ENVIRONMENTAL IMPACTS OF OIL FIELD BRINES IN SOUTHEASTERN CLAY COUNTY, ILLINOIS

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with contributions by:

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Illinois State Geological Survey

Champaign, Illinois

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PART ONE

OVERVIEW - EXECUTIVE SUMMARY

ABSTRACT

Brine waters, characterized by high concentrations of dissolved minerals, can be found at depth throughout the oil producing region of Illinois. Because petroleum traps commonly contain both brines and petroleum, both liquids are commonly pumped to the surface. When brine waters are allowed to come in contact with the near-surface environment, degradation of that environment occurs. The results of an investigation of the environmental impacts of oil field brines in southeastern Clay County, Illinois are presented in this report. This investigation showed that: 1) Brine has been stored and disposed in 384 holding ponds in the study area. Spillage and leakage from these ponds has rendered hundreds of acres of farm land unsuitable for crops. 2) High erosion from unvegetated brine-damaged lands and high concentrations of dissolved minerals in that runoff have increased sedimentation and caused degradation of surface water quality. However, water from the stream investigated for this study still satisfies drinking water quality standards. 3) No evidence for wide-spread degradation of groundwater resources was found. Although groundwater in the vicinity of two filled-in brine holding ponds was highly contaminated.

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SECTION 1 PROJECT OVERVIEW

compiled by

Bruce R. Hensel and Dennis P. McKenna

INTRODUCTION

The production of oil and gas has been a significant part of the economy of Illinois since the discovery of oil in the Illinois Basin in 1903. In 1984, the value of crude oil produced was approximately 830 million dollars, with ten counties in southeastern Illinois producing 70% of that total (Van Den Berg et al., 1986). Direct employment by oil companies and suppliers, as well as related service industries, is a major contributor to the economic well being of this region.

Environmental problems from oil and gas production may occur during drilling, production, or disposal of associated wastes. If appropriate precautions are not taken, drilling fluids and muds, acids used to increase the permeability of reservoir rocks, and corrosion inhibitors and other additives are potential sources of contamination to soils, surface water, and ground-water (Collins, 1971). Also, losses of crude oil to the environment can occur during production, storage, and transportation. However, the greatest potential for environmental damage comes from brine waters that are produced as a waste product with oil.

Brines are naturally occurring fluids, with extremely high concentrations of total dissolved solids(> 100,000 ppm, Freeze and Cherry, 1979), which are present throughout most of the stratigraphic column throughout the world. The composition of brine varies both areally and with depth. In general, the concentration of total dissolved solids, also referred to as salinity, increases with depth. Meents et al., (1952) analyzed hundreds of samples of brines from the oil reservoirs of the Illinois Basin and found high concentrations of chloride (up to 95,000 ppm and commonly exceeding 50,000 ppm), sodium (up to 50,000 ppm), calcium (up to 18,000 ppm) and magnesium (up to 3400 ppm).

Gas, oil, and brine waters are found in subsurface stratigraphic traps. Gas, which has the lowest density of the three fluids, will fill the pores near the top of the trap, oil is typically found immediately below the gas, and the dense brines occur below the oil and gas. Due to this close association of brines and hydrocarbons, it is common to encounter and produce both in an oil well. As oil and gas are removed, the pore spaces formerly occupied by the hydrocarbons are filled with water. Consequently, a well may initially produce mostly oil; however, with increasing time, the ratio of brine to oil will increase. The Illinois Environmental

Protection Agency (1978) has estimated that 973,000 barrels of brine are disposed of daily in Illinois.

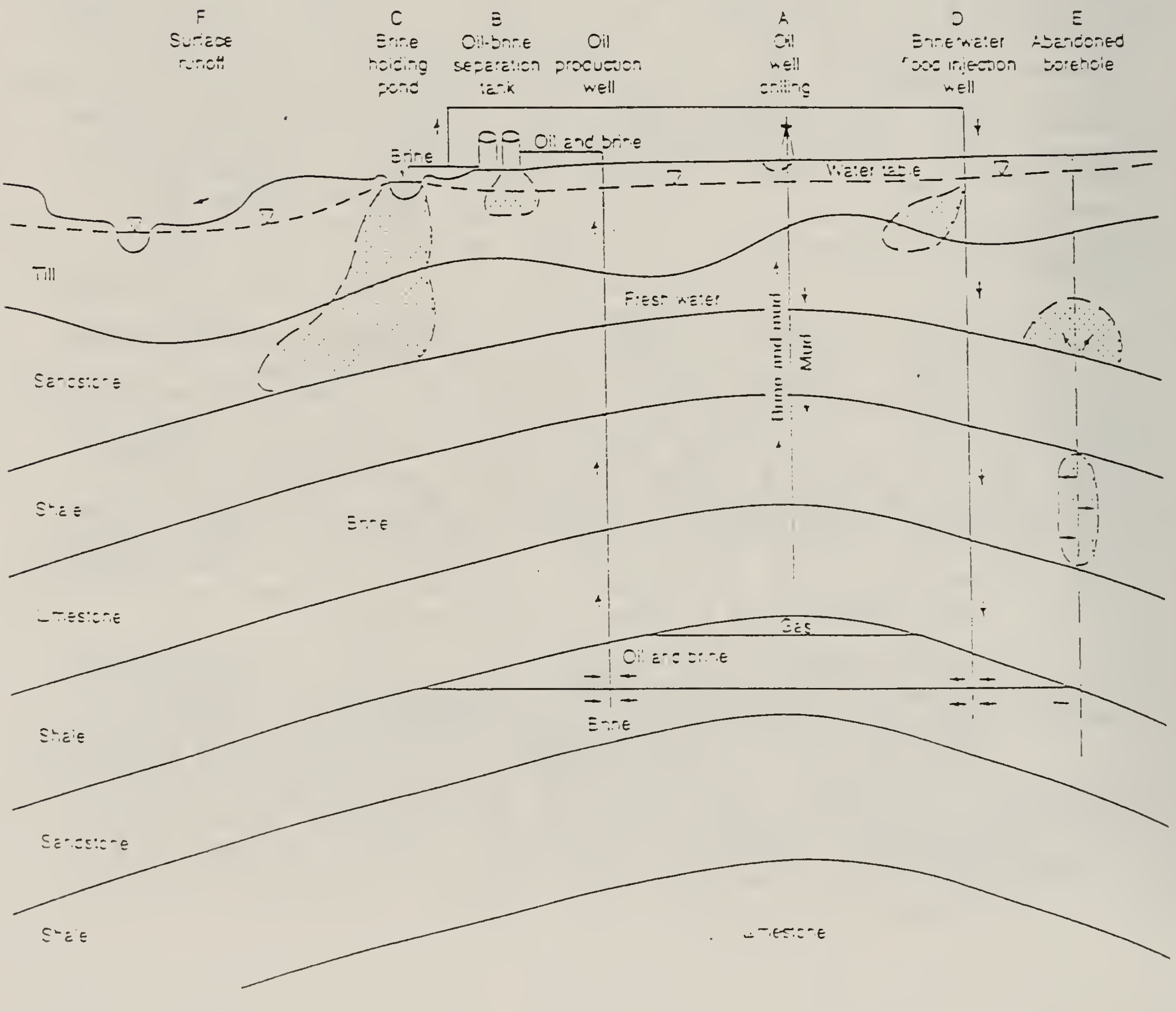
Brine waters, which are highly corrosive, may cause environmental problems during (Figure 1-1): 1) oil well drilling, when brines mixed with drilling mud are brought to the surface; 2) oil production, when the potential exists for brine leakage from pipelines, oil-brine separation tank batteries, waterflood injection wells, and when the potential exists that reservoir pressures created by waterflood operations may force brine waters to upwell through possible vertical conduits such as unsealed, abandoned boreholes; and 3) disposal or storage, when seepage can occur from holding ponds (unlined holding ponds have been banned in Illinois).

Disposal of brine waters has been a problem in Illinois since the early years of oil production when they were treated as an unwanted by-product and were commonly discharged directly into streams and drainage ditches. During the 1940's, injection well technology was developed. Still, the usual method of disposal involved pumping brine into a holding pond for evaporation. However, since the net precipitation rate in Illinois exceeds the evaporation rate (Roberts and Stall, 1967), brines stored in these ponds were infiltrating to the subsurface rather than evaporating. By the 1950's most brine was being disposed by injection (Bell, 1957); although many brine holding ponds continued to be operated until they were phased out from 1980-1985. Currently all oil field brines must be injected, or stored in corrosion resistant tanks until they can be injected.

The environmental consequences of improper brine disposal can be severe. When allowed to mix with surface and groundwaters, the high salinity of brines can make these valuable resources unpotable. One barrel of brine with a chloride concentration of 50,000 mg/L will raise the chloride content of more than 150 barrels of deionized water above the maximum recommended concentration for drinking water (250 mg/L). The environmental consequences of brine contamination in groundwater are especially severe because the residence time is much greater than in surface water and because chloride, the dominant ion other than hydrogen and oxygen, is conservative.

When brine comes into contact with the soil, the excessive sodium causes colloidal particles to disaggregate, thereby destroying the soil structure (United States Salinity Laboratory, 1969). Thus, the soil cannot support plant growth and is easily eroded, which adds to the impact of brines on surface water systems. An estimated 28,000 to 38,000 acres of land in Illinois have been severely damaged by oil field brines (Coleman and Crandal, 1981).

Figure 1-1. Potential routes for oil field related brine contamination of the environment. None of these occurrences are likely if proper oil drilling and brine disposal practices are used. A) Brine and mud returned to the surface during drilling are spilled on the ground surface, contaminating soils and shallow groundwater. B) Brine leakage from a separation tank. C) Brine infiltration from an unlined holding pond (such ponds are now banned; but were common prior to 1980). D) Possible leakage from brine injection/disposal wells. E) Reservoir pressure caused by waterflood injection or brine disposal forces brine up unplugged abandoned borehole. F) Runoff of brines and brine-contaminated sediments to streams causing degradation of water quality and increased sedimentation.



PURPOSE OF STUDY

The primary objective of this research was to assess the impact of oil field brines on the soil, surface water and groundwater resources, and aquatic biota of a study area in the oil producing region of Illinois. An additional objective was to assess the utility and cost-effectiveness of selected geochemical, geophysical, and remote sensing techniques in distinguishing between the various potential sources of brine contamination.

This report describes this research, funded by the Illinois Department of Energy and Natural Resources, and performed by the State Geological, Natural History, and Water Surveys. The report consists of three parts. This first part (Section 1) is a summary of research conducted for the project. Final conclusions and recommendations are presented at the end of this section. The second part of the report (Sections 2-9) contains the results of field investigations conducted for this project. The geology of the study area is described in Section 2; brine effects on groundwater, surface water, and aquatic biota are described in Sections 3-5; and Investigative and remedial techniques for brine contamination are discussed in Sections 6-9. The third part of the report (Section 10) contains appendices.

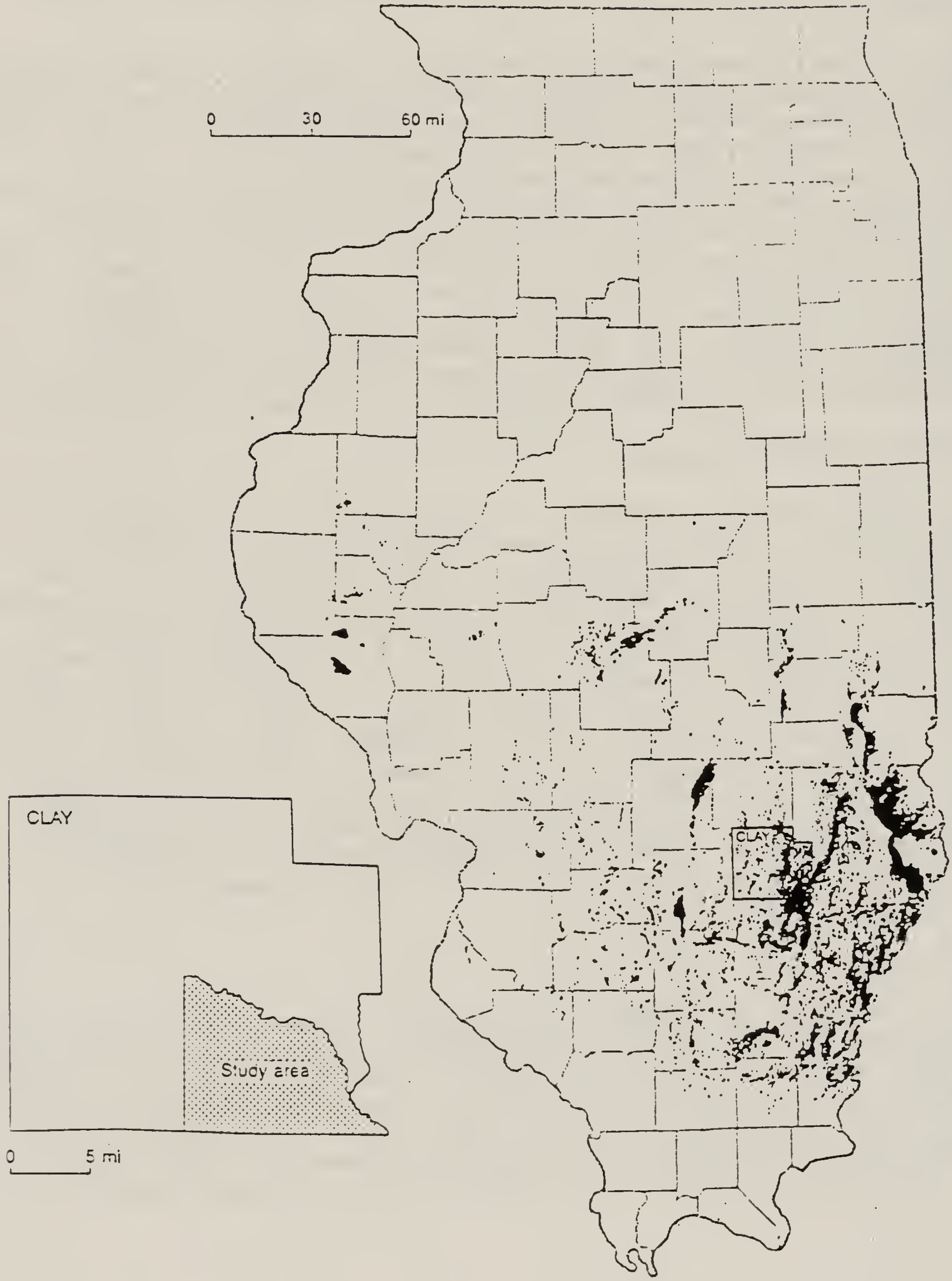
DESCRIPTION OF STUDY AREA

The study area is located in the east-central portion of southern Illinois (Figure 1-2) and includes that part of southeastern Clay County bounded on the north and east by the Little Wabash River, on the south by the Clay County line, and on the west by the west edge of the Flora 15 minute topographic quadrangle. Surface drainage is split by a divide which trends northwest-southeast through the study area. North of the divide drainage is toward the Little Wabash River, south of the divide drainage is toward the Elm River in northern Wayne County. This area was selected because 1) it has numerous, yet localized oil fields; 2) geologic conditions, estimated from maps of bedrock (Willman et al., 1967) and Quaternary (Lineback, 1979) geology, are representative of other oil producing areas of southeast Illinois; and 3) there was significant local interest and support.

Geology

The principal unconsolidated deposit through the study area, except in the valley of the Little Wabash River, is the Vandalia Till Member of the Glasford Formation. The Vandalia Till, which is generally overlain by a thin loess cover, is a compact, sandy to silty till with thin, discontinuous beds of sand and gravel at the base. The thickness of this unit is generally less than 50 feet. The valley of the Little Wabash River is underlain by

Figure 1-2. Map of counties and oil fields in Illinois. Southeastern Clay County study area is shown in inset.



fine-grained lacustrine deposits of the Carmi Member of the Equality Formation with a total thickness greater than 100 feet. Immediately adjacent to the Little Wabash and its major tributaries, the poorly sorted fluvial deposits of Cahokia Alluvium overlie glacial till or lacustrine sediments. Locally, the Cahokia contains sand and gravel deposits.

The uppermost bedrock unit is the Mattoon Formation of Pennsylvanian age. This formation consists of sandstone, shale, limestone, and coal. The average thickness of this formation in southeast Clay County is about 300 to 400 feet. Total thickness of the Pennsylvanian units is greater than 2000 feet. Underlying the Pennsylvanian units are Mississippian age formations.

Oil Resources

In southeastern Clay County, oil is produced from strata in the Mississippian System. These units consist of limestone and sandstone with some shale. The principal oil-producing formations are the Tar Springs Sandstone, the Cypress Sandstone, the Aux Vases Sandstone, and the McClosky Limestone. The Tar Springs Sandstone is typically encountered below 2200 feet, approximately 1750 feet below mean sea level, and is the uppermost oil-producing unit of the Mississippian System. The Mississippian System has an approximate thickness of 2300 feet.

Commercial quantities of oil were first discovered in the study area in May 1937, with the completion of the discovery well for the Clay City Oil Field. This well, the Pure Oil Company Bunyon Travis #1, established production in the oolitic McClosky Limestone Member of the Ste. Genevieve Formation (Mississippian). This discovery, which was based on structural mapping from seismic data, led to a tremendous increase in drilling activity throughout the state.

The major oil field in the area is the Clay City Oil Field. This oil field has been partially subjected to waterflood projects for over 35 years. In 1984, oil production from the field was approximately 3.22 million barrels from 2900 wells. Total cumulative production through 1984 was 333 million barrels (Van Den Berg et al., 1986). Of this total, one million barrels were produced from waterflood projects in 1983, with cumulative recovery from waterflooding totaling 67.5 million barrels through 1983.

Occurrence of Brine Waters

Brine waters occur throughout the entire thickness of the Mississippian System as well as in the overlying Pennsylvanian formations. The depth to the base of the fresh water (TDS > 2500 ppm) has been estimated throughout the study area, based on electrical resistivity well logs. This depth varies from 150 to

250 feet (Figure 1-3). The salinity of water increases with depth, and below 300 to 350 feet total dissolved solids are estimated to exceed 10,000 ppm.

Groundwater Resources

Most groundwater supplies for domestic and farm use are obtained from either the surficial unconsolidated deposits or from shallow sandstones in the Pennsylvanian bedrock. Wells in the drift are typically large-diameter (24 to 36 inch) wells which obtain water from thin, discontinuous sand layers within the glacial till or alluvium or from fractures and joints within these units. Other than along the Little Wabash River, few significant unconsolidated sand and gravel deposits have been located in the study area. However, the sandstone aquifer appears to be continuous throughout much of the study area. Wells finished in the bedrock seldom exceed 150 to 200 feet in depth because the groundwater in this region rapidly becomes saline as depth increases.

Surface Water Resources

At the present time, no public water supplies in southeastern Clay County use groundwater. Fifty-one percent of the population of Clay County is served by public water supplies which are entirely dependent on surface water sources, primarily the Little Wabash River. The quality of the local surface water is equal to or better than that of the potable groundwater; however, its quality is also more variable. The Little Wabash River near Louisville has an average discharge of 575 cubic feet per second (cfs) but stream flow can drop as low as 0.5 cfs during periods of drought. During periods of low flow, the water quality of the river degrades.

ASSESSMENT OF BRINE IMPACTS

Impacts on Aquifers

Water quality within the drift and bedrock aquifers in the study area is generally fair (Figure 1-4). Instances of elevated salt levels in deeper bedrock wells can usually be attributed to naturally saline groundwater which occurs at depth (Section 3). However, localized shallow groundwater contamination does occur in the vicinity of brine holding ponds (Section 9).

Measurements of electrical conductance of water samples from 199 domestic water supply wells in and around the study area (see Section 3) were used to estimate that 53 had calculated total dissolved solids concentrations over 1000 mg/L and five of those 53 had calculated TDS concentrations greater than 2000 mg/L. All of the wells with estimated TDS concentrations greater than 2000

Figure 1-3. Depth to the base of fresh water (TDS less than 2500 ppm) in southeastern Clay County. TDS concentrations are from electric log data.

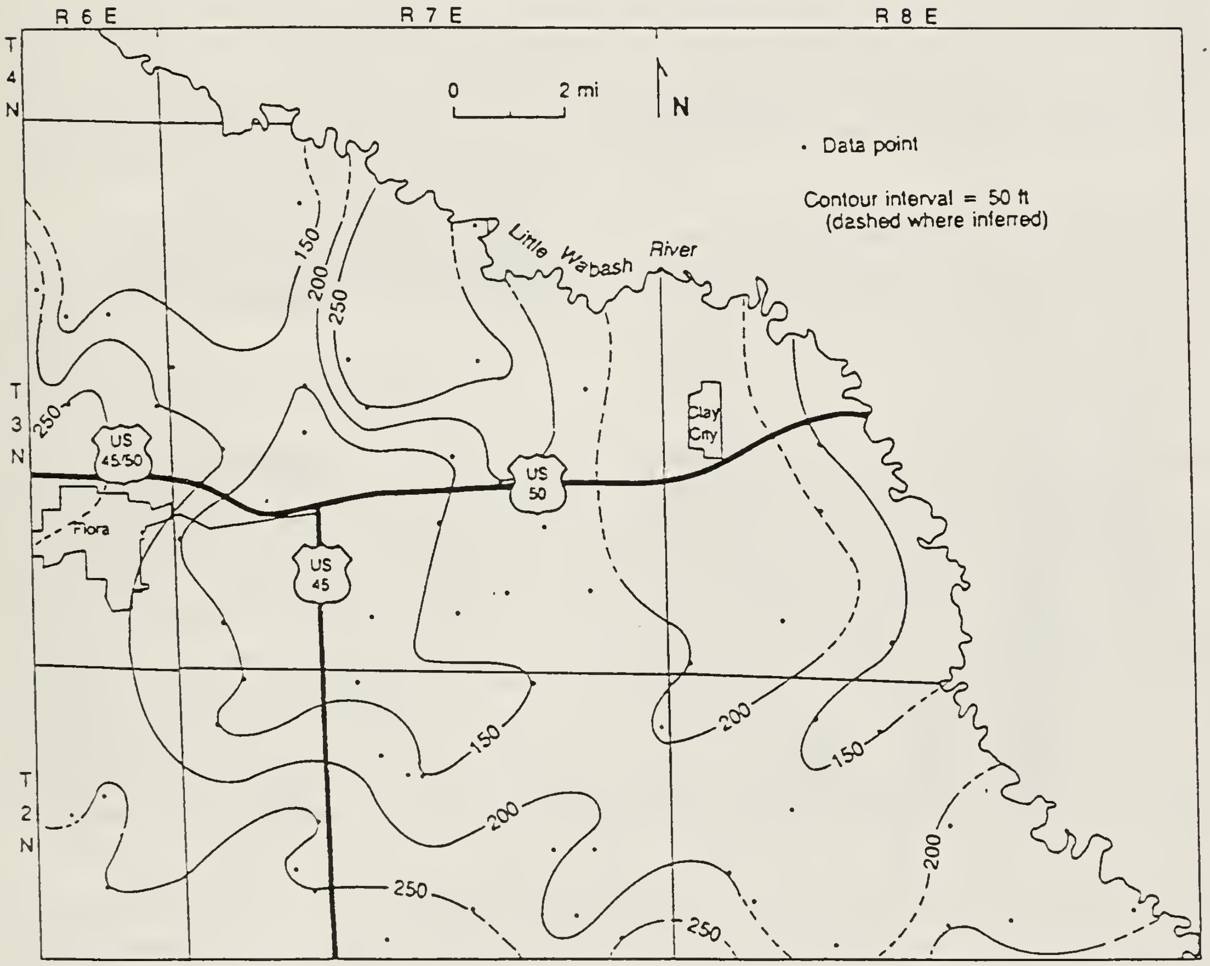
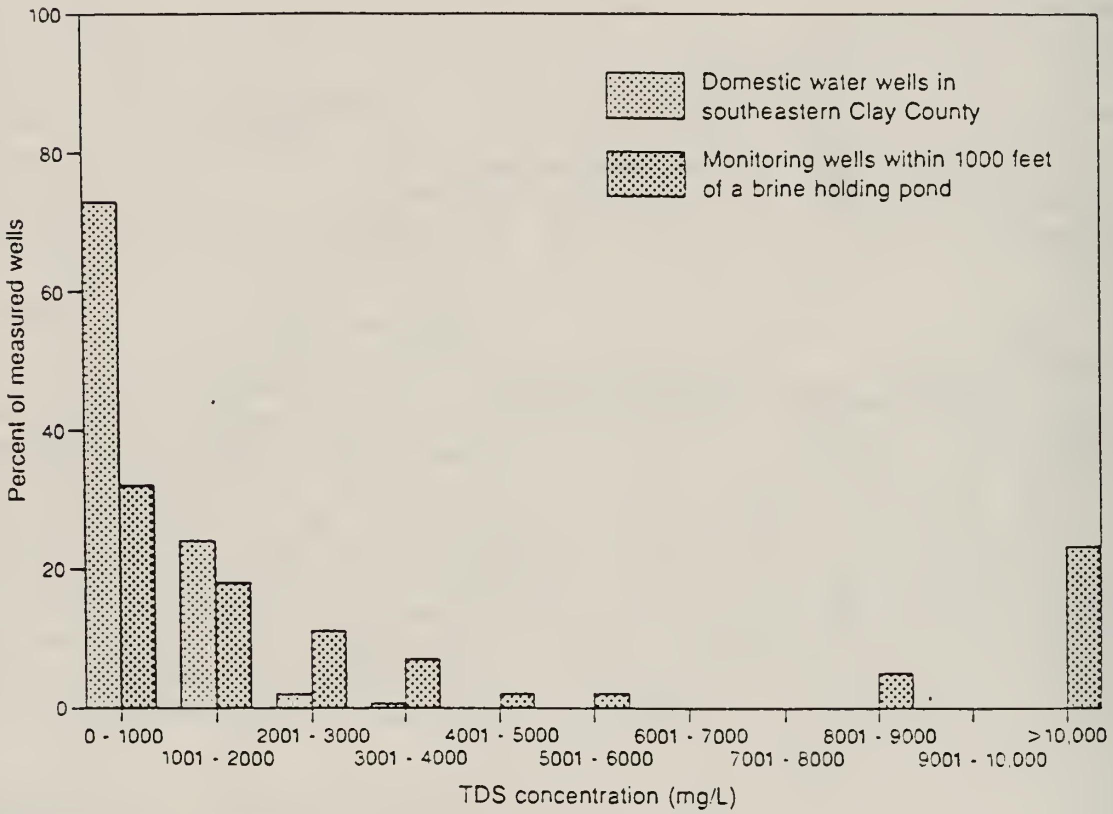


Figure 1-4. Comparison of regional water quality in southeastern Clay County to water quality in the vicinity of a brine holding pond.



mg/L were finished at depths greater than 150 feet. The depth to the base of the fresh water zone in Clay County is estimated to be 150 to 250 feet (see Section 2), which suggests that upconing of naturally saline groundwater is the cause of the high TDS concentrations in those five wells.

No apparent causes could be identified for the high salinity in the 53 wells where TDS concentrations were between 1000 and 2000 mg/L. There were no significant correlations between TDS and depth or TDS and proximity to brine holding ponds. Of the 14 wells located within an estimated distance of 500 feet to brine holding ponds, none had an estimated total dissolved solids concentration greater than 1500 mg/L.

Shallow, localized contamination of groundwater was noted near two intensely studied brine holding ponds. Total dissolved solids in groundwater below the two ponds were as high as 52,000 mg/L.

Impact on Surface Water

An assessment of the water quality in one perennial stream, Buck Creek, indicated generally good water quality; however, brine impacts were evident (see Section 4). An increase in suspended sediment was noted between the upstream and downstream stations, indicating that runoff entering the stream between the two stations carried almost twice the concentrations of suspended solids as was measured at the upstream station. Concentrations of several indicators of oil field brines, including chloride and total dissolved solids, increased significantly between the two stations, although the levels did not exceed Illinois water quality standards. Also, grease and oil concentrations in this stream were higher than those usually found in Illinois rivers.

The increased sediment load and elevated chloride and TDS concentrations between the upstream and downstream stations at Buck Creek, as well as the relatively high grease and oil concentrations, indicate that Buck Creek has been affected by oil field activities. The high suspended solids are a result of increased runoff from areas where vegetation will not grow because brines have damaged the soils. Concentrations of TDS and chloride in runoff from one such area (not in the Buck Creek watershed) were as high as 14,000 and 8,250 mg/L, respectively.

Impacts on Aquatic Ecosystems

Examination of aquatic biota in Buck Creek showed decreased species diversity downstream from the area of heavy oil field activity (see Section 5). This decrease in diversity can partially be attributed to degradation of water quality by oil field brines. However, the absence of a variety of microhabitats was considered to have a greater effect on the decrease in species diversity.

No water quality variables were detected which might be limiting or toxic to aquatic life. However, a limited microhabitat diversity was apparent. Buck Creek has been historically channelized. Rocky riffle areas are absent along most of its downstream length, and the substrate consists primarily of finer or softer sediments. Also, undercut banks, log jams, and other micro-habitats are uncommon. For these reasons, the absence of microhabitat diversity was deemed more limiting to benthic macroinvertebrate diversity than degraded water quality.

EVALUATION OF BRINE INVESTIGATIVE TECHNIQUES

Assessment of actual or potential environmental damage from the production and disposal of oil field brines on a state- or county-wide basis is hampered by 1) the widespread nature of oil production in Illinois (47 counties produced oil or gas in 1983), and 2) the large number of potential sources (more than 8600 brine holding ponds, over 77,000 active and abandoned oil wells, and more than 12,000 injection wells). Identification of site-specific sources of contamination is difficult because 1) saline water may be either natural or the result of oil field brines, and 2) tracing of contaminant plumes in groundwater is often expensive and time-consuming.

During this investigation, air photo interpretation proved to be an efficient method of locating abandoned brine holding ponds (Section 8). Three sets of photos were used (1953, 1966, and 1983) to identify 384 holding ponds (Figure 1-5) in southeastern Clay County.

Subsurface brine plumes were efficiently located using a combined electrical resistivity survey and groundwater monitoring program (Section 9). The electrical resistivity survey can be done relatively quickly and at little expense. The resistivity data can be used to delineate the approximate depth, location, and extent of the plume. Those data can aid in the efficient placement of groundwater monitoring wells (Figure 1-6).

Multivariate statistical analysis showed promise as a technique to differentiate the origin of brine waters (Section 6). Ratios of Ca/Cl, Mg/Cl, Ca/Li, and Mg/Li can be used to differentiate shallow brines from oil field brines from fresh water (Figure 1-7).

CONCLUSIONS

1) An assessment of the environmental impacts of oil field brines in southeastern Clay County shows that both surface waters

Figure 1-5. Brine holding ponds in southeastern Clay County. Identified using air photographs from 1953, 1966, and 1983.

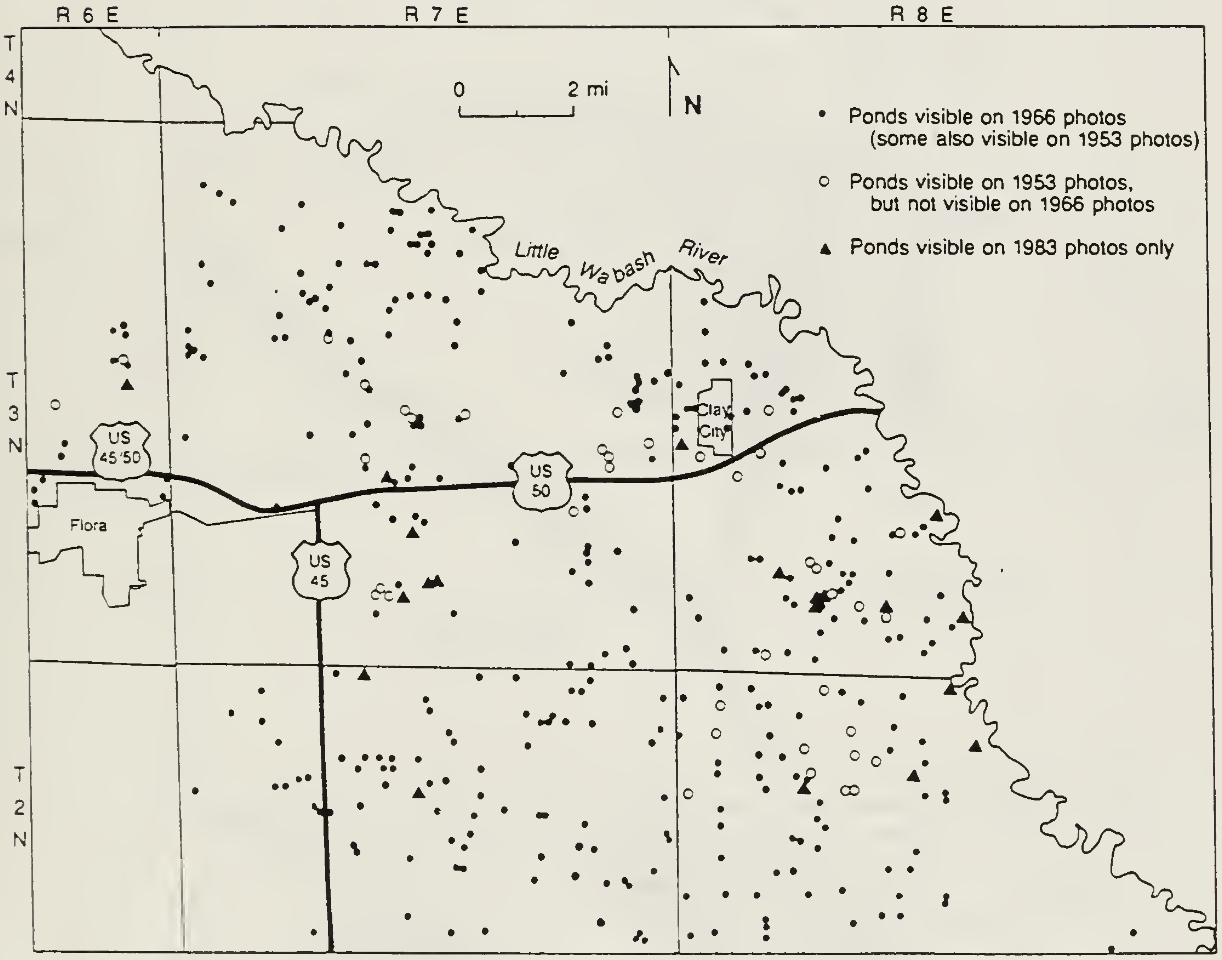
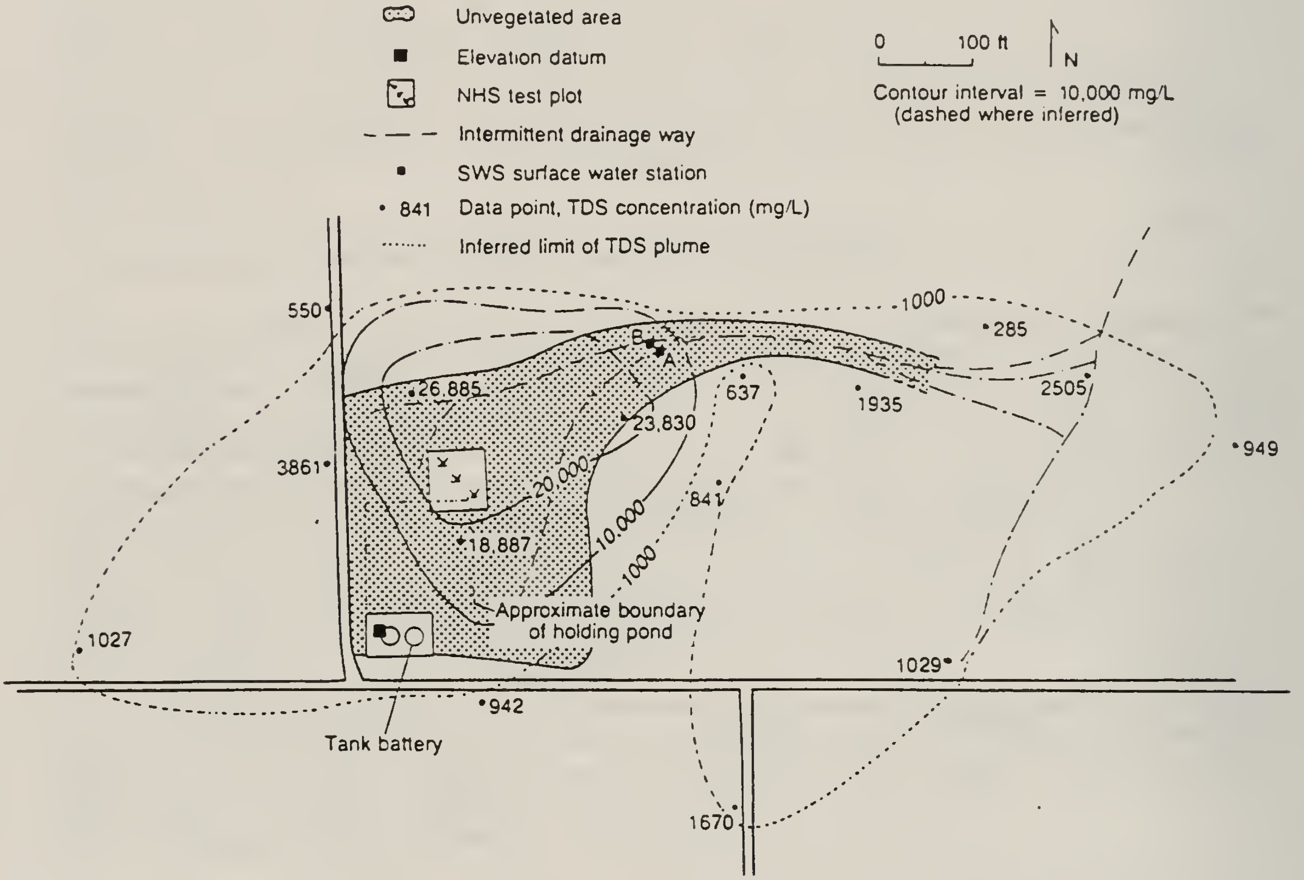


Figure 1-6. Comparison of two brine plume tracing techniques. A - plume mapped according to concentration of total dissolved solids in groundwater. B - plume mapped based on electrical resistivity values.

A.



B.

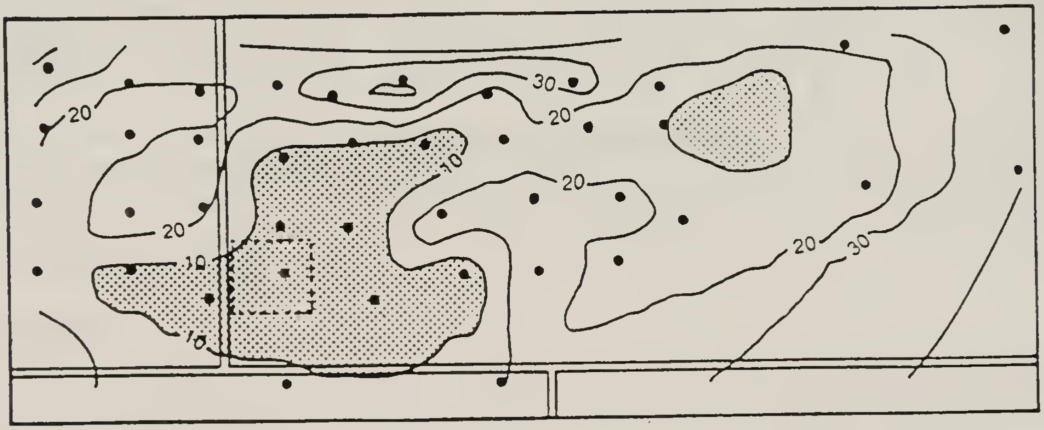
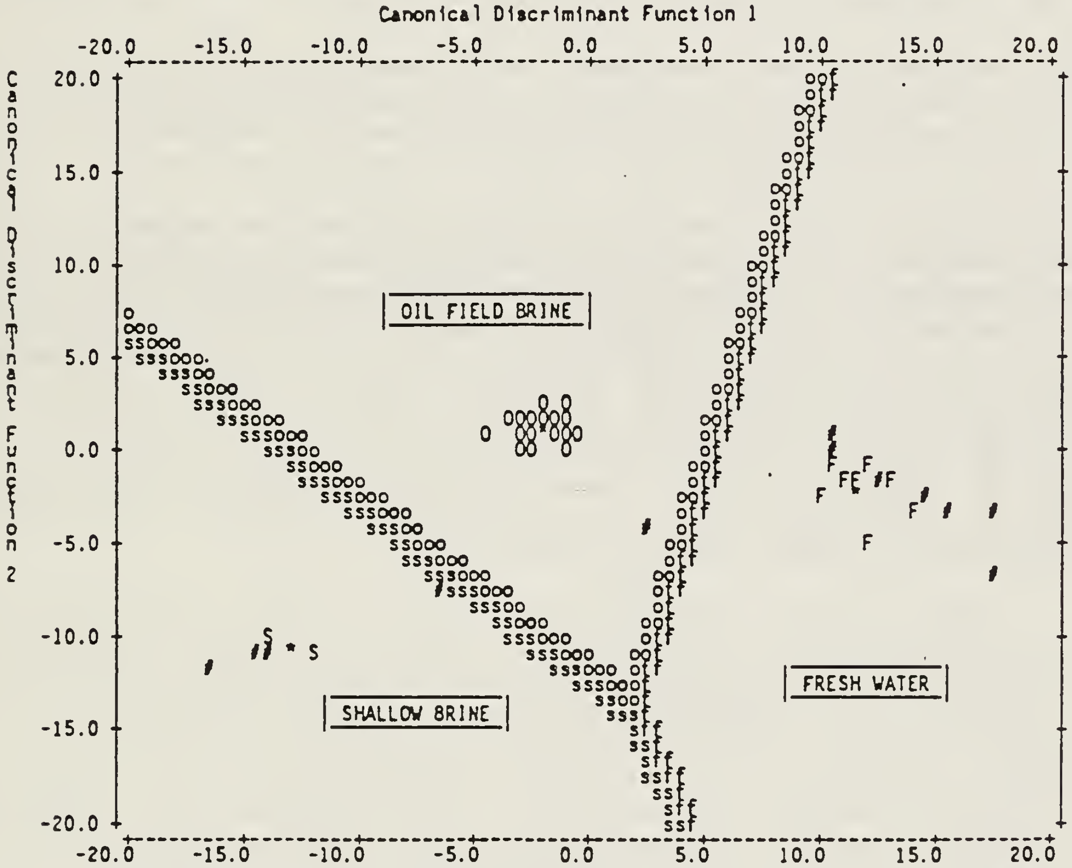


Figure 1-7. Discriminant Analysis territorial map for oil field brine, shallow brine, and fresh water.



* Group centroids, # Unknown, O Oil Field Brine, S Shallow Brine, F Fresh Water

Unstandardized Canonical Discriminant Function Coefficients

	FUNC 1	FUNC 2
log(Ca/Cl)	8.574445	21.62736
log((Ca+Mg+Sr)/Cl)	26.38258	-1.067425
log((Na+Ca+Mg+Sr+Li)/Cl)	-27.94176	-23.43031
log(Na/Ca)	23.79036	10.69833
log(Mg/Li)	8.225558	-3.014662
log(Sr/Li)	-3.403425	1.823528
(constant)	-5.930134	16.52935

(Section 4) and groundwaters (Sections 3 and 9) have been affected. Increased concentrations of suspended solids, chloride, bromide and sulfate were noted in surface water; however, drinking water quality standards were not exceeded for any of these parameters. Groundwater contamination has occurred in localized areas where brine holding ponds once existed. However, no water supply wells appeared to be contaminated by oil field brines.

2) The most severe problem currently associated with oil field brines may be damage of surficial soils caused by brine spills. Hundreds of acres of land in the study area have soils which have been damaged by oil field brines. Where the brine spill has been recent, no vegetation has grown and erosion is severe. With time, the salts are partially leached out of the soils and salt tolerant plant species may be established (Section 7).

3) Brine, which is more dense than fresh water, will tend to sink within an aquifer until a relatively impermeable stratum is encountered. In materials with low permeability, brine will move along pathways of higher hydraulic conductivity. Because many cases of brine contamination of ground-water are caused by leakage from holding ponds, mounding may have had a significant affect on the direction(s) of brine migration (Section 9). Also, brine contaminated fluids and sediments can be carried as surface runoff to lowland areas. These waters may enter surface water bodies or infiltrate into the groundwater system, in either case degredation of water quality may occur.

4) Many of the conclusions noted in this investigation of environmental affects of brine in southeast Clay County may also apply to other oil producing regions of the State (particularly the ten major oil producing counties, listed in order of oil production in 1984; White, Wayne, Lawrence, Marion, Fayette, Crawford, Edwards, Clay, Franklin and Wabash). The degree of environmental damage caused by oil field brines will depend on the disposal practices used in an area, the intensity of oil development, and the regional geology. More information would be needed to adequately describe potential impacts of oil field brines in these areas.

RECOMMENDATIONS

1) Oil field brines can pose a significant threat to groundwater resources in those counties where large scale oil production has occurred. More than 8,600 brine holding ponds, 77,000 active and abandoned oil wells, and 12,000 brine injection wells have been in use in Illinois. These features should be mapped along with geology and surface water resources for each oil producing county so that an assessment can be made as to which counties face the greatest potential for groundwater

quality degradation due to oil field brines. Then, assessments of the impacts of oil field brines should be conducted in a manner similar to that described in Sections 3, 4, and 5 of this report.

2) Additional research on brine movement through permeable materials is needed. The case study sites described in this report (Section 9) were both situated over geologic materials with low hydraulic conductivity. Brine movement through permeable materials should be more rapid; however, dilution will be greater. The ramifications of this relationship should be studied.

3) Research is needed on the potential for brine leakage from injection/ disposal wells as well as upward brine migration through abandoned and unsealed boreholes. Contamination from these sources may be very difficult to detect unless a water supply well is affected, in which case widespread contamination of the aquifer may have already occurred. An inventory of reported cases of contamination could be the first step in such a study, followed by an assessment of possible techniques to detect such contamination and finally by application of those techniques.

REFERENCES

Bell, A. H., 1957, Brine Disposal in Illinois Oil Fields: Circular 244, Illinois State Geological Survey, 12 p.

Coleman, W. B. and D. A. Crandall, 1981, Illinois Oil Field Brine Disposal Assessment - Phase II report: Illinois Environmental Protection Agency, 47 p.

Collins, A. G., 1971, Oil and Gas Wells - Potential Polluters of the Environment?: Journal of Water Pollution Control Federation, V. 43, No. 12, pp. 2383-2393.

Freeze, R. A. and J. A. Cherry, 1979, Groundwater: Prentice-Hall, Inc., 604 p.

Illinois Environmental Protection Agency, 1978, Illinois oil field brine disposal assessment: IEPA Staff Report, 114 p.

Lineback, J. A., 1979, Quaternary deposits of Illinois: Illinois State Geological Survey, 1:500,000 map.

Meents, W. F.., A. H. Bell, O. W. Rees, and W. G. Tilbury, 1952, Illinois Oil Field Brines, Their Geologic Occurrence and Chemical Composition: Illinois State Geological Survey Illinois Petroleum Report No. 66, 38 p.

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

United States Salinity Laboratory Staff, 1969, Diagnosis and Improvement of Saline and Alkali Soils: U.S.D.A. Agricultural Handbook No. 60, U.S. Department of Agriculture.

Van Den Berg, J., J. D. Treworgy, and J. R. Elyn, 1986, Petroleum Industry in Illinois, 1984: Illinois Petroleum 127, Illinois State Geological Survey, 140 p.

Willman, H. B. and others, 1967, Geologic Map of Illinois: Illinois State Geological Survey, 1:500,000 map.

PART TWO

RESULTS OF FIELD INVESTIGATIONS

SECTION 2 DESCRIPTION OF STUDY AREA.

by

Vickie L. Poole, Stephen T. Whitaker, and Edward C. Smith

LOCATION

The study area is located in the east-central portion of southern Illinois and includes the part of southeastern Clay County bounded on the north and east by the Little Wabash River, on the south by the Clay County line, and on the west by the west edge of the Flora 15′ topographic quadrangle (figure 2-1). This area was selected because of its numerous, yet localized, oil fields within an area of limited groundwater resources. This county also has both natural sodium-affected soils and soils damaged by the high sodium content of oil field brines. Clay County lies at the north edge of the Mt. Vernon Hill Country of the Till Plains Section of the Central Lowland Physiographic Province. This province is characterized by thin drift mantling a bedrock surface of low relief; uplands are fairly level and stream valleys generally have broad alluvial plains. Land surface topography is strongly controlled by bedrock surface topography (Leighton et al., 1948; Hunt, 1974).

Surface drainage is split by a divide which trends northwest-southeast through the study area. Drainage of the northern and eastern parts of the area is north and east towards the Little Wabash River. Drainage in the southwest is toward the south-southeastward flowing Elm River, 1/2 to 2 miles south of the study area.

GENERAL GEOLOGY

The bedrock surface is overlain by Pleistocene deposits which consist mainly of till, occasionally interbedded, with thin, discontinuous sand and gravel deposits. Lake deposits, loess and alluvium often overlie the till. The thickness of these deposits varies from less than 5 feet on the uplands to over 100 feet in the bedrock valley underlying the Little Wabash River. In general, drift thickness is less than 50 feet. Generalized drift thickness within the study area is shown in figure 2-2. This map is based on work by Piskin and Bergstrom (1975) and has been updated using recent well log information. Reported locations of bedrock exposures were not field checked for this study.

The till is Illinoian in age and is classified as the Vandalia Till Member of the Glasford Formation; generally a hard, gray silty till with scattered, thin sands and gravels (Willman and Frye, 1970). Wisconsinan-aged lake deposits (Carmi Member

Figure 2-1. Map of Study Area in southeastern Clay County.

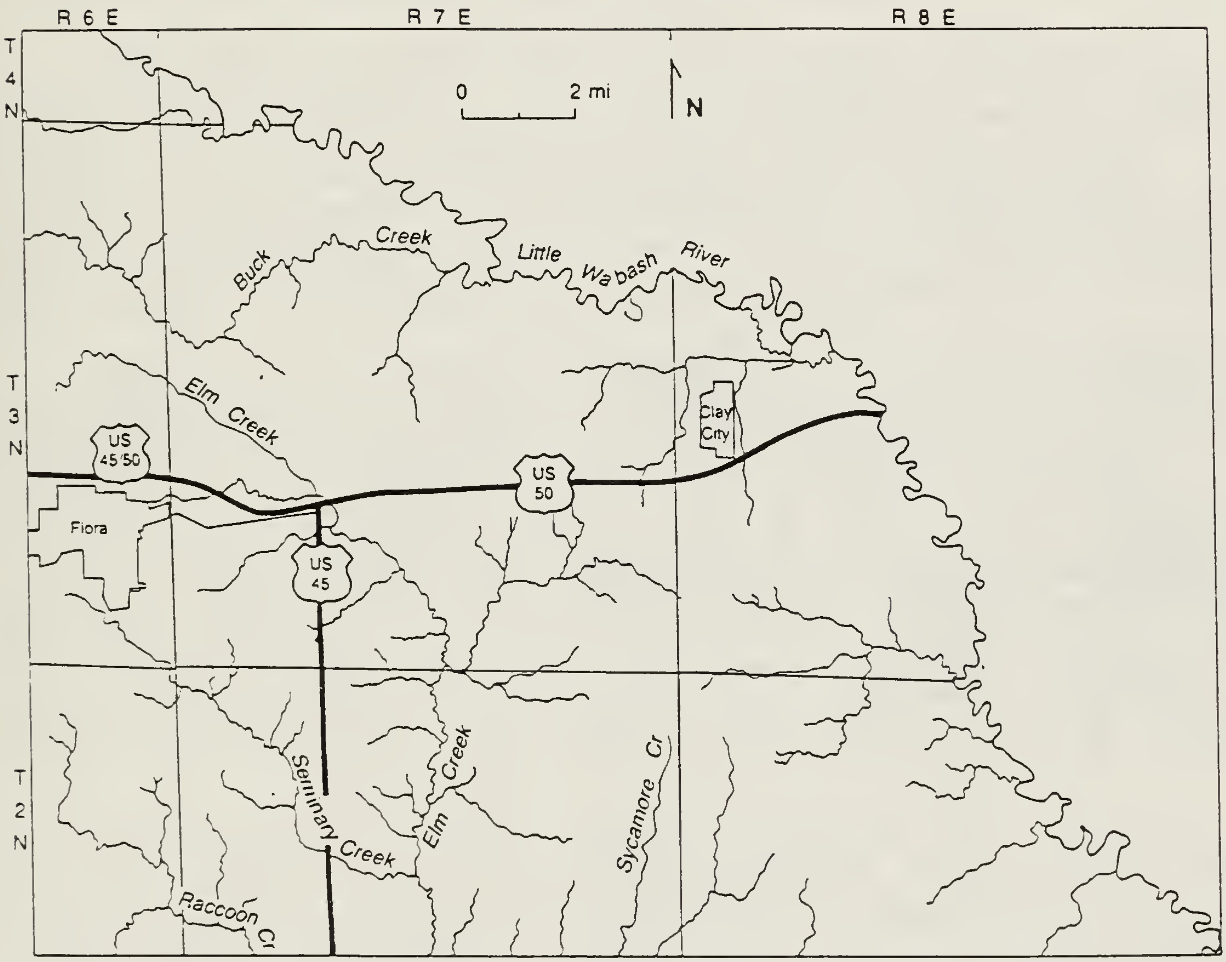
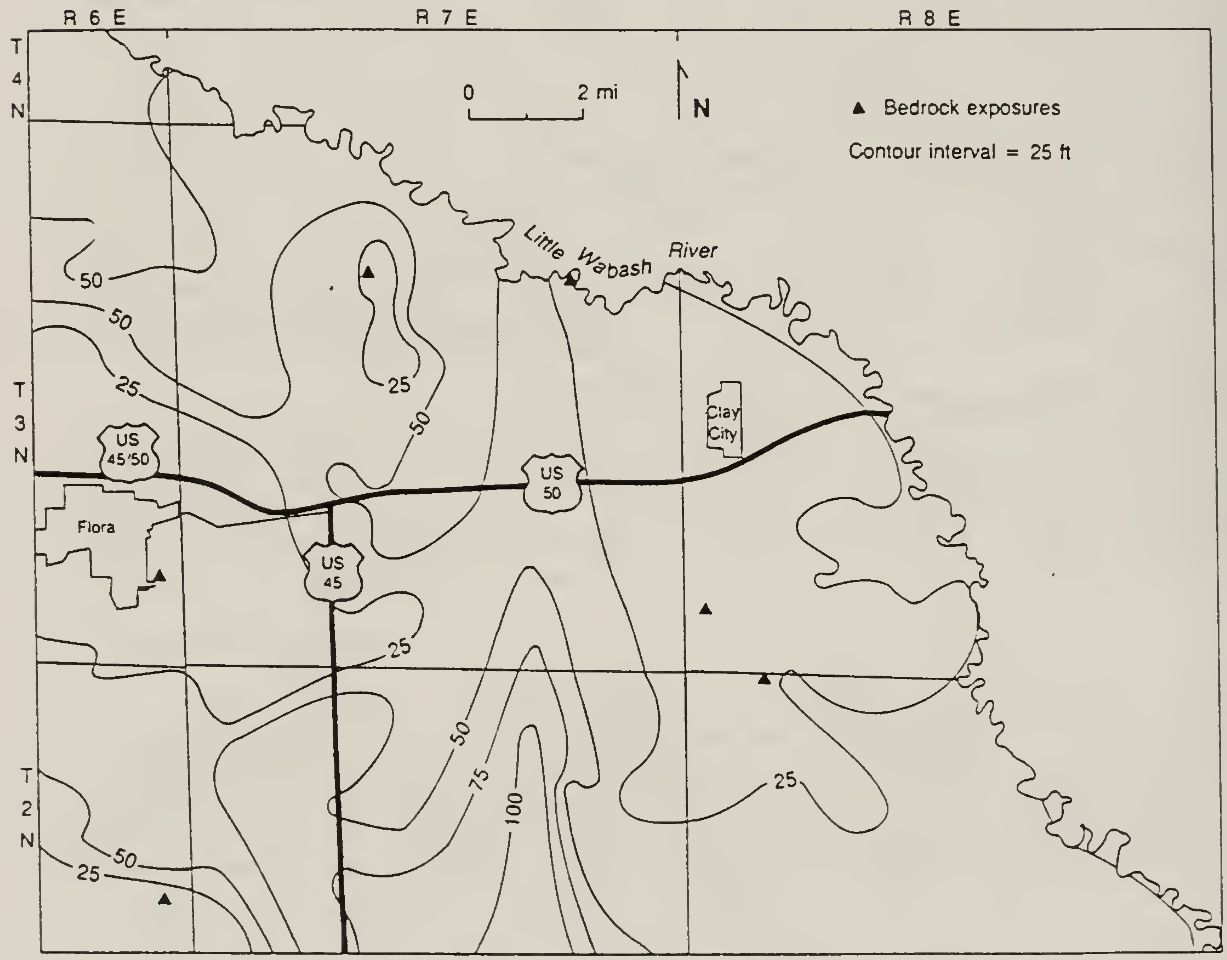


Figure 2-2. Drift thickness in southeastern Clay County. Updated and modified from Piskin & Bergstrom (1975).



of the Equality Formation) are concentrated along the Little Wabash and Big Muddy Rivers. These deposits consist predominantly of lacustrine silts and clays (Willman and Frye, 1970). Loess overlies most of the glacial deposits and its thickness ranges from 2 feet to a little more than 4 feet in the study area (Willman and Frye, 1970). Loess is generally absent in areas where alluvium is deposited. Cahokia Alluvium is Wisconsinan and Holocene in age and usually consists of silty deposits found in the channels and floodplains of present-day streams and rivers (Willman and Frye, 1970). Major alluvial deposits occur along Elm Creek and Buck Creek.

The uppermost bedrock unit is the Mattoon Formation of Pennsylvanian age which is a complex of sandstone, shale, underclay, thin limestone and coal. Average thickness of the Mattoon Formation in southeastern Clay County ranges from slightly more than 300 feet to slightly more than 400 feet (Willman et al., 1975). Lithologies present at the bedrock surface, as determined from drillers' logs, are shown in figure 2-3. Shale is the dominant lithology; sandstones occur in the west-central and southern portions of the area.

The top of the Mattoon Formation is an erosional surface. Its topography reflects the drainage system that developed into the Pennsylvanian rocks prior to glaciation (Horberg, 1950). Figure 2-4 is a generalized topographic map of the bedrock surface. It is based on previous work by Horberg (1950) and was updated using recent well log information. Elevation of the bedrock surface ranges from over 450 feet above mean sea level (m.s.l.) around Flora and just south of Clay City to less than 350 feet above m.s.l. in a tributary bedrock valley in the south-central portion of the study area. A dominant feature of the bedrock surface in this area is the Little Wabash Bedrock Valley. This valley trends roughly north-south just east of the study area.

Geologic cross sections through the study area, shown in figures 2-5a and 2-5b, were constructed using electric logs from oil test wells. Figure 2-6 shows the lines of section and location of electric logs. Correlations of stratigraphic units were made using previously published material for Wayne County (DuBois and Siever, 1955; Sims et al., 1944). The uppermost sandstone units shown on the cross sections are of the Mattoon Formation and are the major source of domestic drinking water supplies.

Underlying the Mattoon Formation are approximately 10,500 to 11,500 feet of other Pennsylvanian and older Paleozoic formations, and the Pre-Cambrian basement rocks (Willman et al., 1975). The deepest oil-producing formations are Devonian carbonates; major oil-producing formations are limestone, dolomite and sandstone of Mississippian age. Figure 2-7 is a

Figure 2-3. Lithology at the bedrock surface in southeastern Clay County. Data are interpolated from drillers' logs.

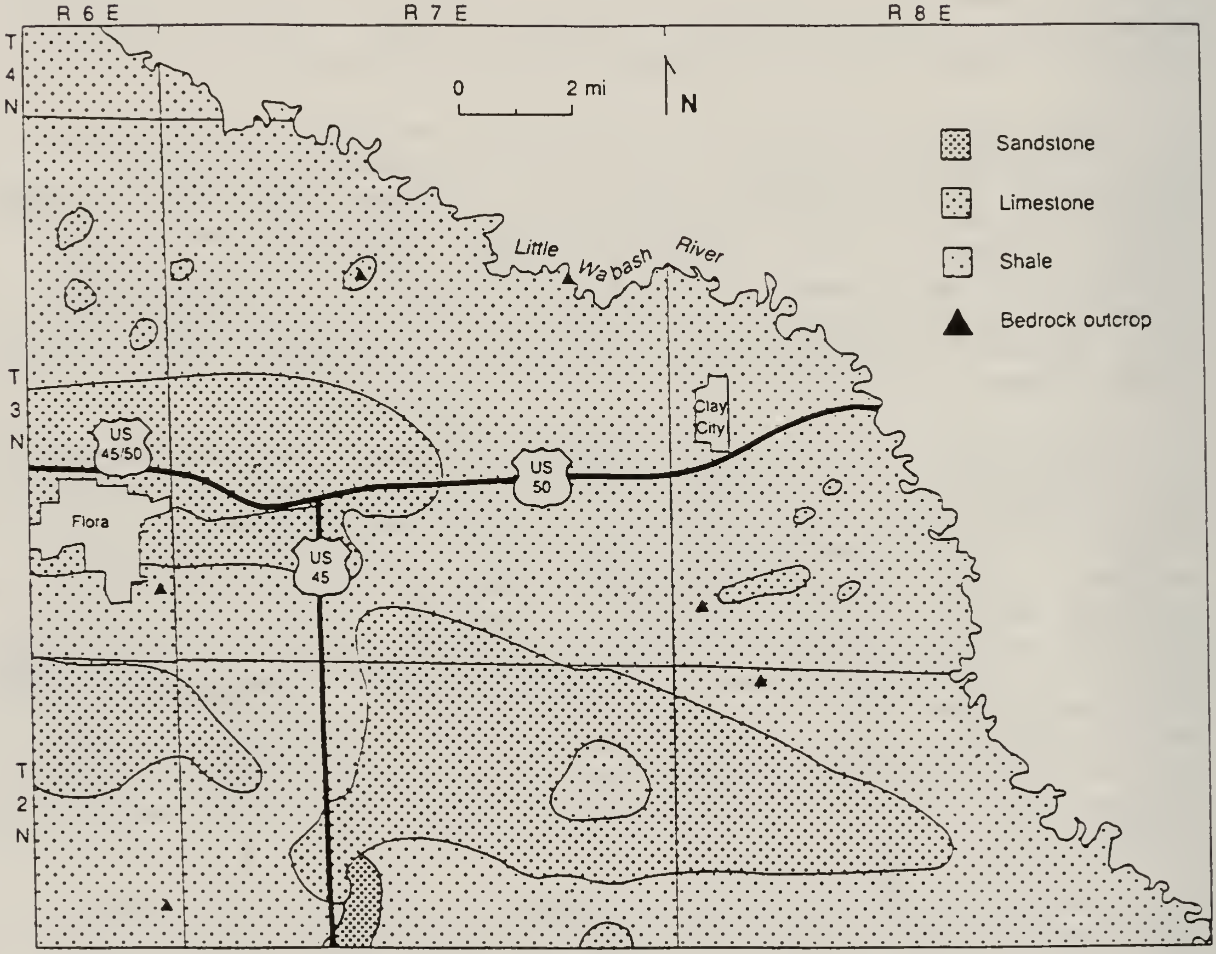


Figure 2-4. Bedrock surface topography in southeastern Clay County. Updated and modified from Horberg (1950).

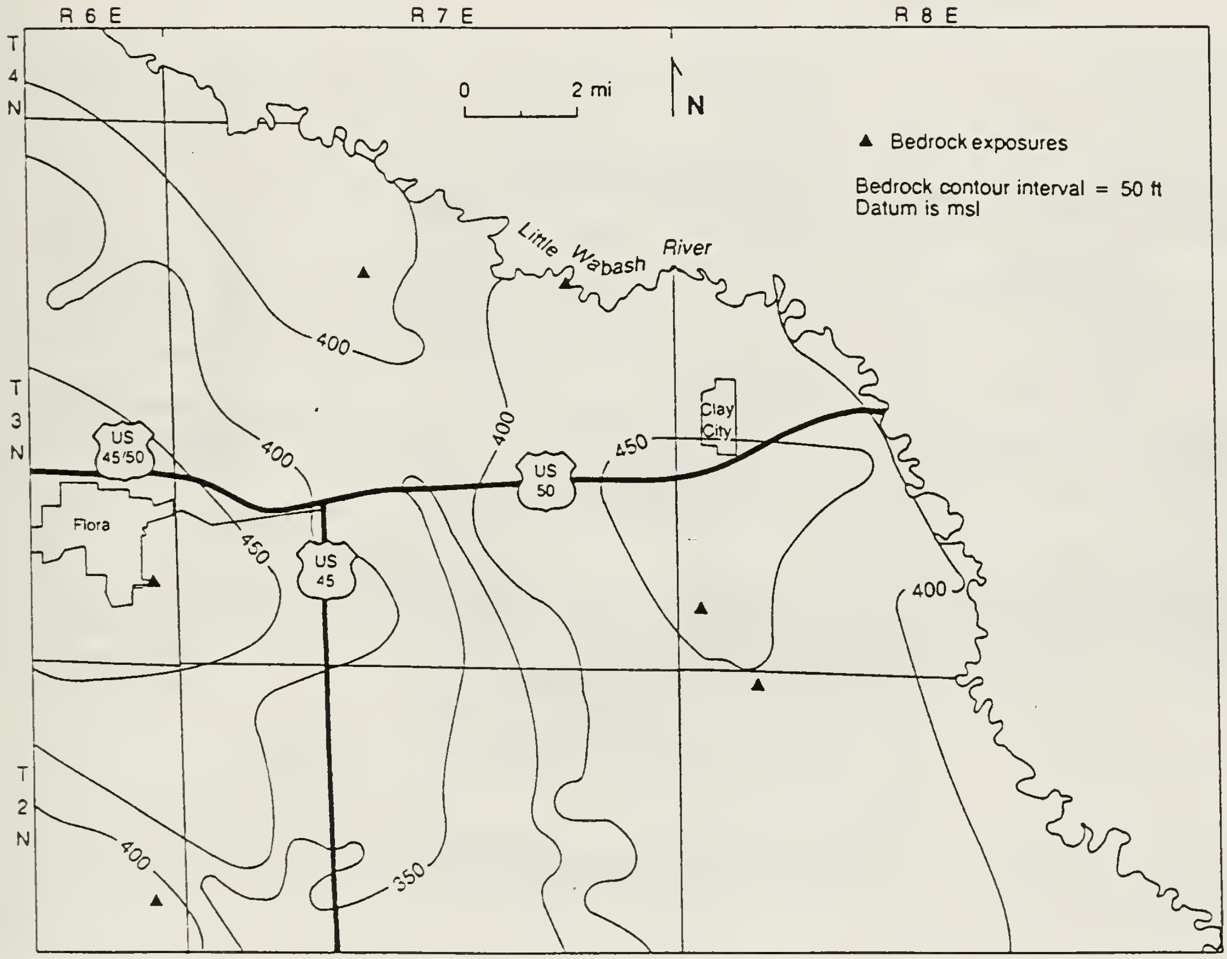


Figure 2-5a. Cross-section A-A', north-south, southeastern Clay County.

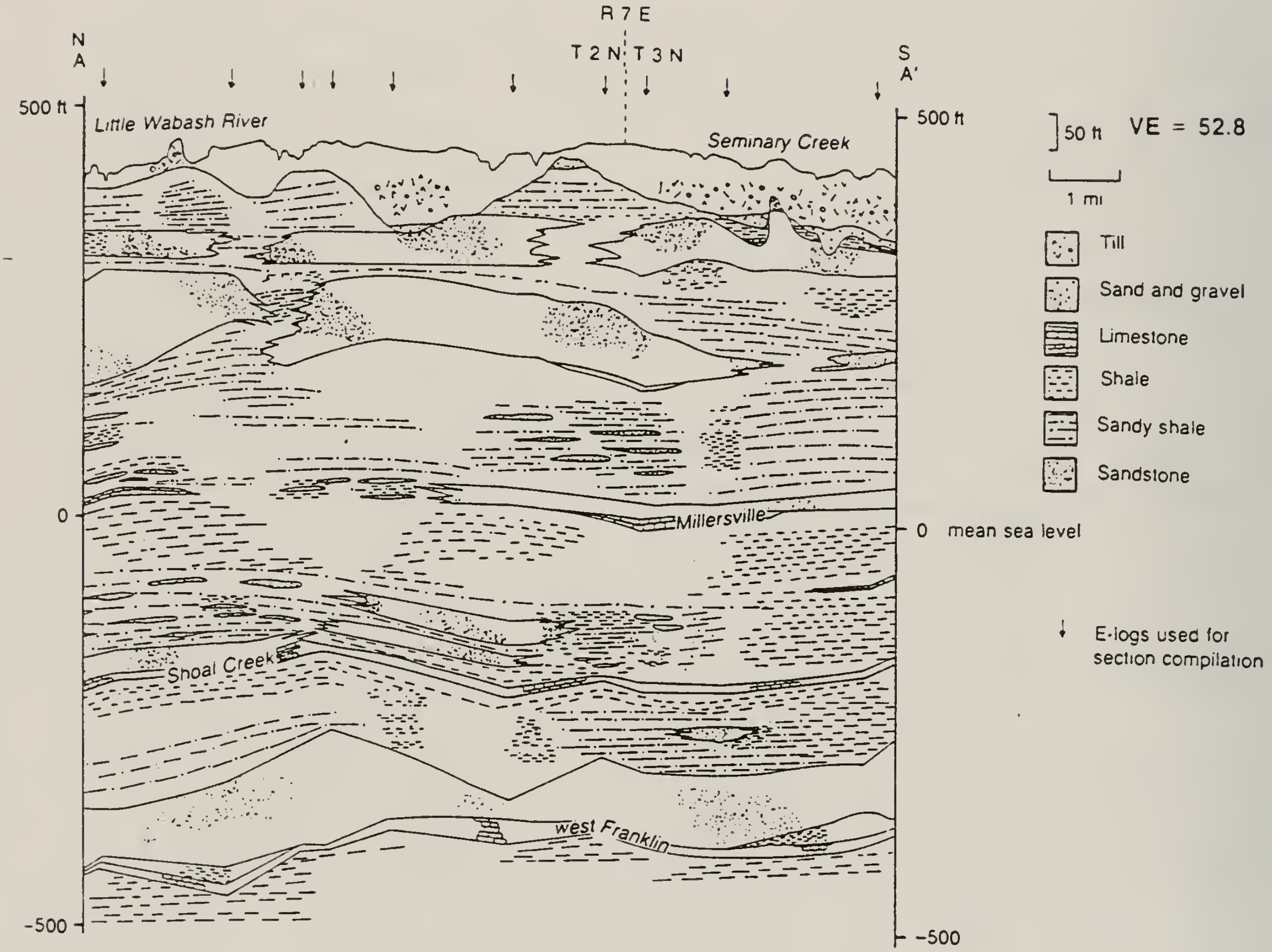


Figure 2-5b. Cross-section B-B′, east-west, southeastern Clay County.

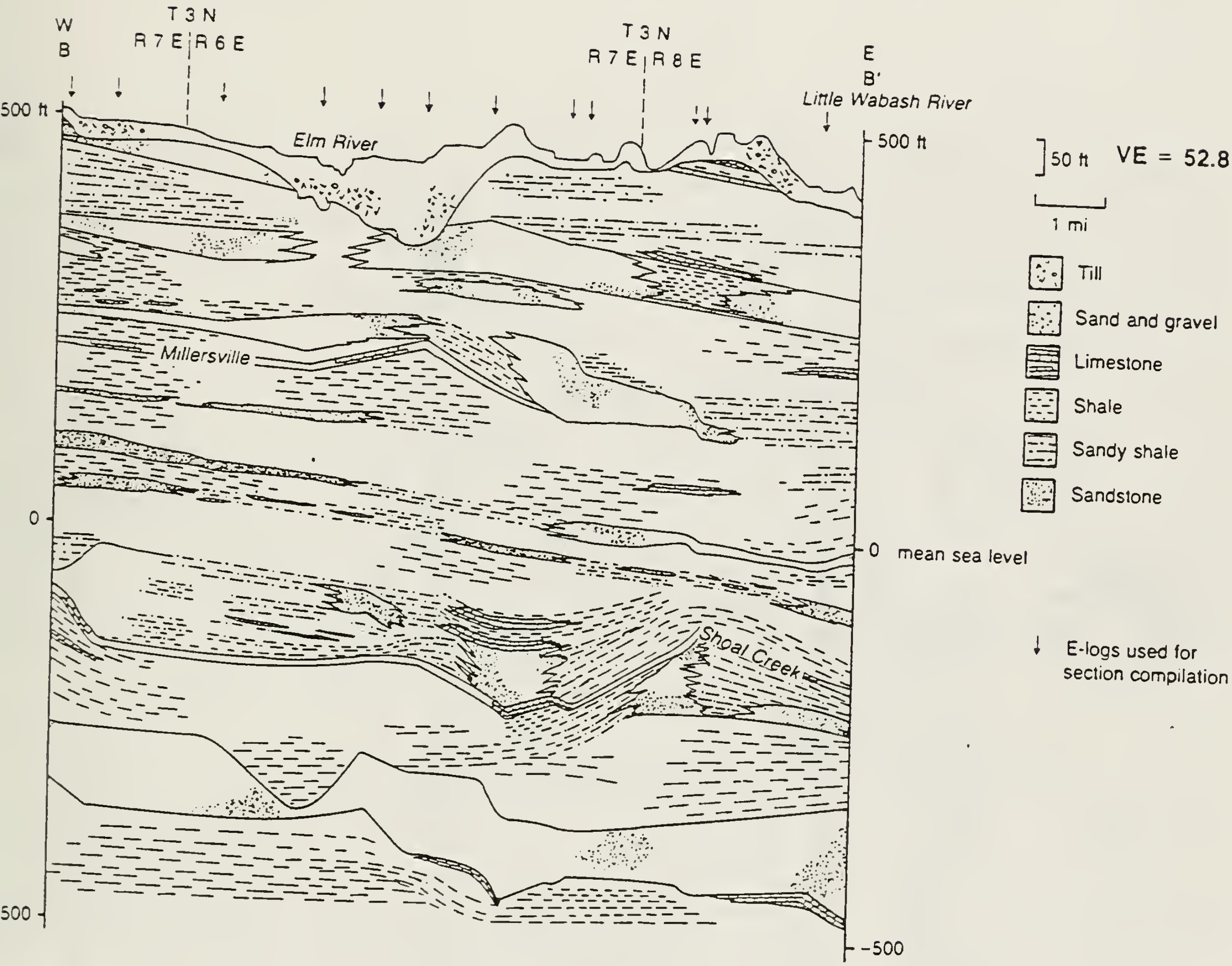


Figure 2-6. Location of cross-sections A-A' and B-B', southeastern Clay County.

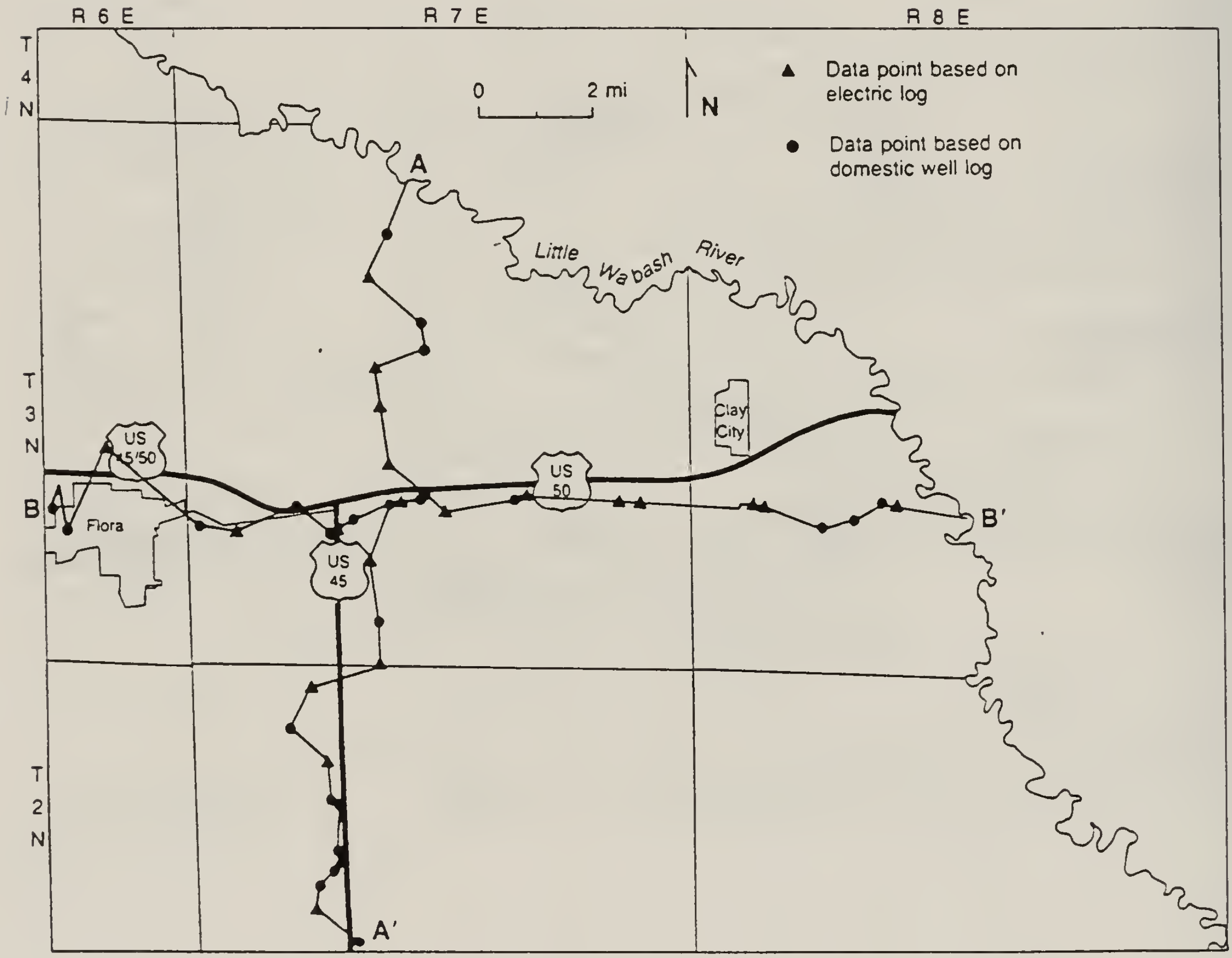
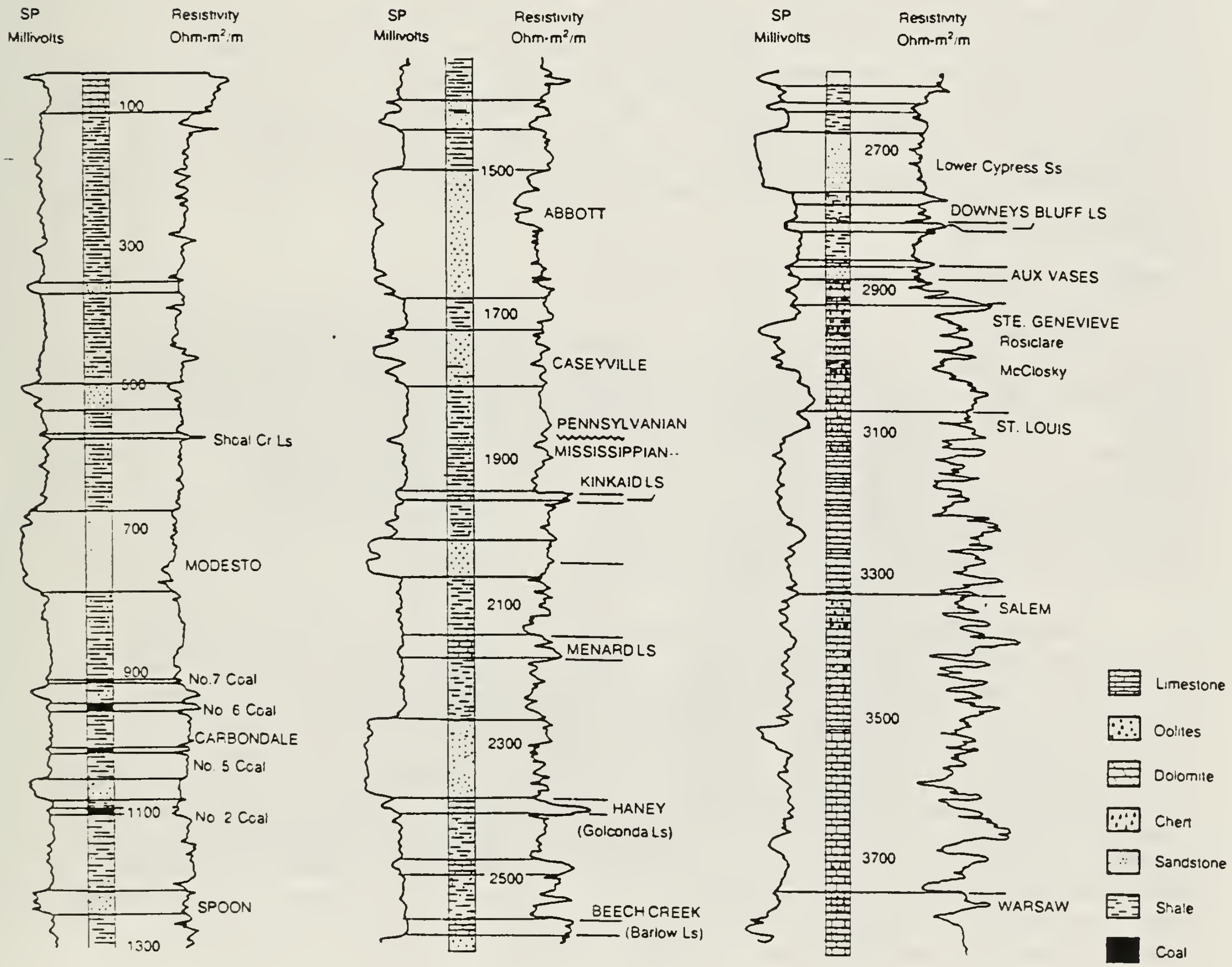


Figure 2-7. Stratigraphic column illustrating a typical sequence of lithologies in southeastern Clay County. Section shows lithologies from Pennsylvanian Age formations through major oil producing formations of Mississippian Age.



stratigraphic column illustrating a typical sequence of lithologies in the study area from the Pennsylvanian through the major Mississippian oil-producing formations.

GROUNDWATER OCCURRENCE

Aquifer Lithologies

Shallow Pennsylvanian sandstone is the principal aquifer of southeastern Clay County. As shown in figure 2-3, the sandstones are concentrated in the west-central and southern parts of the study area. Of the 133 producing water wells with logs on file at the State Geological Survey, 24 were completed in sandy clay, sand, or sand and gravel, 105 were completed in sandstone, 2 were completed in shale or slate, 1 was completed in sandstone and limestone, and 1 was reportedly completed in shale and gravel. Figure 2-8 illustrates the generalized domain of the predominant aquifer types.

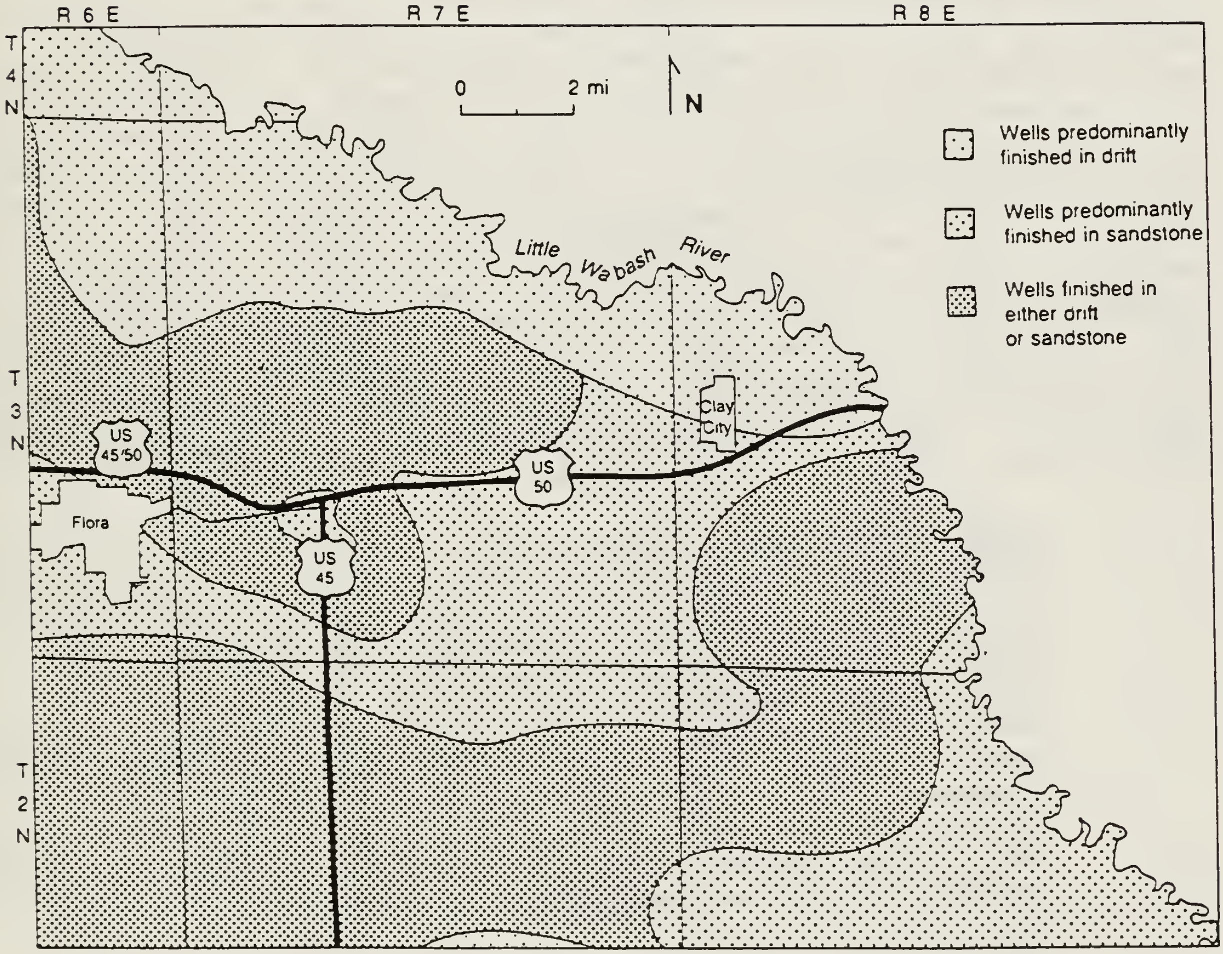
Depth to Saline Water

To delineate the average depth to natural saline water in the study area, a method outlined by Pryor (1956) was used to estimate the quality of ground-water from electric resistivity logs. Water quality determinations were used to define two zones: 1) the zone of potential domestic water supply in shallow Pennsylvanian sandstone, and 2) a zone delineating water with TDS concentration less than 10,000 ppm. A summary of the water quality data estimated from electric logs of 78 wells in the study area is presented in Appendix 2-A.

