Field Verification of Hazardous Wastes Migration from Land Disposal Sites

By

James P. Gibb

Illinois State Water Survey

Keros Cartwright, &

Dave Lindorff

Illinois State Geological Survey

and

Arnold Hartley

Environmental Research Laboratory

Urbana, Illinois

Project Officer

Mike H. Roulier

Solid and Hazardous Waste Research Laboratory

National Environmental Research Center

Cincinnati, Ohio 45268

National Environmental Research Center

Office of Research and Development

U.S. Environmental Protection Agency

Cincinnati, Ohio 45268

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Contents

Preface

Federal and State regulatory agencies have been faced with the difficult assignment of setting standards for the approval of waste disposal sites and for monitoring the environmental effects of waste disposal activities on groundwater. The use of wells or piezometers for collecting water samples and water level data has been the traditional method of monitoring such sites. Recent attention has been given to using other types of research and monitoring tools, such as soil coring, to understand more adequately what occurs in the ground and the groundwater system. Several laboratory studies have been conducted to test the relative attenuation characteristics of different soils for various mineral constituents. This project was designed to test in the field the effectiveness of glaciated region soils in removing hazardous metals and the suitability of soil coring as a monitoring tool.

The study was conceived, planned, and originated by William H. Walker who was an Hydrologist at the Illinois State Water Survey at the time. In September, 1975, Walker left the State Water Survey and the senior author assumed responsibility for completion of this project. The basic goals as set forth for the original project have been adhered to and the results are presented in this report. The conclusions and recommendations are the combined opinions of the authors of this final report.

Abstract

The vertical and horizontal migration patterns of zinc, cadmium, copper, and lead through the soil and shallow aquifer systems at two secondary zinc smelters were defined using soil coring and monitoring well techniques. The vertical migration of the same elements at a third zinc smelter also was defined. The migration of metals that occurred at the three smelters has been limited to relatively shallow depths into the soil profile by attenuation processes. Cation exchange and precipitation of insoluble metal compounds, as a result of pH changes in the infiltrating solution, were determined to be the principal mechanisms controlling the movement of the metals through the soil. Increased metals contents in the shallow groundwater system have been confined to the immediate plant sites. At a fourth site, it appeared that the glacial materials were retarding the migration of organic pollutants. Problems associated with sampling and analyses for chlorinated hydrocarbon waste products prohibited further definition of the effectiveness of the soils in retaining the pollutants from this site. No detectable organic pollutants were found in the shallow groundwater system.

Soil coring was determined to be an effective investigative tool, but not suitable by itself for routine monitoring of waste disposal activities. However, it should be used to gather preliminary information to aid in determining the proper horizontal and vertical locations for monitoring well design. The analysis of water samples collected in this project generally did not provide a

stable, reproducible pattern of results. This indicates the need to develop sampling techniques to obtain representative water samples. The failure of some well seals in a highly polluted environment also indicates the need for additional research in monitoring well construction.

For successful interdisciplinary research, we conclude that active participation of all disciplines is essential in the planning stage of the project.

This report was submitted in fulfillment of Contract No. R803216-01-3 by the Illinois State Water Survey under the sponsorship of the U. E. Environmental Protection Agency. This report covers a period from July 22, 1974 to January 21, 1977, and work was completed April 4, 1977.

Figures

Tables

Abbreviations

AA	- atomic absorption
Amp	- amplifier
APDC	- ammonium PyrolidineDithio Carbamate
ASV	- anodic stripping voltammetry
CEC	- cation exchange capacity
CME	- Central Mining Equipment
DL	- detection limits
DDE	- 1,1 - dichloro - 2,2 - bis (p-chlorophenal) ethalene
EDTA	- ethylenediaminetetracetic acid
GLC	- gas liquid chromatograph
IL	- Instrumentation Laboratories
INAA	- instrumental neutron activiation analysis
JACO	- Jarrell-Ash Company
MCA	- multi channel analyser
MSL	- Mean Sea Level
PP	- Pulse Polarography
Preamp	- preamplifier
PVC	- polyvinyl chloride
SD	- standard deviation
TDE (DDD)	- 1,1 - dichloro - 2, 2- bis (p - chlorphenol)ethane
XRF	- X-ray spectroscopy

Symbols

Am^{241} - americium

e - electron

Ge Li - lithium drifted germanium

hr_2 - emitted energy

I - hydraulic gradient

L - screen length

LN_2 - liquid nitrogen

m - aquifer thickness

P - permeability

pH - hydrogen ion concentration

Q - discharge

r - distance between pumped well and observation well

S - coefficient of storage

s - drawdown

T - coefficient of transmissivity

v - apparent or bulk velocity

Z - atomic number of an element

Conversion Factors
English To Metric

ENGLISH UNIT	MULTIPLIER	METRIC UNIT
acre	0.405	ha
acre-ft	1,233.5	cu m
Btu	0.252	kg-cal
Btu/lb	0.555	kg-cal/kg
bu	35.24	l
bu	0.03524	cu m
cfm	0.028	cu m/min
cfs	1.7	cu m/min
cfs/acre	4.2	cu m/min/ha
cfs/sq mile	0.657	cu m/min/sq km
cu ft	0.028	cu m
cu ft	28.32	l
cu in.	16.39	cu cm
°F	0.555	°C (°F-32)
fathom	1.8	m
ft	0.3048	m
ft-c	10.764	lumen/sq m
gal	3.785	l
gpd/acre	0.00935	cu m/day/ha
gpd/ft	0.0124	cu m/day/m
gpd/sq ft	0.0408	cu m/day/sq m
gpm	0.0631	l/sec
gpm/sq ft	40.7	l/min/sq m
hp	0.7457	kw
in.	2.54	cm
lb	0.454	kg
lb/day/acre-ft	3.68	g/day/cu m
lb/1,000 cu ft	16.0	g/cu m
lb/acre/day	0.112	g/day/sq m
lb/cu ft	16.02	kg/cu m
lb/day/cu ft	16	kg/day/cu m
lb/day/sq ft	0.0049	g/day/sq m
lb/mil/gal	0.12	g/cu m
mgd	3,785	cu m/day
mgd/acre	9,360	cu m/day/ha
ppb	10^{-3}	mg/l
psf	4.88	kg/sq m
psi	0.0703	kg/sq cm
sq ft	0.0929	sq m
sq ft/cu ft	3.29	sq m/cu m
sq in.	6.452	sq cm
sq miles	2.590	sq km
tons (short)	907	kg
tons (short)	0.907	metric tons

Acknowledgements

The authors wish to express their gratitude to the 3 industries that permitted studies to be conducted on their property. Coring and well installations at Site A, B, and C were done by Layne Western Co., Kirkwood, Missouri. Thanks to Marion Scouby, who furnished the drilling crew, equipment, and technical advice.

Personnel of the Illinois State Geological Survey provided geological interpretation. Robert Gilkeson conducted the resistivity and temperature surveys and wrote those portions of the report. Dr. W. Arthur White supervised textural analysis of samples and Dr. Herbert D. Glass performed X-ray analysis of samples. Keith Stoffel and Donald McKay collected samples during drilling. H. Edward Scoggin operated the drilling rig at Site D.

Organic analyses of water and soil samples were screened by Dr. Willis Bruce, Illinois Natural History Survey, Personnel of the Environmental Analytical Research Laboratory at the University of Illinois conducted all metals analysis. Mr. Paul Schroeter maintained the integrity of sample adquisition, preparation, and storage. Drs. Philip Hopke and Mary Ulrich conducted X-ray Fluorscence and Neutron Activation Analysis. John Healy, Paul Amberg, Brad Hess, Clifford Colgan, and Dr. Donald Bath performed the Atomic Absorption measurements. Alan Matton, Mary Perez, Susan Gould, and Jean Mitchell did the electrochemical measurements, soil pH, and CEC determinations.

The project was conducted under the general supervision of John B. Stall, Head of Hydrology, Illinois State Water Survey. Mr. Richard J. Schicht reviewed the manuscript and gave guidance throughout the latter stages of the project. Mr. Steve Wirth and William

Bogner tabulated the tables of data; John Brother and William Motherway prepared the illustrations; T. A. Prickett conducted and analyzed the pumping test at Site D; Mary Schoville and Waneta McDaniel typed the manuscript.

Special thanks are given to William H. Walker who conceived and initiated the project. The patience and understanding of Mike Roulier, the project officer of the U.S.E.P.A., assisted in making the transition of leadership and completion of the project possible.

Section I

Introduction

In Illinois, 62 land disposal sites are under permit by the State Environmental Protection Agency to receive hazardous chemical wastes. In addition, more than 2000 active or abandoned landfill sites and private industrial disposal sites have received large but unknown quantities of all types of wastes, including some toxic chemicals. Some of these are adjacent to or directly underlain by shallow aquifer systems vulnerable to pollution from surface sources.

The amount and areal extent of hazardous material migration from these disposal sites is not known. Many are monitored for possible pollution of contiguous aquifers, but only a few appear to be effectively instrumented. Traditionally, monitoring wells are installed and water samples collected and analyzed periodically. However, these wells generally cannot monitor very large vertical segments of an aquifer, and the water samples are not always analyzed for the many different organic or inorganic chemical compounds that may originate from the disposal sites. In addition, little or no effort has been made to insure that the samples collected are representative of water contained in the aquifer.

Existing air and surface-water pollution regulations have forced large volumes of hazardous chemical waste to the land for ultimate disposal. As a result, many aquifers may be in danger of serious water quality degradation if these disposal activities are not properly controlled and monitored.

The purpose of this study has been to verify in the field the effectiveness of glaciated region soils and associated surface deposits in retaining specific hazardous chemicals. The study also was designed to test investigative and monitoring techniques for detecting and evaluating quantitatively the extent of groundwater pollution from surface toxic waste disposal sites.

Section II

Conclusions

1. The vertical and horizontal migration patterns of zinc, cadmium, copper, and lead through the soil and shallow aquifer systems at Sites A & B were defined. Vertical migration patterns of the same elements were successfully defined at Site D.

2. The pollution which occurred at the three zinc smelters has been contained to general plant areas by attenuation processes in the soil, despite the long period of time and heavy surface loading of the systems with zinc and other heavy metals. Sites A and B are located in regions considered generally acceptable from general geologic principles. Site D is in what generally is regarded as a sensitive environment for waste disposal, and may not attentuate more mobile constituents than studied here.

3. Two principal mechanisms control the distribution zinc and other metals at sites A, B, and D. These are, in order of dominance, cation exchange, and precipitation of insoluble metal compounds as a result of pH changes in the infiltrating solutions. The conclusions pertaining to the mechanism of zinc and other metals fixation which can be drawn from this field study are in accord with the results of recent laboratory studies by Frost and Griffin. They stated that increased removal of metals from solution occurs "with increasing pH values and with increasing concentrations of the heavy metal in solution." Release of calcium and magnesium from the soil into the water substantiates the cation exchange theory and indicates the relative mobility of these catanions through soil systems.

4. The limited data generated at site C is not adequate to define

the limits of migration of pollutants from the plant site. While no evidence of organic pollutant movement is presented, the available information is not sufficient to show to what extent soils have retained organic pollutants. Since access to the plant property was not granted it was not possible to develop the vertical and horizontal profiles as developed at the other sites. Evidence of inorganic pollutants was detected west or downgradient from the plant site.

5. Soil coring has been demonstrated to be an effective investigative or research tool in this project. However, proper geologic interpretation and a thorough understanding of soil chemistry is essential to use the technique effectively. Cost analyses and experience gained during this project suggest that coring has limited application to routine groundwater monitoring cases.

6. The use of piezometers or wells for routine monitoring probably is most cost effective and easily managed. A limited amount of core sampling would provide data for better vertical and horizontal placement of almost all monitoring wells.

7. Proper sampling techniques for collecting representative water samples from monitoring wells have not been determined. Results of a brief experiment in this study suggest that variations as great as 40 to 80 percent in the chemical constituents of water samples could result from improper sampling techniques.

8. Field investigation using geophysical methods at Sites A, B, and D show that electrical earth resistivity and soil temperature measurements can be used to gather information rapidly and economically on the lithology of the geologic materials, define the shallow ground-water flow system, and identify possible zones of contaminated ground water within the flow system. The geophysical investigations

should be conducted at the beginning of groundwater contamination studies. Information gathered from geophysical investigation could be used to determine the proper locations for soil borings or to install monitor wells.

9. Geologic environments consisting predominantly of clay, silt, and tills have been demonstrated to be very effective in retaining the movement of the metals Zn, Cd, Cu, and Pb from very concentrated inorganic sources. In selecting disposal sites, preference should be given to such geologic settings for disposal of these and similar wastes.

10. Chemical analysis usually are regarded as a purchasable service. As a result the laboratory responds in a reflexive manner which may be more expensive and slower than response to anticipated needs. In this project, the felt need at an early date for multi-element analysis influenced the choice of analytical methods not best suited to the final analytical objectives.

11. The lack of proper cooperation between leaders of various disciplines at the planning stage of multidisciplinary studies can create both technical and social problems as a project progresses. Effective communications between discipline leaders also requires time and understanding on the part of all involved. Successful multidisciplinary teams should be sought out for repeated research in their areas of speciality as they are more likely to succeed in additional work.

Section III

Recommendations

1. Coring and soil analysis should be used in research type projects or when the toxicity of a waste product warrants the additional expenditure.

2. A limited number of core holes and soil sampling would be advisable to evaluate a proposed disposal site. A better understanding of the soils interaction with the waste product is gained. Geologic interpretation of the core samples also provides better information for design and location of monitoring wells.

3. Routine monitoring of most disposal sites should be accomplished using wells located and designed based on preliminary coring analysis. Periodic coring and soil analysis may be worthwhile to substantiate original soil effectiveness assumptions.

4. Immediate attention should be given to research aimed at developing satisfactory water sampling techniques from monitoring wells. Such research should examine monitoring wells in different geologic and hydrologic settings for as many chemical constituents as possible. The time of pumping and mechanism of pumping both should be evaluated.

5. Additional research for other types of waste disposal activities using the coring and well installation techniques seems advisable. The use of these techniques in looking at potential organic pollutants would be particularly interesting and challenging.

6. Controlled experiments designed to evaluate various well seal materials in different chemical environments is advisable. If the surficial and shallow soils are to be used as a "living filter" they should not be penalized by bad data from leaky monitoring wells.

7. In studies of this type, chemical analyses should not be regarded as a purchasable service. A brief planning effort of collecting samples, screening applicable laboratory techniques, and deciding what target elements should be analyzed for is recommended. Such planning should provide for a more orderly and economical research program. This should be done even at the "expense" of one field sampling season.

8. Multi-disciplinary projects such as this one should be organized within a framework of co-principal investigators. The project began with a single leader organization which used the practice of individual consultations with key members of the group to further the work efforts. This appears to place an undue critical dependence upon the administrative and scientific talents of the principal investigator. The subsequent shift to a committee-type organization proved much more effective.

9. Three general recommendations are made concerning interdisciplinary research: The dominant roles of the appropriate disciplines and lesser roles of others should be understood clearly by members of all disciplines before an agreement to enter into a group effort is made. Each discipline should take an active part in the planning and budgeting of a project to minimize future conflicts and misunderstandings. If successful teams or groups have been formed, the likelihood of future success is much greater than with new formed groups. They should therefore be given greater consideration by funding agencies if economic use of research funds are desired.

Section IV

Purpose of Study

The primary purpose of this study was to field verify the effectiveness of glaciated region soils and associated surface deposits in retaining specific hazardous chemicals. The study also was designed to develop effective investigative and monitoring techniques for detecting and quantitatively evaluating the extent of groundwater pollution from surface toxic waste disposal activities.

Special emphasis was placed on defining: 1) the vertical and horizontal migration patterns of chemical pollutants through the soil and shallow aquifer systems; and 2) the residual chemical buildup in soils in the vicinity of pollution sources. In accomplishing these goals, an understanding was developed for the practical aspects of core drilling, soil sampling, piezometer installation and water sample collection.

In addition to the principal purposes of this study, a brief evaluation of the merits and problems associated with multidisciplinary studies was made.

Section V

Principal Field Techniques

The collection of continuous vertical core sample for geologic study and chemical analyses and construction of piezometers or monitoring wells for water level measurements and water sampling were the principal field techniques used in this study.

Coring

Continuous vertical core sampling was conducted using conventional Shelby tube and split spoon sampling methods through hollow stem augers. These dry drilling techniques were used to minimize the chemical alteration of samples from drilling fluids or external water sources.

Coring was done with a truck mounted Central Mining Equipment (CME) 55 and a CME 750 rig mounted on an all-terrain vehicle (see figure 1). The drilling crew consisted of an equipment operator and helper, assisted if necessary by the principal investigators. For the first few holes drilled at each site, a geologist from the Illinois State Geological Survey assisted in collecting samples and made preliminary soil identifications for use in subsequent drilling.

