: 150 barrels per day four days a month

Geologic Setting

The Bond County holding pond study site is located in Section 10, T. 6 N., R. 2 W., Bond County, Illinois, in the Woburn Consolidated Oil Field. The land elevation is between 565-580 feet above mean sea level. Drainage is generally westward toward a north flowing tributary to Gilham Creek. The study site is a part of a relatively flat and featureless drift plain underlain by Illinoian glacial deposits. The unconsolidated glacial drift and overlying deposits of loess consist of about 80 feet of clayey silt, sand, and till. Beneath these deposits is bedrock of Pennsylvanian age.

Hydrogeology

The surface materials exposed at the site consist of about 2 feet of Wisconsinan loessial silt and sand which form part of the soil in the region. Below the loess, exposed along the drainageways west and north of the pond, is the Hagarstown Member of the Illinoian Glasford Formation, An abandoned pond directly south of the active pond has been breached by an erosional waterway to a depth of 6 - 7 feet (see photographs). In the pond areas, the Hagarstown extends to about 20 feet below the land surface and consists primarily of sandy silt with minor amounts of sandy ablation till. The silt is differentially weathered, having undergone two periods of soil genesis. The Hagarstown Member is underlain by about 20 feet of the Vandalia Member of the Glasford Formation, a sandy till with a few thin sand layers. Beneath the Vandalia Member is about 30 feet of silty, smooth textured till assigned to the Smithboro Member of the Glasford Formation. The lowermost 8 feet of glacial drift consists of dense Kansan till overlying the Bond Formation of Pennsylvanian age.

The silt, sand, and sandy till of the Hagarstown Member contain greater amounts of coarse clastic material, are less compact (see unconfined compressive strength measurements), and are relatively more permeable than the remaining tills of the Glasford Formation. The best exposure of Hagarstown is on the west side of the active holding pond. Here, about 8 feet of continually moist, unvegetated silt extends from the diked part of the pond, ending abruptly at the waterway (see photograph).

Hydrology

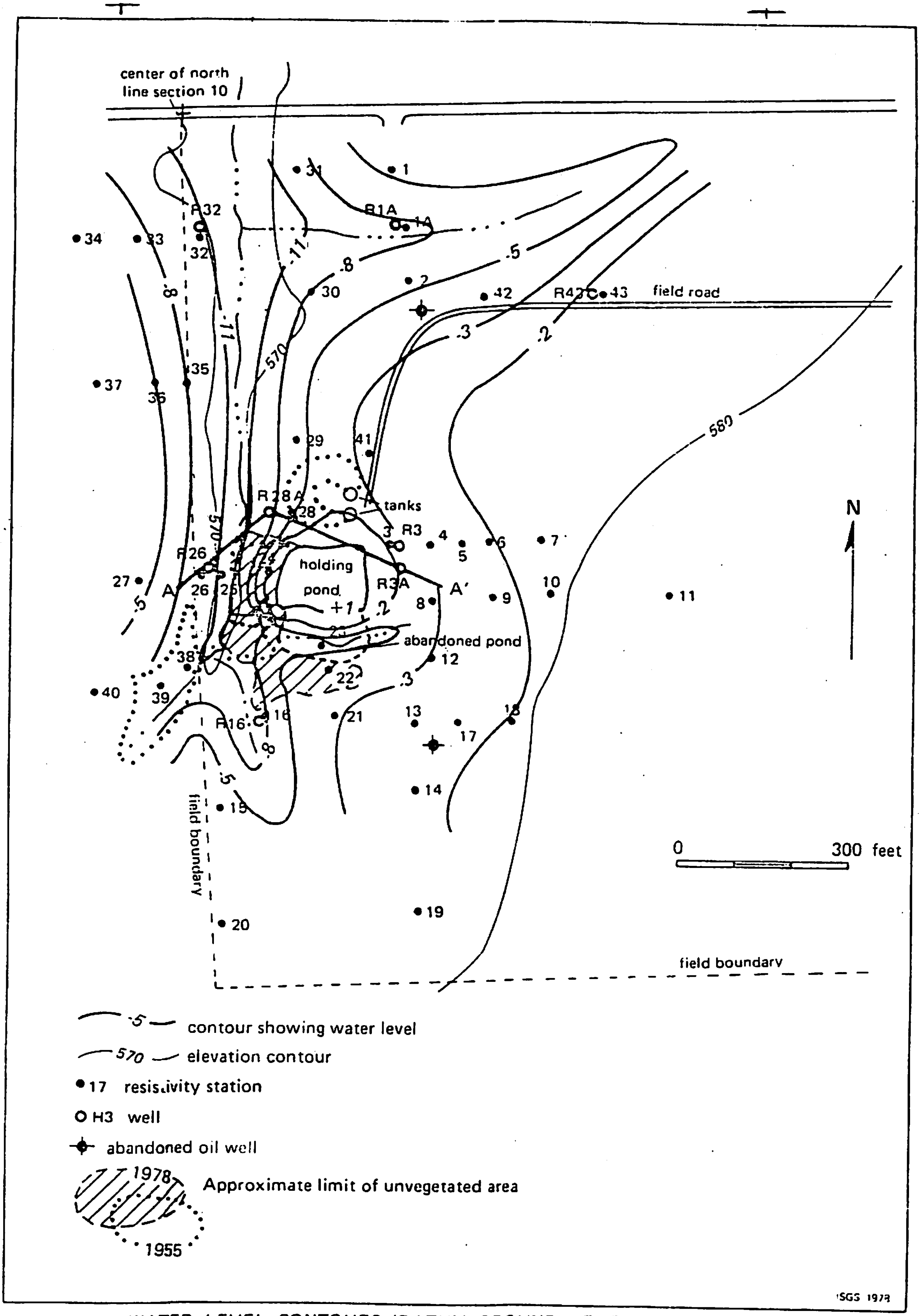
Water level contours at the hold pond reveal a ground-water mound superimposed on a water level surface which increases in gradient toward the drainageway. Water from the mound appears to seep regularly from the west side of the active pond dike into the waterway.

The distribution of apparent resistivity contours indicate the greatest migration of chlorides northward and westward toward drainageways. The extent of unvegetated areas surrounding the holding pond in 1978 is very similar to the area shown on the 1955 aerial photograph accompanying this report. The unvegetated area stops dramatically at the waterway, suggesting change of the flow pattern in this area (see Fig. 1).

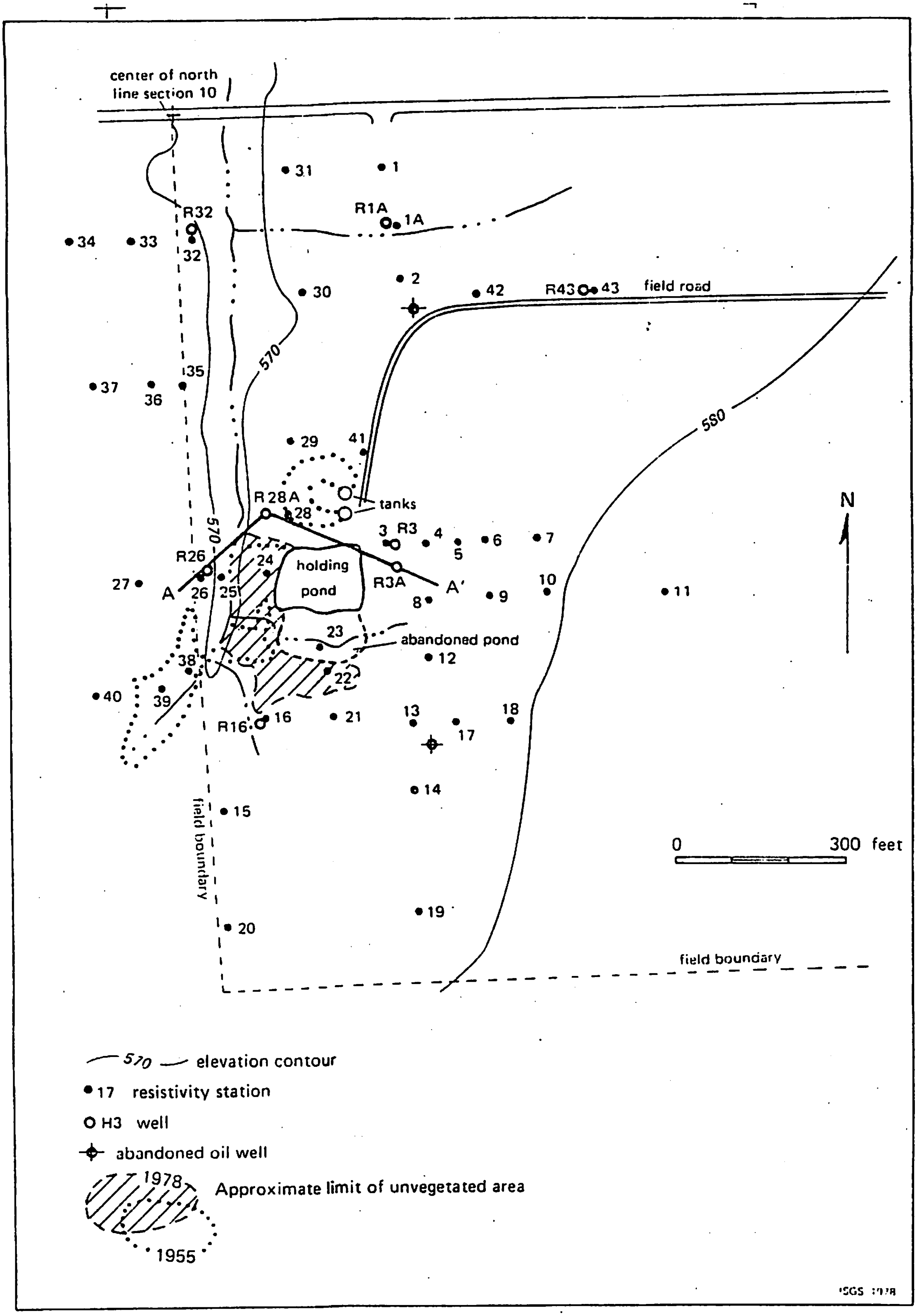
The generally higher apparent resistivity values from split spoon samples below the Hagarstown indicate that for the most part, the highly mineralized holding pond water has not migrated downward into the underlying till.