Estimation of total dissolved solids (TDS) concentration from electric logs is based on the concept that an empirical relationship between TDS concentration and formation water resistivity can be determined for particular geological and hydrochemical settings. Pryor (1956) developed his empirical relationship between NaCP-solution equivalents and measured TDS concentrations from chemical analyses of groundwater from Pennsylvanian sandstone in southern Illinois. He included data from 2 wells in Clay County and 16 wells in neighboring Wayne and Richland Counties in developing his empirical curve. Therefore, his method is assumed to be applicable to water in shallow Pennsylvanian sandstones in Clay County.

Base of the Shallow Sandstone Aquifer. The criteria used in defining a fresh water aquifer are: 1) electric logs indicate a sandstone with sufficient permeability for domestic water supplies to be developed; and 2) the estimated TDS concentration of the water must be less than 2500 parts per million (ppm). Growth and development of livestock may be adversely affected by water with TDS concentrations greater than 2500 ppm (Hem, 1985;

Figure 2-8. Generalized map of aquifers utilized in southeastern Clay County.



McKee and Wolf, 1963). These criteria are satisfied in the shallow Pennsylvanian sandstone unit. Estimated TDS concentration was almost never the limiting factor in determining the base of this fresh water aquifer; in nearly all cases the base of the aquifer coincided with the base of the sandstone. The aquifer appears continuous over the study area except for a small region south of Clay City where the sandstone is absent. Figure 2-9 shows the estimated depth to the base of the fresh-water aquifer.

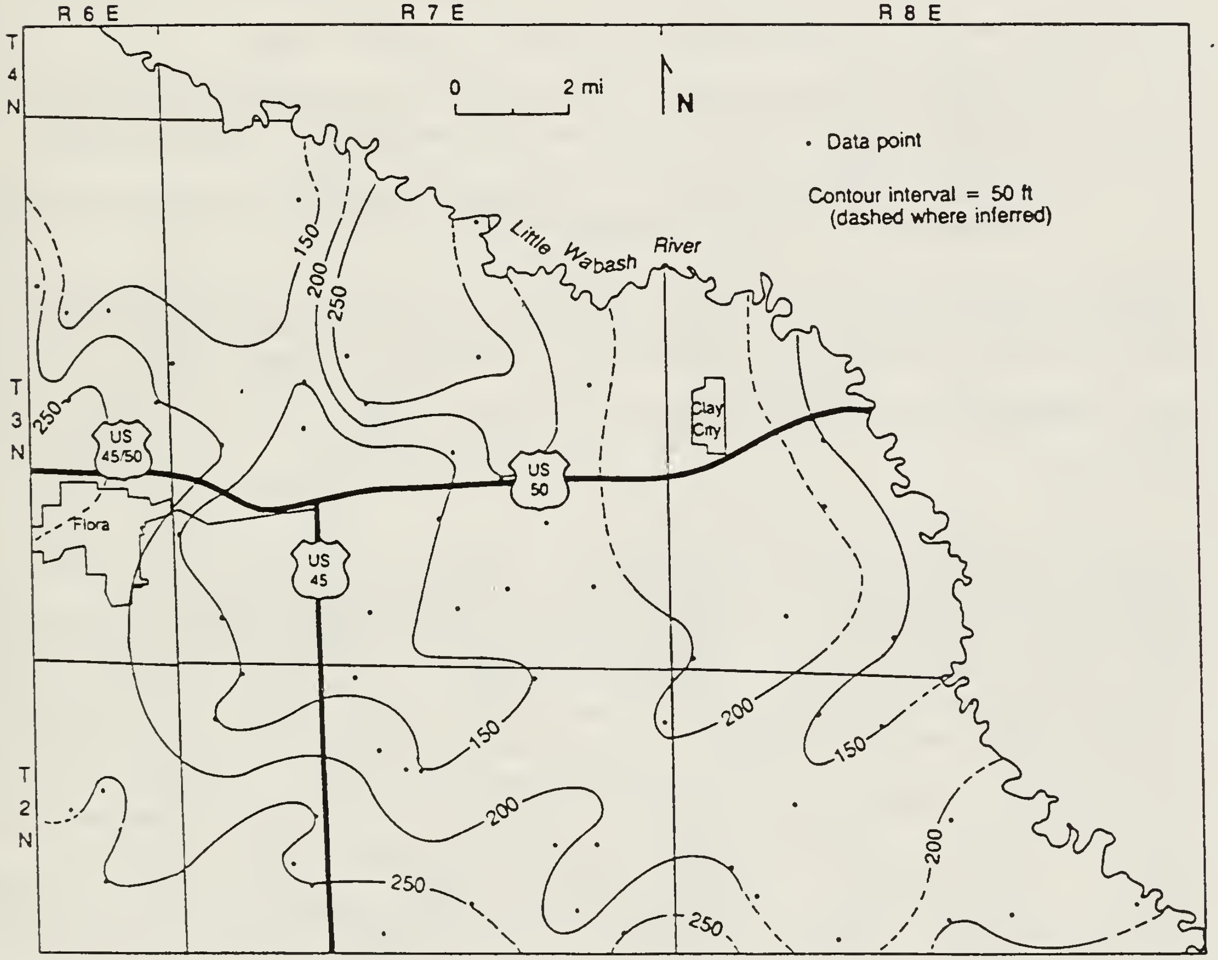
Water Quality Relating to Injection. Deep well underground injection in Illinois is prohibited in or above formations containing water with less than 10,000 ppm TDS. Estimation of water resistivity using electric logs depends on infiltration of drilling mud into the saturated unit. Therefore, the method is not applicable to shale, a formation in which infiltration is negligible. This limitation is important in this study because the 10,000 ppm TDS limit appears to occur within a 300- to 500-foot thick section predominantly consisting of shale. Sandstone above and below this shale contains water with TDS concentrations of less than 10,000 ppm and greater than 10,000 ppm, respectively. Therefore, instead of defining a single 10,000 ppm TDS concentration surface, it was necessary to define two surfaces that essentially represent the top and base of the shale unit. These surfaces divide the near-surface bedrock into three zones related to water quality:

1) <u>Upper Sandstone/Siltstone Unit</u> - The top of this unit is presumably the bedrock surface; however, the electric logs start at the bottom of the drill hole casings; i.e., 100 feet or more below the land surface. The upper part of the recorded interval contains a fresh-water sandstone that appears to be fairly continuous over most of the study area. This sandstone grades downward into fine-grained siltstone with premeabilities that are probably too low and TDS concentrations that may be too high for this part of the unit to be used as a source of drinking water. However, concentrations do not exceed 10,000 ppm.

2) <u>Shale Unit</u> - This unit consists of 300 to 500 feet of shale with interbedded silty layers. Generally, the TDS concentration of water within this unit cannot be estimated using Pryor's (1956) method.

3) <u>Lower Sandstone Unit</u> - This unit consists of a well-developed sandstone that occurs below the shale unit over most of the study area. Only 4 of the resistivity logs examined indicated that water in this unit contains less than 10,000 ppm TDS. A spot check of logs for additional drill holes near these wells did not confirm the presence of TDS concentrations of less than

Figure 2-9. Depth to the base of fresh water (TDS less than 2500 ppm) in southeastern Clay County. TDS concentrations are estimated from electric log data.



10,000 ppm. However, the spot check did locate one additional drill hole in Section 11, T. 2 N., R. 6 E., with an estimated TDS concentration less than 10,000 ppm. In summary, most of the water in this unit has TDS concentrations exceeding 10,000 ppm; however, it may locally contain water with a slightly lower TDS concentration.

Oil industry records indicate that current brine-disposal wells discharge into the lower sandstone unit. This is the shallowest unit into which water disposal should be considered.

Two maps were compiled as part of this task:

1) Depth to the base of the upper sandstone/siltstone unit (less than 10,000 ppm estimated TDS) (figure 2-10).

2) Depth to the top of the lower sandstone unit (greater than 10,000 ppm estimated TDS) (figure 2-11).

General stratigraphic relationships of the units are clearly illustrated by comparing the depths or elevations of figures 2-10 and 2-11 to the cross sections of figures 2-5 and 2-6.

OIL INDUSTRY ACTIVITY IN THE CLAY CITY AREA

History

Oil was discovered near Clay City on May 17, 1937 when the Bunyan Travis #1 well, drilled by the Pure Oil Company, encountered reservoir rock in the Mississippian McClosky oolite. This discovery led to a dramatic increase in drilling activity in the state, and by 1940 had established Illinois as the fourth largest producer of oil. In the study area, oil was initially recovered from Mississippian age reservoirs in the Cypress sands (depth 2600'±) as well as the McClosky oolites (depth 3050'±). Since then, additional pays have been found in the Mississippian age Waltersburg (depth 2175'±), Tar Springs (depth 2560'±), Bethel (depth 2800'±), Ohara (depth 3020'±), Spar Mountain (depth 3030±), Saint Louis (depth 3300'±), Salem (depth 3550'±), Ullin (depth 3600'±), Carper (3810'±), and in Devonian age formations (depth 4350'±).

Through 1983 the combined fields of Clay City Consolidated and Sailor Springs, located in the study area, have injected approximately 1.122 billion barrels of water and produced [illegible]3 million barrels of oil. Annual production from the two fields was approximately 1.2 million barrels of oil and 26 million barrels of water in 1984.

Figure 2-10. Depth to the base of the upper sandstone/siltstone unit in southeastern Clay County. Estimated TDS concentrations in this unit are less than 10,000 ppm.

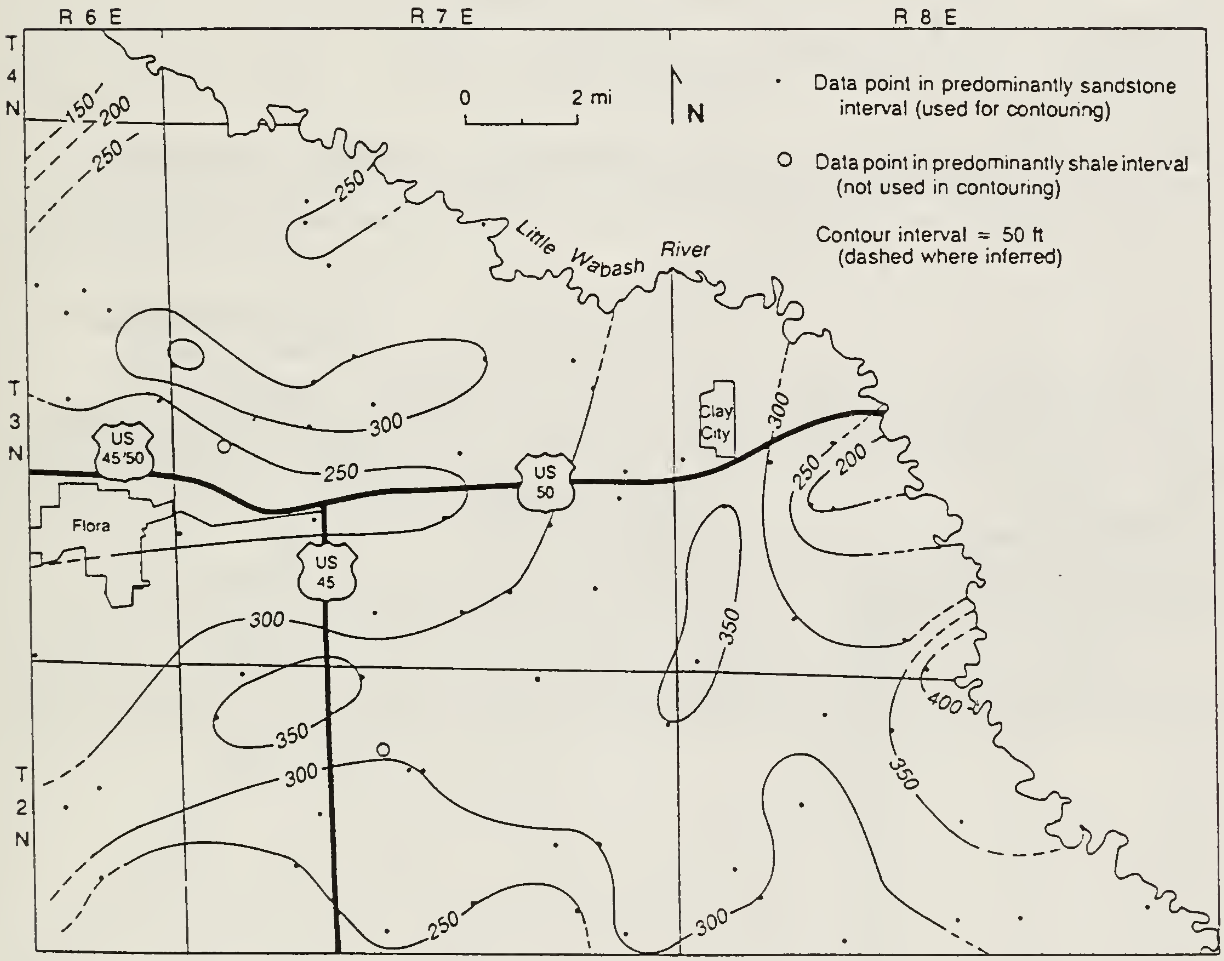
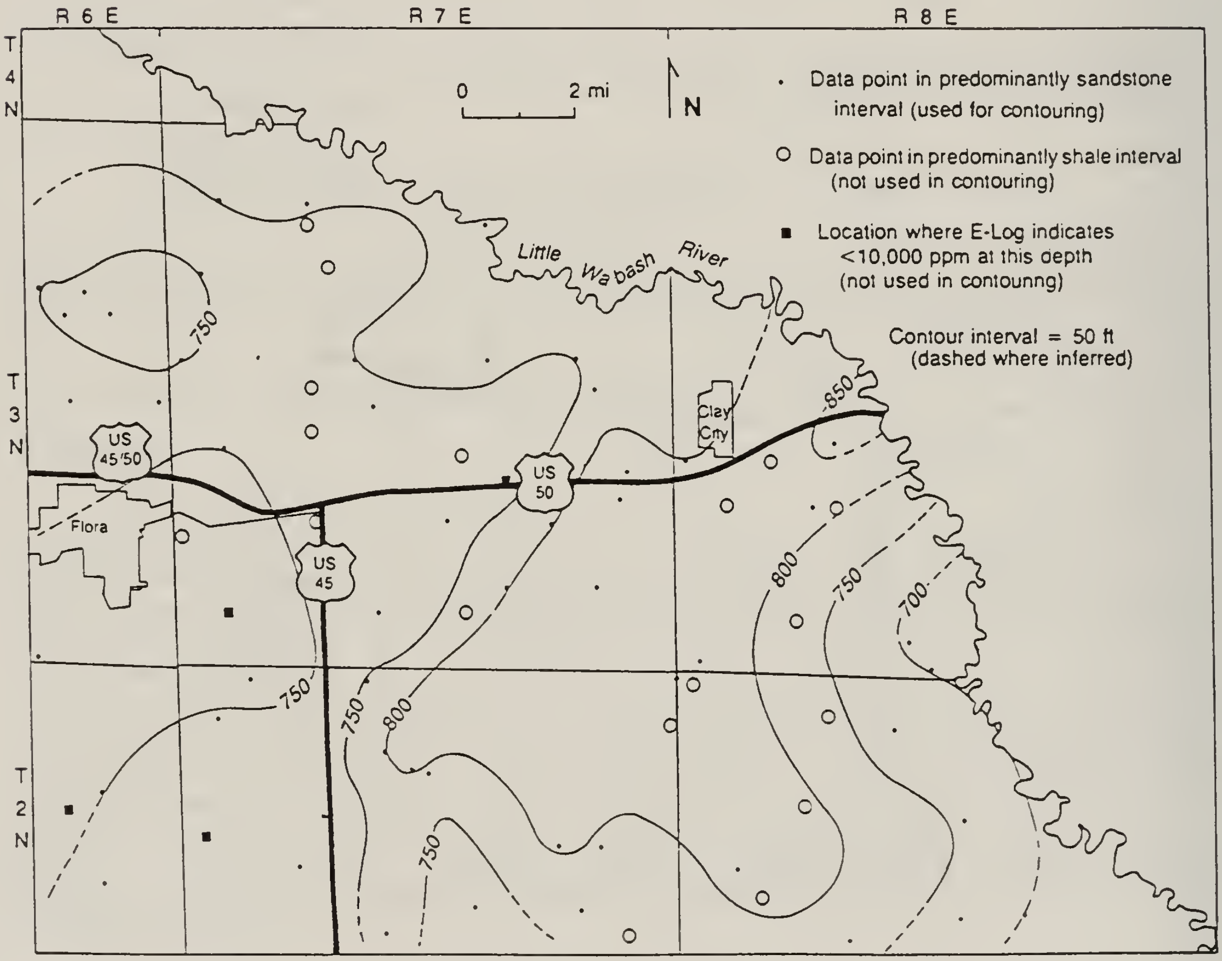


Figure 2-11. Depth to the top of the second sandstone unit in southeastern Clay County. Estimated TDS concentrations in this unit are greater than 10,000 ppm.



Injection

The practice of water injection, or waterflooding, typically requires the conversion of oil wells in downdip structural positions to water injection wells, or the drilling of wells solely for water injection. Water, usually brines produced from neighboring oil wells, is forced down these injection wells and into the particular reservoir being flooded. The influx of water into the reservoir pushes the oil toward higher structural positions where it is recovered. Reservoirs subject to waterflooding in the study area are: Mississippian age Cypress, Bethel, Aux Vases, Ohara, Spar Mountain (Rosiclare), McClosky, and Salem.

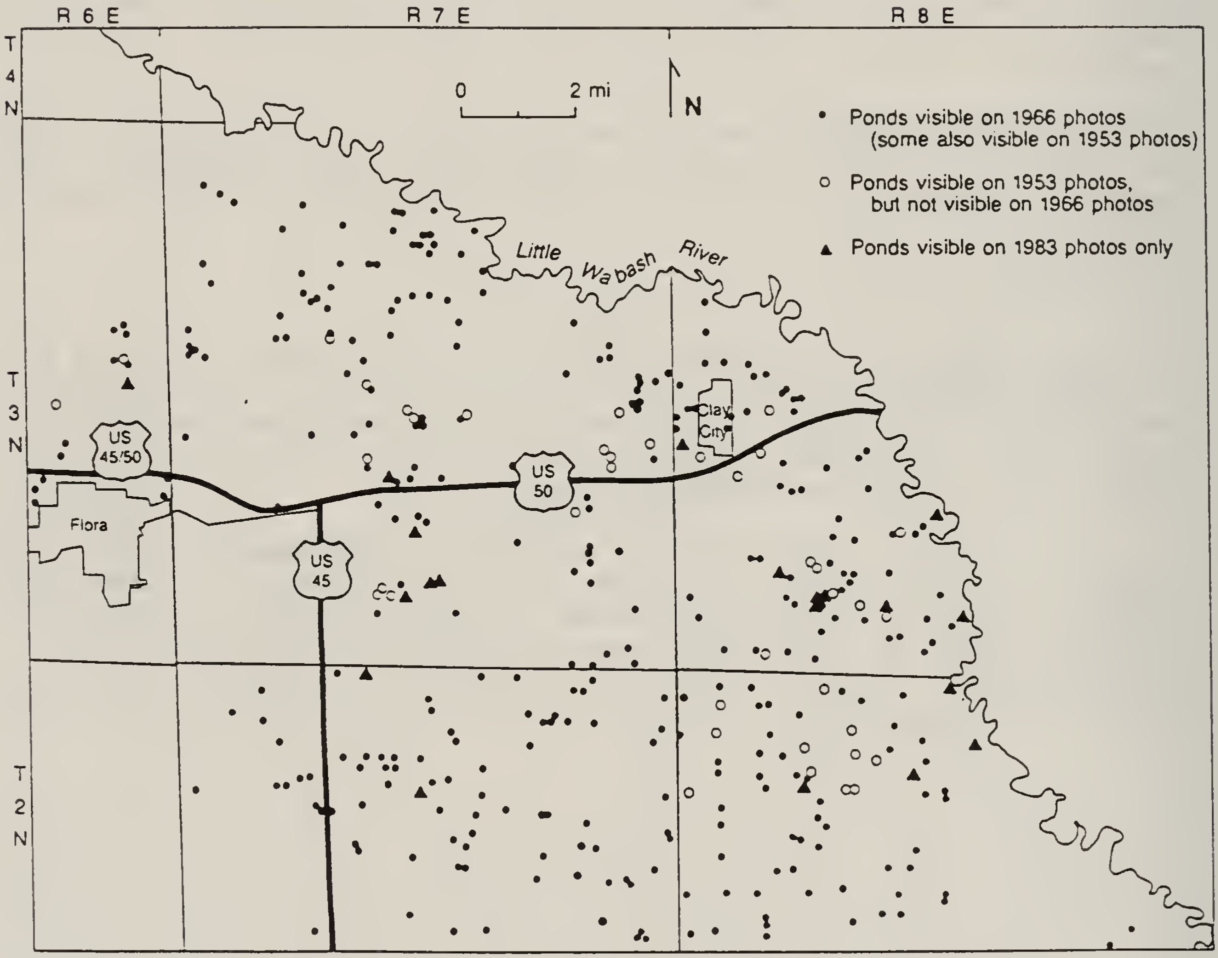
Reservoir pressures caused by injection are not sufficient to force oil to the surface in the study area. Typical fluid levels in waterflooded wells range from 2000′ to 1200′ below land surface.

Brine Disposal

The disposal of brines from oil fields has long been a problem. Transportation costs for salt water are prohibitive for wells with high ratios of brine to oil. This problem was alleviated by the use of brine holding ponds, salt water disposal wells and waterflood injection wells.

The use of brine holding ponds was relatively common in the study area until the 1960s when injection programs became more viable. Figure 2-12 illustrates the distribution of brine holding ponds in the study area as determined from aerial photographs. In 1980, the state began a five-year phase-out of brine holding ponds.

Figure 2-12. Location of brine holding ponds in southeastern Clay County. Ponds located by inspection of aerial photographs from 1953, 1966, and 1983.



REFERENCES

Du Bois, E. P., and R. Siever, 1955, Structure of the Shoal Creek Limestone and Herin (No. 6) Coal in Wayne County, Illinois: Illinois State Geological Survey Report of Investigations 182, 7 p.

Hem, J. D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S.G.S. Water Supply Paper 2254, 263 p.

Horberg, L., 1950, Bedrock topography of Illinois: Illinois State Geological Survey Bulletin 73, 111 p.

Hunt, C. B., 1967 (revised 1974), Natural regions of the United States and Canada: W. H. Freeman and Company, San Francisco, 725 p.

Leighton, M. M., G. E. Ekblaw, and L. Horberg, 1948, Physiographic divisions of Illinois: Illinois State Geological Survey Report of Investigations 129, 33 p.

McKee, J. E., and H. W. Wolf, 1963, Water quality criteria: California State Water quality Control Board Publication 3-4, 548 p.

Piskin, K., and R. E. Bergstrom, 1975, Glacial drift in Illinois: thickness and character: Illinois State Geological Survey Circular 490, 36 p.

Pryor, W. A., 1956, quality of groundwater estimated from electric resistivity logs: Illinois State Geological Survey Circular 215, 15 p.

Sims, P. K., J. N. Payne, and G. H. Cady, 1944, Pennsylvanian key beds of Wayne County and the structure of the "Shoal Creek" Limestone and the Herrin (No. 6) Coal bed: in Progress Reports on Subsurface Studies of the Pennsylvanian System in the Illinois Basin, p. 27-32.

Willman, H. B., and J. C. Frye, 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.

Willman, H. B., E. Atherton, T. C. Buschbach, C. Collinson, J. C. Frye, M.E. Hopkins, J. Lineback, and J. A. Simon, 1975, Handbook of Illinois Stratigraphy: Illinois State Geological Survey Bulletin 95, 261 p.

SECTION 3 ASSESSMENT OF GROUNDWATER QUALITY

by

Vickie L. Poole and Stephen L. Burch

INTRODUCTION

The focus of this section is on groundwater quality within the study area and the extent of possible oil field brine contamination. The study was undertaken to address possible impacts on groundwater resulting from regional oil field activity. Residents of the area have expressed concern that large-scale degradation of groundwater quality has been caused by oil field activities such as brine disposal.

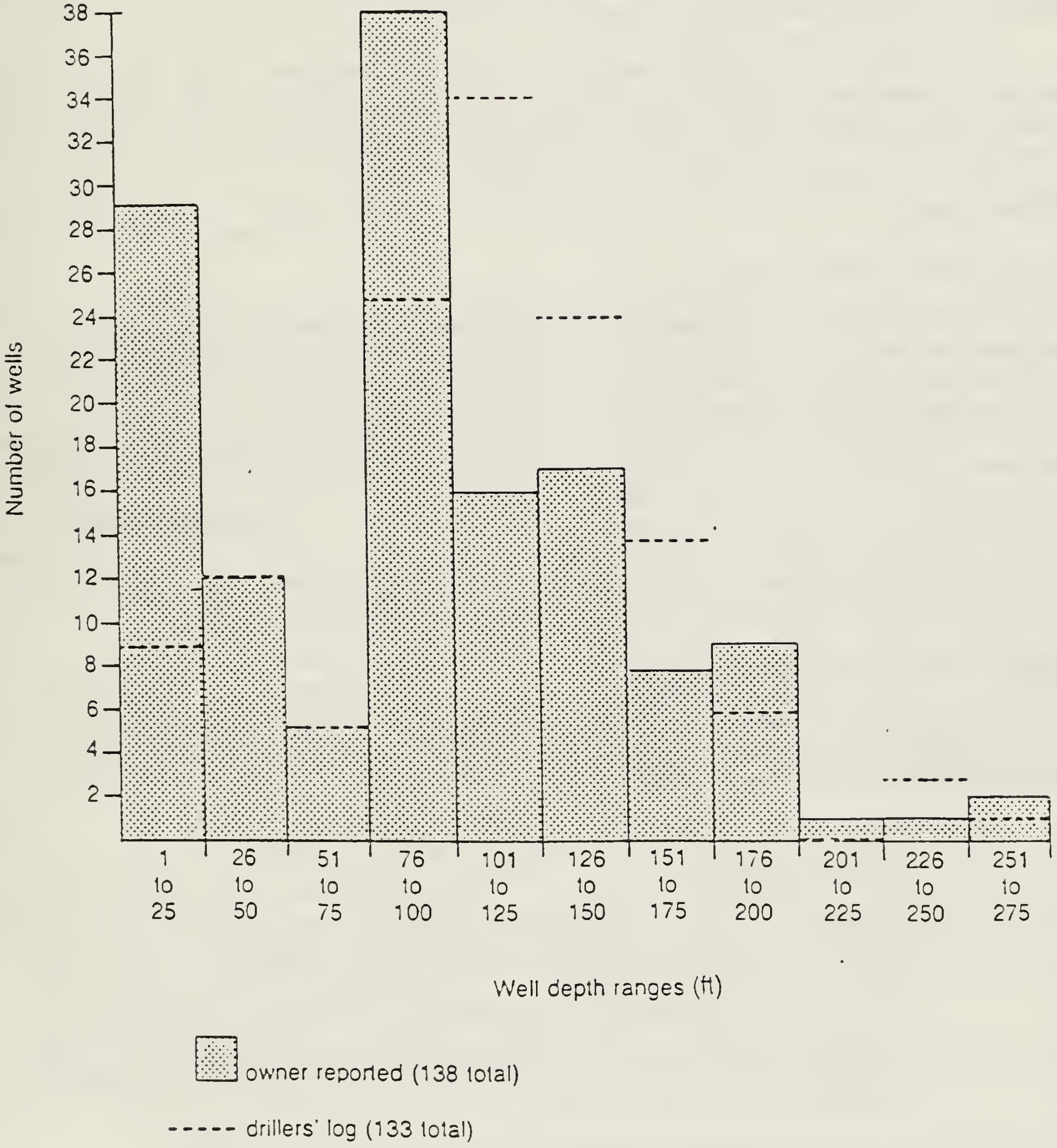
GROUNDWATER UTILIZATION

Drillers' logs of water wells in the study area were examined to determine total depth, length of casing, static water-level, top and base of the aquifer tapped, aquifer lithology and reported yield in gallons per minute (gpm). A total of 143 well logs were examined; 7 wells were reported as dry, and 3 were reported plugged due to high salt content. The plugged wells are located in 23-3N-7E (county ID numbers 26283 and N-17) and 28-3N-7E (county ID number 4688) and were completed at depths of 174, 160, and 169 feet, respectively.

In addition to examining well logs on file, a field inventory of domestic water wells was performed. Location of wells and electrical conductance measurements of water samples were obtained for 238 wells at 227 locations in and around the study area. Eleven landowners had two wells essentially in the same location. Due to problems in reported locations of wells and changes in ownership, most wells could not be matched to drilling logs on file. One hundred and ninety-nine of the wells inventoried were physically located within the study area. Landowners reported estimated depths for 138 of these wells. Figure 3-1 illustrates the depth-range distribution of water wells in the study area as reported by the landowners and as reported on drillers' logs. Discrepancies may be due in part to a large number of shallow dug wells for which logs were never submitted, and to deeper abandoned wells of which current owners are unaware.

Shallow Pennsylvanian sandstone is the principal aquifer lithology of southeastern Clay County. Of the 133 producing water wells with logs, 24 were completed in sandy clay, sand, or

Figure 3-1. Depth-range distribution of water wells.



sand and gravel, 105 were completed in sandstone, 2 were completed in shale, 1 was completed in sandstone and limestone, and 1 was reportedly completed in shale and gravel.

Yields have been reported on drillers' logs of 83 wells completed in sandstone. These values range from 1 to 50 gpm and average approximately 13 gpm.

Most of the shallow wells are completed in sandy clay, sand and/or gravel. They are large-diameter bored or dug wells which rely on seepage that is stored in the wellbore to meet peak water demands.

METHODOLOGY

Electrical Conductance

During the field inventory of domestic water wells, estimates of water quality were obtained from measurements of electrical conductance. Electrical conductance is a measure of the water's ionic strength and is directly related to the concentration of total dissolved solids (TDS) in a water sample. Because conductance is temperature dependent, an automatically compensated conductivity meter (MYRON L. Co., DS Meter, Model 532-M1) was used in this study. Results of the reconnaissance of water samples from 199 domestic water wells, including the name of the owner/controller, well location and reported depth, and conductance measurements, are shown in Appendix 3-B.

Samples for Chemical Analyses

A subset of the inventoried domestic water wells was selected for detailed chemical analysis. Hydrogeologic and conductivity data were used to:

- obtain a uniform distribution of sampling sites over the study area

- sample wells that had drillers' logs on file and which were cased to isolate a specific aquifer

- select sites having anomalously high values of conductance so that they could be compared to sites with lower values, presumably reflecting background conditions.

A 2-mile separation of wells was sought where reliable information was available. Wells were also chosen to represent the three major sources of groundwater being utilized; shallow glacial deposits (dug or bored wells), deeper glacial deposits (drilled wells, generally more than 70 feet deep), and Pennsylvanian sandstone (drilled wells, generally more than 100 feet deep). Twenty-two groundwater samples were collected for analysis.

Laboratory determinations made for this study focused on the major ionic species found in groundwater as well as selected trace metals. Chemical analyses were performed by an EPA Certified Laboratory located at the Illinois State Water Survey. Determinations were made for the following constituents: calcium (Ca); magnesium (Mg), sodium (Na), strontium (Sr), lithium (Li), chloride (Cl), sulfate (SO4), alkalinity as CaCO3, and total dissolved solids (TDS). Specific conductance and laboratory pH were also measured at the time of analysis. Standardized analytical methods were used and are briefly described in Appendix 9-A. Results of the analyses are shown in table 3-1 (mg/L) and table 3-2 (meq).

Strontium and lithium ordinarily occur as trace elements in natural waters and are not usually reported in a normal domestic water well analysis. However, interelement ratios including these elements have been useful in helping to differentiate brines. In Section 6, Ca/Li, Mg/Li, and (Na+Li)/(Ca+Mg-Sr) are among the ratios used to differentiate oil field brine, shallow brine, and freshwater groups.

INTERPRETATION

Conductivity and Regional Estimates of Water Quality

Measurement of conductance and temperature were made in the field at the time of sampling. These data, listed in table 3-3, are shown in comparison with laboratory measurement of specific conductance. Groundwater temperatures observed in this study ranged from 14^{o} to 18^{o}C (57^{o} to 64^{o}F). Field conductance values were found to be approximately 93% that of lab derived values.

In order to estimate water quality on regional scale, an empirical relationship between field conductance and TDS concentration was developed. Figure 3-2 shows the relationship between field conductance measured at the time of sampling and the analytical concentration of TDS, based on 20 of the 22 analyzed samples. Accurate field conductance values were not obtained for samples OFB-16 and OFB-17.

A least squares regression line of best fit through the data is described by the following equation:

$$Y = 0.665\ X + 80.41$$

where: X = measured field conductance (in microsiemens/cm)
Y = predicted average concentrations of TDS (in mg/L)

and the linear correlation coefficient (r^2) is 0.97.

Table 3-1. Concentration (mg/L) of major ions commonly found in groundwater. Samples obtained from private wells in southeastern Clay County.

Sample No.	Ca	Mg	Na	Sr	Li	Cl	SO4	Alkal.	TDS	pH
OFB-01	54.0	34.0	220.	0.2	0.01	55.	190	312	948	7.5
OFB-02	48.8	32.4	102.	0.6	0.03	52.	30	372	502	7.8
OFB-03	80.	40.8	70.	0.5	0.02	44.	60	400	542	7.4
OFB-04	93.	34.8	91.	0.3	0.04	20.	100	413	613	7.4
OFB-05	74.8	40.4	68.7	0.5	0.02	40.	40	396	510	7.9
OFB-06	90.	52.4	81.9	0.4	0.02	50.	140	382	658	7.6
OFB-07	64.0	26.8	51.9	0.2	0.01	58.	70	146	473	7.0
OFB-08	84.4	29.2	57.1	0.2	0.02	10.	40	398	468	7.4
OFB-09	128.	54.4	93.	0.4	0.03	13.	250	450	820	7.3
OFB-10	52.0	33.2	24.3	0.1	0.02	10.	50	220	330	7.4
OFB-11	21.2	9.2	184.	0.2	0.01	44.	<10	440	545	7.8
OFB-12	96.	71.	125.	0.8	0.04	40.	240	444	907	7.6
OFB-13	150.	64.0	144.	0.5	0.02	195.	260	266	1,153	7.1
OFB-14	6.8	2.8	472.	0.1	0.02	410.	<10	462	1,152	8.3
OFB-15	2.4	1.2	584.	0.1	0.02	540.	<10	502	1,410	8.6
OFB-16	6.8	4.0	1376.	0.4	0.05	1750.	<10	571	3,292	8.3
OFB-17	6.0	3.6	1208.	0.2	0.04	1400.	<10	678	2,935	8.5
OFB-18	23.2	13.6	536.	0.3	0.03	450	70	508	1,347	8.1
OFB-19	1.6	0.8	438.	0.1	0.02	310.	30	505	1,074	8.8
OFB-20	40.0	59.2	616.	0.4	0.06	82.	670	787	1,919	8.1
OFB-21	91.	38.8	184.	0.3	0.02	250.	40	353	837	7.5
OFB-22	1.6	0.8	428	<0.1	0.02	260.	<10	508	1,041	8.8

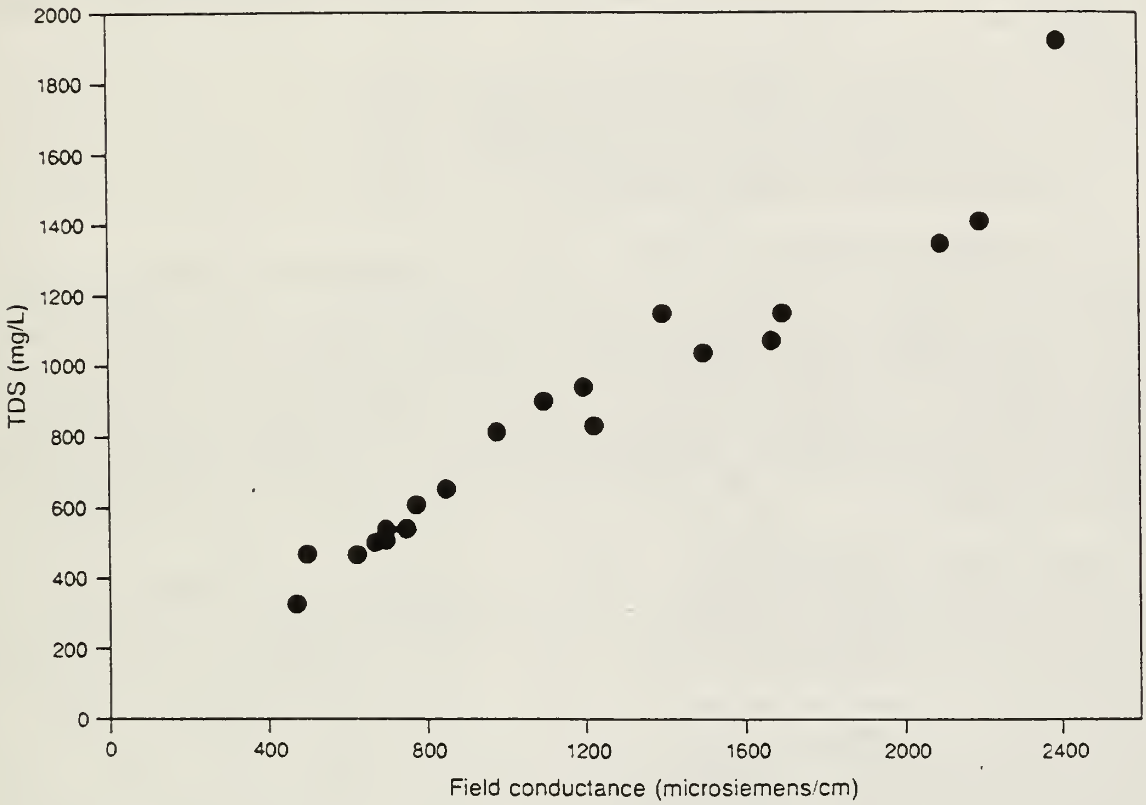
Table 3-2. Concentration (milliequivalents) of major ions commonly found in groundwater. Samples obtained from private wells in southeast Clay County

Sample No.	Ca	Mg	Na	Sr	Li	Cl	SO4	Alkal.	TDS	pH
OFB-01	2.69	2.80	9.57	0.00	0.00	1.55	3.96	6.24	948	7.5
OFB-02	2.44	2.67	4.44	0.01	0.00	1.47	0.62	7.43	502	7.8
OFB-03	3.99	3.36	3.04	0.01	0.00	1.24	1.25	7.99	542	7.4
OFB-04	4.64	2.86	3.95	0.01	0.01	0.56	2.08	8.25	613	7.4
OFB-05	3.73	3.33	2.99	0.01	0.00	1.13	0.83	7.91	510	7.9
OFB-05	4.49	4.31	3.56	0.01	0.00	1.41	2.91	7.63	658	7.6
OFB-07	3.19	2.21	2.26	0.00	0.00	1.64	1.46	2.92	473	7.0
OFB-08	4.21	2.40	2.48	0.00	0.00	0.28	0.83	7.95	468	7.4
OFB-09	6.39	4.48	4.05	0.01	0.00	0.37	5.21	8.99	820	7.3
OFB-10	2.59	2.73	1.06	0.00	0.00	0.28	1.04	4.40	330	7.4
OFB-11	1.06	0.76	8.00	0.00	0.00	1.24	0.00	8.79	545	7.8
OFB-12	4.79	5.84	5.44	0.02	0.01	1.13	5.00	8.87	907	7.6
OFB-13	7.49	5.27	6.26	0.01	0.00	5.50	5.41	5.32	1,153	7.1
OFB-14	0.34	0.23	20.53	0.00	0.00	11.57	0.00	9.23	1,152	8.3
OFB-15	0.12	0.10	25.40	0.00	0.00	15.23	0.00	10.03	1,410	8.6
OFB-16	0.34	0.33	59.85	0.01	0.01	49.37	0.00	11.41	3,292	8.3
OFB-17	0.30	0.30	52.54	0.00	0.01	39.49	0.00	13.55	2,935	8.5
OFB-18	1.16	1.12	23.31	0.01	0.00	12.69	1.46	10.15	1,347	8.1
OFB-19	0.08	0.07	19.05	0.00	0.00	8.74	0.62	10.09	1,074	8.8
OFB-20	2.00	4.87	26.79	0.01	0.01	2.31	13.95	15.73	1,919	8.1
OFB-21	4.54	3.19	8.00	0.01	0.00	7.05	0.83	7.05	837	7.5
OFB-22	0.08	0.07	18.62	0.00	0.00	7.33	0.00	10.15	1,041	8.8

Table 3-3. Comparison of field and laboratory electrical conductance values for water samples obtained from domestic wells in southeastern Clay County.

Sample No.	Field Temp. (deg. Celsius)	Field Conductance (microsiemens/cm)	Specific Conductance (microsiemens/cm @ 25oC.)
OFB-1	15.7	1,200	1,395
OFB-2	14.6	675	847
OFB-3	14.7	700	910
OFB-4	15.4	775	993
OFB-5	14.8	700	892
OFB-6	14.8	850	1,070
OFB-7	18.8	500	759
OFB-8	15.1	625	795
OFB-9	14.8	980	1,241
OFB-10	16.1	470	567
OFB-11	16.4	750	916
OFB-12	16.2	1,100	1,350
OFB-13	14.3	1,400	1,692
OFB-14	15.0	1,700	1,940
OFB-15	15.8	2,200	2,550
OFB-16	14.4	> 5,000	5,970
OFB-17	13.5	> 5,000	5,240
OFB-18	14.5	2,100	2,300
OFB-19	17.7	1,675	1,850
OFB-20	14.0	2,400	2,790
OFB-21	16.7	1,225	1,476
OFB-22	14.6	1,500	1,745

Figure 3-2. Field conductivity (microsiemens/cm) of water samples vs analyzed TDS concentration (mg/L)



Estimated TDS concentrations for 197 of the 199 measured wells located within the study area range from 147 to 2940 mg/L. Conductance measurements of the two remaining wells, OFB-16 and OFB-17, were highly inaccurate due to difficulties with the conductivity meter. Analytical TDS concentrations of these two wells were 3292 and 2935 mg/L, respectively. Only 53 of the 199 wells had an estimated (or measured) TDS concentration in excess of 1000 mg/L. TDS concentrations of these 53 wells were divided as follows:

#	between 1000 and 1500 mg/L	= 38
#	between 1500 and 2000 mg/L	= 10
#	between 2000 and 3000 mg/L	= 4
#	greater than 3000 mg/L	= 1

Although 500 mg/L is the public and food processing water qaulity standard for TDS in Illinois (Illinois Environmental Protection Agency, 1985), several municipalities in Illinois use waters with TDS concentrations of 1500 to 2000 mg/L and domestic wells often have water with up to 1000 mg/L (Illinois State Water Survey 1962). Water with 1000 mg/L or less TDS is generally considered fresh, from 1000 to 10,000 it is considered brackish, and water with 10,000 to 100,000 mg/L is considered saline (Fetter, 1980).

The field inventory of conductance data indicates that only 5 of the 199 wells measured may have anomalously high values of TDS. Sample OFB-16 is the only one with a laboratory derived TDS concentration exceeding 3,000 mg/L. No driller's log is on file for the well from which this sample was taken; however, the owner-reported depth of this well is 253 feet. The approximate depth to the base of fresh water in this area is 250 to 300 feet. Therefore the poor water quality in this well probably reflects the natural salinity which should be expected in groundwater at this depth in this portion of the study area.

OFB-17 (2935 mg/L analytical TDS concentration), located in 23-3N-7E (SW NW NW NW), is known to have originally been an oil well 3063 feet deep (owner reported depth at 2800 feet). It was plugged back to 310 feet (owner reported 280 feet) when it was converted to a water supply well. The generalized depth to the base of the freshwater aquifer (estimated 2500 mg/L TDS) is 150 to 200 feet. While naturally occurring brackish water may be expected at this well depth in this area, poor water quality may also be related to well construction, plugging, or past oil production at the site.

None of the other three wells identified by the field inventory as having TDS concentrations between 2000 and 3000 mg/L were sampled for chemical analysis. (These wells are identified in Appendix 3-B under the name Don Wigley (23-3N-7E), Harold Good (29-3N-8E), and Bonnie Wrey (29-3N-8E).) The wells are reported to be 201, 150, and 185 feet in depth, respectively. All are completed in Pennsylvanian sandstone. A comparison of the depth of each of these wells with the electric-log estimated depth to the base of the fresh water aquifer indicates that the Wigley and Wrey wells are completed within 20 feet of the estimated base of the 2500 ppm TDS aquifer. Therefore, the estimated water quality reflects a natural salinity which should be expected at those depths and locations.

Electric-log derived water quality data is very sparse in the area of the Harold Good well (see figure 2-10). Depth to the base of the fresh water aquifer (estimated 2500 ppm TDS) may be as much as 250 feet or as shallow as 180 feet. Since the well is completed at 150 feet, its estimated TDS concentration of 2541 mg/L may also be a result of naturally occurring brackish water.

Well Depth and Proximity to Brine Pit vs Conductivity

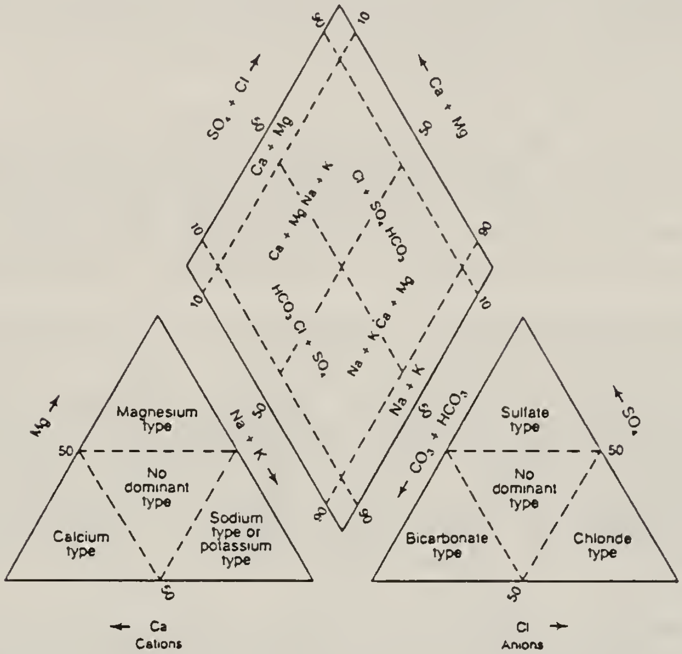
Regression analysis was used to determine whether a relationship exists between conductance (as a measure of water quality), and depth of the well and/or conductance and distance from the nearest brine pit existed. Two single and one multiple regression analyses were performed on the groupings of wells; shallow wells (> 50 feet deep), deep wells (> 50 feet deep), and combined shallow and deep wells. A total of 149 wells with reported depths, located in and around the study area, were included in the analysis. In all cases, conductance was the dependent variable and proximity to a brine pit and well depth were the independent variables. Results of these analyses are shown in Appendix 3-C.

No significant correlation between conductance and well depth and/or distance from the nearest brine pit was observed. The highest linear correlation coefficient (r^2) obtained was 0.39 for two of the deep well (> 50 feet depth) groupings; depth vs conductance and depth and proximity vs conductance. The data indicate that no widespread degradation of water supplies has occurred in this area due to disposal of brine in pits. The lack of correlation may be an artifact of the data; i.e., only 14 wells were located within an estimated 500 feet of a brine pit. However, none of these 14 wells had water with electrical conductance greater than 2000 microsiemens/cm (estimated 1410 mg/L TDS).

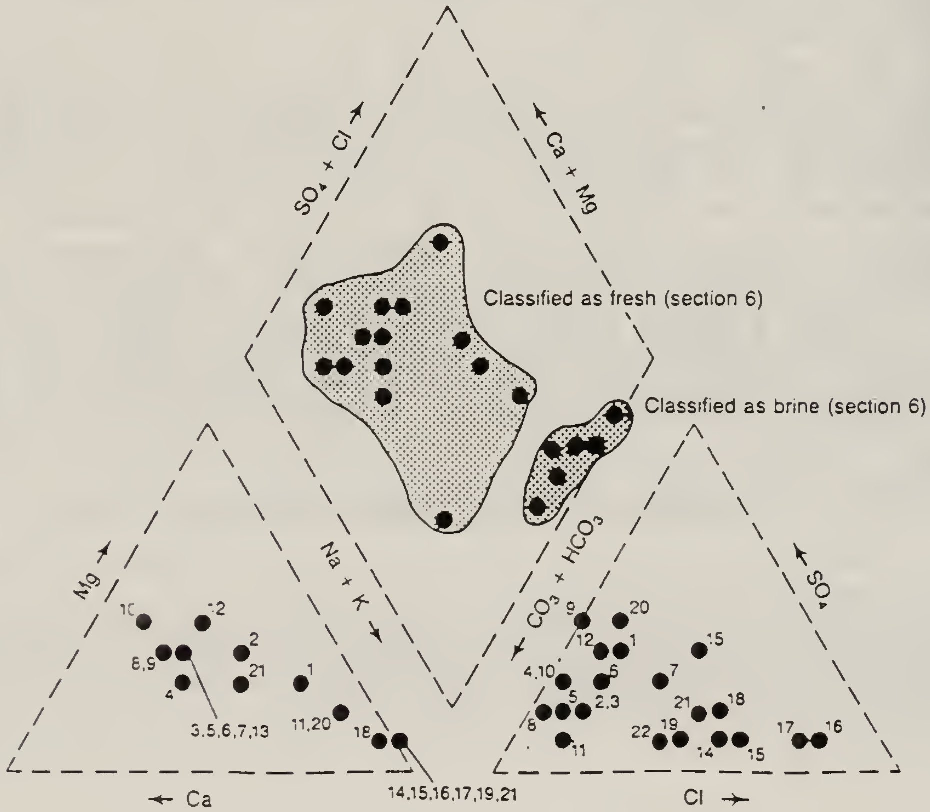
Chemical Analyses and Water Type Characterization

Results of the chemical analyses of the 22 domestic water well samples are graphically presented in figure 3-3. Data used in plotting the trilinear diagram are given in table 3-2. Bicarbonate (HCO3) values were calculated from alkalinity, and potassium was considered negligible.

Figure 3-3. Trilinear diagram of major groundwater quality parameters for samples obtained from domestic wells in southeastern Clay County.



Hydrogeochemical classification system for natural waters using the trilinear diagram



The water samples can be grouped into two types: fresh water and shallow brine. Major cations of the fresh water type (as subsequently described in Section 6) are a mix of sodium (Na), calcium (Ca), and magnesium (Mg). The predominant cation of the shallow brine type is sodium. Anions of the fresh water group are bicarbonate or no dominant type, while anions of the shallow brine group are predominantly chloride or no dominant type. One sample, OFB-22, plots in the bicarbonate domain but its cation facies is over 90% sodium; it is still classified as a shallow brine.

The samples with the highest conductances and TDS concentrations, OFB-16 and OFB-17, also have the highest percentages of sodium (98.9% for both wells) and chloride (81.0% and 74.2%, respectively) as reacting cations and anions. In general, the group of samples identified as shallow brines in Section 6, appear to fall in a domain characterized by 90% or greater sodium as reacting cation and 50% or greater sulfate and chloride as reacting anions.

Figure 3-4 illustrates the relationship of the major ions (calcium, magnesium, sodium, and chloride) with depth. Calcium and magnesium tend to decrease as sodium and chloride increase significantly. Plots of relative sodium and chloride concentrations with well bottom elevations (figure 3-5) indicate that elevated sodium and chloride concentrations are common below 300 feet (referenced to mean sea level).

CONCLUSIONS

Groundwater availability in the study area is limited; however, wells completed in shallow bedrock aquifers do yield potable water at rates adequate for domestic supply. Brackish water commonly occurs at depths of 150 to 250 feet (figure 2-10, Section 2). This water has high, naturally-occurring concentrations of sodium and chloride.

Other potable water is yielded by shallow, large-diameter, bored or dug wells. In general, these wells have water with lower TDS concentrations and better overall water quality than wells finished in shallow bedrock aquifers.

Although shallow, bored or dug wells are susceptible to contamination resulting from abandoned brine pits, it appears that no wells sampled for this study have been affected by oil field brine contamination.

No widespread degradation of groundwater resources related to brine disposal practices has been observed in the study area. All 5 wells with estimated or measured TDS concentrations greater than 2000 mg/L were completed at depths where brackish water could be expected to occur.

Figure 3-4. Well depth (feet) vs concentration of major ions; calcium (Ca), magnesium (Mg), sodium (Na), and chloride (Cl).

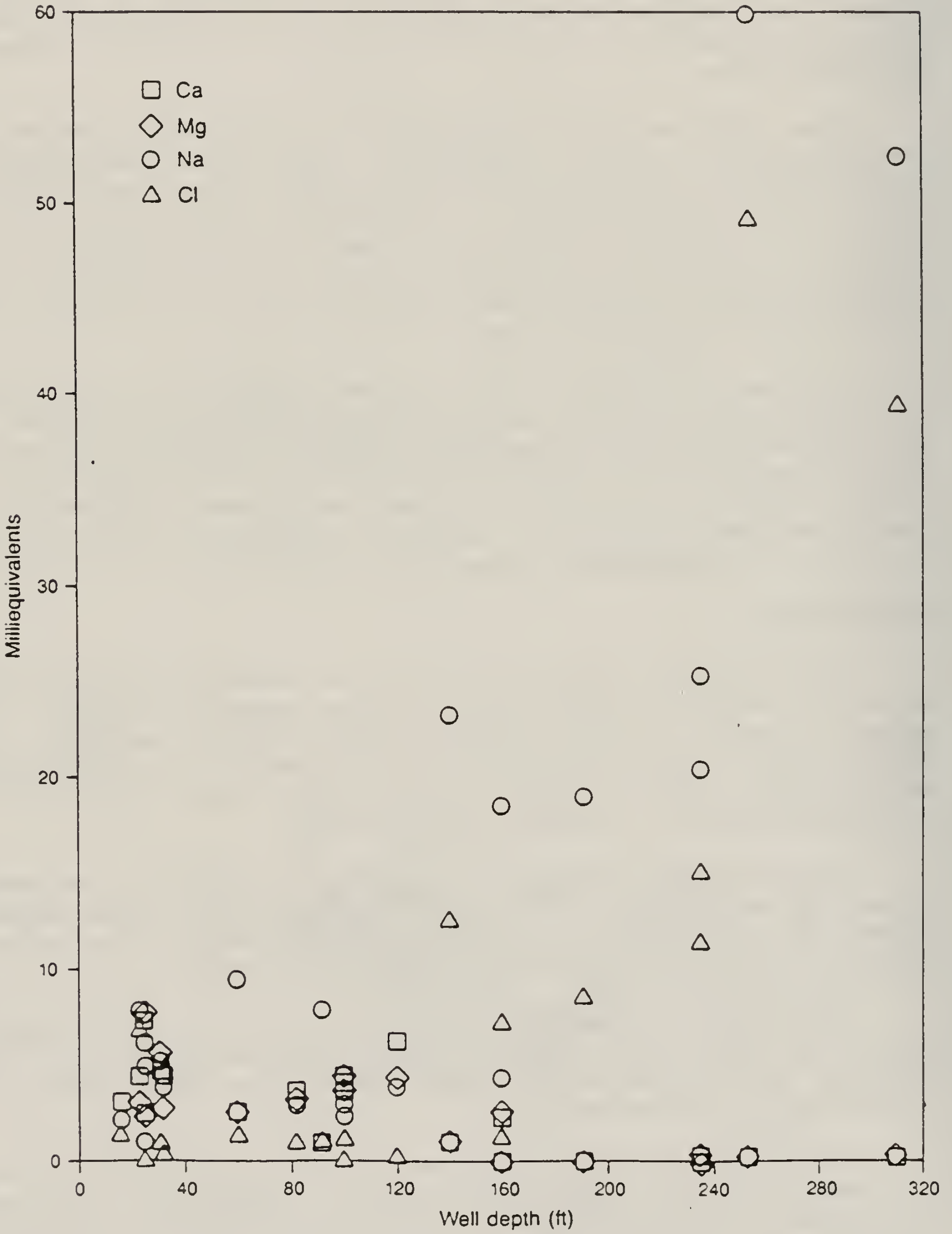
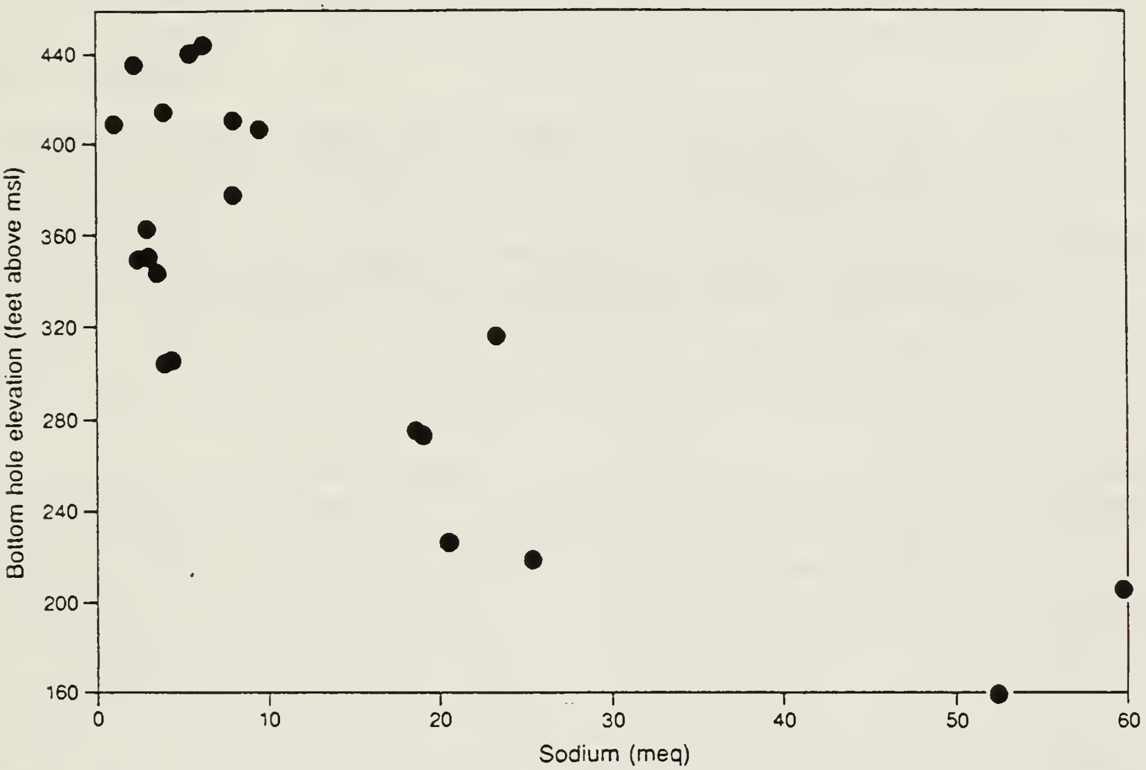
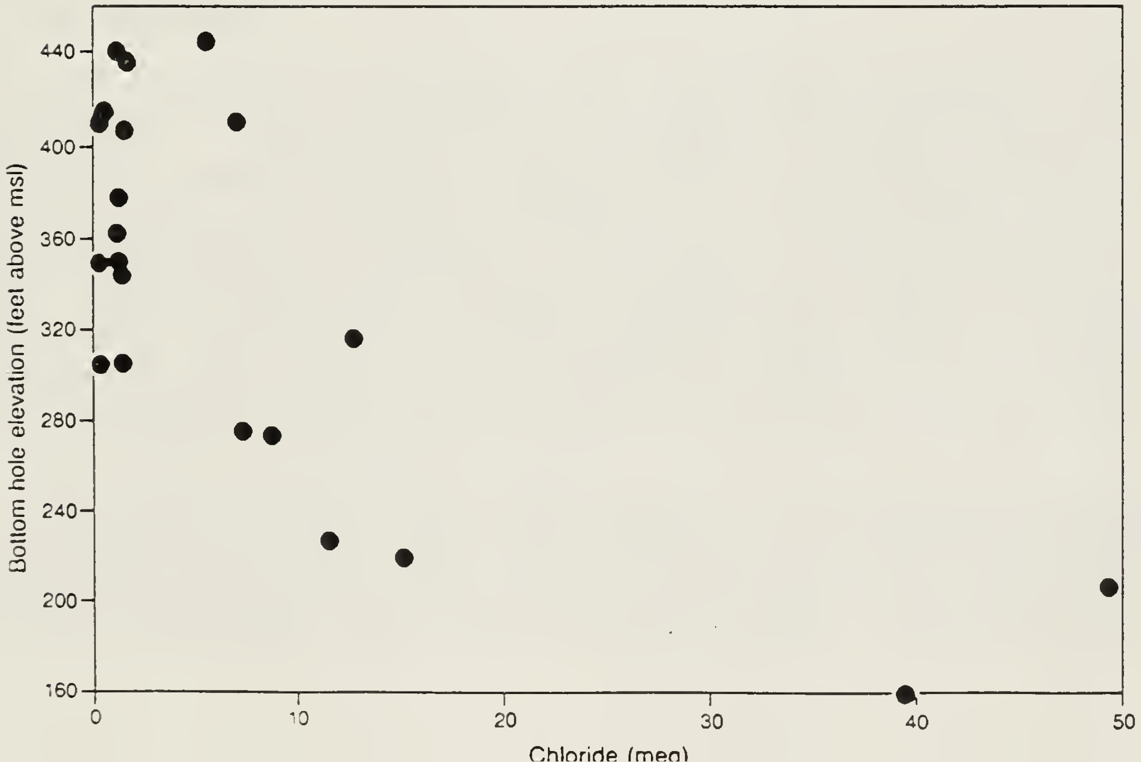


Figure 3-5. Concentration of chloride and sodium (milliequivalents) vs elevation of well bottom (feet) for samples obtained from domestic wells in southeastern Clay County.





REFERENCES

Illinois Environmental Protection Agency, 1985, State of Illinois Rules and Regulations - Title 35: Environmental Protection Subtitle C: Water Pollution Chapter 1; Pollution Control Board; Illinois Environmental Protection Agency, 44 p.

Illinois State Water Survey, 1962, Potential water resources of southern Illinois: Illinois State Water Survey Report of Investigation 31, 97 p.

Fetter, C.W., Jr., 1980, Applied hydrogeology: Charles E. Merril Publishing Company, Columbus, Ohio, 488 p.

SECTION 4 ASSESSMENT OF SURFACE WATER QUALITY

by

J. Rodger Adams, Billy K. Cook, and Raman K. Raman

INTRODUCTION

The surface water investigation focused on two locations: 1) Buck Creek which flows into the Little Wabash River in Clay County and passes through an area of oil production and 2) a surface runoff site near an abandoned and filled brine holding pond. Two sampling sites were selected along Buck Creek to determine any change in water quality as it flows through an area with numerous oil wells and brine disposal sites. Sampling at the runoff site was concentrated in an extensive gully and rill system which is developing in the bare soil at the site.

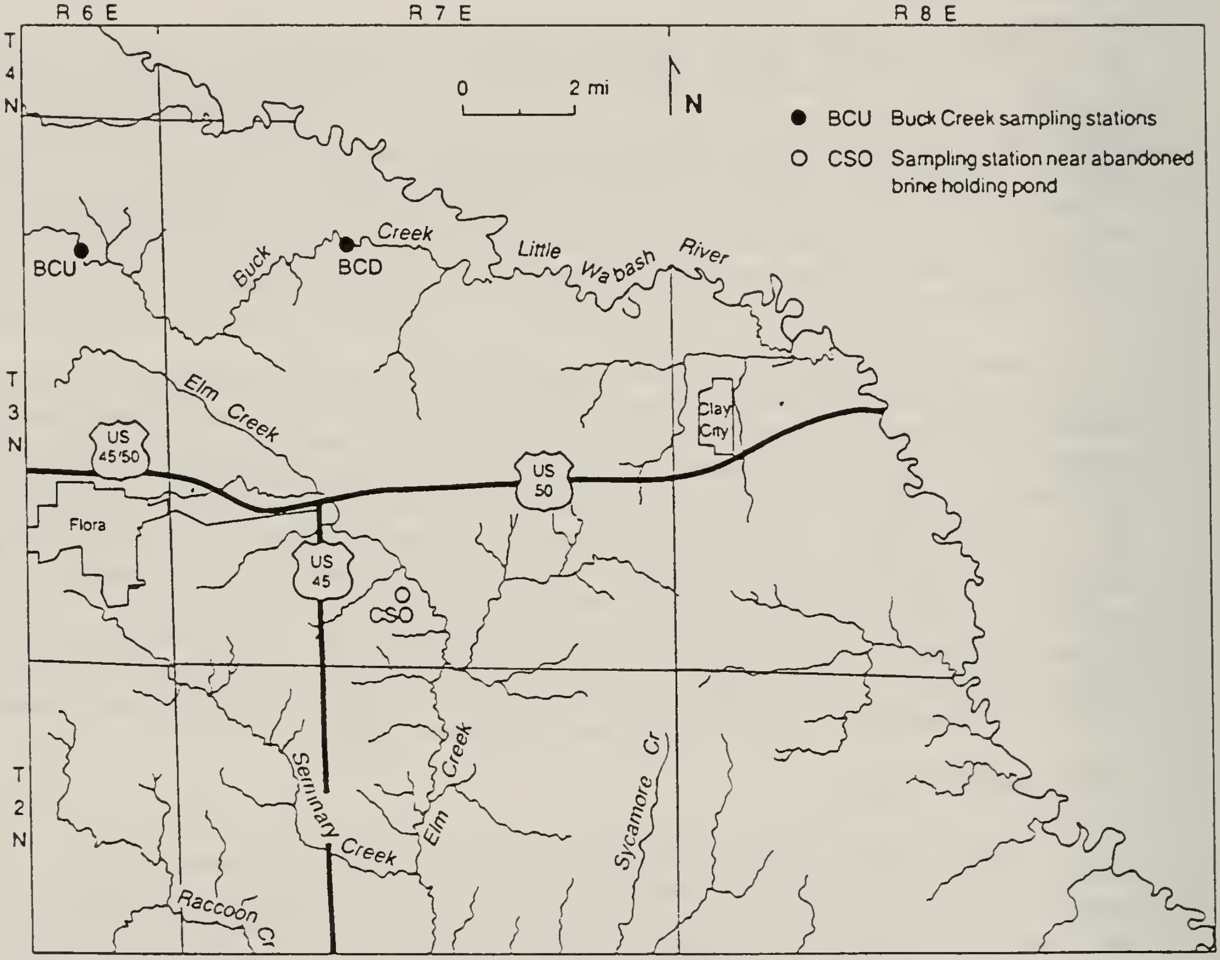
Sampling included measurement of water quality and sediment concentration at each site. In addition, bed material samples were collected from Buck Creek and analyzed for particle size. Generally dry conditions in the study area resulted in low discharges in Buck Creek and only a few measurable runoff events in the gullies. Precipitation at Flora totaled 22.06 inches, or 17.4% less than the normal precipitation of 26.72 inches for the period. July was the only month with above average precipitation. The average temperature for this period was 2.5^{O}F above normal, and August was the only month with below normal temperature. The above normal temperature would cause above normal evaporation and reduced stream flow.

SITE DESCRIPTIONS

Buck Creek has a drainage area of 26.8 square miles. It flows into the Little Wabash River, 145.9 miles upstream from the Wabash River. The main stem has a length of about 21 miles and an average slope of about 5 feet per mile. The basin relief is 120 feet. The Little Wabash River has a drainage area of about 780 square miles at the mouth of Buck Creek. The long-term runoff in the Little Wabash basin is about 0.86 feet per year (USGS, 1986). This is an average discharge of about 20 cfs for Buck Creek. The average annual sediment load is about 3,500 tons (Bhowmik et al., 1986). The surrounding watershed area contains active as well as inactive oil fields including abandoned brine holding ponds and injection wells.

Two sampling sites were selected on Buck Creek and are shown on figure 4-1 with the site codes BCU for the upstream site and BCD for the downstream site. The drainage area is 17.25 square miles at BCU, or 64.4% of the water-shed area. The downstream site has a drainage area of 23.42 square miles, or 87.4% of the

Figure 4-1. Location of Buck Creek water sampling stations (BCU=upstream, BCD=Downstream). Location of gully and rill runoff measurement site is denoted by CSO.



watershed area. The contributing area between BCU and BCD is 6.17 square miles, or 23% of the total watershed area. This is an increase of 35.8% over the area at BCU. However, this area has many more oil wells and brine separation tanks than the area upstream of BCU. The slope between the two sites is 4.1 feet per mile. These stream sampling stations on Buck Creek have provided the necessary data for comparison of the effects of oil field runoff on surface water quality in the study area. The upstream station was used to sample a portion of the creek largely uneffected by oil field activities and the downstream station was used to sample a portion of the creek which may have been heavily effected by these activities. This particular creek is subject to the Illinois General Use Standards which were used to determine the percentage of violation rate for the sampling period of this report at both upstream and downstream sampling stations.

An abandened, filled-in, brine holding pond was selected as a surface runoff site and is located on figure 4-1 by the code CSO. Figure 4-2 shows this site in greater detail. The land slopes down to the east at about 4 percent. Runoff from the bare soil has eroded two gullies which coalesce and flow eastward into a field swale which empties into a road ditch and then flows east into Elm Creek. The total length of the gulley is about 700 feet, Elm Creek is about 1200 feet east of the site.

Runoff from storm events at the runoff site was included in the water quality analysis in order to determine surface water impacts caused by abandoned brine holding pond runoff.

SAMPLING METHODS

Water quality and suspended sediment samples were collected at the Buck Creek sites using the US DH-59 depth-integrating suspended sediment sampler. This sampler and its use are described in detail by Guy and Norman (1970). Water quality samples were composited to make the required volume. Preservation of the samples was carried out as per standard methods (APHA, 1980). The water quality samples were kept iced and shipped to the Illinois State Water Survey laboratory in Peoria for analysis. Suspended sediment samples were delivered to the Inter-Survey Geotechnical Laboratory in Champaign for analysis. Temperature, pH, and dissolved oxygen were measured in the field.

Table 4-1 includes descriptions of methods and materials used for each water quality analyis. Raw data for upstream and downstream sampling stations is contained in Appendix 4-A. Samples were collected at these two stations approximately every two weeks from April through September. All metal analyses were performed in duplicate with blank and control samples for each

Figure 4-2. Location of single stage sampling devices (A and B) and bed material sampling stations (A1-A3, B1-B3, AB) at gully and rill runoff site.

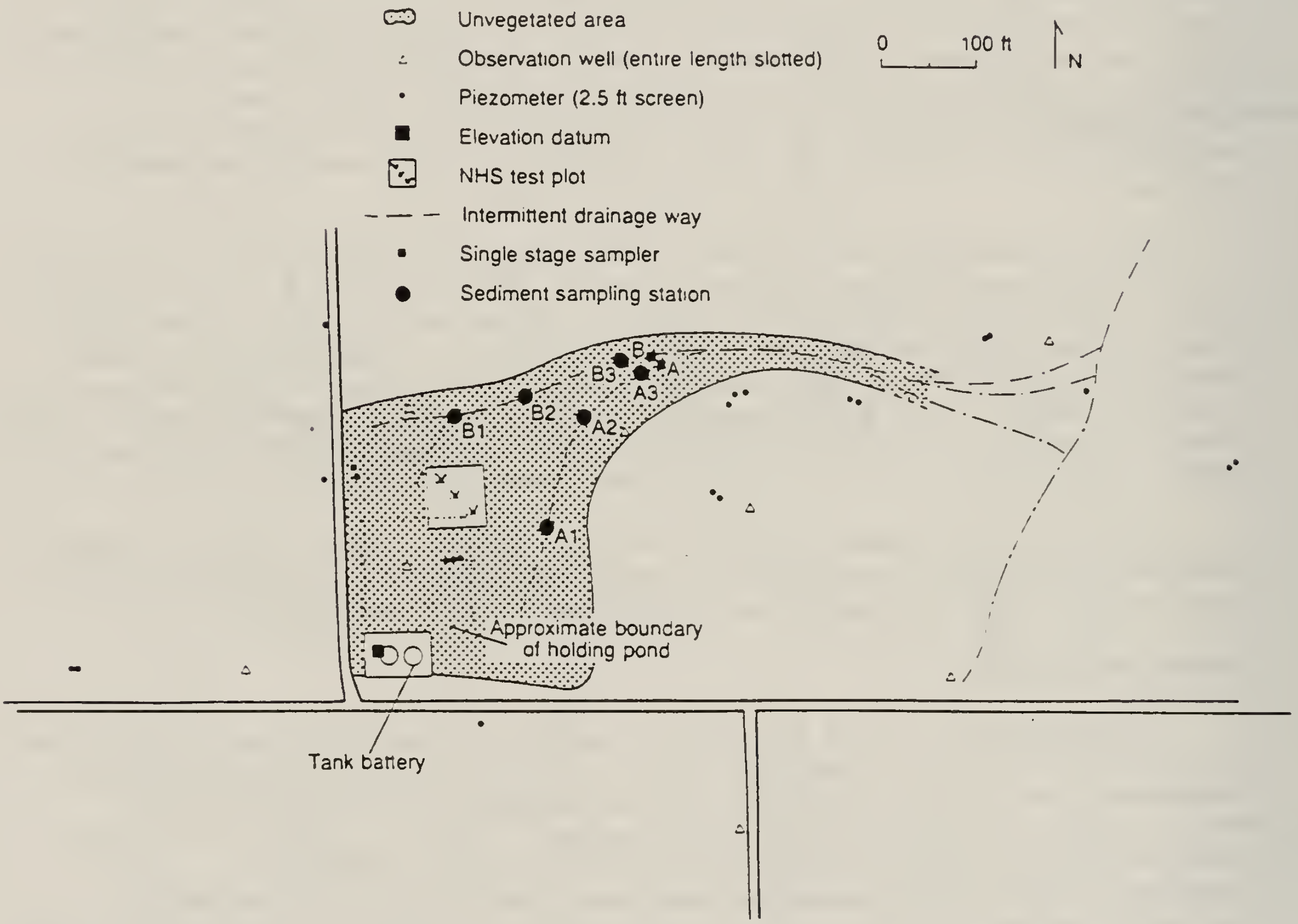


Table 4-1. Methods of Chemical Analysis

Parameter	Method
Ammonia Nitrogen	Steam Distillation/Phenate Method. 417C[1]
Boron	Boron, Total Recoverable (:01022)[2]
Bromide	Datalytic Ocidation (:71870)[2]
Chloride	Argentometric Method. 407[A]
Electrical Conductance	Metrohm Conductometer Model[3]
EDTA Hardness	EDTA Titrimetric Method. 314B[1]
Grease and Oil	Partition-Gravimetric Method. 503A[1]
Iodide	Leuco Crystal Violet Method. 414A[1,4]
Metals	Flame Atomic Absorption. 303[1]
Nitrate & Nitrite	Chromotropic Acid Method. 418D[1]
pH	Metrohm pH Meter/Glass Electrode
Phosphate	Vanadomolybdo Phosphoric Acid Method. 424D[1]
Sulfate	Turbidimetric Method. 426C[1]
Total Alkalinity	Titration to pH 4.5[1]
Total Dissolved Solids	Total Filtrable Residue. 209B[1]
Total Kjeldahl Nitrogen	Steam Distillation/Macromethod. 420A[1]
Total Suspended Solids	Total Nonfiltrable Residue. 209D[1]
Total Volatile Solids	Total Volatile Residue. 209E[1]

1 American Public Health Association. 1980.

2 United States Geological Survey. 1979.

3 nductivities compared well with total filtrable residue as did rdness and selected mineral concentrations.

4 Inference with the Leuco crystal violet method of iodine analysis forced the use of standard addition methods for this analysis.

analysis group. Likewsie, alkalinity, hardness, chloride, boron, bromide and residue analyses were duplicated.

Bed material samples from Buck Creek and soil samples from the runoff site were collected using a shovel and were placed in plastic ziplock bags for shipment to the geotechincal laboratory for particle size analysis. The methods for the laboratory analysis of sediments are given by Guy (1969).

The measurement of sediment on the open field site during runoff events presented particular problems. Unless the field technician was present during a storm, he could not sample the runoff. The exposed nature of the site, which is surrounded by actively cultivated farm fields, precluded the installation of an automatic pumped sampler. Therefore, a device called a single stage sampler (model US SS-59, described in "A study of methods used in measurement and analysis of sediment loads in streams" (Federal Inter-Agency Sedimentation Project, 1981 was used). Each of these samplers consists of a standard pint sample bottle and a stopper with two formed copper tubes which allow the bottle to fill and retain a sample during a flow event. The dimensions of the single stage samplers which were used at this site are given in figure 4-3. Two of these were mounted, one above the other on a post driven into the bed of the gullies at the locations shown in figure 4-2. Because of the shallow depth of the flow, the bottom bottle was actually buried in the bed of the gully.

RESULTS

Buck Creek

Suspended sediment sampling was performed on 16 dates (table 4-2). The gage readings are inches below a fixed measuring point. At the downstream site (BCD) the top of the bridge deck at the downstream center was the measuring point and at the upstream site (BCU) the top of the concrete curb at the downstream center of the bridge was the measuring point. Though discharge was not measured, the observed flow rates were all low and essentially zero for gage readings over 132 inches at BCU and 97.5 inches at BCD. This was the case on 11 of the 16 sampling dates. The specific conductivity was measured in the lab at the time of the suspended sediment concentration analysis. These values are similar to those measured in the water quality samples.

The suspended sediment concentrations ranged from 14 to 48 mg/L at BCU with an average of 30.6 and a standard deviation of 12.0. Suspended sediment concentrations at BCD ranged from 22 to 87 with an average of 42.9 and a standard deviation of 17.6. The average suspended sediment concentrations and average discharges based on the regional runoff rate were used to estimate that the

Table 4-2. Suspended Sediment Data For Buck Creek

Date	Upstream Station Conc. mg/l	Upstream Station Cond. umho	Upstream Station Stage inches	Downstream Station Conc. mg/l	Downstream Station Cond. umho	Downstream Station Stage inches
3/25/86	48	490	130.0	87	673	87.0
4/03/86	26	707	130.5	25	1013	92.0
4/08/86	33	892	130.5	47	948	86.5
4/18/86	14	718	131.2	23	1224	92.0
4/29/86	31	671	131.0	46	897	88.5
5/06/86	18	754	132.0	47	1133	94.0
5/13/86	18	777	132.8	22	1346	97.5
5/20/86	47	730	133.0	51	1208	97.5
6/03/86	29	760	133.8	35	1388	99.0
6/17/86	27	729	134.0	53	1400	100.0
6/24/86	-	-	136.5	-	-	101.5
7/08/86	-	-	137.0	37	1228	106.0
7/22/86	-	-	136.2	-	-	101.0
7/29/86	46	295	131.5	42	638	99.0

Table 4-3. Suspended Sediment Concentrations at Case Study 1 Site.

Date	Gully A	Gully B
5/20/86	-	30,000
7/08/86	-	28,500
7/29/86	100,000	71,300
8/26/86	-	46,900

runoff entering Buck Creek between the two sites would have an average suspended sediment concentration of about 77 mg/L. This is over twice the concentration of BCU. The increases in conductance and total dissolved solids indicate a large influx of soluble compounds between the two sites. The dissolved solids may be a direct result of the brines on the surface or mixed with the surface soils. The increased influx rate of suspended sediment may be due to erosion of the soils resulting from brines raising the soil salinity above the level at which most plants can grow.

Runoff Site

Suspended sediment concentrations were determined on four dates (table 4-3). Low precipitation during the sampling period resulted in infrequent runoff events and limited the number of samples collected. The water quality analyses were also considered to be of greater value than suspended sediment at this location. Thus, when only a partial sample was obtained water quality parameters were analyzed instead of suspended sediment concentration.

PHYSICAL CHARACTERISTICS OF BED MATERIAL

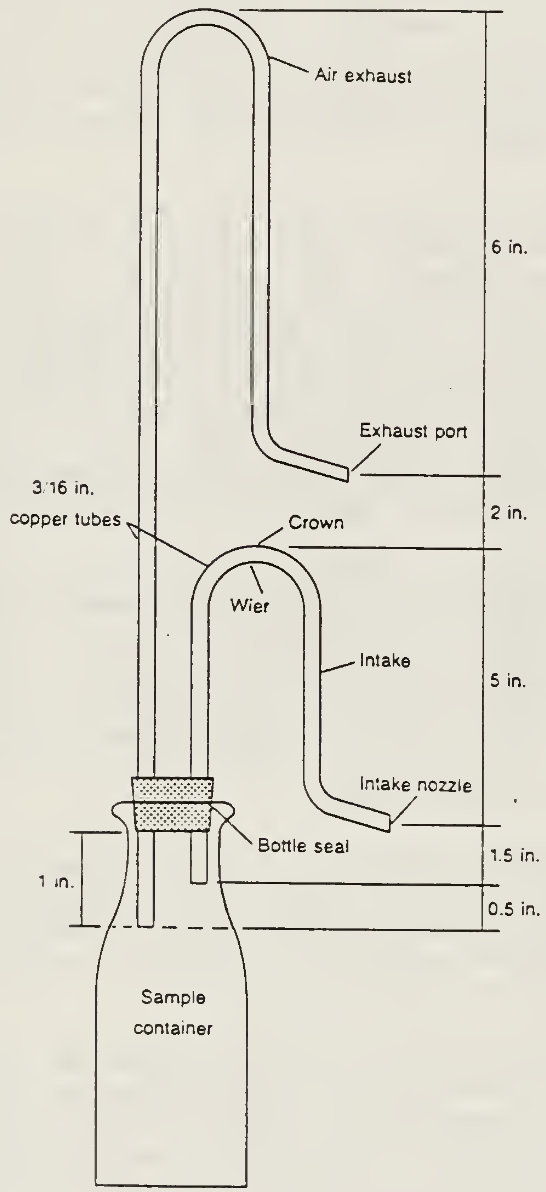
Buck Creek

Samples of creek bed material were collected from the thalweg (deepest point of a cross section) downstream of each bridge across Buck Creek. The six sample sites are marked in figure 4-1 with the same codes given in table 4-4. The two downstream sites have the finest bed material, with over half in the silt and clay size-fractions. These variations in material size are probably local. Using a soil classification (Terzaghi and Peck, 1967) based on the percentages of sand, silt, and clay in a sample, the bed material at locations BK1 to BK4 is either sand or sandy-loam, BK5 is loam, and BK6 is silty-clay-loam.

Runoff Site

Seven surficial samples of bed material were taken at the locations indicated in figure 4-2. The letters "A" and "B" correspond to the gullies in which the single stage samplers were placed. Gulley A and the upstream end of gulley B have bed materials classified as loam or sandy-loam. The downstream sites in gulley B and the site downstream of the junction of the two gullies are classed as sandy-loam. The bed materials at this site primarily consists of sand and silt with less than 20 percent clay (table 4-5).

Figure 4-3. Sketch of US 55-59 single stage sampler (after Federal Interagency Sedimentation Project, 1981).



WATER QUALITY

Buck Creek

The surface water quality in the Buck Creek study area is generally good. Of the 16 General Use parameters studied, four exhibited violations. Ammonia was the only parameter experiencing frequent violations with copper, iron and manganese concentrations near the maximum allowable levels. Of the unregulated parameters, only grease and oil concentrations seem to be slightly elevated from those normally found in Illinois surface waters.

Heavy precipitation in the study area during late May and early June (figure 4-4) may have contributed to the steadily increasing ammonia and phosphate concentrations, as well as that of other constituents analyzed in this study (figures 4-5 through 4-9). Possible contributing factors to the high ammonia and phosphate concentration are agriculture fertilizers in the Buck Creek watershed area coupled with atmospheric sources of ammonia and phosphate (Kothandaraman et al., 1977). Algal blooms observed during the sampling period reflected the elevated concentrations of ammonia and phosphorous.

On only one occasion did dissolved oxygen (DO) concentration in Buck Creek fall below the General Use Standard. This event occurred during a period of no flow and reflected the stagnation of the stream water at the sampling site. During periods of flow, the creek appears to be well aerated with DO levels being slightly lower at the downstream station. This fact could possibly be associated with grease and oil concentrations observed in the creek.

Although grease and oil concentrations fluctuated between 4 and 10 mg/L in the Buck Creek samples, run-off from the Case Study Site contained an order of magnitude more, averaging 70 mg/L. Grease and oil in surface waters may cause decreases in DO sufficient for fish kills.

Locally high concentrations of chloride, total dissolved solids and grease and oil indicates that infiltration of brines from the surrounding watershed may have occurred. Although chloride and TDS concentrations did not exceed General Use Standards, their increase from upstream to downstream stations supports this implication (figures 4-7 and 4-8).

Table 4-6 indicates that bromide and sulfate concentrations increased from upstream to downstream stations. The presence of these two constituents in oil field brines again points to oil production practices in the watershed area as sources. The concentrations of these analytes, however, are not of sufficient magnitude to warrant concern.

Table 4-4. Bed Material Characteristics Along Buck Creek

Location Code	Median Diameter mm	Percentage Composition Gravel	Sand	Silt	Clay
BK1, BCU	0.18	2.4	70.7	17.3	9.6
BK2	0.95	44.9	51.0	4.1	0.0
BK3	0.13	1.3	53.7	28.8	16.1
BK4	2.50	51.1	30.3	10.8	7.8
BK5	0.040	4.9	36.2	41.2	17.7
BK6, BCD	0.020	2.8	13.9	57.5	25.8

Table 4-5. Bed Material Characteristics at Runoff Site

Location Code	Median Diameter mm	Percentage Composition Gravel	Sand	Silt	Clay
A1	0.024	1.1	27.9	55.2	15.8
A2	0.045	1.2	43.4	38.1	17.3
A3	0.040	4.4	33.2	45.9	16.5
B1	0.029	3.1	29.9	54.3	12.7
B2	0.30	4.1	53.4	27.7	14.8
B3	0.17	7.4	51.2	23.7	17.7
AB	0.30	3.9	62.8	18.1	15.2

Figure 4-4. Precipitation on Flora, Illinois, April-August, 1986

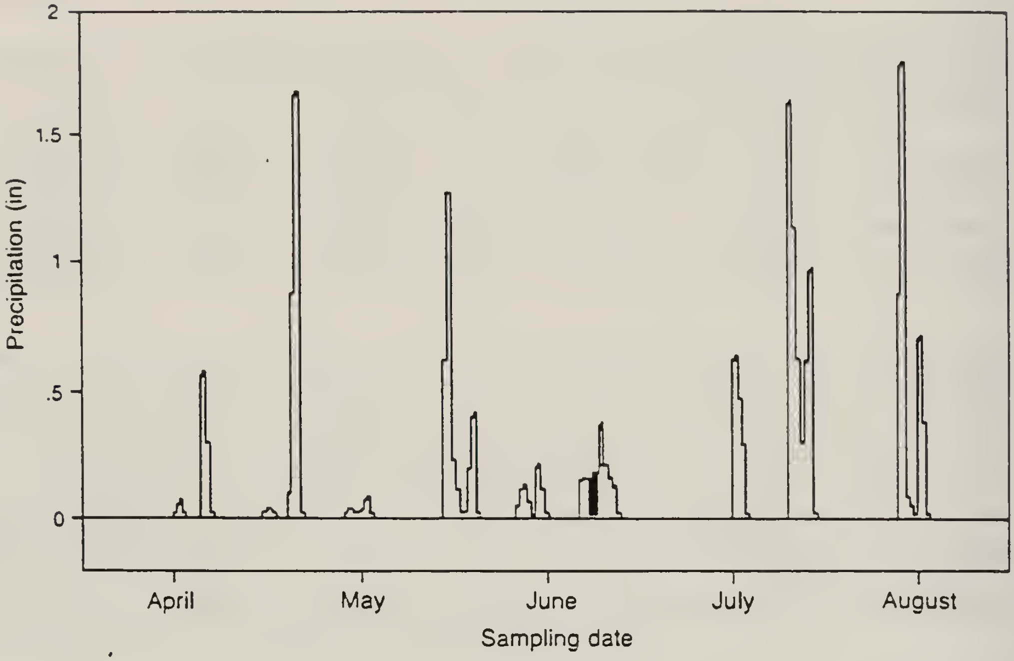


Figure 4-5. Hardness concentrations in Buck Creek.