The first core sample taken at any given location was obtained by pushing a 3-inch O.D., No. 6 gauge, Shelby tube to a depth of 2 1/2 feet. After this tube and sample were withdrawn a 2 3/4-inch O.D., 1/8-inch thick wall, tube was pushed inside the hole to obtain a sample from the 2 1/2-to 5-foot depth. The 5-foot sampled segment of the hole was then cleaned out and enlarged using a 7-inch

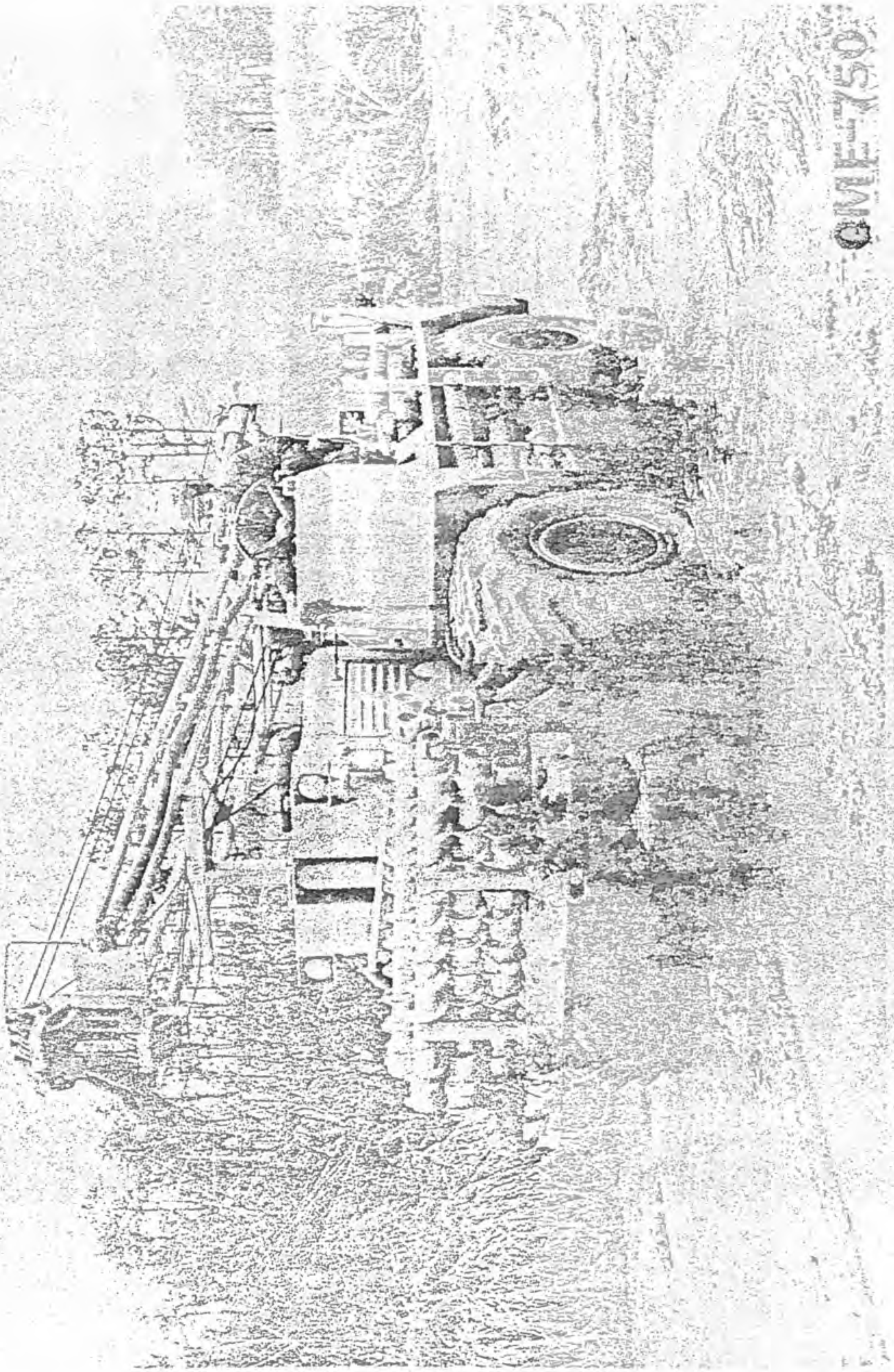


Figure 1. CME drilling rig mounted on all-terrain vehicle

diameter hollow-stem auger. Repeated sequential sampling through the hollow-stem augers continued in the same manner until dense materials were encountered making thin wall tube sampling impossible. At two sites studied in this report (Sites A & B) this usually occurred at a depth of about 15 feet and a thin section of sandy material generally was present just above this depth. Because water from this zone was suspected to be polluted, a 7-inch diameter casing was driven into the underlying dense till material, to prevent downward migration of water from this unit and possible chemical alteration of deeper soil samples. Core sampling of the till materials below the 7-inch casing was done using a 2-inch O.D. split spoon sampler driven through a 6-inch diameter hollow-stem auger. Where soft materials permitted, Shelby tube sampling was reemployed. The split spoon sampler consists of a cutting shoe and sample retaining mechanism at the bottom, a length of longitudinally-split core barrel pipe, and a special top drill rod coupling (see figure 2). The split spoon-drill rod assembly is driven ahead of the hollow stem augers in 2-foot increments using either a 140-or 350-pound hammer depending on the hardness of the material being sampled. In some of the softer materials penetrated, it was possible to drive 2 split spoons coupled together (total sample length 4 feet) before enlarging and deepening the hole with the augers and repeating the sampling procedures.

In some of the first core holes completed, some difficulty was experienced in getting full recovery from each sample probe. By experimenting, it was determined that full recovery was greatly dependent on using clean Shelby tubes; reuse of tubes without

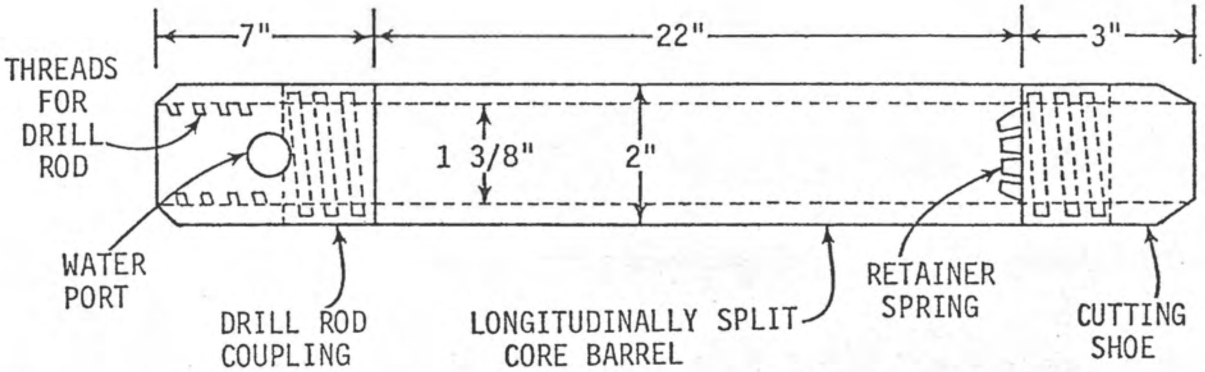


Figure 2. Split Spoon Sampler

thorough cleaning invariably resulted in poor recovery and could result in sample contamination. It was also noted that in some very soft sections, it was occasionally necesary to crimp the cutting edges of the Shelby tubes to get full recovery. A straight and constant vertical pull in withdrawing all samples from the hole also was essential; any jarring of the sampling device during extraction usually resulted in losing the sample.

The thin wall tubes (No. 6 guage) used were easily damaged during sampling, often by small pebbles. When this happened, the damaged end portion of the tube was removed with a pipe cutter, making a thicker-walled cutting edge, and allowing reuse of the tubes. Due to this problem, it is recommended that only thick-walled tubes be specified and used in any future studies of this type.

Because of the type of pollutant (chlorinated hydrocarbon) being investigated at Site C, extreme precautions where necessary during the coring process. Before the drilling rig and equipment were taken to the job site, all oil leaks on the rig were fixed and all equipment were steam cleaned. The Shelby tubes also were steamed and burned clean; washed down with reagent grade acetone and Nanograde hexane to insure that any remaining oil film was removed. The tubes were then sealed in aluminum foil and transported to the job site.

During the drilling process all Shelby tubes were handled by only one individual wearing polyethylene gloves. All pieces of equipment including the sample extruder were repeatedly rinsed with acetone and hexane before each use. When geologic conditions prevented the use of Shelby tubes, a split spoon sampler was used. It also was cleaned thoroughly with acetone and hexane before each use and handled by only one individual wearing polyethylene gloves.

Core drilling at Sites A, B, and C were predominately in clay environments and relatively little drilling and sampling difficulty was experienced. Site D is a river bottom sandy environment and some difficulties were experienced with sand heaving up in the augers. Special care in slowly withdrawing the center drill pin and sampling devices helped to minimize this problem but did not stop it. In extreme cases, the split spoon was slowly washed down through the sand that had heaved up in the auger until the split spoon was at the proper depth to begin sampling. During this process, clear, clean water was circulated down through the drilling rods and split spoon and allowed to flow up the inside of augers. Circulation continued for a short period of time after the proper depth was reached to insure that no sand from inside the augers was in the spoon. The rate of circulating water should be adequate to keep the split spoon clean of sand yet minimize the washing disturbance in front of the spoon. The majority of sand in the augers also must be washed out or the spoon could become locked in the augers after being driven.

In sandy environment drilling where sampling is for geologic definition only or where chemical analysis for the pollutants being investigated would not be affected by bentonite, drilling with mud and sampling through a thin mud cake at the bottom of the bore hole should be considered.

Core Sampling

Shelby tube and split spoon samples were extruded in the field, cut into 6-inch lengths, placed in properly labeled wide mouth glass jars, and subsequently delivered to the Illinois State Geological Survey and Environmental Analytical Research Laboratory for processing and analysis. One 6-inch length of core from each 5-foot segment or change in formation was taken by the drilling contractor for moisture content determination before being sent for geologic and chemical analysis.

At site C soil samples were sealed in glass jars and capped with aluminum foil under the lids. Special care was taken to cleanse repeatedly the cutting knife used to separate each core section into 6-inch lengths. Shelby tube samples were extruded directly into the sample jars following careful cleansing of all extruder parts contacting the sample. As soon as possible after collection, all core samples were stored in a rented freezer room where they remained frozen until they were analyzed.

Core Analysis

Core samples for heavy metals determinations were analyzed at the Environmental Analytical Research Laboratory with zinc as a target element. Previous experience in determining heavy metal contaminants in soil showed that digestion of a dried soil sample in 3 N HCl at slightly elevated temperatures effectively releases the heavy metals without destructing the silicate lattice of the soil. The heavy metals so released were determined primarilarly by atomic absorption spectroscopy.

For a number of soil samples, the multi-element capability of optical emission spectroscopy was used to determine Cd, Cu, Pb, and

Zn concentrations. Instrumentation and methods also were developed for use of nondispersive X-ray emission spectroscopy to permit semi-automated multi-element analysis for a larger number of elements with greater efficiency.

Tests using atomic absorption measurement of small spot samples indicated that the 6-inch long samples were too heterogeneous to permit reproducible analysis. Reproducible results were attained by homogenizing the samples and subdividing them to sample weight levels of 1 gram for atomic absorption and 50 milligrams for emission spectroscopy. Pelletized samples of approximately 2 grams were prepared for X-ray emission spectroscopy.

Core samples for organic analysis were extracted at the Illinois Natural History Survey and analyzed using gas chromotography. Final identifications were accomplished with the aid of mass spectrometry analyses of duplicate water samples from site C conducted by the Illinois Environmental Protection Agency.

Well Construction

Analyses of water samples from observation wells has been the traditional method for monitoring groundwater pollution. To demonstrate the effectiveness of this approach and the relative cost of using wells as compared to coring, a number of small-diameter (2-inch) observation wells were constructed. At Sites A, B, and D, where heavy metal contaminants were expected, plastic casing, screen, and pumping equipment were used. At Site C, where hydrocarbon contaminants were expected, black iron pipe and copper tubing were used.

Observation wells at Sites A and B were constructed in the following manner. A 7-inch diameter hole was constructed, and a 2-inch diameter PVC pipe (bottom 2 feet slotted with a hacksaw) was placed in the open borehole. Gravel was placed from the bottom of the hole

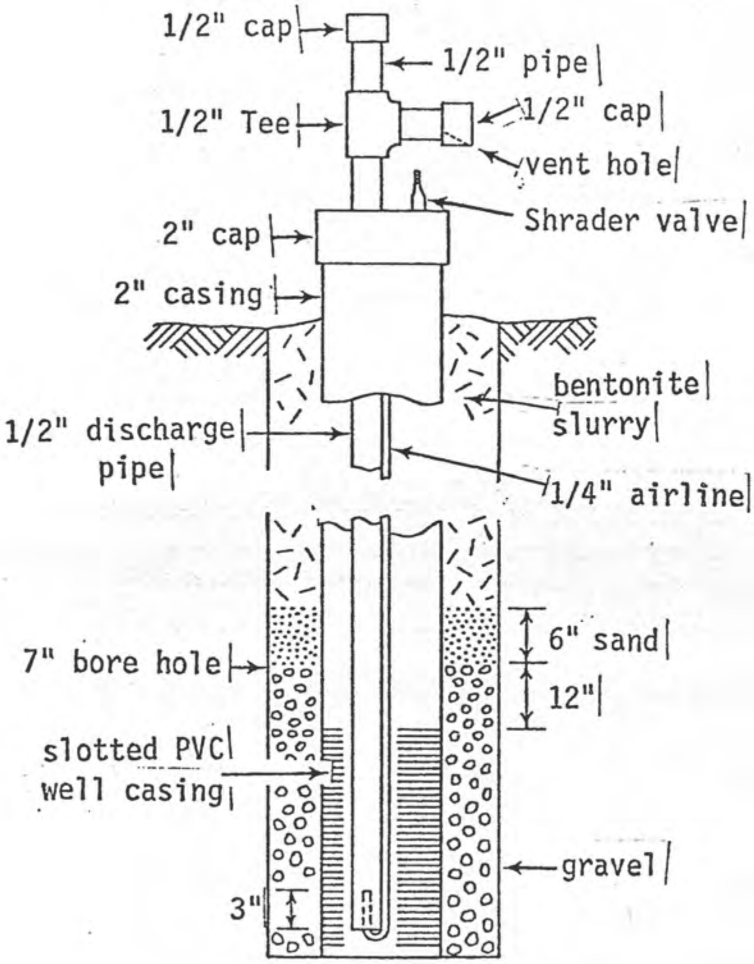


Figure 3. Typical well and pumping mechanism

to a level about 1 foot above the slotted portion of the pipe. The remainder of the annulus was filled with bentonite slurry to land surface (see Figure 3). Shallow observation wells of similar construction were installed in any overlying water-bearing sections present (usually at depths of about 15 to 30 feet below land surface) approximately 3 feet away from the deep well.

At site D, where heaving sand was encountered, and the bore hole would collapse when the augers were removed, more difficulty was encountered in installing observation wells. In many instances the 2-inch diameter pipe and casing was placed inside the hollow stem augers and held down while the augers were slowly pulled allowing sand to collapse in around the screen and casing. In other instances, a completed screen and casing assembly was washed down through the collapsed materials in the bore hole to the desired depth. For the deeper installations the first procedure usually proved more successful. The shallower wells were easily washed down.

Seventeen wells at site B also were constructed using a multi-well technique (placement of several wells of different depths in one bore hole) to evaluate the relative merits of the two methods. In the multi-well method, a deep well (casing, screen, and gravel) was installed at the bottom of the core hole, the annulus between the casing and bore hole was filled with a sand-bentonite mixture from the top of the screen in the bottom well and the bottom of the screen in an intermediate-depth well. The interval from the top of this middle well screen and gravel to the bottom of the shallow well screen and gravel also was backfilled with a sand-bentonite material, and finally that part of the hole from the top of the shallow well screen and gravel to land surface was filled with the sand-bentonite mixture or a straight bentonite slurry. This method of well installation proved to be far more time consuming and costly, and, in addition, subsequent well development efforts indicated that some of the multi-well installations were not effectively sealed between well screens. As a result, noticeable drawdowns occurred in the upper wells each time one of the deeper wells was pumped. If accurate placement of a liquid bentonite slurry or other suitable sealant between wells could be accomplished under normal field working conditions, it is likely that the multi-well concept would be as dependable as the individual well cluster system. However, from our findings during the construction of wells by this method, we are convinced that the multi-well method is not reliable. The individual well-cluster system employing a liquid slurry bentonite mixture appeared to be the most practical method for our project.

In late February 1975, engineers from the American Colloid Company, Volclay Division, informed us of a possible problem associated with using standard sodium bentonite to seal out highly mineralized waters as that encountered at our study sites. They indicated that the normal swelling-sealing capability of sodium bentonite could be so seriously affected by the waters encountered at our sites that well seal failures were almost inevitable. It was their opinion that some of our observation wells may have already failed because of this factor. Water samples from shallow and deep wells at Sites A and B were collected and submitted to American Colloid with a request for them to design a sealant mixture which would insure no leakage between aquifers. A copy of their findings is presented in Appendix A.

In general, they have concluded that an effective seal cannot be achieved with bentonite in an environment that is already affected by pollutants such as at Sites A and B. They suggest that monitoring wells be installed prior to disposal of waste (not always a very practical solution).

To determine more accurately the effectiveness of bentonite as a well sealant, an attempt was made to use strontium chloride as a tracer or indicator of well seal failure. Strontium chloride was added to the water used to make the bentonite slurries placed around several wells. In theory, when the bentonite seal began to break down in a particular well, strontium concentrations several orders of magnitude above naturals levels should have been released and detected in the water samples from that well.

During the entire course of the study this phenomenon was never experienced. In fact, higher strontium concentrations were often detected in water samples from wells where the bentonite seal had not been spiked. It is possible that the sampling procedures used to collect water samples (discussed in the next segment) flushed any released strontium from the bentonite seal from the well before the sample was taken. In any case, we were unable to determine if the bentonite seals had failed by this technique.

Pumping Mechanism. Observation wells were equipped with individual pumping devices to minimize possible contamination of samples from other wells. At sites A, B, and D, the pumping devices consist of a 1/2-inch diameter PVC discharge pipe that extends from about the 2-inch well casing to the bottom of the well. A tee fitted with short nipples and removable caps was placed at the top of this pipe (figure 3). The cap on the vertical segment can be removed to allow for water level measurements within the 1/2-inch pipe. The cap on the horizontal segment (water discharge outlet) was vented to permit stabilization of the water level within this pipe.

A 1/4-inch plastic airline also was installed in each well. The airline was attached to a Shrader valve at the top of the well casing and extends the entire depth of the well. The lower end of the airline was bent up into the bottom of the 1/2-inch discharge pipe for a distance of about 3 inches.

At site C, 3/8-inch diameter black iron pipe was used as the discharge pipe and 1/8-inch diameter copper tubing was used as the airline.

Water was pumped from the wells by removing the cap from the horizontal portion of the 1/2-inch or 3/8-inch pipe and applying air to the system through the Shrader valve. Pumping from depths as great as 70 feet was possible with only a bicycle-type hand pump. A gasoline powered, 4-cylinder, air-compressor capable of delivering about 5 cubic feet per minute at pressures up to 60 psi also was used. An activated charcoal filter was placed in the discharge air line from the compressor to insure that air from the compressor was not introducing airborne contaminants.

Since most of the wells in this study generally had a column of water less than 30 or 40 feet deep to be moved by the air lift mechanisms, it was found that operating the compressor at 20 to 25 psi was most effective. Higher operating pressures caused the air bubbles to rise through the water column instead of pushing slugs of water in front of them as desired. In the very shallow wells, less than 20 feet deep, the bicycle type hand pump actually worked more effectively.

Water Sampling. Water level measurements were made and water samples collected from each well once a month. At Sites A, B, and D water samples were collected in 6-oz. plastic containers and placed on ice until they were brought into the laboratory where they were refrigerated. At Site C samples were collected in glass bottles that had been thoroughly cleansed with acetone and hexane to insure that they were free of any chlorinated hydrocarbons. The bottles also were fitted with teflon-lined caps.

At Sites A, B, and D each well was pumped for a period of time theoretically adequate to insure that all stored water in the well casing had been removed. The wells were allowed to recover, and a sample was then collected from the water that had just entered the well. This procedure was followed in hopes that the water sample collected would be representative of the water flowing through the aquifer at the time of collection. After the water sample was collected, each well was pumped dry if possible.

Near the end of the project a brief experiment was conducted on four wells at Site A to determine if the pumping scheme just described was necessary or adequate for collecting representative water samples. Four wells were selected based on early results of chemical analyses of water samples collected. Zinc concentrations in water from these wells ranged from 6.2 to 25.9 mg/l, 300 to 790 mg/l, 342 to 850 mg/l, and 12,700 to 21,580 mg/l, respectively. These values represent fluctuations in zinc content of 76, 62, 60, and 42 percent using the higher values as base concentrations.

To determine if these fluctuations were real or a function of the sampling procedure, the following experiment was conducted.

Water level measurements were taken in each well and the volumes of water stored in the 2-inch diameter casings and screens were calculated. Pumping was initiated and samples were collected just after pumping began and at 1/2 total stored water volume increments until a total of 5 volumes had been pumped.