B O N D   C O U N T Y

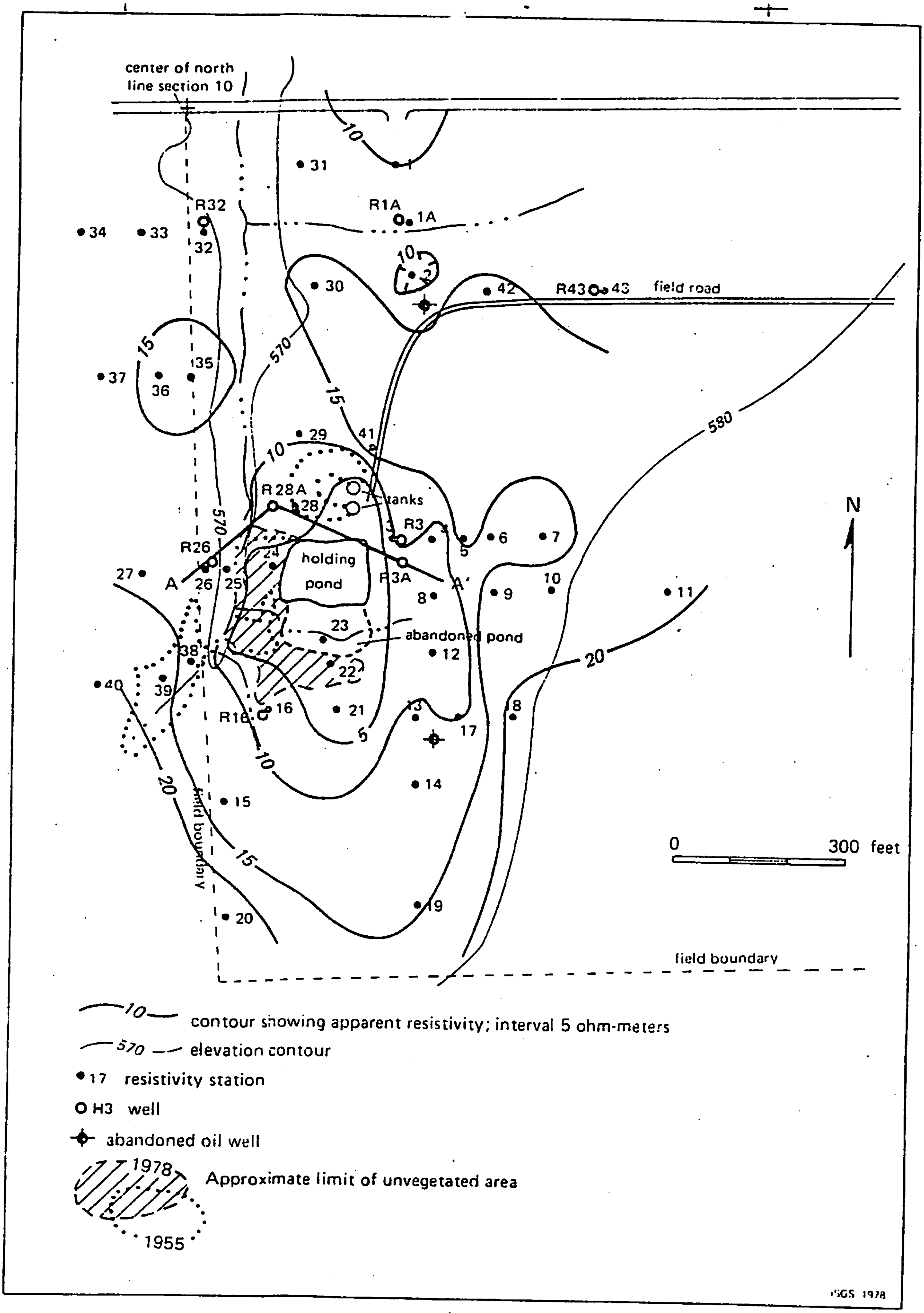
Well No.	Slot Interval	Relative Height Casing	Static Level Below Top Of Casing, July 20, 1978	Height Casing Above Ground	Relative Ground Level At Well	Static Level Below Ground	Ground Level Relative To Datum	Water Levels Relative To Ground Level Datum
R-1A	9-19	-	2.47	0.27	13.12	2.20	-5.92	+(-2.20)=-8.12
R-3	14-19	-	2.90	0.0	7.20	2.90	0.0	+(-2.90)=-2.90
R-3A	4-9	-	2.74	0.42	7.30	2.74	-0.10	+(-2.74)=-2.84
R-16	9-24	-	4.52	0.46	9.86	4.52	-2.66	+(-4.52)=-8.18
R-26	9-24	-	9.13	0.65	8.15	9.13	-0.95	+(-9.13)=-10.08
R-28A	14-19	-	3.39	0.20	12.70	3.39	-5.50	+(-3.39)=-8.89
R-32	9.24	-	7.57	0.15	10.76	7.57	-3.56	+(-7.57)=-11.13
R-43	9-24	-	3.27	0.30	6.55	3.27	+0.65	+(-3.27)=-2.62
R oil test					7.58 (top casing)			-0.38
R pit					6.25 (top fluid)			+0.95
R stream					18.50 (base channel)			-11.30



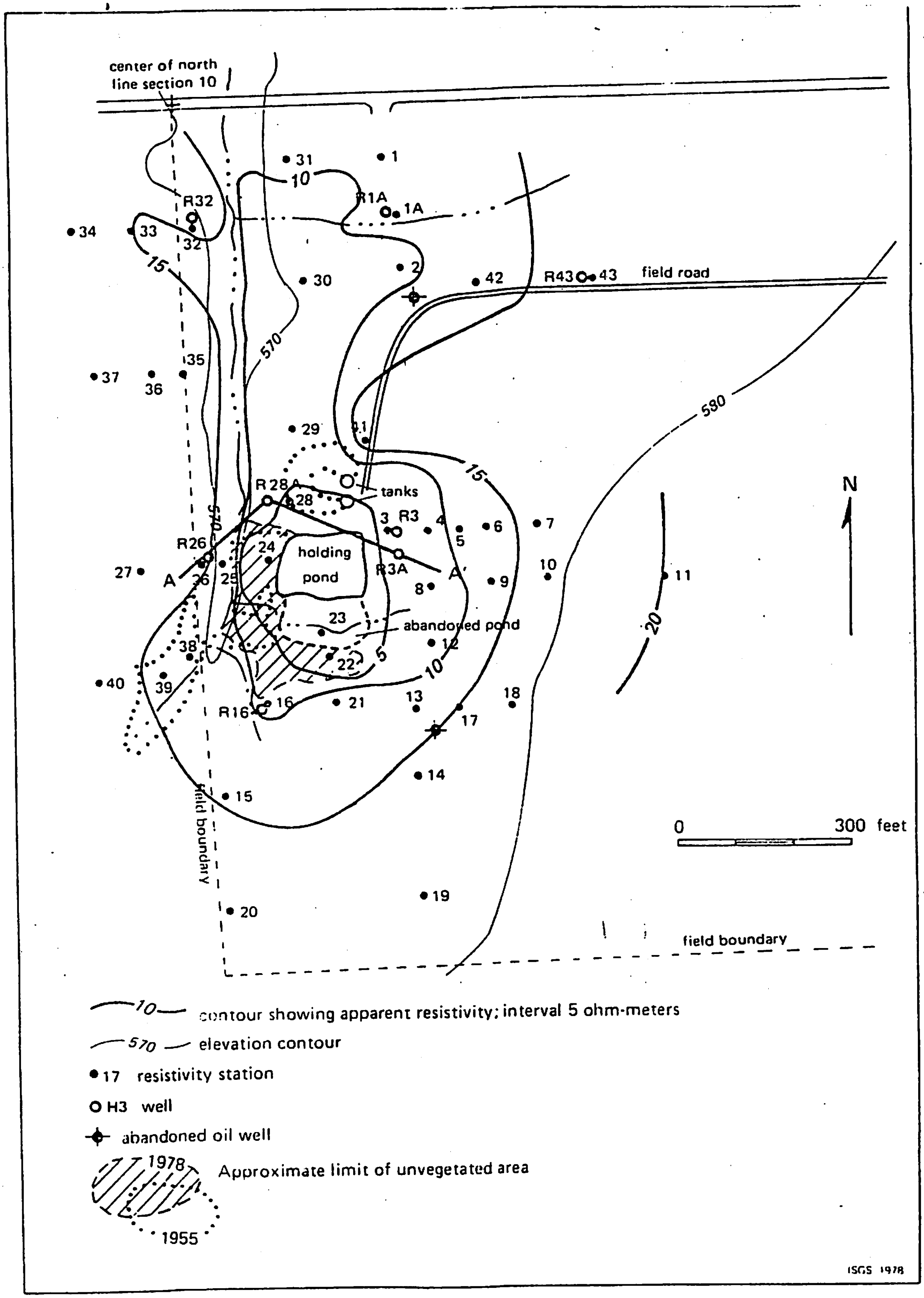
WATER LEVEL CONTOURS (DATUM GROUND LEVEL, WELL R-3)
AT THE WOBURN CONSOLIDATED OIL FIELD
Section 10, T. 6 N., R. 2 W., Bond County, Illinois
June 1978–Murphy, Osby (IEPA); Reed, Franczyk (ISGS)