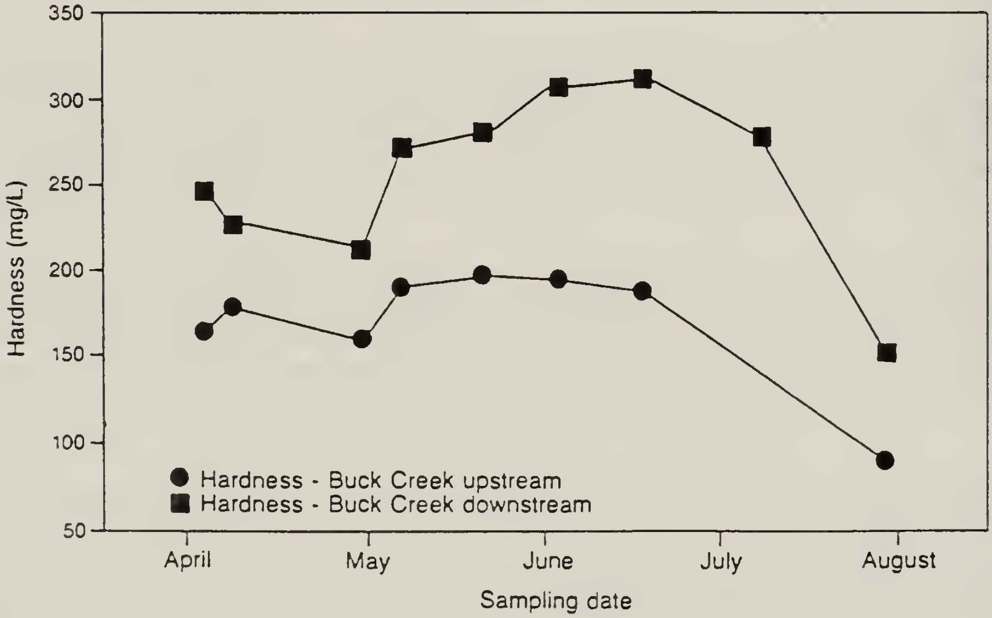


Figure 4-6. Conductivity values in Buck Creek.

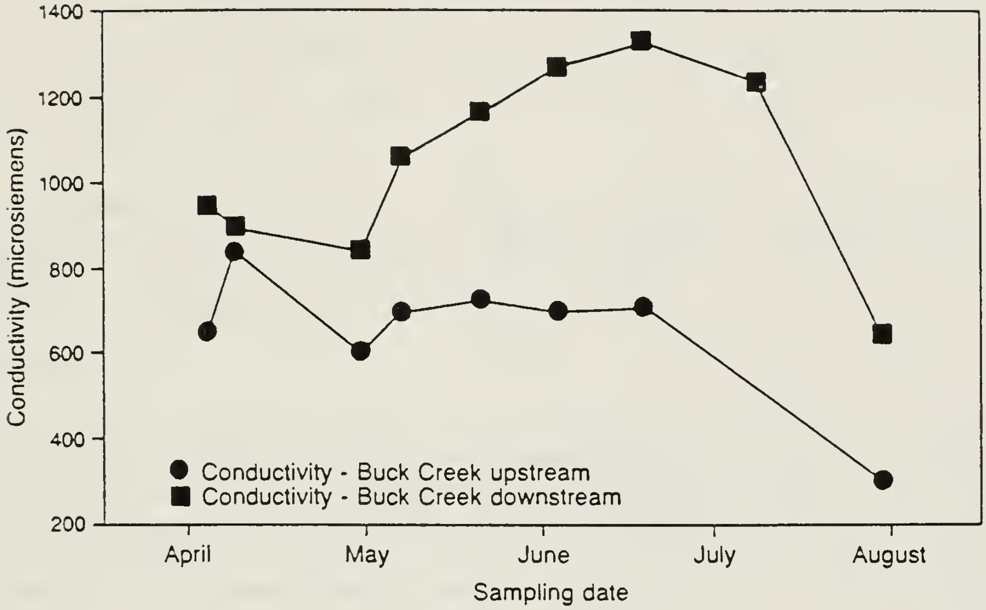


Figure 4-7. Chloride concentrations in Buck Creek.

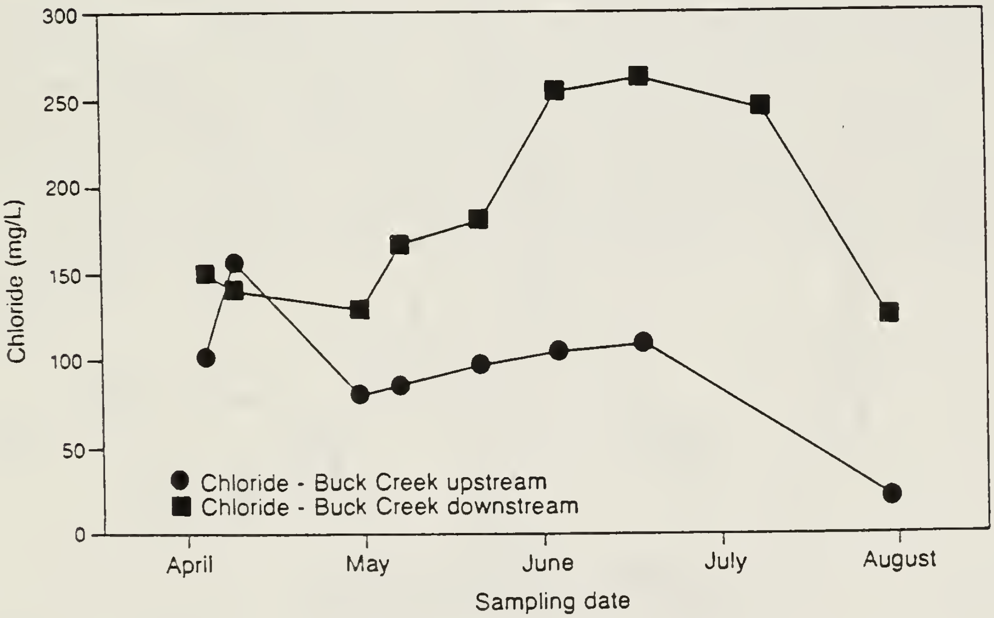


Figure 4-8. Total dissolved solids concentrations in Buck Creek.

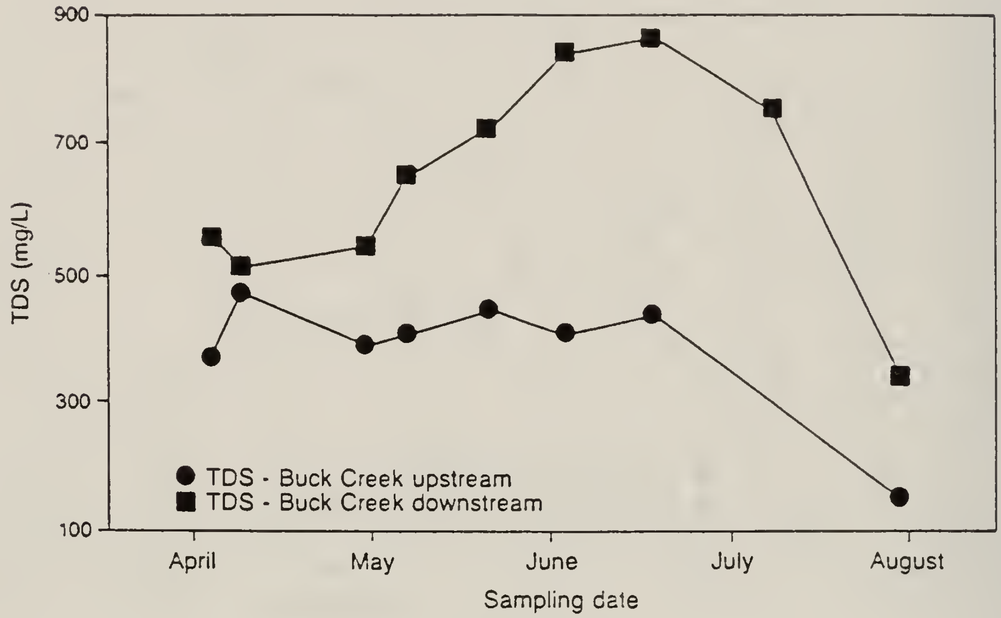
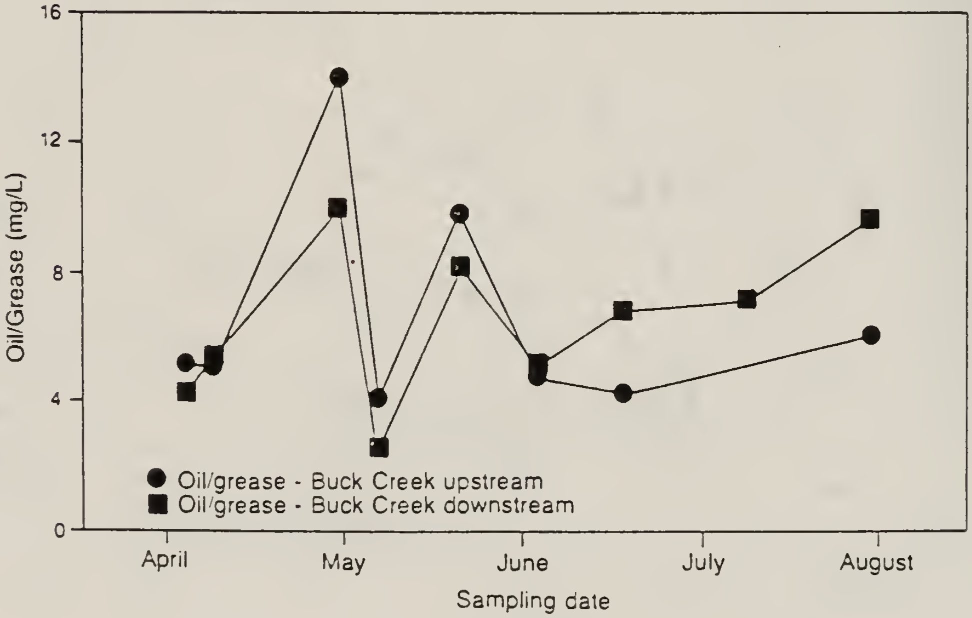


Figure 4-9. Total grease and oil concentrations in Buck Creek.



Metal concentrations, on the whole, were not excessive. Sodium, potassium, calcium and magnesium concentrations appeared typical of Illinois streams with only slight increases from upstream to downstream stations. This may be attributed to natural geochemical processes and poses no health threat at the concentrations observed. Minimal violations for iron, copper and manganese were observed and are attributable largely to background contributions.

Good compliance records for most of the metals appear to be due to limited solubility under ambient water conditions. Those metals which appear to be solubility limited include barium, lead, nickel, copper and zinc.

CONCLUSIONS

Buck Creek complies well with General Use Water quality Standards where compliance can be achieved. Frequent difficulty in maintaining the iron standard is primarily due to natural background concentrations. Non-point sources of ammonia and phosphorous also make it difficult to maintain these standards. In reference to those constituents normally associated with oil field brines, Buck Creek is not unaffected. It is clear that the surrounding watershed area contributes to the increased levels of dissolved solids including barium, bromide, and chloride, along with grease and oil.

Run-off from the gully system at Case Study Site 2 (table 4-7) did contain elevated levels of several salient parameters including bromide, chloride, boron, sodium, barium and manganese. These constituents, frequently found in oil field brines, indicate that runoff from this site could have a negative impact on water quality in the surrounding watershed. Further implications of natural seepage from abandoned brine holding ponds combined with run-off results observed in this study could explain concentrations of these constituents in surrounding surface waters.

Table 4-6. Water Quality Data for Buck Creek
*All concentrations expressed as mg/L unless otherwise noted.

	Upstream Sta.			Downstream Sta.			General Use
	Min.	Max.	Mean	Min.	Max.	Mean.	Standard
NH3-N*	0.09	12.4	3.28	0.18	4.73	1.60	1.5
Boron	0.03	0.12	0.09	0.08	0.14	0.11	1.0
Bromide	0.14	0.70	0.46	0.55	1.10	0.77	-
Chloride	21	155	94	123	260	182	500
Conductance (microsiemens)	295	831	647	638	1321	1035	-
Dissolved Oxygen	5.7	22.0	6.6	1.4	10.5	11.3	>5.0
Grease and Oil	4.1	14.0	6.6	2.6	10.0	6.6	-
Hardness (as CaCO3)	89	196	170	151	310	252	-
Iodide	<0.10	<0.10	-	<0.10	<0.10	-	-
Nitrate & Nitrite	0.09	0.47	0.27	0.05	0.48	0.30	-
pH (unitless)	(7.68-8.79)		-	(7.6-8.0)		-	6.5-9.0
Phosphate	0.07	0.26	0.12	0.09	0.37	0.18	0.05
Sulfate	28	106	67	32	169	107	500
Total Alkalinity	97	155	123	105	201	141	-
Total Dissolved Solids	150	472	386	336	858	640	1000
Total Kjeldahl Nitrogen	0.44	14.4	4.22	0.45	5.82	2.63	-
Total Suspended Solids	12	46	22	27	54	39	-
Total Volatile Solids	1	7	4.1	2	18	6.4	-
Na (Tot.)	38	124	85	38	287	145	-
K (Tot.)	4.2	6.0	5.0	4.3	10.1	6.1	-
Ca (Tot.)	26	60	46	37	86	65	-
Mg (Tot.)	6.3	15	12	13	29	21	-
Ba (Tot.)	0.03	0.07	0.06	0.05	0.13	0.10	5.0
Ba (Sol.)	0.03	0.06	0.05	0.04	0.09	0.07	-
Cd (Tot.)	<0.01	<0.01	-	<0.01	<0.01	-	0.05
Cd (Sol.)	<0.01	<0.01	-	<0.01	<0.01	-	-
Cu (Tot.)	<0.01	<0.02	0	0.01	0.04	0.02	0.02
Cu (Sol.)	<0.01	0.02	-	<0.01	<0.01	-	-
Cr (Tot.)	<0.01	<0.01	-	<0.01	<0.01	-	-
Cr (Sol.)	<0.01	<0.01	-	<0.01	<0.01	-	-
Fe (Tot.)	0.43	2.0	0.92	0.82	1.9	1.3	1.0
Fe (Sol.)	0.01	0.12	0.05	0.01	0.32	0.07	-
Li (Tot.)	<0.01	<0.01	-	<0.01	<0.01	-	-
Li (Sol.)	<0.01	<0.01	-	<0.01	<0.01	-	-
Mn (Tot.)	0.26	1.7	0.78	0.44	3.6	1.8	1.0
Mn (Sol.)	0.13	1.6	0.53	0.22	3.1	1.5	-
Ni (Tot.)	<0.05	<0.05	-	<0.05	<0.05	-	1.0
Ni (Sol.)	<0.05	<0.05	-	<0.05	<0.05	-	-
Pb (Tot.)	<0.05	<0.05	-	<0.05	<0.05	-	0.1
Pb (Sol.)	<0.05	<0.05	-	<0.05	<0.05	-	-
Sr (Tot.)	0.08	0.22	0.16	0.15	0.34	0.25	-
Sr (Sol.)	0.08	0.22	0.16	0.15	0.32	0.25	-
Zn (Tot.)	0.01	0.02	0.02	0.02	0.04	0.03	1.0
Zn (Sol.)	<0.01	0.02	-	<0.01	0.02	-	-

Table 4-7. Water Quality Data for Case Study Site 1
*All concentrations expressed as mg/L unless otherwise noted.

	7/8/86 CSOBQ	7/29/86 CSOA	CSOB	8/26/86 CSOB
NH3-N	ISG	3.95	1.54	IS
Boron	IS	2.97	3.22	IS
Bromide	2.8	12.5	17.5	3.6
Chloride	765	8,250	3,860	975
Conductance (microsiemens)	IS	IS	IS	IS
Grease and Oil	IS	72	62	76
Hardness (as CaCo3)	251	2,120	1,140	634
Iodide	<0.5	<0.5	<0.5	IS
Nitrate & Nitrite	0.57	0.88	1.68	0.9
Phosphate	IS	27.9	18.7	1.9
Sulfate	43	108	68	25
Total Alkalinity	35	6.4	6.4	6.4
Total Dissolved Solids	1,700	9,300	14,900	1,490
Total Kjeldahl Nitrogen	IS	IS	IS	IS
Total Suspended Solids	28,500	100,000	71,300	46,900
Total Volatile Soldis	1,560	3,870	2,580	1,380
Na (Tot.)	500	1,360	800	210
K (Tot.)	12	50	36	28
Ca (Tot.)	105	580	330	140
Ca (Sol.)	69	490	270	IS
Mg (Tot.)	48	280	130	68
Mg (Sol.)	20	180	92	IS
Ba (Tot.)	2.0	10.4	5.6	1.3
Ba (Sol.)	0.13	1.3	0.79	IS
Cd (Tot.)	<0.01	0.04	0.02	0.0
Cd (Sol.)	<0.01	0.02	0.01	IS
Cu (Tot.)	0.64	4.5	2.9	3.0
Cu (Sol.)	0.10	0.46	0.11	IS
Cr (Tot.)	0.18	0.64	0.44	0.4
Cr (Sol.)	<0.01	<0.01	<0.01	IS
Fe (Tot.)	31	125	112	86
Fe (Sol.)	0.02	0.23	0.12	IS
Li (Tot.)	0.09	0.54	0.44	0.2
Li (Sol.)	<0.01	<0.01	<0.01	IS
Mn (Tot.)	5.6	37	17	5.2
Mn (Sol.)	0.79	17	6.2	IS
Ni (Tot.)	0.25	1.0	0.72	0.6
Ni (Sol.)	0.05	0.30	0.10	IS
Pb (Tot.)	0.26	1.5	0.98	0.5
Pb (Sol.)	0.09	0.20	0.08	IS
Sr (Tot.)	1.7	7.5	3.7	1.2
Sr (Sol.)	0.42	7.2	3.6	IS
Zn (Tot.)	0.78	1.9	1.1	0.8
Zn (Sol.)	0.05	0.36	0.14	IS

G IS - Insufficient Sample.
+ CSOA and CSOB represent two gullies sampled at Case Study Site 1.

REFERENCES

American Public Health Association, 1980, Standard methods for the examination of water and wastewater: 15th ed. Washington, D.C., 1134 p.

Bhowmik, Nani G., J. Rodger Adams, Allen P. Bonini, Anne M. Klock, and Misganaw Demissie, 1986, Sediment loads of Illinois streams and rivers: Illinois State Water Survey Report of Investigation 106, Champaign, Illinois.

Federal Inter-Agency Sedimentation Project, 1981, Catalog: Instruments and reports for fluvial sediment investigations: Minneapolis, Minnesota.

Guy, Harold P., 1969, Laboratory theory and methods for sediment analysis: Chapter C1, Book 5, Techniques of Water-Resources Investigations of the United States Geological Survey: U.S. Government Printing Office, Washington, D.C.

Guy, Harold P., and Vernon W. Norman, 1970, Field methods for measurement of fluvial sediment: Chapter C2, Book 3, Techniques of Water-Resources Investigations of the United State Geological Survey, U.S. Government Printing Office, Washington, D.C.

Kothandaraman, V., R. L. Evans, N. G. Bhowmik, J. B. Stall, D. L. Gross, J. A. Lineback, and G. R. Dreher, 1977, Fox Chain of Lakes Investigation and Water quality Management Plan: Cooperative Resources Report 5, Illinois State Water Survey and Illinois State Geological Survey, Urbana, IL, 200 p.

Terzaght, Karl, and Ralph B. Peck, 1967, Soil mechanics in engineering practice: John Wiley & Sons, Inc., New York, New York.

U.S. Geological Survey, 1986, Water resources data for Illinois, Volume 1 Illinois except Illinois River Basin: Water Data Report IL-86-1, Urbana, Illinois.

U.S. Geological Survey, 1979, Methods for Determination of Inorganic Substances in Water: Book 5.

Section 5

EFFECTS OF OIL BRINES UPON BENTHIC COMMUNITIES IN BUCK CREEK, CLAY COUNTY, ILLLINOIS

by

Allison R. Brigham and Edward A. Lisowski

INTRODUCTION

In 1983, the Greater Egypt Regional Planning and Development Commission concluded that the oil field brine problem in Illinois affected 45 percent of the counties. At that time only three counties had been surveyed to assess the extent and nature of brine damage and its affect upon soil and water (GERPDC, 1983). To illustrate the potential for damage to surface waters, data from Jefferson County revealed that 69 percent of sites with brine-damaged acreage occurred within 0.25 mi or less of a stream and 55 percent occurred within 500 ft or less (GERPDC, 1982). Such contamination by oil brines may add boron, bromide, chloride, heavy metals, oil and grease, sodium, sulfate, suspended and dissolved solids, to surface waters.

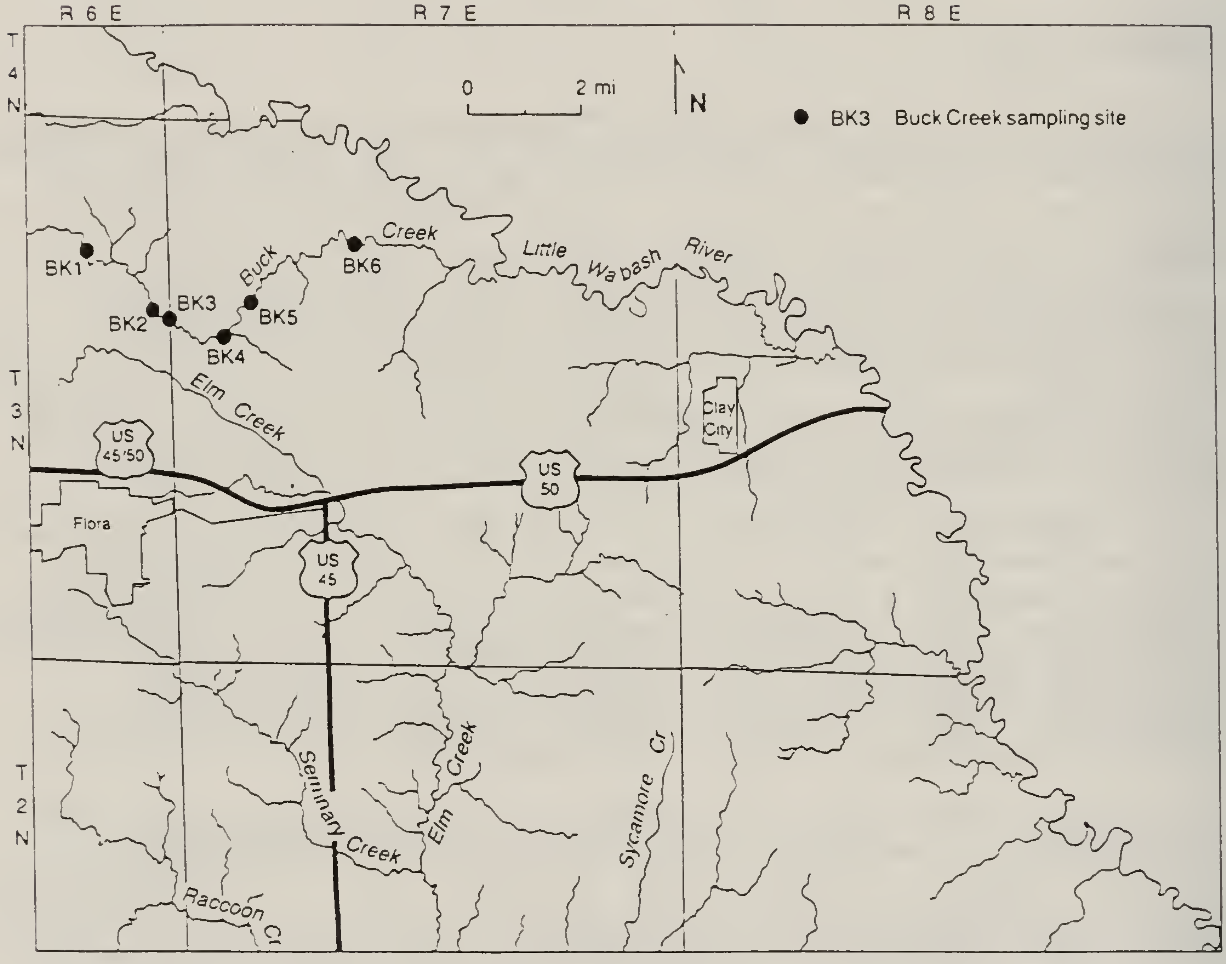
A method of assessing the impact of a particular pollutant upon surface waters is to examine the biological communities. Stream community structure integrates long-term environmental factors and critical conditions of short duration. The structure and composition of benthic macroinvertebrate communities are sensitive to perturbations or alterations in the abiotic environment and, in general, their response to environmental stress is expressed as lower species diversity.

During 1976 and 1977, the benthic macroinvertebrate communities of the Wabash River watershed were studied by the Illinois Natural History Survey (Brigham 1979). Biological and associated chloride data from approximately 500 sites from that study were reexamined to assess the potential for water quality degradation resulting from oil brine contamination of streams.

As part of the present inter-Survey oil brine research, Buck Creek, a tributary of the Little Wabash River in southeastern Clay County, was selected for more detailed investigation. This watershed typifies hydrologic conditions and the level of oil field activities occurring throughout southeastern Illinois. Specifically, there were known cases of brine contamination; numerous, yet localized, oil fields; available shallow groundwater; and the interest and support of the local community.

Six sites were sampled in Buck Creek during August and October, 1986 (figure 5-1). Station 1 corresponded to the upstream surface water quality site monitored by the State Water

Figure 5-1. Location of sampling stations in the Buck Creek watershed Clay County, Illinois.



Survey (see Section 4); station 6 corresponded to their downstream site. Since benthic macroinvertebrate communities may vary greatly temporally and spatially in response to variables other than water quality, four additional sites were included to ensure reliability.

BENTHIC MACROINVERTEBRATES AND CHLORIDE IN THE WABASH RIVER BASIN 1976-1977

In 1976 and 1977, approximately 900 sites were sampled in the Wabash River basin in southeastern Illinois to assess existing stream quality conditions based upon the composition of the benthic macroinvertebrate communities observed. The effects of approximately 200 point sources, agricultural non point sources of pollution, and the presence of oil fields in the basin were assessed (Brigham 1979).

These sites were evaluated using the Illinois Environmental Protection Agency's (IEPA) station classification system (a tolerance-status approach described in Appendix 5-A). Water samples from 477 stations were analyzed for chloride to assist in determining what, if any, effect the presence of oil well operations in the watershed had upon stream quality. Major river basins within the watershed and the number of sites sampled within each are illustrated in figure 5-2; summary benthic macroinvertebrate, chloride, and stream order data are included in Appendix 5-B.

Sites having both benthic macroinvertebrate and chloride concentration data were re-examined. Sites were assigned to one of six categories based upon the chloride concentration, defined in table 5-1.

The IEPA general water quality standard for chloride is 500 mg/L; 458 sites or 96 percent met this stream standard. In fact, nearly 70 percent of all chloride concentrations observed were less than or equal to 50 mg/L. Only 19 sites (4 percent) exceeded the 500-mg/L stream standard.

When a stream is stressed, as might occur from exposure to oil brine contamination through discharge or surface runoff, the biological communities are affected and frequently altered. Generally, the part of its fauna that cannot tolerate the stress (intolerant species) disappears while species less sensitive to the particular change (generally tolerant, but may include some moderate and facultative) are favored or unaffected.

A number of biotic index or classification schemes have been proposed to illustrate the results of such stress or impacts. The one used by IEPA is based upon the percentages of organisms assigned to each of the four tolerance status groups

Figure 5-2. Distribution of sites of sampled for chloride in the Wabash River watershed in Illinois.

Table 5-1

Distribution of Sites Sampled for Benthic Macroinvertebrates Within Six Categories of Chloride Concentrations

Category	Chloride Concentration	Number of Sites	Percent
1	Cl < 50 mg/L	333	69.8
2	100 mg/L < Cl > 50 mg/L	64	13.4
3	250 mg/L < Cl > 100 mg/L	44	9.2
4	500 mg/L < Cl > 250 mg/L	17	3.6
	IEPA General Water quality Standard = 500 mg/L		
5	1,000 mg/L < Cl > 500 mg/L	8	1.7
6	Cl > 1,000 mg/L	11	2.3
	Total:	477	100.0

(intolerant, moderate, facultative, tolerant; defined in Appendix 5-A). The corresponding benthic macroinvertebrate data from the 474 sites (biological data unavailable for three chloride sampling sites) were examined to see if station classifications were generally affected by increasing concentrations of chloride. Results are summarized in table 5-2.

Stations classified as balanced or unbalanced are considered to be less disturbed by adverse environmental impacts than those classified as semi-polluted or polluted. Group 1 (sites with chloride concentrations < 50 mg/L) appeared to have more diverse benthic macroinvertebrate populations. This was reflected in its having 67 percent of its sites classified as either balanced or unbalanced rather than the 45 to 55 percent of sites in groups 2 through 6. From these data, the effect of chloride concentration appeared to be at 50 mg/L rather than the 500 mg/L general water quality standard (table 5-2).

If increasing concentrations of chloride contribute to degradation of water quality, one expected outcome might be a significant reduction in the number of organisms classified as intolerant among sites with increasing chloride concentration. The mean numbers of organisms assigned to each of the four tolerance status groups is summarized in table 5-3.

Table 5-2

Stream Classifications Derived from Benthic Macroinvertebrate Data at Sites Sampled for Chloride

Chloride Category	Number of Sites	Balanced/ Unbalanced (%)	Semi-Polluted/ Polluted (%)
1	332	224 (67)	108 (33)
2	62	29 (47)	33 (53)
3	44	24 (55)	20 (45)
4	17	8 (47)	9 (53)
IEPA General Water Quality Standard = 500 mg/L			
5	8	4 (50)	4 (50)
6	11	5 (45)	6 (55)
Total:	474	294 (62)	180 (38)

Table 5-3

Distribution of Benthic Macroinvertebrates Among Four Tolerance Status Groups Within Six Categories of Chloride Concentrations

Chloride Category	Number of Sites	Mean Number of Individuals				
		Intolerant	Moderate	Facultative	Tolerant	Total
1	332	17	13	23	31	84
2	62	12	12	20	70	114
3	44	12	11	15	52	90
4	17	8	8	16	34	66
5	8	10	11	25	41	86
6	11	8	5	19	50	82
	474	15	12	22	39	88

A linear regression with chloride as the independent variable and the number of intolerant organisms as the dependent variables was performed. The numbers of intolerant (or sensitive) organisms decreased significantly ($P > 0.001$) with increasing chloride concentration.

The presence or absence of a species can also be influenced by factors other than the concentration of a particular contaminant such as chloride (e.g., its presence or absence in the species pool available for colonization, the season of collection, flow conditions at the time of sampling, chance, the availability of the appropriate microhabitat, and longitudinal position in the stream continuum).

One additional variable was determined for each site to distinguish (partially) naturally occurring changes in community structure from those occurring in response to the presence of increasing chloride concentration.

This variable was stream order and ranged from 1 (extreme headwaters) to 8 (Wabash River). A linear regression with stream order as the independent variable was significant ($P > 0.0001$) for intolerant organisms.

To identify the contributions of chloride and stream order, a linear regression with two independent variables (chloride concentration and stream order) was performed. For intolerant organisms both chloride concentration and stream order were significant ($P > 0.001$):

$$\text{\# intolerant } [\ln (X + 1)] = - 0.15 [\ln (\text{chloride conc} + 1)] + 0.76 [\ln (\text{stream order} + 1)] + 1.74$$

Although fewer numbers of organisms classified as intolerant occurred at sites having higher concentrations of chloride, the importance of stream order in the equation illustrates the environmental complexities that influence the kinds and numbers of species which may occur at a given site. Tolerance-status based biotic index schemes, as applied to these data, rely upon the presumed knowledge of the sensitivities of individual species to widely ranging environmental variables. The pool of species for which such information is known is limited. Assumptions are made which are frequently limited or erroneous.

The tolerance-status approach as a tool to describe environmental impact may be more appropriate in regions of the country where the basin lithology results in ion-depauperate, weakly buffered streams and rivers. In such areas the environmental impact of pollutants may be more pronounced. However, it is inappropriate in Illinois where the greater buffering capacity of the water and the apparent wide tolerance of native Illinois species to considerable variations in water quality affords some protection against degradation.

This suggests that, even in the presence of urban, agricultural non-point pollution, or oil brine runoff, the absence of suitable substrate might be more of a limiting factor to invertebrate colonization than we suspect. Extensive channelization of natural streams, agricultural practices which reduce the water-storage capacity of floodplains and transport large quantities of sediment to streams, and the use of streams as conduits to transport stormwater and the wastes of urban areas have either removed or covered much of the natural stream substrates in Illinois.

WATER QUALITY IN BUCK CREEK

The State Water Survey analyzed surface water at 2-week intervals from 3 April through 29 July 1986 at two sites in Buck Creek: station 1, upstream, and station 6, downstream (Section 4). For this statistical analysis, one (8 July 1986) of their nine collections was eliminated since the upstream site had no flow.

Of 34 chemical variables that were monitored, nine showed significant differences between upstream and downstream areas in Buck Creek (table 5-4). These variables include the major anions and cations which constitute dis-solved solids: chloride and sulfate, and sodium, calcium, and magnesium. Specific conductance, a measure of the ability of water to carry an electric current, is often frequently expressed as total dissolved ionizable solids. In most aquatic systems, total dissolved solids is roughly equivalent to total dissolved ionizable solids. Although these concentrations did not exceed any applicable IEPA general water quality standards, all nine variables in table 5-5 reflected sizeable increases in concentration from upstream to downstream, suggesting contributions of runoff or groundwater that were brine-rich.

BENTHIC MACROINVERTEBRATE COMMUNITIES IN BUCK CREEK

Four thousand four hundred thirty-two individuals representing 97 taxa were collected from the six sampling sites in Buck Creek during August and October. Kinds and numbers of benthic macroinvertebrates collected are summarized in Appendix 5-C. These results, in general, illustrate a diverse community representative of an average, low-gradient, slowly flowing, sand/gravel-to-silt substrate stream in central Illinois.

Three major groups of benthic macroinvertebrates were collected: (1) aquatic worms and leeches (Annelida); (2) scuds,

Table 5-4

Surface Water Quality Variables Showing
Significant Differences Between Upstream and Downstream
Sites in Buck Creek

Variable[a,b]	Station 1 (upstream)	Station 6 (downstream)
Chloride	93.5	174
Specific Conductance (umho/cm)	646	1,011
Hardness (as $CaCO_3$)	170	249
Sulfate (as SO_4)	66.8	117
Dissolved Solids	386	626
Suspended Solids	22	40
Sodium	84.9	144
Calcium	46.1	63.6
Magnesium	11.9	20.4

[a] as mg/L unless other units are indicated; data provided by State Water Survey (see Section 4)

[b] means significantly different at the 0.05 level

isopods, crayfishes and prawns (Crustacea); and (3) seven orders of aquatic and semi-aquatic insects. Aquatic and semi-aquatic insects predominated, both in number of taxa and individuals. Among insects, water beetles were the most diverse (28 taxa), followed by aquatic and semi-aquatic true bugs (17 taxa) and dragon-flies and damselflies (13 taxa). Aquatic worms were especially diverse (19 taxa).

Most species were not numerically abundant. Sixty-two species (nearly 64 percent) were represented by 10 or fewer individuals (table 5-5). This numerical dominance of uncommon species is not unusual, although it is often mistakenly believed to be a feature of unimpacted or unaltered ecosystems only. In most communities there are usually a few numerically dominant species and a much larger number of uncommon ones. In an investigation of the physical, chemical, and biological variables of streams receiving mine drainage containing high concentrations of total dissolved solids, Brigham and Stegner (1982) observed that 142 of 271 species from 50 sampling sites were represented by five or fewer individuals.

Table 5-5

The Number of Individuals of Each Species Collected and Related Summary Statistics

Total Number of Individuals Collected[a]	Number of Species	Cumulative Number of Species	Percent of Total	Cumulative Percent of Total
1	23	23	23.7	23.7
2	5	28	5.2	28.9
3	11	39	11.3	40.2
4	3	42	3.0	43.2
5	6	48	6.2	49.4
6 to 10	14	62	14.4	63.8
11 to 20	13	75	13.4	77.2
21 to 30	6	81	6.2	83.4
31 to 40	0	81	-	-
41 to 50	1	82	1.0	84.4
51 to 100	5	87	5.2	89.6
101 to 150	2	89	2.1	91.7
151 to 200	2	91	2.1	93.8
201 to 250	2	93	2.1	95.9
>250	4	97	4.1	100.0

[a] Benthic macroinvertebrate data are summarized in Appendix 5-C.

Twelve species were ubiquitous, occurring at all sites in Buck Creek. These included the aquatic worms *Dero digitata*, *Dero nivea*, and *Aulodrilus pigueti*; the crustaceans *Hyalella azteca* and *Palaemonetes kadiakensis*; the mayfly *Caenis*, the water boatmen *Sigara modesta* and *Trichocorixa calva*; and the water beetles *Hydroporus* sp. *A*. *Dubiraphia Quadrinotata*, *Peltodytes duodecimpunctatus*, and *Scirtes*.

At the other extreme, 33 species occurred at only one of the six sites. These were widely represented among all the major taxonomic groups of organisms: six species of aquatic worms, one leech, one crustacean, one mayfly, two dragonflies, eight aquatic or semi-aquatic true bugs, one dobsonfly, two caddisflies, and 11 water beetles.

If these results were evaluated using the IEPA stream classification system discussed above, Buck Creek would be classified overall as unbalanced since more than 10 percent of the 4432 individuals collected could be classified as intolerant. The upstream site at station 1 was consistently classified as unbalanced and stations 3, 4, and 5 as semi-polluted (both August and October collections). Stations 2 and 6 were classified as semi-polluted in August and unbalanced in October.

Mean chloride concentrations in Buck Creek ranged from 93.5 mg/L upstream at station 1 to 174 mg/L downstream at station 6 (table 5-5). These concentrations place Buck Creek in chloride groups 2 and 3, respectively (table 5-1). These groups were approximately one-quarter of the sites sampled in the Wabash River watershed. In terms of stream classifications, conditions in Buck Creek could be interpreted as being generally poorer than reported for other group 2 and 3 sites in the Wabash River watershed. In Buck Creek unbalanced stations were only 33 percent and semi-polluted 67 percent compared to 47 to 55 percent unbalanced and 45 to 53 percent semi-polluted for the entire watershed (table 5-2).

Relationships Among Benthic Macroinvertebrate Communities

Patterns of similarity among the biological communities at the various sampling stations in Buck Creek were examined using cluster analysis. Results, illustrated by the dendrograms in figure 5-3, are presented separately by date.

In cluster analysis, stations are grouped according to the similarity of aquatic communities present, with lower values indicating greater similarity. The strength of the similarity of stations in a cluster is shown by the proximity of the branching of the dendrogram, i. e., the nearer to 0 the vertical bars joining sites or groups of sites together, the more similar the biological communities. The advantage of the cluster analysis is that it eliminates making value judgements upon individual species by avoiding the ranking of one species as inherently better than another, as in the tolerance-status approach used in many biotic-index schemes. Cluster analysis produces a less biased assessment of the relationships among sampling sites and, therefore, a less biased evaluation of the extent of impact of a particular activity in the watershed.

There were two major groups of stations in the dendrograms illustrating the results of the August and October benthic macroinvertebrate collections from Buck Creek: stations 2, 3, and 5, and stations 4 and 6. The collections at station 1 varied seasonally, clustering with stations 2, 3, and 5 in August and with stations 4 and 6 in October. These results closely followed the relationships demonstrated among stations for species diversity (figure 5-3). Expressing community structure as species diversity condenses biological information into a single numerical value. It assumes that greater diversity of aquatic life implies greater structural and functional stability of the ecosystem.

Species diversity indices and the cluster analyses integrated all data for 97 species in 12 collections. Among those data, eight taxa illustrate some important general species differences among the two major clusters. Station 1 was shown separately in table 5-6 since it was more closely allied to the cluster of stations 2, 3, and 5 in August and stations 4 and 6 in October.

Table 5-6

Differences in Species Composition Among Clusters

Taxa	STATIONS		
	2, 3, 5	1	4, 6
Dero digitata	common	common	very abundant
Hyalella azteca	abundant	common	very abundant
Palaemonetes kadiakensis	common/abundant	uncommon	common/abundan
Caenis	common	common	very abundant
Ischnura posita	uncommon/common	very abundant	uncommon
Corixidae	common/abundant	common	very abundant
Haliplidae	common	very abundant	uncommon
Scirtes	very abundant	uncommon	
uncommon/common			

Benthic macroinvertebrate communities in Buck Creek were more diverse than might otherwise be expected from such a small stream. The total number of taxa observed ranged from 25 to 48. Species diversity was similarly high, with only one station/date below 3.4 (figure 5-3, Appendix 5-C). In such small streams, seasonality and water level, and the diversity of microhabitats available for colonization frequently limit the number of species.

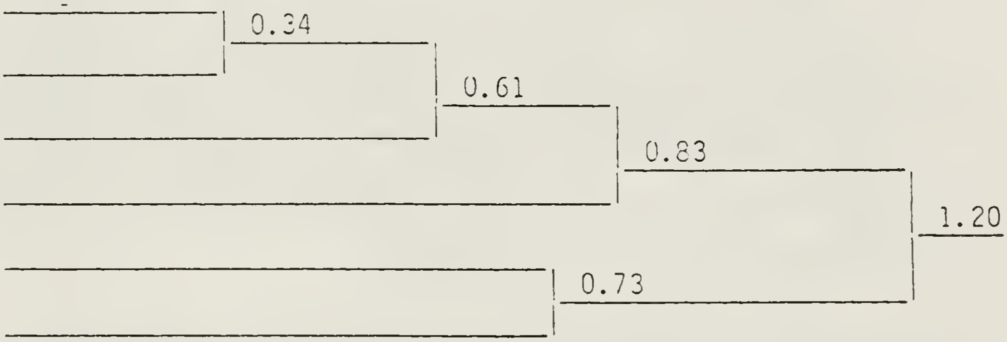
Buck Creek experiences extreme fluctuations in water level. During the summer the upper portions (upstream of station 1) were dry or discontinuous, with flow absent and water reduced to small pools. Downstream channelized portions of the stream were long, stagnant pools with little observable flow. Benthic biological communities in small streams like Buck Creek are composed predominantly of species with wide ecological tolerances that

Figure 5-3. Species diversity and dendrograms illustrating clustering analyses of benthic macroinvertebrates in Buck Creek.

Average Distance Between Clusters

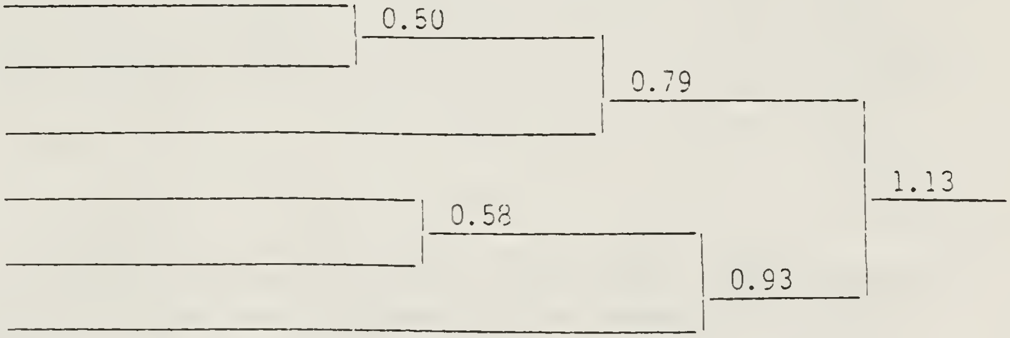
August

Site	Species Diversity
2	4.2
3	3.8
5	3.9
1	4.4
4	3.6
6	3.5



October

Site	Species Diversity
2	3.5
5	3.5
3	2.5
1	3.8
4	3.9
6	3.4



function as "pioneers" (i.e., species that colonize quickly by moving into areas recently modified and unoccupied by other species). Such species are widespread in Illinois and are common components of small streams which occasionally become discontinuous or dry and frequently have little or no microhabitat diversity.

In general, proceeding from source to mouth with increasing stream order, streams become more diverse as more microhabitats become available for colonization and exploitation. In the absence of a constituent in the water which would be toxic to aquatic life, the physical nature of the stream may be of more importance in determining the benthic macroinvertebrate colonizers than the concentration of any water quality variable.

No water quality variables were detected that might be limiting or toxic to aquatic life (i. e., none exceeded the IEPA general water quality standards). The limited microhabitat diversity, however, was apparent in Buck Creek. The stream had been historically channelized, rocky riffle areas were absent along most of its length (only apparent at station 1), the substrate was primarily composed of fine or soft sediments (e.g., sand, clay, silt), and undercut banks, log jams, and other microhabitats were uncommon.

The importance of microhabitat diversity was demonstrated in a study of physical, chemical, and biological variables of streams receiving mine drainage containing high total solids concentrations (Brigham and Stegner 1982.) Although the distribution and abundance of benthic macroinvertebrates suggested strongly that the observed differences among benthic communities were attributable to higher concentrations of total dissolved solids, subsequent analysis using measurements of microhabitat diversity showed that the distribution and abundance of species was not governed solely by water quality. Instead stream order and microhabitat development were significantly more important than any water quality variable tested.

Water quality and Species Diversity

Water quality deteriorated from upstream to downstream in Buck Creek. Chloride, sulfate, sodium, calcium, magnesium, specific conductance, hardness, and dissolved and suspended solids all reflected sizeable increases in concentration from upstream (station 1) to downstream (station 6), suggesting contributions of runoff or groundwater to Buck Creek that were brine-rich (table 5-4).

The benthic macroinvertebrate community of station 1 differed from that observed downstream at station 6. Species diversity decreased from upstream to downstream, declining from 4.4 to 3.5. This is especially apparent in the dendrogram illustrating the August collections (figure 5-3). Although the communities of stations 2, 3, and 5 were more similar to station 1 than either stations 4 or 6, station 1 was still rather distinct. It occupied an intermediate position between the two clusters of stations.

Since the diversity of microhabitats available for colonization declined downstream in Buck Creek and no water quality variable violated existing IEPA general water quality standards, the absence of a variety of microhabitats was considered to be more limiting to benthic macroinvertebrate diversity than degraded water quality.

To verify that water quality was of more limited importance in determining the kinds and numbers of benthic macroinvertebrates observed at the upstream and downstream sites in Buck Creek, a stepwise regression was performed. In this analysis, species diversity for stations 1 and 6 in August was used as the dependent variable. Only August biological data were used because the available surface water quality data were collected from April through July. Results are summarized in table 5.7.

Table 5-7

Stepwise Regression Procedure for Species Diversity[a]

Step	Variable	Variance (percent)	Probability > F
1	Magnesium	51.4	0.0018
2	Suspended Solids	73.5	0.0058
	Magnesium		0.0050
3	Ammonia	83.7	0.0179
	Suspended Solids		0.0004
	Magnesium		0.0080

[a] Alpha level for entry and exit = 0.15. The model selected from the 20 water quality variables described in Appendix 5-A; species diversity from stations 1 and 6 in August.

In this analysis no variable that would be unambiguously associated with contributions of brine was selected as an important predictor of species diversity. Ammonia, suspended solids, and magnesium would account for nearly 84 percent of the variance in predicting species diversity. Although the distribution and abundance of benthic macroinvertebrates suggested that the observed differences among upstream and downstream benthic communities were attributable to higher concentrations of variables associated with oil brine, regression analysis showed that the distribution and abundance of species was not governed solely by water quality. Instead, another variable such as microhabitat development was likely more influential in Buck Creek.

LITERATURE CITED

Brigham, A. R., 1979, An assessment of the water quality of the Wabash River basin derived from a biological investigation: Unpublished report to the Illinois Environmental Protection Agency. vi + 297 pp.

Brigham, A. R., W. U. Brigham, and A. Gnilka, 1982, Aquatic insects and oligochaetes of North and South Carolina: Midwest Aquatic Enterprises, Mahomet, Illinois. 837 pp.

Brigham, A. R., and S. Stegner, 1982, Comparative study of physical, chemical, and biological variables of streams and lakes receiving mine drainage containing high total dissolved solids: Unpublished report to the Mine-Related Pollution Task Force. iv + 53 pp.

Greater Egypt Regional Planning and Development Commission, 1982, An overview of oil field brine problems in three Illinois counties: Publ. No. GERPDC-82-626. iii + 52 pp. + 9 individually number appendices.

Greater Egypt Regional Planning and Development Commission, 1983, Procedures for evaluation and reclamation of oil field brine damage with recommendations for individual, local and state actions: 1983 oil field brine special project report. Publ. No. GERPDC-83-643. 24 pp.

Secton 6 INVESTIGATIONS OF THE ORIGIN OF DOMESTIC WELL WATER CONTAMINATION BY SALINE WATERS

by

John D. Steele and Barbara R. Cline

GEOCHEMICAL CHARACTERIZATION OF BRINES

Oil field brines are highly concentrated (total dissolved solids reaching 160,000 mg/L or more) aqueous solutions which also contain high concentrations of potassium, calcium, and magnesium. The brines of the Illinois Basin have been characterized as calcium chloride brines due to their relatively high concentrations of calcium when compared to halite derived brines or seawater.

Table 6-1 is a summary of data for major constituents (Na+K, Ca, Mg, and Cl) in oil field brines for various formations in Clay County and the counties surrounding the study area (Crawford, Edwards, Effingham, Fayette, Jasper, Lawrence, Marion, Richland, Wabash, and Wayne). The data are taken from Meents et al. (1952).

Observed differences in the compositions of brines from various depths within the Illinois Basin are explained by Nesbitt (1985) as reflecting the geochemical origin of the brines. The chemical compositions of the brines, according to Nesbitt (1985), are controlled by mineral transformations involving the equilibrium of the brines with kaolinite, illite, a sodic clay mineral, and calcite. As proposed by Graff et al., (1966), during the concentration of the brines by ultrafiltration, kaolinite and calcite are consumed while a sodic clay is produced, resulting in a decreased Na/Ca ratio of the brine relative to the precursor solution. When the brines are mixed with near-surface waters and are diluted, calcite and kaolinite are produced while the sodic clay is consumed, causing an increase in the Na/Ca ratio of the brine. Evidence for this behavior can be seen in table 6-2, which shows concentration ratios of Na/Cl, Ca/Cl, Mg/Cl, and Na/Ca for the data from Meents et al. (1952).

The variations in composition of Clay County oil field brines relative to the rest of the Illinois Basin can best be explained by the correlation of composition with depth (both within and between formations) and the nearness of Clay County to the center or deepest part of the basin. The brines of Clay County often have as much as 30 percent higher TDS concentrations relative to the rest of the Illinois Basin although this pattern varies from formation to formation. Tar Springs concentrations are highest in Clay County and to the southwest, and become less concentrated to the north and east. Cypress brines

Table 6-1

Summary of Brine Data from Meents et al. (1952)

Formation and Location		Na & K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)
Pennsylvanian					
Clay Co.		----	----	----	----
Others1(8)	mean	9290	331	201	14251
	std. dev.	5079	236	116	8989
Mississippian					
Tar Spring					
Clay Co.(2)	mean	42691	3876	1189	75896
	std. dev.	163	1	45	437
Others(4)	mean	32446	3177	626	56468
	std. dev.	3428	482	414	6600
All data	mean	35861	3410	813	62944
	std. dev.	5920	519	434	11262
Cyress					
Clay Co.(7)	mean	38187	3060	1216	68467
	std. dev.	5007	1148	143	9504
Others(30)	mean	36565	3975	1260	66890
	std. dev.	4136	831	365	7720
All data	mean	36872	3801	1251	67188
	std. dev.	4286	953	333	7866
Aux Vases					
Clay Co.(5)	mean	43610	4871	1317	79155
	std. dev.	3461	622	183	5746
Others(13)	mean	44044	5877	1475	81692
	std. dev.	4847	715	378	8522
All data	mean	43924	5598	1431	80987
	std. dev.	4410	817	338	7772
Ste. Genevieve					
Clay Co.(17)	mean	44334	5657	1535	82753
	std. dev.	3547	1251	624	5703
Others(38)	mean	38531	5356	2008	73697
	std. dev.	4167	1177	392	7335
1					
All data	mean	40324	5449	1863	76496
	std. dev.	4791	1197	519	8021

[1]Crawford, Edwards, Effingham, Fayette, Jasper, Lawrence, Marion, Richland, Wabash, and Wayne Counties.

Table 6-2

Concentration Raios of Selected Constituents
in Oil Field Brines
(Meents et al., 1952)

Formation	Na/cl	Ca/Cl	Mg/Cl	Na/Ca
Pennsylvanian	0.685	0.0246	0.0166	175.2
Tar Springs	0.575	0.0526	0.0135	11.1
Cypress	0.555	0.0559	0.0189	10.4
Aux Vases	0.547	0.0680	0.0175	8.2
Ste. Genevieve	0.527	0.0714	0.0247	7.8

concentrations are highest west of Clay County and the concentration decreases from west to east. Aux Vases brines concentrations are highest in central Clay County and to the south and west, and show a decrease to the northwest, north, and east. Ste. Genevieve brines are more concentrated in southern Clay County and to the south, and are less concentrated to the west, north, and east.

It can be seen from table 6-1 that, for each constituent, there is a general increase in concentration with increasing depth (age) of formation. This trend is most obvious between the Pennsylvanian and Mississippian formations where the mean concentrations of the major constituents are significantly lower in the Pennsylvanian brines than they are in the Mississippian brines. These differences in composition between formations will be used to differentiate between brines from different sources.

There are numerous examples in the literature of the application of geochemical methods to differentiate brines from different sources. Collins (1978) studied the geochemical relationships between high iodide brines and the geologic strata of Oklahoma. Rittenhouse (1967) used the relationship between bromide and total dissolved solids to subdivide oil field brines into at least five groups based on their origins. More recently, Whittemore (1984a and 1984b) used bromide/chloride and iodide/chloride ratios to identify sources of contamination in aquifers of Kansas.

SAMPLE LOCATIONS AND DATA PRESENTATION

Thirty-one samples of oil field brines were collected from sites shown in figure 6-1. The samples were collected from producing oil wells from the following formations: Tar Springs, Cypress, Aux Vases, McClosky, and Salem. Two samples consisted almost entirely of oil with insufficient brine volume for analysis. The producing zone of one brine sample could not be identified. The analytical data for the brines for which there was sufficient sample volume are shown in table 6-A1 of Appendix 6-A.

INTERELEMENT RELATIONSHIPS

In order to examine the interelement patterns associated with these brines, a matrix of correlation coefficients between each element was produced and used to group the elements into clusters with similar patterns of behavior using cluster analysis (see figure 6-2). In the cluster analysis procedure, each constituent is grouped or clustered with those remaining constituents with which they show a similar pattern of behavior. Each remaining constituent is either assigned to an already existing group with which it most closely resembles or it forms its own group. This procedure is continued until all the constituents are assigned to groups.

As expected, sodium and chloride, comprising 95 percent of the brine, were significantly correlated (0.85). The minor constituents calcium, magnesium, and strontium also showed significant, although lower, correlations with chloride. Sodium showed only one other significant correlation, that with calcium. Calcium, magnesium, potassium, and lithium as a group showed relatively high interelement correlations, with potassium and lithium showing the highest correlation of any of the elements (0.95). Strontium correlates weakly with magnesium and chloride but not with calcium. Iron does not show any significant correlations.

The cluster dendrogram shown in figure 6-2 combines the elements into mutually correlated groups. The measure of similarity decreases from left to right so that clusters shown to form to the left in the dendrogram possess greater similarity than those clusters which form to the right. The clustering of the elements shown in Figure 6-2 appears to follow basic chemical principles. The Na-Cl cluster reflects their dominant influence in the composition of the brines. The alkali elements, K and Li, form a cluster, and the alkaline earth elements, Ca and Mg, form a cluster. These three clusters then form a large six element cluster. Strontium and iron, which show the weakest interelement correlations do not fall into any particular grouping, although strontium does correlate weakly with magnesium and chloride.

Another method of looking at the interelement relationships is with factor analysis, a statistical technique which tries to identify a relatively small number of underlying factors which explain relationships among a large number of variables. A discussion of factor analysis is beyond the scope of this report

Figure 6-1. Location of Mississippian Age Formation Water Sample Sites.

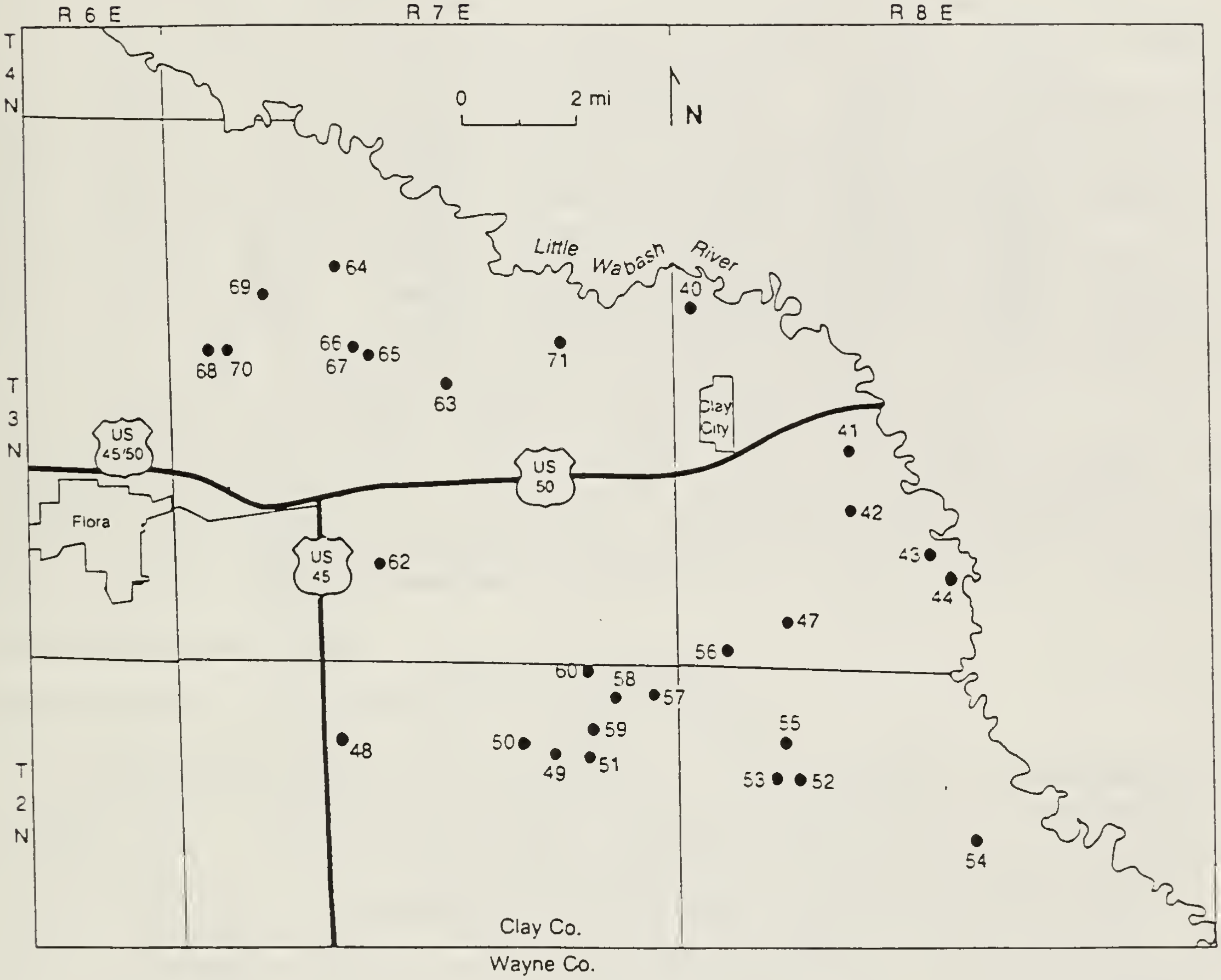


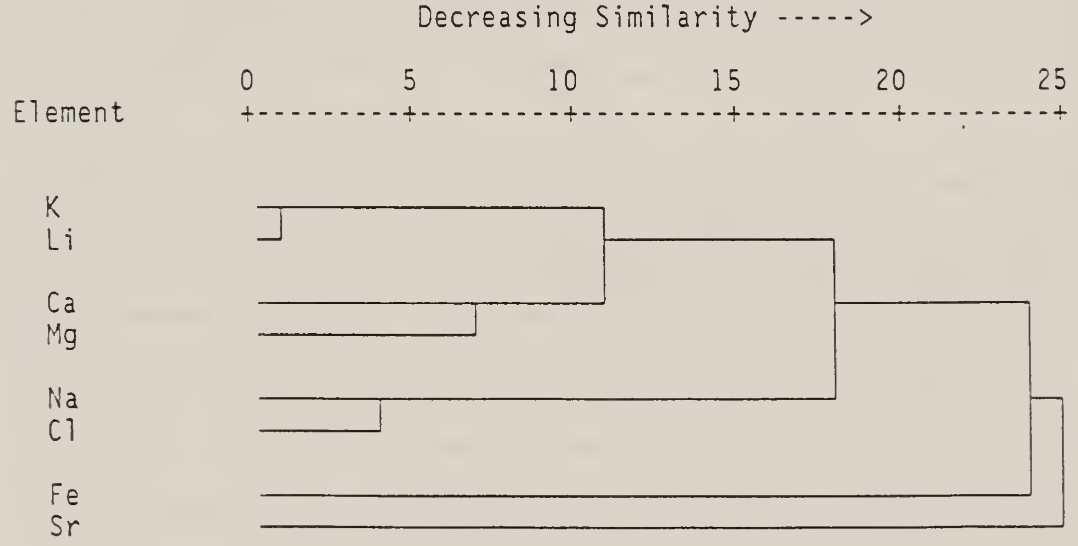
Figure 6-2. Cluster analysis of Clay County oil field brine constituents.

A. INTER-ELEMENT CORRELATION MATRIX

	Na	K	Ca	Mg	Li	Sr	Fe	CL
Na	1.0000	.3144	.6355**	.4063	.1028	.3809	-.0627	.8531**
K	.3144	1.0000	.6662**	.6991**	.9499**	-.0906	.2903	.3804
Ca	.6355**	.6662**	1.0000	.7648**	.5083*	.1828	.3362	.7744**
Mg	.4063	.6991**	.7648**	1.0000	.6413**	.4333*	.4107	.6202**
Li	.1028	.9499**	.5083*	.6413**	1.0000	-.1428	.3133	.1711
Sr	.3809	-.0906	.1828	.4333*	-.1428	1.0000	.1997	.4267*
Fe	-.0627	.2903	.3362	.4107	.3133	.1997	1.0000	.1122
Cl	.8531**	.3804	.7744**	.6202**	.1711	.4267*	.1122	1.0000

1-tailed Signif: * - .01 ** - .001

B. CLUSTER DENDROGRAM



and the reader is referred to Davis (1973), Korth (1975), or Tabachnick and Fidell (1983).

The results of the factor analysis are shown in table 6-3. The right hand portion of the upper table shows that three factors were extracted which account for 88 percent of the variance in the data. The column labeled communality in the upper table shows the proportion of the variance for each constituent which can be accounted for in the three factor model. The lower table of coefficients shows the factor loadings of the three factors for each constituent. In this analysis, the coefficients can be thought of as the correlations between the factors and the constituents. Factors with high loadings (in absolute value) therefore indicate a close relationship between that factor and the constituent. The first factor, which accounts for 50 percent of the variance, shows high loadings for Cl, Na, Sr, and Ca. The second factor, which shows high loadings for K, Li, and Mg, accounts for an additional 25 percent of the variance. The final factor shows a high loading for Fe only, and it accounts for an additional 13 percent of the variance. The first factor most likely reflects the metal-chloride interrelationship found in the brines for the elements loaded for this factor, while the second factor most likely reflects the elements which are not as strongly associated with chloride. The third factor probably reflects the low correlation which iron has with all the other elements.

PRELIMINARY ANALYSIS

Mississippian Brine Groupings by Formation

A summary of mean concentrations of the major constituents by formation for the Clay County oil field brine data are shown in table 6-4. The concentration trends with depth, as discussed for the Meents et al. (1952) data are much less pronounced for the current data. Analysis of variance reveals that the same trends, although fairly subtle and with considerable overlap, are still in effect. The lowest concentrations for the constituents shown are found in the Tar Springs and Cypress brines while the highest concentrations are found in the Aux Vases, McClosky, and Salem brines.

In the previous discussion, cluster analysis was used to examine inter element relationships and to cluster the elements into groups with similar patterns of behavior. The resulting cluster dendrogram is shown in figure 6-3, where the individual samples are identified by the formation of the producing zone. It can be seen that the clustering process is only partially successful. One relatively distinct cluster consists of seven of the eight Salem brines and one Cypress brine. A second cluster is composed of five of the six Cypress brines and one McClosky

Table 6-3

Factor Analysis of Oil Field Brines

Variable	Communality	Factor	Eigenvalue	Pct of Var	Cm Pct
log(Na)	.87504	1	4.00989	50.1	50.1
log(K)	.96943	2	2.01574	25.2	75.3
log(Li)	.94363	3	1.02343	12.8	88.1
log(Ca)	.84485				
log(Mg)	.83333				
log(Sr)	.74506				
log(Fe)	.92054				
log(Cl)	.91720				

Varimax Rotated Factor Loading Matrix

	Factor 1	Factory 2	Factor 3
log(Cl)	.91948	.25264	-.08902
log(Na)	.87542	.15219	-.29242
log(Sr)	.80090	-.21806	.23678
log(Ca)	.70651	.58605	.04734
log(K)	.15697	.97170	.02054
log(Li)	-.10369	.96287	.07586
log(Mg)	.51422	.72506	.20783
log(Fe)	-.04766	.14241	.94762

Table 6-4

Summary Means of Clay County Oil Field Brine Data[1]

FORMATION	#	Na	K	Ca	Mg	Li	Sr	Fe	Cl
Tar Springs	(2)	45900 b	91a	3625a	1230a	2.2a	168a	22a	78070 b
Cypress	(6)	38660a	188a	3632a	1378ab	9.1 b	96a	15a	65890a
Aux Vases	(3)	48280 b	176a	5111ab	1347ab	5.1ab	222a	6a	84170 b
McClosky	(11)	45650 b	180a	4309ab	1610ab	6.5ab	282a	15a	78370 b
Salem	(8)	46960 b	418 b	5498 b	1950 b	16.8 c	139a	44a	81170 b
Grand Mean	(30)	44880	239	4526	1603	9.4	193	23	77180

[1] For each element, means with the same letter are not significantly different at the 95 % confidence level using Duncan's Multiple Range Test.

brine. The remaining clusters consist of a mix of the formations with no dominating single formation.

In the preceding cluster analysis, the samples were grouped into clusters based on similar patterns of behavior of their measured constituents. No prior assumptions were made about the grouping of the samples by formation. If the prior knowledge of the groupings by formation is used, then canonical discriminant analysis can be used to arrive at a grouping scheme. Discriminant analysis derives a linear combination of the best predictor variables so that differences among the groups is maximized. Based on the derived function or functions, new samples may be assigned to their respective groups. A discussion of discriminant analysis may be found in Tabachnick and Fidell (1983), Norusis (1986), or Sanathanan (1975).

It should be emphasized that the applications of discriminant analysis which are to follow cannot be considered statistically rigorous. The major deficiency is the limited number of samples which can be used to define each group. The minimum number of samples in the smallest group should be about twenty if multivariate normality is to be expected.

In applying the method of discriminant analysis to the oil field brine data, interelement ratios were used instead of the individual elements so that factors such as dilution would not affect the groupings. The results of the discriminant analysis for the brine data from the five Mississippian formations is shown in figure 6-4. Effective grouping of all of the brines was achieved using two functions. The calculated discriminant scores for each brine, plotted as upper case letters, fall within the zones established by the discriminant analysis. Based on this grouping scheme, the one brine sample of unknown origin was classified as coming from the Aux Vases, although it should be noted that this sample does not plot very close to the class centroid for the Aux Vases group.

Mississippian Versus Pennsylvanian Grouping

The above discussion has dealt with the grouping of the brines collected from various Mississippian formations. The goal of this project required only that differentiation be made between the shallow Pennsylvanian brines and those Mississippian brines being generated as a result of oil production activity. A major difficulty arose, though, which prevented or at least severely limited the successful completion of this part of the task. We initially anticipated that the shallow brine samples would be collected from Pennsylvanian source water wells used to produce injection water for water flood operations. However the poor economy in the oil industry during the study period resulted in the shut-down of many oil wells and the shallow Pennsylvanian source water wells in the study area.

Figure 6-3. Cluster dendrogram, brines from Mississippian formations in southeastern Clay County.

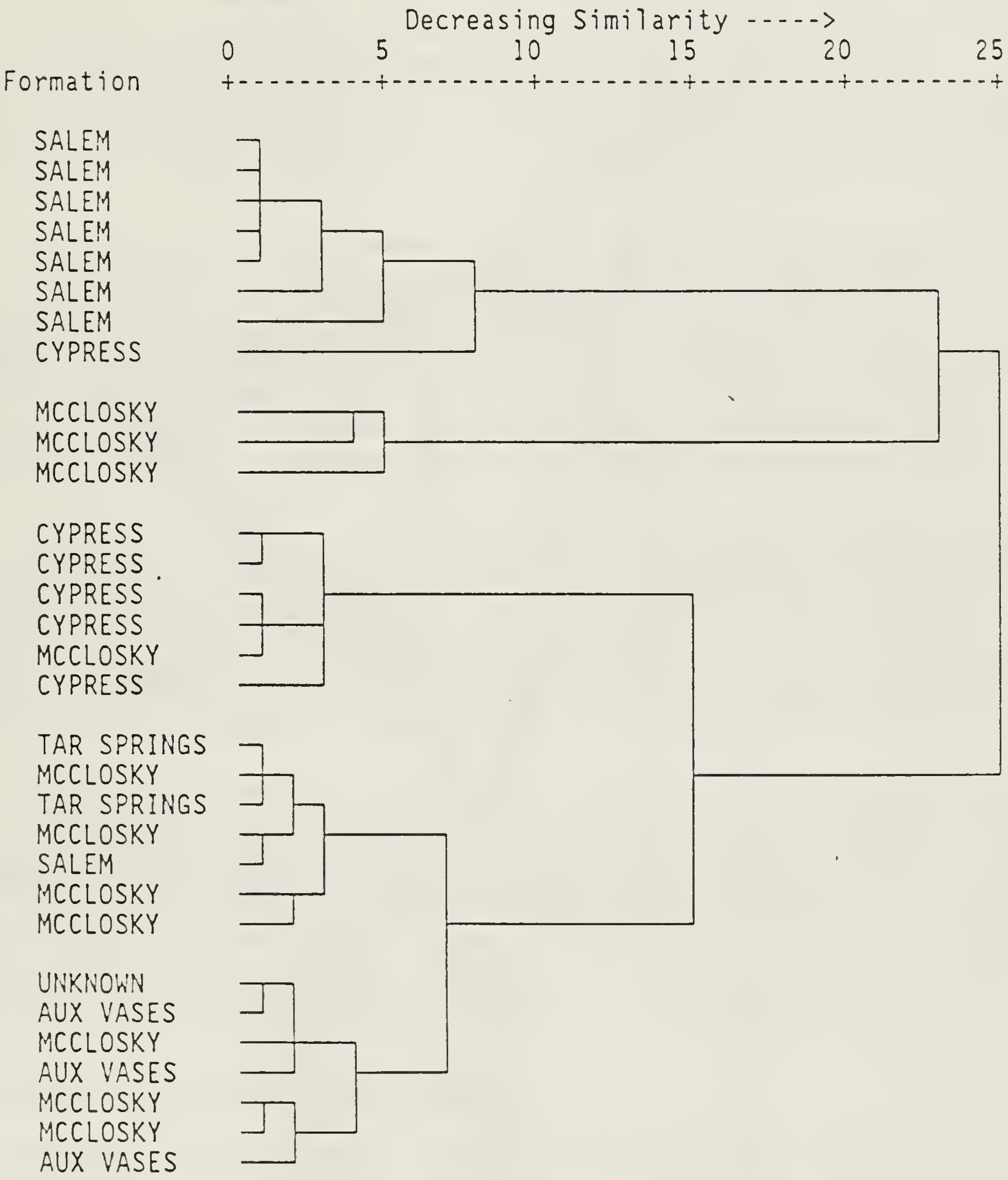
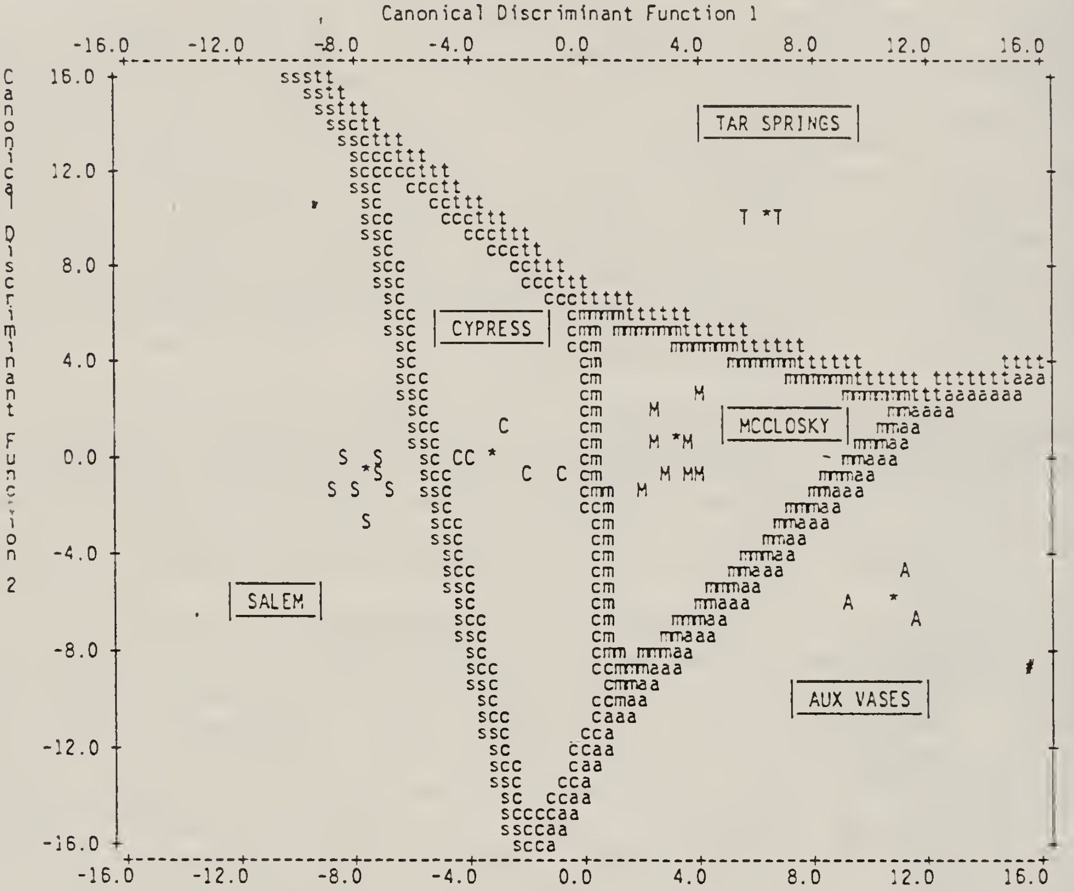


Figure 6-4. Discriminant analysis, brines from Mississippian formations in southeastern Clay County.



* Group Centroids, # Unknown, T Tar Springs, C Cypress, A Aux Vases, M McClosky, S Salem

Unstandardized Canonical Discriminant Function Coefficients

	FUNC 1	FUNC 2
Ca/Cl	-1684.745	-548.4712
Li/Cl	138351.8	205969.1
Na/K	.1054185E-01	-.7259861E-01
Na/Mg	-2.005163	1.827889
Na/Li	-.5056760E-02	-.2747762E-02
Na/Sr	-.8309050E-01	-.2630177E-01
K/Mg	95.93858	21.35844
K/Li	-.6860196	-.9188802
Ca/Mg	46.30396	-3.323473
Ca/Sr	-.2340635	.6690730
Mg/Li	.2426764	.2366895
Mg/Sr	3.356902	.7418412
Li/Sr	-238.9912	-247.4614
(Na+Li)/Cl	119.9517	33.34898
(Na+Li)/(Ca+Mg+Sr)	3.891433	-2.564487
(constant)	-95.12807	-35.79255

Because of our inability to collect samples of shallow Pennsylvanian brines, the data from Meents et al. (1952) for Pennsylvanian waters were used to construct a preliminary differentiation scheme. The use of these brine data introduced considerable uncertainty into the analysis which follows because none of the samples came from Clay County, the number of analyses performed on these samples is limited, and the data are extremely variable. The data for these Pennsylvanian brines are reproduced in table 6-A4 of Appendix 6-A and summary statistics are shown in table 6-1.

The previous discussion of the differences between the Pennsylvanian and Mississippian brine data of Meents et al. (1952) has the same relevance for the current set of Mississippian brine samples. T-tests performed on the two sets of data (current Mississippian brines and Meents et al. (1952) Pennsylvanian brines) show that the means of the two groups for the following constituents and constituent ratios are significantly different at the 95 percent confidence level: Na, Ca, Mg, Cl, Na/Cl, Ca/Cl, Ca/Mg, and Na/Mg.

Cluster analysis was performed on the current brine samples and the Pennsylvanian brines from Meents et al. (1952) using the following interelement ratios: Na/Cl, Ca/Cl, Mg/Cl, Na/Ca, Na/Mg, Ca/Mg, (Ca+Mg)/Cl, and Na/(Ca+Mg). Figure 6-5 shows that the two major clusters, both of which form relatively tight groups, consist entirely of the Mississippian samples in one group, and the Pennsylvanian samples in the other.

The results of the discriminant analysis using the same ratios as those used in the cluster analysis are shown in figure 6-6. A single discriminant function is derived and the resulting discriminant scores for each sample are plotted as a histogram. Figure 6-6 shows that there are two relatively distinct groups representing the two brine types. The current Mississippian brines form a much tighter group than the Pennsylvanian brines and one of the Pennsylvanian brines is classified incorrectly as Mississippian.

EVALUATION OF DOMESTIC WELL WATERS

Mississippian, Pennsylvanian, Fresh Water Groupings

The next step in evaluating the discrimination procedure involves the incorporation of a fresh water group into the process. The domestic well water samples collected for the study of domestic well water quality (Section 3) provide the members for this group. Of the 22 well water samples collected, eight samples with specific conductance values of less than 1000 microseimen/cm were selected as representing the fresh water group. The remaining fourteen domestic well water samples were considered as unknowns.

Figure 6-5. Cluster dendrogram, brines from Mississippian and Pennsylvanian formations in southeastern Clay County.

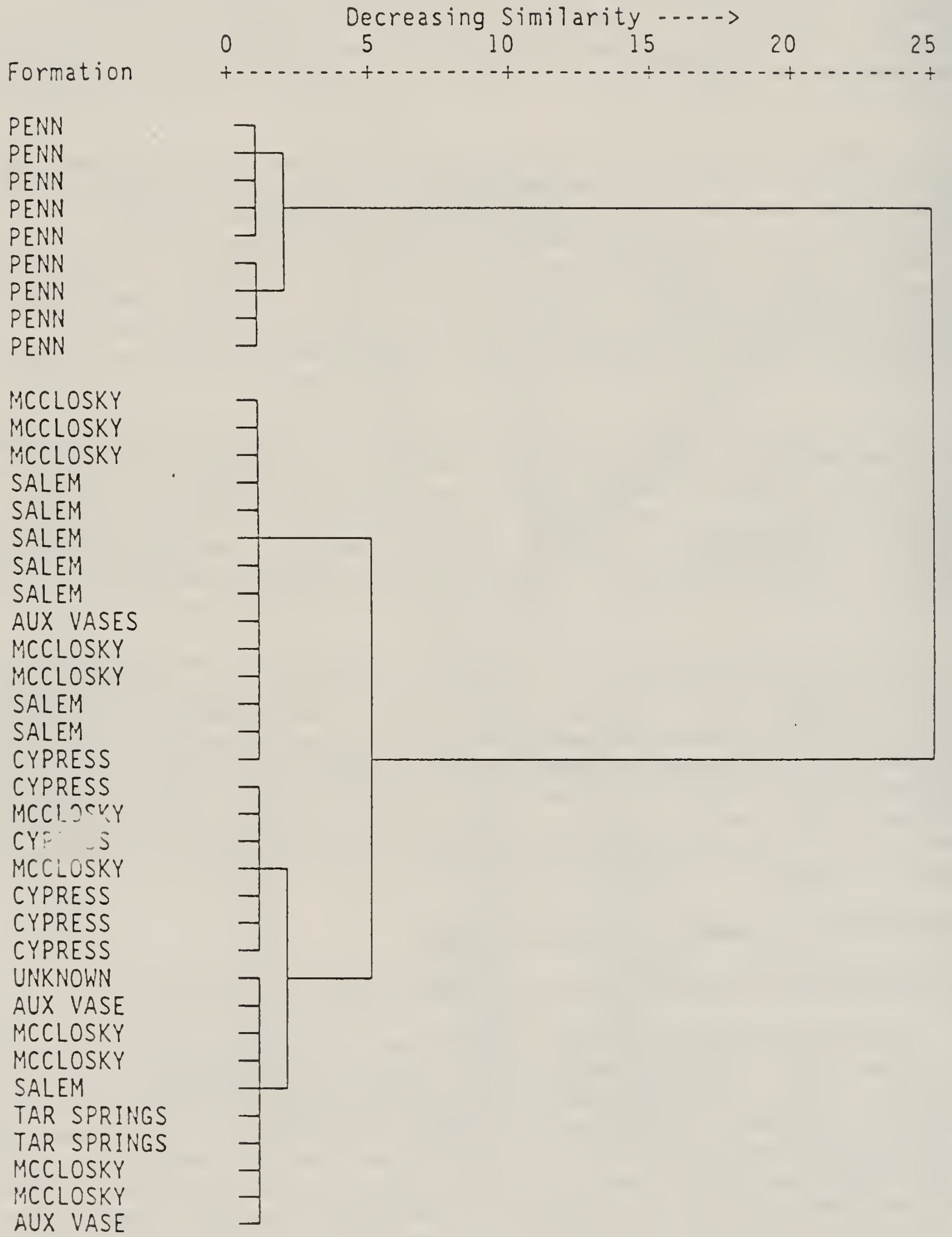


Figure 6-6. Discriminant analysis of brines from Mississippian and Pennsylvanian formation in southeastern Clay County.

```
                Canonical Discriminant Function 1
    8 +                                                      +
      |                                                      |
      |                    MM                                |
      |  Mississippian     MM        Pennsylvanian           |
    6 +                    MM                                +
      |                    MM                                |
      |                    MMMM                              |
      |                    MMMM                              |
    4 +                    MMMM                              +
      |                    MMMM                              |
      |                   MMMMM                              |
      |                   MMMMM                              |
    2 +                  MMMMMM    P                         +
      |                  MMMMMM    P                         |
      |                 MMMMMMMMM PP    PP P P P             |
      |                 MMMMMMMMM PP    PP P P P             |
       X----+----+----+----+----+----+----+----X
    Out -6.0 -4.0 -2.0  0.0  2.0  4.0  6.0    Out
       MMMMMMMMMMMMMMMMMMMMMMMMMMMMPPPPPPPPPPPPPPPP
                           |          |
 Class
 Centroids               -0.85       3.294
```

F = -60.663(Ca/Cl)+352.50(Mg/Cl)-0.60324(Na/Ca)+0.16941(Na/Mg)-9.5688

Table 6-5. Classification results - discriminant analysis of brines from Mississippian and Pennsylvanian formations and water from shallow deposits in southeastern Clay County.

MISS. & PENN. BRINES

ISGS SAMPLE #	ASSIGNED[5]	PREDICTED[4] MEMBERSHIP P[1]	P&S[2]	S[3]
B-5148	O	O	O	O
B-5165	O	O	O	O
B-5166	O	O	O	O
B-5144	O	O	O	O
B-5146	O	O	O	O
B-5152	O	O	O	O
B-5153	O	O	O	O
B-5155	O	O	O	O
B-5161	O	O	O	O
B-5140	O	O	O	O
B-5141	O	O	O	O
B-5168	O	O	O	O
B-5142	O	O	O	O
B-5147	O	O	O	O
B-5154	O	O	O	O
B-5156	O	O	O	O
B-5157	O	O	O	O
B-5162	O	O	O	O
B-5163	O	O	O	O
B-5164	O	O	O	O
B-5167	O	O	O	O
B-5170	O	O	O	O
B-5171	O	O	O	O
B-5143	O	O	O	O
B-5149	O	O	O	O
B-5150	O	O	O	O
B-5151	O	O	O	O
B-5158	O	O	O	O
B-5159	O	O	O	O
B-5160	O	O	O	O
B-5169	O	O	O	O
B-58	P	P	P	
B-56	P	P	P	
B-55	P	P	P	
B-54	P	P	P	
B-57	P	O	O	
B-647	P	P	P	
B-441	P	P	P	
B-379	P	O	O	

DOMESTIC WATER WELLS

ISWS #	ASSIGNED[5]	PREDICTED[4] MEMBERSHIP P[1]	P&S[2]	S[3]
OFB-2	F	F	F	F
OFB-3	F	F	F	F
OFB-4	F	F	F	F
OFB-5	F	F	F	F
OFB-7	F	F	F	F
OFB-8	F	F	F	F
OFB-10	F	F	F	F
OFB-11	F	F	F	F
OFB-1		F	F	F
OFB-6		F	F	F
OFB-9		F	F	F
OFB-12		F	F	F
OFB-13		F	F	F
OFB-20		F	F	F
OFB-21		O	O	F
OFB-16	S	P	S	S
OFB-17	S	P	S	S
OFB-14		P	S	S
OFB-15		P	S	S
OFB-19		P	S	S
OFB-22		P	S	S
OFB-18		P	P	O

1 Analysis using known Pennsylvanian brines. Variables used in analysis: Na, Ca, Mg, and Cl.

2 Analysis using known Pennsylvanian brines & Shallow brines. Variables used in analysis: Na, Ca, Mg, and Cl.

3 Analysis using shallow brines. Variables used in analysis: Na, Ca, Mg, Sr, Li, and Cl.

4 Group categories: O=Oilfield brine, P=Pennsylvanian Brine, S=Shallow Brine, and F=Fresh water.

5 Defining group assignments.

Table 6-6. Summary of constituent ratios from discriminant analysis using known Pennsylvanian brines.