Figure 4 illustrates the results of these tests for the 4 wells. Percentage decreases in zinc concentrations from the 1st sample to the last ranged from about 45 to 78% with the greatest decreases occurring in the wells with the lowest zinc concentrations. Reductions in zinc content at the 1 volume pumped state (the procedure followed in our sampling program) ranged from about 18 to 46 percent. This suggests that all of the zinc determinations of water samples collected could be as much as 30 percent higher than the stabilized zinc content beyond the 5 volume pumped stage. If the sampling procedure employed varied by even as little as 50 percent, pumping only 1/2 or 1 1/2 the stored volume, it could account for as much as 15 to 20 percent of the fluctuations in the sample results.

Additional experiments of this type should be undertaken to design satisfactory sampling procedures for other chemicals. These experiments also should be done at the beginning of a project as opposed to near the end as in this case. The results of these brief tests indicate the need for further research in developing suitable water sampling procedures.

At Site C, a different sampling procedure was used because of the nature of the suspected pollutant (hydrocarbons). The lighter hydrocarbon fractions will float on the water surface, while the heavier fractions will lie near the bottom of aquifer or well.

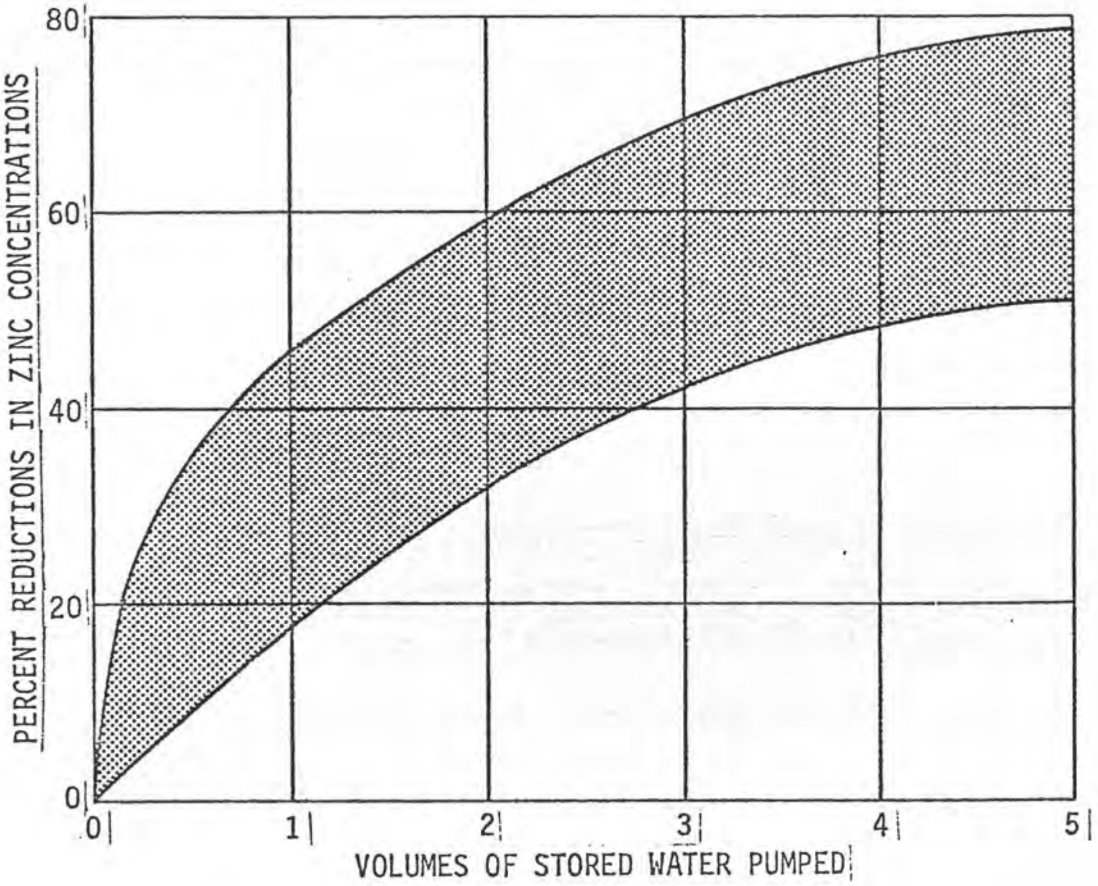


Figure 4. Effects of pumping on zinc content of water samples

To insure that all possible fractions were detected, water from these wells was collected continuously from the time pumping first began. All water was collected until each well was pumped dry or until one gallon of sample was obtained. Most wells constructed at site C pumped dry after collecting less than about 2/3 gallons.

Water Analyses

Water samples for heavy metals analyses were analyzed at the Environmental Analytical Research Laboratory with zinc as the target element. Two electrochemical methods, Anodic Stripping Voltammetry and Pulse Polography, proved to be most effective for making zinc determinations and screening for the presence of other metals of interest. Total mineral analyses were conducted at the laboratories of the Illinois State Water Survey using standard procedures.

Water samples for organic analyses were screened for the presence at the Illinois State Natural History Survey with final identification and quantification being accomplished at the Environmental Analytical Research Laboratory. Gas chromotography techniques were used at both laboratories. Mass spectrometry work conducted by the Illinois Environmental Protection Agency laboratories on duplicate samples assisted in the final indentification of compounds.

Section VI

Supplemental Field Techniques

Early in the investigation of ground-water contamination problems it is essential to have information on geologic conditions in the region. Definition of the ground-water flow system also is important. Because large areas and depths may be involved, gathering this necessary information by a systematic drilling program may be economically unfeasible

Geologists and engineers are making increased use of geophysical methods to rapidly determine the shallow geologic conditions. Two of these geophysical methods, the measurement of electrical earth resistivity and soil temperature, are useful for economic, rapid investigation of geologic conditions related to ground-water contamination problems. These geophysical methods can provide information on the regional variation of the lithologic character of the shallow geologic materials. They also can provide information on the shallow ground-water flow system and possibly define zones of degraded water quality within the flow system.

Electrical Earth Resistivity

A comprehensive review of the theory and interpretation of electrical earth resistivity is presented by Van Nostrand and Cook (3). The use of electrical earth resistivity methods in ground-water contamination studies is presented in many papers. Cartwright and Sherman (4) discuss resistivity methods as a tool useful in locating suitable sanitary landfill sites and in monitoring the effect of a refuse disposal site on the shallow ground-water system. Berk and Yare (5) describe a case history where electrical earth resistivity methods were successfully used to define zones of degraded water quality and locate sites for monitor wells in a ground-water contamination problem caused by disposal of industrial process water into an unlined lagoon in permeable sediments.

A commonly used approach for making electrical earth resistivity measurements in the Wenner Configuration, where four electrodes are spaced equally along a straight line. By systematically enlarging the distance (a-spacing) between electrodes the electrical field is expanded to include a greater volume of earth materials. The value of the apparent resistivity obtained at each a-spacing approximates the average of the true resistivity of all the materials within the impressed field. Empirical study has shown that the a-spacing is approximately equal to the depth of the measurement. The apparent resistivity depth profile generated at a location by taking measurements at several a-spacings can be reduced analytically to determine the number of layers of geologic material present and the thickness and true resistivity of each layer.

The fundamental factors that govern the resistance to the flow of electrical current through earth materials are: 1) water saturation, 2) mineral content of the water, and 3) geologic factors.

The presence of water is important to the conductance of an electric current through earth materials. In general, saturated materials have a higher conductivity (lower apparent resistivity) than similar unsaturated materials.

The mineral content of the water present in earth materials is a major controlling factor of the conductance of electrical current through the material. As the ionic content of the water increases, the apparent resistivity of the earth material decreases.

There are two geologic factors which affect apparent resistivity values. One of these is called the "formation factor" which is dependent upon the porosity of the earth material as well as the shape of the pores and the manner in which they are disposed and interconnected. A second geologic factor which affects apparent resistivity is the presence of conductive solids such as clay minerals. An increase in the amount of clay minerals present in an earth material will lower the apparent resistivity of that material. Generally, fine-grained clayey sediments have lower apparent resistivities then clean, coarse sands and gravels.

An Electrical Earth Resistivity Survey was made at Site A to determine the applicability of this technique. The results of that work are described in the case history section for Site A.

Temperature Surveys

The distribution of temperature within the lithosphere can be significantly affected by the movement of ground water. Theorectical aspects of the simultaneous flow of heat and water were presented by Stallman (6) Cartwright (7) used soil temperatures to locate shallow aquifers and Cartwright (8) discussed the use of soil temperature to trace shallow ground-water flow systems. There is limited published information on the application of soil temperatures as a tool for investigation of ground-water contamination problems. Cartwright and McComas (9) used soil temperature measurements in the vicinity of two sanitary landfills to map shallow ground-water flow systems and discharges of leachate.

In field investigations, soil temperature measurements are commonly made with a thermister at the tip of an insulated probe. The probe can be inserted into the soil to any desired depth. Measurements are usually made at depths greater than 50 cm. (19.7 inches) to eliminate diurnal temperature variations. Temperatures are read after the probe comes into equilibrium with the soil, roughly after about five minutes.

Factors which affect the temperature of the soils in the flow system include the velocity of ground-water movement, the vertical or lateral direction of ground-water movement, lithology of the geologic materials which affect their thermal properties, heating effects due to land cover, and geothermal heat added to the system.

Activity of man can serve as sources of heat which affect local soil temperatures. Cartwright and Reed (10) measured anomalous high soil temperatures in the vicinity of a village. Heat generated at industrial sites may have a significant affect on soil temperatures locally with the distribution of this heat related to the shallow ground-water flow system in the vicinity of the site.

Soil Temperature Surveys were made at Sites A, B, and D to test the applicability of this method.

INFRARED PHOTOGRAPHY

Infrared areal photography of Sites A, B, and C was taken in the early part of October, 1974 by NERC - Las Vegas, U. S. Environmental Protection Agency. Another round of flights were made in June, 1975. Examination of these photos provided very little information concerning the groundwater conditions or effects of groundwater pollution at these sites.

The photos however were helpful in detecting past effects of wind blown pollutants and surface water movement of pollutants. Illustrative examples of these phenomena are presented in Appendix B by Dr. William Edwards, Illinois State Natural History Survey, who conducted a comprehensive study of the plant life at Site A and how it was effected by the zinc smelting operations. Brief results of his work are included in the case history section for Site A.

SECTION VII

Laboratory Techniques

During the planning stages of this project it was decided that a series of continuous soil core samples and associated water samples would be analyzed to follow the suspected penetration of surface originating metal ions, particularly zinc, through the soil and subsoils. The initial plan called for single element analysis of some 2000 core samples for zinc, assays for a set of 11 selected elements for an additional 100 core samples, single element, assays for 500 water samples, and multi-element assays for 100 water samples for a total of 4700 element-assays. The mix of single element-multi-element assays was left open to future judgement.

An initial budget was developed by the Environmental Research Laboratory at the request of the Illinois State Water Survey. Based on the then existing cost factors and a mix of on-stream, in-house capabilities: emission spectroscopy (for multi-elemental assays), atomic absorption spectroscopy (for intermediate level single element assays of soils) and anodic stripping voltammetry (for low level assays of a limited number of elements in waters) a total cost estimate was obtained. This budget, prepared in late Fall of 1974, was an ex post facto exercise since that the dollar amount had already been submitted and awarded in June, 1974. As a result the initial plan contained two major defects: an overdependence on labor-intensive production and an untested ability to measure a sufficient number of the desired multi-elements by the existing emission spectrograph. In sum this was a plan that had an estimated 70 percent chance of reaching its goals.

The arrival on campus of Dr. Philip Hopke to spend a sabbatical year in the School of Chemical Sciences offered the opportunity to accomplish the project objectives in an alternate way. Dr. Hopkes' areas of specialization: multi-elemental analysis by Energy Dispersive X-Ray Spectroscopy (XRF) and Instrumental Neutron Activation Analysis, if applied to the task of multi-element assays of soils and water samples could supplant the emission spectrograph which was of doubtful capability. A second cost analysis showed that it would be possible to accomplish the same objectives within the dollar restraint if the initial budget was rearranged to provide for a single part-time post-doctoral assistant and a transfer of funds to purchase equipment. Approval for this budgetary rearrangement was obtained in November; 1974.

Description of Analysis Methods

At the time this project was initiated, the Environmental Research Laboratory was engaged in a continuing program of analytical support service to a large project for the Institute for Environmental Studies. This project had a large number of externally originating samples and required an in-house pattern of work that was highly chronologically oriented. A backlog existed continually and samples were analysed in order of time of receipt. This project was quite different in the sequence of activities as the field work was accomplished early in the life of the project. As a result the majority of initial core samples were in the laboratory by the end of the first six months of the project. This permitted selection of the samples to be analysed to be somewhat independent of the time of collection resulting in a more efficient examination of the samples. At the present time the laboratory has in storage more than 6,000 core samples obtained in the course of this project. Initial discussions and budget calculations were based on a maximum of some 2,000 core samples to be assayed for some 4,700 element-assays. Had strict chronology been applied, only the first 1/3 of the core samples taken would have been assayed.

As the project leadership changed in the intermediate stages of this investigation, conscious attempts were made to modify the set-piece pattern of field investigation sampling by providing the principal investigator with chemical analysis data from core samples for guidance in siting additional well and core sites. The laboratory was not able to provide these data in the manner hoped for because both this project and the other large program were field oriented and had work patterns dictated by weather. The impact on the laboratory was a cyclic influx of samples from both projects at the same time resulting in analytical turnaround times of nearly 30 days. Because core sampling and well drilling had to be negotiated in advance and for no more than 2-3 weeks at a time, the real-time use of laboratory data was not possible. Since neither the climate nor the weather can be controlled it appears advisable that future investigations of this sort be planned in a "non-linear" mode (vide infra) to minimize analysis impacts on field sampling plans.

Recognition of the above problems prompted an early investigation of possible "field kits" suitable for semi-quantitative estimation of the principal target element, zinc. These efforts proved unsuccessful for several fundamental chemical reasons having to do with zincs' position in the periodic table of elements. It is at the end of the so-called First Transition Series consisting of Chromium, Manganese, Iron, Cobalt, Nickel, Copper, and Zinc. For the majority of chemical reactions which are feasible for this series the reaction tendencies diminish in the order given above. Since all elements in the list are ubiquitous in soils they constitute a collective interference to any reaction involving zinc. Methods for estimation zinc concentrations consist largely of a number of preliminary separations and/or chemical treatments to eliminate the deleterious effects of the other transition elements and final measurement is then made by means of a non-selective chemical reaction. In the present work, the constant and overwhelming presence of Iron proved to be insurmountable on a chemical basis. The commonly used reagents: Dithizone, Zincon, APDC all failed due this fact: they all react more favorably with Iron than with Zinc.

Sample heterogeneity and reaction sensitivities also complicated the search for a suitable field test for zinc. Early work to determine the minimum sample size for reliable results indicated clearly that an entire core segment would have to be homogenized before results based on a 1 gram sample became reproducible. The common chemical reagents for zinc listed above are quite sensitive requiring no more than 1-10 micrograms of zinc for a visible test. This figure translates into a maximum soil core sample of less than 10 milligrams for a valid test on shallow soil samples which contained in excess of 50,000 mg/l Zn. Since the early tests showed these samples to be non-homogeneous at the 1 gram level they were certainly so at the milligram level.

An investigation into the use of a "zinc selective" electrochemical electrode also was made with negative results. Such electrodes enjoy current popularity due the ease of use. With the exception of the solid-state Fluoride electrode, most are complex physical and chemical arrangements within the electrode which collectively produce the desired selective response to the sought-for element. A typical electrode may consist of an inner metal whose electrochemical potential responds to changes in the activity of its own metal ion in solution when in contact with the metal. In turn this metal-metal ion electrode can be surrounded with a liquid ion-exchange chemical solution and separated from the test solution by a ion-size, shape, charge, etc. selective physical barrier such as an ion-exchange membrane or a porous mechanical filter. The result is an electrode of the type:

$$M^{0}/M^{+n}(\text{MEch})\underset{j_1}{//}\text{Test Solution}\underset{j_2}{//}\text{Reference electrode}$$

In use, the response depends on the ability of the separating barrier, j_1, to eliminate some potential interferents on physical grounds while a further degree of selectivity is attained in the chemical reactions of the ion-exchanger. Unfortunately the electrode investigated was new at the time and has since been withdrawn from the market. Initial tests using pure solutions of zinc did not yield appropriate responses and when immersed in test solutions of soil core samples gave exceedingly erratic results. Inquiries to the manufacturer revealed that the inventor was reported to have left the company abruptly leaving no information; the most knowledgeable person was found to be a technician in the company laboratory, and company executive personnel were notably vague about the operation of the electrode. For these reasons, the electrode was returned and the investigation terminated. To date this electrode is still marketed by several supply houses under house brands without the original manufacturer identification. We regard this electrode as suspect.

Attempts were made to compensate for the lack of a reliable field test by using normal laboratory measuring equipment in a "semi-field" situation: a motel room set-up as a spartan laboratory near the field site. The method and instrument chosen was the electrochemical method of Anodic Stripping Voltammetry (ASV). This method was selected because (1) it can be desensitized controllably to contend with high concentrations of zinc and (2) the chemical reaction interferences discussed above do not operate in electrochemical methods. Although the method did produce satisfactory results it was too slow to permit assays to be done on each and every core segment. The initial goal, was to make results available to the field drilling crews while a core was being drilled in time to guide the investigators as to (1) general levels of zinc being encountered, (2) depths of significant zinc concentrations and (3) suitable depths for locations of well screens. Subsequent laboratory work showed that these goals were unattainably high for any presently known assay method for zinc. The previously discussed core heterogeneity would require a more sophisticated field laboratory capable of rapid sample homogenizing. A minimum of 1 sample per Shelby tube would be desired and if the results were to be usable, the total analysis would have to take place within the time for one 30 inch Shelby tube core segment to be taken. It is estimated that a maximum total assay time of 10 minutes would be required during which all operations associated with sub-sampling, homogenization, any chemical pretreatments, measurements and data translation would have to be performed.

Initial results obtained from XRF examination of a representative well core showed the need to change the general approach from the multi-element-single sample to the more sensitive atomic absorption and electrochemical methods. First, the XRF examination for the seven elements: Zn, Cu, Ni, Cr, Mn, Pb, and Cd showed (a) little apparent variation with depth except for Zn and the possible quartet: Cu, Pb, Cd, and Ni and (b) general levels of these elements at or below the detection limits for the XRF method at reasonable exposure times. Of the remaining five elements nickel is not accessible electrochemically with confidence. For these reasons the analyses for the quartet: Zn, Cd, Cu and Pb were done by Atomic Absorption (AA) where applicable and by electrochemical methods where the levels were too low for AA analysis.

Subsequently a total of 4,741 assays was performed on some 1,600 core and water samples. Approximately 25% of these assays were for the multielement quartet; the remainder for Zn alone.