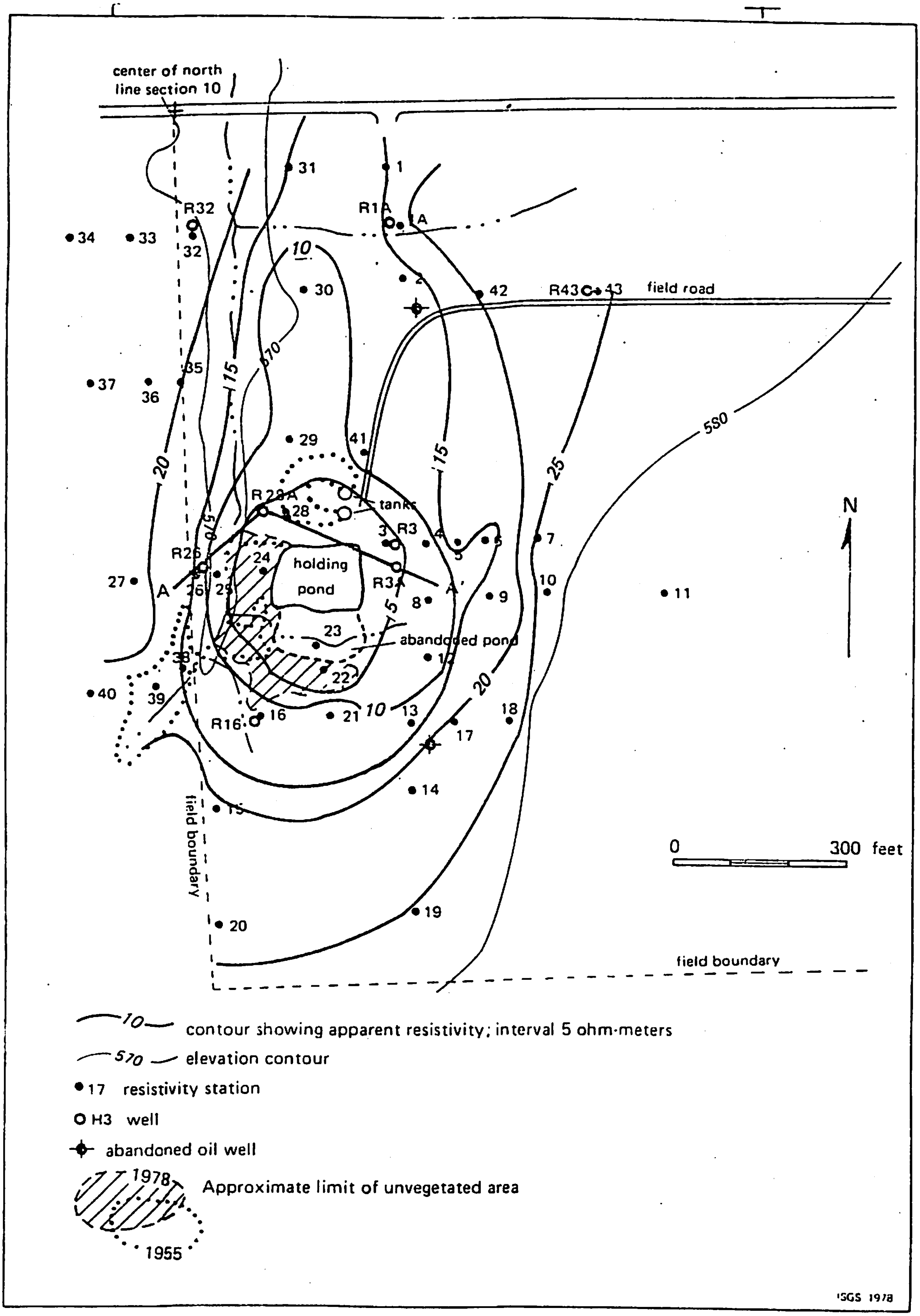
AN ELECTRICAL EARTH RESISTIVITY SURVEY
AT THE WOBURN CONSOLIDATED OIL FIELD
Section 10, T. 6 N., R. 2 W., Bond County, Illinois
June 1978—Murphy, Osby (IEPA); Reed, Franczyk (ISGS)



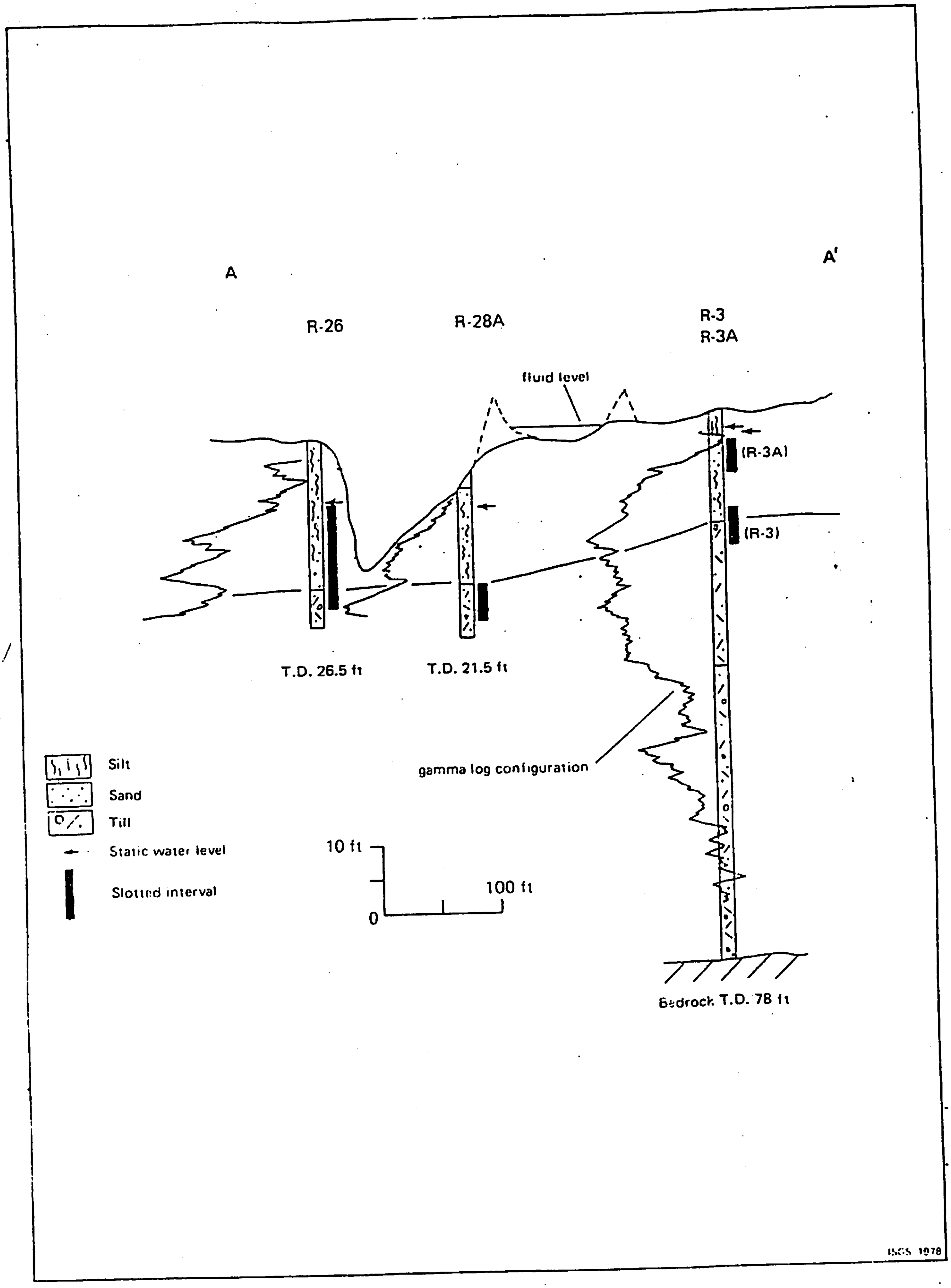
APPARENT RESISTIVITY (OHM-METERS) AT 5-FOOT DEPTH
AT THE WOBURN CONSOLIDATED OIL FIELD
Section 10, T. 6 N., R. 2 W., Bond County, Illinois
June 1978—Murphy, Osby (IEPA); Reed, Franczyk (ISGS)



APPARENT RESISTIVITY (OHM-METERS) AT 10-FOOT DEPTH
AT THE WOBURN CONSOLIDATED OIL FIELD
Section 10, T. 6 N., R. 2 W., Bond County, Illinois
June 1978—Murphy, Osby (IEPA); Reed, Franczyk (ISGS)



APPARENT RESISTIVITY (OHM-METERS) AT 20-FOOT DEPTH
AT THE WOBURN CONSOLIDATED OIL FIELD
Section 10, T. 6 N., R. 2 W., Bond County, Illinois
June 1978–Murphy, Osby (IEPA); Reed, Franczyk (ISGS)



GEOLOGIC SECTION AT THE WOBURN CONSOLIDATED OIL FIELD
Section 10, T. 6 N., R. 2 W., Bond County, Illinois
June 1978—Murphy, Osby (IEPA); Reed, Franczyk (ISGS)

APPENDIX E

Effingham-Fayette County
F.E.R. and Water Table Maps
Lithologic and Gamma Ray Logs

Effingham-Fayette Counties Holding Pond Study Site
Land Administrator: Mr. Dorwin Barr
Operator: Tri Star Oil Company
Pond Size: 110'x110'x6'
Present salt water input: 150-200 barrels daily (reported)

Geologic Setting

The Effingham-Fayette County study site is located in Section 31, T. 9 N., R. 4 W., within the Louden Oil Field. The land elevation ranges between 595-630 feet above mean sea level. Drainage is eastward and southward toward a tributary of Wolf Creek. The site is situated on the south flank of southwestward-northeastward trending series of elongate mounds which are elevated above the surrounding Illinoian till plain. The unconsolidated Illinoian glacial drift consists of sand, silt and till. The glacial drift is about 50 feet thick, and overlies the Mattoon Formation of Pennsylvanian age.

Hydrogeology

The surficial material consists of loessial silt which forms the soil in this area. In places near the abandoned ponds north, northeast, west and immediately south of the active pond a sandy, bleached spoil covering is present to a depth of 3 to 4 feet. Underlying the spoil and the soil is 5 to 18 feet of sand, silt and sandy till of the Hagarstown Member of the Glasford Formation. The Hagarstown is deeply weathered and has a uniform lithology in all parts of the study area except in the area of well no. G-49A where the sandy ablation till phase of the Hagarstown becomes dominant.