	Grp[3] D[1]	P[2]	#	Na/Cl	Ca/Cl	Mg/Cl	Sr/Cl	Li/Cl	AE[4]/Cl	CAT[5]/Cl	Na/Ca	Na/Mg
Known	O	O	31	.5844	.0580	.0205	.0025	.00012	.081	.665	10.5	30.0
Unkn.		O	1	.7360	.3640	.1560	.0012	.00008	.521	1.257	2.0	4.7
Known	P	P	6	.6858	.0178	.0141					228.3	63.6
Known	P	O	2	.6826	.0450	.0243					15.6	34.4
Unkn.		P	5	1.2966	.0172	.0095	.0004	.00006	.027	1.323	163.1	329.1
Known	S	P	2	.8246	.0041	.0026	.0002	.00003	.006	.831	198.9	323.0
Known	F	F	8	2.8757	3.0583	1.3959	.0110	.00099	4.465	7.342	1.9	4.2
Unkn.		F	6	4.0283	2.7142	1.4391	.0116	.00079	4.164	8.194	3.8	4.0

	Grp D	P	#	Na/Sr	Na/Li	Ca/Mg	Ca/Sr	Ca/Li	Mg/Sr	Mg/Li	Sr/Li	ALK[6]/AE
Known	O	O	31	304	7134	2.894	30.2	668	10.6	227	31.08	7.4
Unkn.		O	1	613	9200	2.333	303.3	4550	130.0	1950	15.00	1.4
Known	P	P	6			1.212						
Known	P	O	2			2.109						
Unkn.		P	5	4201	22793	1.995	41.3	283	21.3	153	6.00	105.7
Known	S	P	2	4740	28860	1.625	23.7	145	15.0	90	6.50	119.5
Known	F	F	8	307	5034	2.148	258.3	3376	123.3	1586	16.56	1.3
Unkn.		F	6	586	8298	1.677	222.5	4122	133.2	2293	17.50	1.8

[1] - Defining group category.
[2] - Predicted membership group.
[3] - Group categories:
O=Oil Field Brine, P=Pennsylvanian Brine
S=Shallow Brine, F=Fresh water.
[4] - Ca+Mg+Sr
[5] - Na+Li+Ca+Mg+Sr
[6] - Na+Li

The results of a preliminary three-group discriminant analysis using the Pennsylvanian data of Meents et al. (1952) are shown in table 6-5, column heading P and table 6-6. All of the oil field brines (O), six of the eight Pennsylvanian brines (P), and all of the fresh water samples (F) were classified correctly. The two incorrectly classified Pennsylvanian brines were grouped with the oil field brines. From table 6-6, it appears that the oil field brines are characterized by low Na/Cl and intermediate Ca/Cl, Mg/Cl, and Na/Ca ratios. The Pennsylvanian brines are characterized by low Ca/Cl and Mg/Cl, intermediate Na/Cl, and high Na/Ca ratios. The fresh waters are characterized by low Na/Ca and high Na/Cl, Ca/Cl, and Mg/Cl ratios. The unknown samples show constituent ratio patterns which result in the following groupings: one sample with oil field brine characteristics, seven samples with Pennsylvanian brine characteristics, and six samples with fresh water characteristics.

MISSISSIPPIAN, PENNSYLVANIAN, SHALLOW, AND FRESH WATER GROUPING

The relevance of the above analysis remains suspect due to the inadequacy of the Pennsylvanian data previously discussed. A solution to this problem may be found by a closer examination of those unknown domestic well water samples classified as Pennsylvanian in character. Two samples in particular, OFB-16 and OFB-17 offer promise. Both samples have specific conductance values greater than 5000 microseimen/cm, and both samples come from wells with depths greater than 250 feet (i.e. into the Pennsylvanian). For the next analysis, these two samples were considered as a fourth group, shallow (S) Pennsylvanian, in an attempt to introduce a more appropriate shallow brine group into the analysis.

By incorporating two of the unknown samples into the analysis as shallow brines, the number of unknown samples is reduced from fourteen to twelve while the remaining defining groups remain unchanged. The results of this four-group discriminant analysis are shown in column heading P&S of table 6-5 and in table 6-7. The results for this analysis are nearly identical to the previous one with the assignments to the defining groups remaining unchanged, and with the successful assignment of the two shallow brines. The assignments of unknown samples into groups is also unchanged for the one sample characterized as showing oil field brine patterns and for the six samples characterized as showing fresh water patterns. The only difference in assignments are for those samples which showed Pennsylvanian patterns from before. Four of these samples were characterized as showing shallow brine patterns, while the fifth sample remained assigned to the Pennsylvanian group.

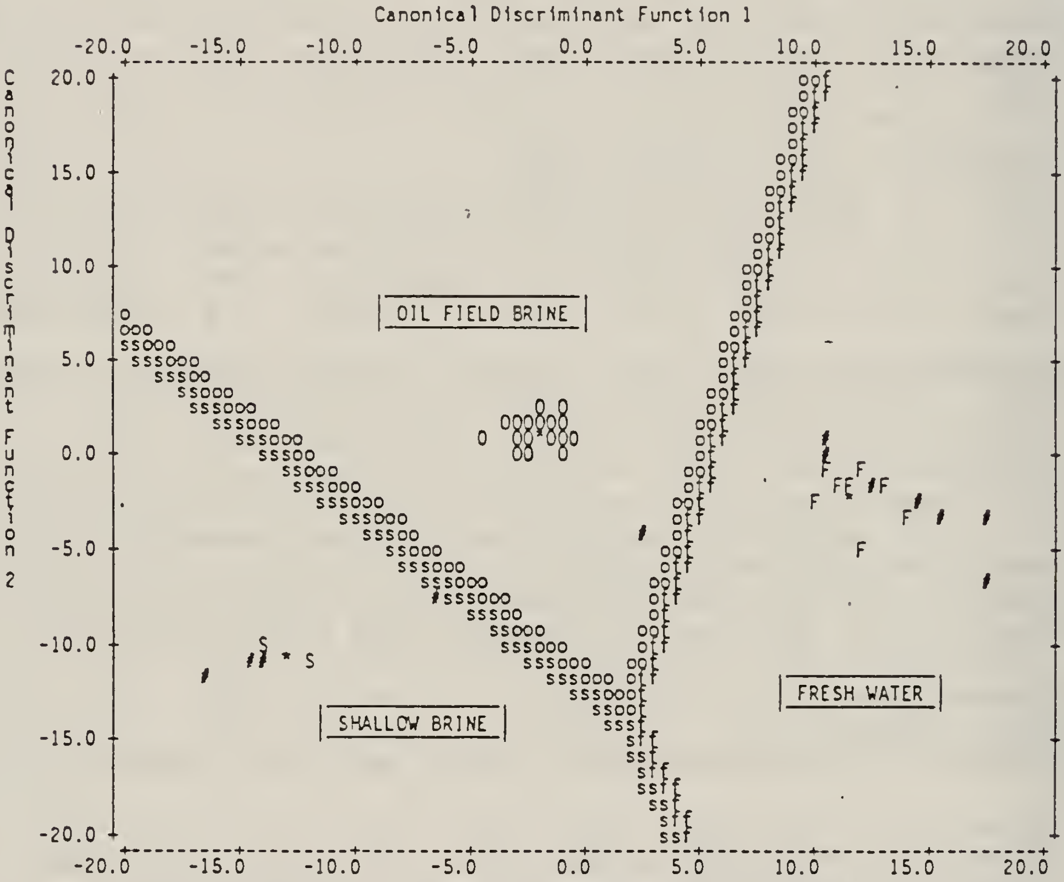
Table 6-7. Summary of constituent ratios from discriminant analysis using known Pennsylvanian brines and shallow brines.

	Grp[3] D[1]	P[2]	#	Na/Cl	Ca/Cl	Mg/Cl	Sr/Cl	Li/Cl	AE[4]/Cl	CAT[5]/Cl	Na/Ca	Na/Mg
Known	O	O	31	.5844	.0580	.0205	.0025	.00012	.081	.665	10.5	30.0
Unkn.		O	1	.7360	.3640	.1560	.0012	.00008	.521	1.257	2.0	4.7
Known	P	P	6	.6858	.0178	.0141					228.3	63.6
Known	P	O	2	.6826	.0450	.0243					15.6	34.4
Unkn.		P	1	1.1911	.0511	.0311	.0007	.00007	.082	1.274	23.3	38.2
Known	S	S	2	.8246	.0041	.0026	.0002	.00003	.006	.831	198.9	323.0
Unkn.		S	4	1.3229	.0087	.0041	.0003	.00006	.013	1.336	198.1	401.8
Known	F	F	8	2.8757	3.0583	1.3959	.0110	.00099	4.465	7.342	1.9	4.2
Unkn.		F	6	4.0283	2.7142	1.4391	.0116	.00079	4.164	8.194	3.8	4.0

	Grp D	P	#	Na/Sr	Na/Li	Ca/Mg	Ca/Sr	Ca/Li	Mg/Sr	Mg/Li	Sr/Li	ALK[6]/AE
Known	O	O	31	304	7134	2.894	30.2	668	10.6	227	31.08	7.4
Unkn.		O	1	613	9200	2.333	303.3	4550	130.0	1950	15.00	1.4
Known	P	P	6			1.212						
Known	P	O	2			2.109						
Unkn.		P	1	1786	17866	1.642	76.6	766	46.6	466	10.00	14.3
Known	S	S	2	4740	28860	1.625	23.7	145	15.0	90	6.50	119.5
Unkn.		S	4	4805	24025	2.083	32.5	162	15.0	75	5.00	128.6
Known	F	F	8	307	5034	2.148	258.3	3376	123.3	1586	16.56	1.3
Unkn.		F	6	586	8298	1.677	222.5	4122	133.2	2293	17.50	1.8

1 - Defining group category.
2 - Predicted membership group.
3 - Group categories:
O=Oil Field Brine, P=Pennsylvanian Brine
S=Shallow Brine, F=Fresh water.
4 - Ca+Mg+Sr
5 - Na+Li+Ca+Mg+Sr
6 - Na+Li

Figure 6-7. Discriminent analysis territorial map for oil field brines from Mississippian formations, shallow brines from Pennsylvanian formations, fresh water from surficial deposits, and unknown samples.



* Group centroids, # Unknown, O Oil Field Brine, S Shallow Brine, F Fresh Water

Unstandardized Canonical Discriminant Function Coefficients

	FUNC 1	FUNC 2
log(Ca/Cl)	8.574445	21.62736
log((Ca+Mg+Sr)/Cl)	26.38258	-1.067425
log((Na+Ca+Mg+Sr+Li)/Cl)	-27.94176	-23.43031
log(Na/Ca)	23.79036	10.69833
log(Mg/Li)	8.225558	-3.014662
log(Sr/Li)	-3.403425	1.823528
(constant)	-5.930134	16.52935

Mississippian, Shallow, and Fresh Water Grouping

The incorporation of the shallow brine group into the analysis represents an improvement over the first analysis, since the shallow brine group is indigenous to the study area but this analysis does have its problems. The deficiencies of the second analysis are two-fold. The first problem is that there are only two shallow brine samples used to define this group, they are not especially saline, and they still may not be representative of the shallow Pennsylvanian brines of the study area. The second problem involves the inclusion of the Pennsylvanian data of Meents et al. (1952). The limited number of constituents reported for Pennsylvanian brines is the limiting factor in the number of constituents used in the discriminant analysis.

The first problem cannot be overcome until the economic situation of the oil industry improves, but the second problem can easily be solved by using the shallow brine group as the only representatives of the Pennsylvanian, thus permitting the inclusion of additional constituents in the analysis.

The results of the final three-group discriminant analysis are shown under column heading S of table 6-5, table 6-8, and figure 6-7. The members of the defining groups are all correctly classified. The constituent ratio patterns for Na/Cl, Ca/Cl, Mg/Cl, and Na/Ca are the same for this analysis as they are for the previous two. In addition, the oil field brine group is characterized by intermediate Li/Cl, Ca/Li, Ca/Sr, Mg/Li, AE(Ca+Mg+Sr)/Cl, Na/Mg, and ALK(Na+Li)/AE ratios. The shallow brine group is characterized by low Li/Cl, Ca/Li, Ca/Sr, Mg/Li, and AE/Cl ratios and high Na/Mg and ALK/AE ratios. The fresh water group is characterized by high Li/Cl, Ca/Li, Ca/Sr, Mg/Li, and AE/Cl ratios and low Na/Mg and ALK/AE ratios. The grouping of the unknown samples again remains mostly unchanged although there are a few exceptions. The four samples grouped with shallow brines are the same ones as before. The six samples grouped as fresh in the prior analyses remain classified as fresh with the addition of a seventh sample previously classified as the only unknown showing oil field brine characteristics. The single unknown sample (OFB-18) classified as having Pennsylvanian characteristics from the previous analysis is now grouped as exhibiting oil field brine characteristics. Although sample OFB-18 shows good agreement with the oil field brine group for the following constituent ratios: Ca/Cl, Mg/Cl, (Ca+Mg+Sr)/Cl, Na/Ca, Na/Mg, Ca/Li, and Mg/Li, its classification is hard to explain from a physical standpoint. The well is not located near any oil wells and its depth is only 140 feet.

The Effect of Mixing on Classification

It should be understood that the classification of the unknowns in the above analyses does not mean that the unknowns are pure representatives of the groups to which they have been assigned. The only inference which should be made from the classifications is that based on the techniques used in this study, the unknowns show interelement patterns similar to those of their assigned groups and that the "contaminated" unknowns most likely represent mixtures of the brines and fresh water.

The simplest way to look at the mechanism of domestic well water contamination is to view the process as one of mixing of waters from three different sources (oil field brine, shallow brine, and fresh water) where no chemical reactions occur. In order to evaluate the effect of mixing on unknown classification, mathematical mixtures of waters from the three different sources were computed and evaluated. The mean composition of each constituent for each of the three basic water types is shown in table 6-9a. Using these compositions, ternary mixtures were computed and the composition of each mixture was used as input for Fisher's linear discriminant functions where each mixture is assigned to the group for which the function produces the largest discriminant score. The coefficients derived for the oil field brine-shallow brine-fresh water discriminant analysis are shown in table 6-9b. The use of Fisher's linear discriminant functions produces the same classification results as the canonical discriminant functions.

The results of this mixing exercise are shown in table 6-9c which show the boundaries for each predicted group as delineated by three end-member compositions of ternary mixtures of oil field brine, shallow brine, and fresh water. Due to the exceptionally high salinity of the oil field brine end-member relative to the shallow brine and fresh water end-members, the discrimination procedure is very sensitive to the proportion of oil field brine in the mixture. For a mixture to be assigned to the shallow brine group, it must consist of at least 77 percent shallow brine with no oil field brine and can have no more than 0.9 percent oil field brine if no fresh water is present. Mixtures containing greater than 0.9 percent oil field brine will be assigned to the oil field brine group. This sensitivity becomes even more extreme for the fresh water group. A mixture must contain at least 92.4 percent fresh water if no oil field brine is present and can have no more than 0.04 percent oil field brine if no shallow brine is present. All mixtures not meeting the above criteria are assigned to the oil field brine group.

It should be noted that within the oil field brine group there is a range of binary mixtures of fresh water and shallow brine where no oil field brine is present. The compositions of these mixtures ranges from greater than 23 percent to less than 92.4 percent fresh water. This anomaly, which represents a major deficiency in the discrimination model used in this study, most likely reflects the lack of an adequate definition of the shallow brine population. This situation may be a possible explanation

Table 6-8. Summary of constituent ratios from discriminant analysis using shallow brines.

	Grp[3] D[1]	P[2]	#	Na/Cl	Ca/Cl	Mg/Cl	Sr/Cl	Li/Cl	AE[4]/Cl	CAT[5]/Cl	Na/Ca	Na/Mg
Known	O	O	31	.5844	.0580	.0205	.0025	.00012	.081	.665	10.5	30.0
Unkn.		O	1	1.1911	.0511	.0311	.0007	.00007	.082	1.274	23.3	38.2
Known	S	S	2	.8246	.0041	.0026	.0002	.00003	.006	.831	198.9	323.0
Unkn.		S	4	1.3229	.0087	.0041	.0003	.00006	.013	1.336	198.1	401.8
Known	F	F	8	2.8757	3.0583	1.3959	.0110	.00099	4.465	7.342	1.9	4.2
Unkn.		F	7	3.5579	2.3784	1.2558	.0101	.00069	3.644	7.203	3.6	4.1

	Grp D	P	#	Na/Sr	Na/Li	Ca/Mg	Ca/Sr	Ca/Li	Mg/Sr	Mg/Li	Sr/Li	ALK[6]/AE
Known	O	O	31	304	7134	2.894	30.2	668	10.6	227	31.08	7.4
Unkn.		O	1	1786	17866	1.642	76.6	766	46.6	466	10.00	14.3
Known	S	S	2	4740	28860	1.625	23.7	145	15.0	90	6.50	119.5
Unkn.		S	4	4805	24025	2.083	32.5	162	15.0	75	5.00	128.6
Known	F	F	8	307	5034	2.148	258.3	3376	123.3	1586	16.56	1.3
Unkn.		F	7	590	8427	1.770	234.0	4183	132.7	2244	17.14	1.8

1 - Defining group category.
2 - Predicted membership group.
3 - Group categories:
O=Oil Field Brine, P=Pennsylvanian Brine
S=Shallow Brine, F=Fresh water.
4 - Ca+Mg+Sr
5 - Na+Li+Ca+Mg+Sr
6 - Na+Li

Table 6-9. The effects of mixing of oil field brine, shallow brines, and fresh water on classification results.

A. PURE END-MEMBER COMPOSITIONS

PURE END-MEMBERS	Na	Ca	Mg	Sr	Li	Cl
Oil Field Brine	44880	4525	1603	193.5	9.37	77180
Shallow Brine	1292	6.5	3.8	0.3	0.05	1575
Fresh Water	81.1	64.8	30.8	0.3	0.02	34.8

B. FISHER'S LINEAR DISCRIMINANT FUNCTION COEFFICIENTS

	COEFFICIENTS		
RATIO	OIL FIELD BRINE	SHALLOW BRINE	FRESH WATER
log(Ca/Cl)	-292.3922	-643.0253	-245.1666
log(AE[1]/Cl)	186.6781	-89.66165	556.8124
log(CAT[2])/Cl)	112.3093	696.5027	-198.0292
log(Na/Ca)	10.59133	-337.0043	305.5829
log(Mg/Li)	175.13	120.8049	299.4482
log(Sr/Li)	-81.68469	-66.04589	-135.0388
(constant)	-223.2602	-494.2072	-428.3567

[1] (Ca+Mg+Sr); [2] (Na+Ca+Mg+Sr+Li)

C. COMPOSITION BOUNDARIES FOR PREDICTED GROUPS

PREDICTED GROUP	END MEMBER COMPOSITIONS OFB[1] (%)	SHB[2] (%)	FRESH (%)
	0	0	100
FRESH WATER	0	7.6	92.4
	0.04	0	99.96
	0	100	0
SHALLOW BRINE	0	77	23
	0.9	99.1	0
OIL FIELD BRINE	ALL OTHERS		

[1] Oil field brine; [2] Shallow brine

for the classification of sample OFB-18 as showing oil field brine characteristics. A mixture of approximately 45 percent shallow brine and 55 percent fresh water produces Ca/Cl, (Ca+Mg+Sr)/Cl, (Na+Ca+Mg+Sr+Li)/Cl, and Na/Ca ratios which are very similar to those found for sample OFB-18, and it is these ratios which carry the greatest weight in determining the group assignments.

SUMMARY AND CONCLUSIONS

This study has shown that there are significant differences in composition between brines of the oil producing formations of the Mississippian and the shallow brines of the Pennsylvanian. It has also been demonstrated that based on these differences in composition, criteria (such as Ca/Cl, (Ca+Mg+Sr)/Cl, Na/Ca, and Mg/Li ratios) can be established which can allow the differentiation between brines from these two basic sources and a third fresh water source. The major limitation in the current study is the lack of available data for brines of the shallow Pennsylvanian. Because of this limitation, the classification results obtained in this study can only be considered preliminary.

BIBLIOGRAPHY

Bower, C. A. and L. V. Wilcox, 1965, Chapter 62, Soluble Salts: in Methods of soil analysis, Agronomy Series #9, (C. A. Black, ed.), Amer. Soc. Agron., Madison, p.933-940.

Collins, A. G., 1978, Geochemistry of anomalous lithium in oil-field bines: Oklahoma Geological Survey, Circular 79, p95-98.

Davis, J. C., 1973, Statistics and data analysis in geology: John Wiley & Sons, Inc., New York, 550 p.

Fletcher, G. E. and A. G. Collins, 1974, Atomic absorption methods of analysis of oilfield brines - barium, calcium, copper, iron, lead, lithium, magnesium, potassium, sodium, strontium, and zinc: U.S. Bureau of Mines Report of Investigations 7861, 14p.

Graff, D. L., W. F. Meents, I. Friedman, and N. F. Sh mp, 1966, The origin of saline formationw Waters, III - calcium chloride waters: Illinois Geological Survey, Circular 397, 60 p.

Korth, B., 1975, Exploratory factor analysis, in introductory multivariate analysis: (D. J. Amick and H. J. Walberg, eds.), McCutchan Pub. Co., Berkeley, p113-146.

Meents, W. F., A. H. Bell, O. W. Rees, and W. G. Tilbury, 1952, Illinois oil-field brine - their occurrence and chemical composition: Illinois Petroleum No. 66, 39p.

Nesbitt, H. W., 1985, A chemical equilibrium model for the Illinois basin formation waters: Amer. Jour. Sci., v.285, p.436-458.

Norusis, M. J., 1986, SPSS/PC+, Advanced Statistics: SPSS Inc., Chicago, 330p.

Rittenhouse, G., 1967, Bromide in oil-field waters and its use in determining possibilities of origin of these waters: Bull. Amer. Assoc. Petrol. Geol., v.51, no.12, p.2430-2440.

Sanathanan, L., 1975, Discriminant analysis, in introductory multivariate analysis: (D. J. Amick and H. J. Walberg, eds.), McCutchan Pub. Co., Berkeley, p236-256.

Tabachnick, B. G. and L. S. Fidell, 1983, Using multivariate statistics: Harper & Row, Pub., New York, 509p.

U.S. EPA, 1979, Chloride, Method 325.3 (Titrimetric, Mercuric Nitrate): methods for chemical analysis of water and wastes: U.S. Environmental Protection Agency, Cincinnati.

Whittemore, D. O., 1984a, Geochemical identification of the source of salinity in groundwaters of southeastern Seward County, Kansas: Kansas Geological Survey: Open-File Report 84-3, 15p.

Whittemore, D. O., 1984b, Initial report on the geochemical identification of the source of salinity in groundwaters in northwestern Harvey County, Kansas Geological Survey: Open-File Report 84-6, 11p.

SECTION 7 RECLAMATION OF OIL BRINE HOLDING PONDS

by

Louis R. Iverson

INTRODUCTION

A survey conducted by IEPA in 1980 estimated that between 28 and 38 thousand acres in Illinois have been severely damaged by oil field brines (Coleman and Crandall, 1981). Surveys via aerial photographs of Hamilton and White Counties revealed the existence of considerably greater amounts of devegetated land. These barren lands are considered to have critical soils by the Soil Conservation Service because of the potential for severe erosion. Calculations made in Hamilton County estimated that an acre of brine damaged soils will annually lose, on average, 113 tons of material, compared with 7 tons for an acre of similar soil which has not been contaminated (Coleman and Crandall, 1981). The importance of reclaiming these brine contaminated soils cannot be understated, as erosional runoff from just a few acres can severely degrade adjacent water courses.

The excessive sodium in brine-affected soils readily enters into cation exchange reactions and disperses colloidal particles, thereby destroying the soil structure. This disaggregation leads to a highly impermeable soil which erodes excessively as water and soil move laterally rather than vertically during rain events (United States Salinity Laboratory Staff, 1969). These soils are considered saline-sodic.

To reclaim saline-sodic soils, the sodium ions must be leached from the soil particles. Two criteria need to be met for this process to occur: (1) sufficient water must be applied so that precipitation plus irrigation exceeds consumptive use, and (2) infiltration rather than runoff must occur. In Illinois, precipitation generally exceeds consumptive use in contrast to locations in the West. To increase percolation in these sites, a vegetative cover of any kind (even dead, mulch material) is needed to reduce runoff and increase infiltration capacity.

The addition of calcium-rich substances, like lime or gypsum, also can aid in the recovery of sodium-rich soils, with the excess calcium replacing sodium on soil exchange sites. The sodium ions then disassociate and become very water soluble for rapid leaching.

Several methods have been utilized to hasten recovery of brine-contaminated soils. One which has been successful in southern Illinois is the "Wayne County Method" which uses a combination of tile drainage, lime or gypsum, mulch, and chiseling to help hasten the process of leaching (Townsend, 1982). The disadvantages of this method are that tiling is an expensive procedure and that the site needs to be left undisturbed for two years while sodium is leached from the soil. The Soil Conservation Service (1986) has developed a set of standards and specifications for establishing a vegetative cover on high sodium and salt-damaged soils. It includes the planting of some salt-tolerant grasses.

The purpose of this study was to further assess whether the use of salt-tolerant species would allow a more rapid establishment of vegetative cover, which in turn, can hasten infiltration of water and leaching of sodium. Most of the selected species were obtained from western sources where naturally salinized soils are common.

MATERIALS AND METHODS

Plant Species Selection

A total of 17 species were selected to test for survival and growth on the brine contaminated soils (table 7-1): seven shrubs (1 from Fabaceae, 1 from Elaeagnaceae, and 5 from Chenopodiaceae), two leguminous forbs, and 8 grasses. Selection of species was based on the author's personal experience during doctoral and post-doctoral research in North Dakota (Iverson and Wali, 1982), discussions with experts in the field, and a review of the literature (Redente et al., 1982; Thornburg, 1982; Fulbright et al. 1982; Kies and Depuit, 1984; Monsen and Plummer, 1978; Best et al., 1971, Vogel, 1981).

Plant materials were purchased from Native Plants, Inc., in Salt Lake City, Utah. The first five species listed in table 7-1 were purchased or grown and planted as containerized seedlings, the remainder were sown as seeds. All species were planted at the rates given in table 7-1. Quantities of seed sown varied according to seed distributor's recommendations for sowing in pure stands, quantity of seed, and tested germination percentage. Seeds of Hedysarum boreale were scarified with sandpaper prior to planting to enhance its germination percentage.

Test Plot Preparation

A test plot was established during the period April 14-24, 1986. It measured 17m by 17.5m and was located in the area of an abandoned brine holding pond in the northeast corner of Section 33, T3N R7E (figure 7-1). A randomized block design was constructed within the plot with three replicates of four treatments for each of the 17 plant species tested (figure 7-2). The treatments were: (1) control - no amendments, (2) fertilizer - addition of 100kg/ha nitrate, 100kg/ha phosphorus,

Table 7-1. Plant materials selected for transplanting or seeding in the test plot. Seed or transplant density also given (PLS = pure live seed) given.

1) Robinia neomexicana - (locust shrub)	4 transplants m-2
2) Atriplex gardneri - (Gardner's saltbush)	6 transplants m-2
3) Atriplex confertifolia - (shadscale)	4 transplants m-2 (poor condition)
4) Atriplex canescens - (four wing saltbush)	4 transplants m-2
5) Shepherdia argentea - (Silver buffaloberry)	4 transplants m-2
6) Agropyron elongatum - (Jose tall wheatgrass)	6.0g (280 PLS) m-2
7) Trifolium subterranean - (Mt. Barker subterranean clover)	5.0g (1500 PLS) m-2
8) Sporobolus airoides - (Alkalai Sacaton)	0.8g (1040 PLS) m-2
9) Puccinellia distans - (Fults alkalai grass)	6.0g (15,600 PLS) m-2
10) Elymus triticoides - (Creeping wildeye 'shoshone')	5.0g (175 PLS) m-2
11) Atriplex cuneata - (Castle Valley saltbush)	3.4g (50 PLS) m-2
12) Hedysarum boreale - (Utah sweetbetch)	10.1g (12 PLS) m-2
13) Elymus junceus - (Russian wildrye)	3.0g (360 PLS) m-2
14) Ceratoides lanata - (winter fat)	3.4g (56 PLS) m-2
15) Agropyron trachycaulum - (slender wheatgrass)	5.0g (250 PLS) m-2
16) Eragrostis curvula - (weeping lovegrass)	0.7g (330 PLS) m-2
17) Panicum virgatum - (switch grass)	5.0g (550 PLS) m-2

Figure 7-1. Location of test plot. Case study site B, Section 33, T. 3 N., R. 7 E., Clay County.

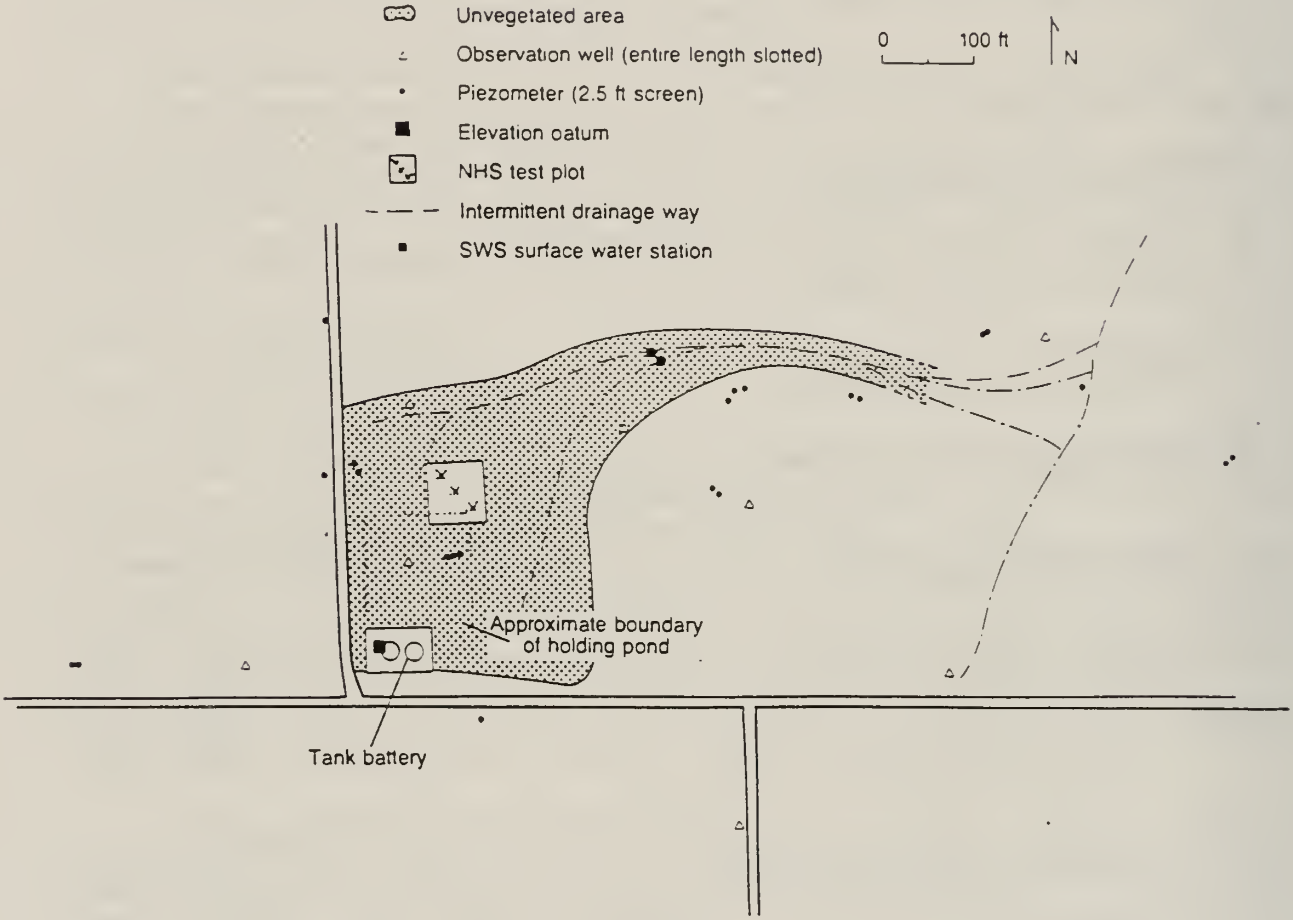


Figure 7-2. Plot layout. Numbers in subplots equate to designation given in table 7-1 for plant species. Four treatments with three replicates were used.

1m

N

G = Gypsum
F = Fertilizer

																	Treatment
7	9	12	14	16	11	17	10	3	4	2	6	1	15	5	13	8	G 1
15	3	2	14	4	12	11	16	6	17	10	7	8	13	5	9	1	F + G 3
11	12	9	6	4	2	7	13	15	10	16	17	5	1	3	14	8	Control 2
12	4	5	13	3	10	6	16	8	14	7	2	1	9	15	17	11	F + G 2
1	16	3	11	12	8	14	7	4	13	10	7	2	9	15	6	5	F 1
13	8	11	12	2	14	4	3	6	15	9	16	7	17	1	10	5	Control 1
10	6	3	14	16	15	13	12	8	2	17	5	1	4	7	11	9	G 3
9	4	11	8	5	10	13	15	3	6	16	12	17	7	14	1	2	F + G 1
15	16	10	13	7	14	6	8	5	9	3	11	17	2	4	12	1	F 2
14	16	7	10	13	15	9	3	2	11	8	17	4	12	6	1	5	Control 3
11	8	5	3	17	1	16	15	14	9	6	10	7	2	4	13	12	G 2
9	10	17	1	3	5	11	16	6	14	2	7	15	13	8	4	12	F 3

100kg/ha potassium; (3) gypsum - addition of 4481 kg/ha (2 tons/acre); and (4) fertilizer plus gypsum - addition as in (2) and (3). The plot consisted of 204 randomly distributed subplots, 1m x 1m in size with 50cm buffer strips between each treatment block (figure 7-2).

The plot area was disked repeatedly to a depth of 20 cm on April 14, 1986. The area was staked out into subplots, and fertilizer and gypsum treatments were then applied to the specific subplots and raked into the soil to a depth of approximately 8cm. Approximately one liter of dilute 'Miracle Grow' (a solution of 2.25 g 20N, 20P, 20K fertilizer per liter water) was applied to each seedling at the time of transplanting. Seeds were broadcast by hand and incorporated to varying depths depending on the size of the seed. All subplots were mulched with a layer of wheat straw to increase moisture retention.

Some additional Atriplex canescens (15 plants) and Atriplex gardneri (8 plants) were transplanted around the plot to assess survival under low care conditions. These plants were placed in the ground by opening up the soil with a spade and packing the soil around the transplant soil tubes; no water, fertilizer, or mulch was applied. The overall appearance of the plot is presented in figure 7-3, a photo taken one month after the plot was established. The area surrounding the plot continued to be completely barren for the entire year.

Plot Monitoring

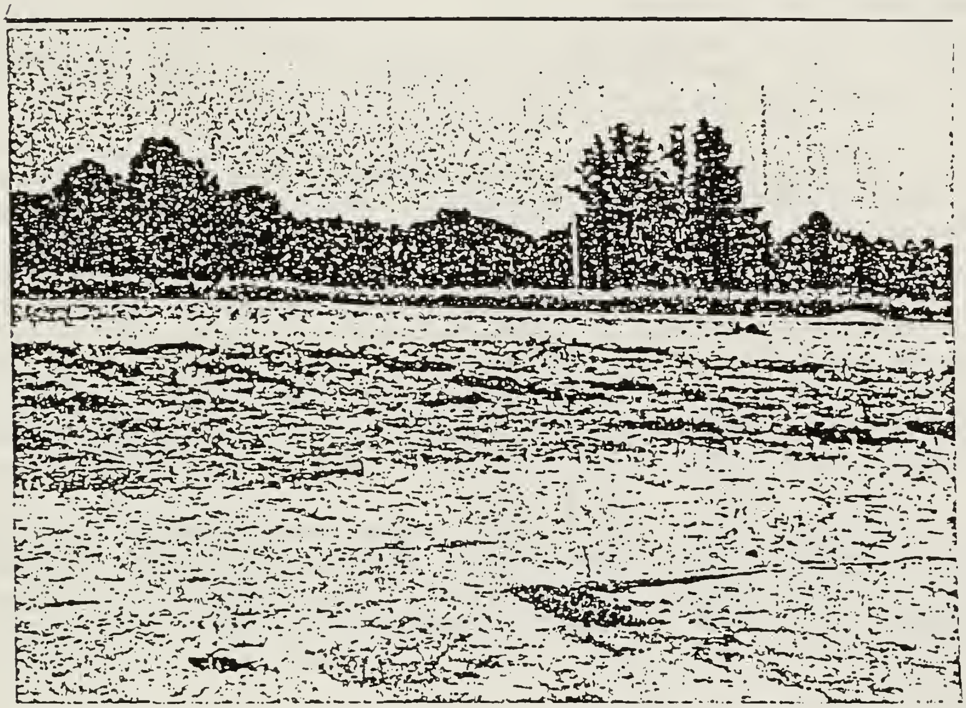
Site visits were made at monthly intervals throughout the growing season. For five monthly site visits, transplant survival and height were recorded for the five transplanted shrubs. The sown species were subjectively evaluated, on a 0-10 rating scheme, for germination, vigor, and growth at each site visit. A rating of 0 indicated no germination whereas a rating of 10 indicated 100% cover and vigorous growth.

Rainfall measurements were recorded daily at the Klein farm, about 2 km west of the site.

At the end of the growing season (mid-October), the eight grass species were sampled for biomass by clipping two 25cm x 25cm quadrats from each subplot. Weeds and planted materials were separated into different bags, the contents were then oven dried at 65 C and weighed. A total of 96 subplots were clipped.

Soil samples were collected on: April 14 (before planting), July 16 mid-season), and October 18 (end of season). Samples were collected from 2 depths (0-15cm, 15-30cm) from all subplots for two species. This amounted to 144 samples (3 dates x 2 depths x 2 species x 4 treatments x 3 replicates).

Figure 7-3. Test plot asit appeared at the time of planting, April 14, 1986.



Laboratory Analysis

The 96 harvested plant biomass samples (weed and planted) were dried and weighed. A subset of these samples from six grass species were selected for further tissue analysis. The harvested plant material from 72 plots was sent to A & L Agricultural Laboratories of Memphis, Inc. for wet digestion and analysis of chloride (Cl), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sodium (Na), aluminum (Al), manganese (Mn), copper (Cu), and zinc (Zn).

Soil samples were dried, ground, and passed through a 2mm screen. Electrical conductivity was performed on the samples by extracting 1 part soil with 2 parts water, filtering the suspension through Whatman No. 1 filter paper and reading conductivity values on the solutions with a Yellow Springs Instruments electrical conductivity meter. Soil samples were also sent to A & L Agricultural Laboratories of Memphis, Inc., for analysis of pH, organic matter (OM), available phosphorus, exchangeable potassium, magnesium, calcium, calculated cation exchange capacity (CEC), soluble salts, and sodium (Na).

Statistics utilized for comparisons among treatments and among species with plant and soil chemical data included the ANOVA and GLM procedures in SAS. The Duncan test was used for multiple comparisons among means if the F statisticic was significant at the 0.05 level.

RESULTS AND DISCUSSION

Environmental Conditions On Site

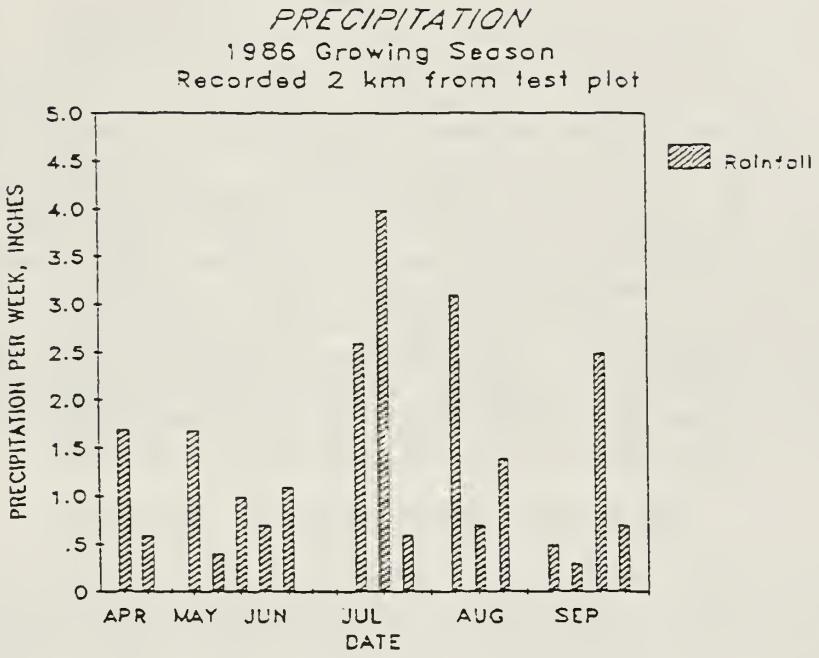
Rainfall measurements were recorded daily at the Klein farm, about 2 km west of the site. Overall, 23.6 inches of rain fell in the vicinity of the plot during the growing season (mid-April to late-September, 1986). This is about normal for that area. Rainfall was not evenly distributed throughout the growing season, however. Weekly rainfall totals show a dry period in late April (just after transplanting) and a very dry two-week period in late June (Fig. 7-4). These two dry periods were harmful to at least some of the transplants and seedlings, as can be seen in the seasonal assessments of the species.

Species Success

a. <u>Agropyron</u> <u>elongatum</u> (Poaceae)

Tall wheatgrass is native to Siberia; it was introduced to this continent in 1929 by the University of Saskatchewan (Best et al., 1971). It is a perennial grass not recorded in the Illinois flora (Mohlenbrock, 1986). It is considered the most salt tolerant of all cultivated grasses, excellent for hayfields and

Figure 7-4. Weekly rainfall amounts at the plot during the 1986 growing season.



pastures on saline soil (Best et al. 1971). It is also considered excellent cover for upland game birds (Thornburg, 1982).

Our first year data concur with these assessments. Rating values for this species were above 8 for all treatments for nearly the entire growing season (figure 7-5). There tended to be higher vigor in the non-control subplots, with the gypsum treated subplots best in August and September (figure 7-5). Productivity data from the tall wheatgrass subplots also show significantly increased yields due to gypsum, it was the only species which showed significant benefits from the addition of calcium sulphate (figure 7-6). The bar graphs like that of figure 7-6 are constructed with planted material biomass on the bottom and weed biomass on the top of each bar; the four bars on the left represent the means of three replicates for each individual treatment with the four bars on the right representing the means of six replicates, with and without fertilizer or gypsum treatment}. Fertilizer-treated subplots showed dramatic and significant increases in both planted and weedy biomass, although even the control plots did relatively well providing cover, forage material, and erosion control.

b. Agropyron trachycaulum (Poaceae)

Slender wheatgrass is native to and has a wide distribution within North America and the northern part of Illinois. It is reported to be tolerant of alkali and is useful as a short-lived species in reclamation plantings and range seeding, primarily in the West (Thornburg, 1982). It persists in rocky areas, but is easily destroyed by cultivation or prolonged grazing (Dore and McNeill, 1980). It was also found to be tolerant of a salinized roadside environment in Maine (Pitelka and Kellogg, 1979). This species was observed on mined lands in North Dakota; it persists well for about three years and then gives way to other species invasions (Iverson and Wali, 1982). This may be the desired effect in reclaiming salt brine contaminated areas.

The rating values for A. trachycaulum are high for the fertilizer-treated subplots, but rapidly diminish for the control and gypsum treatments (figure 7-7). Biomass values also show significant increases due to fertilizer and significantly decreased yields due to gypsum treatments (figure 7-8). The gypsum treatment even caused significant depressions in yield when compared against the control. Addition of fertilizer alone benefitted yields two-fold over the fertilizer plus gypsum treatment and three-fold over the controls (figure 7-8).

c. Atriplex canescens (Chenopodiaceae)

Four-wing saltbush, as the name implies, is tolerant of considerable alkalinity. It is also very drought resistant and

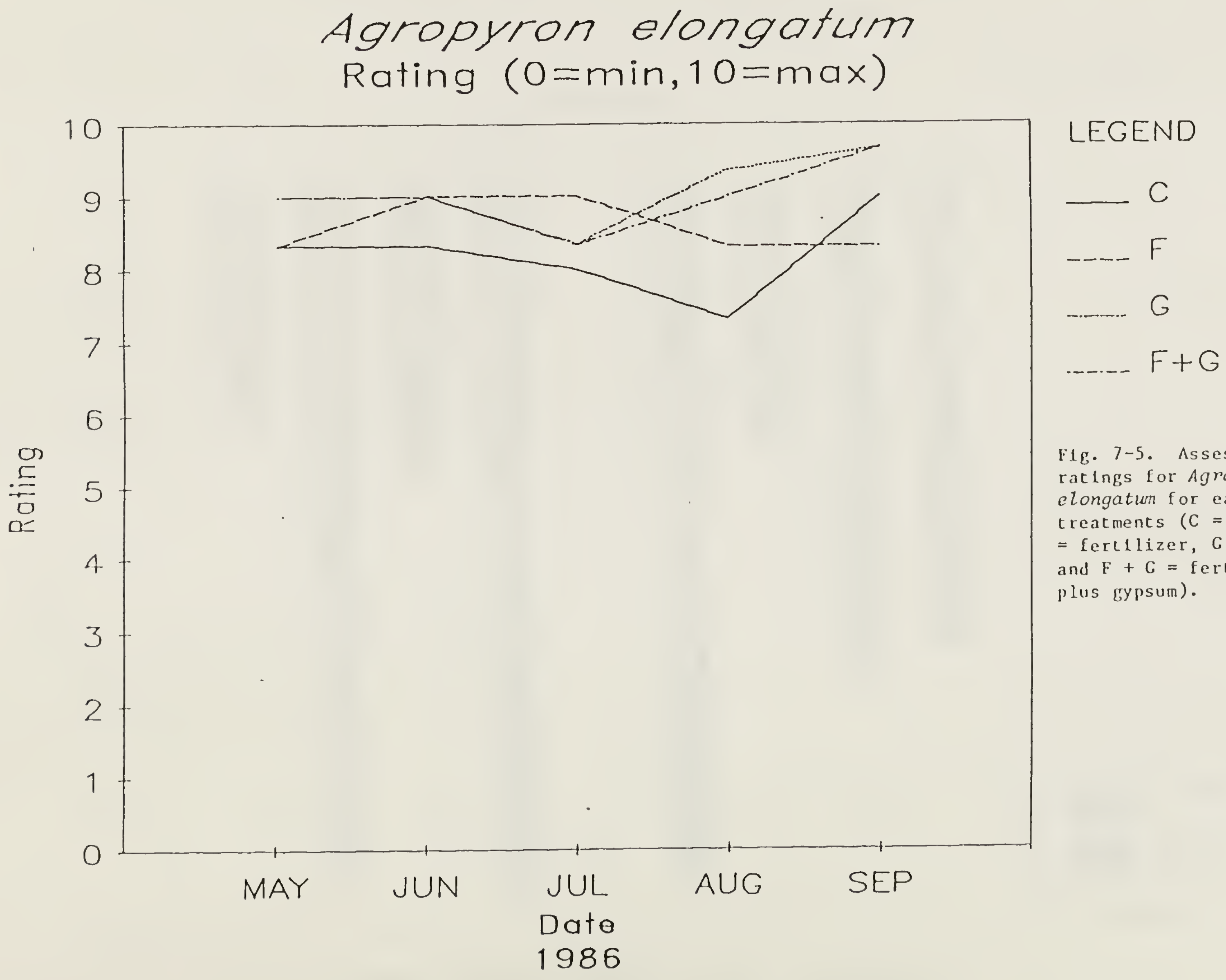


Fig. 7-5. Assessment ratings for *Agropyron elongatum* for each of four treatments (C = control, F = fertilizer, G = gypsum, and F + G = fertilizer plus gypsum).

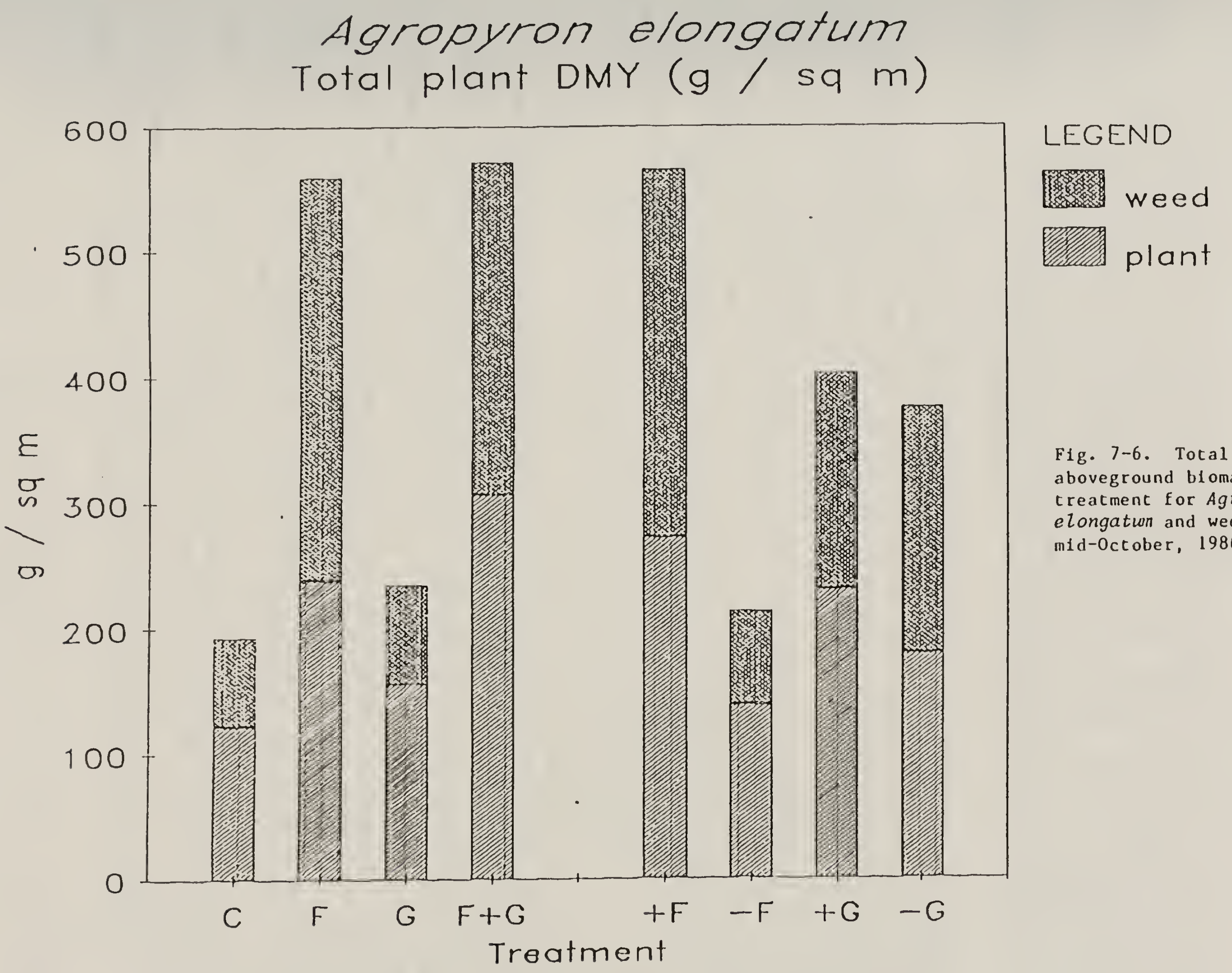


Fig. 7-6. Total aboveground biomass by treatment for *Agropyron elongatum* and weeds in mid-October, 1986.

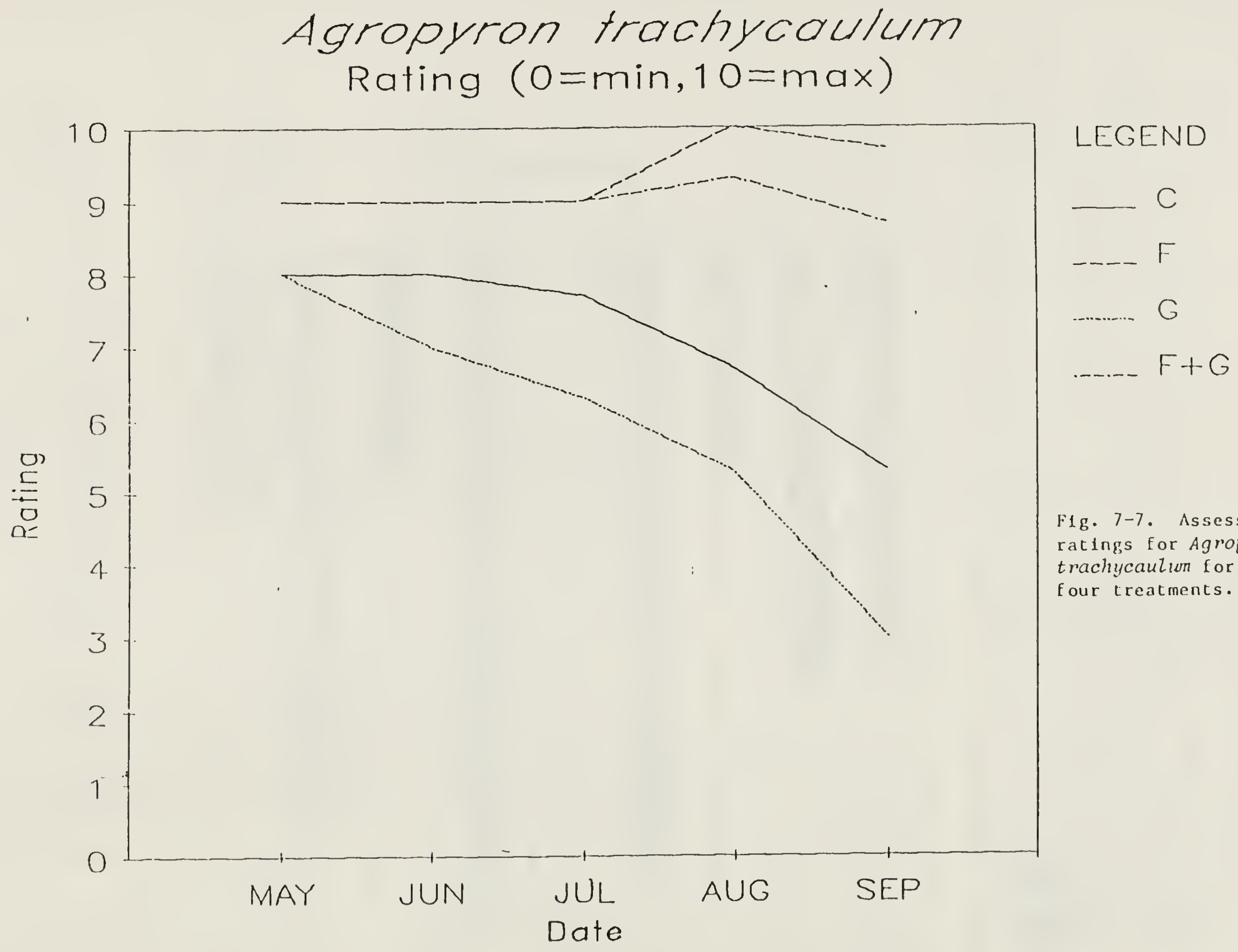


Fig. 7-7. Assessment ratings for *Agropyron trachycaulum* for each of four treatments.

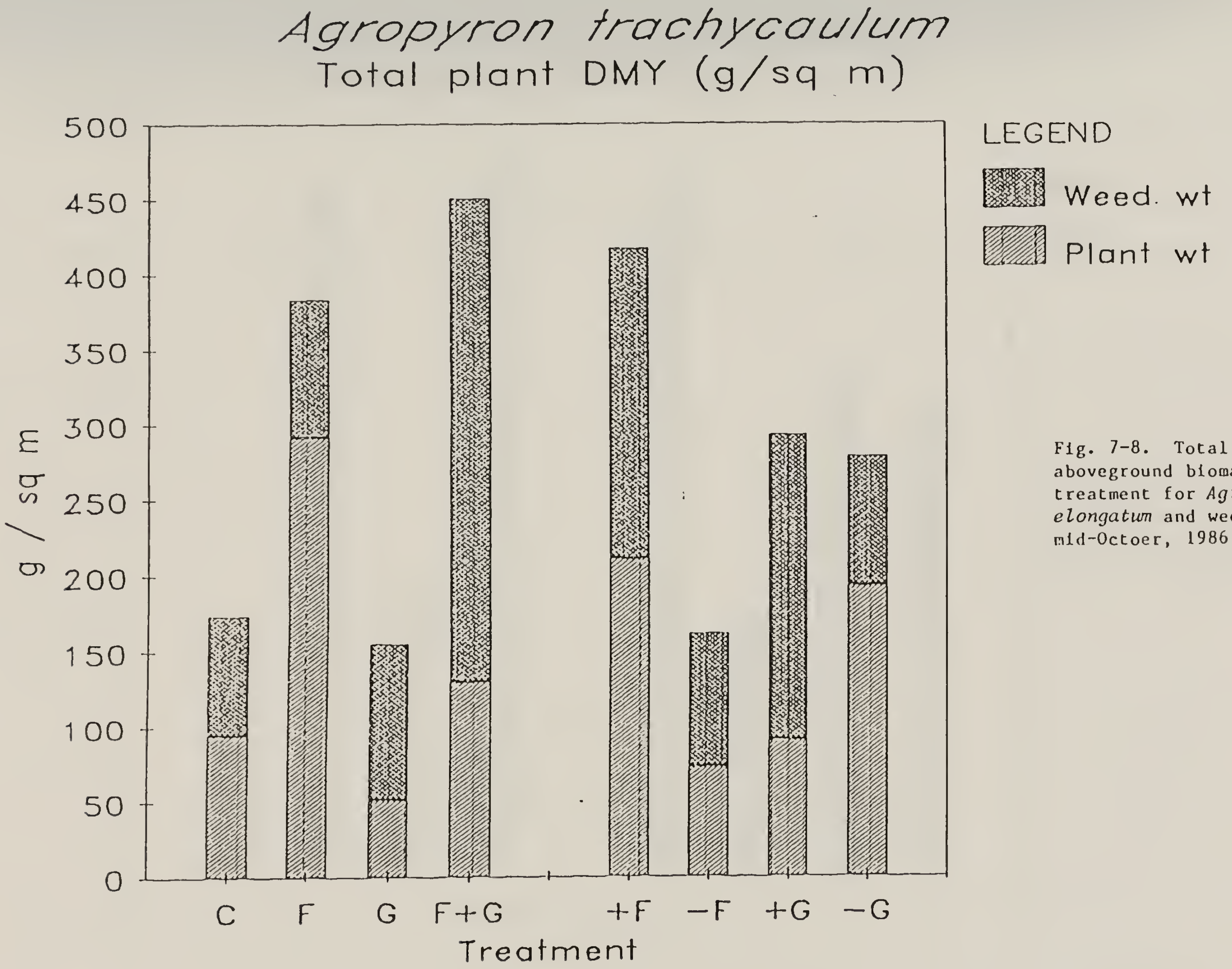


Fig. 7-8. Total aboveground biomass by treatment for *Agropyron elongatum* and weeds in mid-Octoer, 1986.

survives and grows well on dry sites (Blauer et al., 1975). It is a dioecious shrub which occurs widely on desert and foothill ranges in the western United States. It does not occur naturally in Illinois. It persists well in association with other shrubs and grasses, and is a fair to good browse species for deer (Ostyina et al., 1984).

A. canescens was the most successful transplanted species in this study. It had 100% survival in the subplots (figure 7-9), and even 100% in the low-effort transplants which were placed around the plot. It also grew well in all treatments, about 45 cm in non-fertilized subplots and 55 cm in fertilized subplots (figure 7-10).

d. Atriplex confertifolia (Chenopodioceae)

Shadscale is another fairly alkaline-tolerant shrub native to dry alkaline plains and hills in the western United States; it is not found naturally in Illinois (Rydberg, 1954, Martin and Hutchins, 1980). In this study, no transplants survived the full season. However, this is attributed primarily to the poor condition of the transplants upon arrival from Utah. The low vigor transplants were then subjected to abnormally dry, hot southerly winds in the first three days following transplantation. By June, no live A. confertifolia plants existed on the site.

e. Atriplex cuneata (Chenopodiaceae)

This species, called Castle Valley saltbush, is native to the southwestern United States and does not occur naturally in Illinois. It was the only Atriplex species which was sown, rather than transplanted on the site. Direct seeding of shrubs like these is commonly done on western mined lands, but often only about 1 seedling is established per 100 pure live seed sown (Luke and Monsen, 1984).

In this experiment, A. cuneata had very low germination and hence, few seedlings established. The rating assessments were low throughout the year, but were especially low in the early and late parts of the season (figure 7-11). The seeding rate was grossly underestimated for this species. Some seedlings did emerge by June, seemingly slightly better in the non-fertilized plots; the added competition from increased weed growth may have contributed to this. By September, most of the seedlings appeared dead or dying.

f. Atriplex gardneri (Chenopodiaceae)

Gardner's saltbush is native to Wyoming and Colorado, and is not found naturally in Illinois. It appears to prefer alkaline flats or dry lake beds (Rydberg, 1954). It is a low growing,

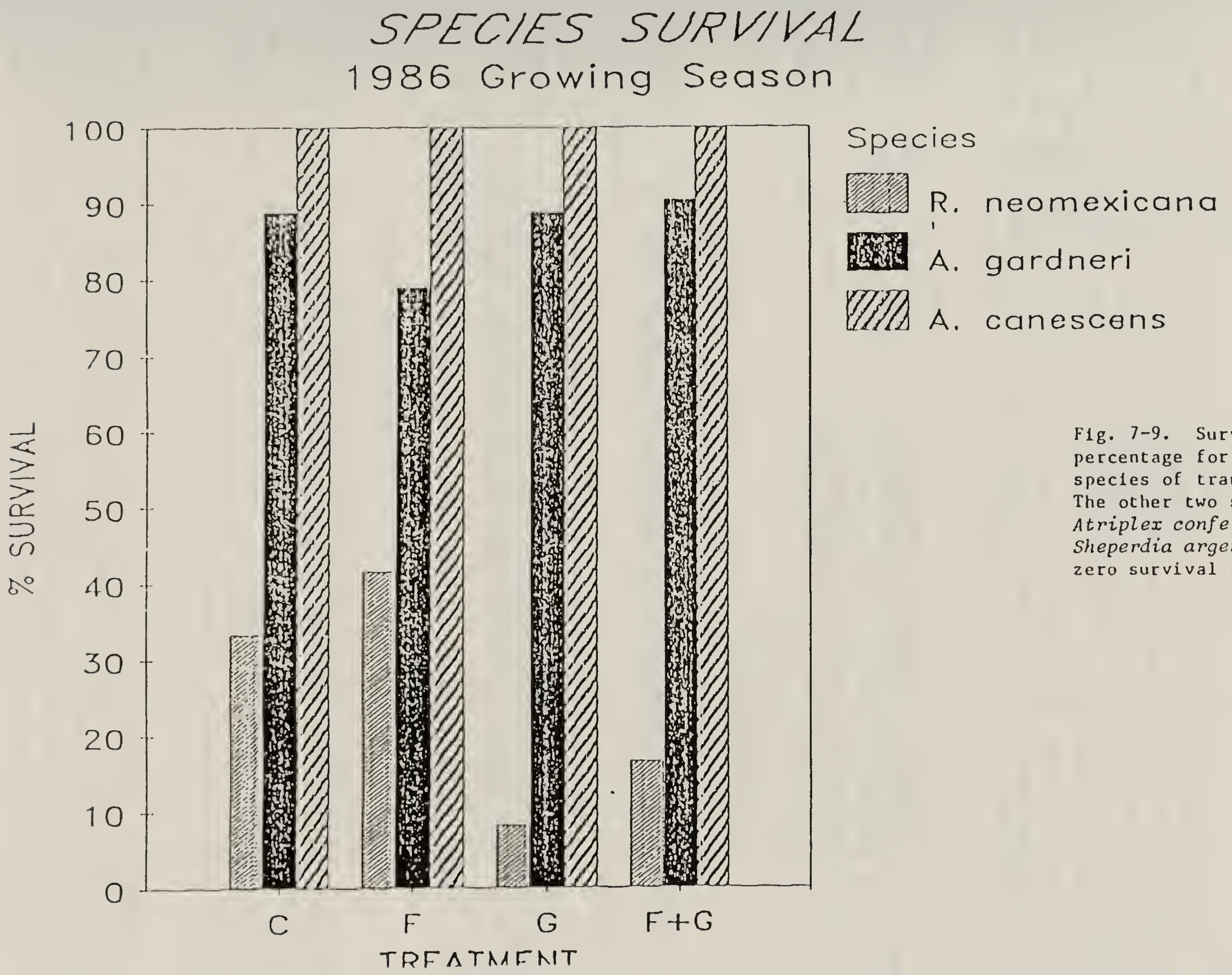


Fig. 7-9. Survival percentage for three species of transplants. The other two species, *Atriplex confertifolia* and *Sheperdia argentea*, had zero survival in 1986.

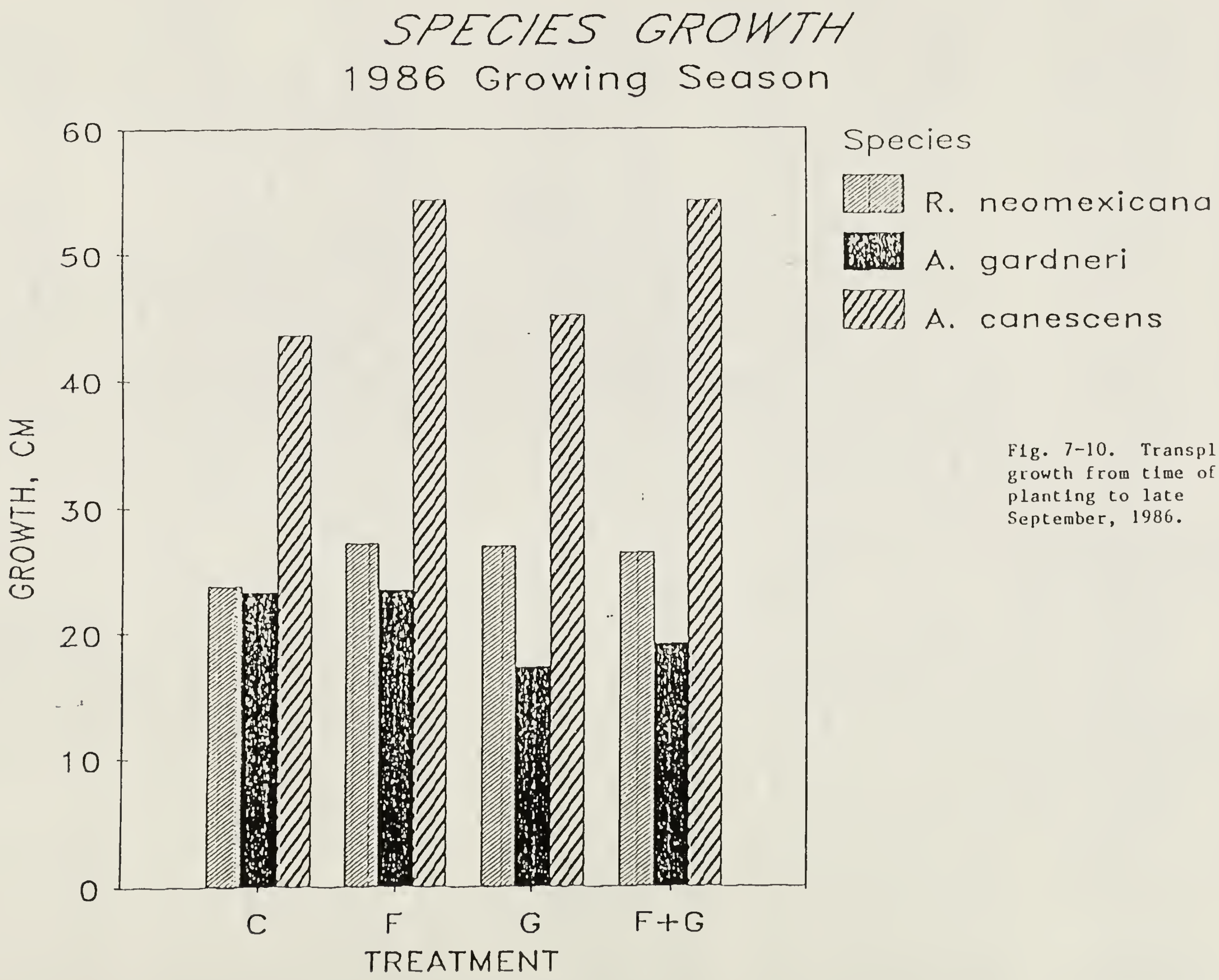


Fig. 7-10. Transplant growth from time of planting to late September, 1986.

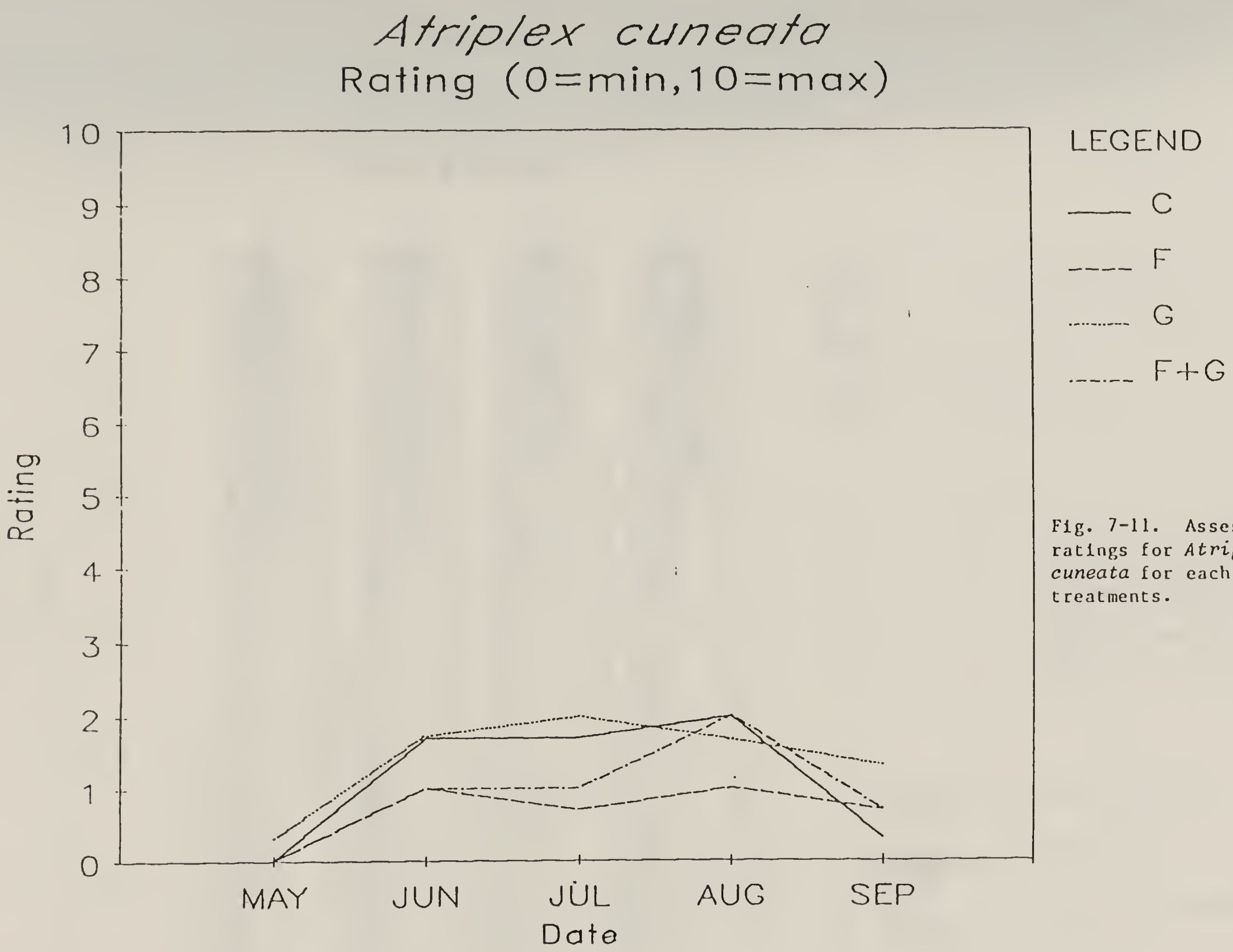


Fig. 7-11. Assessment ratings for *Atriplex cuneata* for each of four treatments.

persistent shrub which has been shown to be successfully established on western mined lands by transplanting (Frischknecht and Ferguson, 1984) or by direct seeding (Luke and Monsen, 1984). In one experiment, 94% of transplants were still surviving after five years of growing on processed oil shale (Frischknecht and Ferguson, 1984).

In this study, four transplants purchased from the Utah nursery were placed in each subplot; additionally, 2 plants grown from seed in the Illinois Natural History Survey greenhouses were transplanted in each subplot. Overall, survival during the first year was 87%, with no significant differences in survival for different treatments (figure 7-9). By the time of the last assessment on September 26, 1986, many previously vigorous A. gardneri plants were showing signs of reduced vigor - some appeared dead. Apparently, these plants were entering season-end scenescence on that date. Growth for this species was only half that of A. canescens, with slightly more growth on nongypsum treated subplots (figure 7-10).

g. Ceratoides lanata (Chenopodiaceae)

Winterfat is a long-lived, low-statured, C3 shrub native to dry, sandy or shallow clay loam soils of western North America (Springfield, 1979). It has been shown to survive very well as transplants into harsh spoil material (Iverson et al., 1984) and can thrive in salinized, droughty environments (Iverson, 1986). However, it is not very competitive against weeds during the seedling establishment phase (Iverson, 1986).

In this study, seedling establishment was sparse; the direct seeding rate was insufficient for adequate seedling establishment (as was the case with Atriplex gardneri, Luke and Monsen, 1984). A few seedlings emerged in May, but the June drought and competition from weeds may have contributed to its poor performance in the summer and fall (figure 7-12). The fertilized plants survived slightly better than non-fertilized plants. Previous studies indicate this species would survive well from transplants into salinized environments (Iverson et al., 1984). This species needs further investigation.

h. Elymus junceus (Poaceae)

Russian wildrye was introduced from Siberia. It is used for pasture in the northern parts of the Great Plains and in the western intermountain area (Thornburg, 1982). It is not found in Illinois. Wildrye is slow to establish but is very persistent (Best et al., 1971).

In this first year of the study, we confirmed that it is slow to establish. The assessment ratings show medium levels were achieved throughout the season for this species (figure

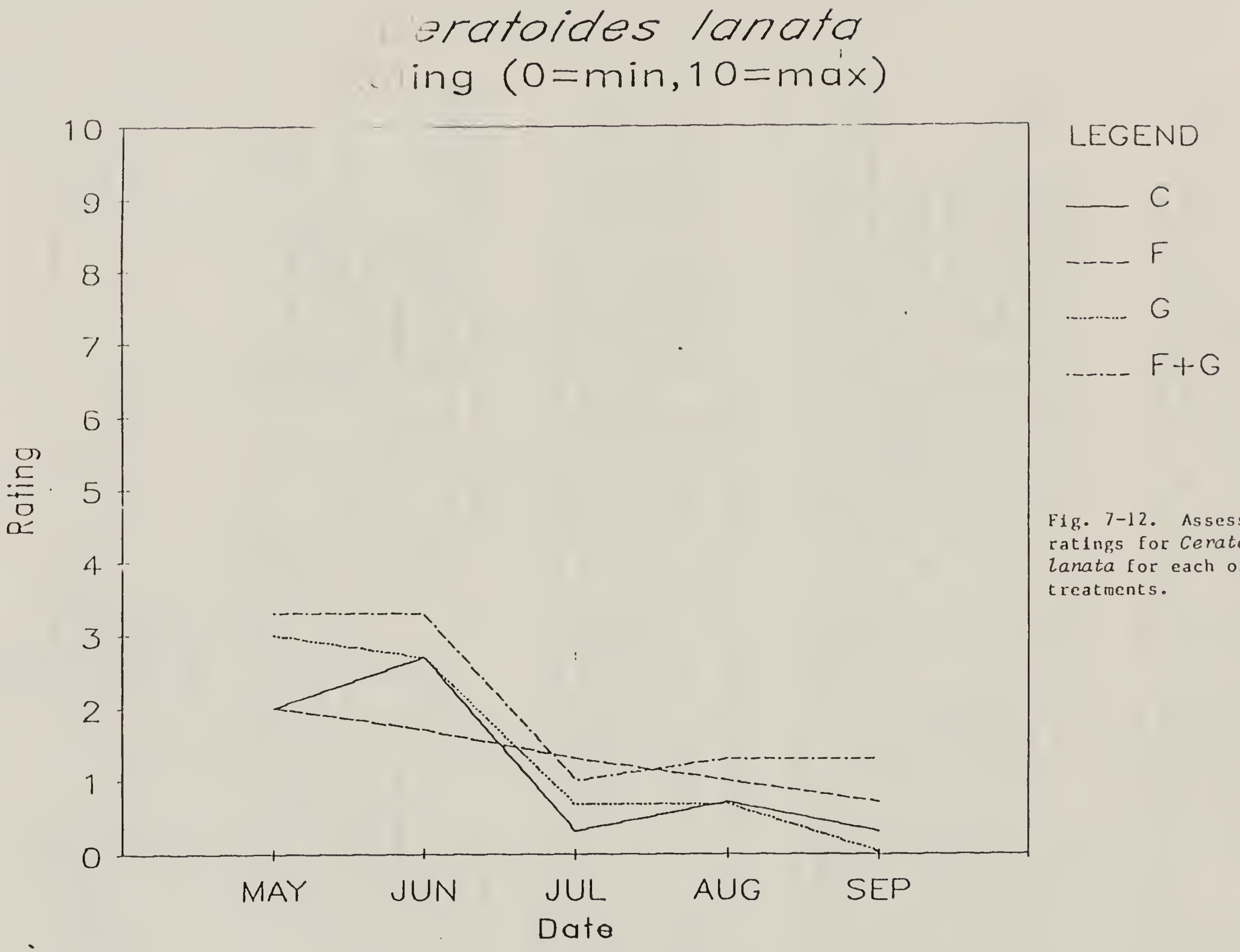


Fig. 7-12. Assessment ratings for *Ceratoides lanata* for each of four treatments.

7-13). It is also important to note that the fertilizer treatment was beneficial to the vigor and survival of the species. The data show a tremendous increase in biomass, especially weed biomass, in the fertilizer treated plots (figure 7-14). A noticeable depression in wildrye growth was evident in the gypsum treated plots. The total planted yields were much lower relative to most other grass species. But, it is yet to be seen whether this species will become more established and become more productive in the second year.

i. Elymus triticoides (Poaceae)

This species, creeping wildrye, also is not native to Illinois but is native to the western states. It is a species highly tolerant to salt and alkali, and is adapted to a wide range of soil textures (Thornburg, 1982).

The subjective ratings for this species indicated relatively poor establishment and growth, especially on non-fertilized subplots (figure 7-15). Yet its vigor did not decrease during the season as some species did. Total wildrye biomass was extremely low, with some benefits apparent from the addition of fertilizer (figure 7-16). The proportion of weed biomass to planted biomass was higher with this species than any other. Fertilizer increased weed biomass 2.5 fold, and doubled wildrye biomass. We believe that this species will improve in the second year, since the species was healthy, though sparse, in its first year of growth, and since weeds commonly decrease in biomass after the first year (Iverson and Wali, 1982).

j. Eragrostis curvula (Poaceae)

Weeping lovegrass was introduced into this country from South Africa in 1927 (Kucera, 1961). It is a warm-season perennial found occassionaly throughout the southern United States, and has been seen in Morgan County, Illinois (Mohlenbrock, 1986). It is useful for controlling erosion and in the revegetation of grasslands because it provides a quick cover (Hitchcock and Chase, 1951). It is relatively short lived (2 to 4 years) unless foliage is removed by mowing, burning, or grazing (Vogel, 1981).

In our experiment, weeping lovegrass did not quickly establish in April and May, but substantially increased in prominence during the warm season (figure 7-17). There was a marked difference in assessment rating among treatments. Fertilizer was beneficial and gypsum was detrimental in establishment rate, amount of vigor and survival, and total biomass of the species (figures 7-17, 7-18). Its yield on the fertilized subplots exceeded that of any other species, with 395 g/m2 produced. The gypsum treatment yield, on the other hand, was only 7% that of the fertilized subplots. This species, not

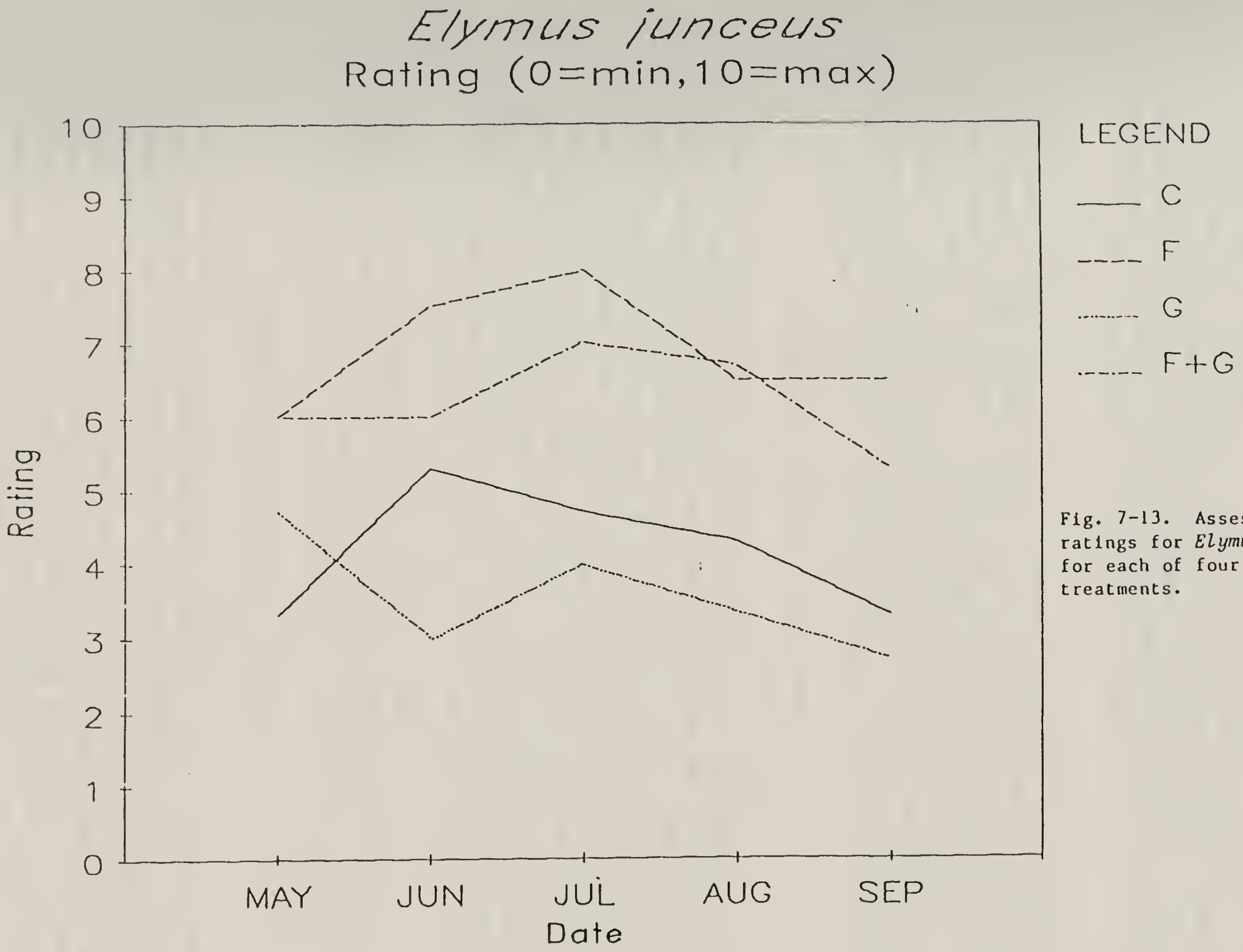


Fig. 7-13. Assessment ratings for *Elymus junceus* for each of four treatments.

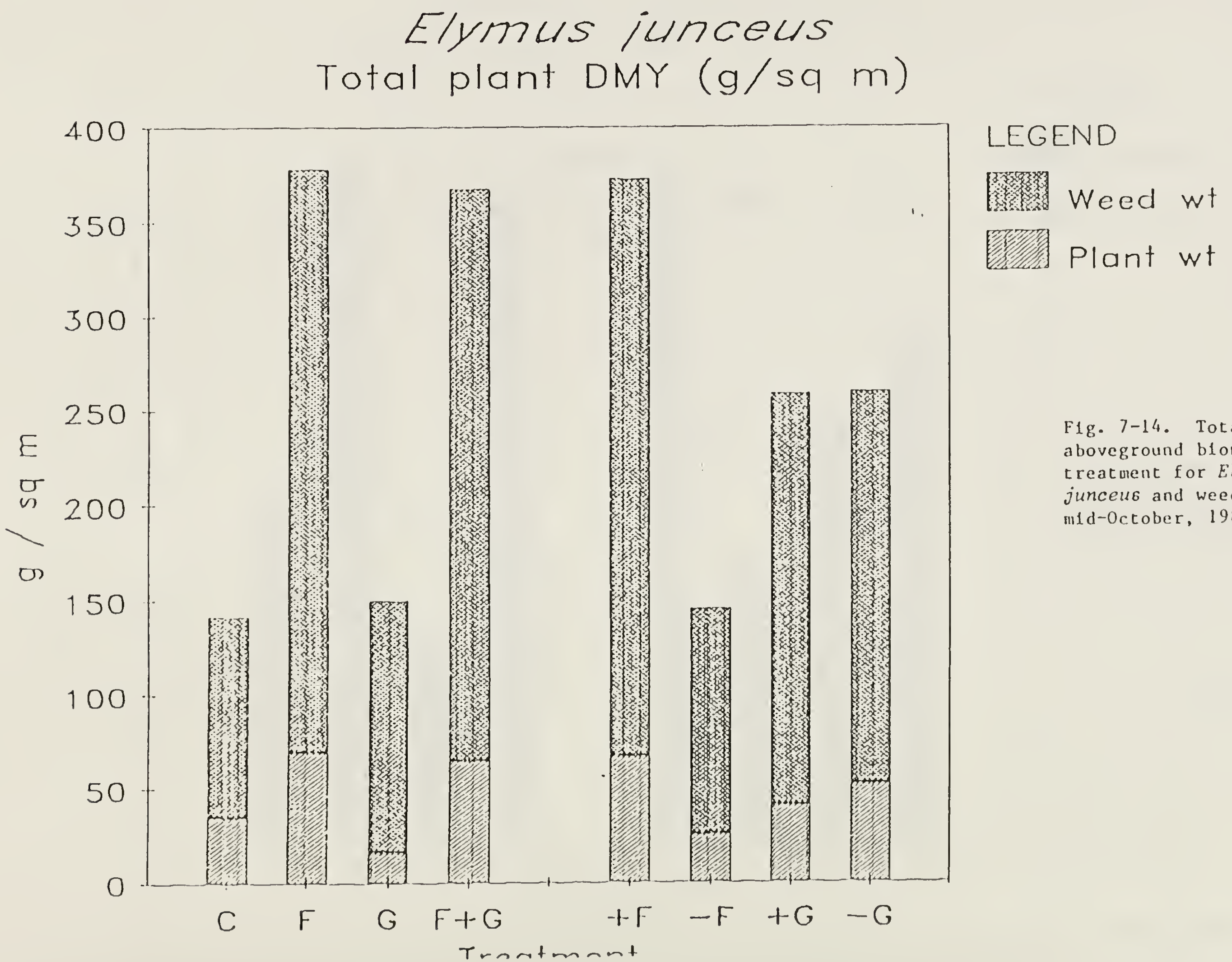


Fig. 7-14. Total aboveground biomass by treatment for *Elymus junceus* and weeds in mid-October, 1986.