During the investigation all methods were probed for reproducibility and accuracy - the latter by internal crosschecks using two different methods. Owing to uncertainties created by the large and variable amounts of iron found in core samples together with low concentrations encountered the XRF method showed a reproducibility of approximately 25% although cross-checks for Zn assays against AA showed an agreement within 12%. The AA analyses were carried out using a previously developed computer program which provided individual sample-by-sample estimates of standard deviations and detection limits. An average figure for standard deviations is between 6 and 12%. Detection limits attained or exceeded published figures for all elements investigated. In no case was the detection limit the limiting factor in the analyses for soils with the exception of Cd assays which in some instances fell below the 0.005 mg/l detection limit generally attained for this element. Electrochemical methods used were shown to have the following reproducibilities: ASV (5%), Pulse Polarography (PP) (3%). A related test showed that the total water analysis procedure had a reproducibility of 5-10%; analysis of variance techniques applied to the data showed the principal error to be associated with the process of pressure filtration to remove particulates.

Energy Dispersive X-Ray Spectroscopy and Neutron Activation Analysis

Approximately 50 multi element assays were conducted on duplicate soil samples using this techniques.

A) X-Ray Spectroscopy

If an element is bombarded with sufficient energy it is possible to eject an electron from one of its orbitals completely:

$$M + hv_1 = M^* + e^- \qquad (1)$$

The unstable excited M* relaxes by filling the orbital from which the original electron was ejected by one from a higher lying (or lower energy) orbital:

$$M^* = M + hv_2 \qquad (2)$$

The emitted energy, hv_2, is quantized and is the difference in energies required to fill the two orbitals involved. The highest energies are obtained from transitions involving the innermost orbital ("K-shell) and the next higher ones, the L and M shells.

The characteristic energies emitted are so-called X-rays and are related to the elemental composition of samples through the relation: $hc/2 = K_n(Z-0)^2$. Quantitative estimates of composition are obtained if the exciting energy is maintained constant in which case the flux of emitted X-rays of a given energy is proportional to the number of atoms in the irradiated sample having the same atomic number, $I = KN_Z$. (3)

The particular instrument chosen for the present work uses the primary X-rays produced by the radiation from a radioactive source, Am^{241}, made incident on thin films of selectable target materials. The requirements are that the energies of the X-rays from the target materials be of lower energy than the primary radiation from Am^{241} (59.6 kev, x-ray). Because this isotope has a long (458 yr) half life the activity and hence the radiant energy will remain constant for the life of the instrument. In turn this means that the flux of secondary X-rays produced from the selected target will be at least as constant as the physical distance from the target to the Am source can be maintained. A second advantage to this form of X-ray production is the very low noise associated with the process. Since the incident energy is quantized there is very little non-quantized, e.g. Bremstrahlung or Compton inelastic scattering, interactions associated with the measurement. The resulting X-rays produced from the sample itself can be highly amplified to overcome the significantly lower flux of original energy as compared to conventional electron tube excitation sources. The latter effect is significant in the quantitative determination in which the resulting flux of emitted X-rays is ultimately dependent upon the flux of excitation energy.

A block diagram of the apparatus chosen for this investigation is shown in Figure 5. It is a combination instrument using a common data reduction system (tape deck) for both Energy Dispersive X-ray use as well as Neutron Activation analysis. The latter was not used in this work.

These and other initial X-ray experimental measurements, were paralleled with measurements of selected elements in the same samples by conventional

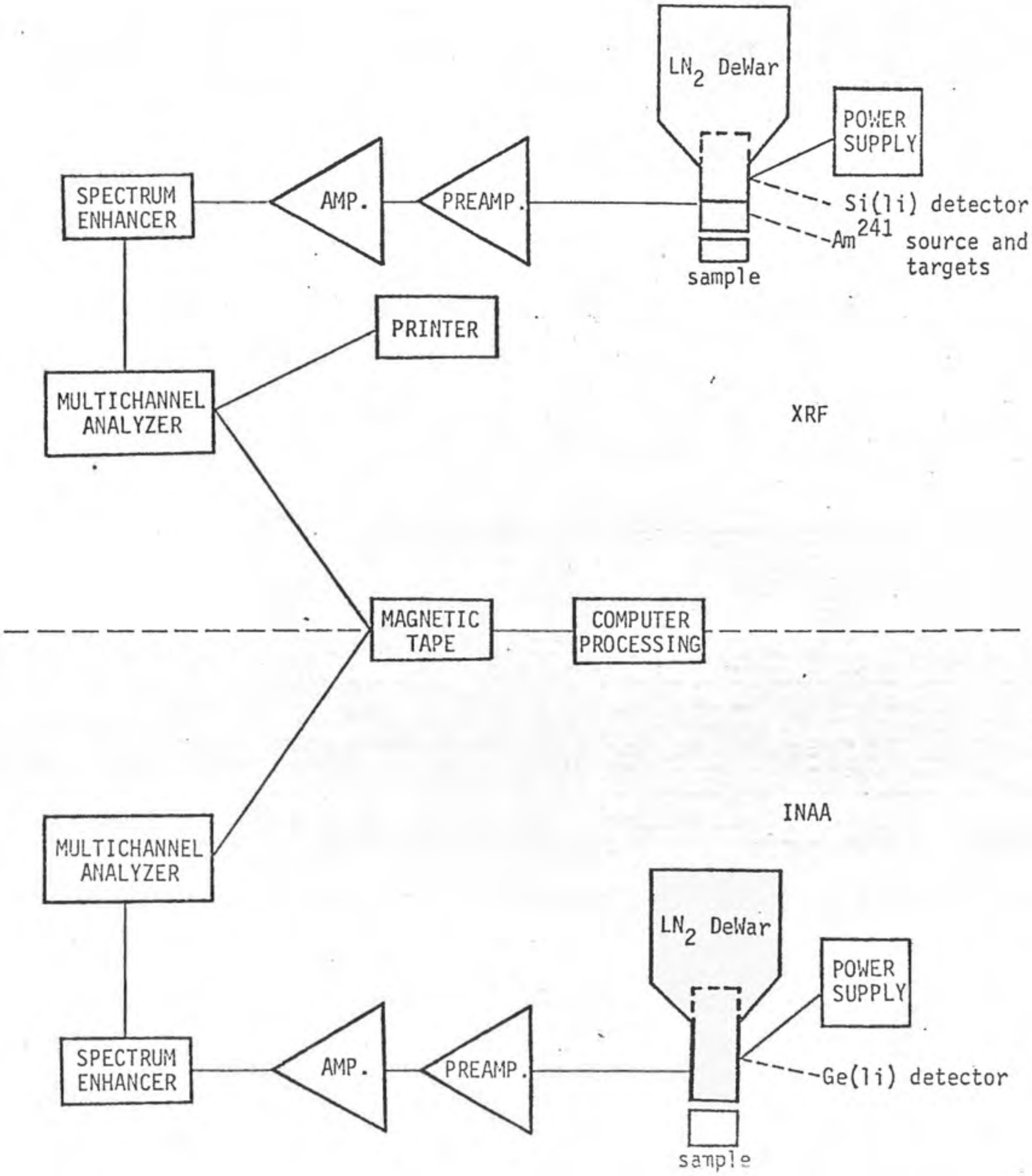


Figure. 5. Block diagram of combined X-Ray Fluorescence and Neutron Activation Analysis Instruments.

Atomic Absorption Spectroscopy. For example a set of secondary standard samples was generated for Zn, Cu, Co, Fe, Cd, Ni, and Pb by AA to serve as calibration points for the XRF measurements.

A second mission of this project for which the X-ray equipment was obtained was to conduct multi-element analyses of water samples in parallel with multi-element assays of core samples. It was known from the literature that the expected concentrations from the water samples would be 1 to 3 orders of magnitude lower than those in the corresponding solid core samples and far below the most optimistic detection limits for XRF. For this reason, experimental work of Dr. Mary Ulrich (11), was devoted to refining and extending published methods of sample preconcentrations. A brief summary of her findings is as follows. It is necessary to present potential X-ray samples as thin films or uniformly thin disks of reproducible density to minimize artifacts such as reflections from sample holder materials, back-scattering, etc. For example, the examination of fine dust particulates is often accomplished by confining the sample in a small plastic container whose top is a piece of thin Mylar. In use the closed container is inverted so that a layer of sample is supported on the thin Mylar. If the total weight of sample is but a few milligrams the dust deposit is a layer of less than a fraction of a millimeter thick. Any radiation which manages to penetrate this thin film finds no backing of either sample or container to reflect from since the next solid surface to be encountered, the bottom of the plastic container, is several contimeters removed. Similar sample preparations for water have tried to combine the requirements for preconcentrations in the physical properties desirable to fabricate a thin disk of sample. The equivalent, for solids not amenable to the Mylar film treatment, is to compress constant weight samples into small (1 inch) disks of constant thickness and density using a high pressure (10-25 tons per square inch) press. For solids which are sufficiently self-adherent, the sample itself is compressed. Where the materials will not self-adhere, a binder substance, such as a deformable plastic powder, a high melting point wax, or a resin, is added to confer some physical strength to the sample. This is regarded undesirable as the presence of the organic binder constitutes a measurable matrix component which affects the calibration - particularly for low Z elements. Similar treatments applied to water have been specially prepared ion exchange resins, resin loaded ion exchange filter papers, and total precipitation of ions using a general precipitant such as APDC (ammonium Pyrolidine DithioCarbamate). This precipitating agent appears to produce the most generally consistent and high recoveries for the widest variety of elements sought. However, the pH of the solution must be maintained above 2.5 to prevent precipitation of the reagent free acid itself and below the pH at which the element hydrous oxide or amphoteric conversion to inaccesible anions occurs.

<u>Atomic Absorption Spectroscope</u>. Approximately 1650 single element assays on soil samples and 120 assays on water samples were conducted using this technique. Eighty percent of the values obtained by AAS were done using a Jarrell-Ash (JACO) Model 810 instrument; the remainder were done with a Instrumentation Laboratories (IL) Model 251 unit. Both are double beam devices and differ mainly in the available manner of background correction. The JACO 810, being a double beam-dual monochromator system, offers the possibility of correcting absorbance signals for so-called non-specific absorbance by using discrete selected narrowband or line radiation appropriately close to but not identical with the analytical wavelength. Two modes are possible: alternate selection of radiation emanating from the same source as the analytical wavelength within the same hollow cathode lamp or use of a completely separate lamp having radiation of the requisite intensity and wavelength. Experience of this laboratory has shown no <u>a priori</u> preference between the two. The principal factors leading to selection are: inherent noise associated with the alternatives and proximity of available wavelengths. In special cases it has been possible to use an alternate "non-absorbing" line for the element in question as the source of correcting radiation. The criterion is the relative sensitivity for the element between the analytical line and the possible non-absorbing line. For Pb it has been possible to find nearby lines with sensitivities less than 1% of the analytical wavelength; use of these would lead to an overcorrection of 1% or less. This laboratory has found the oft-used filler gas lines, Ne or A, to be too noisy for best use. In contrast the Il 251, having

a single monchromator cannot use a different wavelength. Instead the selected band of radiation from a separate continuum source centering around the wave length of analytical interest is used. Such radiation generally is obtained from Hydrogen or Deuterium hollow cathode sources. To date the laboratory has found no gross differences in results obtained by the two methods.

Analysis followed straightforward commonly used practices. Samples were aspirated to achieve steady state conditions in the flame followed by burner cleanout with water and randome but frequent calibration measurements by aspirating suitable standards. Both standards and samples were dissolved in 3M HCl, since we have found a slight but significant difference between results of pure water vs. aqueous acid standards. The principal difference from otherwise standard practices is the use of pump assisted pneumatic aspiration. Normal practice is to inject a spray of nebulised water particles into the analytical flame by use of a Venturi with a centrosymmetrically located capillary liquid sample entry tube surrounded by high velocity oxidizer gas. The Venturi disperses the sample into the flame and draws the sample up to the Venturi from the external sample container. The serious effects of sample viscosity and entry tube length using this mode are well known. Since this results in changes in the effective flow rate of sample and measured steady state signal, corrective practice often requires close simulation of prepared standards with respect to viscosity and regulation of sample inlet tube diameters, lengths, and effective vertical displacement from the Venturi entry. This laboratory pumps the analytical liquid to the Venturi at a rate equal to or slightly less than the measured unassisted pneumatic Venturi flow rate. When using a highly regular pump having a constant flow rate, it has been found that calibrations can be reproduced day-to-day well within overall experimental error independent of solution viscosity. The sensitivity of all elements under a fixed set of conditions is consistently 10-20% higher using the combined pump-aspiration mode as compared to the conventional aspiration mode even when the two are adjusted to have the same sample consumption rate. It is possible that the Venturi, having to do nothing except disperse the sample, becomes more effective in production of the finer fraction of droplets known to be required for sensitive analyses.

For reference table I lists the analytical conditions used for the elements shown.

TABLE I

AA Excitation Conditions

(Settings are nominal. Instruments are optimized daily using both attained absorbance for a set-up standard and signal-to-noise ratio.)

	Cd	Pb	Cu	Zn
Hollow Cathode Current	3ma	5-8ma	10ma	10ma
Wavelengths				
a. analytical	228.8nm	283.3nm	324.7nm	213.9nm
b. background	226.5nm	287.2nm	332.3	226.5nm(Ed)
Flame				
Fuel: Acetylene	3.5 l/min	3.5 l/min	Do	Do
Oxidant: Air	10.5/lmin	10.5 l/min	Do	Do
Sample Flow Rate	2.41 ml/min	2.41 ml/min	2.41 ml/min	2.41 ml/min

Table 1. Excitation conditions for multi-element analyses by Atomic Absorption Spectroscopy

Electrochemical Methods. The Environmental Research Laboratory uses a variety of electrochemical techniques as a supplement to the routine use of atomic absorption spectroscopy. The two methods are complementary in their response to experimental conditions such that conditions which preclude the use of one usually are harmless to the other. For example, spectroscopic methods usually are insensitive to abnormally high acid concentrations that may be convenient or necessary to maintain a sample in solution. Electrochemical methods do not work well in corrosive environments if the metal electrode is mercury, the most commonly used material. On the other hand electrochemical methods are adaptable to the presence of large amounts of foreign ions provided they are not also electroactive. For example, it is possible to determine lead in bone tissue, with its very high concentration of calcium, while the AAS method needs careful dilution and control for moderately precise results.

The two electrochemical methods employed in this work were: Anodic Stripping Voltamentry (ASV) and Pulse Polarography (PP). Approximately 400 water samples analyzed by ASV and about 1180 by P. P. Both are well suited for the determination of metal ion concentrations of electroactive materials at the mg/l levels. Because of difficulties in controlling contaminations at these low levels, the methods are most readily adapted to samples requiring little preparation. The most common use has been for the analysis of water samples. The methods are not universally comparable to AA since the prime requirement for electro-chemical measurements is that the sought-for material be electroactive. ASV obtains its low sensitivity by using a pre-measurement collection step in which the sought-for metals, along with any other equally electrically reducible at the necessary applied potential, are collected on, or dissolved in (in the case of mercury) the test electrode. The collected metals are then "anodically stripped" out of the electrode by application of a slowly changing potential made increasingly oxidizing. Substances are stripped out in order of their difficulty of prereduction (the more difficultly reduced species being oxidized first). If the solution is maintained in a constantly stirred or reproducibly quiet state the oxidized materials yield a measurable Cell current which can be displayed on a recorder chart as a function of the applied potential (see fig. 6). The peak height is proportional to the collection time and original solution concentration for a process of fixed variables such as stirring rate, electrode area, velocity of the changing stripping potential, etc. Normal practice is to determine the concentration of the samples by frequent spiking of randomly selected samples with known amounts of the elements in question. The relationships: $i_p = K(x)$ and $i_p = k(x)$ where i_p is the measured peak current for element X and x is the calculated change in solution concentration for element X induced by the standard addition which produced the measured current difference, i_p.

Pulse Polarography is an alternate technique of nearly equal sensitivity to ASV which obtains its sensitivity primarily by careful sampling of the current potential data and subsequent high gain amplification of the resulting noise free currents. In this method, the potential of the electrode is incrementally changed in a chosen direction, oxidizing or reducing. With each "pulse" the resulting is sampled, then the electrode is returned to its starting potential and again "stepped" by an additional increment. The instrument compares the first current with the next and produces a signal which is the difference between the two. This process continues until the last increment reaches the preset limit for the experiment. The resulting curve is shown in Figure 7. As in ASV, determinations are made by the technique of standard additions. Although, this method does possess the reproducibility to permit establishing a working curve from prepared standard solutions, detection limits for the two methods are similar. Typical values for detection limits are shown in the Data Reduction and Handling Section of this report (Table 2).

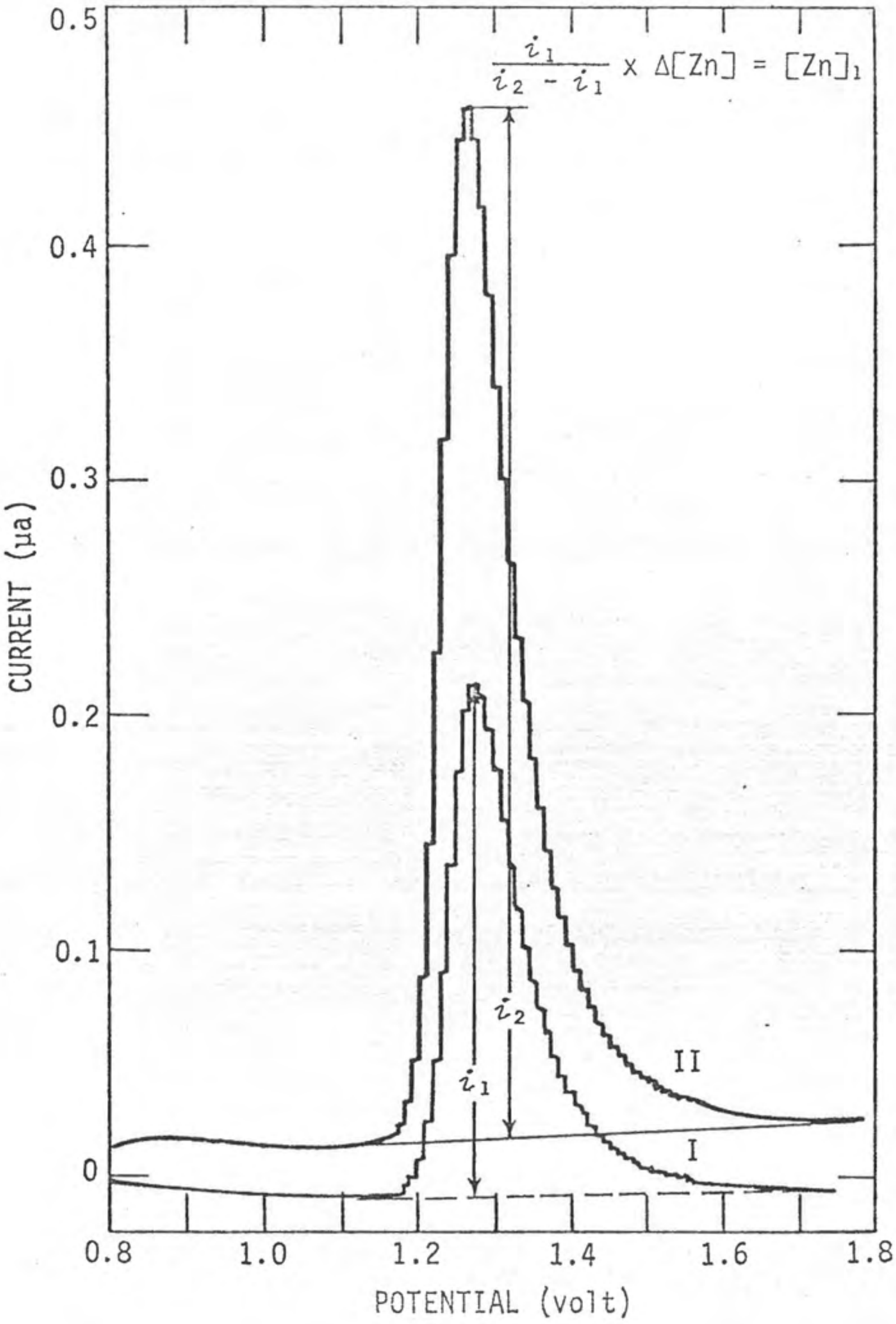


Figure 6. Typical differential Pulse Anodic Stripping Voltammogram.