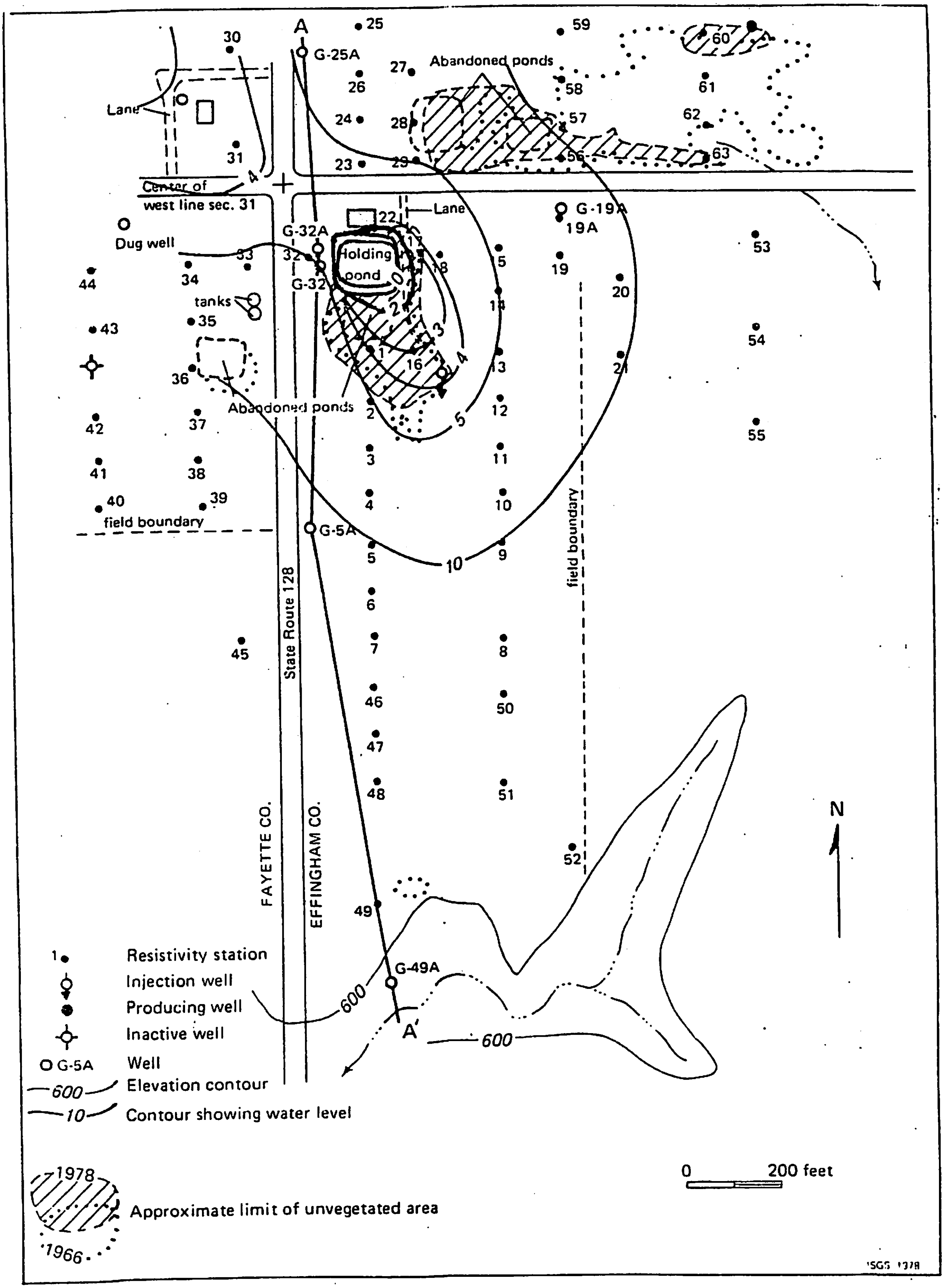
Beneath the Hagarstown is a tough sandy till, the Vandalia Member of the Glasford Formation. The Vandalia Member is greatly compacted in contrast to the overlying Hagarstown (see engineering data in appendix) which has comparatively greater permeability. The Vandalia appears fractured in some of the split spoon samples studied and therefore may be hydraulically connected to the overlying Hagarstown in places.

Hydrology

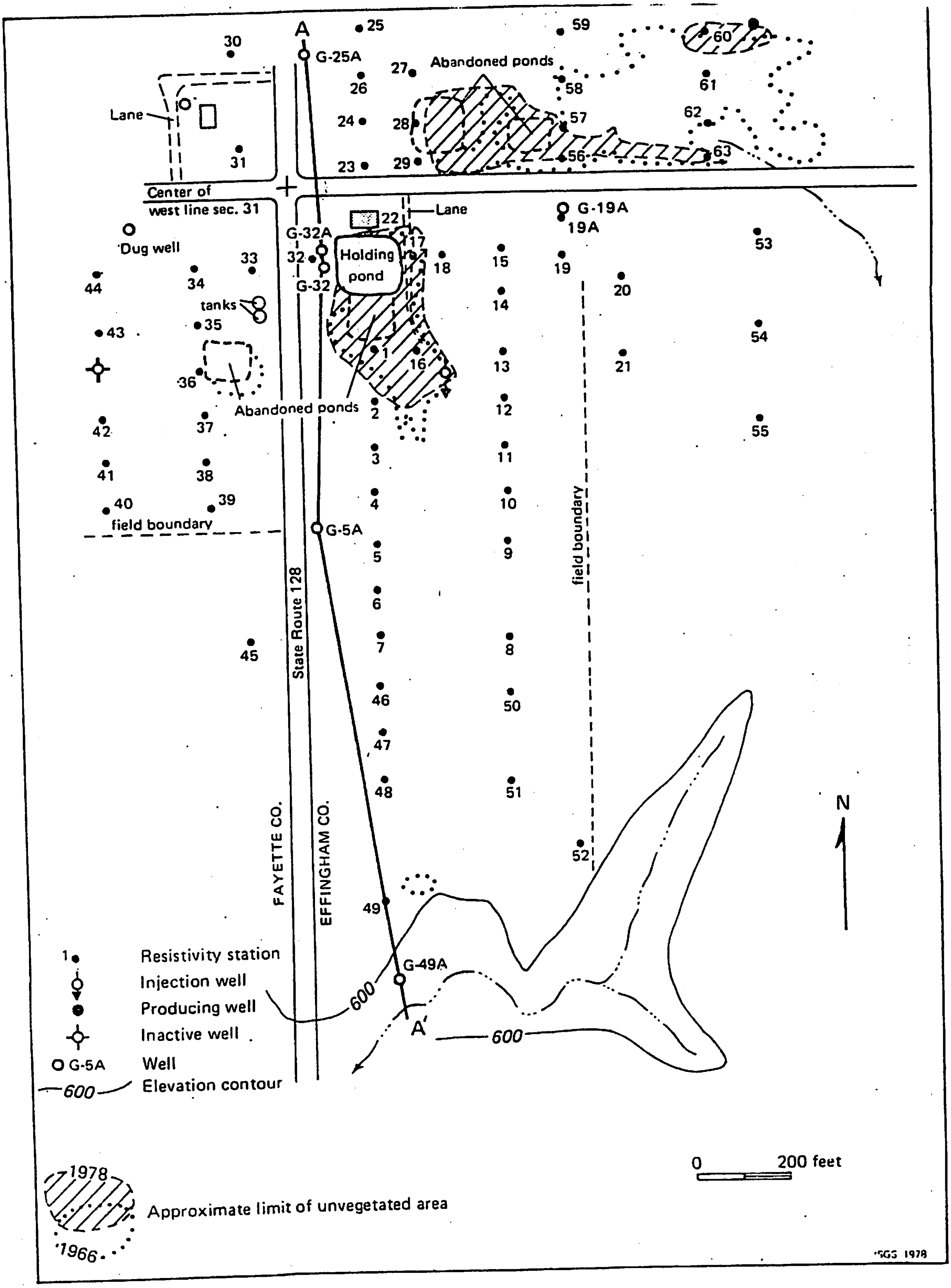
Water level contours around the holding pond indicate a ground-water mound beneath the pit with a gradient southward toward the creek. The distribution of apparent resistivity reflects the coalescing and interaction of the chloride migration from the active pond and the inactive holding ponds. The greatest migration of brine is southward toward the creek and west, northeast and east outward from the vicinity of the abandoned holding ponds. This relationship is shown on the apparent resistivity maps. The limit of the unvegetated area has decreased considerably in the locale of the abandoned holding ponds based on patterns shown on the 1966 aerial photograph.

EFFINGHAM-FAYETTE COUNTIES

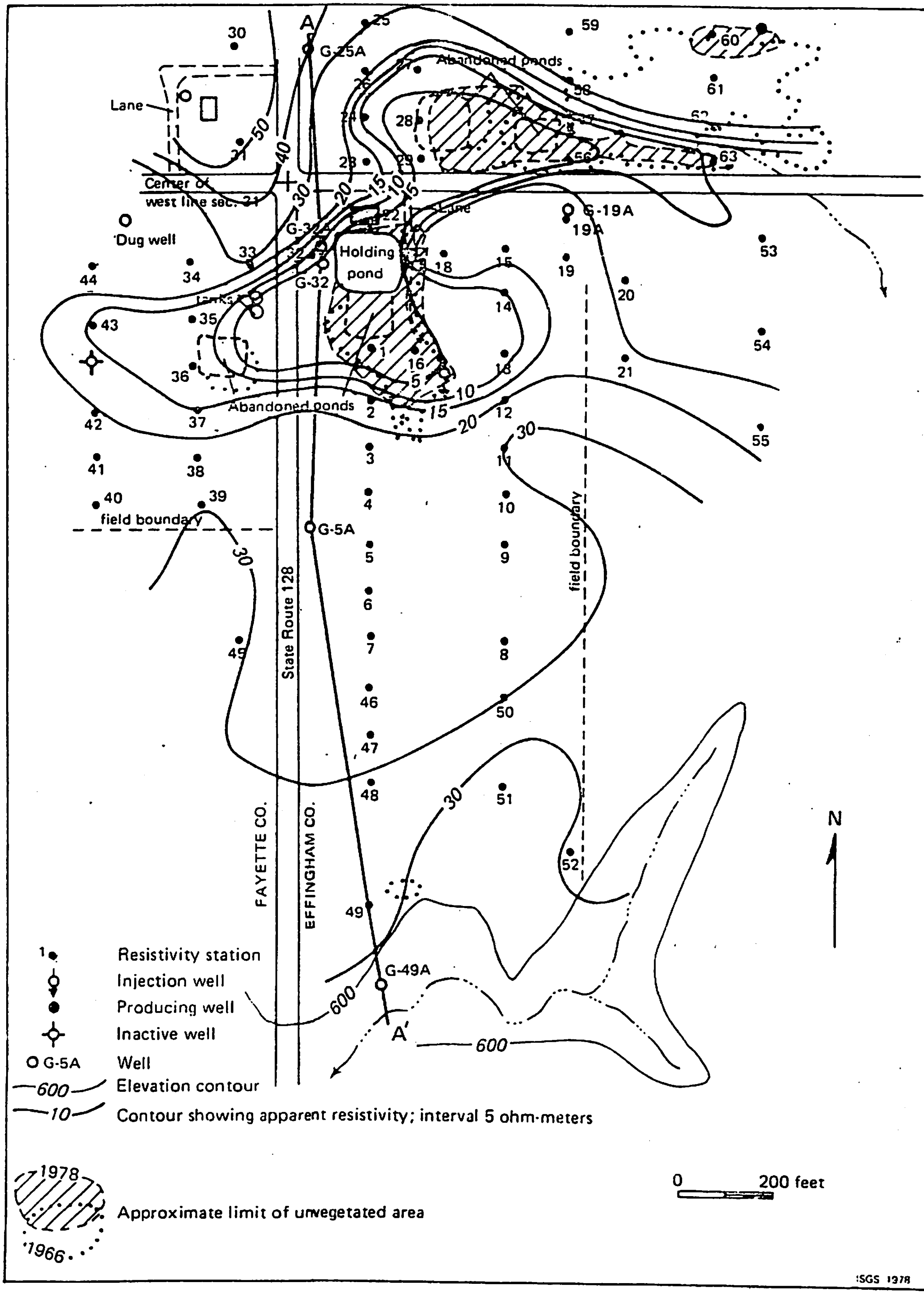
Well No.	Slot Interval	Relative Height Casing	Static Level Below Top Of Casing, July 20, 1978	Height Casing Above Ground	Relative Ground Level At Well	Static Level Below Ground	Ground Level Relative To Datum	Water Levels Relative To Ground Level Datum
G-Huffman		-	8.15	0.0	3.3	8.15	+5.02	+(-8.15)=-3.13
G-5A	4-14	-	5.45	0.3	13.91	5.15	-5.59	+(-5.15)=-10.74
G-19A	4-14	-	6.80	2.45	12.95	4.35	-4.63	+(-4.35)=-8.89
G-25A	9-14	-	5.20	0.60	4.85	4.60	+3.47	+(-4.60)=-1.13
G-32	4-14	-	8.05	2.90	8.32	5.15	0.0	+(-5.15)=-5.15
G-32A	14-17	-	7.45	2.55	8.30	4.90	+0.02	+(-4.90)=-4.88
G-49A	4-9	-	No Water	0.45	23.64	-	-15.32	
Creek					46.26 base channel		-37.94	
Pit		MP 7.18	1.8		8.98 (top fluid)		-0.66	-0.66