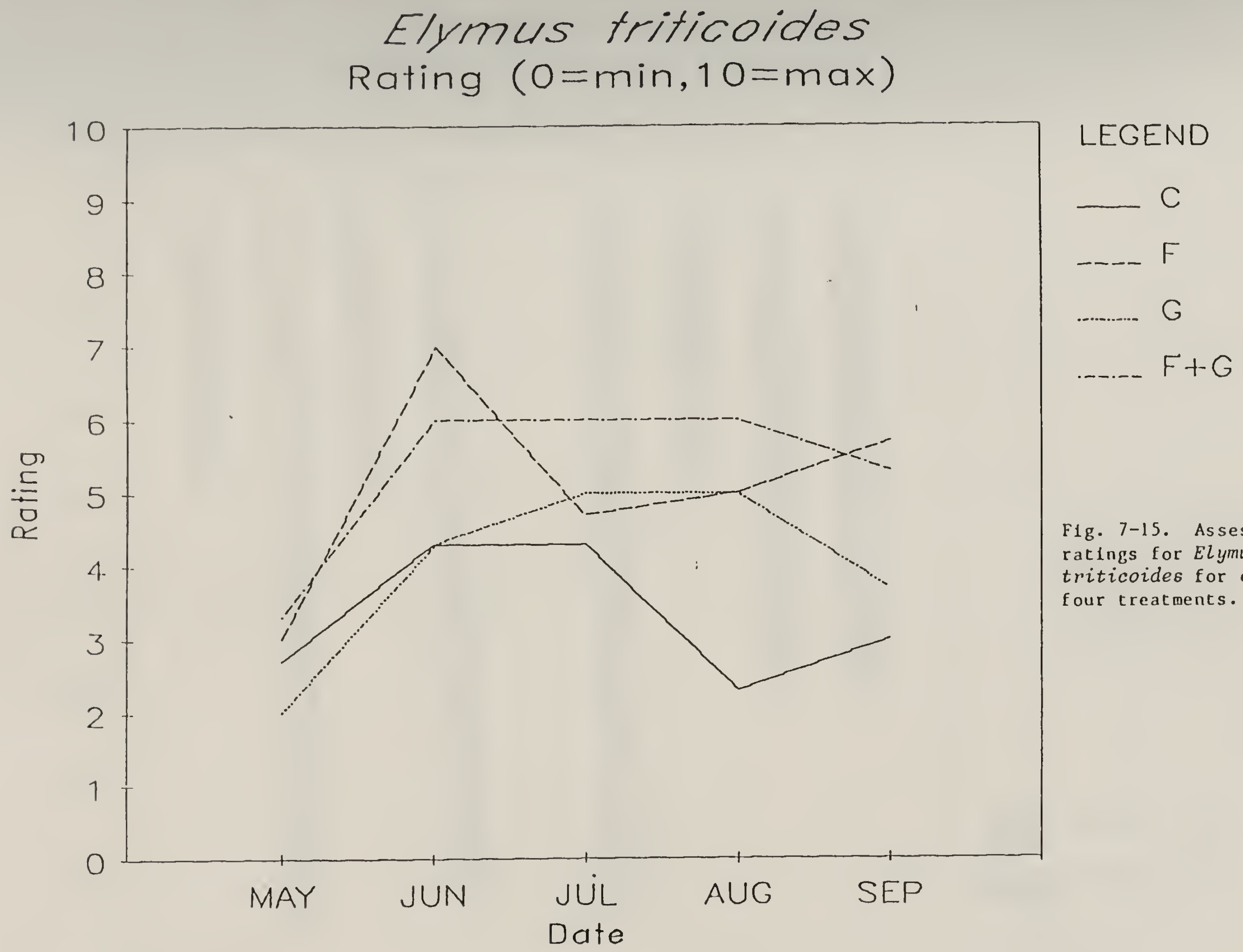


Fig. 7-15. Assessment ratings for *Elymus triticoides* for each of four treatments.

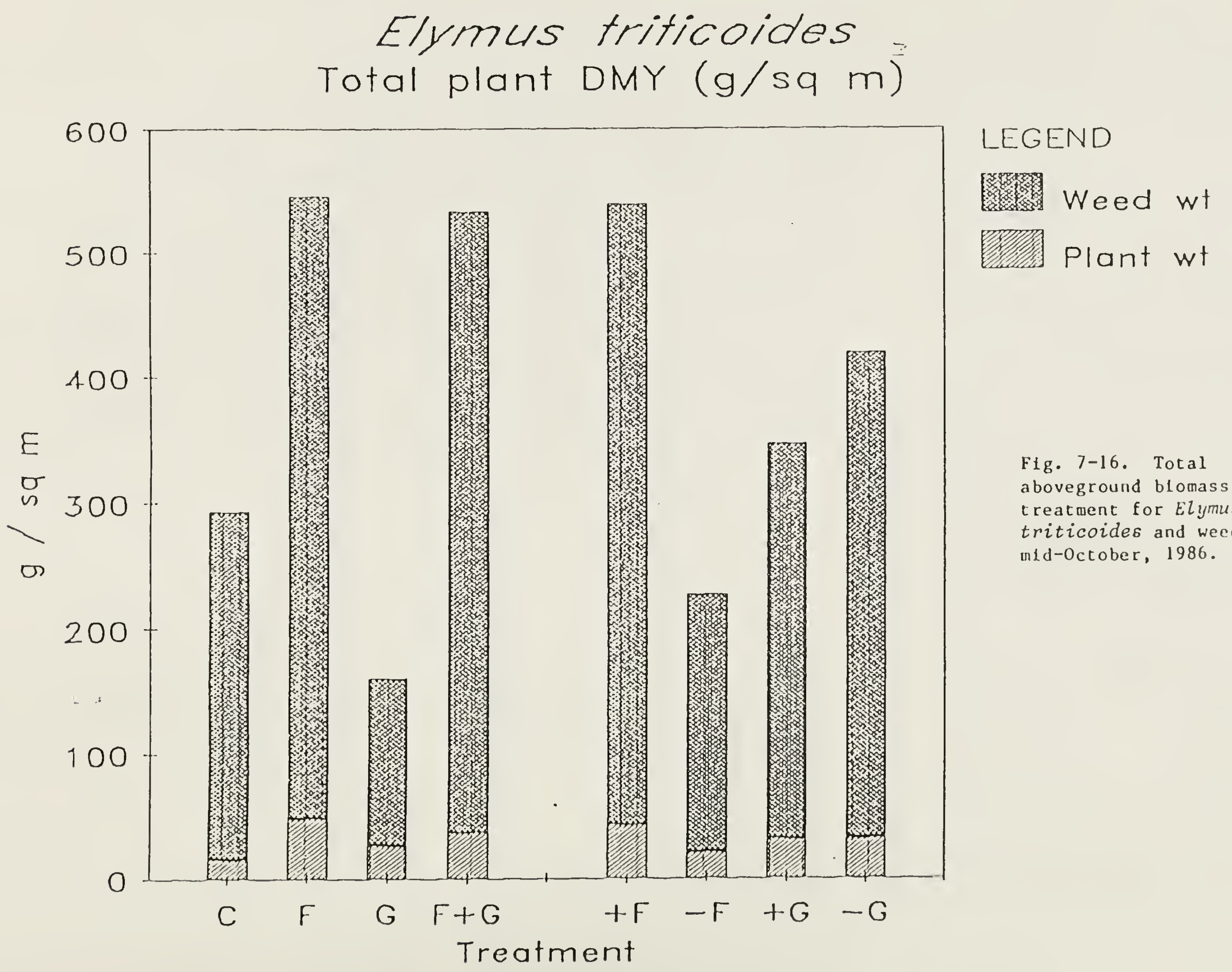


Fig. 7-16. Total aboveground biomass by treatment for *Elymus triticoides* and weeds in mid-October, 1986.

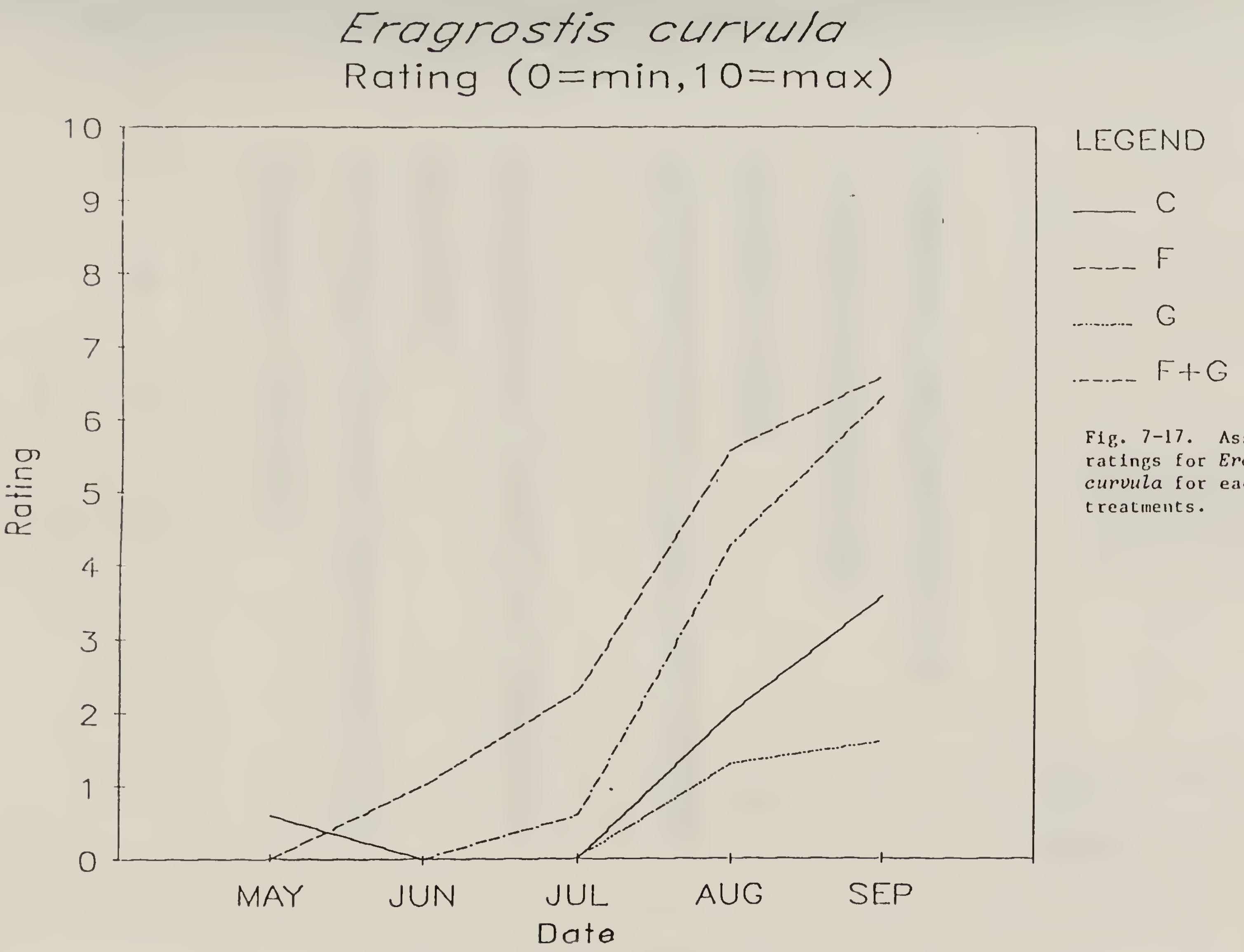


Fig. 7-17. Assessment ratings for *Eragrostis curvula* for each of four treatments.

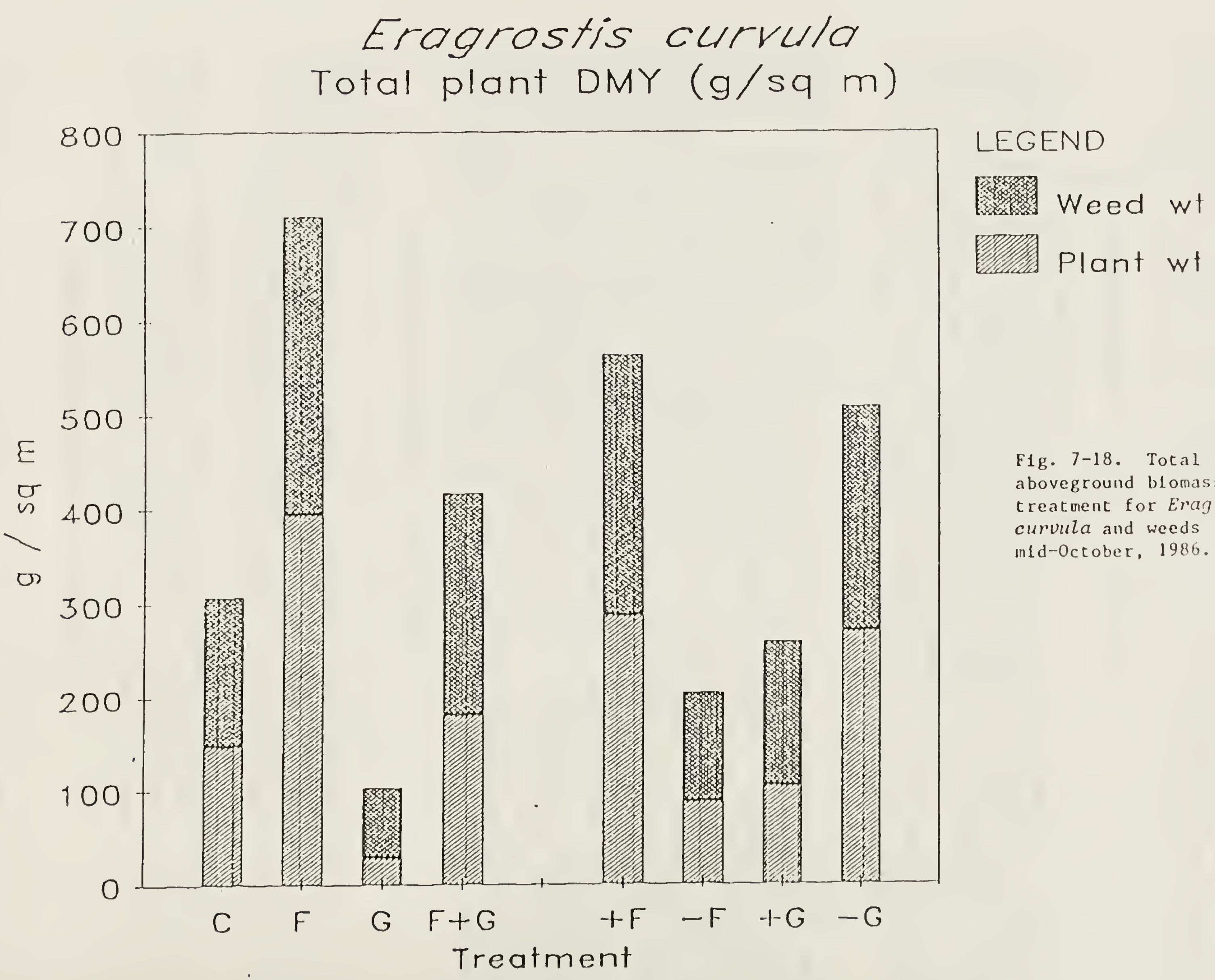


Fig. 7-18. Total aboveground biomass by treatment for *Eragrostis curvula* and weeds in mid-October, 1986.

being strictly a western species, apparently cannot tolerate calcareous conditions which resulted from the addition of calcium sulfate.

k. Hedysarum boreale (Fabaceae)

Northern sweetvetch is native to the northern Great Plains in the United States and Canada; it is not found naturally in Illinois. As a legume, it is capable of nitrogen fixation and has been suggested as a potential species for stressful sites.

It did very poorly in our study. Some germination occurred early; but by September, little or no live activity was apparent (figure 7-19). Part of the problem is the hard seed coat on the seed and apparently the seeds were not adequately scarified prior to planting.

l. Panicum virgatum (Poaceae)

Switchgrass is a widely distributed native, warm-season grass which ranges throughout the United States except for the west coast (Hitchcock and Chase, 1951). In Illinois, it is rather common throughout the state, and is found in prairies, fields, wasteground, rocky stream beds, and woods (Mohlenbrock, 1986). Plants are tall, large-stemmed, and spread by short rhizomes and seed. Stands usually require 2 to 4 years to develop good cover on mine spoils, but once established, require little maintenance (Vogel, 1981). Of the several cultivars available, the one planted in this study, 'Blackwell', has been shown by Soil Conservation Service trials to be the superior grass tested for survival and growth on brine contaminated soils (Soil Conservation Service, 1986). The species also produces excellent wildlife cover and the seeds are eaten by song and game birds (Thornburg, 1982).

In this study, switchgrass established moderately well in the first year of study, with variations in assessment ratings prevalent temporally and across treatments (figure 7-20). The final rating showed an advantage to fertilized subplots. Biomass data revealed a somewhat surprising result in that the control subplots did equally as well as fertilized subplots (figure 7-21), although variation was high among replicates. Addition of gypsum was noticeably detrimental.

m. Puccinellia distans (Poaceae)

This species, Fults alkalai grass, is an exotic, perennial grass introduced from Eurasia. It was introduced to western and northern U.S. and adjacent Canada (Hitchcock and Chase, 1951). In Illinois, it is occasionally found in the northeastern counties on disturbed soil (Mohlenbrock, 1986). It has been observed that along highways, P. distans encroaches closer to the

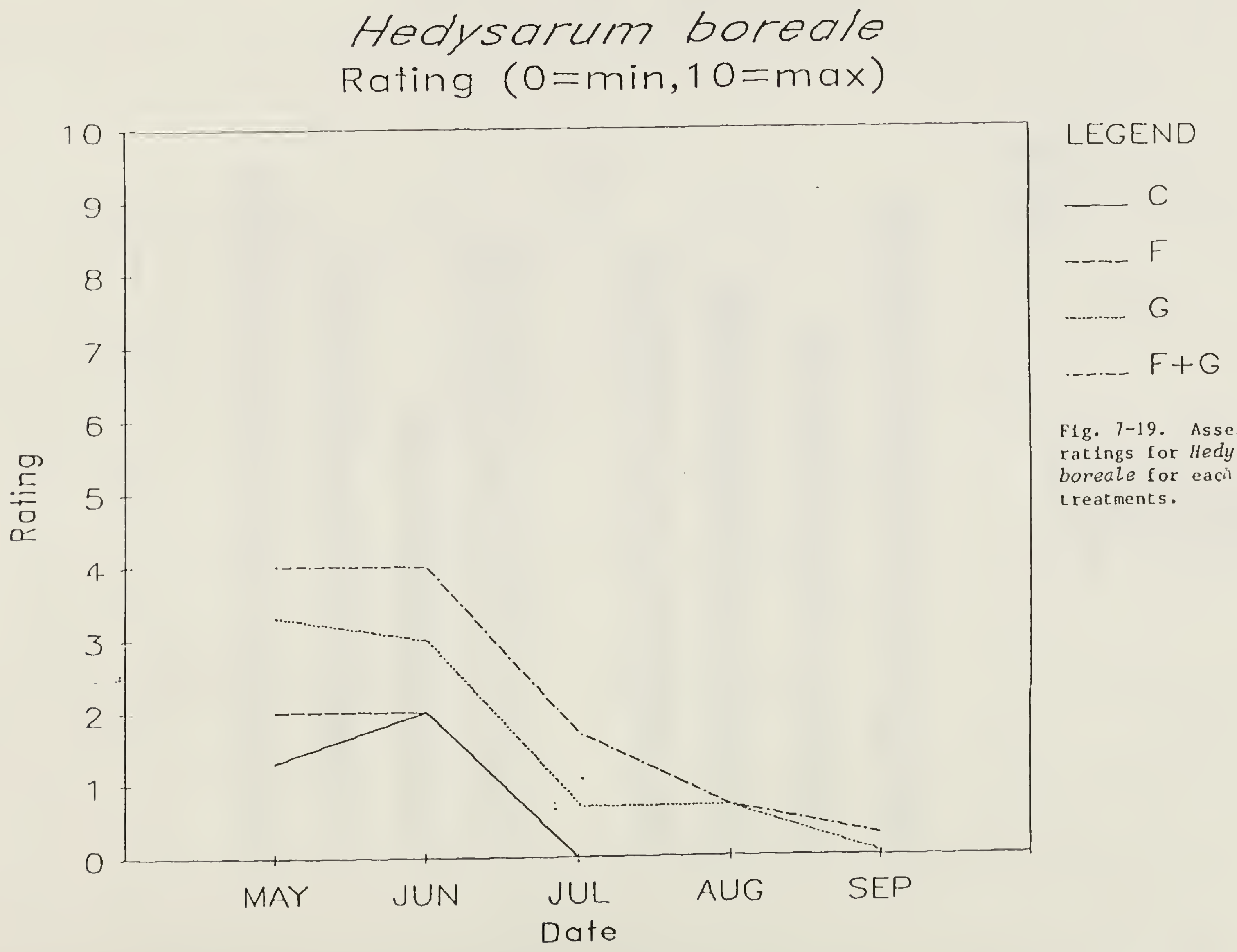


Fig. 7-19. Assessment ratings for *Hedysarum boreale* for each of four treatments.

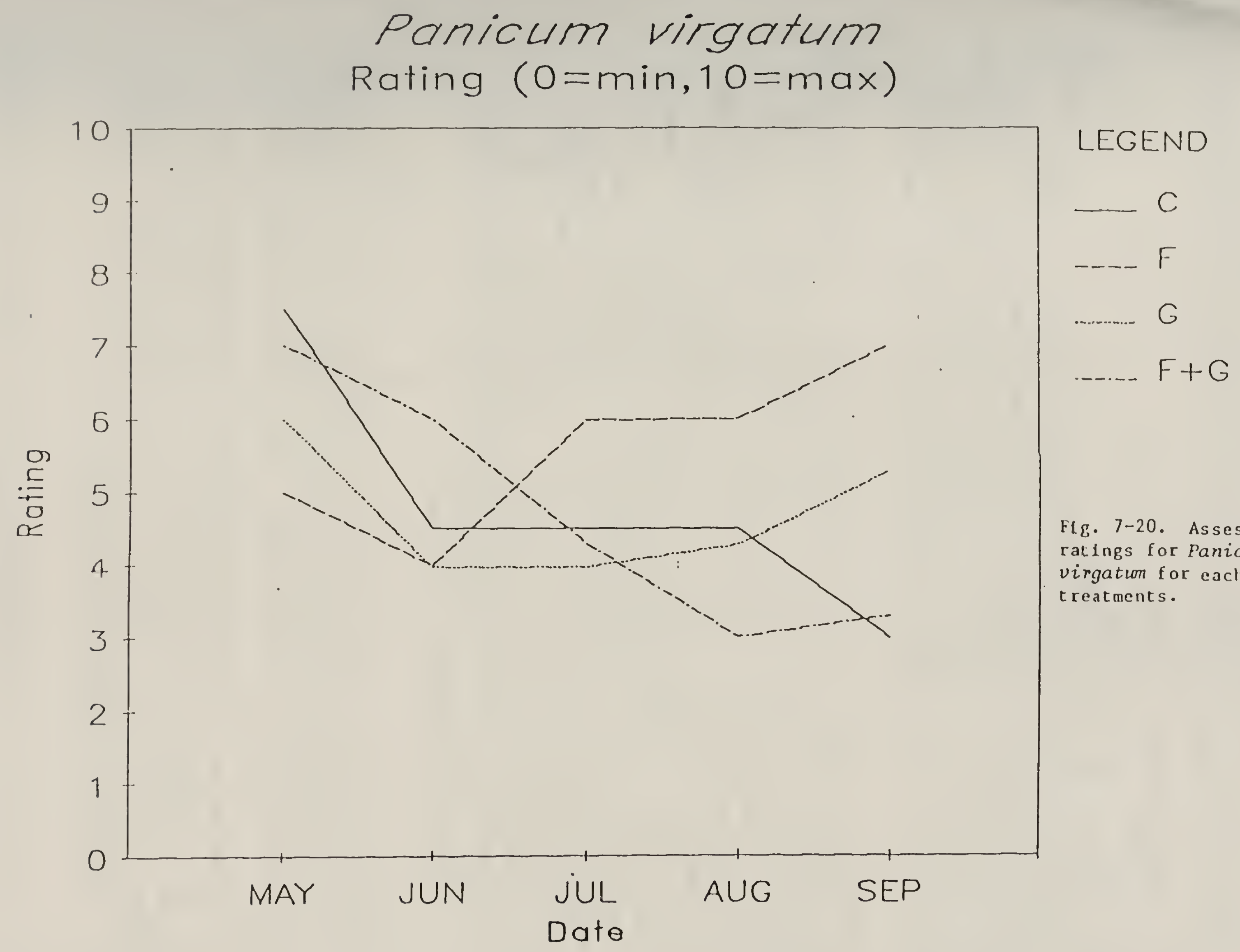


Fig. 7-20. Assessment ratings for *Panicum virgatum* for each of four treatments.

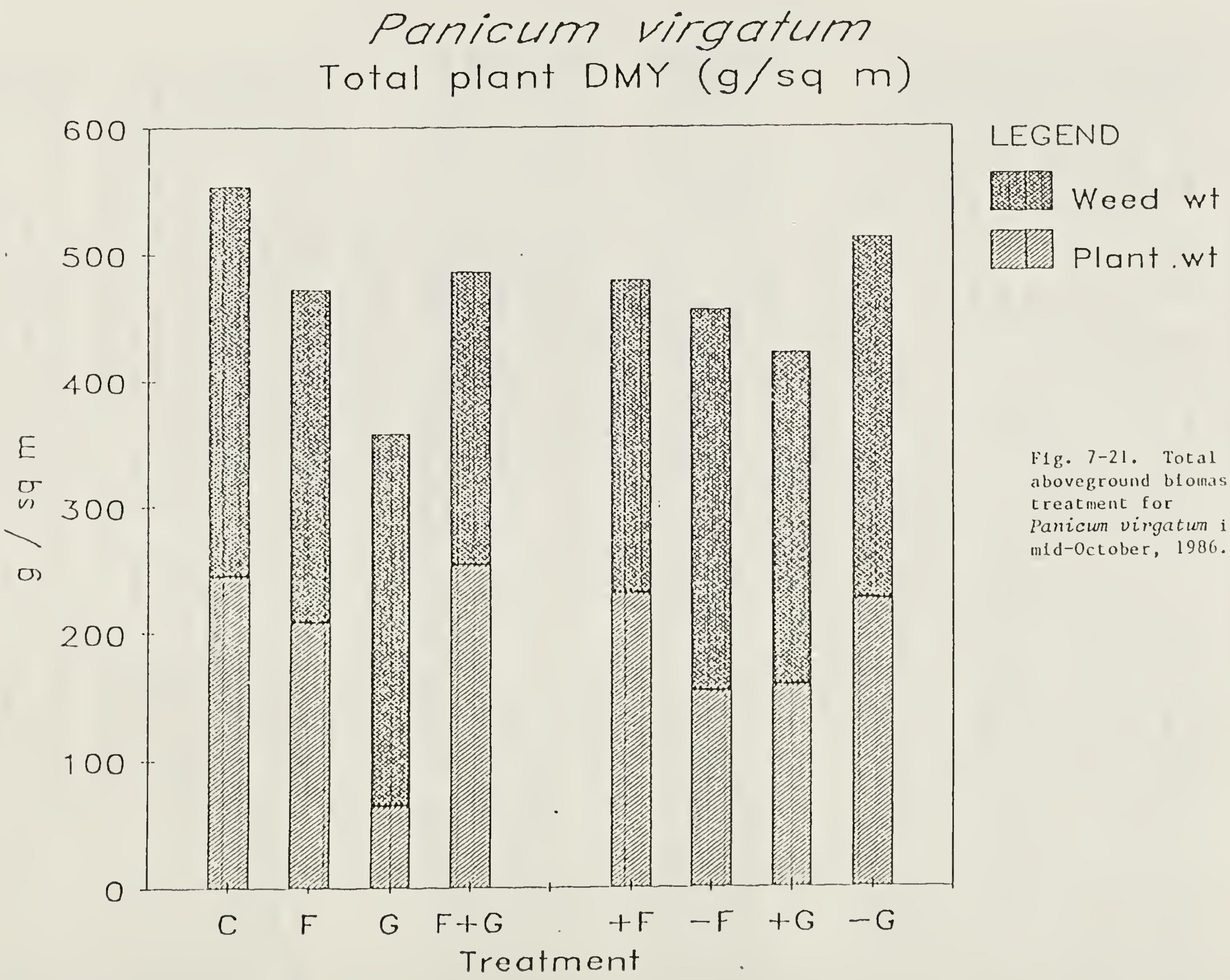


Fig. 7-21. Total aboveground biomass by treatment for *Panicum virgatum* in mid-October, 1986.

paved surface than other weed species, presumably because of its greater salt tolerance; it also may become more prevalent in years to come (Dore and McNeill, 1980). The species is also common on saltflats in the northern Great Plains.

In this experiment P. distans established very quickly from its dense sowing of very small seeds (table 7-1). A division in growth pattern occurred as the season progressed as the non-fertilized subplots appeared to degenerate with time (figure 7-22). With biomass, substantial benefits occurred from the addition of fertilizer (figure 7-23), with no changes resulting from the gypsum treatments. The quick cover and high salt tolerance of this species makes it a desirable candidate for reclaiming brine contaminated soils.

n. Robinia neomexicana (Fabaceae)

This species, a locust shrub with thorns, is native to the Southwest (Colorado, New Mexico, Arizona, Utah, Nevada) and is not in the Illinois flora. It will form thickets and it spreads freely from stumps and roots; in fact, it can be difficult to eradicate (Thornburg, 1982). Its habitat naturally is in moist soils along streams at elevations of 4000 to 8500 feet, quite different from conditions in southern Illinois.

In this experiment R. neomexicana proved to be only marginally successful. Survival rates during the first year ranged from 8 percent on gypsum plots to 42 percent on fertilized plots (figure 7-9). Most of the surviving plants lacked vigor; they averaged about 20cm growth from time of transplanting to season end (figure 7-10).

o. Sheperdia argentea (Eleagnaceae)

Silver buffaloberry is native to Kansas, New Mexico, Nevada, and Utah, north to Saskatchewan and Alberta (Hitchcock and Chase, 1951); it is not reported in the Illinois flora (Mohlenbrock, 1986). It is most common on sandy soils but also grows on moist soils; it is the author's experience to see it growing in swales of higher moisture content in pastures of North Dakota. It produces excellent wildlife food and cover. It is also used as an ornamental plant and in windbreak plantings. It has considerable promise for use on mined lands in the northern Great Plains (Thornberry, 1982), although it is not particularly salt tolerant. Apparently, the salinity was excessive for this species as all of the buffaloberry plants perished in the first year, even though they were highly vigorous when transplanted.

p. Sporobolus airoides (Poaceae)

Alkalai sacoton is native to the western half of North America, it occurs as far east as northwestern Missouri on dry

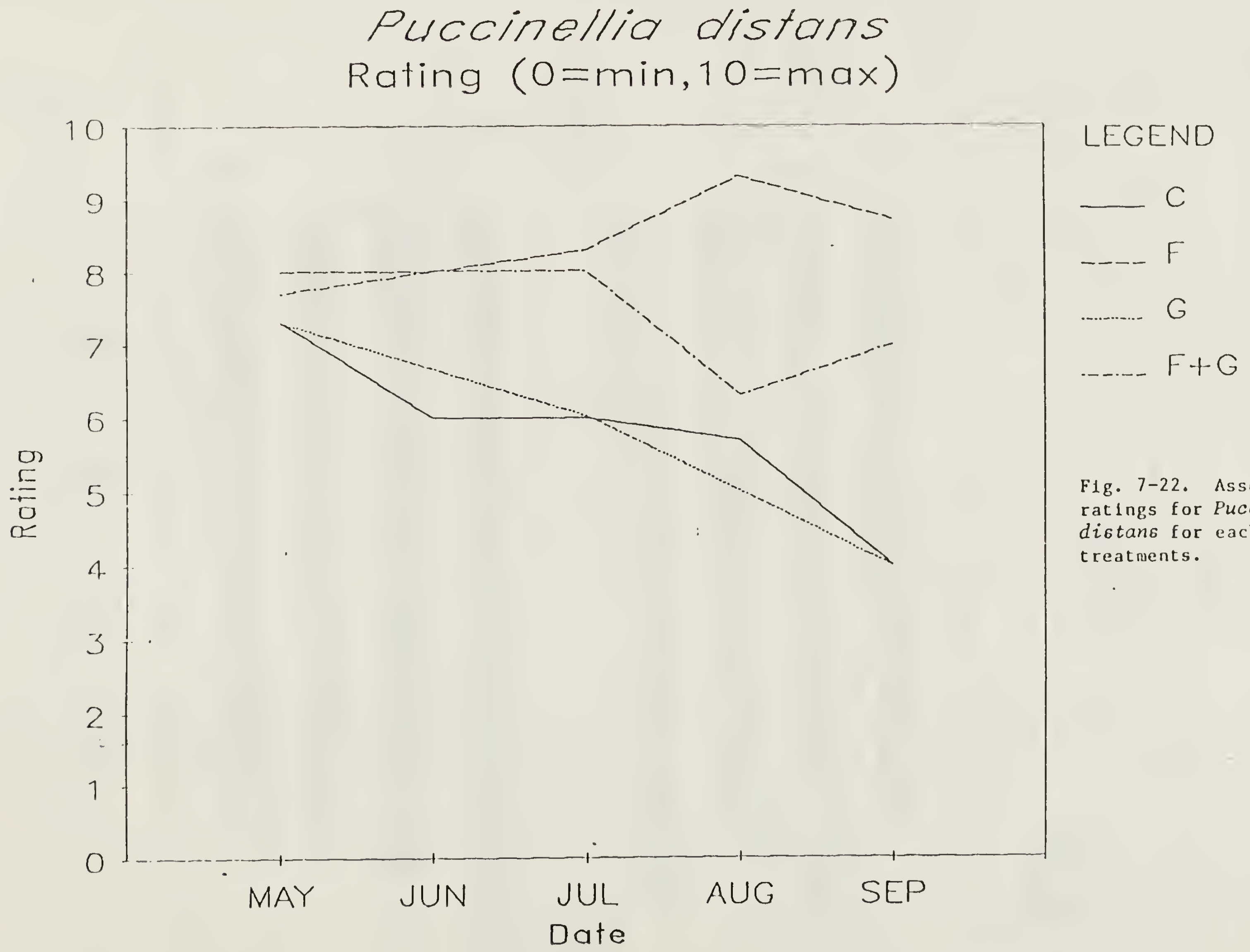


Fig. 7-22. Assessment ratings for *Puccinellia distans* for each of four treatments.

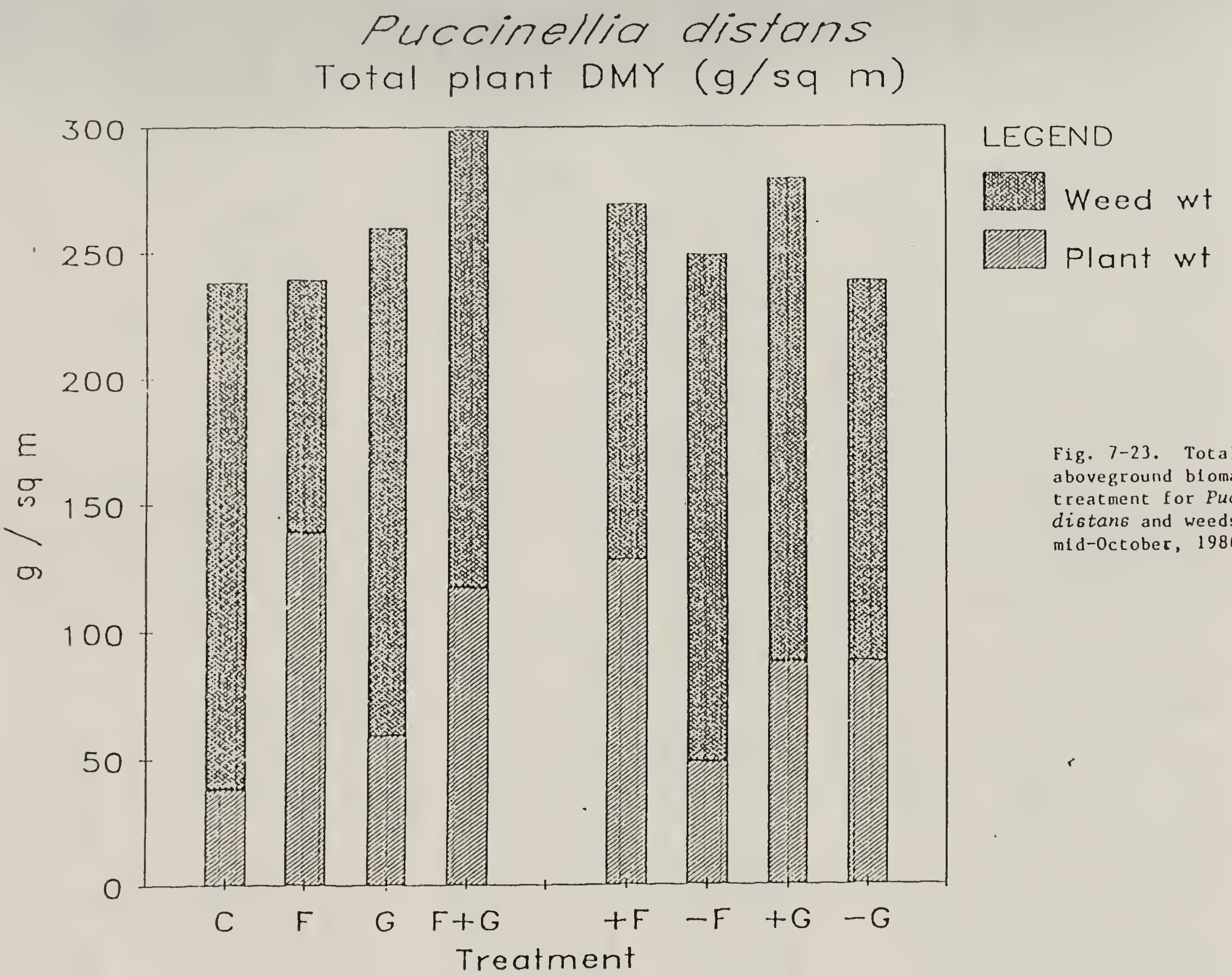


Fig. 7-23. Total aboveground biomass by treatment for *Puccinellia distans* and weeds in mid-October, 1986.

hill prairies (Hitchcock and Chase, 1951; Kucera, 1961). It is not known in the Illinois flora (Mohlenbrock, 1986). It is a perennial grass which naturally occurs in meadows and valleys, especially in moderately alkaline soil. It has been used in species mixes for mined land reclamation in the West.

In this experiment, alkalai sacaton was slow to establish, being found to steadily increase in assessment rankings, especially after July 1 (figure 7-24). Biomass estimates revealed a large increase in yield due to the addition of fertilizer (figure 7-25).

q. _Trifolium subterranean_ (Fabaceae)

Subterranean clover is a winter annual legume which was introduced to the United States from Europe via Australia. It also is not known in the Illinois flora (Mohlenbrock, 1986). It grows best on well-drained, fertile loam soils in areas with a mean annual precipitation of more than 18-20 inches.

In our experiment, there was a very good rate of germination in all plots by early May (figure 7-26). However, the dry period in June was critically damaging to this species, and by the end of the year, most plants were dead.

Overall Species And Treatment Evaluation

Several groups of species emerged upon comparison of the first year results (table 7-2). _Agropyron elongatum_ was the most successful species both in production and rating (table 7-2). _A. trachycaulum_ was next in rating, followed by _Puccinellia distans_. These three species appear to rate the best of the seeded species for their first year overall performance. The next five species, _S. airoides_, _P. virgatum_, _E. curvula_, _E. triticoides_, and _E. junceus_, all clump together as similar in rating. The two species of _Elymus_ were low in stature. Each of these species may or may not become firmly established and highly productive in the second year after seeding. The third group of species, _T. subterranean_, _A. cuneata_, _C. lanata_, and _H. boreale_, did very poorly in the first year of the experiment. _T. subterranean_ germinated well but died off in the later part of the season after the June dry spell. For the other three species, poor germination resulted in very sparse stands of seedlings. _C. lanata_ and _A. cuneata_ should have been planted at a much heavier rate (Luke and Moran, 1984). Apparently _H. boreale_ was not sufficiently scarified for adequate germination.

Of the Transplants, _Atriplex canescens_ came out as clearly the most successful species (table 7-2), with 100% survival and 49 cm growth in 1986. _A. gardneri_ also performed well; it is a lower growing shrub which is indicated in the growth data.

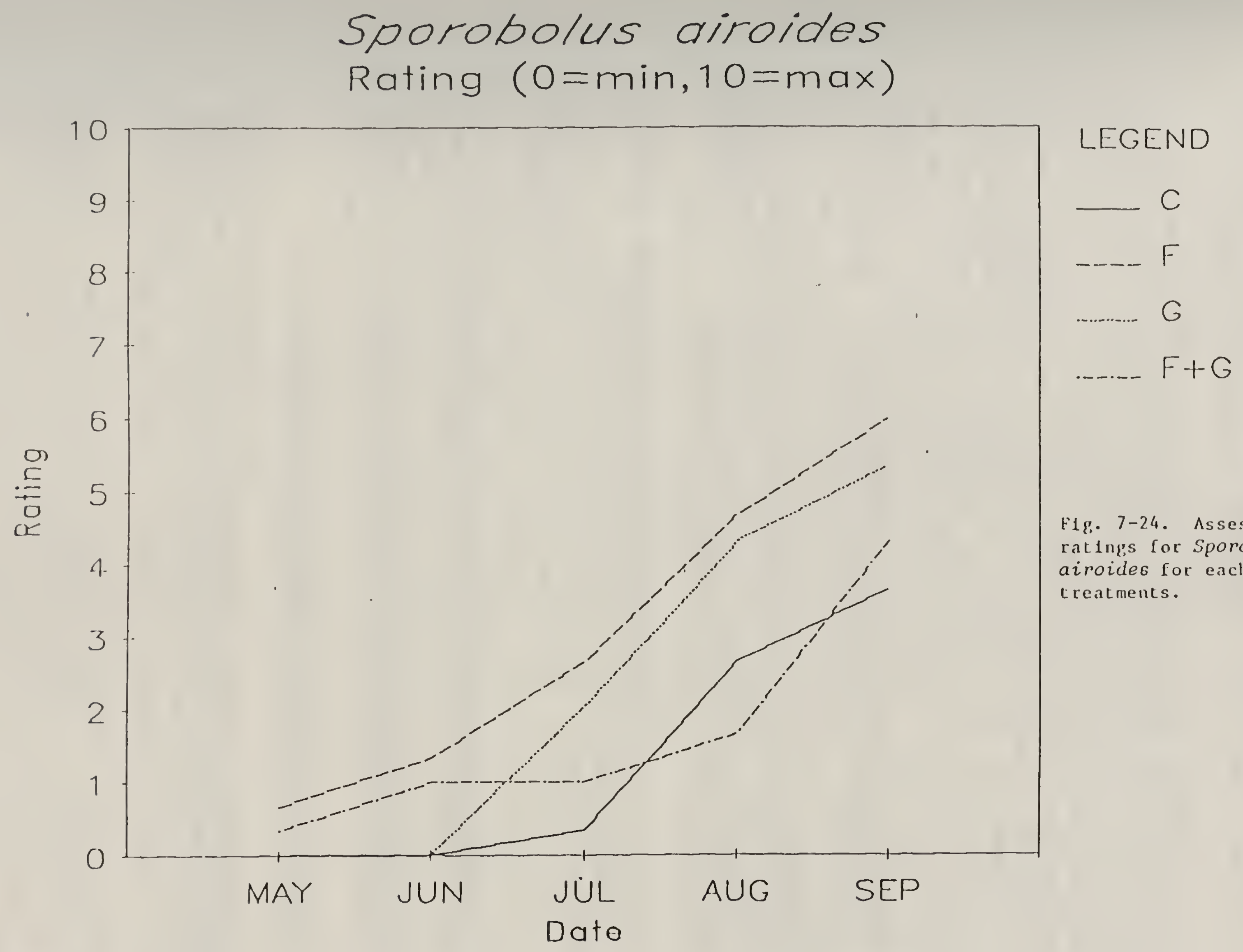


Fig. 7-24. Assessment ratings for *Sporobolus airoides* for each of four treatments.

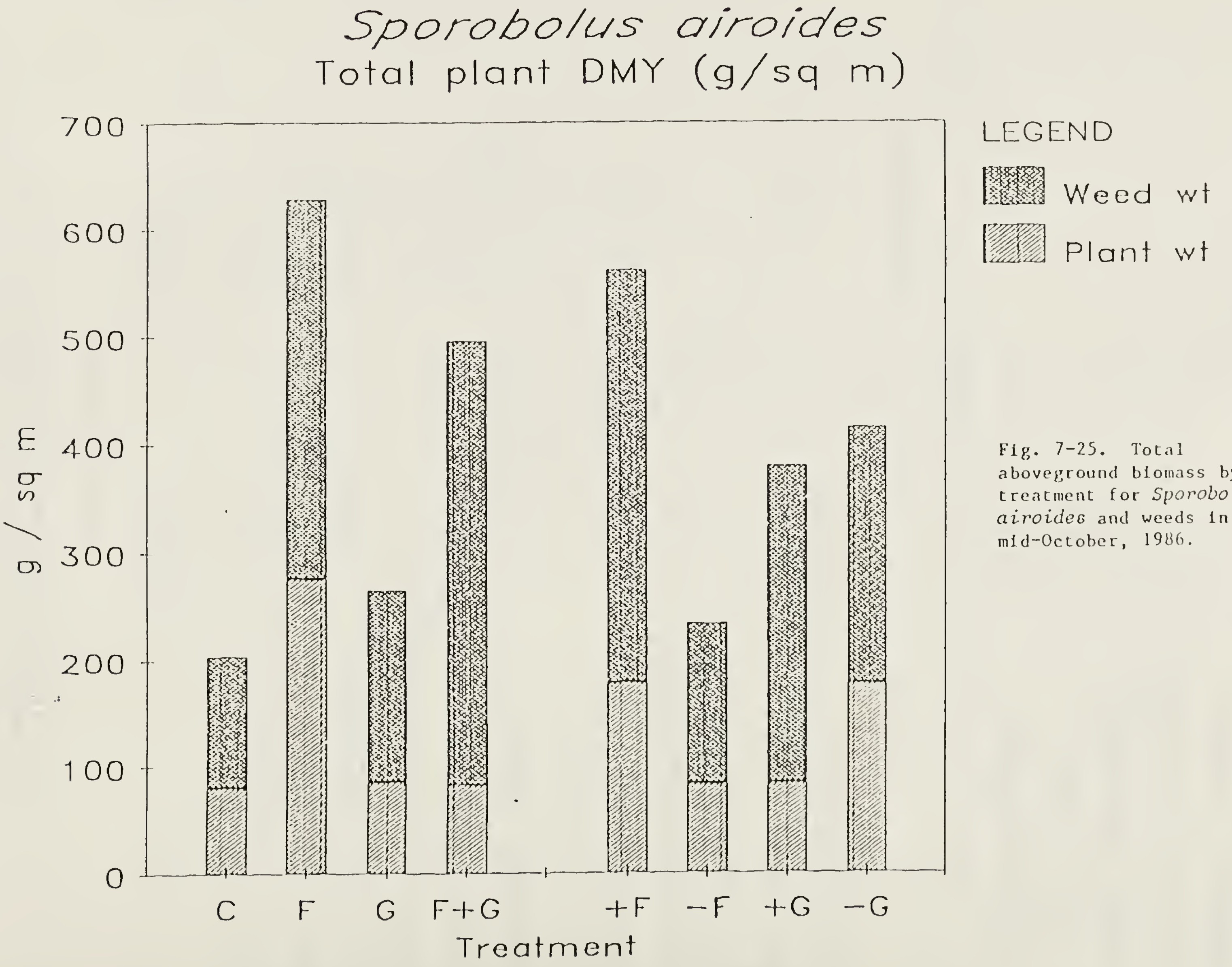


Fig. 7-25. Total aboveground biomass by treatment for *Sporobolus airoides* and weeds in mid-October, 1986.

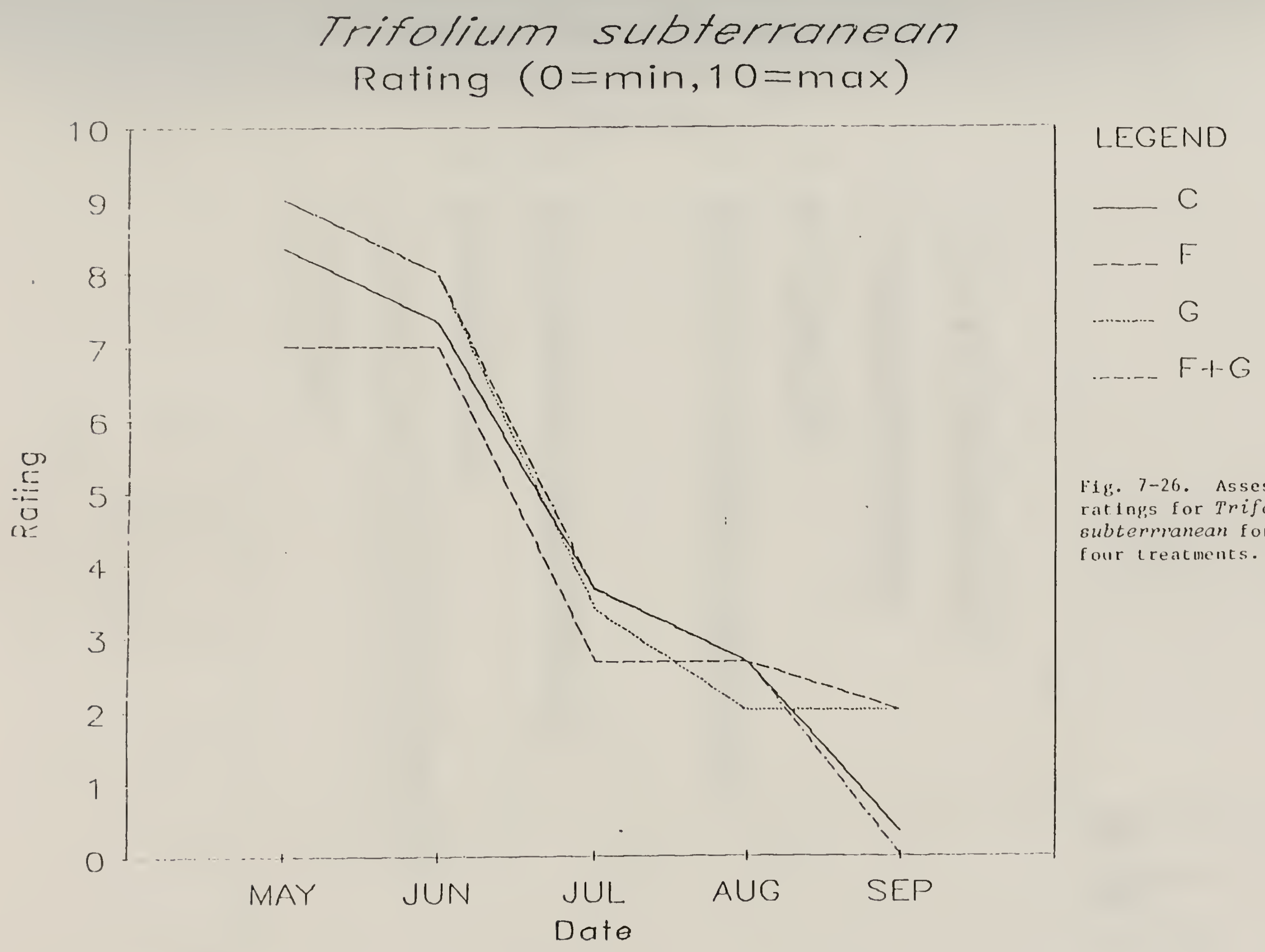


Fig. 7-26. Assessment ratings for *Trifolium subterranean* for each of four treatments.

Table 7-2. Overall assessments of plant species according to the subjective assessment rating in September, biomass estimate in October and overall growth during 1986. Different letters within a column indicate significant differences at the .05 level.

Seeded Species

Species	September Rating	Biomass g/m^2	Growth cm
Agropyron elongatum	9.2 a	206.3 a	26.9 bc
Agropyron trachycaulum	6.7 b	142.2 ab	22.0 cd
Puccinellia distans	5.9 bc	88.5 ab	19.9 cd
Sporobolus airoides	4.8 c	131.3 ab	34.6 b
Panicum virgatum	4.8 c	193.1 a	50.1 a
Eragrostis curvula	4.6 c	188.6 a	32.5 b
Elymus triticoides	4.4 c	32.0 b	20.3 cd
Elymus junceus	4.3 c	46.6 b	16.4 de
Trifolium subterranean	1.1 d	*	5.0 f
Atriplex cuneata	0.8 d	*	11.2 ef
Ceratoides lanata	0.6 d	*	9.6 ef
Hedysarum boreale	0.1 d	*	5.2 f

Transplants

	% Survival	Growth, cm
Atriplex canescens	100 a	49 a
Atriplex gardneri	87 a	21 b
Robinia neomexidana	25 b	26 b
Atriplex confertifolia	0 c	0 c
Sheperdia argentea	0 c	0 c

*no data available

<u>Robinia</u> <u>neomexicana</u> had only 25% survival with 26 cm growth on thesurviving plants. <u>A.</u> <u>confertifolia</u> and <u>S.</u> <u>argentea</u> did not survive the 1986 growing season. <u>A.</u> <u>confertifolia</u> plants were in very poor condition upon planting and none survived the season. <u>S.</u> <u>argentea</u> were in good condition when transplanted but apparently could not tolerate the elevated salt concentrations.

In evaluating the treatment effects, it is clear that fertilizer amendments are highly desirable for growth and production of seeded species (table 7-3). Soil analysis revealed phosphorus deficiencies on these brine soils, and, although nitrogen was not tested, the low organic matter along with other evidence indicated nitrogen to be severely deficient as well. The addition of gypsum was not helpful in the first year growth. The addition of calcium sulphate added osmotic potential to the soils which may have been detrimental initially during the critical establishment phase. It would have been better to apply gypsum several weeks prior to seeding.

Weed Invasion And Growth

Weed invasion was very prevalent in the plot, as indicated by final biomass estimates (figures 7-6, 7-8, 7-14, 7-16, 7-18, 7-21, 7-23, 7-25). The weed species found growing on the plot in October, 1986 are given in table 7-4. It appears likely that of the 12 species found, the seeds of 11 of them were brought in by the straw used for mulch. Only <u>Atriplex</u> <u>patula</u>, a known salt tolerant species in Illinois, appeared to have existed on or near the plot prior to 1986. Most of the other species are common field/barnyard weeds which are characterized by phenotypic plasticity such that they can grow over a wide range of site conditions. Biomass amounts of weeds were even more sensitive to the treatments, especially fertilizer, than were the biomass estimates for planted species. Of the eight species analyzed for weed biomass, five showed a significant fertilizer effect and three showed a significant gypsum effect. In many cases, especially the <u>Elymus</u> species (figures 7-14, 7-16), the weed biomass outstripped the planted biomass. This is a common phenomenon in the first year growth on any restoration attempt (Iverson and Wali, 1982). In the second year of growth, weed production is expected to be much less than planted species production.

Soil Physical And Chemical Characteristics

Soil electrical conductivity (EC) showed a trend in which the upper soil horizon EC (0-15cm) dramatically decreased between the April and July sampling dates (figure 7-27). On the other

Table 7-3. Overall assessments of treatments according to the subjective assessment rating in September, biomass estimate in October, and overall growth in 1986. Different letters within a column indicate significant diffences at the .05 level.

	Seeded Species		
Treatment	September Rating	Biomass g/m2	Growth cm
Control	3.0 b	97.5 bc	19.0 c
Fertilizer	5.1 a	208.6 a	31.4 a
Gypsum	3.2 b	61.3 c	18.0 c
Gypsum & fertilizer	4.4 a	146.9 ab	23.6 b

	Transplants	
	% Survival [3]	Growth[4] cm
Control	44 a	30.9 a
Fertilizer	44 a	36.1 a
Gypsum	39 a	29.6 a
Gypsum & fertilizer	37 a	31.0 a

---

1 mean of 12 species
2 mean of 8 species
3 mean of 5 species
4 mean of 3 species

hand, in the lower sampled horizon there was a gradual increase in EC throughout the season (figure 7-27). The lower soil layers had significantly higher EC levels, overall, with a mean of 1.9 mmhos/cm vs. 1.4 mmhos/cm on the upper horizon. Since these measurements were taken on a 1 part soil to 2 part water soil suspension, values should be considered quite high for plant growth. EC values between 1.2 and 2.4 can cause severe restrictions on plant growth. Only very tolerant species are able to grow satisfactorily in the range, 2.4-4.8. All species are seriously impaired at levels above 4.8 mmhos/cm (Bradshaw and Chadwick, 1980). The range of EC values for the plot was from 0.31 in the upper horizon beneath _Puccinelia distans_ in July to 5.1 mmhos/cm in the upper horizon beneath _Atriplex cuneata_ in April.

The seasonal decrease in surface EC is advantageous for plant growth; levels at the surface generally fell to a range tolerable by many plant species. If low levels could be maintained at the surface in future years, additional species could invade (or be planted) which would increase diversity and stability of the ecosystem. Yet, there is a possibility that elevated winter moisture levels will allow capillary action to bring the salts from the lower horizon back to the surface. It is hoped that the additional roots and moisture retention in the vegetated plots will contribute to leaching salt and permanent reduction in surface EC and therefore progress towards the reclamation of the site. It is also hoped that leaching will continue to deeper horizons in the future and that the EC values at 15-30 cm will decrease further. We will be able to follow this by continued sampling in future years.

Additional soil analyses were conducted by a commercial firm for the following parameters: EC (on a paste rather than a 1:2 soil:water suspension as was used the INHS laboratory), organic matter percentage (OM), a weak Bray extraction for phosphorus (P1), a strong Bray (more acidic) extraction for phosphorus (P2), ammonium acetate extractable potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na), pH, and buffered pH. The data were analyzed by date (table 7-5), by treatment (table 7-6), and by layer and date (table 7-7).

Several parameters showed significant trends with time during the 1986 growing season. Most notable was the decrease in EC and the cations Na, Mg, and Ca as the season progressed (table 7-5). This trend can be attributed to leaching. It is hoped that Na levels will continue to decrease in the coming years. There was also an apparent increase in pH with time, possibly due to the influence of gypsum.

Treatment effects were apparent on chemical parameters and can be attributed to the amendments to the soils (table 7-6). For example, increases of EC, P1, P2, K, and the decrease in pH

Table 7-4. Weed-species located on brine plots.

Scientific Name	Common Name
Melilotus officinalis	Yellow sweet clover
Setaria faberi	Foxtail
Lepidium virginicum	Field peppergrass
Sida spinosa	Prickley sida
Rumex crispus	Curley dock
Ipomoea hederacea	Ivy-leaved morning glory
Panicum dichotomiflorum	Fall panicum
Echinochloa muricata	Barnyard grass
Polygonum pennsylvanicum	Smartweed
Trifolium hybridum	Alsike clover
Atriplex patula	Spear scale
Chenopodium sp.	Goosefoot

Figure 7-27. Soil electrical conductivity at two soil depths taken on three dates in 1986.

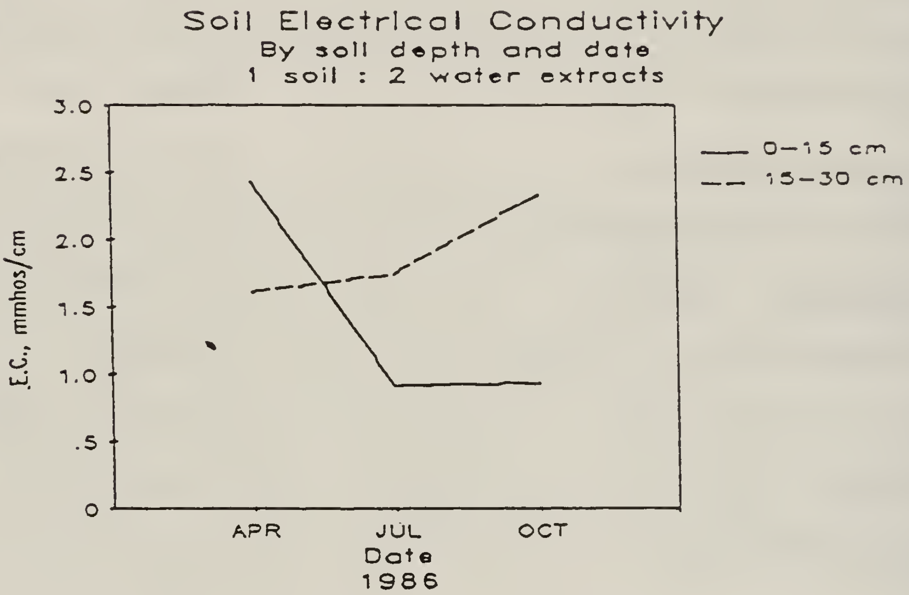


Table 7-5. Chemical attributes of soils summarized by date. All estimated parameters differed significantly (P < .05) among sampling dates. Columns followed by differing letters are significantly different (P < .05).

	Date, 1986		
	April	July	October
EC, mmhos/cm	6.44 a	3.77 b	3.53 b
O.M., %	0.96 b	1.19 a	0.91 b
P1, ppm	11.40 b	15.21 a	10.02 b
P2, ppm	14.69 b	19.15 a	13.98 b
K, ppm	108.1 b	116.6 a	115.8 a
Mg, ppm	220.4 a	200.4 ab	174.1 b
Ca, ppm	875.6 a	902.3 a	779.2 b
Na, ppm	1844.4 a	1185.4 b	212.5 b
pH	5.13 b	5.35 a	5.28 a
Buf-pH	6.25 b	6.44 a	6.44 a

Table 7-6. Soil concentrations of certain chemical characteristics tabulated by treatment. Values represent means over thre dates. Columns followed by differing letters are significantly different ($P < .05$).

	Treatment			
	Control	Fertilizer	Gypsum	Fertilizer & & Gypsum
EC, mmhos/cm	3.60 a	4.36 b	5.08 b	5.27 b
O.M., %	1.03	0.98	0.99	1.09
P1, ppm	8.22 a	14.56 b	9.08 a	16.97 b
P2, ppm	11.69 a	16.78 b	12.50 ab	22.78 c
K, ppm	108.9 a	120.7 b	113.3 ab	111.2 a
Mg, ppm	202.1 ab	225.7 a	195.6 ab	169.8 b
Ca, ppm	766.9 b	779.7 b	977.8 a	885.0 a
Na, ppm	1375.6	1438.6	1430.8	1411.4
pH	5.4 a	5.13 b	5.23 b	5.25 b
Buf-pH	6.48 a	6.29 b	6.36 b	6.37 b

Table 7-7. Chemical attributes of soils summarized by sampling date and laye sampling.

	Date, 1986				
	April		October		
	Upper	Lower	Upper	Lower	Significance[1]
EC, mmhos/cm	8.24	4.63	1.98	5.09	***
O.M., %	1.01	0.91	1.07	0.75	*
P1, ppm	16.72	6.17	13.04	7.00	*
[illegible]	20.00	0.38	17.63	10.33	NS
K, ppm	111.29	04.92	118.04	113.58	NS
Mg, ppm	239.3	201.5	179.8	168.3	NS
Ca, ppm	1016.3	735.0	852.9	705.4	NS
Na, ppm	2136.7	1552.1	812.9	1612.1	***
pH	5.13	5.13	5.54	5.01	***
Buf-pH	6.15	6.35	6.61	6.27	***

* = P < .05, *** = P < .001.

can be attributed to the addition of fertilizer. Additionally, increases in EC and Ca can be related to the addition of gypsum in those treatments.

When one examines the more detailed data reflecting date and layer interactions, temporal trends become more apparent (table 7-7). Most importantly, Na levels in the surface horizon fell from 2137 ppm in April to 813 ppm in October. This 62% reduction in Na brings an excessive and toxic Na level to a tolerable level for most non-halophytic plants. Concurrently Na levels in the lower horizon showed slight increases (table 7-7), again reflecting movements of salts into lower horizons. Mirroring the trend in Na was the changes in EC, a measurement of total salts. Again, an EC level of 8 mmhos/cm or higher at the beginning of the season was excessive for proper growth of most plants (Saturated paste extract - Bradshaw and Chadwick, 1980); by October, the EC level at the surface was sufficiently low for almost any plant species to germinate. The lower horizon salt level tended to be fairly high, however, such that deeper root growth of plants would be somewhat inhibited, and therefore problematic for plants during periods of dry weather. With continued leaching, salt levels in the lower horizons should eventually be reduced. pH also had significant interactions between date of sampling and depth of sampling. The surface pH tended to increase with time, whereas the lower horizon pH decreased slightly (table 7-7). The gypsum treatment is the probable factor controlling the increase in pH as the Ca replaced Na on the exchange sites. The reduction in pH in the deeper horizon can be related to influx of anions and acidity from the leaching phenomena.

Plant Tissue Analysis

Six harvested plant species were chosen for wet digestion and chemical analysis, and the data are reported according to treatment (Table 7-8) and species (table 7-9). Chemical characteristics analyzed included P, K, Mg, Ca, Na, aluminum (Al), manganese (Mn), copper (Cu), zinc (Zn), and chloride (Cl).

No significant differences were apparent among treatments for any of the plant tissue elements (table 7-8). Evidently, differences in the soils were not sufficient for them to become apparent statistically after uptake into the aboveground plant tissue. There was also a high variation in tissue concentrations among species, which apparently overwhelms any treatment differences.

When considering differences in tissue concentrations by species, there were significant differences found in nine the ten elements studied (table 7-9). Many of the trends can be interpreted as resulting from the dilution effect, i.e., plants with lower biomass tend to have higher nutrient concentrations per unit dry weight than those with high biomass. For example, Elymus triticoides had very low production and exhibited the highest concentrations for Cu and Zn, where Panicum virgatum had high biomass production and the lowest concentrations for P, K, Al, Cu, and Zn. Still, real differences exist among species for their capacity to take up (or exclude) elements. Agropyron elongatum had 50% higher Cl concentration than the next highest species. It can apparently tolerate high levels of Cl internally, whereas species like Puccinellia distans and Elymus triticoides do not uptake Cl readily and possibly exclude it before uptake. These latter examples are more characteristic of resistance, rather than tolerance, phenomena.

After one year of testing the most promising species for reclamation of brine damaged soils in Illinois are 3 grasses and 2 chenopod shrubs: A. elongatum, A. trachycaulum, P. distans, A. canescens, and A. gardneri.

CONCLUSIONS AND RECOMMENDATIONS

1. Five species show great promise for growth on salinized soils resulting from oil brine contamination: Agropyron elongatum, Agropyron trachycaulum, Puccinellia distans, Atriplex canescens, and Atriplex gardneri. After one year, these species provided excellent vegetative cover for erosion control and wildlife habitat.

2. An additional five species survived well and provided adequate cover by the end of the first growing season. These species may be even more successful during future years: Sporobolus airoides, Elymus triticoides, Elymus junceus, Eragrostis curvula, and Panicum virgatum.

3. Another seven species were classified as unsatisfactory for reclaiming salt brine soils under the conditions and treatments of this experiment: Robinia neomexicana, Atriplex confertifolia, Shepherdia argentea, Trifolium subterranean, Atriplex cuneata, Hedysarum boreale, and Ceratoides lanata. Some of these species would be acceptable if different conditions had been present (e.g., A. confertifolia transplants had arrived in better condition, C. lanata and A. cuneata had been planted at much higher densities or as transplants).

4. Fertilizer proved to be advantageous to the growth of most of the seeded (and weedy) species. Gypsum was only beneficial for two species during the 1986 growing season. Perhaps gypsum would have been of greater benefit if it had been applied several weeks prior to seeding rather than at the same time of planting.

Table 7-8. Plant tissue concentrations for selected species, summarized by treatment. No elements showed significant differences among treatments. Value represents mean of six grass species.

	Treatment			
	Control	Fertilizer	Gypsum	Fertilizer & Gypsum
P, %	.127	.148	.158	.148
K, %	.842	.980	1.009	.993
Mg, %	.107	.100	.116	.102
Ca, %	.294	.244	.331	.277
Na, %	.147	.202	.172	.138
Al, ppm	650.6	520.6	642.4	527.6
Mn, ppm	313.6	282.8	236.4	284.7
Cu, ppm	9.50	11.61	10.00	8.18
Zn, ppm	15.50	15.06	17.65	14.29
Cl, %	.682	.737	.686	.618

Table 7-9. Plant tissue concentrations for selected species, summarized b
Columns followed by differing letters are significantly differ
(P<.05).

	Species									
	Agropyron elongatum		Sporobolus airoides		Puccinellia distans		Elymus triticoides		Eragrostis curvula	
P, %	.190	a	.108	b	.195	a	.168	a	.132	b
K, %	1.38	a	.82	c	.98	bc	1.21	ab	.79	c
Mg, %	.088	b	.105	b	.095	b	.115	ab	.089	b
	.266	ab	.195	b	.385	a	.286	ab	.214	b
a, %	.203	b	.386	a	.162	bc	.123	cd	.046	d
Al, ppm	770.8	b	286.4	c	1066.7	a	790.8	b	326.7	c
Mn, ppm	318.4	b.	150.4	c	185.6	c	325.1	b	205.2	c
Cu, ppm	8.83		12.64		7.50		14.25		11.42	
Zn, ppm	15.83	a	15.46	a	19.50	a	21.92	a	14.33	a
Cl, %	1.28	a	.84	b	.36	c	.40	c	.45	c

5. Mulching the plots was valuable in retaining moisture, especially during the dry spells in April and June.

6. Electrical conductivity in general and sodium concentration in particular declined in the surface zone during the summer of 1986. EC also increased in the lower horizon during that same period, indicating a leaching of salts into the lower zone.

7. It is recommended that one or more of the species mentioned as promising be planted on brine damaged areas. Fertilizer and mulching are also highly recommended. Then, a plant cover may be established, and leaching of salts and organic matter rejuvenation may occur so that the land can return to meaningful production again, and at a relatively low cost.

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LITERATURE CITED

Best, K. F., J. Looman, and J. B. Campbell, 1971, Prairie grasses identified and described by vegetative characters: Canada Department of Agriculture Publication 1413. 239 pp.

Blauer, A. C., A. P. Plummer, E. D. McArthur, R. Stevens, and B. L. Guinta, 1975, Characteristics and hybridization of some important intermountain shrubs. II. Chenopod family: Res. Paper INT-169, Intermountain Forest and Range Experiment Station, Ogden, UT, 36 p.

Bradshaw, A. D. and M. J. Chadwick, 1980, The restoration of land - the ecology and reclamation of derelict and degraded land: Blackwell Scientific Publications, Oxford, 317 p.

Coleman, W. B. and D. A. Crandall, 1981, Illinois oil field brine disposal assessment-phase II report: Illinois Environmental Protection Agency, Springfield, IL 47 p.

Dore, W. G. and J. McNeill, 1980, Grasses of Ontario: Biosystematics Research Institute. Ottawa, Ontario, 566 p.

Frischknecht, N. C. and R. B. Ferguson, 1984, Performance of Chenopodiaceae species on processed oil shale: Proceedings - symposium on the biology of Atriplex and related chenopods, A. R. Tiedeman, E. McArthur,H. C. Stutz, R. Stevens, and L. Kendall, compilers, Gen. Tech. Rep. INT -172, Intermountain Forest and Range Experiment Station, Ogden, UT, pp. 293-297.

Fulbright, T. E., E. F. Redente, and N. E. Margis, 1982, Growing Colorado plants from seed - a state-of-the-art: FWS/DBS-82/29 Western Energy Land Use Team, USDI Fish and Wildlife Service, Washington, D.C. 113 p.

Iverson, L. R. and M. K. Mali, 1982. Reclamation of coal-mined lands: the role of Kochia scoparia and other pioneers. Reclamation and revegetation Research 1:123-160.

Iverson, L. R., 1986, Competitive, seed dispersal, and water relationships of winterfat (Ceratoides lanata) in western North Dakota: Proceedings of the Ninth North American Prairie Conference, Clambey, G. and Pemble, R., editors, Tri-College Press, Fargo, ND, pp. 25-31.

Iverson, L. R., D. Jordan, M. K. Nunna, 1984, Transplanting Ceratoides lanata (winterfat) for North Dakota coal mine reclamation: Bulletin of the Ecological Society of America 65:260.

Kies, R. E. and E. J. DePuit, 1984, Perennial grasses for mined land. Journal of Soil and Water Conservation 39:26-29.

Kucera, C. L., 1961, The grasses of Missouri: University of Missouri Press, Columbia, 241 p.

Luke, F. and S. B. Monsen, 1986, Methods and costs for establishing shrubs on mined lands in southwestern Wymoing: Proceedings - symposium on the biology of Atriplex and related chenopods, A. R. Tiedeman, E. McArthur, H. C. Stutz, R. Stevens, and L. Kendall compilers, Gen. Tech. Rep. INT-172, Intermountain forest and Range Experiment Station, Ogden, UT, pp. 286-292.

Martin, W. C. and C. R. Hutchins, 1980, The plants of New Mexico: 2 Volumes, J. Cramer, Germany, 2591 p.

Monsen, S. B. and A. P. Plummer, 1978, Plants and treatment for revegetation of disturbed sites in the intermountain area: The reclamation of disturbed arid lands, University of New Mexico Press, Albuquerque, pp. 155-173.

Mohlenbrock, R. H., 1986, Guide to the vascular flora of Illinois: Southern Illinois Univeristy Press, Carbondale, 507 p.

Ostyina, R. M., C. M. McKell, J. M. Malecheck, and G. A. Van Epps, 1984, Potential of Atriplex and other chenopod shrubs for increasing range productivity and fall and winter grazing use: Proceedings - symposium on the biology of Atriplex and related chenopods, A. R. Tiedeman, E. McArthur, H. C. Stutz, R. Stevens, and L. Kendall compilers, Gen. Tech. Rep. INT-172, Intermountain Forest and Range Experiment Station, Ogden, UT, pp. 215-219.

Pitelka, L. F. and D. L. Kellogg. 1979. Salt tolerance in roadside populations of two herbacious perennials: Bulletin of the Torry Botanical Club 2, pp. 131-134.

Redente, E. F., P. R. Ogle, and N. E. Horgis, 1982, Growing Colorado plants from seed - a state-of-the-art: Western Energy Land Use Team FWS/OBS-8320 USDI Fish and Wildlife Service, Washington, D.C. Vol. III, 141 p.

Rydberg, P. A., 1954, Flora of the Rocky Mountains and adjacent plains: 2nd ed. Hafner Publishing Co., New York. 1143 p.

Soil Conservation Service, 1986, Critical area planting oil well salt damaged areas and high sodium areas: Interim Standards and Specifications Technical Guide Section IV, Champaign, IL pp. 1-4.

Springfield, H. W., 1974, Eurotia lanata (Pursh) Mog. Winterfat, Seeds of woody plants in the United States: Forest Service, United States Department of Agriculture Handbook, 450 p.

Thornburg, A. A., 1982, Plant materials for use on surface-mined lands in arid and semi-arid regions: USDA SCS-IP-157, EPA600/7-79-134.

Townsend, W., 1982, The Wayne County Method: Unpublished Professional Paper. 2 p.

United State Salinity Laboratory Staff, 1969, Diagnosis and improvement of saline and alkali soils: USDA Agriculture Handbook No. 60, U.S. Department of Agriculture, Washington, D.C.

Vogel, W. G., 1981, A guide for revegetating coal minespoils in the Eastern United States: U.S. Department of Agriculture (GTR-NE-68), General Technical Report NE-68, Berea, Kentucky.

SECTION 8 REMOTE SENSING

by

Christopher J. Stohr and Edward C. Smith

INTRODUCTION

Two techniques were used to identify possible sources of brine contamination of groundwater. Aerial photograph reconnaissance was successfully used to locate brine holding ponds which had been historically located in the study area. Thermal infrared imagery was also used in an unsuccessful attempt to locate underground sources of oil field brine contamination.

AERIAL PHOTOGRAPH RECONNAISSANCE

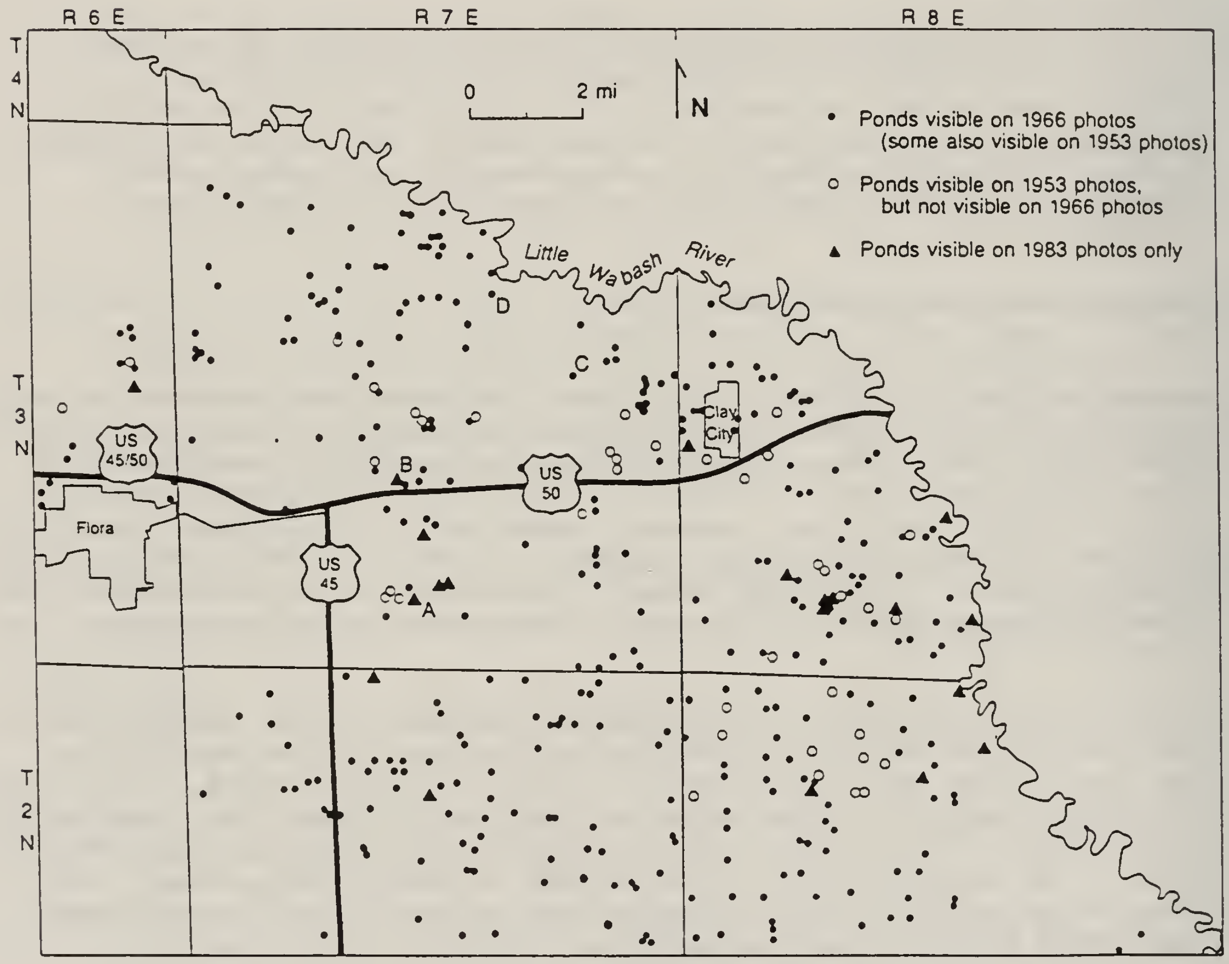
One of the first tasks which must be undertaken when assessing the potential for a brine problem over a given area is location of all brine holding ponds, past and present which have existed in that area. Physically searching the area would be time consuming, labor intensive, and would not guarantee that all holding ponds would be located, especially if holding ponds are located on posted private property. Another problem which might be encountered if an area were to be searched manually would be locating abandoned holding ponds which may have been buried and re-vegetated.

To overcome these problems, a time series of aerial photos was used to locate all brine holding ponds in the study area. It was found that holding ponds are easily recognizable, when using stereo images, by their berms and by the surrounding vegetation kill areas. Photos from 1953, 1966, and 1983 were used for this task. The holding ponds identified on these images were then located on U.S.G.S. 7.5′ topographic quadrangles, which were then used to compile figure 8-1.

The aerial photo reconnaissance was a time and cost efficient method of locating brine ponds. Using this method, both recent ponds and past ponds, no longer evident at the ground surface, were located.

A total of 384 holding ponds were located in the study area. Forty-four of the ponds noted in 1953 had been buried and revegetated by 1966 (figure 8-1). The aerial photo reconnaissance was also used to determine that very few (18) holding ponds were constructed in the 17 years from 1966 to 1983, indicating that injection for waterflooding and disposal have become the dominant forms of brine disposal, and the usage of

Figure 8-1. Brine holding ponds in southeast Clay County. Locations from aerial photos taken in 1953, 1966, and 1983. Also shown are locations A, B, C, and D with were investigate with Thermal Infrared techniques.



brine holding ponds has been curtailed. These holding ponds were concentrated throughout the eastern portion of the study area in general and in particular, around the Camp Travis and Clay City areas. Groundwater in these areas may be subject to contamination due to leakage from these ponds. Further discussion of this topic is given in Section 9.

THERMAL INFRARED SURVEY

Thermal Infrared (TIR) imagery is a nonphotographic method of observing the long wavelength thermal infrared energy radiated from any object with a temperature above 0^{o} Kelvin ($-273^{o}C$ or $-459.4^{o}F$). A TIR image is a black and white representation of the relative amount of thermal energy (heat) radiating from a given object. When the assessment of environmental affects of oil field brines was proposed, it was envisioned that the TIR imagery might be used to locate sites where brine was being forced to the near-surface through leaky abandoned or inactive wells and unsealed boreholes. It was theorized that this procedure would be possible because the brine water which would have been upwelling would be warmer than ambient near-surface ground-water. However, no locations could be found within the study area where brine migration of this type was occurring and budgetary limitations precluded a search outside the study area. Therefore, there was no control with which to test the ability of TIR as a method of locating areas where brine water would be upwelling. A secondary goal was to observe differences between brine-effected soils and nonaffected soils and compare the results with black and white photographs of the area to determine which type of imagery was best suited for identification of brine-spoiled sites.

The theoretical and technical aspect of TIR imagery are discussed by Sabins (1978) and Estes (1983). In general, materials absorb thermal energy from the sun at different rates dependent on their composition, conductance, heat capacity, and density. Water, for instance, absorbs thermal energy slowly and radiates it slowly in contrast to most earth materials which absorb and radiate the energy quickly. A TIR image, or thermograph, shows the differences in radiant heat of materials so that interpretations can be made of the types of materials present based on their thermal properties. Areas which radiate high thermal energy (i.e., warm areas) will be represented as light-colored areas on the TIR image; areas of low thermal energy (i.e., cold areas) will be represented by darker areas on the image.

In order to obtain the best TIR imagery, some considerations must be made regarding the time of day, season , and surface and atmospheric conditions. TIR imagery is best taken at night, preferably in the predawn hours, so that the effects of shadows and differential heating of surface topography, which occur during daylight hours are minimized. The season of the year was important to this study because green vegetative cover can obscure the features of the ground surface. The optimum time of the year is after leaf-fall in the winter. During this season, colder temperatures of the ground surface contrasting with relatively warm groundwater. This contrast can allow observation of groundwater movement into gullies and streams or possibly the presence of shallow aquifers. Surface conditions are ideal if the ground is dry. Complete snow cover would be unacceptable for most TIR surveys since the snow would obscure the thermal energy radiated from the underlying earth materials. Atmospheric conditions are ideal if it is not hazy, cloudy or windy.

Site Selection

Four sites were selected for the TIR survey (figure 8-1). Sites A and B are the brine holding pond study sites discussed in Section 9. These sites were selected for the comparison of TIR versus black and white and color infrared imagery for use in identification of brine spoiled sites.

Sites C and D were selected as possible locations of brine water upwelling. The reconnaissance of groundwater quality (Section 3) identified wells with total dissolved solids concentrations greater than 2500 mg/L at these sites.

Results

The TIR survey was conducted during late evening of February 23, 1987. A helicopter, furnished by the Illinois Department of Transportation - Division of Aeronautics, carried two instruments; a FLIR Systems thermal scanner mounted on the helicopter and an Inframetrics portable thermal scanner. The imagery was recorded on videocassette recorders for later interpretation of the data. Prior to the aerial survey, flashing road hazard lights had been placed at the four sites to aid in navigation.

Much of the area to be surveyed was moist due to recent rain and melting snow. A few small areas were still covered by snow. Also, a low fog affected several isolated areas and dew began to form on the grass and field stubbles before and during collection of the imagery.

The time of day and weather conditions may have hindered the acquisition and interpretation of the TIR imagery. The flight should have been made in the fall just after leaf-fall when the ground was dry and dew formation was at a minimum.

º Site A Section 33 Study Site (figure 8-2)

The TIR imagery thermogram from this site shows that the brine affected-areas have a higher thermal radiance than the non-affected areas. The higher thermal radiance may indicate higher moisture being held by salts and saline soils. The area of the filled-in brine pond does not appear to have a significantly higher thermal radiance than the surrounding area. The warmest areas are the bases of the numerous erosional gullies that dissect the area. The heat in these areas is likely due to groundwater seepage into the gullies from the soil. The presence of brine salts in the gullies may have added to the thermal radiance seen on the imagery. The areas of the heaviest brine salt accumulations downgradient from the brine pit have a high thermal radiance.