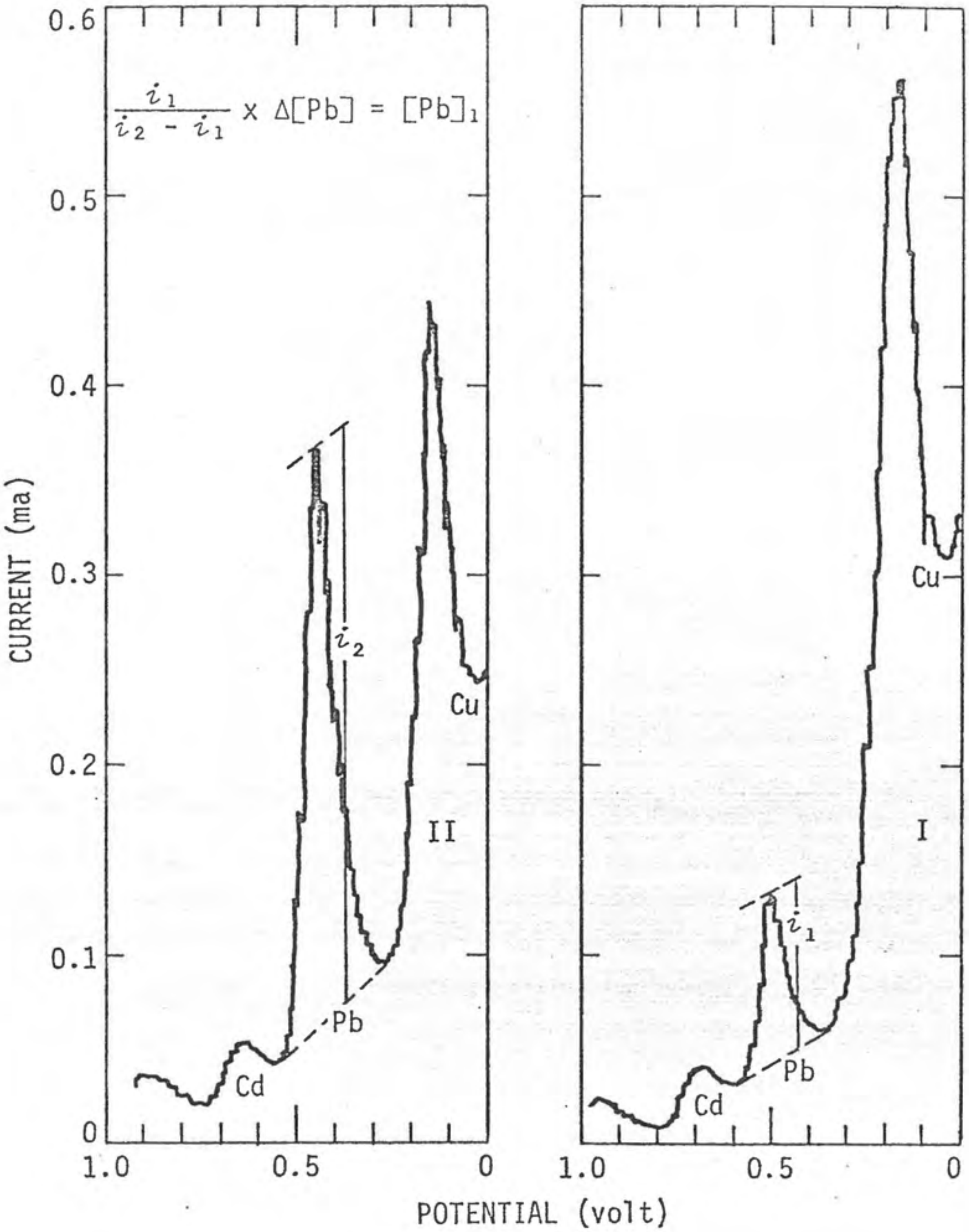


Figure 7. Typical differential Pulse Polarogram

Gas Chromatography

Water Samples: 1000 ml of water was extracted with 100 ml nanograde hexane in a separatory funnel. The hexane layer was reduced, using a Snyder redistilling column, to 10 ml for injection into Gas Liquid Chromatography (GLC).

Core Samples: 20 grams of soil or rock was extracted over a 24 hour period with nanograde acetone, decanted and rinsed 3 times with acetone. This extract was reduced with a Snyder column, dried over anhydrous sodium sulfate, exchanged with nanograde benzene, and adjusted to 10 ml for injection into GLC. Extraction with chloroform and acetonitrile did not change the character of the peaks. Sample clean-up with florisil and with microfiber thin layer chromatography using acetonitrile as the ascending phase did not alter the pattern of the peaks.

In a more thorough effort, 200-244 grams of selected samples were extracted with 200 ml redistilled ethyl alcohol for 12 hours. Then 200 ml water and 250 ml of 50% ethyl ether-hexane were mixed with the sample and allowed to stand for 5 days. The ether-hexane supernatant was decanted and the residue rinsed 3 times with hexane, to effect a transfer of the exteact. The sample was dried over anhydrous sodium sulfate and transferred to a distillation flask fitted with a Snyder column. Most of the solvents were removed by distillation on a steam bath. Residues obtained by this method were taken up in benzene for use with the 63 Ni detection system or in chloroform for analysis by the thermionic or flame ionization detectors.

Five different detection systems were used:

Detection systems

Traco 550 Gas Chromotograph conditions

1. Ni 63 detector 340^0C
2. Column temp. 210^0C
3. Port temp. 235^0C
4. Nitrogen 30 ml per minute
5. Two 6 ft x 1/4 inch glass columns
    - A. 3% OV-17 on 100-120 mesh Gas Chrom Q
    - B. 3% OV-210 and 1.5% OV-17 on mesh Gas Chrom Q

Varian 2100 gas chromotograph conditions

1. Ni^{63}, thermionic* and flame ionization detectors
2. Column temp. 210^0C
3. Port temp. 235^0C
4. Nitrogen 15 ml per minute
5. Two 6 ft x 1/8 inch glass columns
    - A. 3% OV-17 on 100-120 mesh Gas Chrom Q
    - B. 3% OV-210 and 1.5% OV-17 mesh Gas Chrom Q
6. Column A was programmed at a rate of 4^0 per minute from 120 to 250^0C when the flame or thermionic detector was used

* Thermionic with rubidium sulfate for the detection of nitrogen and phosphorus containing compounds.

ERAL Gas Chromatographic Analysis Method for Marshall Water Samples

500 ml of unfiltered water sample was extracted 3X with 25ml portions of Nanograde Hexanes. The combined extracts were dried over anhydrous sodium sulfate, filtered and the solvent removed with gentle hotplate heat to incipient dryness and diluted to 10 grams total weight with Manaograde Benzene in precleaned polyethylene scintillation vials.

Samples were chromatographed on a Varian Model 2740 instrument fitted with a 6'x ¼" glass column packed with 2250 on 100/120 mesh Supelcoport. Operating conditions were as follows:

Temperatures:
Column: 220^0C
Injection Port: 250^0C
Detector: 300^0C
Detector: Flame Ionization
Carrier Gas: Nitrogen @30ml/min.
Recorder: Hewlett-Packard 3380 Reporting Integrator
Recorder Settings:
  Attenuation: 8X to 256X selected as necessary
  Report: %Area
  Rejection: 1000:1
  Rate: 0.5 or 2 cm/min.

Constituents were identified by retiontion times compared with known samples consisting of (a) Standard samples MX_2 and MX_3 from Duke Standard Company and (b) authentic single samples of MDE and DDD obtained from Dr. Willis Bruce of the Illinois State Natural History Survey. The components of The Duke standards are:

MX_2	MX_3
Lindane	BHC
Heptachlor	MDE
Aldrin	p,p'-TDE(DDD)
Heptachlor Epoxide	Carbophenothion
p,p'-DDE	Methoxychlor

Measurement of Soil pH

Acidities of a series of soil core samples were measured to test the hypothesis that changes in soil composition as reflected in X-ray crystallographic data were responsible for the transport zinc through the soil. The method of pH measurement followed that of McLean (12) modified by substituting the addition of water by weight rather than the volume measurement originally specified. Measurements were made immediately upon addition of the water and 24 hr. later. The two sets of measurements agreed within 0.1 pH. A Sensorex general purpose gel-filled glass electrode was used for all measurements. The pH meter was standardized daily against Beckman pH Buffer standard solutions, pH 4 or pH 7 depending upon the range of pH values expected. A Beckman Electromate battery operated unit initially was used in conjunction with a Health Model EU 700 Multirange Recorder used as a scale expander. When initial results proved too noisy, the Electromate was replaced by a Zeromatic II unit which proved much less noisy even though it is a line operated device compared to the DC battery operated Electromate. Reproducibilities of pH values for standard buffers varied less than 0.02 pH, the limit of dial readability for the Zeromatic II. Estimates of method standard deviation of 0.03 pH were obtained from measurements of the same buffer solution over a period of days.

Cation Exchange Capacity (CEC) Measurements. A procedure modelled after that proposed by Jackson (13) was developed for this work. The original procedure determined the exchange capacity of a NaOAc-HOAc prewashed specimen after exchange with neutral 0.1M $CaCl_2$. The Ca equivalent to the total cation capacity was then determined by displacement of the Ca with 1N NaOAc and final determination of the displaced Ca with a Versene (EDTA)-Eriochrome Black T. titration. The literature on CEC determination is extensive with a variety of methods having been proposed. There appears to be at least modest agreement that the acetate calcium method varies least from soil type to soil type. Inasmuch as the measurements were to be applied to a vertical sampling from surface to bedrock the Ca method was chosen.

At the time the Jackson procedure was developed the use of metal-specific electrodes other than the H+ (pH) electrode had not been extensively developed. The normal terminations of the procedure were either flame photometric measurement of the Ca++ or the then popular EDTA complexometric titration of Schwarzenbach. Neither of these is particularly attractive in present day practice. Flame photometric determinations of calcium are notoriously sensitive to the presence of other ions in the final solution and the precise flame-oxidizer mixture used; response curves are notably non-linear. Where the issue is forced, the photometric determination is linearized at some sacrifice in sensitivity by the overwhelming addition of a Ca+++ solution. Likewise the EDTA titration is characterized by a vague indicator color change at the endpoint requiring some skill in obtaining reliable results. The procedure adopted terminates the measurement by use of a calcium selective electrode in a final solution that is composed so as to minimize variation in ionic strength.

Nearly all published procedures for this measurement recommend use of a centrifuge for the several phase separations required during the washing and exchange steps. A centrifuge of the appropriate volume capacity was not available and samples were decantated through filter funnels. Although this procedure is tedious, it appears that the final results may be slightly improved over those possible by the centrifuge. This process required up to five times as many washing steps as called for in the original publication before the required test response was obtained. It may be that the total time and number of washings contributed to a better equilibration.

The final modification was to use the Heath Multi-range recorder with the Zeromatic II pH meter and the Orion Ca Selective Electrode. For most measurements the recorder range was set such that a meter response of 50 mv or approximately the ideal response for a 100-fold difference in Ca++ concentration was displayed full-scale on the recorder.

<u>Procedure</u> Weigh out 4-5 g. of soil sample into a clean labelled beaker. Wash with two 10ml portions of neutral IN NaOAc. Exchange the soil with 5 washings with N $CaCl_2$ solution or LN Ca $(OAc)_2$-4X followed by N $CaCl_2$-1X. Remove excess salt by washing with 80% aqueous acetone until the washings give a faint constant opalescence when treated with 1-2 drops of N $AgNO_3$. Allow soils to drain well. Displace the exchanged Ca by 5 washings with N NaOAc retaining all washings. Dilute the washings to a constant 50g of

solution with D.I. water, mix and measure the Ca concentration using a Ca selective electrode standardized with known Ca solutions. Calculate:

$$CEC = (Ca{+}{+})_{meas.} \times \frac{\text{Wgt of final sol}^{1}\text{n}}{\text{Sample wgt.}} \times 100$$

Notes: (Ca++) should be expressed in mg/l after calibration with mg/l based standards.

If the final diltion weight is as suggested the calculation is:

$$CEC = (Ca{+}{+}) \times 1000$$

Experiments with remeasurement of the final solutions indicate a reproducibility of 10-15%. However, it was noted that solutions over a week old developed mold growths on the liquid surfaces. These solutions proved impossible to remeasure; readings became erratic and very sensitive to solution motion. It is surmised that growth metabolites of unknown character were active on the sensitive electrode surface or reacted adversely with the liquid ion-exchanger of this electrode.

Conductivity Measurements

A Beckman Model RC 16B2 Conductivity Bridge with a Beckman K-1 dip-type conductivity cell was used for all measurements. Solutions to be measured as well as calibrating standards were allowed to equilibrate to room temperature before measurement. The K-1 cell has a nominal cell constant of 1.00/cm: re-calibration using deci-normal potassium chloride solutions according to Jones and Bradshaw (14) yielded a value of 0.996/cm. Since the temperature coefficient of conductivities averages about 3.5%/degree and all measurements reported were obtained at varying ambient temperatures the value of 1.00/cm was used for all calculations.

Solutions were filtered through Millipore 5um pore size filters before measurement.

Sample Preparations

1) Soil Cores. Soil cores were submitted as 6 inch segments of 3 inch diameter Shelby tube samples or 1 inch diameter slit spoon samples. They were found to be sufficiently inhomogeneous that random "grab" samples would not be representative of the entire core section. A sub-sampling technique was developed as follows: the original core hemi-cylinder was longitidinally halved with a large knife, the selected half was again halved longitudinally saving only the narrow inner segment of the core to minimize effects of the core tubing and/or surface water contamination which may have contacted the exterior of the segment. This sub-sample was then dried for a minimum of 3 hours at 105°C, crushed to pass a 40 mesh seive and ground to less than 200 mesh size. Samples were stored in small screwcap glass jars or polyethylene snap-cap

drinking cups for future analysis. Aliquot analysis of selected samples showed this method of preparation to yield a product that was homogeneous (at least for the test element: Zinc) at the 250mg sample level.

2) Water samples. Water samples were obtained in the field in plastic drinking cups (5 oz.) and immediately frozen and kept so until arrival at the laboratory. Depending upon existing priorities and work loads the samples were either (a) stored in a laboratory freezer or (b) filtered through 5µm Millipore filters into precleaned polyethylene scintillation vials and acidified at the rate of 50µl per 20 ml of sample with concentrated HCl obtained from the National Bureau of Standards. These subsamples amounting to 20-25 ml were then refrozen until needed for analysis.

3) Plant Materials. Plant materials were dried for 102 hr @ 105°C and weighed in clean tared 200 ml lidless beakers. Samples were then ignited in a controlled temperature program set such that the temperature rose to 490°C over a 4 hour period, was maintained at 490°C for 4 hours and then allowed to slowly cool to room temperature overnight. Ashed samples were reweighed to obtain ash weights and then diluted with 3N HNO_3 to a fixed 20:1 w/w ratio of ash weight to final solution weight. Samples were measured by AA for zinc.

Data Reduction and Handling

This project utilized three principal methods of analysis: Atomic Absorption Spectroscopy, X-Ray Fluorescence, and Pulse Polarography-Anodic Stripping Voltammetry. In the vast majority of cases, sample conditions, quantities available, and levels of concentrations expected were such that measurements were made by only one technique. Where it was desirable to make cross comparisons between zinc concentrations in water samples and in soil samples from the same well site, it was necessary to be aware that the three methods differ significantly in how they are treated when the measured value approaches the so-called Detection Limit. The following is intended to permit the reader to properly compare values obtained from two different methods when the values themselves appear to merge with background data. The fundamental differences lie in how the measured instrumental signal reacts as the concentration of the material is reduced to everdecreasing values. Two of the above methods produce signals which are inherently "noisy" or subject to random fluctuations of no assignable cause. The third, electrochemical measurements in general, are rendered imprecise as the measured concentrations diminish toward zero by factors external and prior to the measurement act itself. In each case, a subjective judgement about the precision of measurement of a very small signal is made to inform the user of the data so that they may properly interpret low lying values. As a general rule, the subjective judgement is made at the point where the estimation of signal magnitude carries a 50% probable error, (no better than a guess).