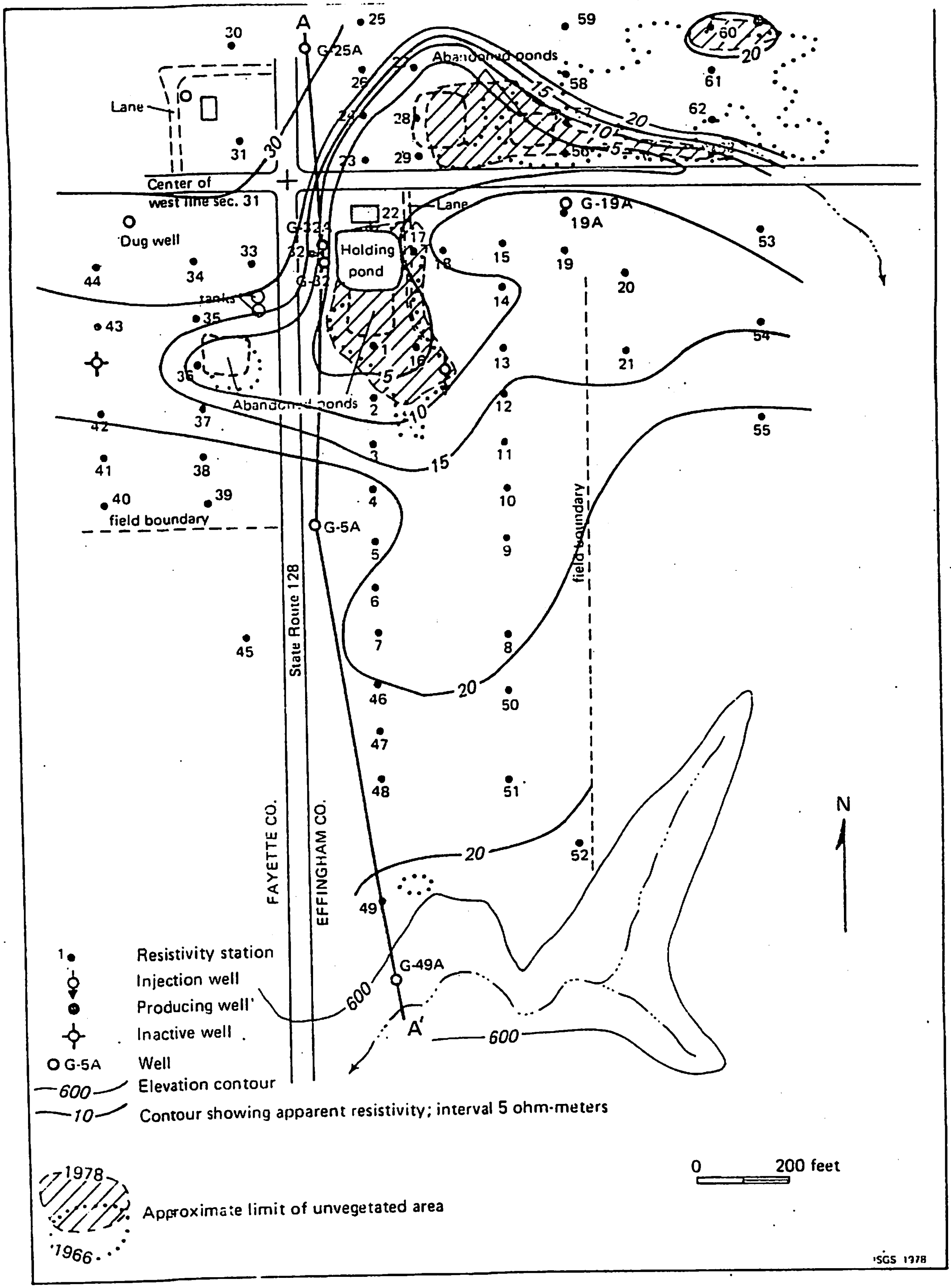
WATER LEVEL CONTOURS (DATUM GROUND LEVEL, G-32)
AT THE LOUDEN POOL OIL FIELD
Section 31, T. 9 N., R. 4 E., Effingham County, Illinois,
and Section 36, T. 9 N., R. 3 E., Fayette County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



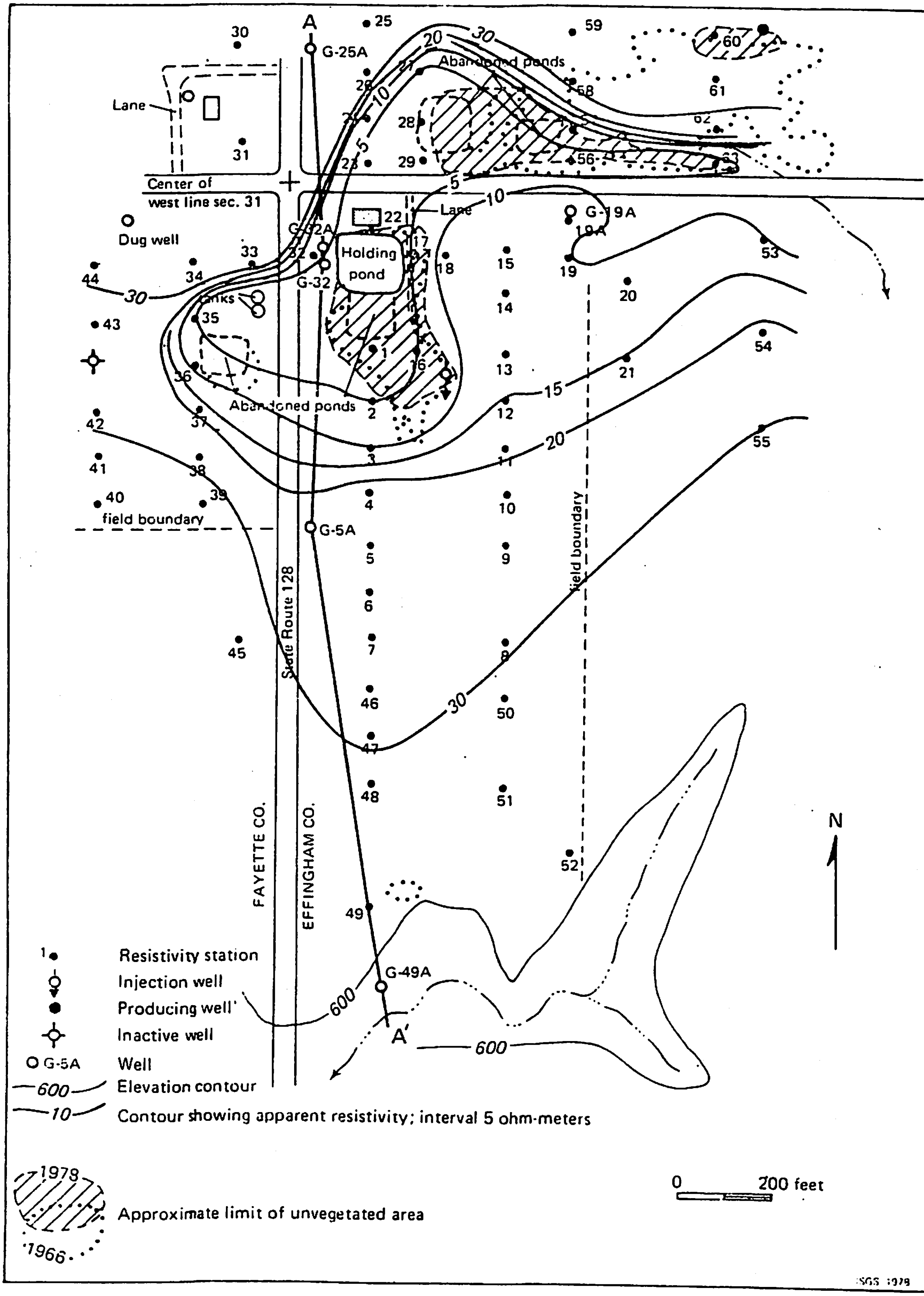
AN ELECTRICAL EARTH RESISTIVITY SURVEY
AT THE LOUDEN POOL OIL FIELD
Section 31, T. 9 N., R. 4 E., Effingham County, Illinois
and Section 36, T. 9 N., R. 3 E., Fayette County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