º Site B Section 21 Study Site (figure 8-4)

Drainage patterns are enhanced at this site. Brine affected areas appear warm. A bright spot (indicating relatively high temperature) on the imagery appears near the center of the abandoned pit area (figure 8-5). The spot is located in a depression which has remained continually moist even when air temperatures were below freezing. The reasons for the high thermal radiance at this spot are not known.

A ground TIR Survey of this area made several weeks after the aerial survey indicated slight variances (figure 8-3) in the thermal radiance. The center of the depression had the highest reading but that was only slightly higher than the surrounding area. There may be an unreported abandoned well at this site; however, none is recorded in ISGS files. Without excavation or detection by some other means there is no conclusive evidence that the high temperature "hot spot" is an abandoned well or upwelling brine waters.

º Site C High TDS in abandoned well NE-1/4 NW-1/4 Section 23, T. 3 N., R. 7 E.

No evidence of surficial brine damage or upwelling brine waters from abandoned wells was observed.

º Site D High TDS in old well SE-1/4 SE-1/4 , T. 3 N., R. 7 E.

No evidence of surficial brine damage or upwelling brine waters from abandoned wells was observed.

Conclusions

The airborne thermal infrared imagery proved useful in observing differences in thermal radiance at the study sites. Brine-affected areas were especially noticeable. However,

Figure 8-2. Sketch of thermograph for site A. Large light colored areas indicate brine affected soils. White, rectangular patch in lower right corner is NHS test plot (section 7).

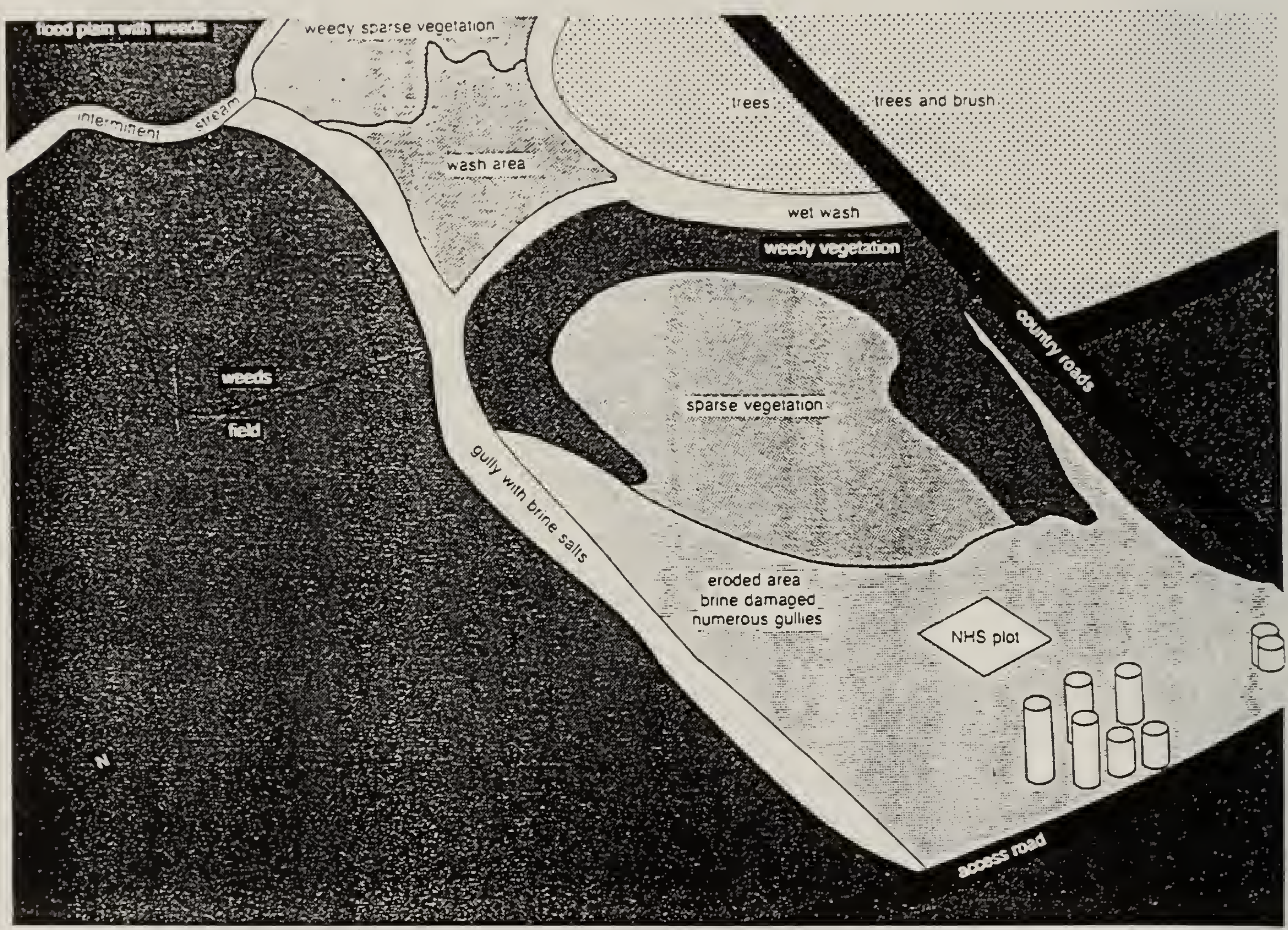


Figure 8-3. Traverse across "hot spot" at Site B.

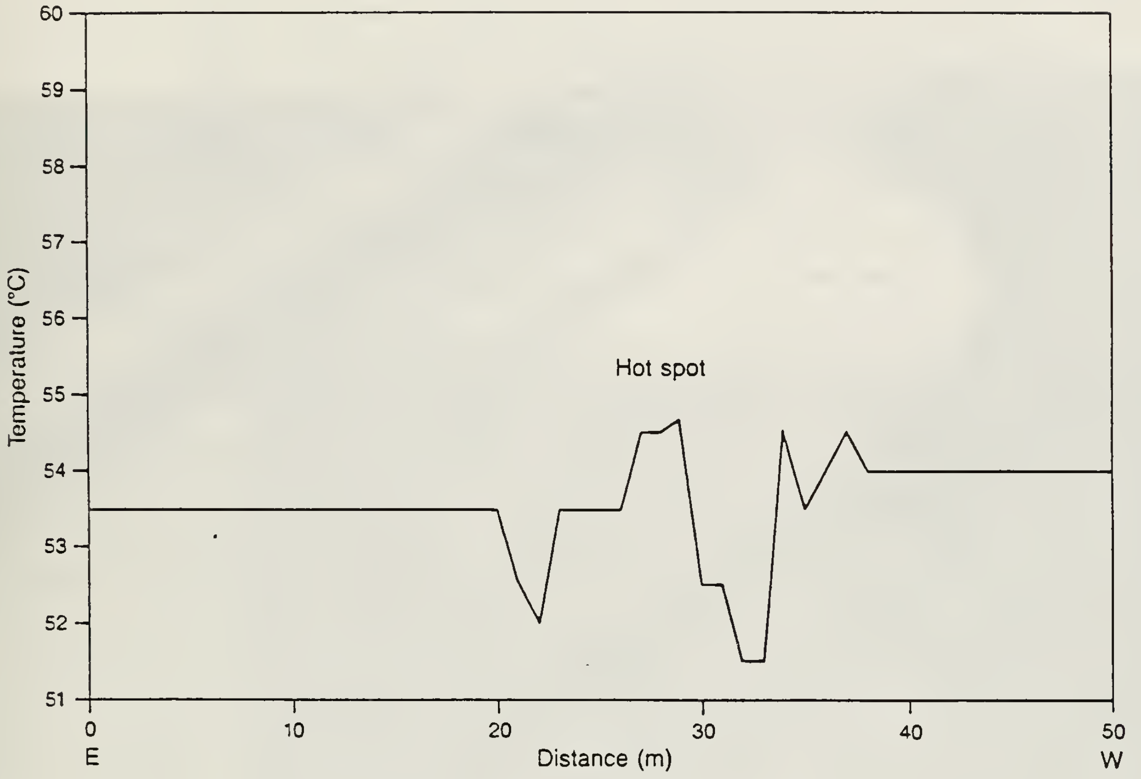


Figure 8-4. Sketch of thermograph for Site B study site. Light colored areas are brine affected soils. Thin light area at lower right edge shows groundwater discharge to creek. Ground survey traverse line is indicated.

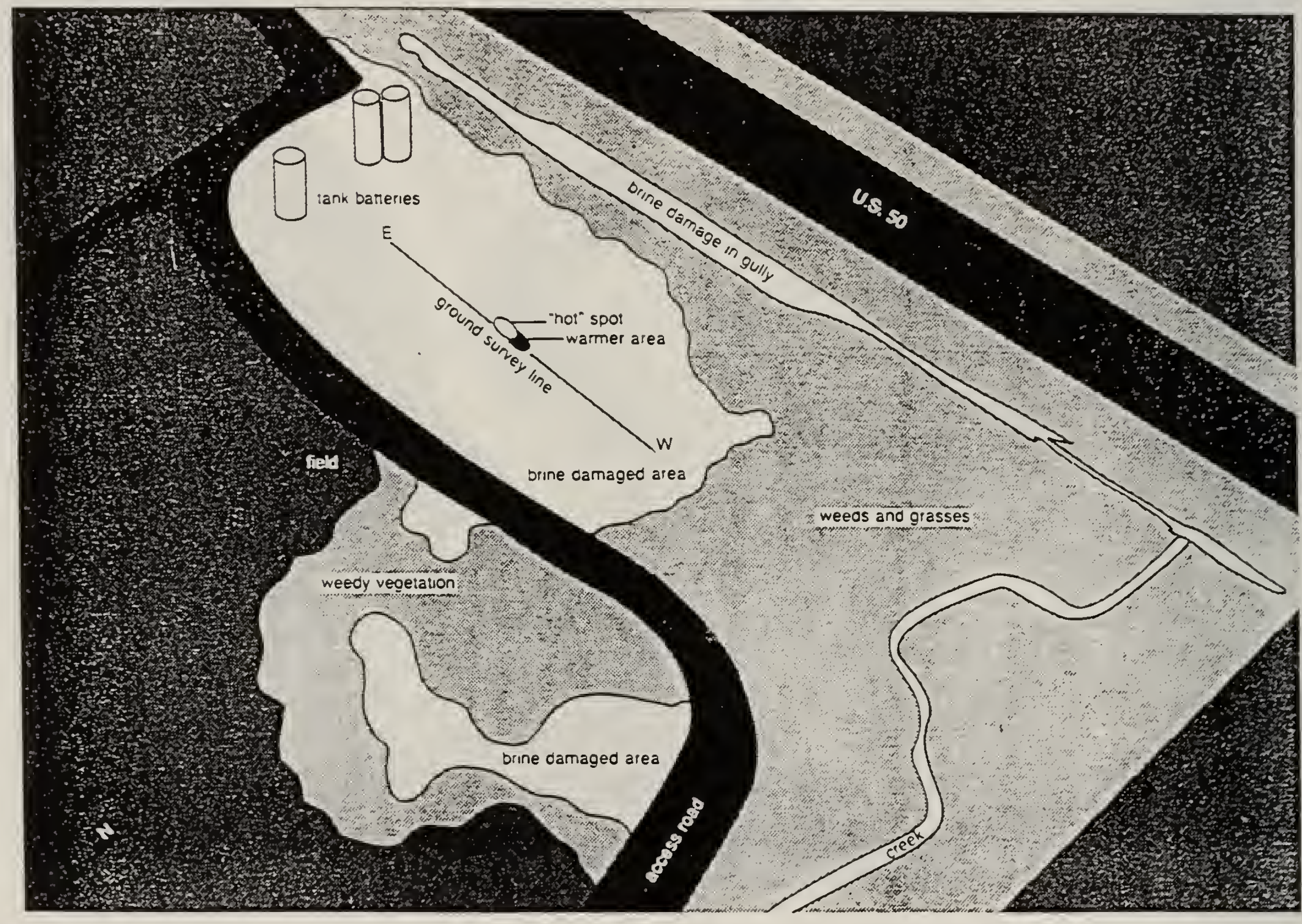
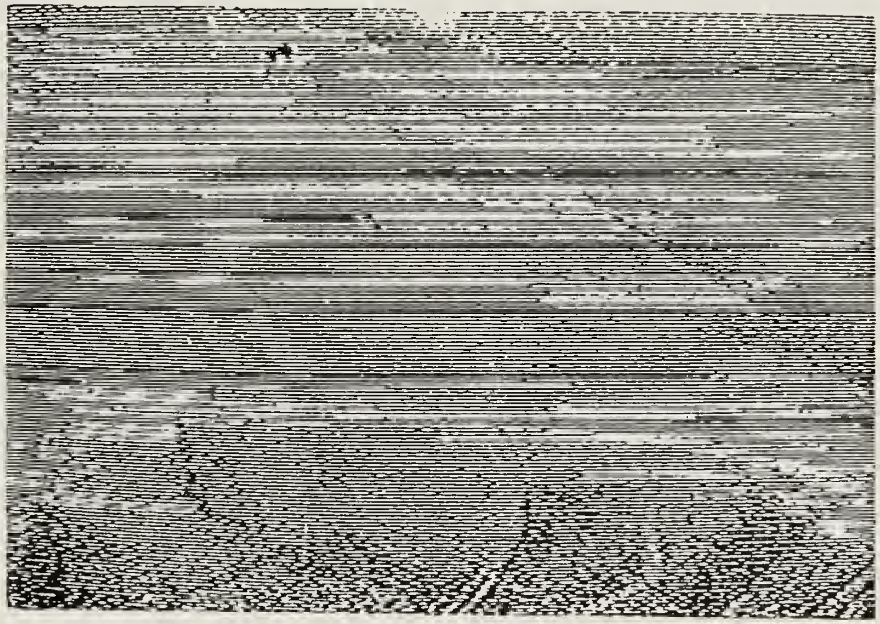


Figure 8-5. Postsunset, airborne thermal infrared imagery (thermograph) of Site B, Clay Co., IL. Light areas represent relatively high temperatures (thermal radiance); dark areas represent relatively low temperatures. A stream appears in the lower right of the image, U.S. 50 is in the upper right, and a dirt access road makes an S-shaped curve from the upper left to the lower center of the image. Brine-affected soils which probably hold more moisture and therefore appear relatively light (warm). The unusual bright spot near the center of the image is a thermal anomaly.



brine-affected areas are also observable on large to medium scale aerial and color infrared photographs. Thermal infrared imagery had to be flown especially for this project, and consequently was more expensive than the photography which was borrowed locally.

Groundwater flow into stream and gullies could be discerned from thermal infrared imagery. This may prove useful for identifying areas of aquifer discharge, groundwater flow along near-surface joints, and groundwater flow into surface water bodies. As expected, no evidence of leaky wells could be identified by airborne thermal infrared imagery.

Imagery collected at Site B shows an abrupt change (a hot spot) in radiance. The increase in radiance could possibly come from an underground source such as an abandoned, unplugged well. Other evidence supports the hypothesis:

a) The TIR imagery shows an abrupt increase in temperature at the muddy depression indicating a restricted heat source.

b) There was a continuous presence of water in the depression where the change in radiance was recorded.

c) Nearby oil production is being actively promoted by injecting water into deep (about 3000 to 3500 feet) bedrock formations. At this depth groundwater temperatures rise to about 90 degrees F (Whitaker, 1987) which would contrast sharply with the below freezing air temperature (daily maximum was 47 F; minimum was 28.2 F as recorded at the Flora weather observation station on February 23, 1987).

However, there are no records of a well being drilled at this site. Although the thermal IR data suggest the existence of a leaky well, there has been no confirmation by other methods.

REFERENCES

Estes, J. E., E. J. Hajic, and L. R. Tinney, 1983, Chapter 24, Fundamentals of Image Analysis: Analysis of Visible and Thermal Infrared Data: in Manual of Remote Sensing, 2nd ed., Robert N. Colwell, editor, Am. Soc. of Photogramm, 2440 p.

Sabins, F. S., Jr., 1978, Remote Sensing: Principles and Interpretation: W. H. Freeman and Company, San Francisco, CA., 426 p.

Stohr, C. H., 1974, Delineation of Sinkholes and the Topographic Effects on Multispectral Response, M.S. Thesis, Purdue Univ., Lafayette, IN., 132 p.

Whitaker, S., 1987, personal communication, Geologist, Oil and Gas Section, Illinois State Geological Survey.

TASK 9 CASE STUDIES OF GROUNDWATER CONTAMINATION ORIGINATING FROM BRINE HOLDING PONDS

by

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Paul C. Heigold, and Douglas E. Laymon

INTRODUCTION

Brine water produced in association with oil pumpage in Clay County, Illinois typically has high concentrations of chloride (55000 - 89000 ppm), sulfate (28 - 2100 ppm), sodium (32000 - 48000 ppm), calcium (2300 - 8900 ppm), and magnesium (100 - 2800 ppm) (from Meents et al., 1952). Total dissolved solids concentrations of brines produced in this county are typically three to four times higher than that of sea water.

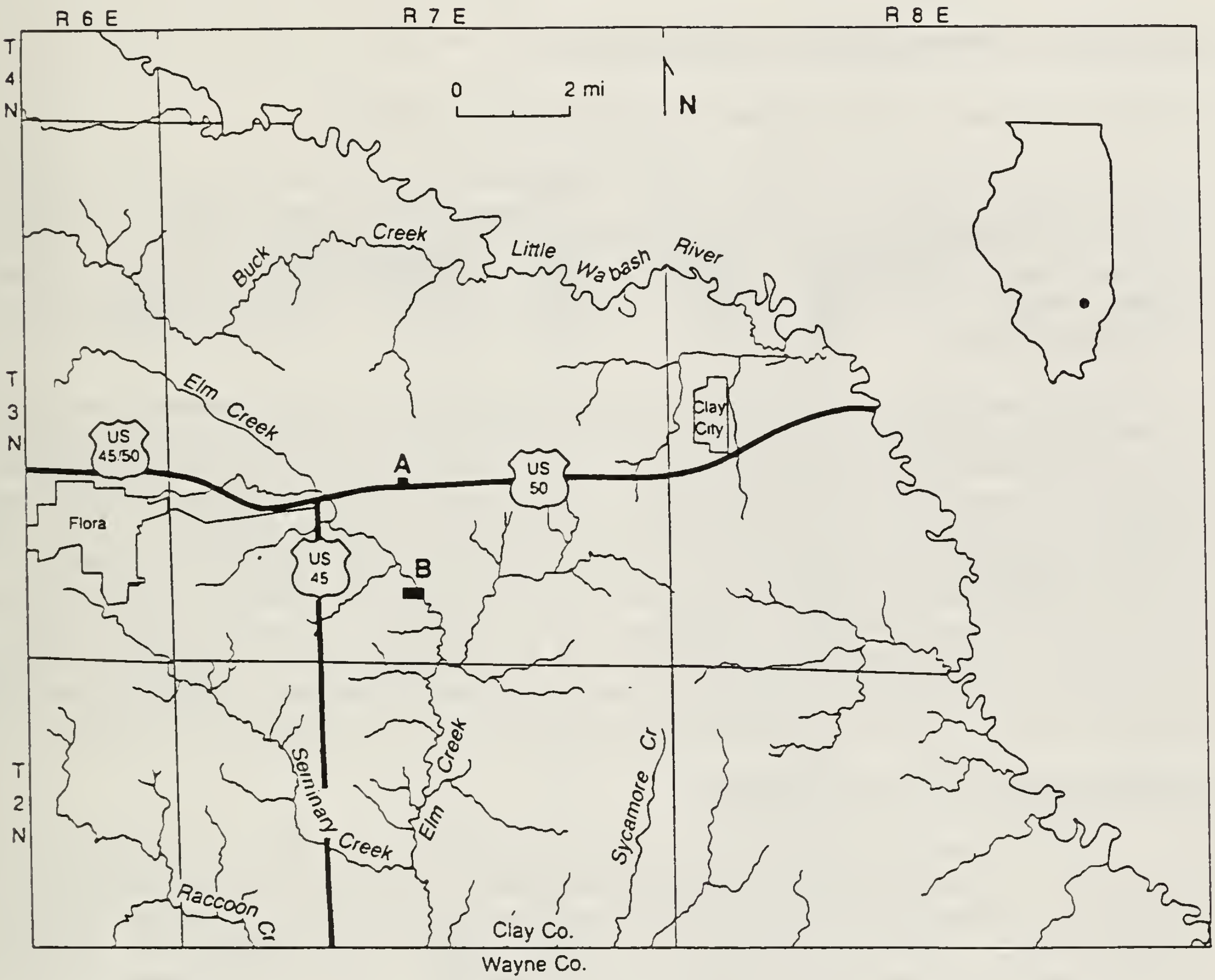
Disposal of oil field brines has been a problem since the 1930's when the brines from the first oil wells in the state were allowed to spill onto the land surface and into rivers and streams. Beginning in the 1940's brines were stored in holding or 'evaporation' ponds. However, since the average precipitation rate in Illinois exceeds the average evaporation rate (Roberts and Stall, 1967), large quantities of brines may have been infiltrating into local aquifers from these ponds (Reed et al., 1981). Unlined brine holding ponds were phased out during the 1980's and have been banned since 1985.

It has been estimated that over 8600 brine holding ponds have been in recent use in Illinois (Illinois Department of Mines and Minerals, Division of Oil and Gas, 1985). All of these holding ponds should now be closed; however, the brine which has seeped into the earth beneath these ponds still remains as a potential source of groundwater contamination.

The first objective of the case study was to investigate the movement of brines through the subsurface. The second objective was to investigate the use of a cost- and time-efficient geophysical method to trace subsurface brine plumes.

Two sites were chosen for study and are labeled A and B on figure 9-1. Site A was chosen because the holding pond at this site is isolated from other potential sources of brine contamination (other holding ponds, oil wells, abandoned wells, and injection wells), and because a study had previously been conducted at this site (Reed et al., 1981). That study provided background data and information on the shape of the plume in 1978, as determined by geophysical techniques. Site B was selected because of its isolation from other possible sources of

Figure 9-1. Location of case study sites A and B, southeastern Clay County.



brine. Also, since a large portion of this site was not to be used as cropland, sufficient area was available for surface water and plant reclamation investigations (see sections 4 and 7) as well as for the groundwater investigation.

METHODS OF GROUNDWATER MONITORING

Installation of Groundwater Observation Wells

Fifteen observation wells were installed at the two study sites (7 at site A, 8 at site B; figures 9-9 and 9-16). The wells were placed in locations most suitable for measuring the elevation of the water table at or near the study sites. Thus, these wells were not necessarily located in areas of suspected brine plumes.

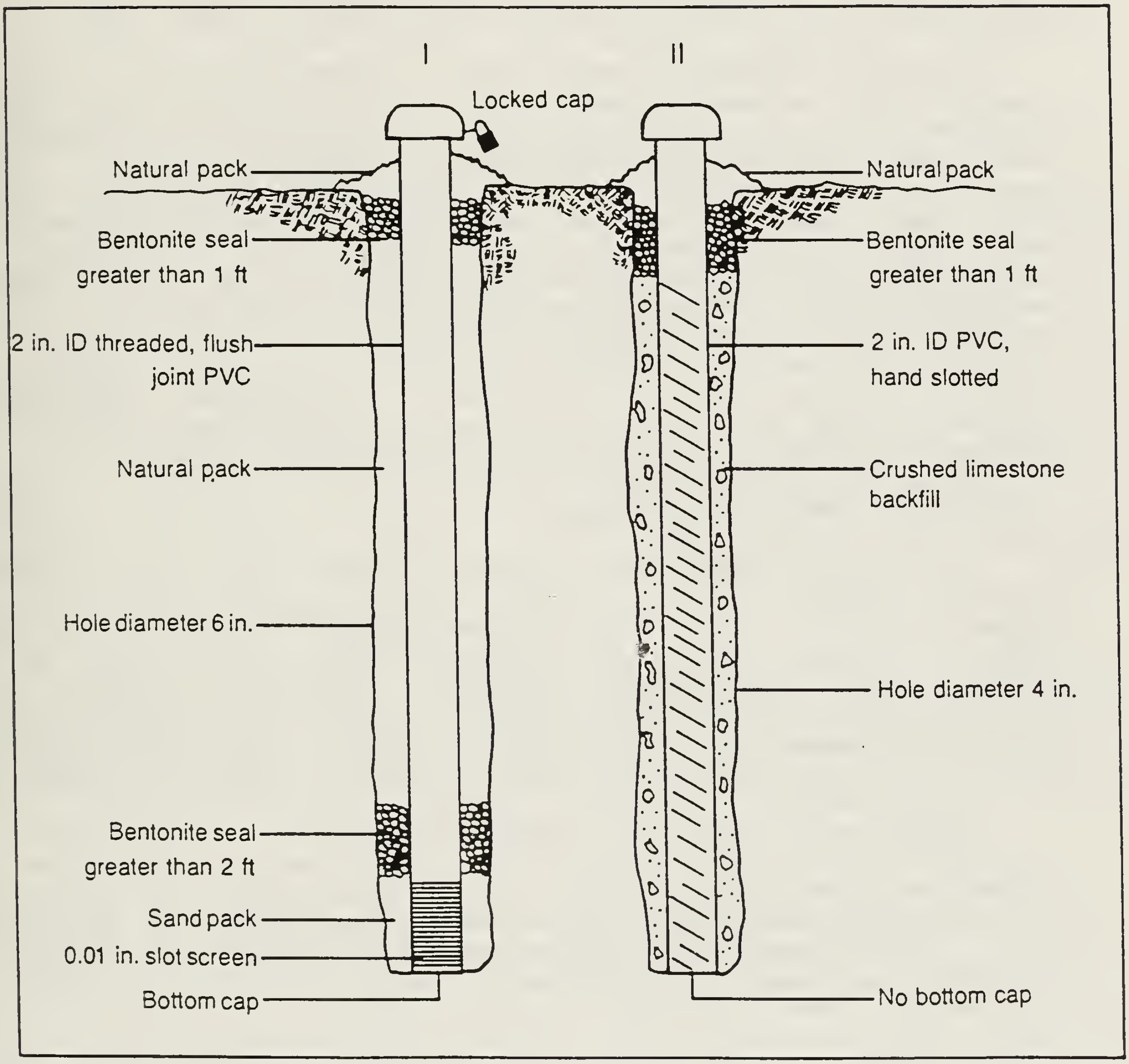
The borings for these wells were made with 4-inch, solid-stem auger driven by the Illinois State Geological Survey Mobile B-30 trailer-mounted drilling rig. The wells were constructed of 2-inch diameter PVC pipe which was hand slotted from 2 feet below ground surface to total depth of 12 to 24 feet (figure 9-2). The entire slotted interval was back-filled with washed, crushed limestone and a bentonite seal, 1-foot thick, was placed at the top of the bore hole. Because the crushed limestone may have affected the chemical composition of groundwater samples, the results of chemical analysis on samples obtained from these wells were used only as gross indicators of the presence of brine.

Installation of Piezometers

Forty-one piezometers were installed at the two sites (19 at site A, 22 at site B) for the purpose of obtaining groundwater samples. Most of the piezometers were located in nests of two or three wells which were finished at different depths. A total of 9 monitoring stations were established at site A (figure 9-9) and 11 stations at site B (figure 9-16). The stations were located in places where data from the geophysical survey indicated a plume should exist as well as in places where no plume was detected.

All piezometers were drilled with 6-inch hollow-stem auger driven by the Illinois State Geological Survey Mobile B-30 trailer- mounted drill rig. Samples of the earth material were collected from the deepest borings at each well nest. Soil tubes were pushed to collect a continuous sequence of samples of the surficial materials, usually to a depth of between 5 and 10 feet. After the maximum penetration of the soil tube, the borehole was advanced with the hollow stem-auger and split-spoon samples were collected at 5-foot intervals.

Figure 9-2. Schematic drawing of typical piezometer (I) and observation well (II) used at case study sites A and B.



The piezometers were constructed of 2-inch diameter, threaded, flush-joint PVC pipe. Each well was completed with a 2.5 foot, 0.01 inch slotted screen at the base. The annulus of the borehole was filled with; 1) silica sand to the top of the screen, 2) a bentonite seal of at least 2 feet overlying the sand pack, 3) cuttings from the lower seal to near surface, and 4) another foot of bentonite at the surface (figure 9-2).

Samples collected during drilling were described using standard soil survey nomenclature. Characteristics described included color, texture, structure, root occurrence, presence of carbonates, concretion occurrence, jointing and mottling. The presence of clay skins, siltans, iron or other deposits on joint faces were noted, as well as laminations and other sedimentary structures. Selected samples were analyzed for grain-size distribution and clay-mineral composition by the Inter-Survey Geotechnical Lab This lab work was done to facilitate determination of stratigraphic relationships. Grain-size analysis followed the standard hydrometer procedure (ASTM D-422): clay is less than 4 microns. Clay-mineral composition was determined by X-ray diffraction procedures described by Killey (1982) and Hallberg, Lucas and Goodmen (1978).

Groundwater Sampling Methods

Preliminary field measurements of the electrical conductance of water samples from all of the wells were made during the summer of 1986. The preliminary electrical conductance data were used to determine the order in which water samples would be taken from the wells for detailed chemical analysis of common ion concentrations (Ca, Li, Mg, Na, Sr, Cl, SO4, and alkalinity). Wells with water of low electrical conductivity were sampled first to reduce the possibility of cross-contaminating samples.

Sampling of water for detailed chemical analysis was conducted in the fall of 1986. All wells were first purged of standing water with a teflon/-PVC diaphragm pump. The majority of the wells recovered comparatively slowly and were pumped until dry. Those wells which recovered more rapidly were pumped until at least two (three in the case of the shallow wells) well volumes had been extracted. Water samples were then taken from all of the piezometers and some of the observation wells, using a teflon bailer, while water was still recharging to the wells. The water samples were filtered in the field with either a peristaltic pump and 142mm diameter, 0.45um membrane filter or a pressurized tank and 47mm diameter, 0.45um filter. The filtered samples were split into acidized and non-acidized high-density polyethylene containers, and stored on ice until returned to labs of the State Water and Geological Surveys for analysis of ion concentrations. The procedures and results of the chemical analyses are listed in Appendix 9-A.

Collection of Hydrogeologic Data

Water levels in both the observation wells and the piezometers were recorded at approximately three-week intervals. Slug testing was performed at five piezometer stations to determine the hydraulic conductivity of the sediments underlying the sites. The results of the slug tests were analyzed using the method of Horslev (1951). The relative recovery of water levels in the piezometers, after sample purging, was noted. These recovery rates may be indicative of the ability of the materials near the piezometers to transmit water. Recovery to within 10% of pre-purge levels, after 24 hours, was considered high. A 24 hour recovery of less than 50% was considered low. Some piezometers did not recover at all, recovery rates for these wells are very low. Figure 9-3 shows the relationship of the observed piezometer recovery rates to slug test derived valves of hydraulic conductivity at those piezometers. Even though the correlation is not strong, the relationship is significant.

GEOPHYSICAL METHODS.

The geophysical surveying consisted of a number of shallow seismic refraction profiles and vertical electrical soundings (VES). The purpose of the geophysical surveys were to: 1) determine the depth to bedrock at the study areas; and 2) map the configuration of the subsurface brine plumes.

Shallow Seismic Refraction Profiling

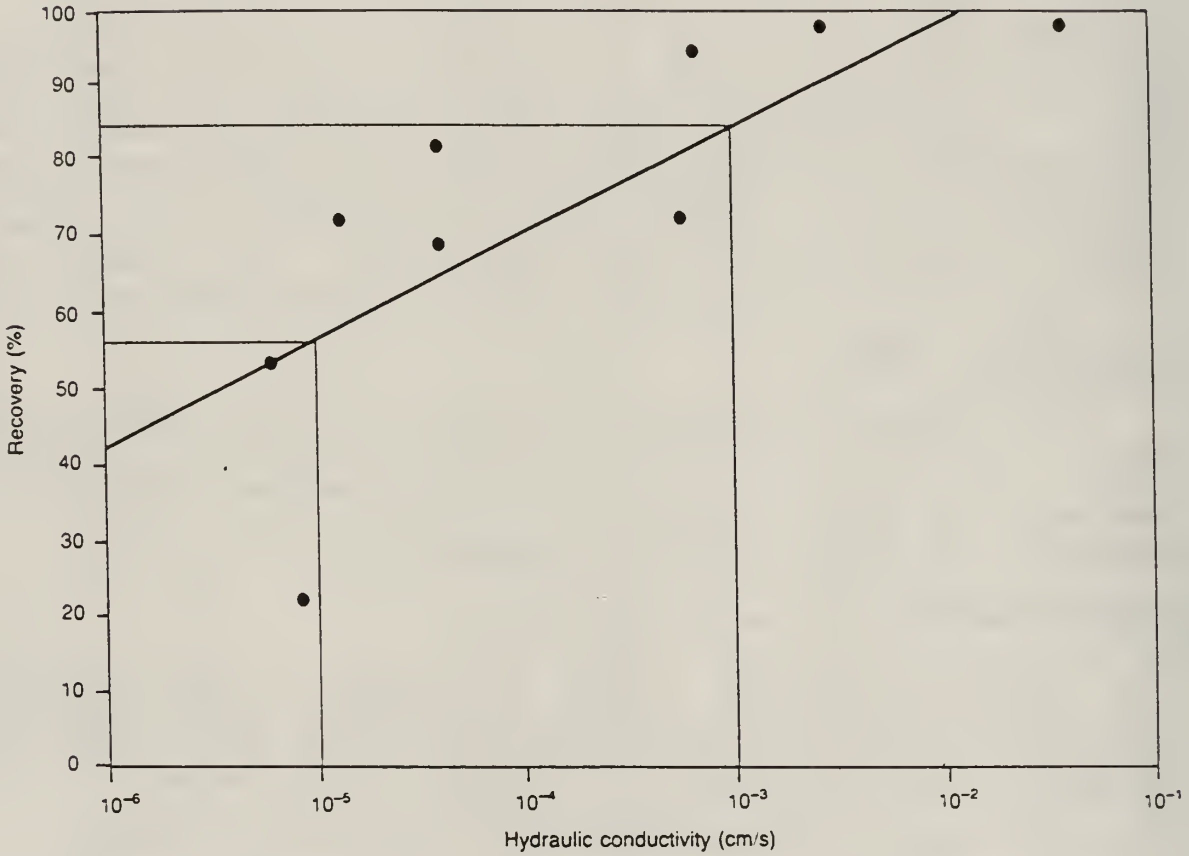
The shallow seismic refraction surveying at the two holding ponds was conducted with an EG&G multichannel, signal enhancement seismograph, model ES 2415 F, owned by the Illinois State Geological Survey. This instrument is commonly used by the ISGS in studies to determine seismic properties of subsurface materials and to estimate the depth to the bedrock surface.

At each of the two brine ponds, four 600-foot reversed profiles, oriented in north-south and east-west directions (figure 9-4) provided information about the depth to the bedrock surface as well as the seismic properties of the drift and bedrock.

Vertical Electrical Sounding

The vertical electrical sounding surveying at the two brine ponds was conducted with an ABEM Terrameter, model SAS 300 B, owned by the Illinois State Geological Survey. This instrument, which has an alternating current power source, is commonly used by the ISGS to characterize the glacial drift when searching for domestic, community, and industrial groundwater supplies. In recent years the VES method has been successfully used to locate

Figure 9-3. Semi-log plot of % recovery vs hydraulic conductivity at the Clay County study sites. Correlation is significant at the 95% level. R^2 is .58.



and monitor the migration of contaminant plumes within the glacial drift.

A number of vertical electrical soundings were made in the vicinity of each brine holding pond. The distribution of the soundings is shown on figures 9-13, and 9-19 . In all of these soundings the electrode spacings were expanded to a distance that assured that the corresponding VES curves adequately represented the resistivity of the near surface deposits and groundwater within those deposits.

The Schlumberger electrode configuration was employed in this study (figure 9-5). In this configuration, four electrodes are placed along a straight line on the earth surface. The two outer electrodes, the current electrodes (I_1 and I_2), are located at a distance, L, from the center of the array, while the two inner electrodes, the potential electrodes (P_1 and P_2), are located a distance a/2 from the center of the array. For this electrode configuration, the resistivity (P_n) of a homogeneous and isotropic medium, in which the electrodes are inserted, is given by:

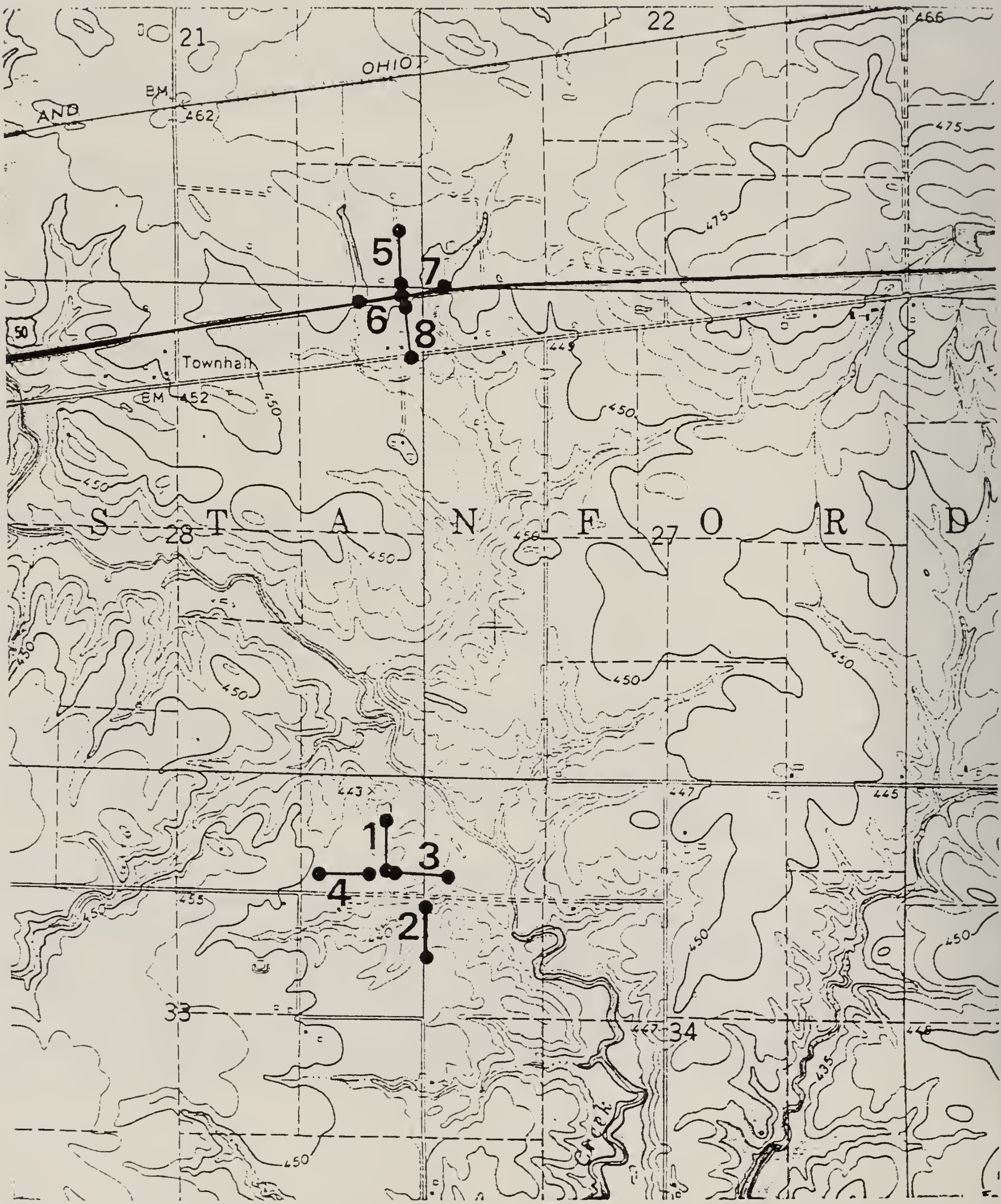
$$P_n = 2 \frac{(P_2-P_1)}{I} \frac{(a)}{2} \frac{L^2}{a} \frac{1}{4}$$

where a = the distance between the potential electrodes
L = the distance from the center of the array to either current electrode
$P_2 - P_1$ = the difference in potential between electrodes P_1 and P_2
I = the current flowing between electrodes I_1 and I_2.

When the medium into which the electrodes are inserted is not homogeneous, the resistivity given by the above equation is an apparent resistivity (Pa)-- a weighted average of whatever resistivities may exist in the region between the potential surfaces (P_1 and P_2) that intersect the ground surface at the potential electrodes.

As the electrode spacings, a/2 and L, are increased (in this study, the ratio of L to a/2 was kept at a constant value of 10), the resistivities of deeper materials have an effect on the measured apparent resistivity. The method of expanding the electrode configuration systematically around the center point, measuring current and potential differences, and calculating apparent resistivity values is called vertical electrical sounding (VES). A plot of apparent resistivity values versus electrode spacings is a vertical electrical sounding (VES) curve.

Figure 9-4. Location of seismic lines at Clay County case study sites A (5-8) and B (1-4).



Qualitative information about near surface materials can be obtained from the maxima, minima, inflection points, and apparent resistivity values of a VES curve. However, the types of information most often desired are the layering parameters, that is, the "true" thicknesses and the "true" resistivities of the strata immediately below the center of the VES profile. Several quantitative interpretation or inversion techniques can be used to determine the layering parameters from VES curves. The technique developed by Zohdy (1973) was used in this study. However, this technique, like most of the others available, provides only one of many geoelectrically equivalent layering parameter solutions for a given VES curve. Prior knowledge of the geologic conditions in the study area helped to compensate for this shortcoming.

A typical vertical electrical sounding (VES) curve corresponding to a vertical electrical sounding (made using the Schlumberger electrode array) near the north brine pond (site B) is shown in figure 9-6. In this particular sounding the distance from the center of the array to an outside current electrode was expanded to 46 meters (150 ft). The layering parameter solution for this sounding, using the Zohdy inversion technique, is shown in figure 9-7. As can be qualitatively surmised from the inspection of the VES curve, the unconsolidated materials near the earth's surface are a series of low resistivity layers overlying materials of considerably higher resistivity.

The electrical resistivity of a material is inversely proportional to the conductance of the material. Consequently, materials with a high electrical conductance will have a low resistivity. The measured electrical resistivity of an earth material will be affected by two factors, the conductance of the material and the conductance of the fluids in the void spaces of that material. Water is more conductive than most earth materials, hence it has a strong effect on the resistivity values of saturated earth materials. As the mineral content (ion concentration) of the pore water increases, so does its conductivity. Thus materials saturated with brine waters, which have high mineral content, are more conductive and have lower resistivity than similar materials saturated with fresh water. The low resistivity value of 12 ohm-meters (figure 9-7) probably represents materials containing brine water.

In order to determine the configuration of a plume which has migrated away from a given brine pond, the following scheme was employed: first, data from all vertical electrical soundings around a brine pond were inverted so that a set of layering parameters (layer thicknesses and resistivities) was obtained

Figure 9-5. Basic elements of an earth resistivity meter and the Schlumberger electrode configuration.

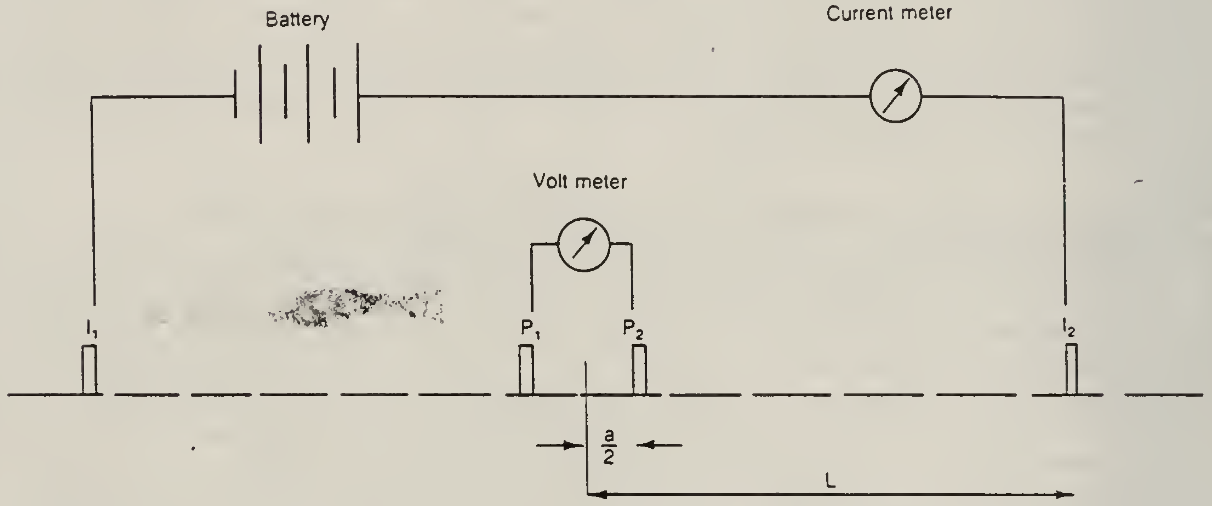


Figure 9-6. Vertical electrical sounding (VES) curve from data gathered at a resistivity station near piezometer P3, case study site B (figure 9-15).

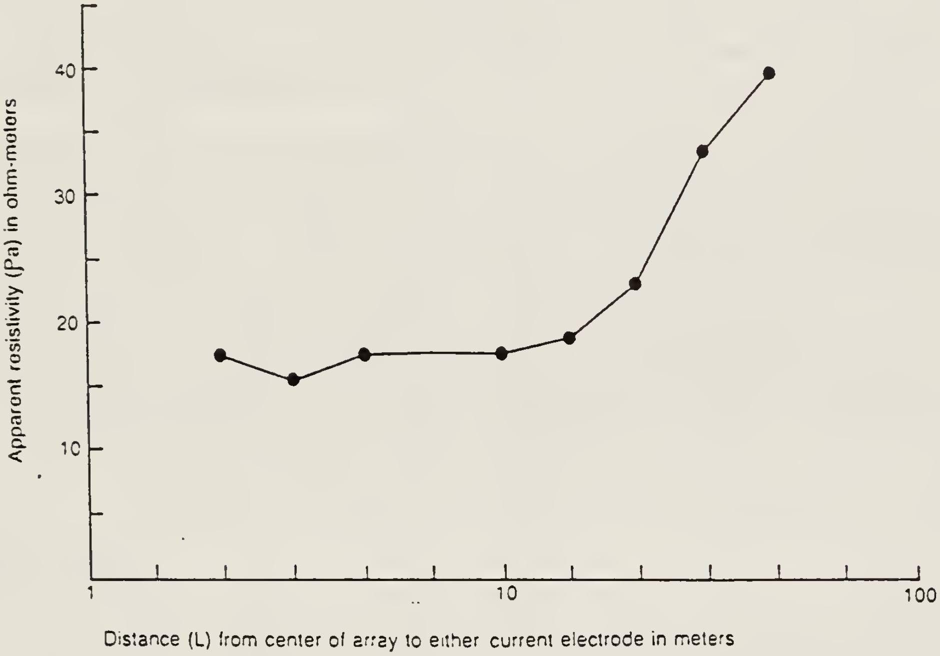
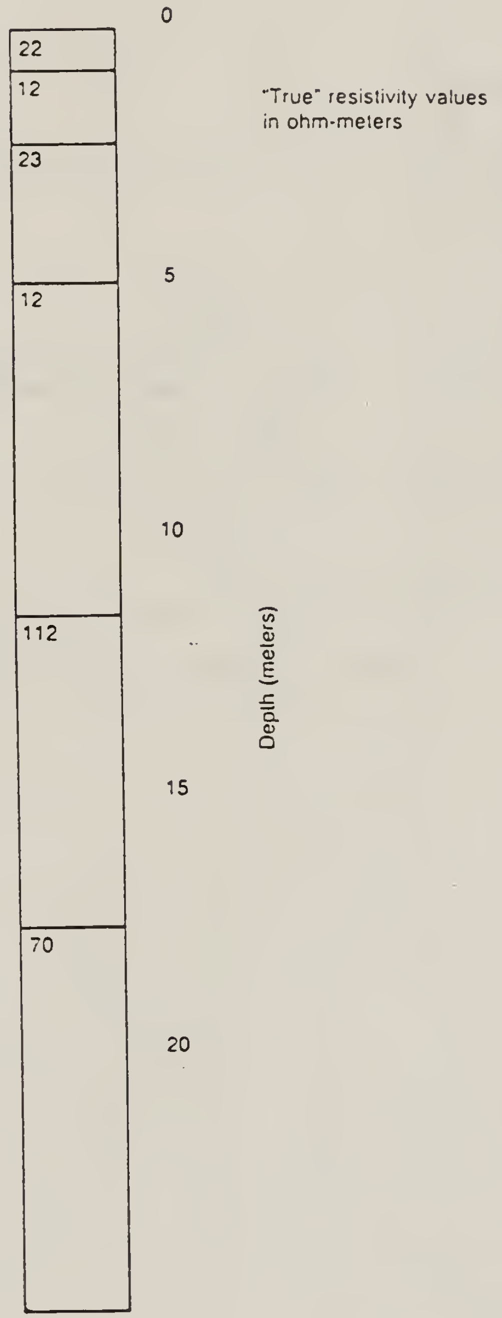


Figure 9-7. Layering parameter solution for VES curve presented on figure 9-6.



for each discrete VES point; next, at each VES point the "true" resistivity values associated with depths of 3 and 6 meters were recorded; then, these "true" resistivity values were plotted and contoured. Low "true" resistivity values (more specifically, "true" resistivity values lower than those that would be expected for the observed lithology saturated with fresh water) were of special interest. These exceptionally low "true" resistivity values are most likely indicative of brine contamination. The expected or normal "true" resistivity values at a given depth would likely occur in areas distant from the brine pond where earth materials are more likely to be saturated with fresh water.

The interpretation and evaluation of the resistivity results was hampered by imprecise mapping of VES stations. The VES grid was laid out according to taped measurements and markers were left at each VES station. However, when the sites were surveyed, many of these markers were missing; thus the location of those stations represented by the missing markers had to be interpolated based on taped measurements. Because more than half of the VES stations are mapped imprecisely, direct comparison of resistivity values with data on ion concentrations (obtained at precisely located piezometers) was not attempted.

RESULTS

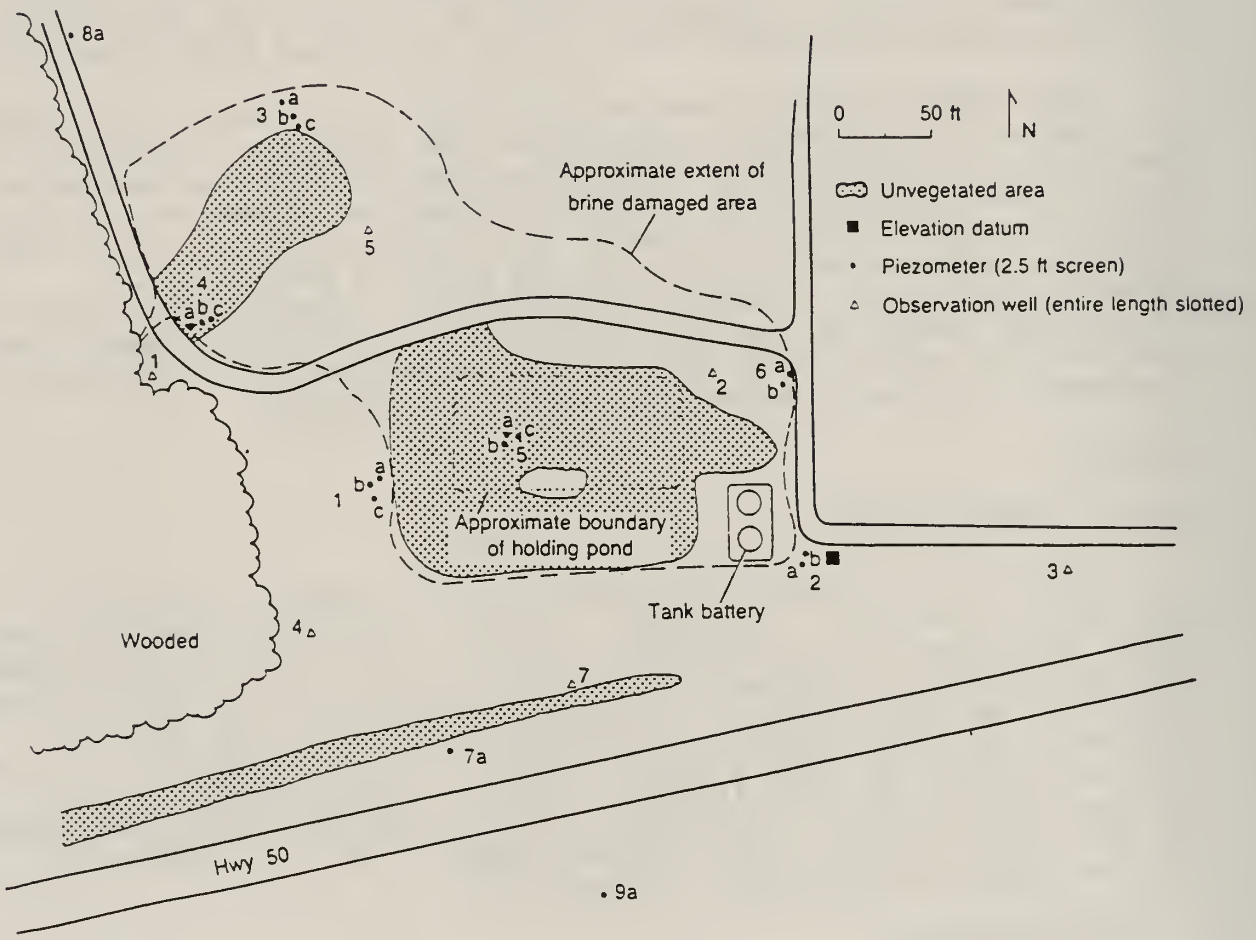
Site A (NORTH SITE)

Site A is located on a nearly level upland in sections 21 and 28, T. 3 N., R. 7 E., Clay County. Surface drainage is south to a road ditch along U.S. Route 50 and west to an intermittent channel which is a tributary of the Elm River (also the discharge point of the road ditch). A brine holding pond had been in operation at this site for more than 20 years (Reed et al., 1981) and was filled in 1984 (Klein, personal communication, 1986). At the time of this investigation there was no vegetation growing in the area of the former holding pond or along a wash which drains into the tributary (figure 9-8).

Site Geology

This site is underlain by moderately well to somewhat poorly drained soils formed in Wisconsinan age loess and loamy diamicton of the Glasford Formation of Illinoian age. The soils are strongly developed with thin silt loam A horizons and clay loam B horizons that have moderately slow to slow permeability. The underlying diamicton is generally uniform in texture in the upper 25 feet. Evidence of oxidation along vertical and horizontal joint faces within the generally massive material of the diamicton and the presence of oil stains along vertical joints at depths of up to 31 feet in core samples below the holding pond suggests that there is preferential flow through the diamicton along the joints. Below 25 feet, the materials become

Figure 9-8. Location of observation wells, piezometers, and cultural features at site A.



stratified, consisting of fine to coarse sand, diamicton, and bedded silts. Bedrock was not encountered during drilling.

The seismic refraction data show that the bedrock surface at this site generally slopes down to the southeast. The depth to bedrock immediately below the area of the filled-in pond is approximately 94 feet.

º **Previous Investigation**

Reed et al. (1981) conducted an investigation at this site in 1978. Four piezometers were installed (one nest, two single wells) and a VES survey was conducted to determine the extent of brine migration. The results of that study are shown on figure 9-9. Groundwater at the site was determined to be flowing in a radial pattern away from the holding pond, which was still in use. The radial flow pattern indicated leakage of brine from the holding pond into the subsurface. The plume detected in the VES survey had extensions to the northeast, south and west. Air photo interpretation indicated that from 1966 to 1978 the unvegetated area surrounding the holding pond had expanded (figure 9-9).

º **Groundwater Flow Direction and Hydraulic Conductivity at Near-Surface Materials**

The relative elevation of the water table, as measured in the observation wells, is shown on figure 9-10. In general, the horizontal component of shallow groundwater flow is toward the southwest and is controlled by the tributary to Elm Creek as well as by the drainage ditch. Horizontal gradients range from 0.02 to 0.03. The vertical component of groundwater flow is generally downward. Downward vertical gradients, measured at the piezometer nests, range from 0.38 to 0.02 (table 9-1). However, the gradients measured between the shallow and intermediate wells at station P4 and between the intermediate and deep wells at station P3 indicated groundwater flow in an upward direction. The upward flow at station P4 is believed to have been a result of seepage toward the adjacent gully, which is probably a local groundwater discharge area. The upward flow at station P3 could be upward seepage toward the relatively high permeability sediments overlying the intermediate well (the shallow well is finished in these sediments). This effect is probably local and not typical of groundwater flow conditions for most of the site.

Slug tests were conducted at piezometer stations P3 and P5. Hydraulic conductivity for the four wells tested ranged from 3×10^{-2} to 8×10^{-6} cm/s.

Figure. 9-9. Resistivity contours and extent of unvegetated area in 1978 at site A (from Reed et al., 1981).

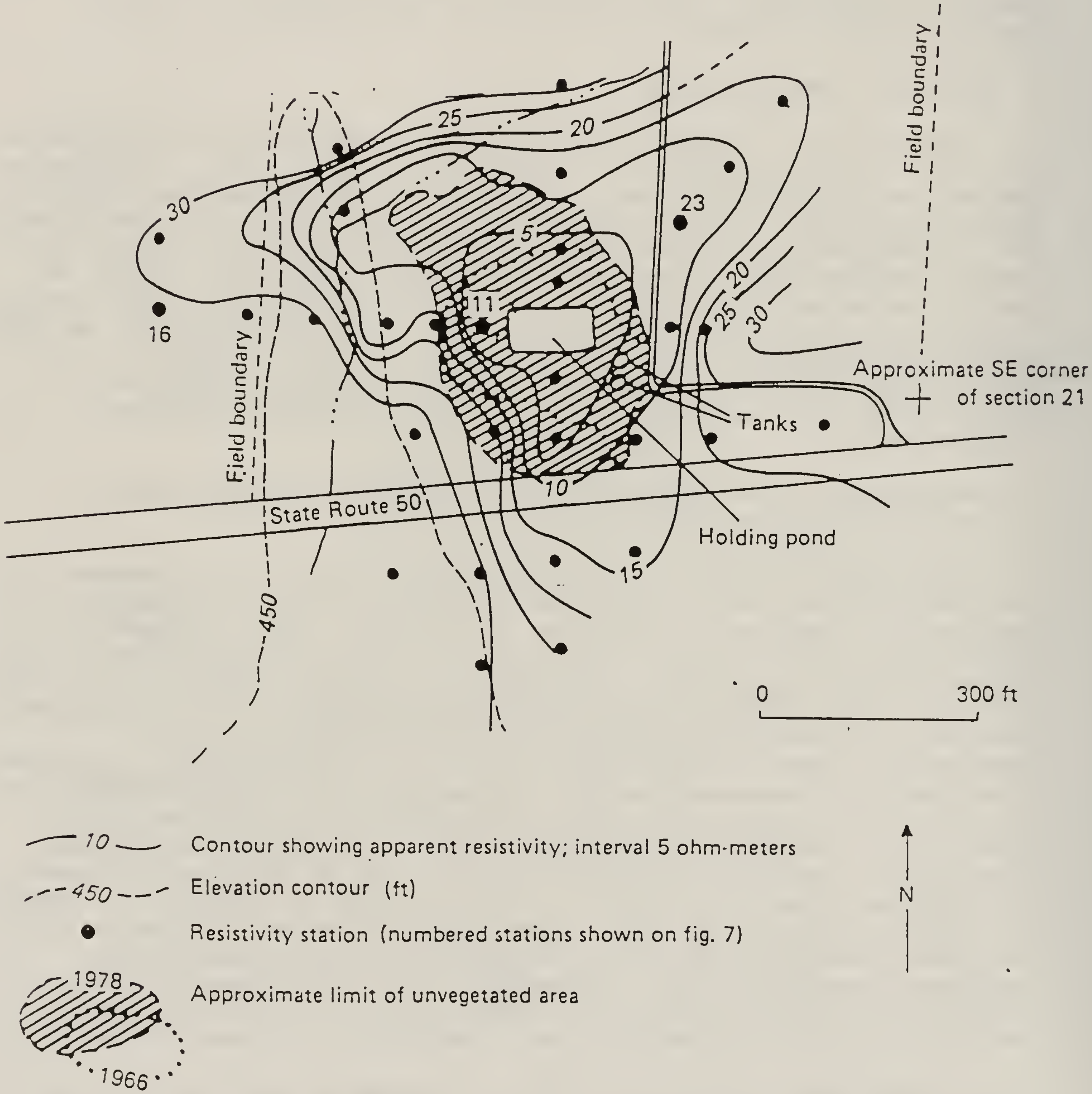
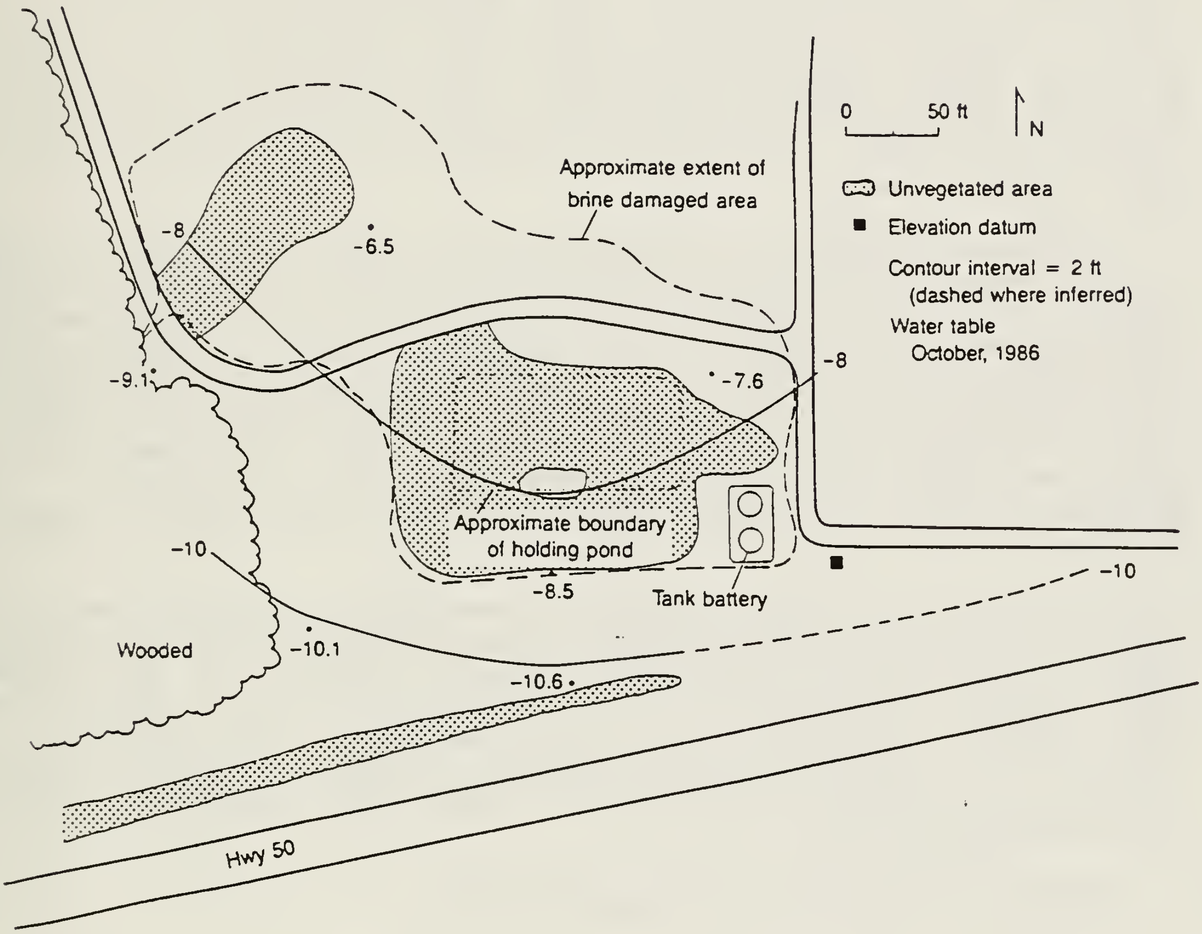


Figure 9-10. Relative water table elevation (in feet), site A, October 1986.



º Groundwater Chemistry

The results of the chemical analyses of groundwater samples from this site are tabulated in Appendix 9-B. In general, the chloride concentrations were very high (up to 32,000 mg/L) in areas affected by the brine. Water samples from the two piezometer stations outside of the brine plume had higher concentrations of sulfate (134-329 mg/L) than chloride (21-27 mg/L). The concentration of sodium is very high (630-15,000 mg/L) in waters sampled toward the central part of the plume. At the fringe and outside of the plume, the concentration of calcium and sodium are roughly equivalent (87-310 and 55-590 mg/L, respectively).

Because chloride is a highly mobile and conservative anion, as well as the major constituent of Illinois oil brines (Meents et al., 1952), it was chosen as an indicator of brine impacts on groundwater. The extent of the chloride plume, as interpreted from chloride concentrations in water samples taken from the piezometers, is shown on figure 9-11. This figure only shows data from wells less than 20 feet deep. With the exception of three wells near the center of the plume, the chloride concentration in the wells greater than 20 feet deep is less than 250 mg/L.

Two lobes of high chloride concentration are apparent on figure 9-11. One lobe of high concentration extends from the area of the holding ponds south beneath highway 50. The second lobe extends northwest from the holding pond area. This plume has a similar configuration to that mapped by Reed et al., (Figure 9-9) except that the northeast lobe is absent. Data for other ions, including strontium (figure 9-12), suggest a similar plume configuration.

º Vertical Electrical Sounding Survey

Two VES surveys were conducted at site A. Resistivity values for the entire site were measured during the first survey. A second, less extensive, survey was conducted to better define the extent of the plume's south lobe. Figure 9-13 shows the distribution of the "true" resistivity values at a depth of 3 meters in the vicinity of the north brine pond. The area within the 10 ohm-meter contour represents an area at a depth of 3 meters that is likely contaminated with brine.

The selection of the 10 ohm-meter value as an indicator of brine contamination was based on comparison of resistivity vs.

Table 9-1. Hydrogeologic data, Site A piezometers.

Station	Well Depth - feet (materials)[1] c	b	a	Vertical Hydraulic Gradient c-b	b-a	c-a	Recovery Rate (Hydraulic Conductivity-cm/s) c	b	a	Station Location
1	7.5-10 (C L)	16.5-19 (C L)	26.5-29 (C L)	+.01	-.38	--	· H	H	VL	Unvegetated area at west edge of filled-in holding pond.
2	-----	9.5-12 (C L)	22.5-25 (C L)	No Data				M	H	Vegetated area east of filled-in holding pond.
3	7.5-10 (S Si L)	17.5-20 (Si L)	32.5-35 (Si L)	-.30	+.11	--	H ($3x10^{-2}$)	M ($3x10^{-5}$)	Vl ($8x10^{-6}$)	Unvegetated area north of filled-in holding pond.
4	7.5-10 (Si L)	17.5-20 (Si L)	26.5-29 (Si L)	+.11	-.02	--	H	L	L	Unvegetated area north of filled-in holding pond.
5	7.5-10 (L)	24.5-27 (L)	42.5-45 (Si C L)	*2	*2	-.05	H	VL	M ($4.3x10^{-4}$)	Unvegetated area over filled-in holding pond.
6	----	12.5-15 (S C L)	27.5-30 (C L)		*2			L-M ($2.0x10^{-5}$)	M	Vegetated area southeast of filled-in holding pond.
7	----	----	21.5-24 (C L)						M	Vegetated area in north road ditch of Highway 50.
8	---- ----	---- ----	19.5-22 (S C L)						L	Vegetated area north of holding pond (background well).
9	----	----	7.5-10 (--)[3]						(H)[3]	Vegetated area in south road ditch of Highway 50.

Notes

1) C = clay
Si = silt
S = sand
L = loam

2) no data for well b

3) Hand augered well, no soil data, recovery rate may not be comparable to other wells due to different borehole diameters.

Figure 9-11. Chloride concentrations in groundwater at site A. Concentrations at nested piezometer stations are from shallow well only. Samples taken in November, 1986.

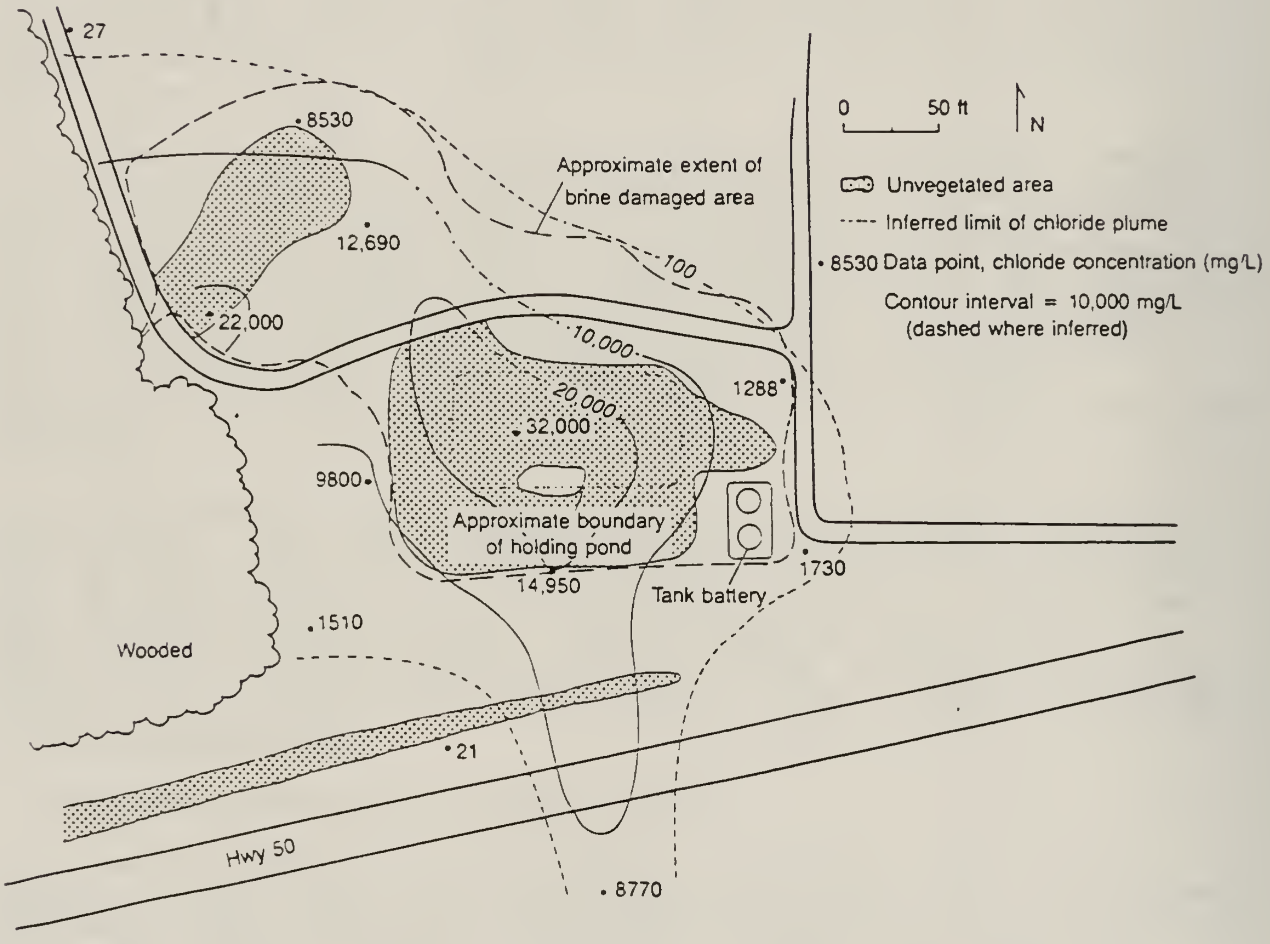


Figure 9-12. Strontium concentration in groundwater at site A. Concentrations at nested piezometer stations are from shallow well only. Samples taken in November, 1986.

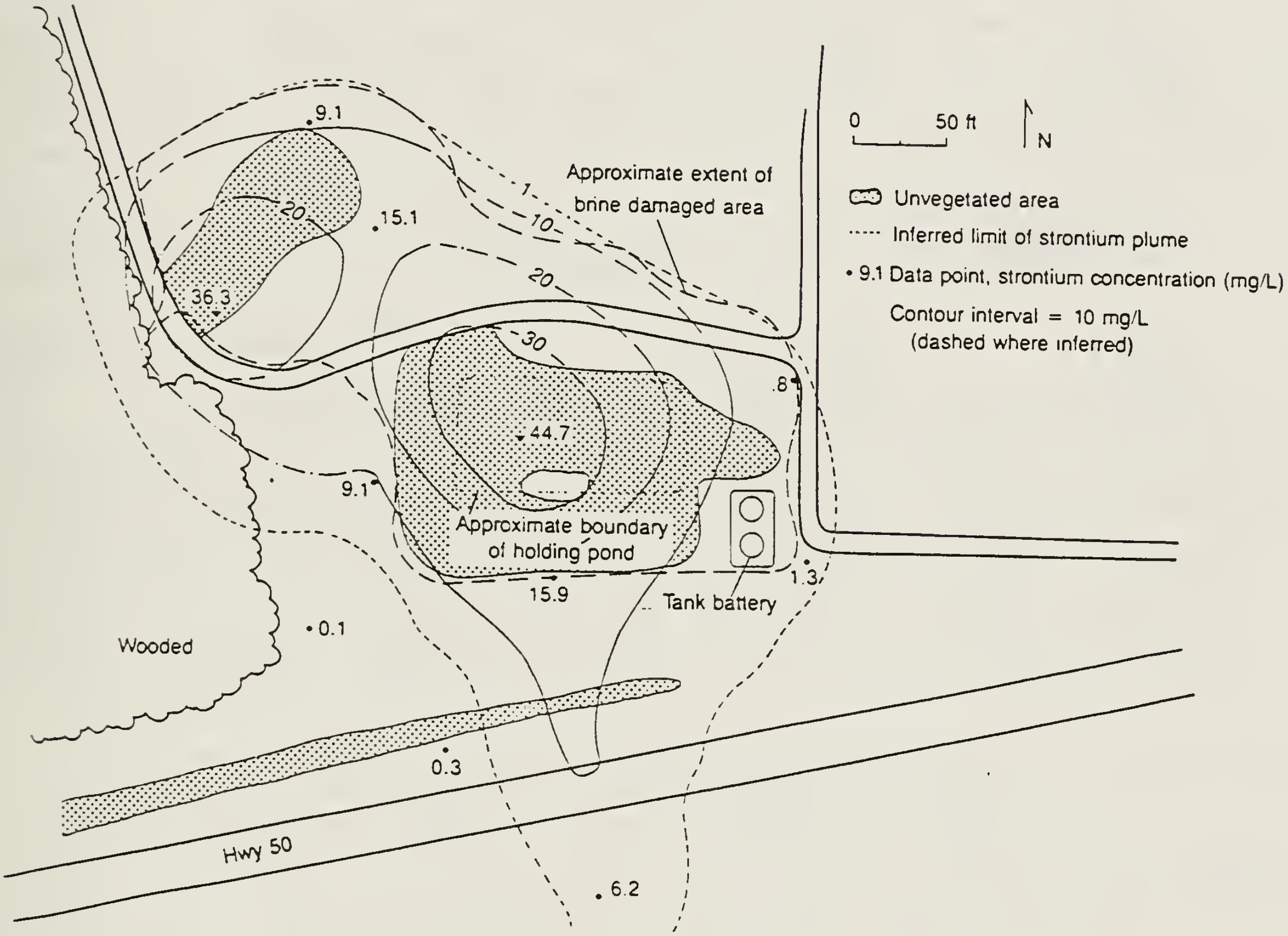


Table 9-2. Chloride concentrations and total dissolved solids compared to resistivity, site A. Underlined values indicate data for observation wells.

Resistivity (ohm-meters)	Chloride Concentrations (mg/L)	Average
0-10	8530, 8770, 32000, <u>12690</u>, <u>14950</u>	15,388
11-20	4400, 9800	7,100
21-30	21, 27, 36, <u>1510</u>, 1730, 2500	970

Resistivity (ohm-meters)	TDS (mg/L)	Average
0-10	12, 817, 13182, 52006, <u>19827</u>, <u>23809</u>	24,328
11-20	8928, 21054	14,991
21-30	560, 894, 959, <u>2589</u>, 2893, 5206	2,183

chloride concentration and resistivity vs total dissolved solids (table 9-2). For both comparisons, the wells within the 20 ohm-meter resistivity contour have water contaminated with brine. However, wells outside of the 20 ohm-meter contour may or may not be contaminated. Therefore, the conclusion may be made that the area within the 20 ohm-meter contour is likely contaminated by brine. However, the more conservative value of 10 ohm-meters was used because only two data points lie within the 11 to 20 ohm-meter range (table 9-2). Figure 9-14 shows the resistivity values at a depth of 6 meters. At the 6-meter depth only two rather small, discrete areas in the vicinity of the brine pond are enclosed by the 10 ohm-meter contour. Since the low "true" resistivity values at the 6 meter depth may be an artifact of the inversion technique caused by low "true" resistivity values at shallower depths, it appears that the earth materials and groundwater at, and possibly above 3 meters has a greater concentration of brine ions than at the 6-meter depth.

º Site A Summary

A brine plume exists at site A with lobes extending south, northwest, and northeast. This plume configuration is similar to that mapped by Reed et al. (1981). However, it does not follow current groundwater flow patterns at the site which are generally south and east (figure 9-10). The existence of lobes in directions currently upgradient of the location of the holding pond is explained by the observed groundwater mounding beneath the pond in 1978, before it had been filled in (Reed et al., 1981). Mounding would have caused a groundwater gradient away from the pond in all directions.

Recovery rates, a gross indicator the ability of the soil to transmit water were high at shallow wells where brine concentrations were high and low to moderate where brine concentrations were lower. This relationship suggests that brine migration at this site was principally through the more permeable materials. Downward migration at this site may have been restricted because the deeper materials are generally less permeable than those near the surface.

SITE B (SOUTH SITE)

Site B is located in sections 33 and 34, T. 3 N., R. 7 E., Clay County. The holding pond at this site was in existence for approximately 10 years and was filled in 1984 (Klein, personal communication, 1986). The holding pond was situated on top of a hill. Surface relief across the entire study site is about 15 feet. Surface drainage is primarily east toward Elm Creek (figure 9-15) along a gully which has cut one to two feet into the unvegetated soil of the brine damaged portion of the site. Headward erosion of the gully exceeded twenty feet during the summer of 1986.

Figure 9-13. "True" resistivity contours at site A. Approximate depth is 3 meters.

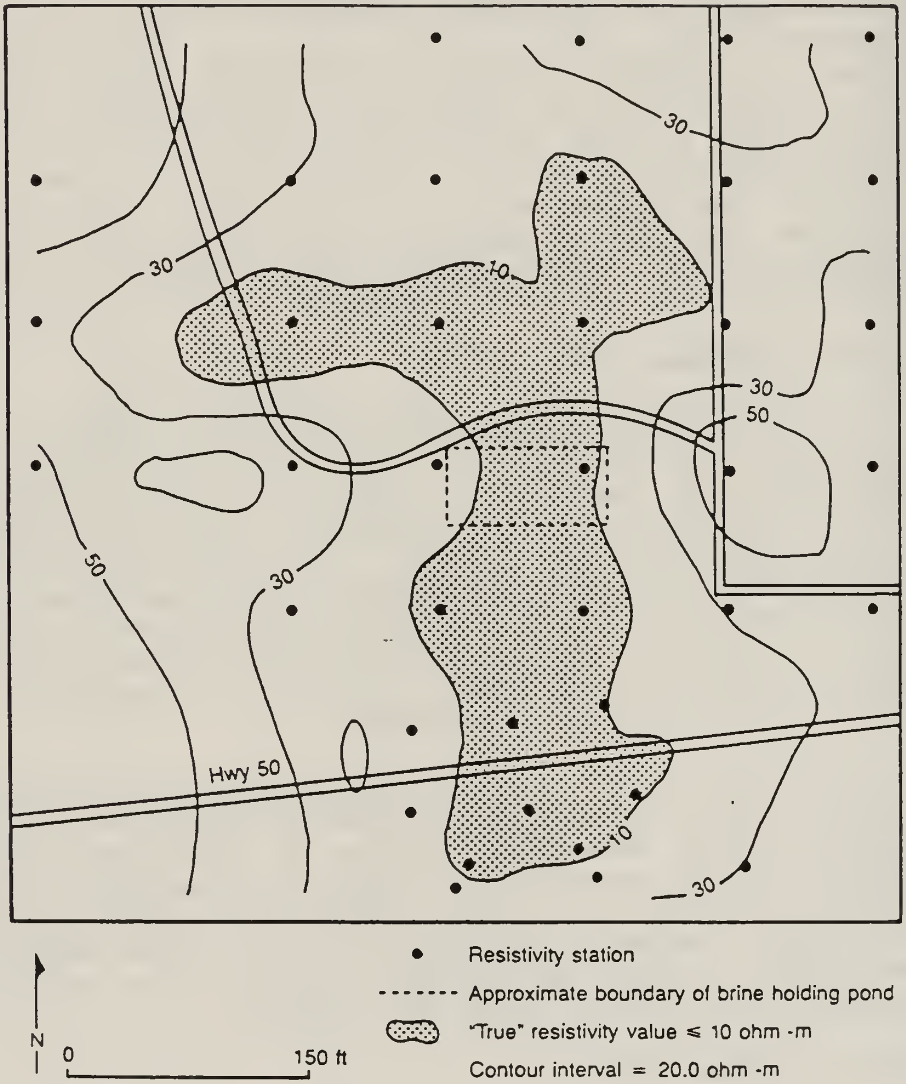
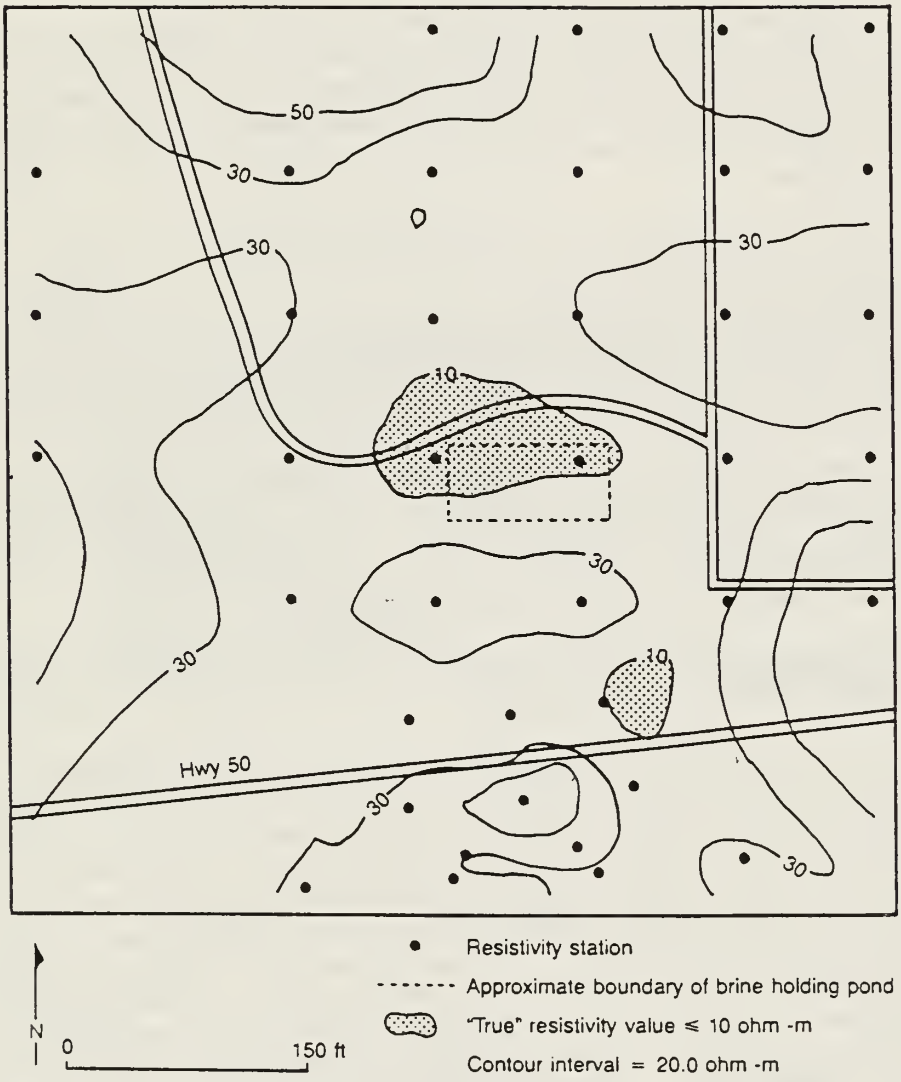


Figure 9-14. "True" resistivity contours at site A. Approximate depth is 6 meters.



Site Geology

The soils at site B range from moderately well to well drained soils on the convex sideslopes to poorly drained soils on the concave toe slope positions and on the flood plain of Elm Creek (east of the site). Somewhat poorly drained soils occur on the nearly level upland west of the holding pond area.

The upland soils formed in thin loess (10 to 40 inches) and the underlying silty diamicton of the Glasford Formation. The poorly drained soils formed in up to seven feet of loess and silty alluvial and colluvial sediments. These soils are less well developed than soils which formed in the more stable upland positions.

The diamicton at site B is generally finer-textured and less variable than at site A. This unit also exhibits less evidence of secondary structures, such as root channels and voids. The finer texture and lack of pedologic features which would increase permeability in this unit suggest that it would have lower hydraulic conductivities than the diamicton at site A.

On the uplands, weathered sandstone and shaly sandstone of the Pennsylvanian age Mattoon Formation were encountered at depths of 25 to 45 feet below ground surface. The seismic refraction data indicate that the bedrock surface generally slopes downward toward the northeast.

º Groundwater Flow Direction and Hydraulic Conductivity of Near-Surface Materials

The relative elevation of the water table was contoured based on data from late October (before water samples had been collected (figure 9-16). Groundwater flow at this site reflects surface topography, with a horizontal component of flow primarily to the east. Horizontal gradients range from 0.01 to 0.03. Vertical gradients measured at the piezometer nests are generally downward (table 9-3). These gradients range from 0.01 to 0.45. Station P6 did not have a deep well). These upward gradients are believed to be due to seepage toward the adjacent gully. Also, station P4 had a slight upward gradient (0.04) which is believed to be seasonal. Measurements at station P4, taken in January of 1987 after a snow-melt, indicated a downward gradient of 0.36.

Slug tests were performed at piezometer stations P1, P6, and P8. The hydraulic conductivities calculated at these stations range from $2x10^{-3}$ to $5x10^{-6}$ cm/s (table 9-3).

Figure 9-15. Location of observation wells, piezometers, and cultural features at site B.