AAS measurements are inherently noisy, subject to daily fluctuations and lack a convenient means of absolute calibrations. A typical single operation consits of (a) establishing the single level for a solution having none of the desired material present (see Fig. 8), A solution of the sample is then aspirated through the flame resulting in the transient signal shown in Fig. 8 . After sufficient time has elapsed to establish that this signal is a "steady state" one, the sample aspirator tube is switched to the original "zero" solution to allow the burner to be cleaned out. The simplest determination of the concentration of the material giving ride to the measured difference in "zero" and "sample" signals would require a duplicate sequence of measurements to be performed on a "standard" solution which closely duplicated the sample solution with the single exception that the concentration of the desired material is known. There exists the definite possibility that both the sample and the standard solutions may be subject to a "blank" or contamination contribution from the chemicals and/or surroundings used to prepare the solutions. In this case a third measurement of a "blank", a solution which has experienced all the situations of the sample and standard is required. For most common elements measured with instruments that operate properly, the relation between substance concentration and signal response is a straight line passing through zero if a proper "blank" correction is made. In this simple case, the unknown concentration is determined from the ratio of corrected signals for the

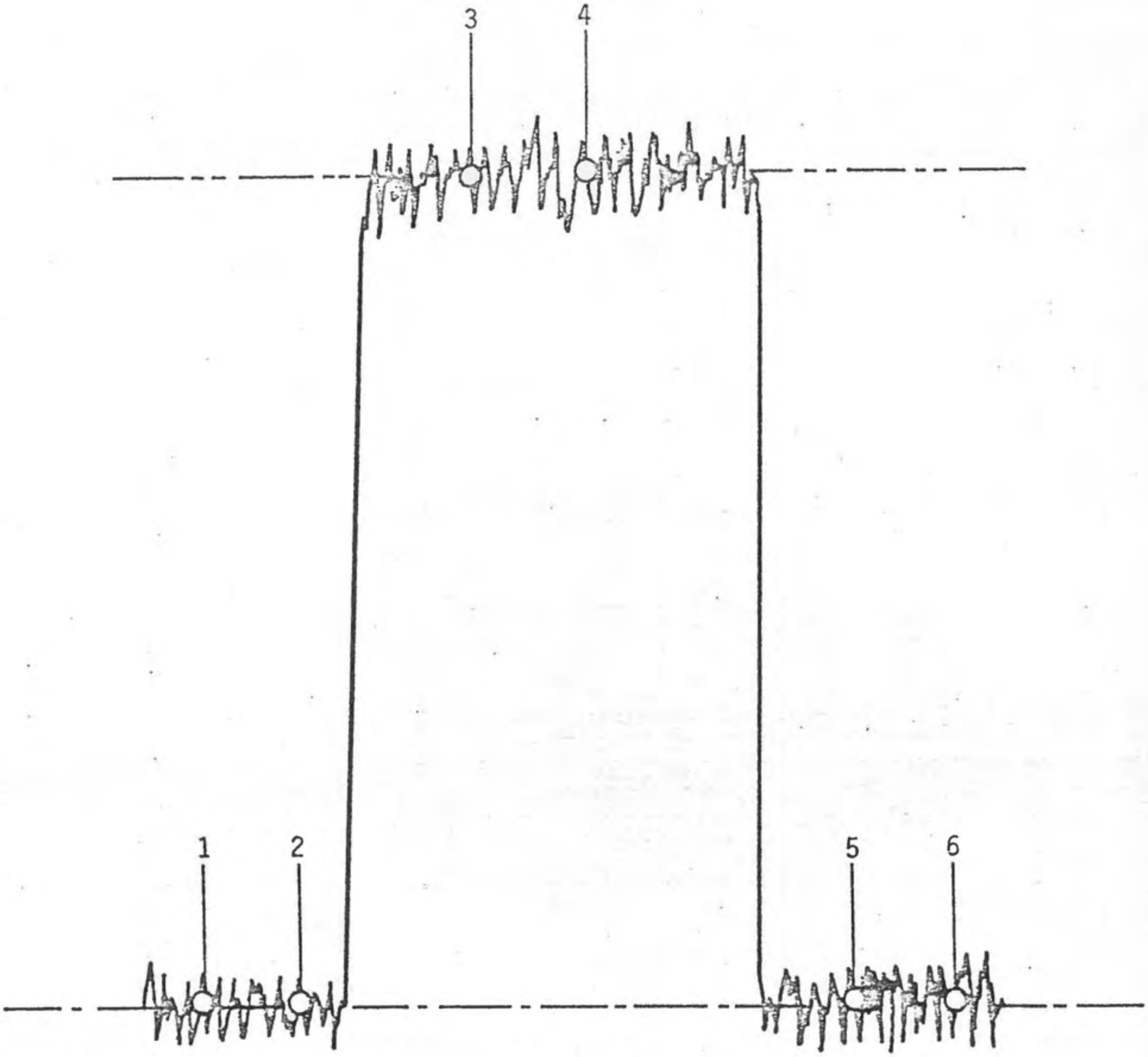


Figure 8. Typical absorption transient signal.

unknown and the standard. Normal practice is to measure and calculate these signals as the straight line average drawn through the chart recorded signals. The Environmental Research Analytical Laboratory uses a teletypewriter-computer system operating in a batch mode to carry out the necessary signal conditioning and calculations. When this program was written in 1972 some experiments were performed to compare the normal method of signal estimation-visual chart recorder estimations - to the alternate use of the periodically updated digital signal which is simultaneously displayed on the instrument panel meter. Using the Jarrell-Ash Model 810 instrument as a test, it was found that two single sequential updated digital signals, represented by the dots in Figure were a good reliable measure of the entire analog signal over the same period. This also applied to the estimation of the upper signal magnitude as well. The computer program now in use for over 5 years requires that the operator establish to his satisfaction that the signal as shown on the strip chart recorder is a valid one, either a "zero" or a "signal". The operator is then required to enter any two consecutive updated digital signal values into the tape cassette recording teletypewriter operating off-line. The sample is introduced and the process repeated. In the simplest case it is done twice more for a single standard and a "blank". The computer software then manipulates the data by (a) determining the average, the standard deviation and the trend line (slope - if any) for the "zero", the "signal" and the corresponding two values for the standard and the blank. Detection limits are calculated for each sample measured using the criterion (D.L.) = 2 x S.D.$_{zero}$, where D.L. is the concentration of analyte sufficient to yield a corrected signal twice the noise limited standard deviation as measured by the two point process.

The equally noisy signals of XRF are treated somewhat differently. These data, similar to radioactive counting methods, are governed by the Poisson statistics of counting discrete events. The primary signal consists of the accumulated total counts acquired in a single designated energy region (or channel) and, in principal could be as large as necessary for any given concentration of material as long as time permitted. In this project,

the samples usually were counted for a total of 4000 sec. (1.11 hr.) in a total of 2000 channels of information. Assuming no "deadtime" or other information losses each channel would be examined for a total of 2 sec. If a precision of 10% is desired the pertinent channel would have to accumulate 100 counts in 2 sec. The detection limit for twice the standard deviation would then be that concentration (expressed in mass units for solids) that would produce a count rate of 100 cps. As in the case of AA these figures are taken as the background corrected values.

Electrochemical measurements are far less noisy than the two spectroscopic methods. Utilization of the 2x S.D.$_{noise}$ criterion leads to unrealistically low detection limits because the measured signal is so quiet. The criterion developed in these laboratories was to use the experimentally measurable value for method repeatability as the criterin. Detection

Table II

Measurement and Sample Detection Limits for Selected Elements

	Method			
Element	ASV	PP	XRF	AA
Ca	NR(c)	NR	20(b)	.0004(a)
Sr	"	"	20	.005
V	"	"	30	ND(d)
Cr	"	"	--	.008
Mo	"	"	20	--
Mn	"	"	20	.010
Fe	"	.2	20	.015
Co	"	.2	20	.04
Ni	"	.2	20	.04
Cu	.001	.1	20	.01
Zn	.005	.05	20	10
Pb	.0001	.05	10	.05
Tl	.0001	.05	10	.02
Bi	.0001	.05	10	30
Cd	.0001	.05	10	.005

(a) mg/l in solution, D.L for solid samples = 20 x solution value

(b) ug/g in solid samples

(c) No Reaction

(d) Not Determined

Table 2. Detection limits for selected elements

limits then were set to be that concentration yielding a measured signal twice the standard deviation of repeated measurements. The two electrochemical methods of ASV and PP have the advantage that the materials electrolysed as a consequence of the act of measurement can be recovered into the test solution without loss. It is thus possible to "repeat" an experiment by repeating the potential-time processes used in the method without removing the test solution. In this operation none of the usual method variables except the electronic and electrochemical variables can operate. The repeatability has been found to be much smaller values than other parts of the total experiment such as sample preparations, dilutions, etc. Typical figures are: Repeatability (S.D. units) 1-2%, sample-to-sample reproducibility, 6-10% and overall total reproducibility, 10-12%. Detection limits are calculated as the concentration necessary to yield a signal twice the measurement repeatability.

Section VIII

Site Selection

Four industrial complexes (Sites A, B, C, & D) were selected to study the effects of their waste disposal practices on the soils and shallow groundwater systems. Four additional locations (Sites E, F, G, & H) also were selected to test the areal applicability of informatinn gained at the industrial sites.

Three sites (A, B, and C) located in moraine and ridged drift areas of southcentral Illinois (see figure 9) initially were selected for study on the basis of geology, the types and quantities of waste generated, and the manner of disposal. It was thought desirable to study areas where the unconsolidated materials are relatively thin (less than 50 to 75 feet) and underlain by Pennsylvanian age shales. Special emphasis also was given to sites where the glacial materials predominately were low-permeability clays, silts, and tills. Such sites theoretically would be desirable for disposal activities with little resulting groundwater pollution.

To determine the general applicability of the coring technique as a monitoring tool, a fourth site (D) located in a sandy alluvium environment in north central Illinois (presumably undesirable for disposal activity) was chosen later. Sites A, B, and D are secondary zinc smelting plants that have generated large volumes of metals rich waste material over many years of operation. Most of this waste has been in the form of cinders that have been piled on or spread over the plant properties as fill material. The other site (C) is a chlorinated hydrocarbon plant where waste products principally are in liquid form. Approximately half the liquid waste at this site is stored and pretreated in lagoons or retention basins on the plant property

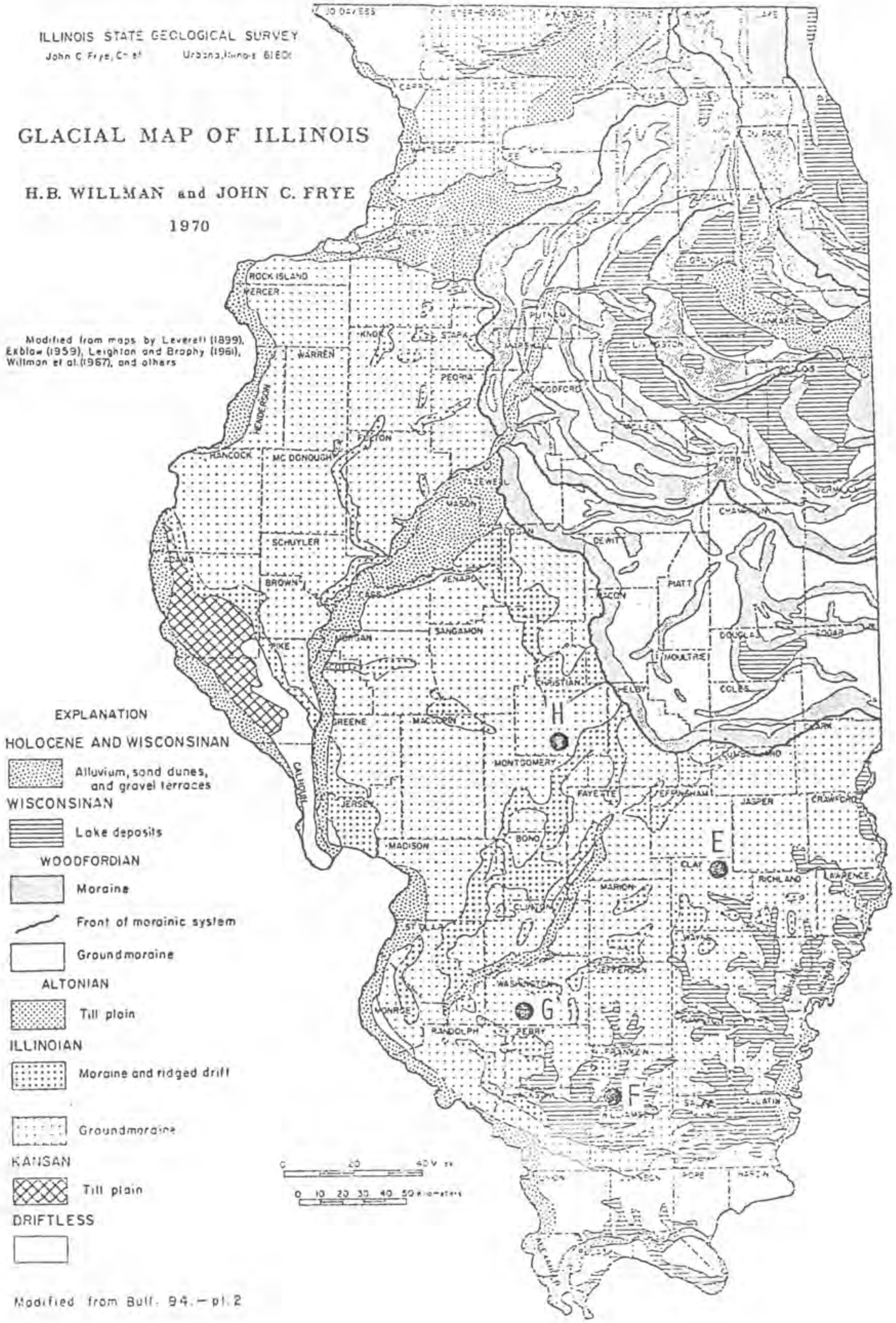


Figure 9. Glacial Map of Illinois

and then injected into a deep disposal well. The possible effects of the surface disposal or storage activities at all four sites are the principal concerns in this study.

. The selection of sites to be studied, ultimately are effected by industrial politics. Due to the necessity of releasing all data collected during a study, it is often difficult to convince the officers of an industry of the merits of the proposed research project. In most cases the industry involved has very little to gain and the potential for great loses (bad publicity, regulatory action by state and federal government, or the discovery of unknown pollution problems).

In the planning of any proposed research, it is recommended that written permission be obtained from the appropriate industrial officers to insure that the desired sites can in fact be studied. Failure to do so in this study resulted in the necessity of having to work on the properties surrounding Site C, thus reducing the effectiveness of the study. It also prohibited the study of a hazardous waste disposal facility that had been described and submitted as a Site in the original project proposal.

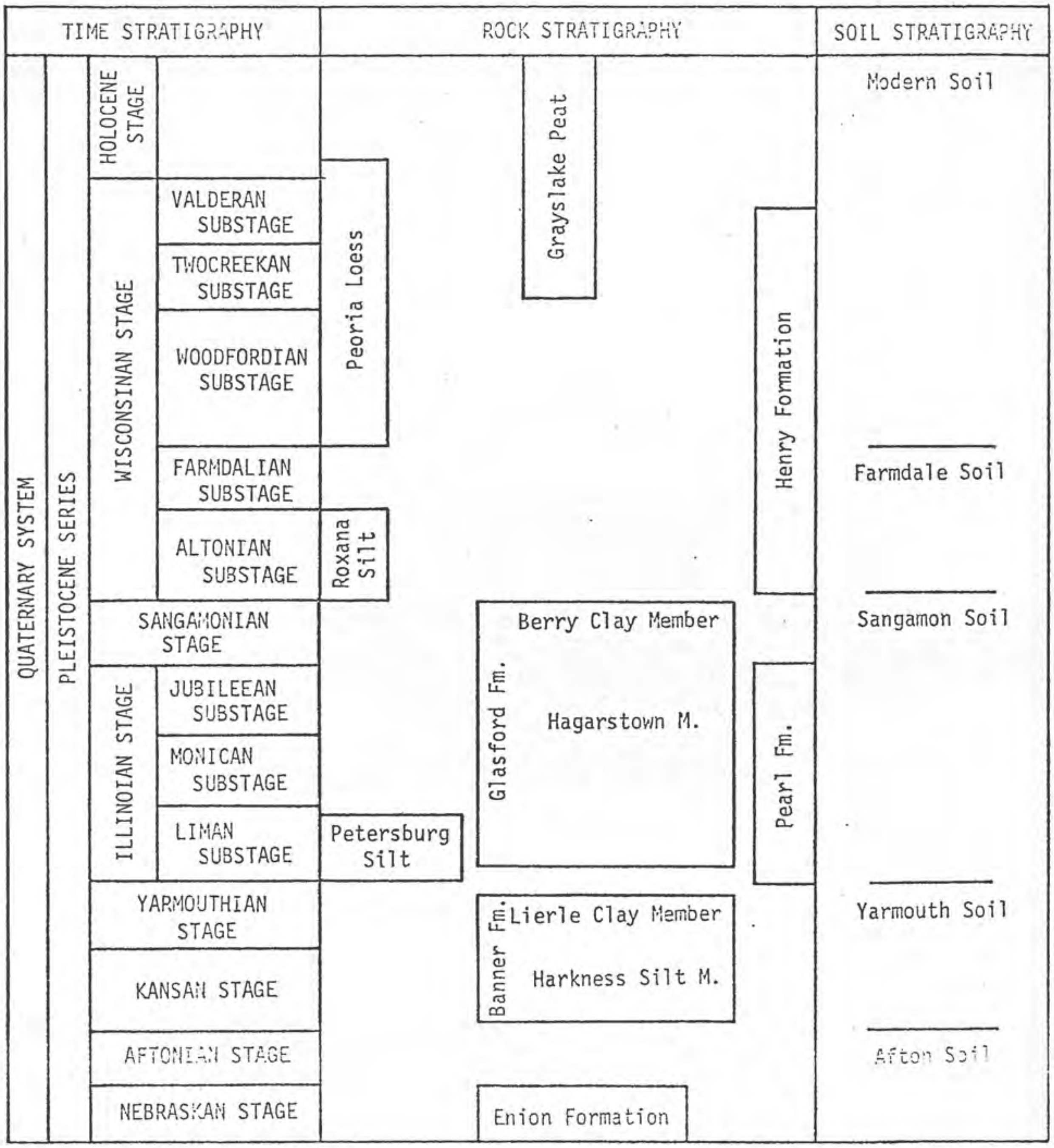
Regional Geology

The areas of study in this project all are underlain by varying thicknesses of unconsolidated materials of Pleistocene age over bedrock. During the Pleistocene, four major periods of glacial advance (Nebraskan, Kansan, Illinoian, and Wisconsin) occurred in Illinois. These periods were separated by interglacial episodes of soil formation (Aftonian, Yarmouthian, and Sangamonian Stages). Figure 10 indicates the time relationships of the glacial periods, unconsolidated sediments (rock stratigraphy), and soil development in Illinois.

The Nebraskan glacial advance represented the first episode of Pleistocene glaciation in Illinois. The ice sheet moved into western Illinois from a Canadian source and covered a relatively small portion of the state resulting in a scarcity of Nebraskan-age glacial deposits. (Fig.11) The retreat of the glaciers was followed by dissection of the region by streams and soil formation. The Afton Soil is a product of this interglacial period, the Aftonian Stage.

During the Kansan glacial episode, ice sheets advanced into Illinois from both the northwest and northeast from two seperate Canadian sources. The glacial drift deposits of these two ice sheets apparently do not overlap, but they almost meet in central Illinois (Fig.11). The Yarmouth Soil profile which developed on the Kansan glacial deposits is quite thick, suggesting a long period of soil formation.

The Illinoian Stage was marked by three major glacial advances into Illinois from the northeast which covered most of the state (Fig.11). The Sangamon Soil developed on the Illinoian deposits following the retreat of the ice sheets with local accumulation of predominantly fine-grained sediments in poorly drained areas.



Fm. = Formation; M. = Member

(after Willman, et al., 1975)

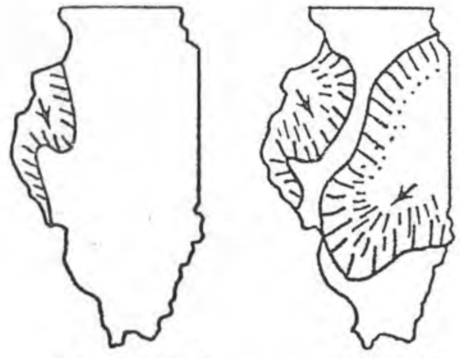
Figure 10. Time relationships of glacial periods, unconsolidated sediments, and soil development in Illinois.