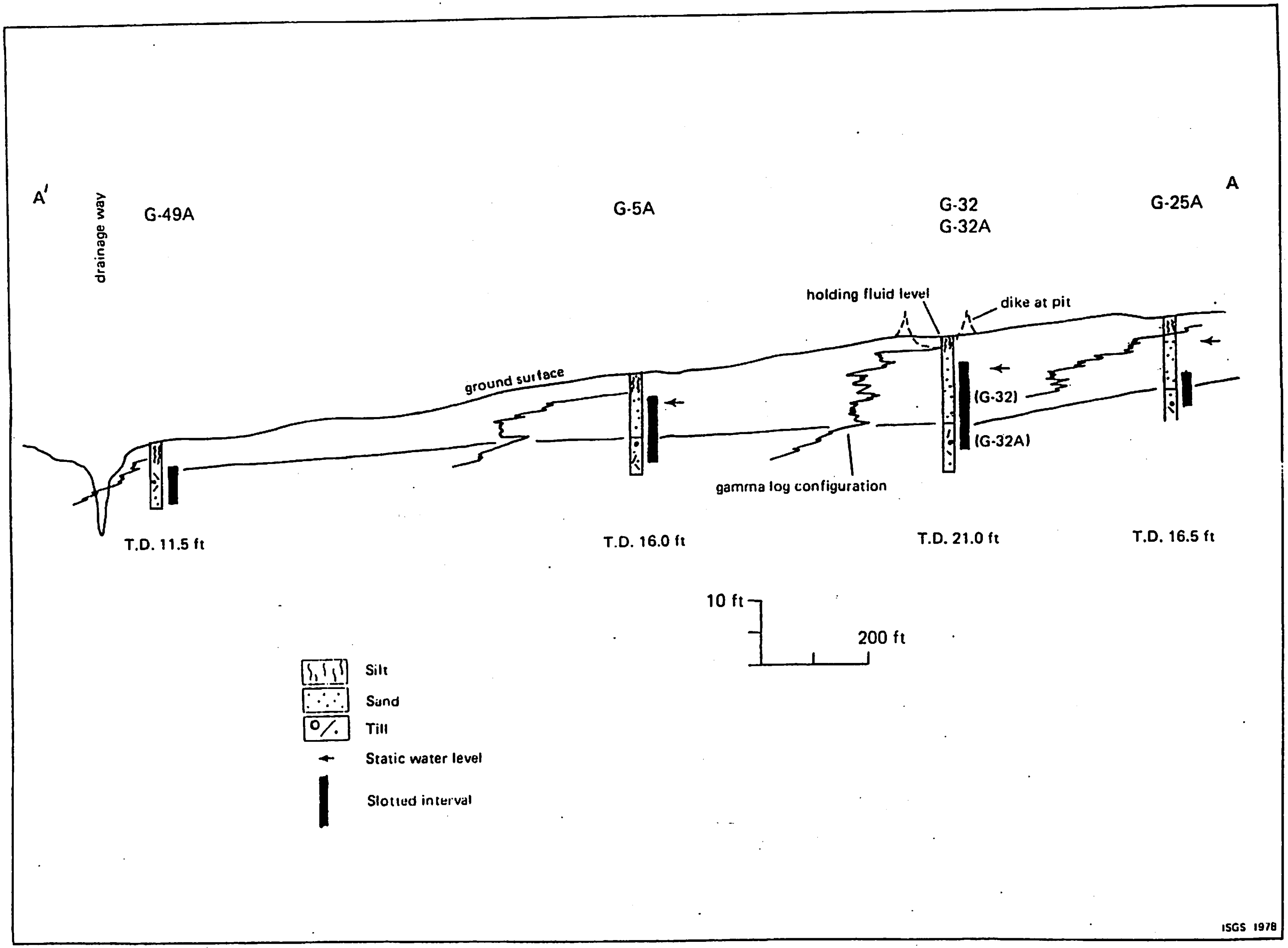
APPARENT RESISTIVITY (OHM-METERS) AT 5-FOOT DEPTH
AT THE LOUDEN POOL OIL FIELD
Section 31, T. 9 N., R. 4 E., Effingham County, Illinois
and Section 36, T. 9 N., R. 3 E., Fayette County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



APPARENT RESISTIVITY (OHM-METERS) AT 10-FOOT DEPTH
AT THE LOUDEN POOL OIL FIELD
Section 31, T. 9 N., R. 4 E., Effingham County, Illinois
and Section 36, T. 9 N., R. 3 E., Fayette County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



APPARENT RESISTIVITY (OHM-METERS) AT 20-FOOT DEPTH
AT THE LOUDEN POOL OIL FIELD
Section 31, T. 9 N., R. 4 E., Effingham County, Illinois
and Section 36, T. 9 N., R. 3 E., Fayette County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



GEOLOGIC SECTION AT THE LOUDEN POOL OIL FIELD
Section 31, T. 9 N., R. 4 E., Effingham County, Illinois,
and Sectı[illegible] 36, T. 9 N., R. 3 E., Fayette County, Illinois
[illegible] July [illegible] Re[illegible] [illegible]GS)

APPENDIX F

Clay County
E.E.R. and Water Table Maps
Lithologic and Gamma Ray Logs

Clay County Holding Pond Study Site
Land Administrator: Mr. Albert Hayes
Operator: Shelby A. Britton
Pond Size: 150'x60'x6'. Date Constructed: 1950?
Present salt water input: 4 barrels daily (reported)

Geologic Setting

The Clay County study site is located in Sections 21 and 28, T. 3 N., R. 7 E., within the Sailor Springs Consolidated Oil Field. The land elevation ranges between 445-455 feet above mean sea level. Drainage is westward toward a tributary of Elm River. The unconsolidated Illinoian glacial drift and loess which consists of silt, sand and glacial till is about 25 feet thick and overlie the Mattoon Formation of Pennsylvanian age.

Hydrogeology

The site is overlain to the west and north with 0-3 feet of loose, often moist, fairly clean sand with granules, probably spoil derived from the pond excavation. This surficial material is porous and permeable and appears to transmit pond fluid readily. Beneath this spoil and in areas where the spoil is not present is about 10-15 feet of loosely compacted soil, sand, silt and deeply weathered till of the Hagarstown Member of the Glasford Formation. Underlying the Hagarstown is ten or more feet of tough dry compacted (see unconfined compressive strength measurements) relatively impermeable till which is believed to lie on bedrock.

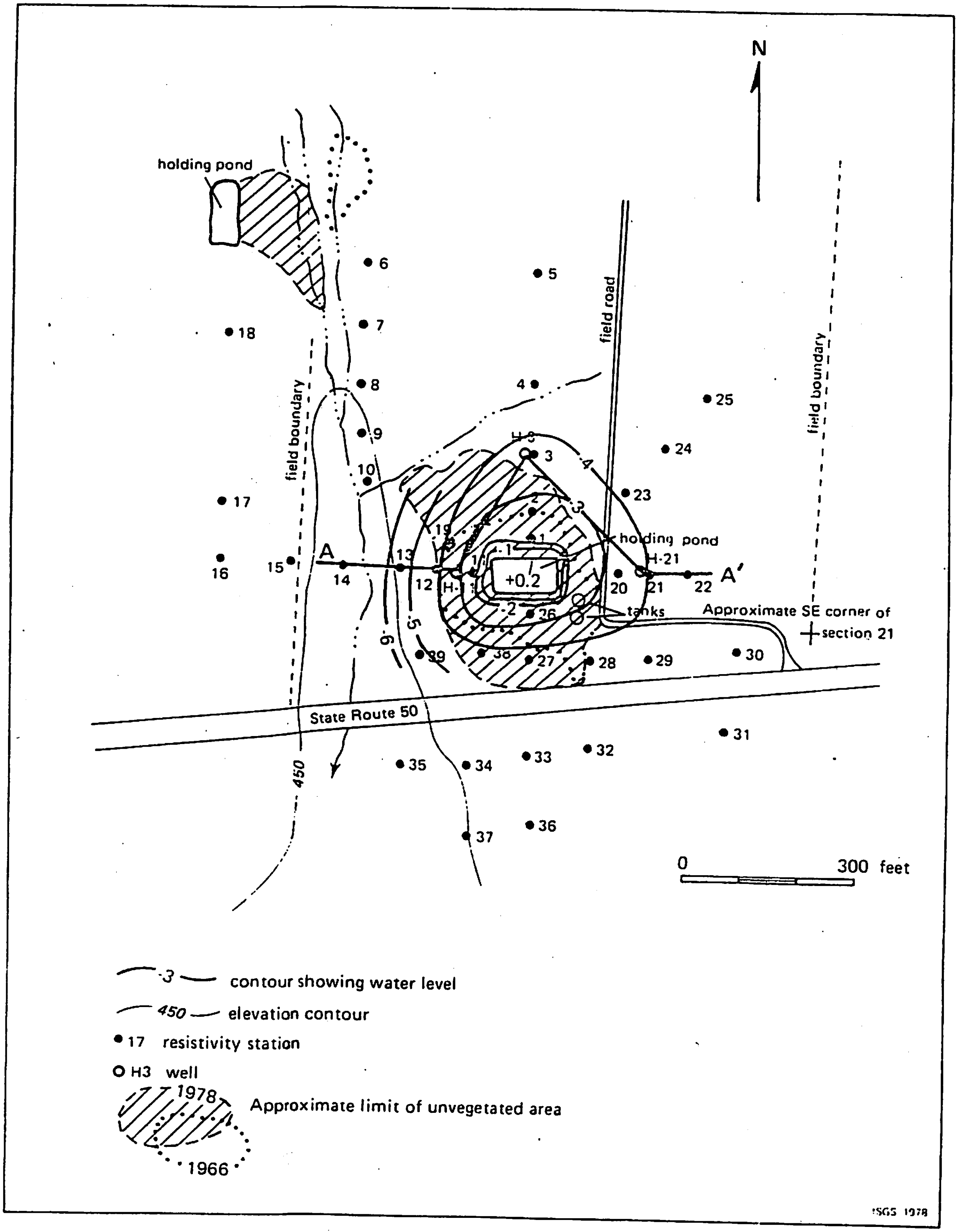
Hydrology

Water level contours around the holding pond indicate a ground-water mound beneath the pond with a general gradient westward toward the creek.