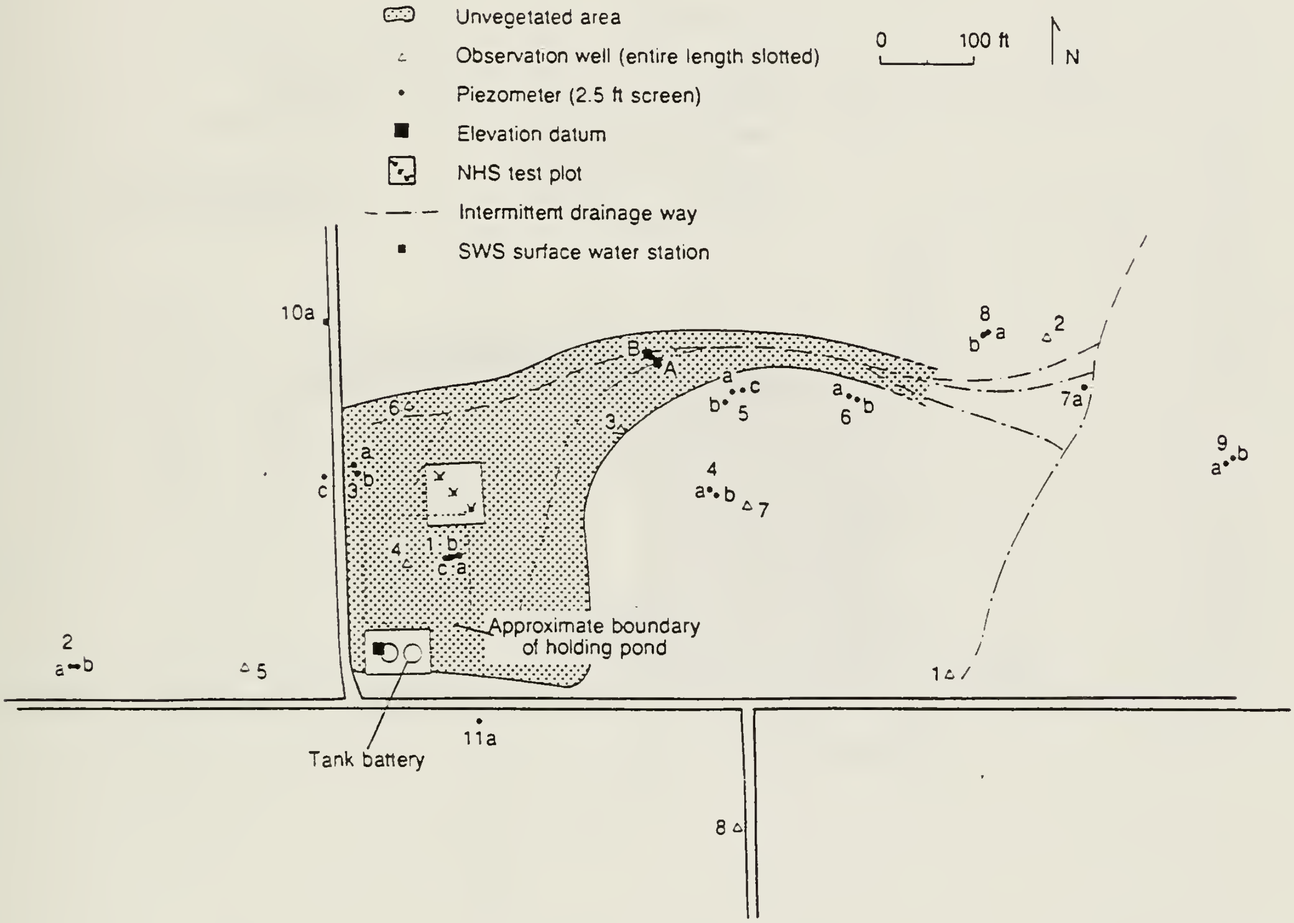


Figure 9-16. Relative water table elevation, site B, October 1986.

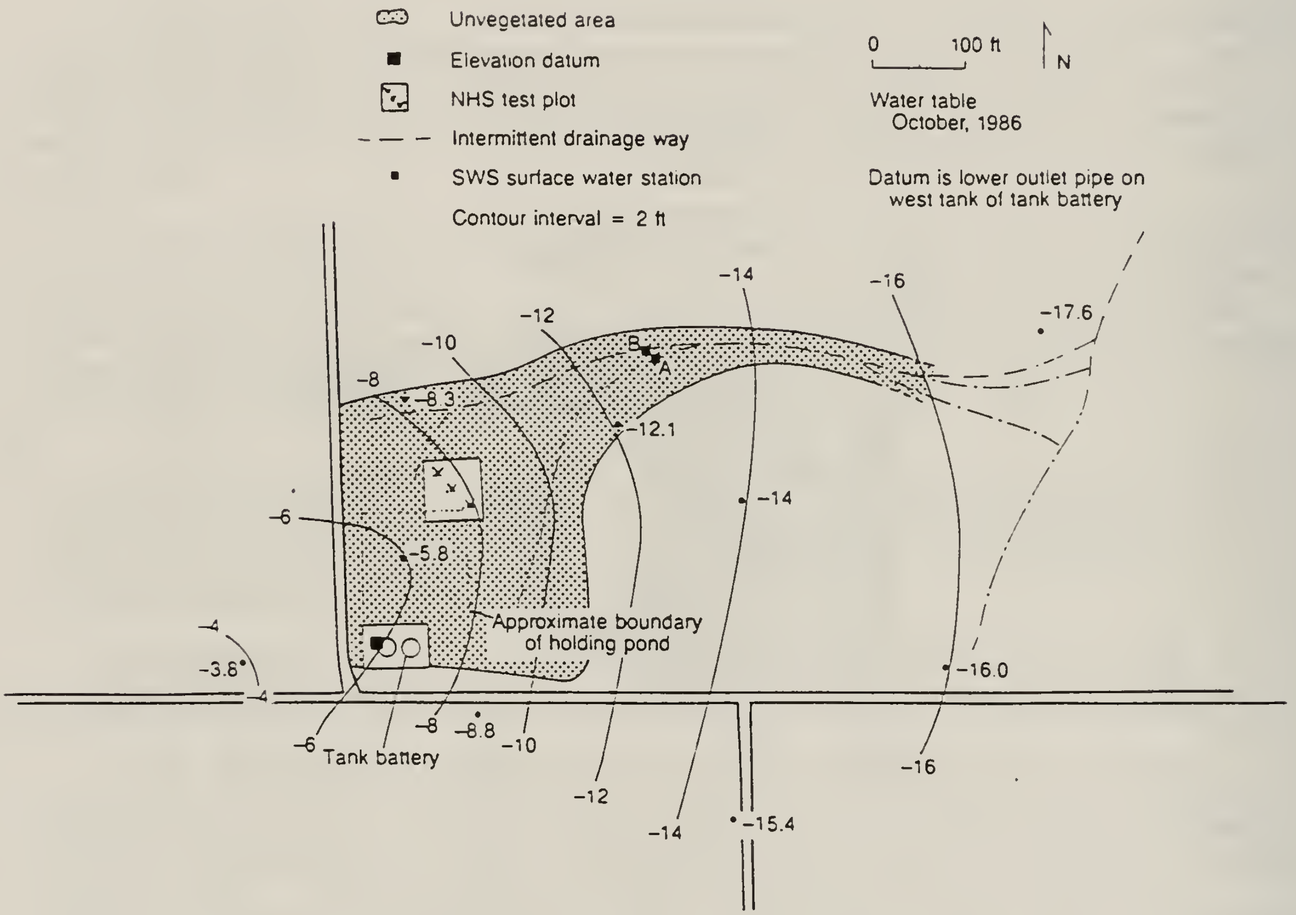


Table 9-3. Hydrogeologic data, site B piezomete

Station	Well Depth - feet (materials)[1] c	b	a	Vertical Hydraulic Gradient c-b	b-a	c-a	Recovery Rate (Hydraulic Conductivity-cm/s) c	b	a	Station Location
1	12.5-15 (C L)	27.5-30 (L)	42.5-45 (L S)	*[2]	*[2]	-.03	. L ($4.9x10^{-6}$)	L	H ($2.1x10^{-3}$)	Unvegetated area over filled-in holding pond.
2	----	12.5-15 (Si C L)	24.5-27 (C L)	---	-.10	---	---	M-H	M-H	Vegetated area west of filled-in holding pond, (background well).
3	9.5-12 (Si L)	17.5-20 (C L)	29.5-32 (C L)	-.08	-.02	---	H	L	L	Unvegetated area at west edge of filled-in holding pond.
4	----	12.5-15	30.5-33	---	+.04	---	---	H	VL	Vegetated area on hill east of filled-in holding pond.
5	9.5-12 (C L)	22.5-25 (C L)	31.5-34 (C L)	+.05	-.01	---	M-H	L-M	VL	Vegetated area adjacent to gully. Northeast of fill-in holding pond.
6	----	10.5-13 (Si C L)	22.5-25 (C L)	---	+.02	---	---	M ($1.1x10^{-5}$)	H ($5.1x10^{-4}$)	Vegetated area along gully, 100 feet east of station 5.
7	----	----	22.5-25 (S C L)	---	---	---	---		L	Vegetated area in lowland east of filled-in holding pond.
8	----	9.5-12 (C L)	22.5-25 (C L)	---	-.22	---	---	M ($3.3x10^{-5}$)	L	Vegetated area northeast of filled-in holding pond.
9	----	9.5-12 (Si C L)	22.5-25 (C L)	---	-.45	---	---	H	VL	Vegetated area, far east of filled-in holding pond.
10	----	----	17.5-20 (C L)	---	---	---	---	---	H	Vegetated area north of filled-in holding pond, (background well).
11	----	----	12.5-15 (---)[3]	---	---	---	---	---	(M)[3]	Road-ditch south of filled-in holding pond.

Notes

1) C = clay
Si = silt
S = sand
L = loam

2) No data for well b

3) Hand-augered well, no soil data, recovery rate may not be comparable due to different borehole diameters.

Groundwater Chemistry

The results of chemical analyses of groundwater samples from this site are tabulated in Appendix 9-B. The concentration of chloride in groundwater in areas affected by the plume is as high as 11,000 mg/L. Away from the plume, the concentration of sulfate (35-650 mg/L) is higher than the other anions including chloride (11-57 mg/L). Sodium (56-3900 mg/L) and calcium (62-1760 mg/L) are the cations with highest concentrations.

The configuration of the chloride plume at site B, as detected by concentrations in groundwater samples, is shown on figure 9-17. Only two stations, both near the area of the filled-in pond (piezometer stations 1 and 3), showed evidence of elevated levels of chloride in groundwater at a depth greater than 20 feet. Total dissolved solids concentrations were also mapped and show a similar plume configuration (figure 9-18).

The presence of a plume in the lowland area east of the filled-in pond and the area of low chloride concentrations between the lowland and the holding pond area may indicate that processes other than migration through groundwater are responsible for brine movement at this site. There are two mechanisms of brine transport which may explain the lowland (east) plume. One possible mechanism is saline runoff waters from the holding pond area flowing downhill along the gully and seeping into the ground at the base of the hill. Another possible mechanism may be groundwater seepage from the pond area to the sandstone which occurs 45 feet below ground surface. If the brine water entered the sandstone and then moved downgradient toward the creek, it may have discharged at the lowland. However, the general shape of the plumes, as determined from the map of chloride concentration and the VES survey, indicate that overland and transport of sediments flow along the drainage way is the primary transport mechanism. Also, the likelihood of migration through the sandstone and toward the lowland is low because the concentrations of brine indicators are lower in the deepest well in the area of the holding pond (88 mg/L chloride at well P1a, depth 42.5-45 feet) than in the lowland plume (about 400 mg/L chloride). If transport through the sandstone were the cause of the lowland plume, the chloride concentration at piezometer P1a would be expected to be higher than that measured. Furthermore, the vertical hydraulic gradient measured at station P9, which is within the lowland plume, is strongly downward (table 9-3), indicating that groundwater discharge does not occur in this area.

º Vertical Electrical Sounding Survey

Figure 9-19a shows the distribution of the "true" resistivity values at a depth of 3 meters at this site. The areas enclosed by the 10 ohm-meter contours, one in the immediate

Figure 9-17. Chloride concentrations in groundwater at site B. Concentrations at nested piezometer stations are from shallow wells only. Samples taken in November, 1986.

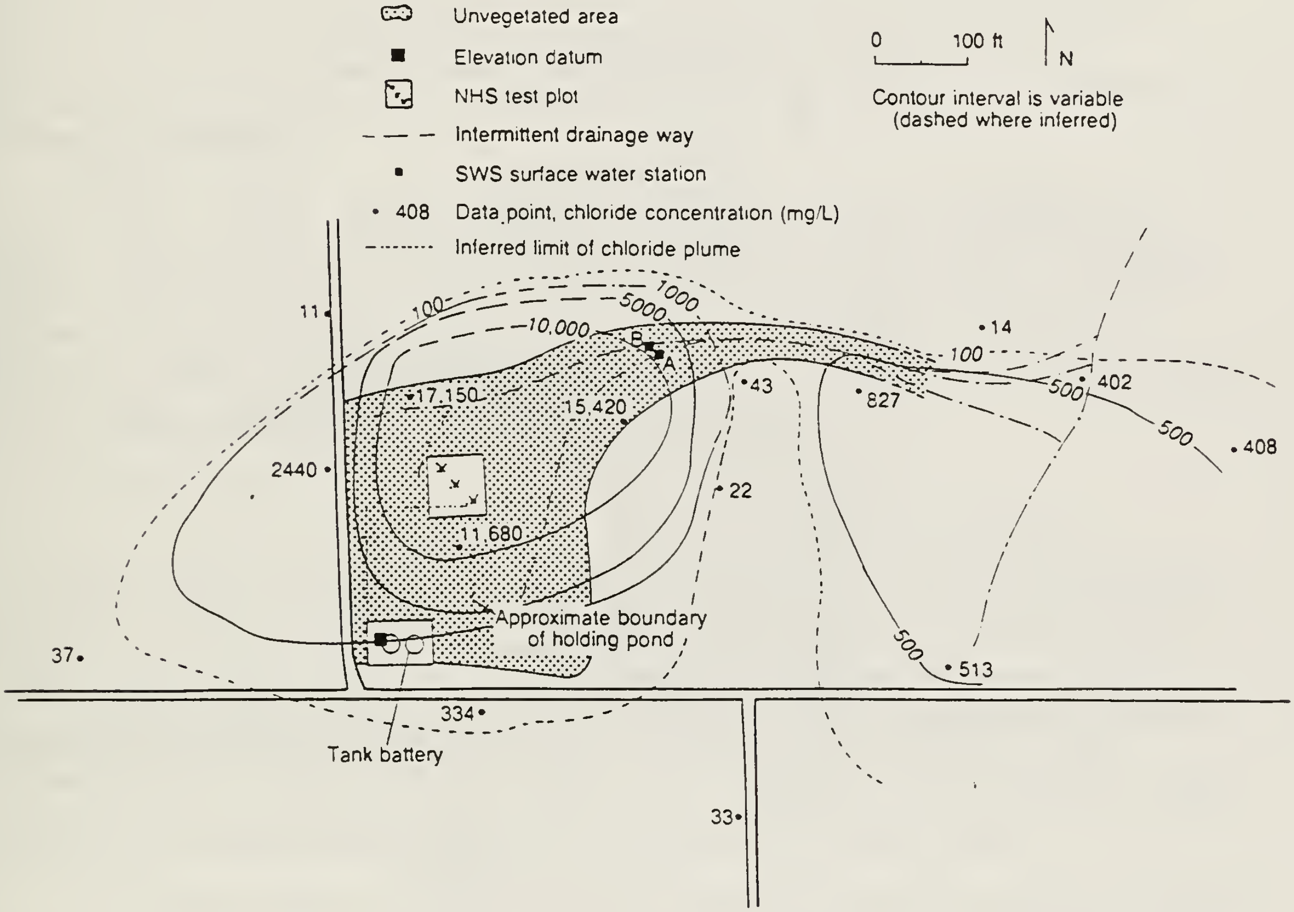
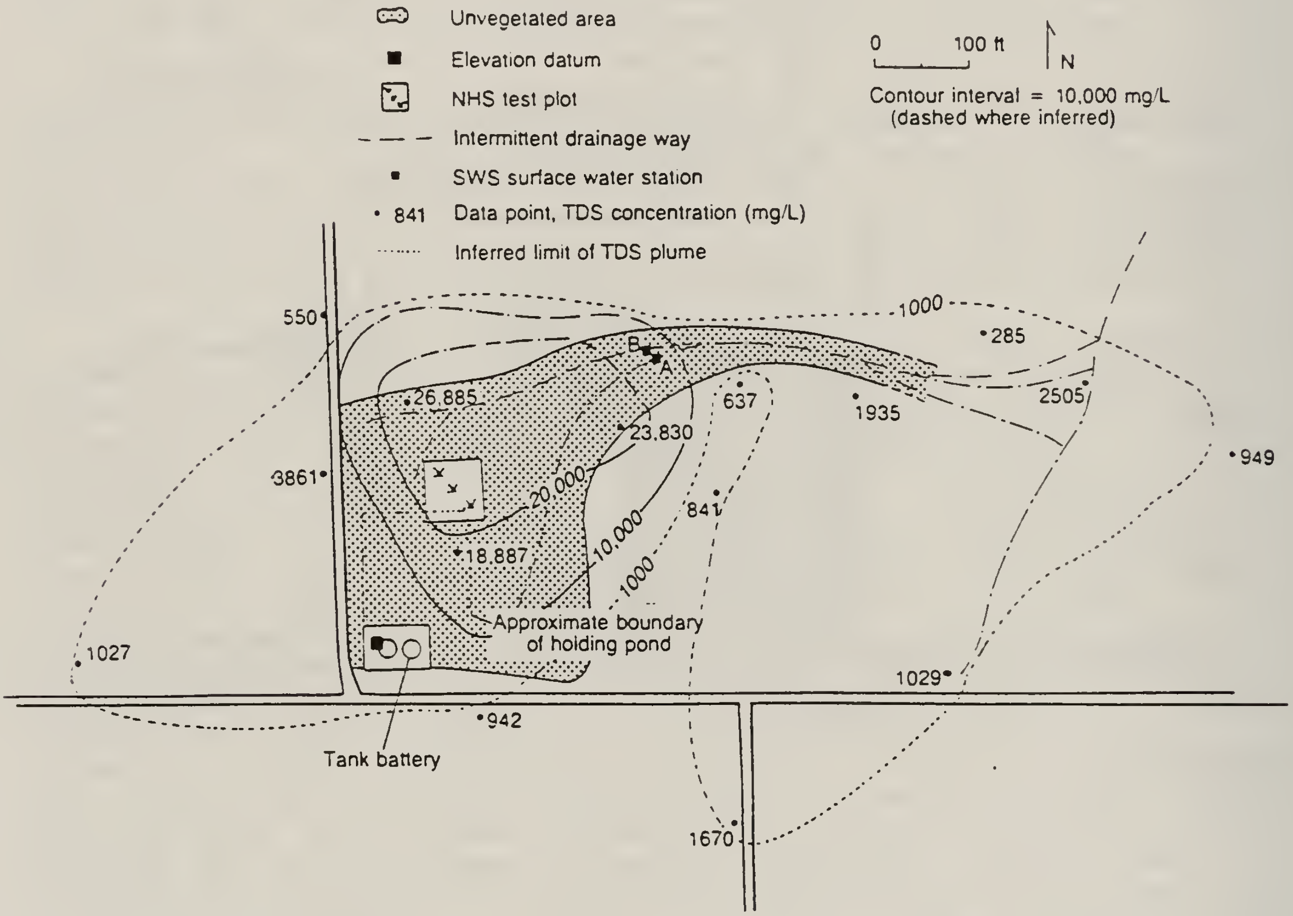


Figure 9-18. Total dissolved solids concentrations in groundwater at site B. Concentrations at nested piezometer stations are from shallow wells only. Samples taken in November, 1986.



vicinity of the brine pond and a smaller one in the eastern (lowland) portion of the site, represent areas at a 3-meter depth that are likely to be contaminated by brine. Table 9-4 shows chloride and total dissolved solids values for wells within the VES survey grid for various ranges of resistivity values. Those wells within the 10 ohm-meter range are clearly within the confines of the brine plume. However, some of the wells in areas with electrical resistivity values greater than 10 ohm-meters have elevated chloride concentrations while others do not. Therefore, only those areas with resistivity values of 10 ohm-meters or less can be mapped, with confidence, as a part of the brine plume.

Figure 9-19b shows the distribution of the "true" resistivity values at a depth of 6 meters. Areas of possible brine contamination at the 6 meter depth are indicated by three small, discrete areas in the immediate vicinity of the filled-in brine pond which have "true" resistivity values less than or equal to 10 ohm-meters. The reasons for these low "true" resistivity areas at the 6 meter depth are similar to those given in the discussion of the pond at site A.

º **Site B Summary**

The migration of brine at this site has been strongly influenced by two factors, surface water runoff and groundwater mounding. The extension of the plume west and upgradient of the filled-in holding pond (figures 9-17 and 9-19a) is evidence of groundwater mounding. The presence of a second plume of lower ion concentration in the lowland area east of the holding pond may be a result of brine transport by overland flow. This transport may have been drainage from the pond while it was still in use, or the result of erosion and transport of sediments with high salt content from the area of the filled-in pond.

The VES method was successfully used to locate areas of high brine concentration in the groundwater. However, definition of the fringe areas of the plume was poor because of uncertainties in interpreting the resistivity data in areas where the brine concentration was relatively low.

The VES method was useful for delineating the plume boundaries in the areas south and west of the site where there were few piezometers. In other areas, the plume traced with the VES method generally coincided with that mapped based on chloride concentrations.

SUMMARY & CONCLUSIONS

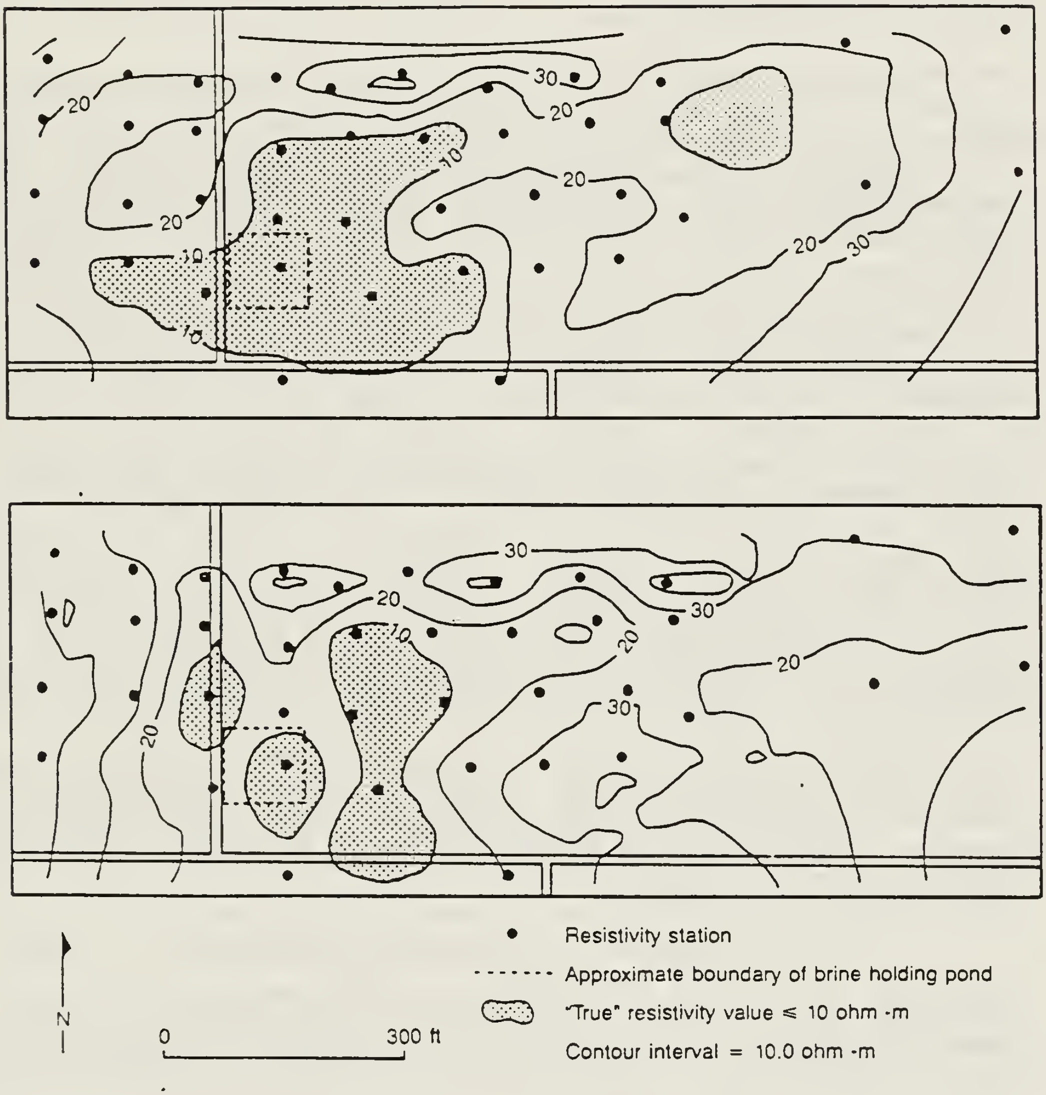
The first objective of this task was to evaluate brine migration in the subsurface. The typical conceptualization of contaminant migration is that of a plume with a single lobe

Table 9-4. Chloride concentration and total dissolved solids compared to resistivity, site B. Underlined values indicate data for observation wells.

Resistivity (ohm-meters)	Chloride Concentration (mg/L)	Average
0-10	7545, 11680, 15420, 17150	12,949
11-20	12, 43, 402, 827, 2440	745
21-30	22, 513	268

Resistivity (ohm-meters)	TDS (mg/L)	Average
0-10	13755, 18887, 23837. 26885	20,841
11-20	732, 637, 854, 1935, 3861	1,604
21-30	841, 1029	935

Figure 9-19. "True" resistivity contours at site B. Approximate depths are 3 and 6 meters.



migrating steadily in a direction downgradient from the source. However, groundwater mounding below brine holding ponds may change local groundwater gradients so that brine migration can occur radially. Once the pond is abandoned and filled in, the mounding effect will eventually diminish and unidirectional groundwater flow will probably resume. The pathway of brine migration will also be influenced by the hydraulic conductivity of the earth materials.

Another important factor affecting the movement of a brine plume in groundwater is density. Brine waters are more dense than fresh water (Hoskins, 1947; Jeffords, 1948), therefore they will tend to migrate downward in the aquifer until they have thoroughly mixed with aquifer waters or a less permeable stratum is reached (Van Diersel, 1985). This effect was not apparent at the sites studied for this project because of the generally low hydraulic conductivity of the earth materials below a depth of 3 to 6 meters. However, in an area of highly permeable, coarse grained deposits, density differences may have significant effects on the flow of brine in the subsurface.

Brine contaminated water and sediments may also be transported by surface runoff from a holding pond to an area of lower elevation where the sediments will settle and the water will pond and infiltrate. Depending upon the concentration of brine and volume of runoff, significant degradation of the quality of groundwater may occur some distance from the holding pond. This degradation may occur at greater distances than if groundwater were the only mechanism of groundwater transport.

The second objective of this task was to test the accuracy and effectiveness of the vertical electrical sounding (VES) method for tracing brine plumes. This method was used to map the general shapes of brine plumes at two sites. The advantages of VES are:

1) Delineation of the extent of the brine plumes was more detailed than that possible by interpretation of groundwater chemistry data along. Lobes of the plume which would not have been detected by the groundwater monitoring were identified with the VES results.

2) The method is quicker and less expensive (table 9-5) than groundwater monitoring. A complete VES survey can be implemented at a site in less than one week. Installation of piezometers may take two or more weeks plus time for well development and sampling. Processing of the VES data can be done on a desktop computer. Chemical analyses of water samples may require expensive laboratory procedures.

Table 9-5. Estimated costs for brine plume investigation, Clay County case study sites A and B.

	Time	Cost
Vertical electrical sounding	6 days	$2,500
Groundwater monitoring study	15 days	10,000

(field only, does not include sampling and chemical analyses)

3) Vertical electrical sounding stations can be placed where piezometers can not, such as the middle of a farm field or woodland. Also, because of the lower costs, more VES stations than piezometers may be used at a site, thus providing greater areal coverage.

However, there are several limitations to this method:

1) Resistivity values may be affected by factors other than the conductivity of the groundwater. Some of these factors are lithologic changes, soil moisture differences, and/or cultural features such as overhead power lines, wire fences, and buried conductors.

2) Vertical electrical sounding results may be difficult to interpret, especially if no groundwater quality data are available. At both case study sites, the determination of significant low resistivity values was dependant on groundwater quality data. Also, lithology will have an affect on resistivity values. A coarse-grained material saturated with fresh water will have a higher resistivity than a fine-grained material saturated with fresh water. However, when both materials are saturated with brine, the coarse-grained material will have lower resistivity. Therefore, data on lithology and the ion concentrations of local groundwater are needed for dependable interpretation of observed resistivity values.

3) Vertical electrical sounding data can not be used to interpret parameters affecting plume migration, particularly groundwater gradients and hydraulic conductivity. While the rate and direction of migration may be estimated from the size and configuration of the plume, complexities in plume configurations, such as at site A, may cause estimates of this type to be in serious error.

4) Electrical resistivity is a measure of the conductance of the soil and water. Thus, it is comparable to a measurement of the concentration of total dissolved solids in groundwater and yields no data on individual chemical species.

The optimal method of evaluating the extent and source of possible brine contamination of groundwater should include both a VES survey and groundwater monitoring. The VES survey should be conducted first. The distance between stations should by small, preferably 100 feet or less. If, after processing the data, areas of anomalously low resistivity are found to extend past the boundaries of the VES grid, additional surveying should be conducted in those areas. After the VES data are complete, a limited number of piezometer nests should be installed. These wells should be finished in areas of very low resistivity as well as areas of high resistivity, so that ion concentrations may be obtained for both brine contaminated and ambient groundwater. Also, an attempt should be made to locate the piezometer nests at VES stations so that resistivity values can be directly compared to ion concentrations. Observation wells should be installed prior to installation of piezometer nests to allow determination of the direction of groundwater flow.

REFERENCES

Hallberg, G. R., J. R. Lucas and C. M. Goodmen, 1978, Part I. Semi-quantitive analysis of clay mineralogy: in Standard Procedures for Evaluation of quaternary Materials in Iowa: Iowa Geological Survey Technical Information Series 8, p. 5-21.

Hoskins, H.A., 1947, Analysis of West Virginia brines: West Virgin Geological Survey Report of Investigations 1, 22 p.

Hvorslev, M. J., 1951, Time log and soil permeability in groundwater observations: U.S. Army Corps of Engineers Bulletin 36, 50 p.

Illinois Division of Oil and Gas, 1985, Mid-Year review FY ’85 SDWA Section 1425 Class II Underground Injection Control Program: 11 p.

Jeffords, R.M., 1948, Graphic Representation of oil field brines in Kansas: State Geological Survey of Kansas Bulletin 76, Part 1, 12 p.

Killey, 1982, The Dwight mineralogic zone of the Yorkville Till Member, northeastern Illinois: Illinois State Geological Survey Circular 526, 25 p.

Klein, J., 1986, Personal communication, Clay County Soil and Water Conservation District.

Meents, W.F., A.H. Bell, O.W. Rees, and W.G. Tilbury, 1952, Illinois oil field brines, their geologic occurrence and chemical composition: Illinois State Geological Survey Illinois Petroleum Report No. 66, 38 p.

Reed, P.C., K. Cartwright, and D. Osby, 1981, Electrical earth resistivity surveys near brine holding ponds in Illinois: Illinois State Geological Survey Environmental Geology Notes 95, 30 p.

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

Van Diersel, T.P.V., 1985, Hydrogeology and chemistry of an oil-field brine plume within a shallow aquifer system in southern Bond County, Illinois: Unpublished M.S. Thesis, Southern Illinois University, 162 p.

Zohdy, A.A.R., 1973, A computer program for the automatic interpretation of Schlumberger sounding curves over horizontally stratified media: U.S. NTIS PB-232 703.

PART THREE

APPENDICES

APPENDICES

Appendix 2-A. Depth to base of fresh water estimated from southeastern Clay County electric logs.

Well ID #	Section/Township/Range Footage/Quarters	Ground Surface Elevation (msl)	Depth to Base of Fresh Water Aquifer est. <2500 ppm TDS	Base of Interval with est. < 10,000 ppm TDS Depth	Base of Interval with est. < 10,000 ppm TDS Elev.	Top of Interval with est. > 10,000 ppm TDS Depth	Top of Interval with est. > 10,000 ppm TDS Elev.	Comments
2060	11- 2N- 6E 330 SL,330 WL,NWSE	442	210	310	132	-	-	
912	12- 2N- 6E 330 SL,330 WL,NW	465	270	320	145	750	-285	
671	13- 2N- 6E 330 SL,330 WL,NW	456	250	250	206	730	-274	
1224	1- 2N- 7E 330 SL,330 WL,NESE	462	210	350	112	480	- 18	base in SS in Sh section
324	2- 2N- 7E 330 SL,660 EL,NENW	443	150	300	143	-	-	
580	4- 2N- 7E 330 NL,330 EL,NW	450	140	350	100	750	-300	
1803	4- 2N- 7E 330 SL,330 EL,SWSE	444	170	470	- 26	800	-356	top in SS in Sh section
1177	5- 2N- 7E 330 SL,990 WL,NWNW	465	150	340	125	770	-305	
1414	6- 2N- 7E 330 NL,330 EL,NWSE	456	150	350	106	740	-284	
2082	8- 2N- 7E 330 SL,330 WL,NESESE	440	250	260	180	720	-280	
1654	9- 2N- 7E 330 NL,330 WL,NENE	446	170	270	176	800	-354	
1791	10- 2N- 7E 330 NL,330 EL,NWNW	420	150	320	100	760	-340	
1228	11- 2N- 7E 330 NL,330 WL,SWSE	442	220	290	152	820	-378	
2104	12- 2N- 7E 330 NL,330 EL,SESE	447	180	300	147	770	-323	
2117	13- 2N- 7E 330 SL,660 WL,SESW	416	250	310	106	550	-134	base in SS in Sh section
1230	14- 2N- 7E 330 NL,660 EL,SE	449	170	250	199	780	-331	
2130	15- 2N- 7E 330 SL,330 WL,NWSE	430	250	250	180	730	-300	
2140	16- 2N- 7E 330 SL,330 EL,SWSE	432	280	280	152	760	-328	
2150	17- 2N- 7E 330 SL,330 EL,NWNE	441	240	250	191	720	-279	
574	4- 2N- 8E 330 NL,330 WL,SE	440	150	350	90	720	-280	

[illegible]ix 2-B.
E[illegible] Log Data

Depth[illegible]

Well ID #	Section/Township/Range Footage/Quarters	Ground Surface Elevation (msl)	Base of Fresh Water Aquifer est. <2500 ppm TDS	Base of Interval with est. < 10,000 ppm TDS Depth	Base of Interval with est. < 10,000 ppm TDS Elev.	[illegible] of Interval [illegible]ith est. > [illegible]000 ppm TDS Depth	[illegible] of Interval [illegible]ith est. > [illegible]000 ppm TDS Elev.	Comments
2199	5- 2N- 8E 330 SL,330 WL,SENE	447	150	340	107	540	- 93	base in SS above Shoal Creek
2235	6- 2N- 8E 330 SL,990 EL,NWNW	461	-	-	-	810	-349	log starts too deep to est TDS of upper interval
535	8- 2N- 8E 330 NL,330 WL,SWNE	463	160	270	193	610	-147	base in SS above Shoal Creek
2336	10- 2N- 8E 330 NL,660 EL,SW	432	210	360	72	740	-308	
1237	13- 2N- 8E 330 SL,330 WL,NE	409	230	330	79	660	-251	
2357	14- 2N- 8E 990 NL,330 WL,SW	432	230	330	102	700	-268	
1514	15- 2N- 8E 330 NL,330 WL,NESE	448	250	310	138	710	-262	
2394	16- 2N- 8E 330 SL,330 EL,SWSW	442	150	260	182	780	-338	
2416	17- 2N- 8E 330 SL,330 WL,SWNW	449	180	300	149	590	-141	base in SS above Shoal Creek
2436	18- 2N- 8E 330 NL, 660 EL,NE	452	200	330	122	820	-368	
1017	2- 3N- 6E 355 NL,330 EL,SW	474	140	150	324	780	-306	
1265	11- 3N- 6E 330 SL,330 EL,SWSE	465	210	260	205	750	-285	
1266	12- 3N- 6E 330 SL,330 WL,SWSW	469	-	290	179	780	-311	
2542	13- 3N- 6E 330 SL,330 WL,NWNW	470	180	280	190	770	-300	
2554	14- 3N- 6E 330 SL,330 EL,NENE	460	130	280	180	760	-300	
1813	23- 3N- 6E 330 NL,330 EL,NE	462	250	260	202	720	-258	
2603	24- 3N- 6E 330 SL,330 WL,NENE	470	200	240	230	730	-260	
688	35- 3N- 6E 330 SL,330 EL,SW	500	-	260	240	780	-280	
1531	4- 3N- 7E 1650 SL,330 EL,SE	431	250	300	131	590	-159	
1022	5- 3N- 7E 330 SL,330 WL,SESE	461	130	300	161	760	-299	

Appendix 2-B
Electric Log Data

Well ID #	Section/Township/Range Footage/Quarters	Ground Surface Elevation (msl)	Depth to Base of Fresh Water Aquifer est. <2500 ppm TDS	Base of Interval with est. < 10,000 ppm TDS Depth	Base of Interval with est. < 10,000 ppm TDS Elev.	Top of Interval with est. > 10,000 ppm TDS Depth	Top of Interval with est. > 10,000 ppm TDS Elev.	Comments
894	6- 3N- 7E 330 NL,330 WL,SESE	464	-	-	-	750	-286	
2667	7- 3N- 7E 330 NL,340 EL,NWSE	469	-	-	-	750	-281	
2669	8- 3N- 7E 330 NL,330 EL,NE	450	-	210?	240?	620	-170	base in SS above Shoal Creek
2692	9- 3N- 7E 330 SL,336 EL,NWSW	459	-	260	199	620	-161	base in SS above Shoal Creek
2727	10- 3N- 7E 330 SL,330 EL,NENE	430	210	260	170	790	-360	
815	13- 3N- 7E 330 NL,330 WL,SWNW	453	150	300?	153?	780	-327	
2762	14- 3N- 7E 330 NL,330 EL,SE	446	-	280	166	750	-304	
2767	15- 3N- 7E 330 SL,330 EL,NESE	465	280	300	165	770	-305	
2780	16- 3N- 7E 330 NL,330 EL,SW	461	270	300	161	750	-289	
2810	17- 3N- 7E 330 NL,330 EL,SESE	457	150	300	157	600	-143	
708	18- 3N- 7E 330 NL,330 WL,SW	462	180	350	112	750	-288	
2821	19- 3N- 7E 42 SL,178 EL,NW	466	200	400	66	750	-284	top in SS below 1st SS
2828	20- 3N- 7E 380 SL,330 EL,NE	454	130	300	154	520	- 66	base in SS above Shoal Creek
2833	21- 3N- 7E 330 SL,990 WL,NWNE	455	250	320	135	720	-265	
2860	22- 3N- 7E 330 SL,330 WL,NWSE	465	150	260	205	610	-145	base in SS above Shoal Creek
2866	23- 3N- 7E 346 NL,330 EL,SWSW	492	200	-	-	-	-	base of fresh water below 930' (?)
2874	24- 3N- 7E 660 SL,330 EL,SW	456	-	310	146	820	-364	
2880	25- 3N- 7E 330 NL,660 EL,NW	462	-	330	132	830	-368	
1903	26- 3N- 7E 330 NL,330 EL,NESENE	453	160	300	153	800	-347	
2891	27- 3N- 7E 990 SL,330 WL,SENW	445	150	250	195	730	-285	

Appendix 2-B./1
Electric Log Data

Depth to

Well ID #	Section/Township/Range Footage/Quarters	Ground Surface Elevation (msl)	Base of Fresh Water Aquifer est. <2500 ppm TDS	Base of Inter[illegible]l with est. < 10,000 ppm TDS Depth	Elev.	Top of Interval with est. > 10,000 ppm TDS Depth	Elev.	Comments
2901	29- 3N- 7E 330 SL,330 EL,NE	452	-	240	212	500	- 48	base in SS above Shoal Creek
1425	30- 3N- 7E 1650 SL,330 EL,SW	472	150	250	222	550	- 78	base in SS above Shoal Creek
2904	31- 3N- 7E 330 NL,330 EL,SENE	469	150	-	-	-	-	entire hole looked relatively fresh
1290	33- 3N- 7E 330 NL,660 EL,SWNE	453	140	.260	193	690	-237	
1292	34- 3N- 7E 330 SL,330 WL,NE	448	160	300	148	600	-152	base in SS above Shoal Creek
757	35- 3N- 7E 330 NL,330 EL,NWNW	438	170	300	138	800	-362	
2915	36- 3N- 7E 330 SL,330 EL,NWSW	459	190	310	149	810	-351	
2978	17- 3N- 8E 330 NL,330 EL,NE	410	150	290	120	620	-210	base in SS above Shoal Creek
3000	19- 3N- 8E 330 SL,330 EL,SW	453	-	310	143	800	-347	
3003	20- 3N- 8E 1 NL,330 WL,NESW	447	-	300	147	590	-143	base in SS above Shoal Creek
643	21- 3N- 8E 330 NL,330 WL,SWNW	485	150	250	235	860	-375	
3075	28- 3N- 8E 330 SL,330 EL,NWNW	449	200	200	249	570	-121	base in SS above Shoal Creek
1608	29- 3N- 8E 330 SL,330 EL,NENE	473	-	200	273	820	-347	
30[illegible]6	30- 3N- 8E 330 NL,330 WL,NENE	476	-	350	126	580	-104	base in SS above Shoal Creek
1308	31- 3N- 8E 330 NL,330 EL,SWSE	476	200	360	116	830	-354	
3108	32- 3N- 8E 330 SL,330 WL,NE	454	250	300	154	560	-106	base in SS above Shoal Creek
1097	33- 3N- 8E 330 SL,330 EL,NESE	411	150	300	111	690	-279	
3166	34- 3N- 8E 330 SL,330 WL,SW	430	-	410	20	700	-270	

Appendix 3-A. Summary of data from water well drilers logs for southeastern Clay County.

Appendix 3-A - Water Well Drilling Log Data (ISGS)

Well ID #	Location Sec/Twnshp/Range footage/quarters	Surface Elevation (feet above m.s.l.)	Well Depth (feet)	Casing Length (feet)	Static Water Level (feet below surf.)	Depth to Top of Aquifer	Depth to Base of Aquifer	Aquifer Lithology	Reported Yield (gpm)	Comments
25822	1-2N-6E 300 NL,250 WL,NW	480	100	25.5	10.5	74	100	SS	20	
4767	1-2N-6E 105 SL,160 WL,SE SE	470	126	81.5	23	111	126	SS	24	location verified by plat
25932	1-2N-6E 410 SL,200 WL, NW NW	480	87	44	10	74	87	SS	20	.tion verified by plat
4585	11-2N-6E 150 NL,1120 EL,NE	460	91	63	12	59	91	SS	12	
25935	11-2N-6E 475 SL,200 EL,SE	435	170	63	24	148	150	Slate	2	
4384	11-2N-6E 110 NL, 1530 WL, NW	445	103	84	-	93	103	SS	12	
25734	12-2N-6E 450 NL,310 WL,NW SW	460	116	58	24	74	116	SS	10	
4461	12-2N-6E NW NW NW	470	110	62	30	91	110	SS	20	
26093	13-2N-6E 600 NL,325 EL,NE	455	200	97	54	175	200	SS	10	
4462	13-2N-6E Not Given	-	116	88	25	93	116	SS	28	
N-4	14-2N-6E NE NE NW	460	85	75	19.67	75	85	SS	-	
4393	1-2N-7E 1300 SL,2600 EL,SE	470	170	88	40	142	170	SS	18	location verified by plat
N-5	2-2N-7E 150 SL,200 EL,SE	455	110	69	13	66	110	SS	5	location verified by plat
N-6	5-2N-7E 200 NL,280 EL,NE	455	140	81	29	78	127	SS	7	
4443	6-2N-7E SW SW NW	470	115	80	20	103	115	SS	36	
25268	6-2N-7E 250 SL,200 EL,NW	460	120	44.5	17	59	120	SS	15	
4479	7-2N-7E Not given	-	130	88	35	110	130	SS	18	
N-1	7-2N-7E 320 SL,300 EL,NW SW	470	100	81	7	74	100	SS	20	
4385	7-2N-7E 600 EL,SE	450	120	102	-	99	120	SS	11	
25312	7-2N-7E 210 NL,200 WL,SW	455	128	43	9	116	128	SS	16.5	location verified by plat
4586	7-2N-7E 300 NL,1570 EL,NE	460	105	64	30	84	105	SS	12	location verified by plat
4444	8-2N-7E SE/C NE SE SE NE	450	102	43	20	61	102	SS	2	
4614	8-2N-7E 450SL,75 EL,SE SE	435	102	82	28	81	102	SS	9	
4386	8-2N-7E 1815NL,200 EL,NE	440	130	89	-	95	130	SS,LS	13	
N-2	9-2N-7E 980 NL,300 WL,NE	460	140	81	24	106	140	SS	12	location verified by plat

Appendix 3-A - Water Well Drilling [illegible]ta (ISGS)

Well ID #	Location Sec/Twnshp/Range footage/quarters	Surface Elevation (feet above m.s.l.)	Well Depth (feet)	Casing Length (feet)	Static Water Level (feet below surf.)	Depth to Top of Aquifer	Depth to Base of Aquifer	Aquifer Lithology	Reported Yield (gpm)	Comments
4686	9-2N-7E 600 SL,250 WL,SW	435	82	69	-	67	82	SS	-	
25433	9-2N-7E 200 NL, 350 WL,SE	440	122	46	38	96	122	SS	15	
5034	10-2N-7E 150 SL, 150 EL,SE	440	115	103	29	110	115	SS	25	location verified by plat
4989	10-2N-7E 125 SL,150 EL,NE	440	135	100	24	100	135	SS	10	owner's land 125 ft south of this site
4913	10-2N-7E NE NE NW	435	115	93	19?	91	115	SS	10	
26534	11-2N-7E 860 NL,425 WL,NW	445	120	105	33	101	120	SS	10	location verified by plat
25463	11-2N-7E SW NE NE	455	172	61	33	114 155	119 155	SS SS	20	
4550	11-2N-7E NE SW NE	455	100	70	29.75	70	100	SS	10	
25937	12-2N-7E 250 SL, 225 WL, SW	455	130	60.5	29	98	130	SS	12	
26535	12-2N-7E 810 SL,225 WL,SW	455	122	122	44	120	136	SS	8	
4447	12-2N-7E 330 NL,660 EL,SE NW	460	185	-	-	38	185	SS	-	log notes SS water-bearing full thickness d.1937
4615	13-2N-7E 480 NL,400 EL,SW NW	455	145	88.6	28	117	145	SS	18	
25577	13-2N-7E SE NW NW	460	100	80	flows	80	100	SS	-	
4394	14-2N-7E 1100 NL,100 EL,NE	455	145	113	40	131	145	SS	18	location verified by plat
25714	14-2N-7E 190 SL,150 WL,SE	-	140	105	30	102	140	SS	25	
4449	14-2N-7E not given	-	83	71	-	69	80	Sand ?	4	
4645	14-2N-7E 210 NL,150 EL,SE	445	131	-	26	79	130	SS	6	location verified by plat
25689	14-2N-7E NW SE NE	450	150	100	39.6	100	145	SS	-	location verified by plat
25187	15-2N-7E 160 NL,150 WL,NW	420	140	73	28	97	140	SS	30	
4450	16-2N-7E 120 SL,1000 WL,SW	435	105	89	24	94	105	SS	12	location verified by plat
4451	16-2N-7E 900 NL,200 WL,NW	435	138	115	-	116	136	SS	-	oil company well
25736	17-2N-7E 580 NL,570 EL,NE	430	120	94	11	94	117	SS	11.5	location verified by plat
25938	17-2N-7E 420 NL,220 EL,NE	430	120	90	13	87	120	SS	10	location verified by plat
4452	17-2N-7E NE SW NE	435	102	85	12	93	102	SS	15	
25737	17-2N-7E 200 NL,150 WL,NE	435	121	97	9.5	110	121	SS	10	location verified by plat

Appendix 3-A - Water Well Drilling Log Data (ISGS)

Well ID #	Location Sec/Twnshp/Range footage/quarters	Surface Elevation (feet above m.s.l.)	Well Depth (feet)	Casing Length (feet)	Static Water Level (feet below surf.)	Depth to Top of Aquifer	Depth to Base of Aquifer	Aquifer Lithology	Reported Yield (gpm)	Comments
25218	3-2N-8E 111 SL,115 WL,NW NE SE	410	38	38	-	15	16	sandy clay	bored well	location verified by plat
N-7	4-2N-8E NW NW NW	445	115	60	14.67	60	110	SS	-	location verified by plat
25578	4-2N-8E NW NW NW	440	115	110	19.6	50	110	SS	-	location verified by plat
25313	5-2N-8E 74 NL,60 WL,NE NW NE	450	41	41	-	16	41	SH	bored well	
25365	5-2N-8E 175 NL,1600 EL,NE	450	148	105	34.6	105	148	SS	4	checked by Meents for gas location verified
26536	5-2N-8E 200 NL,250 EL,NE NW	460	160	64	48	135	157	SS	8	location verified by plat
N-8	8-2N-8E SE SW NW	465	170	110	29.67	110	165	SS	-	location verified by plat
4646	9-2N-8E 80 NL,120 EL,SE SE	450	82	44.5	8.5	61	82	SS	11	
4436	9-2N-8E SW/C SW NW	455	86	28	14.6	28	85	SS	-	
4653	11-2N-8E 174 SL,165 EL,SW SW SE	425	86	86	17	51	85	SS	3.5	casing perforated 51'-85'
N-9	13-2N-8E 136 SL,195 WL,SW	440	32	32	-	11	12	S&G	bored well	location verified by plat
N-10	14-2N-8E NW NE NE	415	120	50	-	50	115	SS	-	location verified by plat
4820	1-3N-6E 94 SL,63 EL,SW SW NE	470	23	23	-	20	23	sandy clay	bored well	location verified by plat
4399	11-3N-6E 1450 SL,160 EL,SE	470	150	66	15	26	37	S&G	9	location verified by plat
25314	11-3N-6E 650 SL,200 EL,SE	470	113	83	19	82	113	SS	15	
N-11	12-3N-6E 500 SL,500 EL,SE	450	61	61	-	53	54	SH, G	bored well	location verified by plat
25394	12-3N-6E 117 SL,108 WL,SE SE SE	455	45	45	-	41	42	sand	bored well	location verified by plat but is now a subdivision
25943	12-3N-6E 122 NL,107EL,SE SE SE	450	54	54	-	41	43	G streaks	bored well	subdivision
25149	12-3N-6E 109 NL,102 WL,SE NE SW	450	23	23	-	22	23	S&G	bored well	
25251	12-3N-6E 1140 SL,300 EL,SE	460	37	-	-	-	-	-	dry hole	
25395	12-3N-6E 100 SL,104 WL,SE SE SE	455	26	26	-	23	26	G	bored well	subdivision
N-12	13-3N-6E SW NW NW	465	80	60	1.67	60	80	SS	-	
N-13	13-3N-6E SW NW NW	465	120	-	-	-	-	-	dry hole	
25826	13-3N-6E 435 SL,500 WL,NE	470	92	93	12.5	86	91	G	14	location verified by plat
5071	13-3N-6E NE NE SW	460	120	100	flows	100	120	SS	10	

Appendix 3-A - Water Well Drilling Log Data (ISGS)

Well ID #	Location Sec/Twnshp/Range footage/quarters	Surface Elevation (feet above m.s.l.)	Well Depth (feet)	Casing Length (feet)	Static Water Level (feet below surf.)	Depth to Top of Aquifer	Depth to Base of Aquifer	Aquifer Lithology	Reported Yield (gpm)	Comments
4476	14-3N-6E C. S 1/2 NE	465?	93	48	-	?	93	SS	12	owner verified, location uncertain
4814	14-3N-6E 290 NL,135 EL,NE	470	85	53.25	8.5	51	83	SS	12	
25818	23-3N-6E 104 NL,108EL,SE SE SW	490	14	-	-	-	-	-	dry hole	location verified by plat
25819	23-3N-6E 50 SL,100 WL,SE SE SW	490	50	26	1	40	50	SS	-	location verified by plat
25751	24-3N-6E 300 NL,320 WL,SW SE	480	91	43	9	38	91	SS	6	location verified by plat
25507	26-3N-6E 81 SL,93 WL,SE NE NW	500	19	19	-	10	19	SS	bored well	
25945	35-3N-6E 300 SL,150 EL,SE	485	120	40	12.5	48	120	SS	15	location verified by plat
N-14	6-3N-7E 96 NL,112 WL,NW	450	14	14	-	12	13	sand, clay	bored well	location verified by plat
N-15	6-3N-7E 720 NL,250 WL,NW	450	160	42	89	76	81	SS?	1	location verified by plat
4768	8-3N-7E 160 SL,130 WL,SW	450	177	-	-	-	-	-	dry hole	location verified by plat
4480	8-3N-7E SW SW SE	460	160	99	10	145	160	SS	8	
25100	8-3N-7E 100 SL,125 WL,SW SE SE	455	30	30	-	12	13	sandy clay	bored well	
25955	8-3N-7E 106 SL,109 WL,SE	460	30	30	-	-	-	-	bored well	
N-16	11-3N-7E SW SE SW	450	80	80	19.67	35	40	G	2	location verified by plat
25754	11-3N-7E 116 SL,106 WL,SE SW	450	27	27	-	-	-	-	dry hole	location verified by plat
26545	13-3N-7E 150 SL,100 WL,NE SW NW	440	30	30	14	14	16	sand	bored well	
4551	16-3N-7E 65 NL,125 WL,SW NE	460	239	225?	39.67	225	239	SS	-	location verified by plat
4481	16-3N-7E NE NE NW	460	230	127	35	220	230	SS	12	location verified by plat
4482	16-3N-7E SW NE NE	455	235	91	20	196	235	SS	5	owner has land nearby, but not here
26546	16-3N-7E SE SE NE	445	265	197	74.67	197	260	SS	6	location verified by plat
25358	18-3N-7E 150 SL,200 EL,SE	465	115	86	17	85	115	SS	15	
25755	21-3N-7E SW SW SW	450	120	80.5	8.5	80	118	SS	8	
25219	21-3N-7E 225 SL,100 EL,SE SE SW	450	100	43	5	58	100	SS	10	
N-17	23-3N-7E SE NE NW	465	160	-	-	140	160	SS	-	location verified by plat well plugged due to salt content
26283	23-3N-7E SE NE NW	465	174	-	-	-	-	SS	-	well plugged because salt content was high

Appendix 3-A - Water Well Drilling Log Data (ISGS)

Well ID #	Location Sec/Twnshp/Range footage/quarters	Surface Elevation (feet above m.s.l.)	Well Depth (feet)	Casing Length (feet)	Static Water Level (feet below surf.)	Depth to Top of Aquifer	Depth to Base of Aquifer	Aquifer Lithology	Reported Yield (gpm)	Comments
5049	27-3N-7E 120 NL,125 EL,NE	470	185	51	29	138	185	SS	12	
N-18	28-3N-7E NE SW NW	440	120	80	34.67	80	120	SS	-	location verified by plat
26547	28-3N-7E 350 NL,330 EL,NE	450	120	92	29	89	120	SS	12	
4815	28-3N-7E 280 NL,150 EL,NE	450	114	101	18.67	97	114	SS	30	
4387	28-3N-7E SW NW NE	455	115	90	-	83	115	SS	18	
4762	29-3N-7E NE NE SE	-	93	53.67	flows	49	93	SS	30	
4414	29-3N-7E 1290 NL,1270 WL,SE	460	120	67	30	104	120	SS	24	
4928	29-3N-7E 800 NL,200 EL,NW	450	87	30	4	48	87	SS	11.5	
4488	30-3N-7E SE SW NW	470	150	85	110	117	150	SS	24	
5016	31-3N-7E 200 NL,600 EL,NE	470	145	56	14	116	145	SS	7.5	
25756	33-3N-7E NW SW NE	440	126	-	-	107	126	SS	18	owner just north of this location
4907	33-3N-7E SW NW NW	460	91	38	19	36	91	SS	10	owner just south of this location
25757	33-3N-7E SE SE NW	455	94	25	14	23	92	SS	10	location verified by plat
4490	35-3N-7E SW NE	455	93	66	24	64	91	SS	24	location verified by plat
25269	35-3N-7E SE SW SE	445	75	60	3.67	60	75	SS	50 (bailed)	owner just west of this location
4178	3-3N-8E 1900 SL,1900 EL,SE	-	90	60	flows	60	90	sand	-	location verified, but maybe under lake now; gas flow measurement-Meents
25152	3-3N-8E 2050 SL,1600 WL,SW	425	42	38	1.67	38	42	sand	20	location verified, but new owner; gas flow measurement-Meents
4953	3-3N-8E NE NE SW	430	60	59	3.67	60	60?	sand?	10	
N-3	20-3N-8E 150 NL,75 EL,NE	440	25	25	2	12	14	sand	1	location verified by plat; lawn & garden
821	21-3N-8E 70 EL,1530 NL,SW	480	62	20	20	50	62	SS	5	d. 1931
4493	21-3N-8E 500 NL,200 WL,SE SW	440	155	130	35	130	155	SS	1.5	
4972	27-3N-8E 76 SL,88 WL,SW SW SW	480	18	17	-	15	16	sandy clay	bored well	location verified by plat
25956	27-3N-8E SE SE SW	435	160	120	34.67	120	155	SS	-	
25690	27-3N-8E NE NE NW	415	160	120	29.67	120	160	SS	-	
4688	28-3N-8E SW/C SW SW	445	169	-	-	150	169	SS	-	well plugged due to high salt content

Appendix 3-A - Water Well Drilling Log Data (ISGS)

Well ID #	Location Sec/Twnshp/Range footage/quarters	Surface Elevation (feet above m.s.l.)	Well Depth (feet)	Casing Length (feet)	Static Water Level (feet below surf.)	Depth to Top of Aquifer	Depth to Base of Aquifer	Aquifer Lithology	Reported Yield (gpm)	Comments
25571	28-3N-8E 130 SL,105 WL,SW SE	430	21	21	-	20	21	S&G	bored well	
25595	28-3N-8E NW NW NW	465	255	-	-	-	-	-	dry hole	location verified by plat
N-19	29-3N-8E SE SE SE	450	160	120	24.67	120	155	SS	6	
4621	29-3N-8E 90 SL,340 WL,SE SE	450	132	106	37	100	132	SS	5	
4495	29-3N-8E SE NW NE	500	135	68	-	102	135	SS	8	
25957	29-3N-8E SE SE SE	450	160	95	39.67	95	150	SS	5	
25762	29-3N-8E NE/C SE SE SE	450	160	100	39.67	100	160	SS	-	location verified by plat
4404	29-3N-8E 2010 SL,180 EL,SE	455	185	75	50	170	185	SS	4	
26549	30-3N-8E SE SE	500	195	195	-	40?	46?	SS	3	location verified by plat
N-20	31-3N-8E SE SW NW	470	22.5	22.5	-	-	-	sandy clay	-	location verified by plat
4910	31-3N-8E 162 NL,74 EL,NE NW NE	490	26	26	-	12	13	SS	bored well	
25220	31-3N-8E 98 NL,104WL,SE NW NW	470	26	26	-	12	13	sandy clay	bored well	
25124	32-3N-8E 600 SL,400 WL,SW	465	191	174	79	135	190	SS	6	location verified by plat SS described as poor
4954	32-3N-8E SE SE SW	445	200	-	-	130	175	SS	dry hole	location verified by plat sandstone was too poor
25958	33-3N-8E NW NE NE	430	160	-	49.67	95	150	SS	-	location verified by plat
4631	33-3N-8E NE NW NW	435	132	51	24.67	51	132	SS	4	location verified by plat
4771	36-4N-6E 134 SL,78 WL,NW	475	20	20	-	12	14	sand	bored well	location verified by plat

Appendix 3-B. Results of water quality reconnaissance in southeastern Clay County.

Appendix 3-B. List of domestic wells sampled during reconnaissance of the study area.

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
JAKE KLEIN (OFB-1)	16	T.3N, R.7E, Sec. 32 NW NW SE NW	1225
JAKE KLEIN	150	T.3N, R.7E, Sec. 32 NW NW SE NW	1100
CANDY PAYNE	?	T.3N, R.7E, Sec. 33 NW NW SW NW	900
CT HOME	?	T.2N, R.7E, Sec. 05 NW SE NW NW	2775
ARTHUR SNELL	DUG	T.3N, R.7E, Sec. 34 SW NW NW SW	625
CHARLES HEMPHILL	DRILLED	T.2N, R.7E, Sec. 03 NW NW NW NW	1000
STEVE MILLER	195	T.3N, R.7E, Sec. 34 SW NW SW SE	900
VIVIAN HOARD	128	T.3N, R.7E, Sec. 34 SW NW NW NW	950
VIVIAN HOARD	20	T.3N, R.7E, Sec. 34 SW NW NW NW	1300
PENNY PYLE	18	T.3N, R.7E, Sec. 26 SE SW SE SW	1050
FRED GIFFORD (OFB-18)	140	T.3N, R.7E, SEC. 26 SW NW SW SE	2450
BERNICE MISENHEIMER	20	T.3N, R.7E, Sec. 23 SW SW SE SE	1600
ELANOR HALE	?	T.3N, R.7E, Sec. 26 SE NW SE SE	1900
GLENDA WILEY	75	T.3N, R.7E, Sec. 35 SE NW SE NW	1050
MAXINE STAFFORD	20	T.3N, R.7E, Sec. 36 SW NW SW SW	1350

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
EARL BAYLOR	100	T.2N, R. 7E, Sec. 02 NW NW SW SE	700
HARLEY MIX	135	T.2N, R.7E, Sec. 10 NW SE NW NW	800
RON GIBBS	125	T.2N, R.7E, Sec. 10 NW NW SW NW	1050
NANCY PIERCE	DEEP	T.2N, R.7E, Sec. 10 NW SE NW NW	800
RICH RUDY	100	T.3N, R.7E, Sec. 33 NW NW SE NW	500
ROBERT SNELL	93	T.3N, R.7E, Sec. 33 NW NW SW NW	600
LOUIS WICKEY	70	T.3N, R.7E, Sec. 33 SE SE NW NW	1400
DOLAN BAYLOR	100	T.2N, R.7E, Sec. 03 NW NW SE SE	1100
IVAN COLCLASURE	14	T.2N, R.7E, Sec. 03 NW NW SW SE	300
MARGE MCALLISTER	85	T.2N, R.7E, Sec. 04 NW SE NW SE	700
EDWIN PEARCE	144	T.2N, R.7E, Sec. 08 SE SE SE NW	750
LOWELL AYRES	?	T.2N, R.7E, Sec. 08 SE NW SE NW	800
BECKY KOHN	?	T.2N, R.7E, Sec. 05 SE NW SE SE	950
NOT HOME	?	T.2N, R.7E, Sec. 04 NW SW NW SW	1400
JERRY STANFORD	DUG	T.2N, R.7E, Sec. 05 NW NW NW SE	1150

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
HAROLD STANFORD	150	T.2N, R.7E, Sec. 05 SE SE SE NW	900
JAMES DAVIS	?	T.2N, R.7E, Sec. 04 NW SW SW NW	950
WILLIAM KLINE (OFB-2)	160	T.2N, R.7E, SEC. 05 NW NW NW NW	1000
BILL LUSK	100	T.2N, R.7E, Sec. 06 NW SE NW NW	700
FRANK BURT	160	T.3N, R.7E, Sec. 31 NW SW SW SW	600
DON LUSK	90	T.2N, R.7E, Sec. 06 NW NW SW NW	650
MARK KRESCH	100	T.2N, R.7E, Sec. 06 NW NW NW NW	600
NOT HOME	80-120?	T.2N, R.7E, Sec. 06 NW SW SW NW	800
SUSAN STRANGE	102	T.2N, R.7E, Sec. 05 NW NW NW SW	850
BILL PEARCE	100	T.2N, R.7E, Sec. 06 NW SE SE SW	700
DON WILLIAMS	110	T.2N, R.7E, Sec. 07 NW NW NW NW	650
SHARON GREENWOOD	DEEP	T.2N, R.7E, Sec. 08 SW SW SW NW	800
DON LUSK	SHALLOW	T.2N, R.7E, Sec. 07 SE SW SW NW	1000
DON LUSK	DEEP	T.2N, R.7E, Sec. 07 SE SW SW NW	700
LARRY HENDERSON	DEEP	T.2N, R.6E, Sec. 12 NW NW NW NW	800

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
THE CURTLISS'S	?	T.2N, R.6E, Sec. 11 NW NW NW NW	2600
FLOSSY RITTER	?	T.2N, R.6E, Sec. 11 NW SE NW NW	850
BARNEY STEELE	DRILLED	T.2N, R.6E, SEC. 02 NW SE SE SE	900
ILENE PARISH	75	T.2N, R.6E, Sec. 02 SE NW NW SE	900
BERNICE DENTON	35	T.2N, R.6E, Sec. 01 NW SW SW NW	600
BOB GRAHAM	120	T.2N, R.6E, Sec. 01 NW NW SW NW	800
DONALD MOORE	?	T.3N, R.6E, Sec. 36 NW NW SW SW	600
ALAN MCKNELLY	SHALLOW	T.3N, R.6 E, SEC. 35 SE NW SE NW	300
CARL ECKART	40	T.3N, R.7E, Sec. 29 SE NW SW NW	1350
RON MCGEE	100	T.3N, R.7E, Sec. 29 NW NW SE NW	500
SHIRLYE MARKHAM	90	T.3N, R.7E, Sec. 29 NW NW SE NW	800
DON DELANEY	90	T.3N, R.7E, Sec. 29 SW SE SE NW	650
RAY SHARP	?	T.3N, R.7E, Sec. 28 NW SW NW SW	650
THE KITLEYS	?	T.3N, R.7E, Sec. 28 SE NW SW SW	1000
MORRIS DUNAHEE (OFB-15)	234	T.3N, R.7E, Sec. 16 SE SW SW NW	2300

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
RANDY HARDEE	265	T.3N, R.7E, SEC. 16 SE SW SE NW	1700
WALTER HARRY	180	T.3N, R.7E, Sec. 16 NW SE NW SE	1100
THE DUNIGANS	195	T.3N, R.7E, Sec. 15 NW NW NW SW	1700
KATHY CROY	180	T.3N, R.7E, Sec. 15 SW SE SE NW	1000
JIM COSTNER	?	T.3N, R.7E, Sec. 22 SW NW NW NW	2000
TAMMY MONICAL	110-120	T.3N, R.7E, Sec. 22 SW NW NW NW	1500
CARL CASH (OFB-17)	310	T.3N, R.7E, SEC. 23 SW NW NW NW	3500
NOT HOME	?	T.3N, R.7E, Sec. 14 SW NW SE SW	1200
THE KELLYS	?	T.3N, R.7E, Sec. 23 NW NW SE NW	850
RALPH PAYNE	15	T.3N, R.7E, Sec. 23 SW SW NW SE	200
GENEVA HOHLBAUCH	22	T.3N, R.7E, Sec. 14 NW NW SE NW	1400
DAVIE CAILTEUX	22	T.3N, R.7E, Sec. 11 NW SW SW SE	1550
RON COLEMAN	POND	T.3N, R.7E, Sec. 11 SW SW SE SW	200
GEORGE HARRISON (OFB-16)	253	T.3N, R.7E, SEC. 10 SE SW SE SE	3300
GEORGE HARRISON	23	T.3N, R.7E, Sec. 10 SE SW SE SE	300

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
B. SEHIE	22	T.3N, R.7E, Sec. 16 NW NW NW NW	2800
GLEN BURK	35	T.3N, R.6E, Sec. 24 SE NW SE SE	1300
WILMA MERRITT	?	T.3N, R.6E, Sec. 19 NW NW SW SW	650
JOHN COX (OFB-14)	235	T.3N, R.7E, Sec. 16 SE SW NW NW	1750
SAM THOMPSON	14	T.3N, R.7E, Sec. 09 SE SE NW SW	750
RALEY GALEN	POND	T.3N, R.7E, Sec. 09 NW SW NW SE	100
NORMAN SMITH	60-70	T.3N, R.7E, Sec. 05 NW NW SE SW	2300
NOT HOME	?	T.3N, R.7E, Sec. 06 SE SE NW SE	1150
DEBRA HOGAN	CISTERN	T.3N, R.7E, Sec. 06 NW SE NW SE	800
BILL HENSON	?	T.3N, R.7E, Sec. 06 NW NW NW SW	1400
BILL HARNED	15	T.3N, R.7E, Sec. 06 SW SW SE NW	650
NYAL DICKEY	25	T.3N, R.6E, Sec. 01 SE SW SW NW	800
BURLIN BATEMAN (OFB-13)	23	T.3N, R.6E, Sec. 01 SW SW SW NW	1150
FRANK ZIMMERMAN	?	T.4N, R.6 E, Sec. 36 SE SW NW SW	500
LEE MATANICH	?	T.3N, R.6E, Sec. 11 SE NW NW NW	1500

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
ROLLA GREENWOOD (OFB-12)	31	T.3N, R.6E, Sec. 12 SW SW SW SW	750
KAREN BEARD	35	T.3N, R.6E, Sec. 13 NW NW NW NW	1100
CHARLES STOCKON	35	T.3N, R.6E, SEC. 12 SE SW SW SE	500
HERB BROWN	26	T.3N, R.7E, Sec. 18 NW NW NW NW	2200
ALICAN PRATER	?	T.3N, R.6E, Sec. 24 NW SW SW NW	1000
GENEVA FISK	?	T.3N, R.6E, Sec. 13 SE SE NW SW	700
WELDON MCVAY (OFB-11)	92	T.3N, R.6E, SEC. 13 SW SE SW NW	800
DON CASEY	20	T.3N, R.6E, Sec. 12 SW SE SE SW	550
JOE BEHNKE	93	T.3N, R.6E, Sec. 14 SE NW SE NW	800
LELAND GUINN	115	T.3N, R.7E, Sec. 17 SW SE NW SE	600
LELAND GUINN	15	T.3N, R.7E, Sec. 17 SW SE NW SE	200
BOB BRISCOE	100	T.3N, R.7E, Sec. 17 NW SE NW SE	600
KENT WARREN	80	T.3N, R.7E, Sec. 16 NW SE SE SW	650
BOB GILLSOTROM	30	T.3N, R.7E, Sec. 08 NW SW SE SE	2300
RON KECK	100	T.3N, R.7E, Sec. 17 NW NW NW NW	1300

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
NOT HOME	?	T.3N, R.7E, Sec. 18 NW NW NW NW	1200
JOHN LEWIS	20-25	T.3N, R.7E, SEC. 07 SE NW NW SE	1500
STEVE RUDY	?	T.3N, R.6E, Sec. 12 SE NW SE SE	700
JOHN RASTOVSKI	30	T.3N, R.7E, Sec. 27 NW SE NW NW	850
JAN BURT	?	T.3N, R.7E, Sec. 28 SE SE NW WN	450
JAN BURT	?	T.3N, R.7E, Sec. 28 SW SE NW NW	600
EDAG BRYAN	127	T.2N, R.6E, Sec. 13 NW SW NW SW	700
REX VAN MEDER	120	T.2N, R.6E, Sec. 14 SE SE NW SE	700
EARL SLOVER	136	T.2N, R.6E, Sec. 13 SE SW SE NW	1800
JOHN LUSK (OFB-3)	100	T.2N, R.7E, Sec. 07 NW NW SW SW	700
FRED GLASFORD	95-100	T.2N, R.7E, Sec. 07 NW NW NW SW	1600
LAURENCE AUVIL	95-100	T.2N, R.6E, Sec. 12 SE SE NW SE	800
BOB HALE	110	T.2N, R.6E, Sec. 24 SE NW NW NW	950
BOB HALE	20	T.2N, R.6E, Sec. 24 SE NW NW NW	400
MYRON WOOMER	90	T.2N, R.7E, Sec. 18 SE SW SE NW	1900

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
JOSEPHINE WILLIAMS	112	T.2N, R.7E, Sec. 18 NW NW SE NW	700
CHARLES PEARCE	129	T.2N, R.7E, Sec. 07 SW SW SE SE	600
LAUREEN WILLIAMS	100	T.2N, R.7E, Sec. 17 SW SW NW NW	650
CARL MCGREW	119	T.2N, R.7E, Sec. 17 SE SE NW NW	700
WATER ANDERSON	120	T.2N, R.7E, Sec. 17 NW SE NW NW	600
SAM HOWELL (OFB-5)	82	T.2N, R.7E, Sec. 09 NW NW SW SW	750
SAM HOWELL (OFB-6)	100	T.2N, R.7E, Sec. 09 NW NW SW SW	900
MARK DAWKINS	100	T.2N, R.7E, Sec. 08 NW SE SE NW	700
HENRY SKELTON	110	T.2N, R.7E, SEc. 17 SE NW SE SE	1000
CLIFF HURD	103	T.2N, R.7E, Sec. 21 NW NW NW NW	800
RON JURD	97	T.2N, R.7E, Sec. 16 SE SE SE SE	1100
HUGH BUFFINGTON	117	T.2N, R.7E, Sec. 22 NW NW NW NW	2400
JIM BUFFINGTON	35	T.2N, R.7E, Sec. 22 NW NW NW NW	900
GEORGE HENDERSON	137	T.2N, R.7E, SEc. 23 NW NW NW NW	3800
FRED SHELTON	35	T.2N, R.7E, SEc. 23 SW NW NW NW	1000

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
MILDRED SHELTON	130	T.2N, R.7E, Sec. 14 SE NW SE SE	850
GILBERT HALE	120	T.2N, R.7E, Sec. 14 NW NW SE NW	850
EVERT LEWIS	100	T.2N, R. 7E, Sec. 10 SW SE SW SW	800
DAVID LEWIS	100	T.2N, R.7E, SEc. 09 SW SE SW SE	900
ROY YOUNG	140	T.2N, R.7E, Sec. 09 NW NW NW SE	800
ROY KITLEY (OFB-4)	32	T.2N, R.7E, Sec. 09 SW NW NW SW	900
DAVID DUKE	40	T.3N, R.6E, Sec. 02 NW SW NW SW	850
ANDREY KAMPSCHRADER	82	T.3N, R.6E, Sec. 02 SW NW NW SW	3500
ALICE MCKNEELY	14-18	T.3N, R.6E, Sec. 02 SW SW SW NW	450
KEITH WILLISON	80	T.3N, R.6E, Sec. 02 NW NW NW SW	1500
DONALD KEMMER	34	T.4N, R.6E, Sec. 34 SE NW NW SE	1000
GENE REDDISH	?	T.3N, R.6E, Sec. 03 SE NW NW SE	900
ROBERT BUTE	110	T.3N, R.6E, Sec. 03 SW NW SE SE	1800
ROBERT BUTE	60	T.3N, R.6E, Sec. 03 SW NW SE SE	1600
EARL PHILLIPS	115	T.3N, R.6E, Sec. 11 SW SW SW SW	1500

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
WENDELL PHILLIPS	18	T.3N, R.6E, Sec. 11 NW SE SW SW	550
E. B. JENNINGS	100	T.3N, R.6E, Sec. 15 SE NW NW SE	700
RAY RUTLAND	?	T.3N, R.6E, Sec. 15 SE SE SE SE	1300
WILLIAM TOLLIVER 80	80	T.3N, R.6E, SEc. 23 NW NW NW NW	700
DOROTHY ENGELMEIER	120	T.3N, R.6E, Sec. 14 SW SE SW SW	1000
DOROTHY ENGELMEIER	80	T.3N, R.6E, Sec. 14 SW SE SW SW	600
OREN DENNIS	90	T.3N, R.6E, Sec. 23 NW NW NW NW	750
ROBERT GREENWOOD	80	T.3N, R.6E, Sec. 23 NW NW SW NW	850
BOB RUTLAND	190	T.3N, R.6E, Sec. 23 SW SE SW NW	1100
D. L. POWELL	?	T.3N, R.6E, Sec. 23 SW SW SW NW	850
LLOYD WATSON	18	T.3N, R.6E, Sec. 26 NW SW NW NW	450
GARNET HALL	24	T.3N, R.6E, SEc. 26 SW SW NW SW	500
NOT HOME	?	T.3N, R.6E, Sec. 35 NW NW NW NW	1000
DAVE PETTIT	30	T.3N, R.6E, Sec. 35 SW SW SW NW	800
DAVE PETTIT	20	T.3N, R.6E, Sec. 34 NW SE NW SE	1000

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
RANDY STANFORD	DUG	T.2N, R.6E, Sec. 03 NW NW NW NW	1300
DON LEWIS	90	T.2N, R.6E, Sec. 02 NW SW SW NW	900
MILDRED PERRINE	100	T.2N, R.6E, Sec. 03 SE SE SE SE	950
MIKE PERRINE	103	T.2N, R.6E, Sec. 11 NW NW NW NW	850
CARL BURNS	162	T.3N, R7E, Sec. 27 NW NW NW NW NW	1600
RICH WIGEL	12	T.3N, R.7E, Sec. 26 NW NW NW NW	1800
DON WIGLEY	201	T.3N, R.7E, Sec. 23 NW SW SW SE	4300
M. D. WATSON	14	T.3N, R.7E, Sec. 24 NW SW SW SE	200
JERRY MAYO	SHALLOW	T.3N, R.8E, Sec. 30 NW NW NW NW	100
CAROL WOLF	?	T.3N, R.8E, Sec. 30 NW SE SW NW	1300
DEBBIE PARRISH	?	T.3N, R.8E, Sec. 30 NW NW SE SW	900
ED CRAIG	196	T.3N, R.8E, Sec. 30 NW NW SE SE	2500
RICH SNIPPER	?	T.3N, R.8E, Sec. 31 SW SW SW NW	1800
CLIFFORD PIERCE	190	T.3N, R.7E, Sec. 36 NW NW NW SE	1800
GENE CARPENTER	?	T.2N, R.7E, Sec. 01 NW NW SW SE	1100

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
VANCIL ULLON (OFB-7)	18	T.2N, R.7E, Sec. 13 SE NW NW NW	500
VANCIL ULLOM (OFB-8)	100	T.2N, R.7E, Sec. 13 SE NW NW NW	700
HAROLD GIBBS	22	T.2N, R.8E, Sec. 18 SW NW SW NW	800
DON SMITH	SHALLOW	T.2N, R.8E, Sec. 06 NW NW SE NW	900
JOHN THOMAS	132	T.2N, R.8E, Sec. 05 SW NW NW NW	1000
HERBERT BURT (OFB-19) (OFB-20)	190 ?	T.3N, R.8E, Sec. 32 SW SE NW SW	1700
HAROLD GOOD	150	T.3N, R.8E, Sec. 29 NW NW SW SW	3700
FRANCES MORRIS	168-180	T.3N, R.8E, SEC. 32 SE NW SW NW	2400
TOM MITCHELL	96	T.2N, R.8E, Sec. 05 SE NW SE SE	600
OWEN HENRY	90	T.2N, R.8E, Sec. 08 SE SE NW NW	700
KENT HENRY	80	T.2N, R.8E, Sec. 09 NW NW NW SW	500
REXFORD GILL	25	T.2N, R.8E, Sec. 17 SE NW NW NW	1000
WAYNE PRUITT	DUG	T.2N, R.8E, Sec. 17 SE SE SE SE	1000
HUGH LYNN	24	T.2N, R.8E, Sec. 15 NW SW NW SW	1100
HIGH LYNN	70	T.2N, R.8E, Sec. 15 NW SW NW SW	1000

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
KEN HASSELTON	35-40	T.2N, R.8E, Sec. 22 NW NW NW NW	1000
JUDY SCHOFIELD	?	T.2N, R.8E, Sec. 15 SW SE SE SE	750
RAY PIERCE	190	T.2N, R.8E, Sec. 14 NW SW SW SE	1000
BARBARA MILLER	?	T.2N, R.8E, Sec. 14 NW NW SE NW	950
DARRELL CURTIS (OFB-9)	120	T.2N, R.8E, SEC. 14 SE NW NW NW	1200
MAURICE HERMAN	90	T.2N, R.8E, Sec. 11 SE SE SW SE	900
HUBERT EVANS	85	T.2N, R.8E, Sec. 15 SE SE NW SE	900
BEN SHARP	18	T.2N, R.8E, Sec. 15 SW NW NW NW	1100
WILLIAM PIERCE	100	T.2N, R.8E, Sec. 10 SE NW SE SE	700
JIM BROWN	30	T.2N, R.8E, Sec. 10 NW NW SE NW	1400
LOUIE LUSK	80	T.2N, R.8E, Sec. 10 SW NW SW NW	700
JANICE SMITH	6-8	T.2N, R.8E, Sec. 09 NW SE NW SE	450
SHERMAN THOMAS	115	T.2N, R.8E, Sec. 04 NW NW NW NW	700
MARIE WEILER	DEEP	T.2N, R.8E, Sec. 04 NW NW NW NW	700
ROY SHARP	142	T.3N, R.8E, Sec. 34 NW NW SW SW	900

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
ROY SHARP	12	T.3N, R.8E, Sec. 34 SW SW SW SW	800
ALBERT ABBOTT	160	T.2N, R.8E, Sec. 03 NW SW NW NW	1100
KEN WYATT	DEEP	T.2N, R.8E, Sec. 03 NW NW SW SW	1650
THE LYNNS	?	T.2N, R.8E, Sec. 10 NW NW SW NW	600
TONY STANDLER	?	T.3N, R.8E, Sec. 34 NW SW SW NW	100
BILL YOUNG	167	T.3N, R.8E, Sec. 27 SW SW SW SW	1500
BILL SMITH (OFB-22)	160	T.3N, R.8E, Sec. 27 SW SE SW SW	1500
JIM THOMAS (OFB-21)	23	T.3N, R.8E, Sec. 28 SW SW SW SE	1400
DEAN TRAVIS	132	T.3N, R.8E, Sec. 33 SW NW NW NW	1050
W. W. WEATHERFORD	150	T.3N, R.8E, Sec. 33 NW NW NW NW	1500
CARROLL MURBARGER	75-90	T.3N, R.8E, Sec. 33 NW SW SW NW	750
ART HENDERSON	90	T.3N, R.8E, Sec. 33 NW NW NW SW	900
KERN DOERNER	CITY WTR	T.3N, R.8E, Sec. 20 NW SE SW SE	500
BONNIE ULREY	185	T.3N, R.8E, Sec. 29 NW SE NW SE	3100
?	?	T.3N, R.8E, Sec. 28 SW NW SW SW	2000

Appendix 3-B (continued)

Owner/Controller	Well Depth (ft)	Location Township-Range-Section (Given in quarters)	Field Conductivity (microsiemen)
CANDY RAY	?	T.3N, R.8E, Sec. 28 NW SW SW SW	2000
JOY HUDSON	133	T.3N, R.8E, Sec. 29 NW SE SE SE	1850
NORMA ?	165	T.3N, R18E, Sec. 29 NW SE SE SE	2100
LYNNE THOMPSON	?	T.3N, R.8E, Sec. 29 SE SE SE SE	1950
JOE DENTON	135	T.3N, R.8E, Sec. 29 SW SE SW SE	1450
JOE DENTON	185	T.3N, R.8E, SEc. 32 NW NW NW NW	1100
NOEL WYATT	30	T.3N, R.8E, Sec. 29 SE SW SW SE	400
NOEL WYATT	160	T.3N, R.8E, Sec. 29 SE SW SW SE	300
MARVIN SHARP	30	T.3N, R.8E, Sec. 16 SE NW SE SW	1400
FLOYD WELLS	20	T.3N, R.7E, SEc. 13 SW NW NW NW	1400
LOWELL FERRIS	DEEP	T.4N, R.6E, SEc. 26 NW SW NW SW	1850
MILDRED GUFFY	30	T.4N, R.6E, SEc. 26 NW NW NW SW	1200
TOM CARPENTER	SHALLOW	T.4N, R.6E, Sec. 26 SW SW SW NW	800
ALVIN HARRIS	?	T.4N, R.6E, Sec. 35 SW NW NW NW	1700

Appendix 3-C. Regression analysis - well depth and proximity to brine holding pond vs conductance.