There were two glacial advances into Illinois during the Wisconsinan Stage (Fig.11). Glacial deposits were limited to northern Illinois with large quantities of wind-blown silt, called loess, deposited over much of the rest of the state. The two advances were separated by an interval of soil formation which produced the Farmdale Soil. Radiocarbon dating indicates the retreat of glaciers from Illinois about 12,000 years ago. The Modern Soil has been developed on the surficial glacial deposits from that time to the present.

Soils

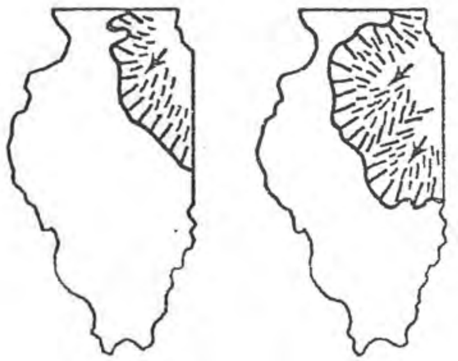
Soil formation is characterized by a number of processes, which, over a period of time, tend to develop three soil zones or horizons. Organic material accumulates in the upper zone or A horizon and the parent material is broken down by weathering, forming soluble minerals and collodial suspensions which are leached from the A horizon and moved to or through the underlying zone, the B horizon. Clay minerals and iron and manganese commonly are transported downward and deposited in the B horizon. The B horizon also is characterized by increasing color segregation or mottling due to alternating wet and dry conditions. The organic A horizon often is considered the zone of depletion while the B horizon is the zone of accumulation.

Carbonates are leached from the A and B horizons and usually are carried downward in the pore water into the groundwater system. In some cases, carbonate minerals accumulate or precipitate from the pore water at the top of the lowest horizon, the C horizon which is commonly called the parent material.



NEBRASKAN KANSAN
inferred glacial limits

ILLINOIAN GLACIAL ADVANCES



WISCONSINAN GLACIAL ADVANCES
(After Willman and Frye, 1970)

Figure 11. Glacial advances in Illinois

The preglacial bedrock surface in Illinois varies in age from Pennsylvanian to Cambrian. All sites studied are underlain by Pennsylvanian age rocks consisting predominately of shale interbedded with thin sandstone, limestone, and coal layers.

Sites A, B, and C are located in south-central Illinois in relatively flat and featureless drift plains underlain by till sheets of Kansan and Illinoian age, Illinoian water-laid deposits, and Wisconsin loess and silts (see figure 9). Site D is located in north-central Illinois on the flood plain of the Illinois River and is underlain by recent alluvial materials over Wisconsinan glacial outwash (see figure 9). The stratigraphy of all four sites is described in detail in the following case history sections.

Section IX

Case Histories

Site A

Site A is a secondary zinc smelter located in south-central Illinois. The plant started operations between 1885 and 1890, initially processed zinc ore and was converted to a secondary zinc smelting facility in about 1915. Wastes from the smelting operations during the first 85 years were principally heavy metals-rich cinders, and ashes. During the early years large quantities of cinders were used as road fill or surfacing for secondary roads and farm lanes in the plant area. The remainder was used as fill material around the plant buildings and as surfacing over the property. As a result of these disposal practices, there now is a 1- to 10-foot thick layer of metals-rich cinders covering about 12 acres of the plant property.

In compliance with air pollution control regulations, a scrubber was installed on the plant stack in 1970. Prior to that time, wind-blown ash, rich in zinc and other heavy metals, was deposited on the plant site and on the surrounding farmland. This source of pollution has now been minimized, but wastewater from the scrubber is disposed of in a seepage pit constructed on the cinder materials that form the present day land surface. Several hundred tons of high zinc content sludge have accumulated from the frequent cleaning of this pit and are being reprocessed for zinc recovery. Most of the water from the pit infiltrates into the ground underlying the plant property.

Prior to the study, it was felt that groundwater pollution might be occurring from three possible sources: 1) the large volume of solid waste materials (cinders and stored junk waiting to be processed; 2) the highly mineralized liquid wastes from the stack scrubbers; 3) the wind-blown ash from the smelter furnace prior to installation of the scrubbers.

Table 3 illustrates the chemical properties of these waste materials at Site A.

Because of the long period of operation of this facility and the various sources and forms of pollution likely to be present, this site was selected for detailed study. Maximum time, effort, and money was devoted to the study of this site to develop the study methodology and optimize its application to other sites.

A total of 49 wells at 36 locations were completed at Site A. Core samples were taken at each of these locations and at an additional 23 sites (see Figure 12). Total well and core sampling footages are about 1309 and 1454 feet respectively.

Geology

The glacial materials at this site range in thickness from about 55 feet on the east to about 75 feet on the west. The stratigraphic units recognized are essentially uniform in character and thickness and generally flat lying across the site (Figure [illegible]). The elevation of the bedrock surface dips from 449 feet above sea level on the east to 432 feet on the west.

Data from selected borings are included at the end of the Site A discussion. A tabulation of data from all sites is available from N.T.I.S. Table 4 summarizes the textural and mineralogical information for each unit. A brief description of each stratigraphic unit is as follows:

Table 3. Chemical analyses of waste materials - Site A

	Cinder fill	Stock piled dried sludge from disposal pit	Slurry from disposal pit sample	Supernatant liquid from disposal pit sample
SiO_2	29.8 %	.42 %	.28 %	-
TiO_2	.52 %	.01 %	-	-
Al_2O_3	10.4 %	1.28 %	2.01 %	-
Fe_2O_3	9.53 %	1.01 %	.88 %	-
MgO	.92 %	.29 %	.08 %	-
CaO	3.68 %	.25 %	.15 %	-
Na_2O	.54 %	.08 %	.07 %	-
K_2O	.91 %	.20 %	.14 %	-
P_2O_5	.21 %	.006 %	-	-
Total S	1.22 %	1.14 %	1.03 %	-
V_2O_5	.007 %	.0006 %	.0004 %	-
ZnO	16.4 %	68.3 %	71.8 %	-
PbO_2	6.2 %	9.4 %	4.6 %	-
Cd	5.6 mg/l	180 mg/l	114 mg/l	75 mg/l
Cu	1010 mg/l	1079 mg/l	829 mg/l	.23 mg/l
Ni	56 mg/l	160 mg/l	118 mg/l	3.3 mg/l
Mn	498 mg/l	198 mg/l	202 mg/l	-
Hg	.19 mg/l	2.0 mg/l	1.6 mg/l	-
As	46 mg/l	90 mg/l	75 mg/l	-
Sb	160 mg/l	-	38 mg/l	-
Se	3.3 mg/l	-	26 mg/l	-
Pb	-	-	-	15.3 mg/l
Zn	-	-	-	26,000 mg/l

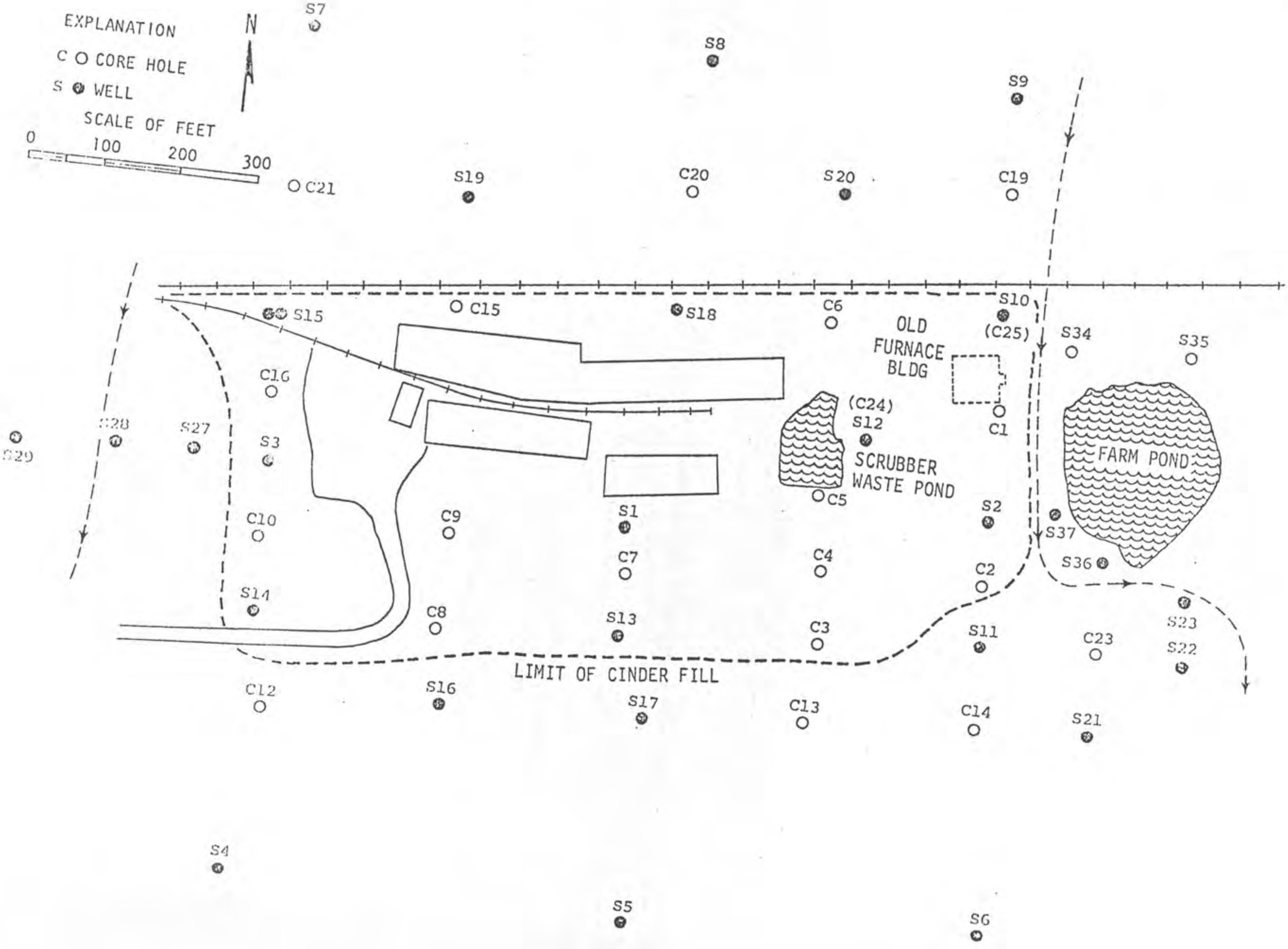


Figure 12. Location Map - Site A

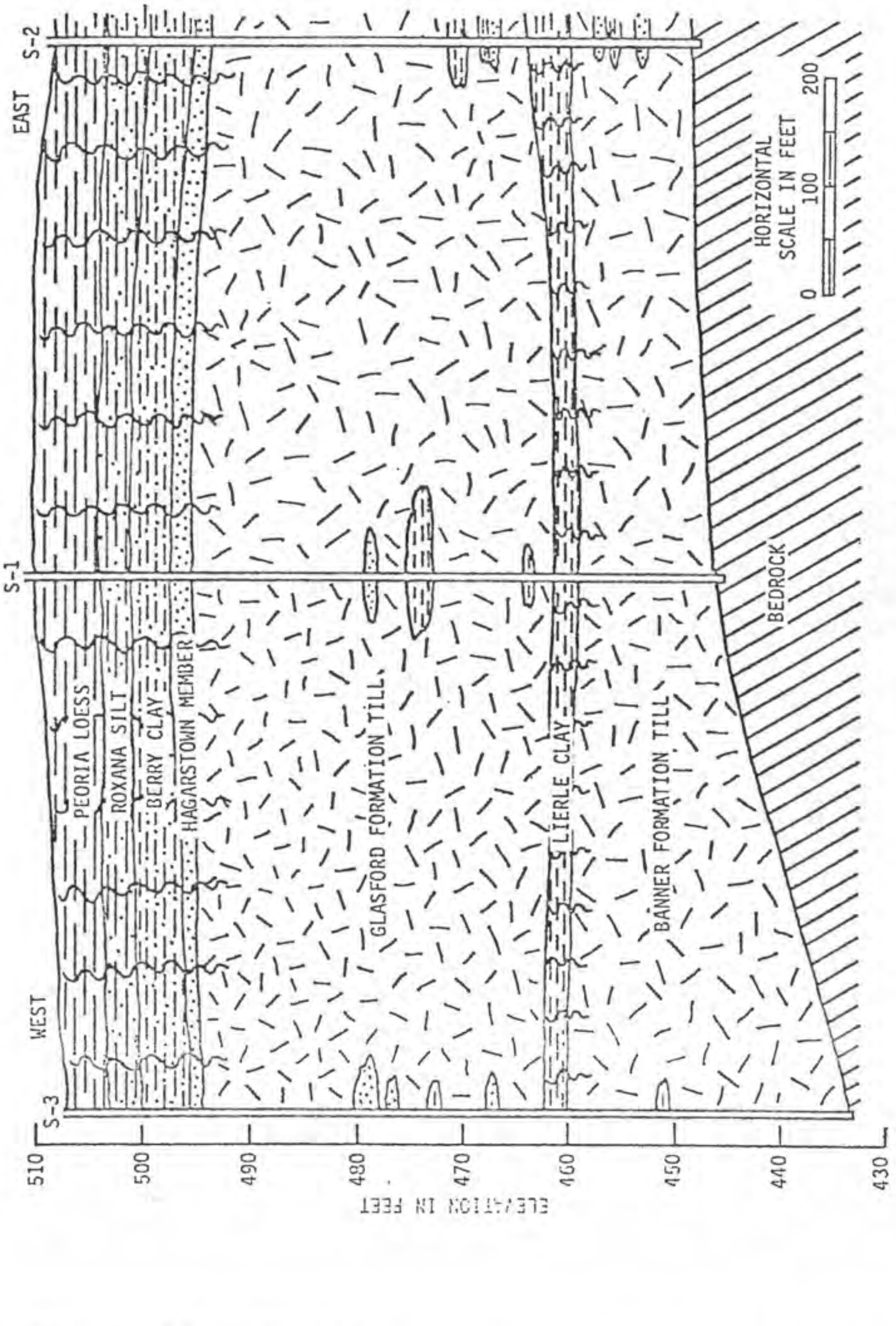


Figure 13. Stratigraphic cross-section - Site A

STAGE	UNIT	AVERAGE TEXTURE	AVERAGE CLAY MINERALOGY (<2μ)	CARBONATE MINERALOGY (<2μ)
WISCONSINAN	PEORIA LOESS	(4-59-37) 10 samples	M 84.5% I 11% 8 samples	LEACHED
	ROXANA SILT	(20-47-33) 9 samples	M 85% I 8% 7 samples	LEACHED
SANGAMONIAN	BERRY CLAY MEMBER-GLASFORD FORMATION	(33-31-36) SAND INCREASES TOWARD BASE 13 samples	M 77% I 13% 13 samples	LEACHED
ILLINOIAN	HAGARSTOWN MEMBER-GLASFORD FORMATION	(46-33-21) VARIABLE 3 samples	M 30% I 51% 3 samples	LEACHED
	GLASFORD FORMATION TILL	(31-40-29) SANDIER NEAR TOP 79 samples	M 45% INCREASES WITH DEPTH I 40% DECREASES WITH DEPTH 51 samples	CONTAINS CARBONATES MAY BE LEACHED AT TOP
YARMOUTHIAN	LIERLE CLAY MEMBER-BANNER FORMATION	(24-41-35) 8 samples	M 45% I 37% VARIABLE 6 samples	LEACHED
KANSAN	BANNER FORMATION TILL	(25-44-31) SANDIER NEAR TOP 40 samples	M 16% I 55% VARIABLE 31 samples	CONTAINS CARBONATES MAY BE LEACHED AT TOP
PENNSYLVANIAN SYSTEM	BOND FORMATION	NO INFORMATION	M 3% I 4% 2 samples	LEACHED

(4-59-37) = Average percentage of sand, silt, and clay excluding gravel.

M 64% = Average percentage of montmorillonitic (expandable) minerals in clay fraction (<2μ).

I 11% = Average percentage of illite in clay fraction.

Table 4. Textural and mineralogical data for stratigraphic units - Site A

Wisconsinan Stage

A) Peoria Loess (4-6 feet thick) - Brownish-gray clayey silt. Sand content averages 4 percent. Montmorillonitic (expandable) clay minerals average 84.5 percent, illite averages 11 percent. Consists of wind-blown deposits during and following Woodfordian glaciation beyond the limits of Woodfordian glaciation (Wedron Formation). The Modern Soil profile has developed in the Peoria Loess as evidenced by abundant organic material, iron stains, and absence of carbonates.

B) Roxana Silt (0-5 feet thick) - Dark brown clayey silt. Average sand content 20 percent, may be as high as 34 percent. Similar to the Peoria Loess in clay mineral content. Distinguished from the overlying Peoria Loess by color and greater sand content. Consists of wind-blown deposits mixed with underlying material. Contains Farmdale Soil and probably part of the Modern Soil profile; it is leached and contains iron stains and organic material.

Sangamonian Stage

Glasford Formation

C) Berry Clay Member (3-5 feet thick) - Dark gray sandy silty clay with a trace of gravel; distinguished from the overlying Roxana Silt by color and/or texture. Sand and gravel content increases toward the base. Clay mineral composition similar to the Peoria and Roxana. Considered an accretion-gley deposit produced by slow accumulation of predominantly fine-grained sediments in poorly drained areas. Development of the Sangamon Soil in the Berry Clay is evidenced by abundant organic material, iron stains and absence of carbonates.

Illinoian Stage

D) Hagarstown Member (1-2 feet thick) - Silty sand with some gravel. Clay mineral compostion similar to underlying till, illite averages 51 percent and montmorillonitic clay minerals average 30 percent. Sand content variable, may be up to 50 percent. In some borings, less sandy and hard to distinguish from the underlying Illinoian till. Variability of the Hagarstown and the similar clay mineral composition to the underlying till suggest an ablation origin related to the melting of the glacier which deposited the underlying till. Typically leached and iron-stained, indicating that the Sangamon Soil extends through this unit.

E) Glasford Till Member (20-43 feet thick) - Gray to dark gray sandy and silty glacial till. Contains carbonates except where Sangamon Soil extends into the uppermost portion. Illite over 50 percent of the clay fraction near the top of the unit and decreases with depth. Montmorillonitic clay content increases with depth. Sand content averages 35 percent near the top, decreases to less than 30 percent near the base. Lenses of dark olive-brown leached clay are locally present, apparently sheared up from the underlying Lierle Clay (see fig. 9). Discontinuous lenses of sand and silt also are present.

Yarmouthian State

Banner Formation

F) Lierle Clay Member (0-4 feet thick) - Dark olive-brown silty clay. Sand content averages 24 percent. Clay mineral composition is variable. An accretion gley, contains Yarmouthian Soil; leached and iron stained.

Kansas Stage

G) Banner Formation Till (10-29 feet thick) - Gray to pinkish gray sandy silty clay till with some gravel. Carbonates are present except locally at the top. A higher illite content and lower montmorillonitic clay content than Glasford Formation Till (E). Montmorillonitic clay minerals average 16 percent and illite 55 percent of the clay fraction. Average sand content 25 percent as compared to 31 percent in the Glasford Till. Shale fragments and discontinuous sand and silt lenses are present. Yarmouth Soil has developed into the till. Evidence of soil formation extends well into the till, suggesting a long period of soil formation or intense weathering.