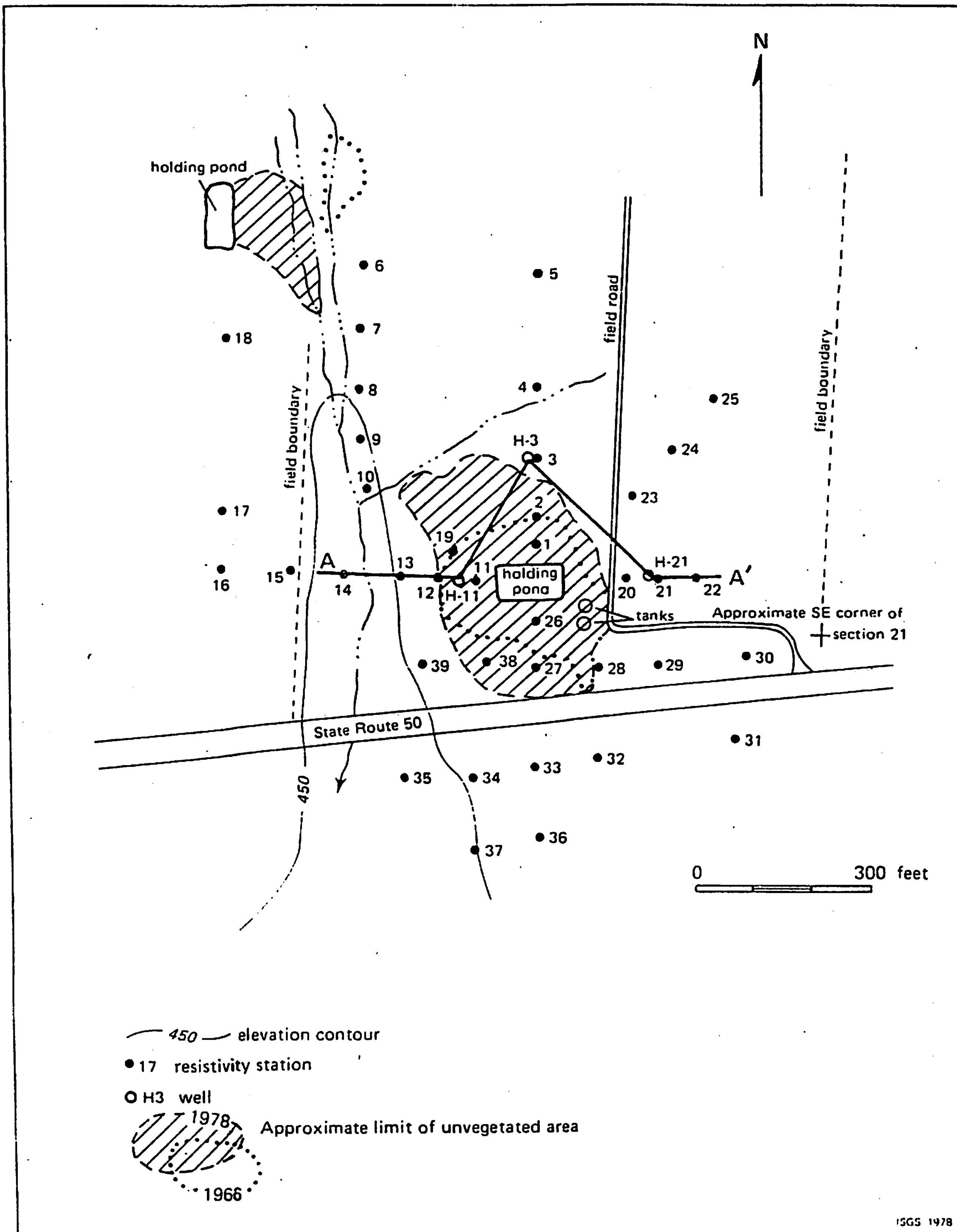
The distribution of the isoresistivity contours indicate that the greatest migration of chlorides is toward the southeast and northwest. The construction of state route 50 in the early 1970's appears to have interrupted a part of the southeastward migration of the unvegetative area around the pit. To the northwest, since 1966, the unvegetated area has extended outward 200 feet to a field waterway coincident with the chloride migration (note photographs).

CLAY COUNTY

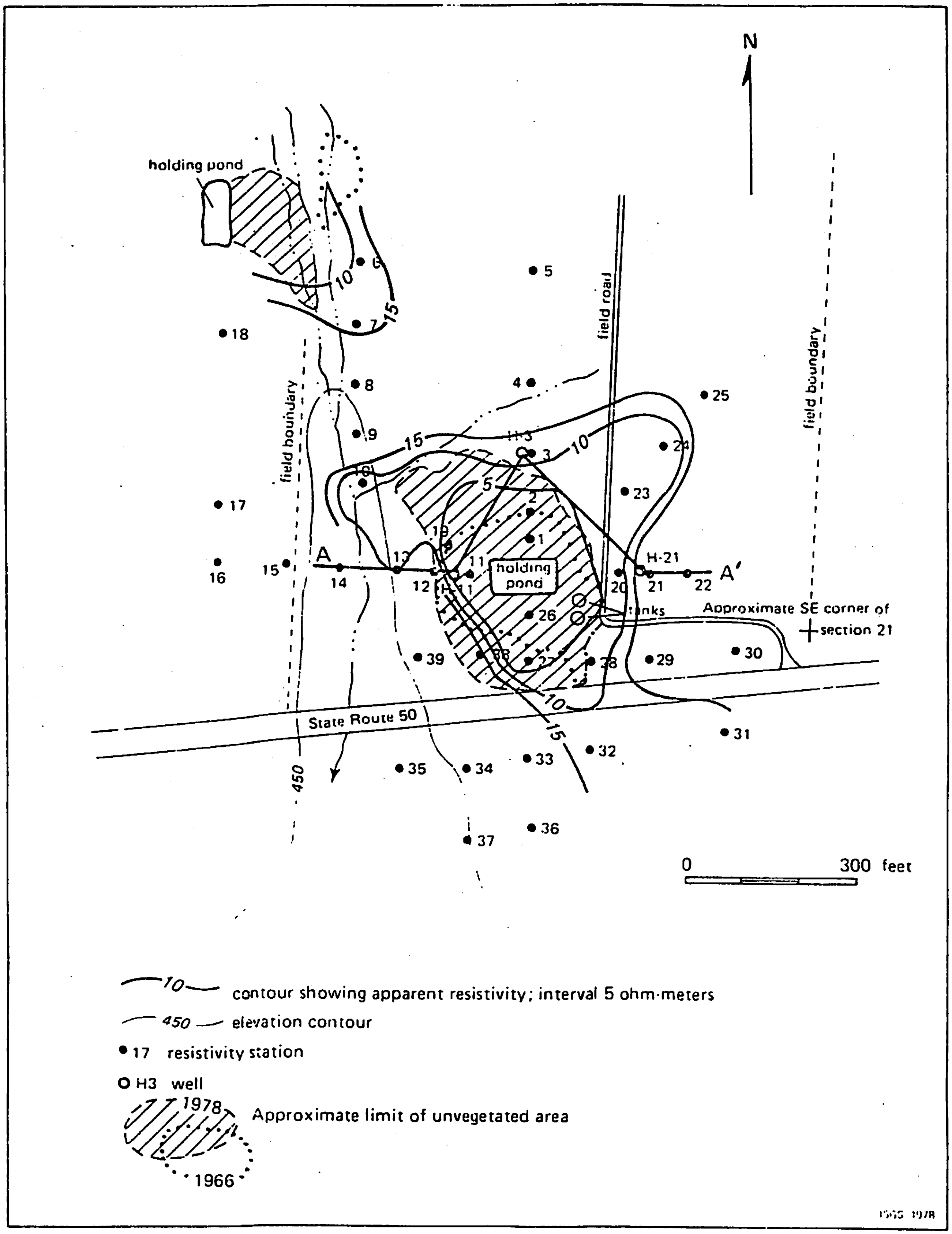
Well No.	Slot Interval	Relative Height Casing	Static Level Below Top Of Casing, July 20, 1978	Height Casing Above Ground	Relative Ground Level At Well	Static Level Below Ground	Ground Level Relative To Datum	Water Levels Relative To Ground Level Datum
H-3	4-14	5.00	3.65	0.3	4.70	3.35	+0.15	+(-3.35)=-2.20
H-11	4-14	4.85	3.90	0.0	4.85	3.90	0.0	+(-3.90)=-3.90
H-21	4-14	5.10	4.20	0.35	4.75	3.85	-0.05	+(-3.85)=-3.90
H-21	21-24	4.90	21.35	0.15	4.65	21.20	+0.20	+(-21.20)=-21.00



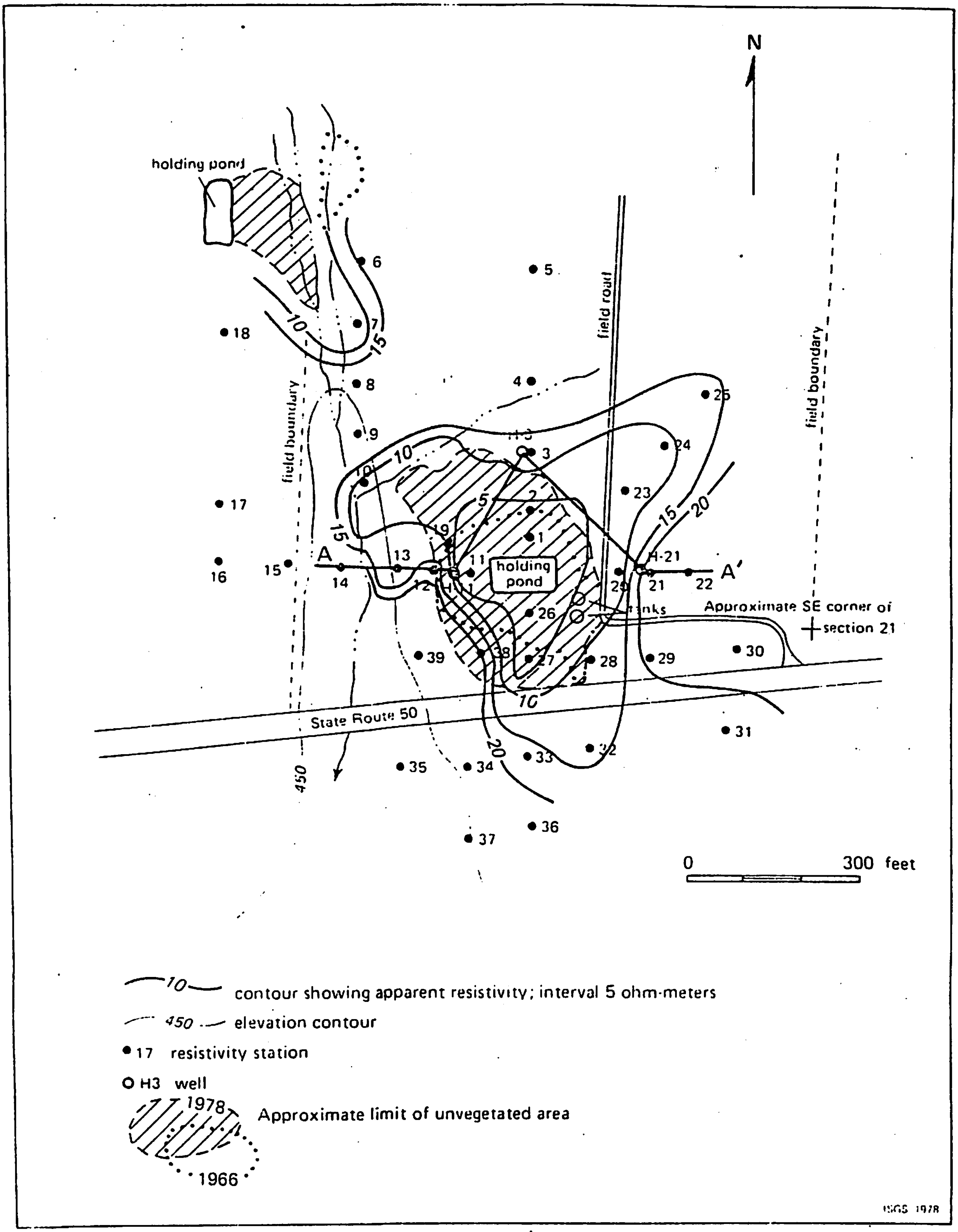
POTENTIOMETRIC SURFACE (DATUM GROUND LEVEL, WELL H-11)
SAILOR SPRINGS CONSOLIDATED OIL FIELD
Section 21, T. 3 N., R. 7 E., Clay County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