--------------------- REGRESSION ANALYSIS ----------------------

:ADER DATA FOR: B:SHALLOW LABEL: Shallow Wells < 50' Clay County Brines
'MBER OF CASES: 46 NUMBER OF VARIABLES: 4

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nductivity vs Proximity Shallow Wells Clay County Brine Study

IDEX	NAME	MEAN	STD.DEV.
1	well	111.89	65.30
2	depth	23.28	7.88
3	proximit	2085.87	1793.84
:P. VAR.:	conduct	988.59	545.53

:PENDENT VARIABLE: conduct

\R.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 44)	PROB.
·oximit	-2.68E-02	4.567E-02	-.586	.56077
)NSTANT	1044.42			

:D. ERROR OF EST. = 549.55

r SQUARED = .01
r = -.09

ANALYSIS OF VARIANCE TABLE

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
:GRESSION	103759.24	1	103759.24	.344	.5608
:SIDUAL	13288373.91	44	302008.50		
)TAL	13392133.15	45			

-------------------- REGRESSION ANALYSIS ----------------------

ADER DATA FOR: B:SHALLOW LABEL: Shallow Wells < 50' Clay County Brines
MBER OF CASES: 46 NUMBER OF VARIABLES: 4

Conductivity vs Depth Shallow Wells Clay County Brine Study

DEX	NAME	MEAN	STD.DEV.
1	well	111.89	65.30
2	depth	23.28	7.88
3	proximit	2085.87	1793.84
P. VAR.:	conduct	988.59	545.53

PENDENT VARIABLE: conduct

R.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 44)	PROB.
pth	11.98	10.27	1.167	.24969
NSTANT	709.57			

D. ERROR OF EST. = 543.36

r SQUARED = .03
r = .17

ANALYSIS OF VARIANCE TABLE

URCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
RESSION	401746.62	1	401746.62	1.361	.2497
IDUAL	12990386.53	44	295236.06		
AL	13392133.15	45			

-------------------- REGRESSION ANALYSIS ----------------------

\DER DATA FOR: B:SHALLOW LABEL: Shallow Wells < 50' Clay County Brines
IBER OF CASES: 46 NUMBER OF VARIABLES: 4

;onductivty vs Depth and Proximity Shallow Wells Clay County

)EX	NAME	MEAN	STD.DEV.
l	well	111.89	65.30
2	depth	23.28	7.88
3	proximit	2085.87	1793.84
?. VAR.:	conduct	988.59	545.53

?ENDENT VARIABLE: conduct

R.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 43)	PROB.	PARTIAL r^2
[illegible]	12.56	10.37	1.211	.23232	.0330
ximit	-3.13E-02	4.558E-02	-.686	.49642	.0108
NSTANT	761.29				

). ERROR OF EST. = 546.66

JUSTED R SQUARED = -.00
R SQUARED = .04
MULTIPLE R = .20

ANALYSIS OF VARIANCE TABLE

OURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
3RESSION	542359.34	2	271179.67	.907	.4111
IDUAL	12849773.81	43	298831.95		
[illegible]	13392133.15	45			

-------------------- REGRESSION ANALYSIS ----------------------

ADER DATA FOR: B:DEEP LABEL: CLAY COUNTY BRINES STUDY DEEP WELLS
MBER OF CASES: 103 NUMBER OF VARIABLES: 4

CONDUCTVITY VS PROXIMITY CLAY COUNTY DEEP > 50' WELLS

DEX	NAME	MEAN	STD.DEV.
1	WELL	109.90	67.49
2	DEPTH	125.82	41.69
3	PROXIMIT	2098.54	1954.50
P. VAR.:	CONDUCT	1445.63	3215.75

PENDENT VARIABLE: CONDUCT

R.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 101)	PROB.
OXIMIT	-.14	.16	-.855	.39461
NT	1738.30			

D. ERROR OF EST. = 3220.00

r SQUARED = .01
r = -.08

ANALYSIS OF VARIANCE TABLE

OURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
GRESSION	7578409.92	1	7578409.92	.731	.3946
SIDUAL	1047207124.06	101	10368387.37		
TAL	1054785533.98	102			

--------------------- REGRESSION ANALYSIS ----------------------

IEADER DATA FOR: B:DEEP LABEL: CLAY COUNTY BRINES STUDY DEEP WELLS
IUMBER OF CASES: 103 NUMBER OF VARIABLES: 4

CONUCTVITY VS DEPTH CLAY COUNTY DEEP > 50' WELLS

NDEX	NAME	MEAN	STD.DEV.
1	WELL	109.90	67.49
2	DEPTH	125.82	41.69
3	PROXIMIT	2098.54	1954.50
EP. VAR.:	CONDUCT	1445.63	3215.75

EPENDENT VARIABLE: CONDUCT

AR.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 101)	PROB.
EPTH	30.00	7.07	4.243	.00005
ONSTANT	-2329.33			

TD. ERROR OF EST. = 2977.16

r SQUARED = .15
r = .39

ANALYSIS OF VARIANCE TABLE

SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
EGRESSION	159572076.57	1	159572076.57	18.003	4.900E-05
ESIDUAL	895213457.41	101	8863499.58		
OTAL	1054785533.98	102			

-------------------- REGRESSION ANALYSIS ----------------------

ADER DATA FOR: B:DEEP   LABEL: CLAY COUNTY BRINES STUDY DEEP WELLS
MBER OF CASES: 103   NUMBER OF VARIABLES: 4

NDUCTIVTY VS DEPTH AND PROXIMITY CLAY COUNTY DEEP > 50' WELLS

DEX	NAME	MEAN	STD.DEV.
1	WELL	109.90	67.49
2	DEPTH	125.82	41.69
3	PROXIMIT	2098.54	1954.50
P. VAR.:	CONDUCT	1445.63	3215.75

PENDENT VARIABLE: CONDUCT

R.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 100)	PROB.	PARTIAL r^2
PTH	29.68	7.18	4.134	.00007	.1460
OXIMIT	-4.77E-02	.15	-.311	.75613	9.68884E-04
NSTANT	-2188.48				

D. ERROR OF EST. = 2990.56

JUSTED R SQUARED = .14
R SQUARED = .15
MULTIPLE R = .39

ANALYSIS OF VARIANCE TABLE

OURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
GRESSION	160439434.13	2	80219717.07	8.970	2.613E-04
SIDUAL	894346099.85	100	8943461.00		
TAL	1054785533.98	102			

------------------- REGRESSION ANALYSIS ---------------------

\DER DATA FOR: B:BRINES   LABEL: CLAY COUNTY BRINE STUDY
IBER OF CASES: 149   NUMBER OF VARIABLES: 4

Conductivity vs Proximity Clay County Brine Study

)EX	NAME	MEAN	STD.DEV.
:	WELL	111.86	66.40
?	DEPTH	94.16	58.95
3	PROXIMIT	2094.63	1900.31
'. VAR.:	CONDUCT	1304.53	2694.87

'ENDENT VARIABLE: CONDUCT

?.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 147)	PROB.
)XIMIT	-.11	.12	-.931	.35334
ISTANT	1531.97			

). ERROR OF EST. = 2696.08

r SQUARED = .01
r = -.08

ANALYSIS OF VARIANCE TABLE

OURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
GRESSION	6301337.29	1	6301337.29	.867	.3533
SIDUAL	1068518729.82	147	7268834.90		
TAL	1074820067.11	148			

------------------ REGRESSION ANALYSIS ---------------------

ER DATA FOR: B:BRINES   LABEL: CLAY COUNTY BRINE STUDY
ER OF CASES: 149   NUMBER OF VARIABLES: 4

Conductivity vs Depth Clay County Brines Study

X	NAME	MEAN	STD.DEV.
	WELL	111.86	66.40
	DEPTH	94.16	58.95
	PROXIMIT	2094.63	1900.31
VAR.:	CONDUCT	1304.53	2694.87

NDENT VARIABLE: CONDUCT

	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 147)	PROB.
H	13.30	3.61	3.688	.00032
TANT	51.98			

ERROR OF EST. = 2587.00

r SQUARED = .08
r = .29

ANALYSIS OF VARIANCE TABLE

RCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
ESSION	91014551.50	1	91014551.50	13.599	3.177E-04
DUAL	983805515.61	147	6692554.53		
	1074820067.11	148			

-------------------- REGRESSION ANALYSIS ----------------------

DER DATA FOR: B:BRINES   LABEL: CLAY COUNTY BRINE STUDY
IBER OF CASES: 149   NUMBER OF VARIABLES: 4

Conductivity vs Depth and Proximity Clay County Brine Study

)EX	NAME	MEAN	STD.DEV.
1	WELL	111.86	66.40
2	DEPTH	94.16	58.95
3	PROXIMIT	2094.63	1900.31
P. VAR.:	CONDUCT	1304.53	2694.87

PENDENT VARIABLE: CONDUCT

R.	REGRESSION COEFFICIENT	STD. ERROR	T(DF= 146)	PROB.	PARTIAL r^2
TH	13.13	3.62	3.625	.00040	.0826
XIMIT	-8.13E-02	.11	-.724	.47052	.0036
NSTANT	238.77				

). ERROR OF EST. = 2591.20

JUSTED R SQUARED = .08
R SQUARED = .09
MULTIPLE R = .30

ANALYSIS OF VARIANCE TABLE

OURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F RATIO	PROB.
GRESSION	94529359.61	2	47264679.81	7.039	1.206E-03
SIDUAL	980290707.50	146	6714319.91		
TAL	1074820067.11	148			

Appendix 4-A. Water quality data for Buck Creek.

Appendix 4-A. Complete Water quality Data for Buck Creek
*All concentrations expressed in mg/L unless otherwise noted.

	4/3/86		4/8/86		4/29/86		5/6/86		5/20/86		6/3/86	
	BCU	BCD+	BCU	BCD	BCU	BCD	BCU	BCD	BCU	BCD	BCU	BCD
NH3-N	0.09	0.28	0.41	0.37	1.22	0.18	0.27	1.61	0.37	4.73	1.95	1.75
Boron	0.11	0.12	0.12	0.11	0.11	0.12	0.12	0.14	0.10	0.13	0.05	0.08
Bromide	0.35	0.55	0.70	0.62	0.33	0.69	0.40	0.61	0.55	0.88	0.60	1.1
Chloride	101	150	155	139	79	127	84	165	96	179	104	253
Cond. (umho)	647	937	831	886	597	834	690	1056	718	1154	694	1260
Dissolved Oxygen	11.7	10.5	9.8	7.5	9.5	8.4	7.5	8.7	12.5	7.2	22.0	7.0
Grease and Oil	5.1	4.3	5.0	5.4	14	10	4.1	2.6	9.8	8.2	4.7	5.1
Hardness	164	243	177	224	159	210	190	270	196	280	194	306
Iodide	<0.10	<0.10	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrate & Nitrite	0.09	0.05	0.47	0.07	0.22	0.38	0.11	0.11	0.19	0.47	0.37	0.46
pH	7.78	7.60	7.68	7.61	7.96	8.00	7.88	7.81	8.01	7.84	8.79	7.77
Phosphate-P	0.10	0.09	0.11	0.15	0.07	0.12	0.08	0.11	0.07	0.09	0.11	0.16
Sulfate	78	136	106	116	88	125	86	169	72	157	44	82
Temperature (oC)	14	14	16	15.5	16	16	19	18	13	14	19	18
Total Alkalinity	102	112	97	117	102	105	131	135	142	149	155	160
Total Diss. Solids	372	556	472	510	390	540	410	650	445	720	410	840
Total Kjel. Nit.	0.44	0.64	1.40	1.08	1.37	0.45	1.26	2.52	1.07	5.82	2.88	2.82
Total Sus. Solids	19	28	24	27	19	28	18	48	12	54	15	40
Total Vol. Solids	6	6	7	6	1	3	5	6	3	7	5	6
Na (Tot.)	90	140	120	130	63	100	75	130	82	150	87	175
K (Tot.)	4.2	4.4	4.5	4.3	4.7	5.2	4.9	5.4	5.1	5.4	5.8	6.0
Ca (Tot.)	44	64	44	52	43	54	49	66	53	73	60	86
Mg (Tot.)	12	20	12	15	11	16	12	20	13	22	15	29

+ BCU - Buck Creek Upstream; BCD - Buck Creek Downstream

Appendix 4-A. Complete Water quality Data for Buck Creek (Continue)

	6/17/86		7/8/86		7/29/86	
	BCU	BCD	BCU	BCD	BCU	BCD
NH3-N	9.56	3.48		0.58	12.4	1.02
Boron	0.09	0.12		0.10	0.03	0.09
Bromide	0.61	0.95		0.99	0.14	0.55
Chloride	108	260	N	245	21	123
Cond. (umho)	700	1321	O	1228	295	638
Dissolved Oxygen	11.6	2.5		1.4	5.7	6.0
Grease and Oil	4.2	6.8	F	7.2	6.0	9.6
Hardness	187	310	L	278	89	151
Iodide	<0.1	<0.1	O	<0.1	<0.1	<0.1
Nitrate & Nitrite	0.30	0.29	W	0.35	0.42	0.48
pH	8.09	7.68		7.89	7.78	7.92
Phosphate-P	0.17	0.21		0.37	0.26	0.34
Sulfate	28	109		32	32	39
Temperature (oC)	22	21		25	29	28
Total Alkalinity	150	176		201	106	118
Total Diss. Solids	440	858		753	150	336
Total Kjel. Nit.	11.0	5.11		2.30	14.4	2.9
Total Sus. Solids	20	50		37	46	42
Total Vol. Solids	2	4		2	4	18
Na (Tot.)	124	287		155	38	38
K (Tot.)	4.7	6.3		7.9	6.0	10.1
Ca (Tot.)	50	77		72	26	37
Mg (Tot.)	14	28		25	6.3	13

+ BCU - Buck Creek Upstream; BCD - Buck Creek Downstream

Appendix 4-A. Complete Water quality Data for Buck Creek (Continue)

	4/3/86		4/8/86		4/29/86		5/6/86		5/20/86		6/3/86	
	BCU	BCD+	BCU	BCD	BCU	BCD	BCU	BCD	BCU	BCD	BCU	BCD
Ba (Tot.)	0.07	0.05	0.05	0.07	0.05	0.11	0.06	0.10	0.06	0.10	0.07	0.10
Ba (Sol.)	0.03	0.05	0.05	0.04	0.05	0.07	0.05	0.09	0.05	0.08	0.05	0.08
Cd (Tot.)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cd (Sol.)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu (Tot.)	0.02	0.01	0.01	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
Cu (Sol.)	0.02	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02
Cr (Tot.)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cr (Sol.)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe (Tot.)	0.95	1.2	0.95	0.1	0.50	0.88	0.45	0.82	0.43	0.91	1.0	1.6
Fe (Sol.)	0.04	0.32	0.04	0.04	0.05	0.04	0.05	0.03	0.01	0.01	0.08	0.04
Li (Tot.)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Li (Sol.)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mn (Tot.)	0.32	0.06	0.26	0.44	0.37	0.58	0.68	1.4	0.56	1.7	1.7	3.8
Mn (Sol.)	0.28	0.51	0.13	0.22	0.22	0.39	0.37	0.84	0.48	1.5	0.78	2.1
Ni (Tot.)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ni (Sol.)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Pb (Tot.)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Pb (Sol.)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Sr (Tot.)	0.17	0.24	0.22	0.27	0.18	0.30	0.13	0.20	0.12	0.19	0.17	0.34
Sr (Sol.)	0.17	0.24	0.22	0.26	0.19	0.30	0.12	0.20	0.12	0.17	0.17	0.32
Zn (Tot.)	0.01	0.02	0.02	0.04	0.01	0.02	0.02	0.03	0.01	0.03	0.02	0.02
Zn (Sol.)	0.01	0.01	<0.01	<0.01	0.02	0.02	<0.01	0.01	0.01	0.01	0.01	0.02

+ BCU - Buck Creek Upstream; BCD - Buck Creek Downstream.

Appendix 4-A. Complete Water quality Data for Buck Creek (Continue)

	6/17/86		7/8/86		7/29/86	
	BCU	BCD	BCU	BCD	BCU	BCD
Ba (Tot.)	0.06	0.10		0.13	0.07	0.10
Ba (Sol.)	0.03	0.08	N	0.09	0.04	0.09
Cd (Tot.)	<0.01	<0.01	O	<0.01	<0.01	<0.01
Cd (Sol.)	<0.01	<0.01		<0.01	<0.01	<0.01
Cu (Tot.)	0.01	0.02	F	0.02	0.01	0.01
Cu (Sol.)	<0.01	<0.01	L	0.01	0.01	0.01
Cr (Tot.)	<0.01	<0.01	O	<0.01	<0.01	<0.01
Cr (Sol.)	<0.01	<0.01	W	<0.01	<0.01	<0.01
Fe (Tot.)	1.1	1.7		1.7	2.0	1.9
Fe (Sol.)	0.03	0.04		0.04	0.12	0.05
Li (Tot.)	<0.01	<0.01		<0.01	<0.01	<0.01
Li (Sol.)	<0.01	<0.01		<0.01	<0.01	<0.01
Mn (Tot.)	1.7	3.6		3.1	0.65	1.7
Mn (Sol.)	1.6	3.1		3.0	0.40	1.4
Ni (Tot.)	<0.05	<0.05		<0.05	<0.05	<0.05
Ni (Sol.)	<0.05	<0.05		<0.05	<0.05	<0.05
Pb (Tot.)	<0.05	<0.05		<0.05	<0.05	<0.05
Pb (Sol.)	<0.05	<0.05		<0.05	<0.05	<0.05
Sr (Tot.)	0.17	0.29		0.28	0.08	0.15
Sr (Sol.)	0.17	0.29		0.28	0.08	0.15
Zn (Tot.)	0.02	0.03		0.03	0.02	0.02
Zn (Sol.)	0.01	0.02		0.01	0.02	0.02

+ BCU - Buck Creek Upstream; BCD - Buck Creek Downstream.

Appendix 5-A. Methods used for assessment of oil brines impacts on aquatic biota.

Appendix 5-A. Methods used for assessment of oil brines impacts on aquatic biota.

<u>Selection and General Description of Stations</u>. Six stations were chosen to characterize the benthic macroinvertebrate communities along Buck Creek, Clay County, Illinois, from source to mouth. Sites were sampled on 22, 24, 31 August and 2, 24 October 1986. These sites, illustrated in figure 5-1, are located on the Flora, Illinois 7.5′ quadrangle map, 1970 edition, as follows:

Station 1 - Buck Creek, 5.3 km (3.3 mi) N Flora 3rd P M: T13N, R6E, E/2, NE/4 SE/4, NE/4, Sec. 11 T M: Zone 16, $^{3}70^{500}$mE, $^{42}86^{250}$m N width 0.5 to 5 m; depth 0.05 to 0.4 m; substrate primarily sand with some clay, silt, and gravel; few rocks; water turbid, with a slight oil film on water; banks steeply sloping; stream completely shaded

Station 2 - Buck Creek, 4.3 km (2.6 mi) NNE Flora 3rd P M: T3N, R6E, S/2, SW/4, SE/4, SE/4, Sec. 12 U T M: Zone 16, $^{3}71^{800}$m E, $^{42}85^{130}$mN width 1 to 5 m; depth 0.1 to 1 m; substrate primarily sand with some silt/detritus and clay; water moderately turbid; solid mat of duckweed on water; little flow; banks steeply sloping; stream shaded approximately 50 percent

Station 3 - Buck Creek, 4.1 km (2.5 mi) NE Flora 3rd P M: T3N, R7E, W/2, SW/4, NE/4, NW/4, Sec. 18 U T M: Zone 16, $^{3}72^{130}$m E, $^{42}84^{790}$m N width 1 to 4 m; depth 0.2 to 0.8 m; substrate primarily sand, with gravel, silt, and detritus; water moderately turbid; logjam present; duckweed present in small accumulations in quiet areas; little flow; banks steeply sloping; stream completely shaded

Station 4 - Buck Creek, 4.5 km (2.8 mi) NE Flora 3rd P M: T3N, R7E, NW/4, NW/4, SW/4, NW/4, Sec. 17 U T M: Zone 16, $^{3}73^{300}$m E, $^{42}84^{620}$m N width 1 to 4 m; depth to 0.4 m; substrate primarily sand, with some silt and gravel; water clear; duckweed present; little flow; banks steeply sloping; stream shaded approximately 50 percent

Station 5 - Buck Creek, 5.1 km (3.1 mi) NE Flora 3rd P M: T3N, R7E, SE/4, SE/4, SW/4, SW/4, Sec. 8 U T M: Zone 16, $^{3}73^{670}$m E, $^{42}85^{090}$m N width 1 to 5 m; depth to 0.4 m; shallow riffle area present; substrate primarily sand and silt; water moderately turbid; duckweed present; banks steeply sloping; stream unshaded

Station 6 - Buck Creek, 7.0 km (4.4 mi) NE Flora 3rd P M: T3N, R7E, SW/4, NE/4, SE/4, NW/4, Sec. 9 U T M: Zone 16, $^{3}75^{620}$m E, $^{42}86^{030}$m N width 1 to 4 m; depth <0.25 m; substrate primarily sand and silt; water moderately turbid; duckweed present; banks steeply sloping; stream 80 percent shaded

Benthic Macroinvertebrates. Benthic macroinvertebrate samples consisted of semi-quantitative, hand-picked collections from the six sites, distributed among the microhabitats at each station to characterize riffle and pool areas, predominantly, and beds of aquatic vegetation, undercut banks, exposed roots, leaf packets, where present. Sampling continued until the return of usable data no longer justified further collecting (about 2 to 2.5 man-hours). Sufficient buffered formalin was added to algal and detrital samples to produce a 10 to 15 percent final concentration. All other material was preserved in 95 percent ethanol.

All samples were sorted under stereoscopic microscopes at a magnification of 10X. Identifications to generic or species level were performed by taxonomists specializing in each of the major groups of aquatic organisms. Nomenclature follows Brigham, Brigham, and Gnilka (1982). Mollusca and aquatic Diptera were excluded from further treatment since species-level identification of aquatic forms is uncertain. Summarized numbers represent actual numbers of individuals taken. These techniques were designed to secure a thorough representation of species and an idea of the relative abundance of each.

Specialists providing identification of various invertebrate groups included Dr. Allison R. Brigham (Lepidoptera), Dr. Warren U. Brigham (Coleoptera, Megaloptera), Mr. Donald G. Huggins of the Kansas Biological Survey (Odonata), Dr. Lawrence M. Page (Crustacea), Dr. Milton W. Sanderson, retired, (Heteroptera), Dr. John D. Unzicker (Ephemeroptera, Trichoptera), and Mr. Mark J. Wetzel (Annelida). All are staff of the Illinois Natural History Survey unless otherwise indicated.

IEPA Station Classifications. The review of historic benthic macroinvertebrate data from the Wabash River watershed in Illinois is presented in the stream evaluation system used by the Illinois Environmental Protection Agency (IEPA). Their system includes assignment of identified species to one of four categories based upon their "tolerance" to pollution. These categories, summarized below include:

intolerant - organisms whose life cycles are dependent upon a narrow range of ideal environmental conditions.

moderate - organisms without the extreme sensitivities to environmental stresses of intolerant species, but unable to adapt to severe environmental degradation.

facultative - organisms able to survive over a wide range of environmental conditions and possessing a greater degree of tolerance to adverse conditions than either intolerant or moderate species. Some of the macroinvertebrates which utilize surface air for respiration are classified as facultative.

tolerant - organisms able to survive over a wide range of environmental extremes, including water of extremely poor quality.

Station classifications followed the system utilized by IEPA:

balanced environment (B) - intolerant species numerically important in both number and diversity. For a station to be classified as balanced, intolerant species represent more than 50 percent of the specimens collected at a site while moderate, facultative, and tolerant species comprise less than 50 percent.

unbalanced environment (UB) - intolerant species numerically less important than other forms combined, but combined with moderate forms, usually outnumber tolerant forms. For a station to be classified as unbalanced, species classified as moderate, facultative, and tolerant comprise more than 50 percent of the sample while intolerant species comprise more than 10 percent but less than 50 percent of the sample.

semi-polluted environment (SP) - intolerant species few or absent with moderate, facultative, and tolerant species predominating. For a station to be classified as semi-polluted, intolerant species comprise 10 percent or less of the individuals collected while moderate, facultative, and tolerant organisms combined comprise 90 percent or more of the sample.

polluted environment (P) - generally only tolerant species present although some facultative forms may be observed. For a station to be classified as polluted, either all or virtually all organisms collected are classified as tolerant, or no organisms are present.

<u>State Water Survey Water quality Data</u>. The State Water Survey analyzed surface water at 2-week intervals from 3 April through 29 July 1986 at two sites in Buck Creek: station 1, upstream, and station 6, downstream. For this statistical analysis, one (8 July 1986) of their nine collections was eliminated since the upstream site had no flow.

Thirty-four chemical variables were analyzed. After examining the means and variances of these data, variables exhibiting little or no variance were eliminated from further treatment. In addition, examination of the mean concentration relative to the observed detection limits eliminated several other variables from consideration. Twenty variables were retained following this preliminary selection.

Variables eliminated included boron, bromide, iodide, nitrate + nitrite, pH, phosphorus, and the heavy metals barium (total, soluble), cadmium (total, soluble), chromium (total, soluble), copper (total, soluble), iron (soluble), lead (total, soluble), lithium (total, soluble), nickel (total, soluble), strontium (total, soluble), and zinc (total, soluble).

A one-way analysis of variance with the chemical variables as depedent variables eliminated 11 additional variables that demonstrated no significant differences between the upstream and downstream sampling sites. Variables eliminated included ammonia, dissolved oxygen, iron (total), manganese (total, soluble), oil and grease, organic nitrogen potassium, temperature, total alkalinity, and total volatile solids.

<u>Other Statistical Analyses</u>. Species diversity was calculated using the Shannon-Weaver function:

D = 3.3219 [log%1N - (1/N)   n%2. %010 %0i]

where N = total number of individuals and n%1= number of individuals of the ith species. The Shannon-Weaver index is commonly used because of its relative insensitivity to sample size; it is preferred when samples from a community rather than the complete community are being analyzed.

All data were transformed [ln (X + 1)] for statistical analyses. The SAS linear regression model with one and two independent variables (chloride concentration and stream order) was performed with the number of intolerant organisms as the dependent variable.

The SAS stepwise regression procedure with the stepwise technique was performed on 20 transformed, standardized (zero mean, unit standard deviation) water quality variables.

The SAS cluster procedure with the unweighted pair-group method with arithmetic averages was used to find hierarchical clusters of benthic macroinvertebrates at the six sampling stations in August and October. Actual numbers of individuals were used.

Appendix 5-B. Benthic Macroinvertebrate, chloride, and stream order data from Wabash River watershed, 1976 and 1977.

Hierarchical Ranking of Stations with Benthic Macroinvertebrate and Chloride Data in the Wabash River Basin by (1) Chloride Group and (20) Chloride Concentration

Number	Station	Chloride Group	Chloride mg/L	Total	Int	Mod	Fac	Tol	Station Class[a]	Stream Order
1	CAYZ-10	1	4	26	5	0	10	11	UB	2
2	CZR-11	1	4	89	16	1	58	14	UB	3
3	BEZA-11	1	5	91	21	32	28	10	UB	2
4	BJBZ-10	1	5	88	11	2	52	23	UB	2
5	CA-20	1	5	71	2	6	55	8	SP	2
6	CANBB-10	1	5	31	3	0	3	25	SP	2
7	CAWD-10	1	5	138	48	18	53	19	UB	2
8	CJC-10	1.	5	74	1	2	25	46	SP	3
9	COA-11	1	5	53	5	5	20	23	SP	2
10	BEAZ-10	1	6	130	13	5	38	74	UB	1
11	CA-19	1	6	33	5	1	21	6	UB	2
12	CANB-11	1	6	143	6	5	105	27	SP	3
13	CARB-10	1	6	115	21	55	15	24	UB	3
14	CAV-11	1	6	128	6	5	43	74	SP	2
15	CAW-14	1	6	36	9	1	16	10	UB	3
16	CAW-15	1	6	12	3	1	2	6	UB	2
17	CAZBZ-10	1	6	42	8	0	22	12	UB	2
18	CJDA-10	1	6	110	29	38	25	18	UB	2
19	COA-10	1	6	113	1	3	31	78	SP	2
20	CQ-11	1	6	37	0	1	31	5	SP	4
21	CZR-10	1	6	62	6	0	37	19	SP	3
22	BEZZAA-10	1	7	142	32	30	69	11	UB	2
23	CAKZ-12	1	7	20	7	8	4	1	UB	1
24	CJ-16	1	7	24	11	1	7	5	UB	3
25	CJC-11	1	7	33	4	0	17	12	UB	2
26	CJE-11	1	7	71	16	0	27	28	UB	3
27	CJEC-10	1	7	63	11	15	22	15	UB	1
28	CM-12	1	7	71	14	4	26	27	UB	3
29	CZQ-10	1	7	61	3	1	34	23	SP	3
30	BEGA-10	1	8	48	25	13	4	6	B	3
31	BEZA-12	1	8	85	25	21	5	34	UB	2
32	BEZZA-11	1	8	100	3	5	78	14	SP	3
33	BHZ-10	1	8	107	3	1	44	59	SP	3
34	CAGBZ-13	1	8	168	0	4	160	4	SP	1
35	CAGC-14	1	8	93	4	11	17	61	SP	4
36	CAKZ-10	1	8	127	0	0	106	21	SP	1
37	CAV-10	1	8	71	3	1	19	48	SP	3
38	CAWZ-10	1	8	78	8	12	17	41	UB	2
39	CDFZ-10	1	8	33	9	11	7	6	UB	1
40	CHB-10	1	8	16	3	2	2	9	UB	3
41	CHH-11	1	8	56	1	7	31	17	SP	3
42	CJ-14	1	8	107	27	25	42	13	UB	4

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Chloride Group	Chloride mg/L	Total	Int	Mod	Fac	Tol	Station[a] Class	Stream Order
43	CJ-15	1	8	44	9	2	15	18	UB	3
44	CJEC-11	1	8	39	1	1	11	26	SP	2
45	CQ-10	1	8	42	1	4	33	4	SP	4
46	CQ-12	1	8	72	17	5	15	35	UB	3
47	CZF-10	1	8	127	31	38	41	17	UB	1
48	BEGA-11	1	9	91	39	1	12	39	UB	3
49	BEGA-12	1	9	39	13	0	21	5	UB	2
50	BEZA-10	1	9	115	17	15	37	46	UB	3
51	BEZZA-10	1	9	138	50	37	24	27	UB	3
52	BFA-11	1	9	51	25	1	15	10	UB	1
53	BFB-10	1	9	117	21	40	22	34	UB	4
54	BH-10	1	9	74	41	0	4	29	B	5
55	BH-17	1	9	54	25	3	16	10	UB	2
56	BHL-10	1	9	47	18	0	14	15	UB	3
57	BJBB-11	1	9	68	4	0	8	56	SP	2
58	BK-11	1	9	70	21	10	13	26	UB	3
59	CANB-12	1	9	49	1	8	8	32	SP	3
60	CANB-13	1	9	21	9	0	12	0	UB	2
61	CF-10	1	9	117	3	12	80	22	SP	2
62	CHEA-11	1	9	38	2	0	27	9	SP	3
63	CHEAZ-10	1	9	1	0	1	0	0	P	1
64	CJDB-10	1	9	63	10	0	25	28	UB	1
65	CJEA-10	1	9	100	18	13	39	30	UB	2
66	CZZDA-11	1	9	36	12	3	19	2	UB	3
67	BEFD-10	1	10	34	23	2	4	5	B	2
68	BEFN-10B	1	10	73	37	23	5	8	B	3
69	BG-12	1	10	46	10	0	27	9	UB	3
70	BH-15	1	10	48	19	0	10	19	UB	4
71	BHA-10	1	10	60	9	2	7	42	UB	2
72	BHCA-10	1	10	29	6	2	15	6	UB	3
73	BHD-10	1	10	131	34	9	37	48	UB	2
74	BHG-10	1	10	43	6	4	6	27	UB	2
75	C-33	1	10	75	15	27	31	2	UB	4
76	CAGBZ-10	1	10	97	5	33	48	11	SP	2
77	CAGC-15	1	10	103	53	14	14	22	B	4
78	CAK-14	1	10	58	3	2	35	18	SP	3
79	CR-10	1	10	64	6	1	41	16	SP	3
80	CZG-11	1	10	47	14	3	22	8	UB	3
81	CZQ-11	1	10	46	2	0	32	12	SP	2
82	BFA-10	1	11	159	43	30	31	55	UB	1
83	BH-16	1	11	41	20	2	6	13	UB	3
84	BIB-10	1	11	164	6	0	103	55	SP	2
85	BJB-11	1	11	57	37	1	7	12	B	4
86	BJB-12	1	11	26	10	5	4	7	UB	3
87	BJBB-10	1	11	37	3	0	21	13	SP	3
88	BJD-10	1	11	51	8	0	37	6	UB	2

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Group	Chloride mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
89	CAGB-12	1	11	24	16	4	4	0	B	3
90	CAUA-10	1	11	73	2	17	12	42	SP	2
91	CAWB-10	1	11	213	30	10	20	153	UB	2
92	CJB-10A	1	11	128	2	34	21	71	SP	3
93	CJEB-10	1	11	57	2	0	7	48	SP	3
94	CZ-14	1	11	47	0	1	38	8	SP	1
95	CZN-10	1	11	131	6	13	22	90	SP	3
96	BEFA-12B	1	12	53	24	1	9	19	UB	3
97	BEFA-13	1	12	35	6	2	2	25	UB	3
98	BEFAA-10	1	12	45	25	3	3	14	B	3
99	BHC-12	1	12	57	13	1	17	26	UB	3
100	BHCB-10	1	12	152	1	0	41	110	SP	2
101	BJ-12	1	12	32	6	2	5	19	UB	3
102	BJC-12	1	12	42	10	3	14	15	UB	3
103	CG-13	1	12	46	5	1	32	8	UB	3
104	BEZC-10	1	13	117	3	23	19	72	SP	3
105	BG-13	1	13	49	31	0	16	2	B	2
106	BGA-10	1	13	46	18	0	7	21	UB	3
107	BH-11	1	13	89	52	1	22	14	B	5
108	BH-12	1	13	134	62	30	16	26	UB	5
109	BHC-11	1	13	29	4	2	6	17	UB	3
110	BIB-11	1	13	67	22	0	41	4	UB	2
111	BJ-11	1	13	112	35	22	32	23	UB	4
112	BJB-10	1	13	26	15	2	3	6	B	4
113	BJC-10	1	13	108	38	43	14	13	UB	4
114	BK-10	1	13	204	0	0	0	204	SP	3
115	BZT-10	1	13	71	11	1	18	41	UB	2
116	C-10	1	13	50	6	4	35	5	UB	5
117	C-27	1	13	203	20	140	31	12	SP	5
118	C-34	1	13	70	27	12	15	16	UB	4
119	CAGB-11	1	13	14	2	1	10	1	UB	4
120	CEA-10	1	13	50	1	9	26	14	SP	3
121	CEA-11	1	13	57	0	7	37	13	SP	3
122	CJE-10	1	13	134	16	8	27	83	UB	3
123	CPA-10	1	13	73	6	0	5	62	SP	3
124	BH-13	1	14	88	56	3	14	15	B	5
125	BHFZ-13	1	14	37	17	1	0	19	UB	3
126	BJ-10	1	14	67	37	17	2	11	B	4
127	BZ-15	1	14	130	3	0	6	121	SP	2
128	C-28	1	14	36	10	0	5	21	UB	5
129	CAWA-10	1	14	75	10	8	34	23	UB	1
130	CHE-10	1	14	86	3	14	34	35	SP	2
131	CHEA-10	1	14	52	10	4	14	24	UB	3
132	CPC-10	1	14	102	1	2	6	93	SP	2
133	CPC-11	1	14	74	8	15	21	30	UB	2
134	CPZ-10	1	14	76	4	10	17	45	SP	3

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Chloride Group	mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
135	BFBZ-10	1	15	155	7	54	31	63	SP	1
136	BH-01B	1	15	59	20	22	12	5	UB	4
137	BH-14	1	15	102	34	24	19	25	UB	5
138	BHH-10	1	15	55	16	2	11	26	UB	2
139	BZV-10	1	15	134	5	17	87	25	SP	1
140	C-29	1	15	100	34	13	48	5	UB	5
141	C-30	1	15	185	49	88	4	44	UB	5
142	CANBZ-11	1	15	75	8	4	11	52	UB	2
143	CAU-10	1	15	51	0	0	50	1	SP	3
144	CAZB-10	1	15	74	5	20	30	19	SP	3
145	CAZBA-10	1	15	24	3	0	17	4	UB	1
146	CJ-17	1	15	66	0	0	29	37	SP	3
147	CJD-10	1	15	67	26	3	32	6	UB	3
148	CO-11	1	15	55	4	17	7	27	SP	3
149	CR-13	1	15	264	53	102	19	90	UB	2
150	BEFI-10	1	16	73	12	0	13	48	UB	3
151	BH-01A	1	16	70	25	1	17	27	UB	4
152	BHCA-11	1	16	74	9	0	34	31	UB	2
153	BJ-01	1	16	115	75	7	2	31	B	4
154	BZN-11	1	16	51	4	31	11	5	SP	2
155	BZS-10	1	16	47	20	5	16	6	UB	2
156	CA-04	1	16	48	11	13	19	5	UB	5
157	CDB-11	1	16	42	4	12	8	18	SP	2
158	CDBZ-12	1	16	40	7	0	21	12	UB	2
159	CS-10	1	16	48	21	1	16	10	UB	3
160	BEAC-10B	1	17	133	3	78	30	22	SP	2
161	BEFA-11	1	17	48	36	2	3	7	B	3
162	BEFJ-10	1	17	103	31	0	30	42	UB	3
163	BEZ-18	1	17	92	15	22	29	26	UB	1
164	BFB-13	1	17	126	52	6	35	33	UB	2
165	BG-11	1	17	59	5	1	20	33	SP	4
166	BJB-13	1	17	63	15	5	13	30	UB	3
167	BL-10	1	17	84	50	1	7	26	B	4
168	BL-11	1	17	86	21	6	19	40	UB	4
169	BL-12	1	17	27	5	1	6	15	UB	3
170	BLB-10	1	17	51	12	0	27	12	UB	3
171	C-31	1	17	84	33	2	42	7	UB	5
172	CAGBZ-15	1	17	35	7	2	26	0	UB	3
173	CAGC-12	1	17	92	0	3	63	26	SP	4
174	CAU-11	1	17	73	14	3	7	49	UB	2
175	CDH-10	1	17	53	5	16	21	11	SP	1
176	CFAA-10	1	17	86	2	47	11	26	SP	1
177	CZZE-11	1	17	50	8	7	33	2	UB	3
178	BC-11	1	18	75	12	33	22	8	UB	4
179	BE-44	1	18	308	101	128	32	47	UB	6
180	BEFAAA-10	1	18	73	9	5	21	38	UB	2

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Chloride Group	Chloride mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
181	BEFAB-10	1	18	42	13	0	24	5	UB	3
182	BJB-14	1	18	48	18	0	6	24	UB	3
183	BJC-11	1	18	46	9	5	16	16	UB	4
184	BJZ-11	1	18	206	3	23	61	119	SP	1
185	BZN-10	1	18	115	8	102	2	3	SP	2
186	BZO-11	1	18	108	51	2	11	44	UB	3
187	C-32	1	18	66	26	10	10	20	UB	4
188	CE-11	1	18	79	1	16	38	24	SP	3
189	CJ-18	1	18	38	9	0	10	19	UB	3
190	BJ-13	1	19	106	5	19	28	54	SP	3
191	C-35	1	19	77	49	0	23	5	B	3
192	CT-10	1	19	50	27	0	22	1	B	4
193	BC-12	1	20	127	23	32	53	19	UB	4
194	BCF-10	1	20	76	5	7	23	41	SP	2
195	BL-13	1	20	110	40	30	22	18	UB	3
196	BZU-10	1	20	64	17	20	6	21	UB	3
197	BZUZ-10	1	20	57	6	12	20	19	UB	2
198	C-06	1	20	146	61	53	12	20	UB	3
199	CAR-10	1	20	188	76	14	82	16	UB	4
200	CO-10	1	20	38	0	3	13	22	SP	3
201	CS-11	1	20	131	19	2	30	80	UB	2
202	CT-11	1	20	50	12	0	21	17	UB	3
203	BLB-11	1	21	41	6	0	17	18	UB	2
204	BZO-10	1	21	30	0	0	9	21	SP	3
205	CAE-10	1	21	62	14	6	29	13	UB	3
206	CTC-10	1	21	55	14	0	26	15	UB	3
207	CZW-10	1	21	92	5	8	24	55	SP	2
208	BEZZAB-10	1	22	74	51	0	21	2	B	3
209	BJC-13	1	22	109	25	1	16	67	UB	3
210	BJZ-10	1	22	104	15	13	72	4	UB	1
211	BZ-14	1	22	69	12	4	40	13	UB	3
212	BZU-11	1	22	31	12	8	5	6	UB	2
213	CAGBZ-16	1	22	16	2	5	3	6	UB	1
214	CFAB-11	1	22	31	1	11	13	6	SP	2
215	CR-11	1	22	111	8	9	21	73	SP	2
216	CT-12	1	22	29	8	4	9	8	UB	2
217	CAGB-10	1	23	13	1	0	9	3	SP	4
218	CANBZ-10	1	23	52	3	2	17	30	SP	2
219	CPA-11	1	23	48	2	2	10	34	SP	3
220	CPD-10	1	23	112	3	0	73	36	SP	3
221	BB-10	1	24	99	5	28	37	29	SP	1
222	BCE- 10	1	24	108	28	42	27	11	UB	4
223	BE-40	1	24	111	37	11	36	27	UB	6
224	BEFA-15	1	24	79	37	4	13	25	UB	1
225	BEFAAA-11	1	24	52	4	12	15	21	SP	2
226	BEGB-10	1	24	75	36	6	3	30	UB	3

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Chloride Group	mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
227	BEZB-10	1	24	134	2	1	13	118	SP	4
228	BFZ-14	1	24	29	5	0	12	12	UB	2
229	CAK-15	1	24	212	13	157	22	20	SP	2
230	CAKZ-11	1	24	18	12	0	4	2	B	1
231	CTB-10	1	24	86	26	2	43	15	UB	3
232	BE-01	1	25	144	27	21	31	65	UB	6
233	BEFO-10	1	25	69	27	21	15	6	UB	1
234	BEGB-11	1	25	98	31	1	12	54	UB	3
235	BG-10	1	25	99	35	0	30	34	UB	4
236	BJB-15	1	25	73	11	1	18	43	UB	2
237	BZO-12	1	25	44	11	0	20	13	UB	3
238	CE-10	1	25	50	1	5	41	3	SP	4
239	CHE-11	1	25	83	11	14	41	17	UB	2
240	CJ-19	1	25	140	24	15	37	64	UB	3
241	BEFF-10	1	26	79	74	0	3	2	B	3
242	BEFG-11	1	26	55	38	1	1	15	B	2
243	BFB-11	1	26	100	25	23	26	26	UB	4
244	CDFB-10	1	26	96	20	6	34	36	UB	4
245	CGZ-11	1	26	116	0	47	32	37	SP	2
246	CZM-10	1	26	40	7	5	25	3	UB	2
247	BE-37	1	27	99	35	9	19	36	UB	6
248	BEABA-10	1	27	102	21	5	41	35	UB	2
249	BZA-10	1	27	62	7	22	27	6	UB	1
250	C-24	1	27	116	20	43	52	1	UB	6
251	CDF-12	1	27	153	17	27	37	72	UB	3
252	BZS-11	1	28	125	15	10	20	80	UB	2
253	C-25	1	28	182	33	67	64	18	UB	6
254	CAB-10	1	28	30	4	5	14	7	UB	3
255	BEF-23	1	29	75	31	2	8	34	UB	3
256	BHF-10	1	29	89	10	0	8	71	UB	4
257	C-37	1	29	58	26	1	9	22	UB	3
258	CH-03	1	29	46	5	5	24	12	UB	4
259	CR-12	1	29	211	14	2	38	157	SP	2
260	B-20	1	30	95	0	1	0	94	SP	8
261	BE-43	1	30	258	55	102	13	88	UB	6
262	BEFH-10	1	30	37	23	0	0	14	B	1
263	BEZJ-10	1	30	73	0	0	0	73	P	3
264	BFB-12	1	30	96	26	28	16	26	UB	3
265	BFZ-17	1	30	52	15	0	2	35	UB	1
266	BL-14	1	30	58	15	0	8	35	UB	2
267	BZ-10	1	30	173	32	79	56	6	UB	3
268	CAZA-10	1	30	84	10	3	65	6	UB	3
269	CGAB-11	1	30	28	3	9	13	3	UB	1
270	CP-01	1	30	33	8	4	11	10	UB	4
271	CRB-10	1	30	204	6	0	18	180	SP	1
272	BEA-11	1	31	200	36	103	27	34	UB	4

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Chloride Group	Chloride mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
273	CAGC-16	1	31	38	4	9	2	23	UB	3
274	CFAB-10	1	31	165	53	1	80	31	UB	2
275	CHEAZ-12	1	31	56	6	2	15	33	UB	1
276	CPZ-12	1	31	114	1	0	0	113	P	1
277	B-16	1	32	169	1	1	0	167	SP	8
278	B-17	1	32	155	0	1	2	152	SP	8
279	B-19	1	32	58	1	28	1	28	SP	8
280	B-22	1	32	67	1	6	28	30	SP	8
281	BE-42	1	32	239	105	105	24	5	UB	6
282	BEAC-10A	1	32	73	0	3	15	55	SP	2
283	BFBZ-11	1	32	137	5	100	18	14	SP	2
284	C-38	1	32	94	43	14	17	20	UB	2
285	CANBAA-10	1	32	50	21	5	16	8	UB	1
286	CHH-10	1	32	123	22	17	44	40	UB	3
287	CZZB-10	1	32	89	7	11	66	5	SP	2
288	B-18	1	33	236	1	15	0	220	SP	8
289	BE-41	1	33	180	36	9	34	101	UB	6
290	BHFZ-12	1	33	51	6	1	11	33	UB	2
291	CZZA-10	1	33	97	0	1	43	53	SP	1
292	B-04	1	34	190	8	38	3	141	SP	8
293	BE-38	1	34	268	138	79	41	10	B	6
294	BE-39	1	34	89	45	5	23	16	B	6
295	BE-45	1	34	112	26	11	15	60	UB	6
296	CH-13	1	34	79	9	2	33	35	UB	4
297	CN-10	1	34	74	18	14	33	9	UB	2
298	B-21	1	35	51	3	11	7	29	SP	8
299	BZS-12	1	35	54	12	0	30	12	UB	2
300	BED2	1	36	113	13	5	2	93	UB	3
301	BFZ-16	1	36	29	15	0	1	13	B	2
302	BFZ-18	1	36	13	2	0	2	9	UB	1
303	BE-02	1	37	153	82	44	14	13	B	6
304	BLB-12	1	37	84	50	0	21	13	B	2
305	BFBZ-12	1	38	81	61	3	9	7	B	1
306	BEZB-11	1	39	111	7	0	1	103	SP	4
307	CAGC-13	1	39	57	15	14	23	5	UB	4
308	C-07	1	40	107	17	7	27	56	UB	5
309	CDF-10	1	40	79	14	4	55	6	UB	4
310	CK-10	1	40	123	39	23	46	15	UB	3
311	CUA-10	1	40	90	12	2	14	62	UB	2
312	BF-12	1	41	46	3	0	26	17	SP	1
313	CG-12	1	41	125	9	16	74	26	SP	3
314	CO-12	1	41	67	0	20	21	26	SP	2
315	BEG-10B	1	42	24	4	11	0	9	UB	4
316	CAGBA-10	1	42	131	8	43	65	15	SP	2
317	CN-11	1	42	26	0	0	2	24	SP	2
318	BE-36	1	43	127	42	6	35	44	UB	6

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Chloride Group	mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
319	BEFSZ-10	1	43	68	7	7	12	42	UB	2
320	CHZ-11	1	43	77	2	1	10	64	SP	1
321	CJB-10B	1	43	153	0	9	16	128	SP	3
322	CP-14	1	43	72	17	10	23	22	UB	3
323	C-26	1	46	26	1	1	24	0	SP	5
324	CP-11	1	46	22	8	0	8	6	UB	4
325	CANB-10	1	47	77	19	4	24	30	UB	3
326	CD-16	1	47	138	5	18	11	104	SP	2
327	CAVA-10	1	48	150	0	5	40	105	SP	2
328	BBA-10	1	49	71	5	17	21	28	SP	2
329	CA-14A	1	49	-	-	-	-	-	-	6
330	CAJA-10	1	49	99	21	14	24	40	UB	2
331	C-23	1	50	135	21	54	53	7	UB	6
332	C-36	1	50	83	43	7	27	6	B	3
333	CD-14	1	50	96	6	47	38	5	SP	4
334	CAK-11	2	52	32	3	5	19	5	SP	3
335	CANZ-10	2	52	12	3	1	5	3	UB	2
336	BJAZ-11	2	54	52	0	0	0	52	P	1
337	CAK-12	2	54	59	15	17	16	11	UB	3
338	CG-10	2	54	41	1	3	32	5	SP	4
339	CM-11	2	54	75	18	0	29	28	UB	3
340	BFZ-19	2	55	302	0	0	0	302	P	1
341	CAK-13	2	56	92	58	12	10	12	B	3
342	CAA-10	2	57	13	1	4	6	2	SP	2
343	CAG-10	2	57	33	0	2	30	1	SP	5
344	BHFZ-11	2	58	28	0	0	2	26	SP	1
345	CDG-12	2	58	113	4	0	9	100	SP	1
346	BHFZ-10	2	59	1000	0	0	0	1000	P	1
347	CP-12	2	59	184	2	0	12	170	SP	3
348	CAJB-10	2	60	42	7	9	26	0	UB	2
349	CDB-10	2	60	16	0	11	2	3	SP	3
350	CG-11	2	60	77	11	26	29	11	UB	4
351	CGZ-10	2	61	41	4	5	28	4	SP	1
352	CRZ-11	2	61	122	3	2	1	116	SP	1
353	CGAB-10	2	63	64	4	13	23	24	SP	1
354	CB-10	2	64	97	4	17	62	14	SP	4
355	CBBZ-10	2	64	78	0	5	39	34	SP	2
356	CJA-13	2	64	66	6	16	32	12	SP	2
357	BFZ-15	2	67	65	50	0	13	2	B	2
358	CD-13	2	67	40	2	13	22	3	SP	4
359	CA-14B	2	69	-	-	-	-	-	-	6
360	BFZ-13	2	71	91	19	0	34	38	UB	2
361	CAJ-13	2	75	15	0	2	4	8	UB	4
362	CDG-10	2	75	39	6	6	13	14	UB	2
363	CC-10	2	77	44	0	15	20	9	SP	3

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Chloride Group	Chloride mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
364	CC-11	2	77	92	2	41	23	26	SP	3
365	CD-15	2	77	53	3	45	3	2	SP	3
366	CZXZ-11	2	77	124	26	1	39	58	UB	1
367	CZB-10	2	78	75	1	3	58	13	SP	3
368	BJA-10	2	79	63	21	11	10	21	UB	2
369	CH-15	2	79	72	18	13	25	16	UB	3
370	CP-13	2	80	161	4	5	8	144	SP	3
371	CJ-04	2	81	89	8	11	46	24	SP	4
372	CZ-10	2	81	129	0	33	9	87	SP	3
373	BFZ-20	2	82	17	3	0	1	13	UB	1
374	BEB-10	2	83	203	53	37	31	82	UB	4
375	CDBZ-10	2	83	36	8	3	13	12	UB	2
376	BCZ-10	2	85	268	63	152	48	5	UB	3
377	CZXZ-10	2	87	215	0	2	2	211	SP	1
378	BEDA-11	2	88	66	28	8	10	20	UB	1
379	CH-14	2	88	140	30	5	31	74	UB	4
380	BEFE-11	2	90	87	44	2	8	33	B	3
381	CAGBZ-12	2	90	8	0	1	6	1	SP	2
382	CCA-11	2	90	237	1	0	1	235	P	2
383	CCZ-11	2	90	-	-	-	-	-	-	-
384	BEF-25B	2	92	94	11	14	26	43	UB	3
385	CZX-10	2	92	69	16	2	36	15	UB	2
386	CAGBZ-11	2	93	16	0	1	1	14	SP	2
387	CAK-10	2	93	125	70	38	6	11	B	3
388	BEF-15	2	95	81	24	35	13	9	UB	5
389	CDBA-11	2	95	109	6	1	65	26	SP	3
390	CDZ-11	2	97	83	2	25	41	15	SP	2
391	CJA-12	2	97	53	1	19	10	23	SP	2
392	BEB-12	2	98	44	16	8	7	13	UB	4
393	CDF-11	2	98	126	50	22	45	9	UB	3
394	CD-17	2	99	57	11	19	8	19	UB	2
395	BEZG-10	2	100	76	17	9	30	20	UB	3
396	CAKA-10	2	100	72	2	12	35	23	UB	2
397	CDG-11	2	100	1009	0	0	2	1007	P	1
398	CAGC-17	3	104	20	12	2	0	6	B	2
399	CZA-11	3	108	22	0	7	14	1	SP	3
400	BEB-11	3	110	139	27	33	36	43	UB	4
401	BEB-13A	3	110	43	2	17	5	19	SP	2
402	BEF-16	3	110	102	36	34	21	11	UB	5
403	BZK-10A	3	110	12	4	1	6	1	UB	4
404	CAJ-11	3	110	89	14	44	20	11	UB	4
405	CM-01	3	110	69	14	13	27	15	UB	3
406	BEBB-10B	3	112	23	1	14	0	8	SP	3
407	CD-11	3	116	131	21	20	69	21	UB	4
408	BEB-13B	3	118	68	3	28	9	28	SP	2
409	BEG-10A	3	120	115	89	11	3	12	B	4

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Group	Chloride mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
410	C-39	3	120	111	3	5	2	101	SP	2
411	CDD-10	3	120	37	1	0	9	27	SP	3
412	CHEAZ-11	3	120	100	3	1	1	95	SP	1
413	BZK-10B	3	122	20	17	2	1	0	B	4
414	COB-10	3	126	80	4	17	36	23	SP	2
415	BEFEZ-10	3	130	106	0	0	0	106	P	1
416	CAJC-11	3	130	39	8	6	2	23	UB	3
417	CDBA-10	3	138	70	15	30	12	13	UB	2
418	BEF-03	3	140	42	19	4	9	10	UB	4
419	BEF-19	3	140	26	7	3	1	15	UB	4
420	BGB-10	3	140	54	5	0	30	19	SP	3
421	CJA-10	3	145	86	38	12	19	17	UB	3
422	BEDB-11	3	150	209	4	0	5	200	SP	3
423	CAJ-14A	3	150	28	10	3	9	6	UB	3
424	CPZ-13	3	150	49	4	5	16	24	SP	1
425	CD-12	3	151	71	4	2	22	43	SP	4
426	CGA-10	3	152	53	9	10	28	6	UB	3
427	CPZ-11	3	160	107	0	0	1	106	P	1
428	CH-16	3	163	122	2	8	0	112	SP	3
429	CJA-11	3	176	17	2	0	9	6	UB	3
430	BEC-10	3	180	33	16	4	7	6	UB	3
431	BEF-17	3	180	139	36	59	20	24	UB	5
432	CAN-10	3	184	101	10	68	2	21	SP	4
433	BJAZ-10	3	190	1000	0	0	0	1000	P	1
434	CAL-10	3	190	82	1	1	44	36	SP	2
435	CAZCZ-10	3	190	44	5	1	27	11	UB	4
436	BED-10	3	200	42	14	8	20	0	UB	3
437	CDZ-12	3	212	61	6	22	19	14	SP	1
438	BF-13	3	220	45	9	0	21	15	UB	1
439	BZK-11	3	220	86	5	1	36	44	SP	4
440	BEDB-10	3	230	54	23	12	18	1	UB	2
441	BEFC-11	3	240	27	8	0	7	12	UB	2
442	CZA-10	4	256	52	0	21	17	14	SP	4
443	BED-11	4	260	21	12	5	0	4	B	3
444	BDZ-10	4	264	61	33	0	17	11	UB	3
445	CAJ-12	4	270	30	3	5	16	6	UB	4
446	BEDC-10	4	280	69	15	21	25	8	UB	2
447	BF-11B	4	288	128	0	13	14	101	SP	3
448	C-10B	4	290	80	3	16	23	38	SP	2
449	CBC-10	4	297	91	2	13	53	23	SP	3
450	BEBB-10A	4	370	31	1	9	8	13	SP	3
451	BFZ-10	4	390	36	0	0	3	33	SP	3
452	BCA-10	4	406	76	9	16	27	24	UB	3
453	BFZ-11A	4	430	26	0	0	0	26	P	3
454	BFZ-11B	4	430	127	0	0	6	121	SP	3
455	CCZ-10	4	430	68	25	6	17	20	UB	1

(a) IEPA station classification defined in Appendix 5.1

Number	Station	Chloride Group	mg/L	Total	Int	Mod	Fac	Tol	Station(a) Class	Stream Order
456	CAC-11	4	450	24	7	1	7	9	UB	3
457	BEBZ-10	4	470	111	21	12	34	44	UB	2
458	BF-11A	4	500	88	0	0	2	86	SP	3
459	CAJC-10	5	510	41	5	2	10	24	UB	3
460	BEBZ-11	5	520	73	14	13	40	6	UB	2
461	BZ-13	5	520	40	20	11	5	4	B	2
462	CZH-10	5	525	54	3	28	12	11	SP	2
463	CZ-15	5	540	73	6	1	54	12	SP	3
464	BF-01	5	550	97	0	0	0	97	P	3
465	BZKA-10	5	550	179	15	25	49	90	SP	3
466	BZJZ-10	5	580	132	17	6	26	83	UB	2
467	BEZB-12	6	1100	91	5	6	11	69	SP	3
468	CANBA-10	6	1150	170	0	0	3	167	SP	1
469	CBA-10	6	1170	94	1	11	44	38	SP	3
470	BEZE-10	6	1200	126	5	14	35	72	SP	2
471	BZJZ-11B	6	1350	20	3	0	0	17	UB	2
472	CHD-10	6	1500	23	2	0	20	1	SP	4
473	BEDA-10	6	1600	36	25	3	3	5	B	2
474	CU-10	6	1600	108	24	0	55	29	UB	3
475	BZJZ-11A	6	1940	56	11	5	26	14	UB	2
476	BEA-10	6	3700	129	14	2	7	106	UB	5
477	CAJ-14B	6	4900	48	0	10	3	35	SP	3

(a) IEPA station classification defined in Appendix 5.1

Appendic 5-C. Benthic Macroinvertebrates (Except Diptera and Mollusca) Collected in Buck Creek, Clay County, Illinois, August and October, 1986

Taxa[a]	Tolerance Status[b]	STATIONS 1 Aug	1 Oct	2 Aug	2 Oct	3 Aug	3 Oct	4 Aug	4 Oct	5 Aug	5 Oct	6 Aug	6 Oct	TOTAL
Worms, Leeches														
NNELIDA														
OLIGOCHAETA														
Haplotaxida														
Enchytraeidae	T	-	-	-	-	-	-	-	-	-	1	-	1	2
Naididae†	T	37	31	18	32	21	48	24	29	18	42	22	49	371
Chaetogaster diaphanus (Gruithuisen)	T	-	-	-	6	-	-	-	-	-	-	-	-	6
Chaetogaster sp.	T	-	-	-	1	-	-	-	-	-	-	-	-	1
Dero (Aulophorus) furcata (Muller)	T	-	-	-	3	-	-	-	-	-	-	-	1	4
Dero (Aulophorus) vaga (Leidy)	T	-	-	-	5	2	4	-	-	-	12	2	37	62
Dero (Dero) digitata (Muller)	T	31	3	28	7	20	1	73	13	26	5	47	7	261
Dero (Dero) nivea Aiyer	T	-	38	-	12	-	9	-	23	-	7	-	14	103
Dero (Dero) obtusa d'Udekem	T	-	-	-	9	-	4	-	-	-	7	-	9	29
Dero sp.	T	-	1	-	6	-	1	-	-	-	1	-	3	12
Haemonais waldvogeli Bretscher	T	-	-	-	3	-	-	-	-	-	-	-	3	6
Nais communis Piguet	T	-	-	-	5	-	3	-	-	-	1	-	1	10
Nais pardalis Piguet	T	-	3	-	-	-	-	-	-	-	-	-	-	3
Nais variabilis Piguet	T	-	-	-	2	-	-	-	-	-	-	-	-	2
Pristina leidyi (Smith)	T	1	-	-	18	-	4	2	-	-	3	-	-	28
Pristina plumaseta Turner	T	-	-	-	-	-	-	8	-	-	-	-	-	8
Slavina appendiculata (d'Udekem)	T	-	-	-	-	-	-	-	-	-	1	-	-	1
Stylaria lacustris (*f*) (Linnaeus)††	T	1	1	-	6	1	-	-	-	-	-	-	-	9
Tubificidae														
Aulodrilus limnobius Bretscher	T	-	-	-	-	-	4	-	-	-	3	-	-	7
Aulodrilus pigueti Kowalewski	T	8	14	6	4	-	8	33	5	2	7	11	7	105
Ilyodrilus templetoni (Southern)	T	1	-	2	1	-	6	-	-	4	-	-	1	15
Limnodrilus claparedianus Ratzel	T	-	-	-	-	-	-	-	-	1	-	-	-	1
Limnodrilus hoffmeisteri Claparede	T	2	-	3	-	-	1	-	-	7	-	-	-	13
Limnodrilus sp.§	T	-	2	-	1	-	1	-	-	-	-	-	-	4
*UIW/OCC (primarily Tubificidae)	T	18	49	36	52	62	41	24	8	28	9	11	16	354
**UW/CC (primarily Tubificidae)	T	1	4	6	5	5	31	3	-	1	4	-	3	63
HIRUDINEA														
Glossiphoniidae	T	-	-	-	1	-	-	-	-	-	-	-	-	1
Placobdella parasitica (Say)	T	-	-	-	-	-	-	-	-	-	-	1	-	1
Hirudinidae	T	-	-	-	-	-	-	-	-	-	3	-	2	5
Amphipods, Isopods, Crayfishes, Prawns														
RTHROPODA														
CRUSTACEA														
Amphipoda														
Talitridae														
Hyalella azteca (Saussure)	I	11	20	6	46	1	11	13	17	5	7	16	95	248
Isopoda														
Asellidae														
Caecidotea forbesi (Williams)	M	-	-	-	-	-	-	-	4	-	9	-	-	13
Decapoda														
Astacidae														
Cambarus diogenes Girard	I	-	-	1	-	-	-	-	-	-	-	-	-	1
Orconectes virilis (Hagen)	I	1	1	1	2	-	-	-	1	6	2	2	-	16
Palaemonidae														
Palaemonetes kadiakensis Rathbun	M	3	2	20	1	5	3	30	10	74	16	70	5	239
Aquatic and Semi-Aquatic Insects														
INSECTA														
Ephemeroptera (mayflies)														
Baetidae														
Callibaetis ferrugineus (Walsh)	I	6	16	2	1	-	1	24	-	1	-	-	-	51
Caenidae														
Caenis spp.	F	16	37	5	37	-	15	51	31	9	28	30	111	369
Ephemeridae														
Hexagenia limbata (Serville)	F	-	-	-	-	-	-	-	6	-	-	-	1	7
Hexagenia sp.	F	-	-	-	-	-	2	9	-	2	1	-	-	14

† = individuals identified as "Naididae" appeared primarily to be anterior portions of *Dero* spp.
†† = (*f*) refers to the *foreularia* form of *Stylaria lacustris*.
§ = developing penis sheaths were present in these individuals.
* = unidentifiable immature specimens without capilliform chaetae.
** = unidentifiable specimens with capilliform chaetae.

Taxa[a]	Tolerance Status[b]	STATIONS 1 Aug	1 Oct	2 Aug	2 Oct	3 Aug	3 Oct	4 Aug	4 Oct	5 Aug	5 Oct	6 Aug	6 Oct	TOTAL
Heptageniidae														
Stenacron interpunctatum (Say)	I	-	1	-	1	-	-	-	1	1	1	-	-	5
Stenonema femoratum (Say)	I	-	1	-	-	-	-	-	-	-	-	-	-	1
Leptophlebiidae														
Leptophlebia spp.	I	-	2	-	4	-	1	-	-	-	-	-	-	7
ODONATA														
ZYGOPTERA (damselflies)														
Coenagrionidae														
Argia sp.	M	2	1	-	-	1	-	4	1	1	-	5	2	17
Enallagma antennatum (Say)	M	-	-	1	-	-	-	2	-	-	2	-	-	5
Enallagma divagans Selys	M	-	-	-	1	-	-	-	-	-	-	-	2	3
Enallagma signatum (Hagen)	M	1	1	1	-	-	-	-	-	-	-	-	-	3
Enallagma spp.	M	-	-	-	-	-	-	2	2	-	-	5	1	10
Ischnura posita (Hagen)	I	33	67	4	14	1	20	-	-	-	-	-	37	176
ANISOPTERA (dragonflies)														
Aeshnidae														
Nasiaeschna pentacantha (Rambur)	M	1	1	-	-	-	-	4	1	4	-	2	-	13
Corduliidae														
Somatochlora sp.	M	-	-	-	-	-	1	-	-	1	-	-	-	2
Tetragoneuria sp.	M	2	-	-	4	-	-	-	-	-	-	-	-	6
Gomphidae														
Gomphus nr *exilis* Selys	T	-	-	1	-	-	1	-	-	1	-	-	-	3
Libellulidae														
Libellula pulchella Drury	M	-	3	-	-	-	-	-	-	-	-	-	-	3
Libellula sp.	M	3	-	-	-	-	-	-	-	-	1	-	-	4
Pachydiplax longipennis (Burmeister)	M	-	-	-	4	-	-	-	-	-	-	-	1	5
Perithemis tenera (Say)	M	-	-	-	-	1	-	-	-	8	-	5	-	14
Plathemis lydia (Drury)	I	6	-	-	-	-	-	-	-	-	-	-	-	6
Heteroptera (true bugs)														
Belostomatidae														
Belostoma sp.	F	1	-	-	-	-	-	-	-	-	-	-	-	1
Corixidae														
Corisella edulis (Champion)	F	-	-	-	-	-	1	-	-	-	-	-	-	1
Palmacorixa buenoi Abbott	F	6	-	2	1	-	-	-	-	1	-	7	2	19
Sigara alternata (Say)	F	6	-	-	-	6	-	32	2	14	3	13	1	77
Sigara modesta (Abbott)	F	21	2	29	3	13	1	104	23	33	7	138	12	386
Trichocorixa calva (Say)	F	1	1	20	-	8	2	12	4	7	6	24	10	95
Gerridae														
Gerris marginatus Say	F	-	-	-	-	-	-	-	-	1	-	-	-	1
Gerris nebularis Drake and Hottes	F	-	-	1	-	-	-	-	-	-	-	-	-	1
Gerris remigis Say	F	17	-	-	-	-	-	-	-	-	-	-	-	17
Gerris spp.	F	1	1	-	-	-	-	9	-	1	-	1	-	13
Rheumatobates palosi Blatchley	F	11	-	-	-	4	-	26	-	3	-	2	-	46
Trepobates pictus (Herrich-Schaeffer)	F	5	-	-	-	1	-	1	-	-	-	-	-	7
Hydrometridae														
Hydrometra martini Kirkaldy	F	-	-	-	-	-	-	1	-	-	-	-	-	1
Mesoveliidae														
Mesovelia mulsanti White	F	-	-	3	3	2	2	-	-	1	-	6	3	20
Nepidae														
Ranatra buenoi Hungerford	F	-	-	-	-	-	-	-	-	-	-	2	-	2
Notonectidae														
Notonecta irrorata Uhler	F	-	-	-	-	4	-	1	-	1	-	2	-	8
Pleidae														
Neoplea striola (Fieber)	F	-	-	-	-	-	1	-	-	-	-	-	-	1
Veliidae														
Microvelia americana (Uhler)	F	1	-	1	-	-	-	1	-	-	-	-	-	3
Megaloptera														
Corydalidae (dobsonflies)														
Chauliodes rastricornis Rambur	M	-	-	1	-	-	-	-	-	-	-	-	-	1
Sialidae (alderflies)														
Sialis sp.	M	1	2	-	-	-	-	1	-	-	-	-	-	4
Trichoptera (caddisflies)														
Hydropsychidae														
Cheumatopsyche sp.	M	-	1	-	-	-	-	-	-	-	-	-	-	1
Leptoceridae														
Oecetis inconspicua (Walker)	F	-	-	-	-	-	-	-	1	-	-	-	2	3
Ceraclea sp.	M	-	-	-	-	-	-	1	-	-	-	-	-	1
Coleoptera (beetles)														
Dryopidae														
Helichus fastigiatus (Say)	F	1	1	-	-	-	-	-	4	-	-	-	-	6
Helichus lithophilus (Germar)	F	2	-	-	-	-	-	-	-	-	-	-	-	2
Helichus striatus LeConte	F	1	-	-	-	-	-	-	-	-	-	-	-	1
Dytiscidae														
Laccophilus fasciatus rufus Melsheimer	F	16	-	1	-	4	-	1	-	-	-	-	-	22
Laccophilus m. maculosus Say	F	5	-	-	-	-	-	-	-	-	-	-	-	5
Uvarus lacustris (Say)	F	-	-	-	-	-	-	-	-	1	-	-	-	1

Taxa[a]	Tolerance Status[b]	STATIONS 1 Aug	1 Oct	2 Aug	2 Oct	3 Aug	3 Oct	4 Aug	4 Oct	5 Aug	5 Oct	6 Aug	6 Oct	TOTAL
Dytiscidae (concluded)														
Hydroporini (larvae)	F	-	11	-	3	-	13	-	7	-	31	-	25	90
Hydroporus sp. A	F	1	1	1	-	3	-	-	2	6	-	10	-	24
Hydroporus sp. B	F	-	-	1	-	-	-	-	-	-	-	-	-	1
Hydroporus sp. C	F	-	-	-	-	2	-	-	-	-	-	1	-	3
Agabus sp.	F	-	4	-	1	-	1	-	-	-	-	-	-	6
Elmidae														
Dubiraphia quadrinotata (Say)	F	2	5	3	-	-	4	9	7	10	6	10	9	65
Stenelmis sp.	F	-	-	-	-	-	-	-	1	-	-	-	-	1
Gyrinidae														
Gyrinus sp.	F	1	-	1	-	-	-	-	-	-	-	-	-	2
Haliplidae														
Peltodytes dunavani Young	F	1	1	1	-	-	-	1	-	1	-	-	-	5
Peltodytes duodecimpunctatus (Say)	F	85	8	10	-	32	1	15	3	17	8	2	-	181
Peltodytes edentulus (LeConte)	F	3	2	1	-	-	-	-	-	1	-	-	-	7
Peltodytes litoralis Matheson	F	3	2	5	-	1	-	-	-	-	1	-	-	12
Peltodytes muticus (LeConte)	F	1	-	-	1	1	-	-	-	1	-	-	-	4
Peltodytes sexmaculatus Roberts	F	5	2	2	-	1	-	-	1	3	1	-	-	15
Peltodytes spp.	F	-	-	4	-	-	-	-	-	-	-	-	-	4
Hydrophilidae														
Tropisternus collaris striolatus (LeConte)	F	2	1	-	-	-	-	-	-	-	-	-	-	3
Tropisternus lateralis nimbatus (Say)	F	1	-	-	-	-	-	-	-	-	-	-	-	1
Tropisternus natator d'Orchymont	F	10	4	-	-	1	-	-	-	-	-	-	-	15
Tropisternus spp.	F	12	-	-	-	-	-	2	-	-	-	-	-	14
[illegible]cres *maculicollis* Mulsant	F	1	-	-	-	-	-	-	-	-	-	-	-	1
Berosus aculeatus LeConte	F	-	-	-	-	1	-	2	-	-	-	-	-	3
Berosus peregrinus (Herbst) .	F	-	-	-	-	3	-	-	-	-	-	-	-	3
Berosus spp.	F	3	5	-	-	-	1	-	-	2	-	-	-	11
Helophorus sp.	F	-	-	-	1	-	-	-	-	-	-	-	-	1
Hydrochus sp.	F	-	-	-	-	-	-	-	-	-	-	1	-	1
Scirtidae														
Scirtes sp.	F	4	14	3	121	3	197	-	2	-	79	9	31	463
Lepidoptera (moths)														
Pyralidae														
Synclita obliteralis (Walker)	F	-	12	-	4	-	4	-	-	-	2	-	-	22
Total Number of Taxa		48	39	32	37	26	33	29	25	34	30	27	28	97
Total Number of Individuals by Tolerance Status:														
Intolerant		57	108	14	68	2	33	37	19	13	10	18	132	511
Moderate		13	11	23	10	7	4	44	18	68	28	87	11	344
Facultative		246	114	94	175	90	245	277	94	114	173	258	207	2087
Tolerant		100	146	100	179	111	167	167	78	68	106	94	154	1490
Total Number of Individuals		416	379	231	432	210	449	525	209	303	317	457	504	4432
Percent Intolerant		14	28	6	16	1	7	7	9	4	3	4	26	12
IEPA Station Classification[c]		UB	UB	SP	UB	SP	SP	SP	SP	SP	SP	SP	UB	UB
Species Diversity		4.4	3.8	4.2	3.5	3.8	2.5	3.6	3.9	3.9	3.6	3.5	3.4	

[a]Entries represent actual number collected in semi-quantitative sample. Site locations are illustrated in Figure 5.1 and described in Appendix 5.1.

[b]Tolerance status = intolerant (I), moderate (F), facultative (F), tolerant (T); defined in Appendix 5.1.

[c]IEPA station classification scheme defined in Appendix 5.1.

Appendix 6-A. Methods used during investigation of origin of domestic well contamination by saline waters

Sample Collection

Brine samples were collected at the well head in 500 mL acid washed high density polyethylene bottles and stored on ice until the samples were returned to the laboratory for further processing. The brine-oil mixture was transferred to a separatory funnel and the brine was allowed to separate from the oil. The brine was drawn off, filtered, and one split for metal analysis was acidified with 50 percent (v/v) $HNO3$ to a final acid content of 1 percent and stored in acid washed high density polyethylene bottles. Another split for chloride was stored in acid washed high density polyethylene bottles and refrigerated until the analyses could be performed.

Chemical Analysis

A. Metals

All metal constituents reported in this report were determined using an atomic absorption spectrophotometric method adapted from Fletcher and Collins (1974). The spectrometer used was a Perkin-Elmer Model 306 Atomic Absorption Spectrophotometer and signals were recorded with a Perkin-Elmer Model 056 strip chart recorder.

Due to the high dissolved solids content of the brine samples and the potential for matrix interferences, all metals except barium were determined by the method of standard additions. Barium could not be determined by standard additions because added Ba precipitates with the SO_4 in the sample. Calibration parameters and sample dilutions are shown in table 6-A2.

The instrumental conditions used for the metal determinations are shown in table 6-A3.

B. Chloride.

Chloride was determined by mercuric nitrate titration, U.S. EPA (1979). Unacidified brine samples, diluted 0.1 mL to 50 mL were made slightly acidic with 0.036M $HNO3$ and 5 drops of a mixed diphenylcarbazone-bromphenol blue indicator was added. The sample was titrated in duplicate against standardized 0.141N $Hg(NO_3)H_2O$ titrant. The mercuric nitrate titrant was standardized daily against 0.087N NaCl. The mean of the duplicate determinations was reported.

TABLE 6-A1.

CLAY COUNTY OIL FIELD BRINE SAMPLES (mg/L)

SAMPLE	FORMATION	LOC	Na	K	Ca	Mg	Li	Sr	Ba	Fe	Cl
B-5148	Unknown	2N-7E- 9 NENWNW	49470	165	5281	1332	5.2	277	<7	4	84520
B-5165	Tar Springs	3N-7E-16 SESWSE	44600	104	3730	1240	2.3	174	<5	6	78080
B-5166	Tar Springs	3N-7E-16 N2SWSE	47200	79	3520	1220	2.1	163	<5	39	78060
B-5144	Cypress	3N-8E-34 SWSWNE	36720	180	2700	1353	12.0	84	<7	31	60490
B-5146	Cypress	3N-8E- 3 C NENW	35000	198	2370	1350	11.9	85	<7	5	59800
B-5152	Cypress	2N-8E- 8 NENWSE	38670	177	3956	1325	7.3	103	<7	14	65830
B-5153	Cypress	2N-8E- 8 NENESW	39190	159	3215	1153	7.5	94	<10	6	61730
B-5155	Cypress	2N-8E- 8 WHNWNE	36460	130	2551	970	5.2	90	<10	15	57240
B-5161	Cypress	2N-7E-35 NWNESE	45900	289	7000	2120	10.9	125	<10	24	90220
B-5140	Aux Vases	3N-8E-18 SWSWNE	50500	178	4940	1170	4.7	211	<7	6	84400
B-5141	Aux Vases	3N-8E-21 SESESW	48550	168	6174	1683	5.4	231	<7	6	83370
B-5168	Aux Vases	3N-7E-18 NESESE	45800	183	4220	1190	5.4	226	<5	7	84750
B-5142	McClosky	3N-8E-28 NENESW	35700	137	3603	1358	6.3	110	<7	11	62940
B-5147	McClosky	3N-8E-32 E2SWSE	42540	124	2995	1221	6.7	170	<7	<3	66210
B-5154	McClosky	2N-8E-15 NESWNE	49270	186	4568	1422	6.7	150	<10	2	77680
B-5156	McClosky	2N-8E- 6 W2NENE	44070	143	4064	1258	4.8	135	<10	7	69480
B-5157	McClosky	2N-7E- 1 SWNESE	52020	221	4534	2121	8.8	750	<10	4	84100
B-5162	McClosky	3N-7E-33 SWNENE	45800	214	6050	2290	6.3	587	<10	113	85170
B-5163	McClosky	3N-7E-22 S2NWNE	48900	239	5020	2000	7.3	167	<10	1	84480
B-5164	McClosky	3N-7E- 9 SESESW	46000	224	4070	2130	8.9	576	<5	6	88620
B-5167	McClosky	3N-7E-16 N2SWSE	46100	184	3600	1050	6.7	149	<5	7	79520
B-5170	McClosky	3N-7E-17 NESWSW	44400	91	3440	1160	2.6	176	<5	4	75110
B-5171	McClosky	3N-2E-14 C SESE	47400	217	5460	1710	6.9	132	<5	7	88780
B-5143	Salem	3N-8E-34 NWNENW	43880	378	6299	2392	17.7	289	<7	183	82230
B-5149	Salem	2N-7E-11 NESWNE	46560	489	5684	1948	19.6	114	<7	10	80370
B-5150	Salem	2N-7E-11 SWNENW	46300	139	3157	1168	4.7	115	<7	16	74380
B-5151	Salem	2N-7E-12 NWSWNW	47900	520	5700	1960	19.5	116	<7	7	77790
B-5158	Salem	2N-7E- 1 SENESW	50000	475	6287	1974	20.0	126	<10	16	83210
B-5159	Salem	2N-7E-12 NWNWNW	45900	508	5630	1820	19.2	107	<10	115	80080
B-5160	Salem	2N-7E- 1 SWSWNW	48000	417	5620	2000	18.6	119	<10	2	82950
B-5169	Salem	3N-7E-17 S2NWNE	47100	421	5610	2340	15.3	130	<5	8	88330

TABLE 6-A2.

ATOMIC ABSORPTION CALIBRATION PARAMETERS

Element	stock solution mg/L	1st add. mg/L	2nd add. mg/L	sample dilution
Na	500	50	100	0.1 to 50
K	10	1	2	0.1 to 50
Ca	100	10	20	0.1 to 50
Mg	30	3	6	0.1 to 50
Li	10	1	2	5 to 50
Fe	10	1	2	5 to 50
Sr	200	20	40	5 to 50
Ba[1]	100	10	20	5 to 50

[1] barium determined using conventional calibration, calibration standard matrix 45 g/l Na, 69.8 g/l Cl, and 4 g/l Ca.

TABLE 6-A3.

ATOMIC ABSORPTION INSTRUMENTAL CONDITIONS

Parameter	Na	K	Li	Ca	Mg	Sr	Ba	Fe
Wavelength, nm	330.2	766.5	670.8	422.7	285.2	460.7	553.6	302.1
Slit, nm	0.7	1.4	1.4	0.7	0.7	0.4	0.4	0.2
Flame oxidant	air	air	air	N_2O	N_2O	N_2O	N_2O	air
Burner[1]	5	5	5	90	30	90	0	0

[1] orientation of burner in degrees from parallel

TABLE 6-A4.

PENNSYLVANIAN BRINES; MEENTS ET AL., (1952)

Sample	Na+K	Ca	Mg	Cl
B- 58	4572	246	212	6153
B- 56	5673	5	53	7096
B- 55	7086	59	87	10354
B- 54	7023	174	94	10372
B- 57	4505	340	220	6200
B-647	14553	562	283	24106
B-441	19643	648	431	32349
B-379	11101	612	229	17383

Appendix 9-A. Brief description of analytical procedures performed on water samples taken at case study sites and domestic water wells in southeastern Clay County.

Conductivity	-	taken in the lab, with an instrument that was appropriately standardized beforehand. Sample was allowed to come to room temperature and scraped and shaken.
pH		-Taken with a standardized pH meter in the lab. Again, sample was allowed to come to room temperature and shaken.
Alkalinity	-	After the pH was established on a 25 ml. sample, it was titrated to a pH of 4.3 with 0.02N H2SO4.
Residue (TDS)	-	A filtered portion of the unpreserved sample was evaporated from a glass dish, of which the before and after weights were subtracted to give the TDS.
Chlorides and Sulfates	-	These were determined by Ion Chromatography. Known standards are compared with the unpreserved sample.
Calcium, Magnesium, Sodium, Strontium, Lithium	-	These were determined by Flame Atomic Adsorption. The HNO_3 preserved portion of the sample was used.

Appendix 9-B. Results of chemical analysis on groundwater samples collected at Clay County case study sites.

CLAY COUNTY BRINE STUDY
CHEMICAL ANALYSIS

SITE	WELL	INTERVAL	CALCIUM (CA)	MAGNESIUM (MG)	STRONTIUM (SR)	SODIUM (NA)	LITHIUM (LI)
A	1-A	26.5- 29.0	112.0	53.2	0.30	82.0	0.03
A	1-B	16.5- 19.0	1750.0	480.0	3.70	650.0	0.11
A	1-C	7.5- 10.0	3110.0	1070.0	9.10	1380.0	0.20
A	2-A	22.5- 25.0	87.0	37.0	0.20	55.0	0.01
A	2-B	9.5- 12.0	307.0	134.0	1.30	514.0	0.05
A	3-A	32.5- 35.0	346.0	186.0	2.30	778.0	0.14
A	3-B	17.5- 20.0	416.0	205.0	1.90	1144.0	0.21
A	3-C	7.5- 10.0	2040.0	979.0	9.06	1200.0	0.18
A	4-A	26.5- 29.0	470.0	150.0	1.60	570.0	0.08
A	4-B	17.5- 20.0	1640.0	600.0	20.20	6880.0	0.24
A	4-C	7.5- 10.0	2350.0	550.0	36.30	11840.0	0.35
A	5-A	42.5- 45.0	100.0	48.8	0.30	122.0	0.03
A	5-B	24.5- 27.0	370.0	120.0	9.90	630.0	0.12
A	5-C	7.5- 10.0	3600.0	1120.0	44.70	15280.0	0.44
A	6-A	27.5- 30.0	106.0	50.0	0.40	224.0	0.05
A	6-B	12.5- 15.0	256.0	122.0	0.80	588.0	0.07
A	7-A	21.5- 24.0	115.0	50.0	0.30	110.0	0.02
A	8-A	19.5- 22.0	0.0	0.0	0.00	0.0	0.00
A	9-A	7.5- 10.0	1640.0	800.0	6.18	1960.0	0.12
A	OB-4	2.0- 18.0	212.0	90.0	0.09	613.0	0.01
A	OB-5	2.0- 18.0	3200.0	1520.0	15.10	1080.0	0.25
A	OB-6	2.0- 23.0	2200.0	880.0	15.90	4960.0	0.23

SITE	WELL	CHLORIDE (CL)	SULFATE (SO)	ALKALINITY AS CACO3	TOTAL DISS MINERALS	SPECIFIC COND	PH (IN LAB)
A	1-A	160.0	64.0	322	711	1152	7.6
A	1-B	4400.0	27.0	166	8928	12040	7.2
A	1-C	9800.0	32.0	119	21054	24600	7.1
A	2-A	36.0	102.0	343	560	900	7.7
A	2-B	1730.0	75.0	90	2893	5400	7.0
A	3-A	1940.0	427.0	293	4196	6530	7.9
A	3-B	2500.0	720.0	266	5206	8630	7.7
A	3-C	8530.0	58.0	156	12817	23600	7.0
A	4-A	1800.0	160.0	358	3189	5650	7.5
A	4-B	15860.0	480.0	240	26667	42200	7.3
A	4-C	22000.0	283.0	168	37282	57900	7.2
A	5-A	75.0	81.0	460	684	1144	7.9
A	5-B	1050.0	746.0	367	3238	4820	7.7
A	5-C	32000.0	376.0	165	52006	80500	6.7
A	6-A	225.0	161.0	525	1129	1778	7.6
A	6-B	1288.0	230.0	179	2646	4300	7.5
A	7-A	21.0	329.0	395	894	1273	7.6
A	8-A	27.0	134.0	342	959	893	7.8
A	9-A	8770.0	9.0	84	13182	24300	6.7
A	OB-4	1510.0	70.0	164	2589	4830	7.4
A	OB-5	12690.0	300.0	180	19827	32800	7.4
A	OB-6	14950.0	50.0	141	23809	41000	7.0

SITE	WELL	INTERVAL	CALCIUM (CA)	MAGNESIUM (MG)	STRONTIUM (SR)	SODIUM (NA)	LITHIUM (LI)
B	1-A	42.5- 45.0	97.0	40.0	0.39	96.0	0.01
B	1-B	27.5- 30.0	243.0	98.0	0.90	392.0	0.03
B	1-C	12.5- 15.0	1760.0	680.0	12.40	4240.0	0.27
B	2-A	24.5- 27.0	62.4	20.0	0.10	98.0	0.01
B	2-B	12.5- 15.0	69.0	26.4	0.20	250.0	0.01
B	3-A	29.5- 32.0	563.0	205.0	4.90	2160.0	0.11
B	3-B	17.5- 20.0	760.0	280.0	5.40	3920.0	0.22
B	3-C	9.5- 12.0	435.0	198.0	1.78	643.0	0.04
B	4-A	30.5- 33.0	154.0	66.0	0.40	247.0	0.02
B	4-B	12.5- 15.0	113.0	53.0	0.30	98.0	0.02
B	5-A	31.5- 34.0	109.0	50.0	0.40	123.0	0.01
B	5-B	22.5- 25.0	104.0	45.0	0.03	84.0	0.01
B	5-C	9.5- 12.0	71.0	29.6	0.02	110.0	0.02
B	6-A	22.5- 25.0	80.0	34.4	0.30	225.0	0.04
B	6-B	10.5- 13.0	275.0	115.0	0.89	218.0	0.06
B	7-A	22.5- 25.0	214.0	103.0	0.86	456.0	0.06
B	8-A	22.5- 25.0	137.0	70.0	0.05	192.0	0.02
B	8-B	9.5- 12.0	154.0	90.0	0.50	140.0	0.05
B	9-A	27.5- 30.0	79.0	36.0	0.40	311.0	0.02
B	9-B	12.5- 15.0	81.0	30.4	0.41	97.0	0.01
B	10-A	17.5- 20.0	86.0	28.8	0.20	56.8	0.03
B	11-A	12.5- 15.0	131.0	65.0	0.04	117.0	0.03
B	OB-1	2.0- 13.0	112.0	38.0	0.60	147.0	0.01
B	OB-3	2.0- 21.0	3160.0	1480.0	13.50	960.0	0.24
B	OB-6	2.0- 24.0	3520.0	1520.0	15.50	3560.0	0.27
B	OB-8	2.0- 13.0	159.0	84.0	0.30	130.0	0.01

SITE	WELL	CHLORIDE (CL)	SULFATE (SO)	ALKALINITY AS CACO3	TOTAL DISS MINERALS	SPECIFIC COND	PH (IN LAB)
B	1-A	88.0	3.5	526	669	1028	7.7
B	1-B	560.0	635.0	480	2270	3520	7.7
B	1-C	11680.0	490.0	208	18887	33100	7.3
B	2-A	5.1	35.0	438	522	815	7.5
B	2-B	37.0	310.0	535	1027	1480	7.5
B	3-A	4440.0	668.0	361	8163	14070	7.8
B	3-B	7545.0	185.0	230	13755	25200	7.8
B	3-C	2440.0	23.0	79	3861	7120	6.8
B	4-A	22.0	650.0	544	1546	1970	7.6
B	4-B	22.0	229.0	485	841	1270	7.2
B	5-A	29.0	105.0	480	893	1342	7.2
B	5-B	12.0	158.0	486	732	1090	7.5
B	5-C	43.0	129.0	361	637	1004	7.7
B	6-A	14.0	353.0	541	1043	1496	7.6
B	6-B	827.0	220.0	352	1935	3430	7.5
B	7-A	402.0	854.0	581	2505	3680	7.7
B	8-A	57.0	410.0	606	1250	1775	7.5
B	8-B	14.0	444.0	646	1285	1748	7.3
B	9-A	182.0	185.0	579	1161	1822	8.2
B	9-B	408.0	132.0	126	949	1653	6.7
B	10-A	. 11.0	161.0	373	550	828	7.3
B	11-A	334.0	63.0	356	942	1700	7.4
B	OB-1	513.0	20.0	82	1029	1732	6.3
B	OB-3	15420.0	83.0	149	23837	40300	6.8
B	OB-6	17150.0	50.0	160	26885	44800	6.7
B	OB-8	33.0	910.0	244	1670	1917	7.2