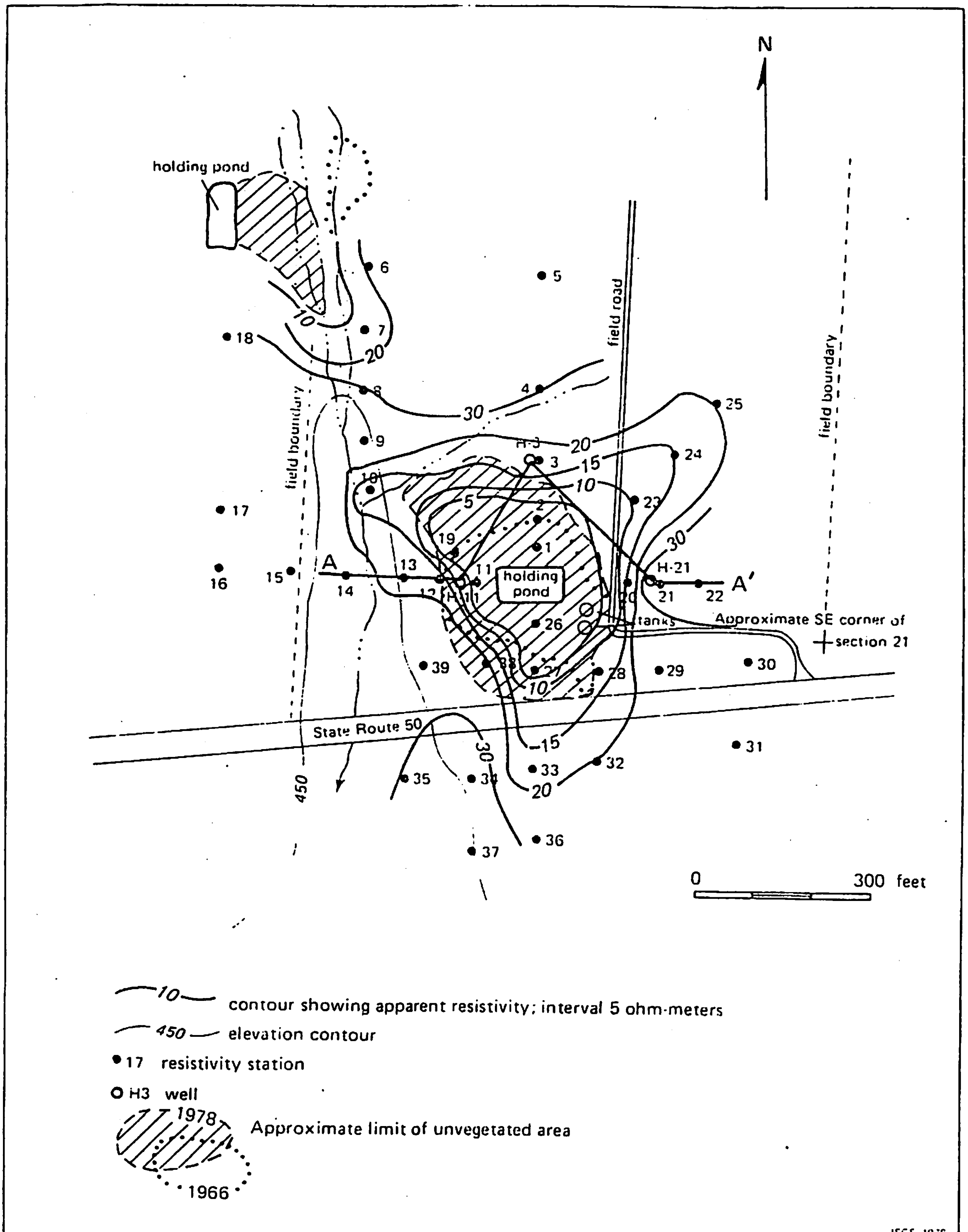
AN ELECTRICAL EARTH RESISTIVITY SURVEY
AT THE SAILOR SPRINGS CONSOLIDATED OIL FIELD
Sections 21 and 28, T. 3 N., R. 7 E., Clay County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



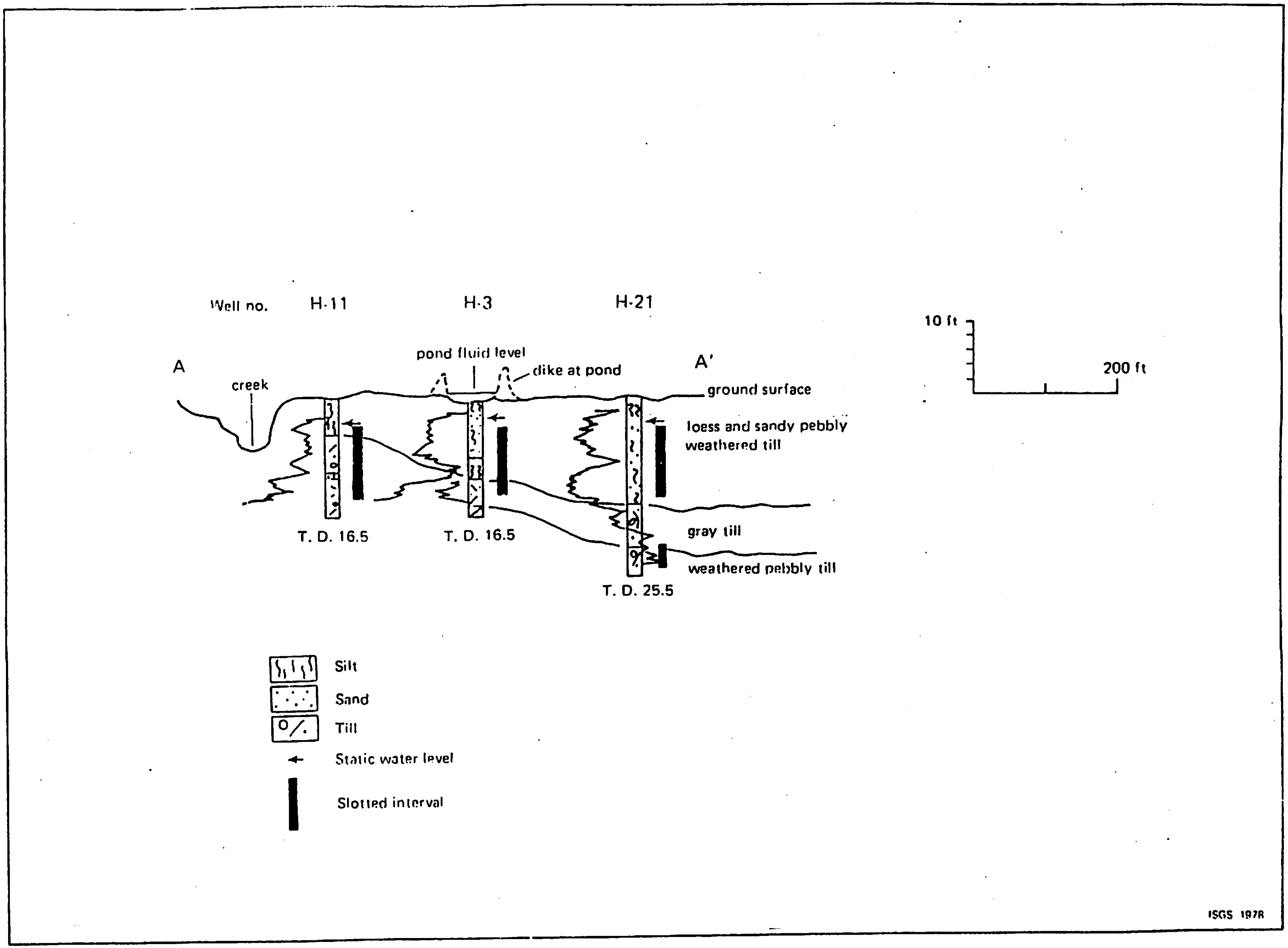
APPARENT RESISTIVITY (OHM-METERS) AT 5-FOOT DEPTH
AT THE SAILOR SPRINGS CONSOLIDATED OIL FIELD
Sections 21 and 28, T. 3 N., R. 7 E., Clay County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



APPARENT RESISTIVITY (OHM-METERS) AT 10-FOOT DEPTH
AT THE SAILOR SPRINGS CONSOLIDATED OIL FIELD
Sections 21 and 28, T. 3 N., R. 7 E., Clay County, Illinois
July 1978–Murphy, Osby (IEPA); Reed (ISGS)



APPARENT RESISTIVITY (OHM-METERS) AT 20-FOOT DEPTH
AT THE SAILOR SPRINGS CONSOLIDATED OIL FIELD
Sections 21 and 28, T. 3 N., R. 7 E., Clay County, Illinois
July 1978—Murphy, Osby (IEPA); Reed (ISGS)



GEOLOGIC CROSS SECTION A-A'
SAILOR SPRINGS CONSOLIDATED OIL FIELD
Section 21, T. 3 N., R. 7 E., Clay County, Illinois
July 1978–Murphy, Osby (IEPA); Reed (ISGS)