Pennsylvanian System

Bond Formation - Bedrock consisting of green shale containing abundant mica.

High kaolinite and illite content and low montmorillonitic clay content. Bedrock is leached. No textural data.

At Site A, four soils are recognized in the glacial drift. In addition to the Modern Soil which has developed in the Peoria Loess and Roxana Silt, the Farmdale Soil has developed on the Roxana Silt, the Sangamon Soil on the Berry Clay and underlying Illinoian deposits, and the Yarmouth Soil on Kansan sediments.

Inasmuch as the upper four units are relatively thin and contain three soil profiles, the glacial drift is leached to a depth of 12 to 15 feet. The zone of leaching typically extends into the Hagarstown or Glasford Formation Till.

Resistivity Survey

An electrical earth resistivity survey was conducted at Site A by the Illinois State Geological Survey on October 21 and 22, 1974. The location of the 35 resistivity stations is shown on figure 14. The Wenner configuration was used in the study with a-spacings for electrodes at regular intervals ranging from 2 feet to 100 feet at a majority of stations. The apparent resistivity values at a-spacings of 2, 5, and 30 feet at each station are shown on figure 14. The 2 foot a-spacing was not used on the line of traverse immediately north of the railroad. ~~The a-spacing is approximately is equal to the depth~~ of ~~in measurement of resistivity value.~~ Resistivity measurements within the immediate vicinity of

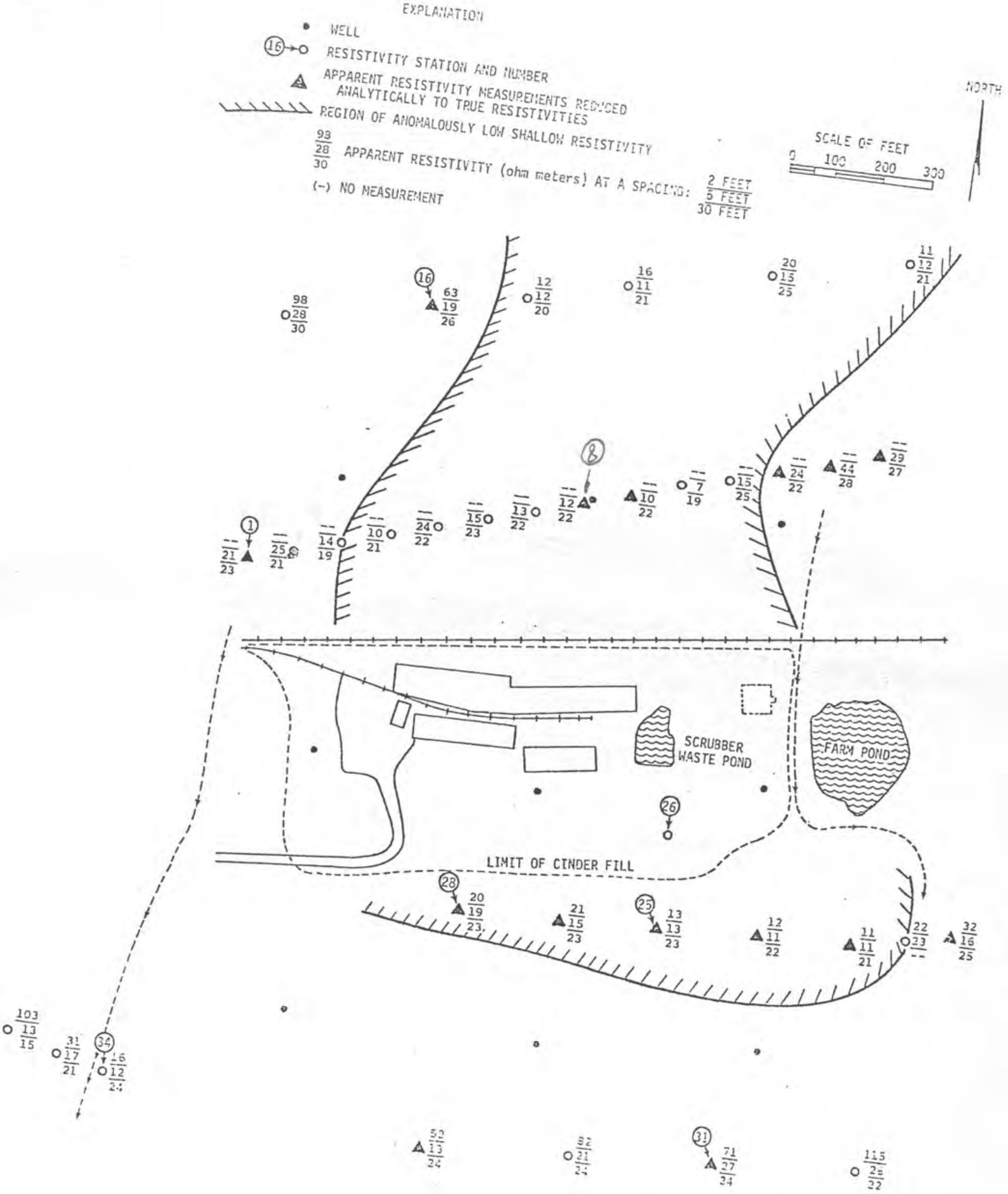


Figure 14. Electrical Earth Resistivity Stations and results Site A

the site were not possible due to the extensive cinder fill and presence of conductors such as electric lines, fences and railroad tracks. ←

Apparent resistivity measurements at the 30 foot a-spacing are shown on figure 14. The resistivities at this a-spacing range from 15-30 ohm-meters with an average value of 22.7 ohm-meters. The apparent resistivity values measured at larger a-spacings are similar to those measured at 30 feet. From an overall view, the resistivity values were uniformly low and indicate that the general region of the site is underlain by fine-grained materials. Thick, permeable zones of sand and gravel were not detected. Extensive lateral or vertical migration of significant quantities of contaminated ground water through the fine-grained sediments is unlikely. However, the electrical earth resistivity methods cannot reliably detect thin, shallow,silty sand lenses which may locally be pathways for the slow, lateral movement of small quantities of contaminated ground water. The study of cores from borings at Site A show that a thin, silty sand (Hagarstown Member of Glasford Formation) does occur locally at depths less than 15 feet.

Anomalously low, shallow resistivity values (measured at a-spacing of 2 feet and 5 feet) north to northeast of the smelter and south of the site, appear to define a region of contamination apparently from deposition of wind-blown materials, or possibly from dumping of material on the surface. The general region of low surface resistivities is indicated on figure 14.

Station no. 34 is located in the southwestern part of the study area in the floodplain of the small stream which received runoff from the western part of the site. The low, apparent resistivity readings for a-spacing of 2 feet and 5 feet at this station may be due to presence of contaminants at a shallow depth deposited along the stream.

Station no. 26 is located in cinder fill south of the scrubber waste pond. The resistivity instrument would not read out reliable measurements at this station.

At fifteen of the resistivity stations (shown on figure 14) analytical methods were used to reduce the apparent resistivity values to the true resistivities of the geologic materials present at different depths. The following values were determined for six of these stations.

	Depth Interval (ft)	Thickness (ft)	True Resistivity(ohm-m)
No. 1	0-2.2	2.2	43
	2.2-3.2	1.0	22
	3.2-7.6	4.4	8
	7.6-30	22.4	29
No. ~~2~~ 8	0-3	3	12
	3-5	2	9
	5-8	3	15
	8-34	26	30
No. 16	0-1.4	1.4	105
	1.4-2	0.6	32
	2-5	3	8
	5-55	50	32
No. 25	0-1.0	1	12
	1.0-2.2	1.2	19
	2.2-9	6.8	10
	9-37	26	30
No. 28	0-1.6	1.6	21
	1.6-7.5	5.9	17
	7.5-60	52.5	27
No. 31	0-1.8	1.8	97
	1.8-4.8	3	11
	4.8-32	27.2	25

The shallow, high resistivity values are caused by the low conductance of unsaturated geologic materials. This shallow, high resistivity layer is absent at stations located in the region of suspected surface contamination.

The extremely low resistivity values which occur in the depth interval of approximately 3 to 8 feet are due to clayey geologic materials which are saturated with water of naturally high mineral content. This low resistivity zone occurs across the entire area and cannot be related to poor quality ground water from the industrial site. The low resistivity zone correlates with the Berry Clay Member of the Glasford Formation which is present in this depth interval.

The low resistivity zone is underlain by geologic materials with true resistivities ranging from 25-32 ohm-meters. These uniform low values indicate clayey fine-grained sediments are present.

Hydrology

Based on the geologic description of this site, it is quite obvious that there is no significant aquifer present in the immediate vicinity of the plant site. The Hagerstown Member, a thin (1 to 2 feet thick) continuous silty sandy zone appears to be the only permeable zone that could allow for significant lateral groundwater movement away from the site. To develop even a domestic water supply from this sand unit probably would require the construction of two or more large-diameter bored wells.

To determine the hydrologic characteristics of this unit a pumping test using 3 observation wells was conducted at well site S-2 on August 12, 1975. Well S-2S was pumped for a period of 3 hours at rates from .180 to .111 gallons per minute. Observation wells 1, 2, and 3 were located 7.2, 14.0 and 28.0 feet north of the pumped well, respectively. All drawdown data were adjusted to the final pumping rate (.111 gpm) for analysis purposes.

Adjusted time-drawdown data for observation wells 1 and 2 were plotted on log-log graph paper (see fig. 15 a & b). Adjusted distance-drawdown data for observation wells 1, 2, and 3 at 180 minutes also were plotted on log-log graph paper (see figure 15c). These curves were matched to the nonleaky artesian formula presented by Walton (17):

$$s = (114.60/T)\ W(u)$$

where: $W(u) = \int_{u}^{\infty} e^{-u}/u\,du$

and $u = 2693\ r^2\ S/Tt$

s = drawdown in observation well, in ft.

Q = discharge, in gpm

T = coefficient of transmissivity, in gpd/ft.

r = distance from observation well to pumped well, in ft.

S = coefficient of storage, fraction

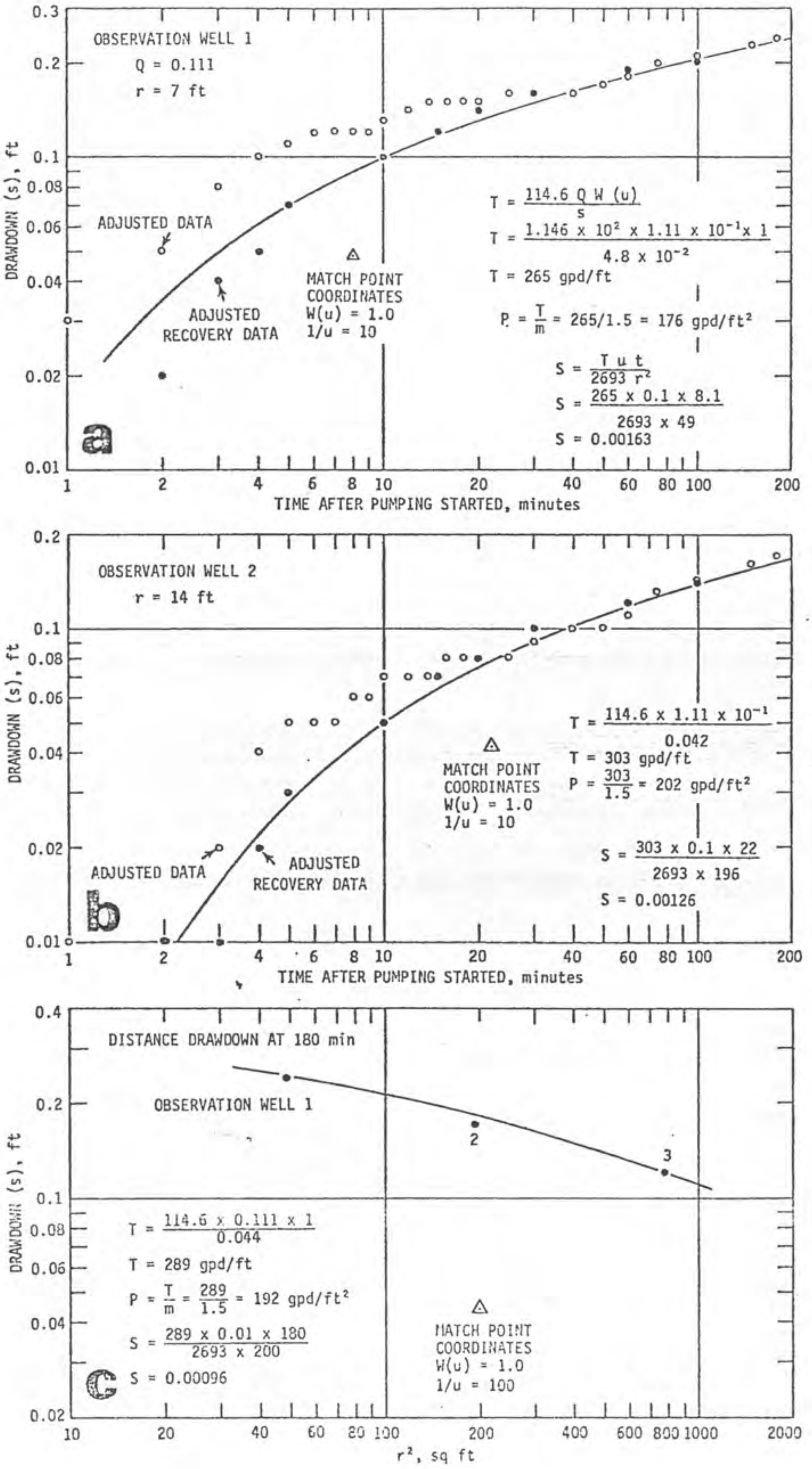


Figure 15. Pumping test data for well S-25 - Site A

t = time after pumping started, in min

The average computed coeficients of transmissivity, permeability, and storage are 285 gpd ft., 190 gpd ft^2, and .00128, respectively. Deviations between the early adjusted drawdown data and the type curve is probably due to the effect of removing stored water from the casing of pumped well. For this reason, heavy emphasis was placed on matching recovery data and late pumpage data to the type curve.

Water level hydrographs for all shallow wells at Site A are presented in figure 16. Also included are graphs of precipitation and the zinc plant water consumption for the period of record. The hydrographs generally can be divided into three categories: 1) upland type wells responding principally to precipitation, 2) those located in lowland areas and responsive to precipitation, and 3) those responging more to the liquid disposal activity at the plant site.

The upland type wells responding principally to precipitation are best characterized by the hydrographs for wells SCH-1S, S-4S, S-5S, S-7S, S-21, and S-29. Wells in lowland areas but responsive to precipitation are best illustrated by the hydrographs for wells S-16, S-19, S-20, and S-23. The hydrographs for wells S-2S, S-10S, S-12, and S-18 best illustrate water levels of wells responsive to the disposal activity of the plant. Maximum and minimum water levels for all shallow wells are summarized in Table 5.

Water table contour maps were drawn for each round of water level measurements made. Figures 17A and B for March 1976 and November 1975 illustrate the high and low water table configurations respectively. In both instances there is a water table mound beneath the plant site and movement of water is in all directions away from the plant complex. The relatively high permeability of the fill

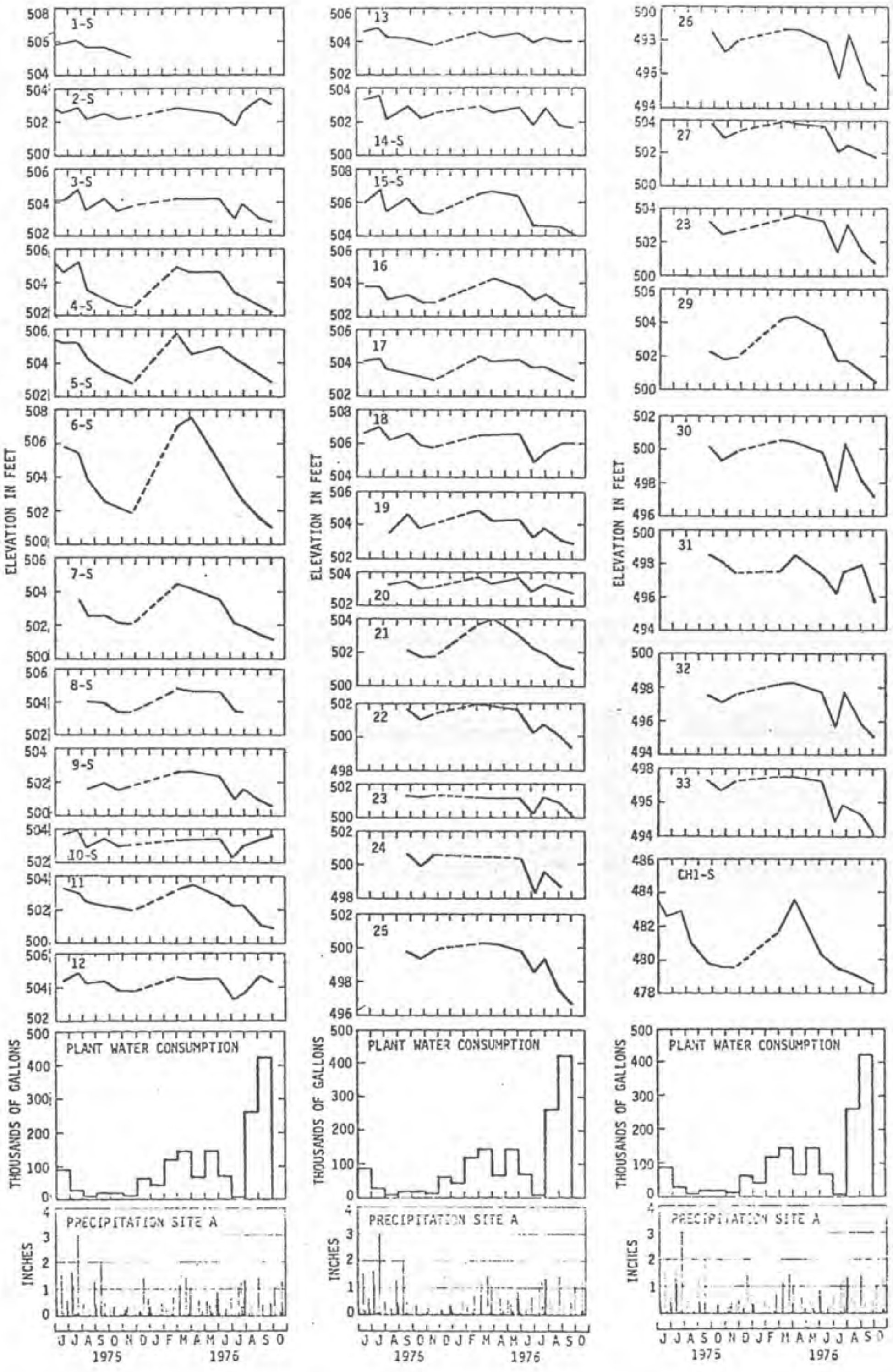


Figure 16. Water level hydrographs of shallow wells - Site A

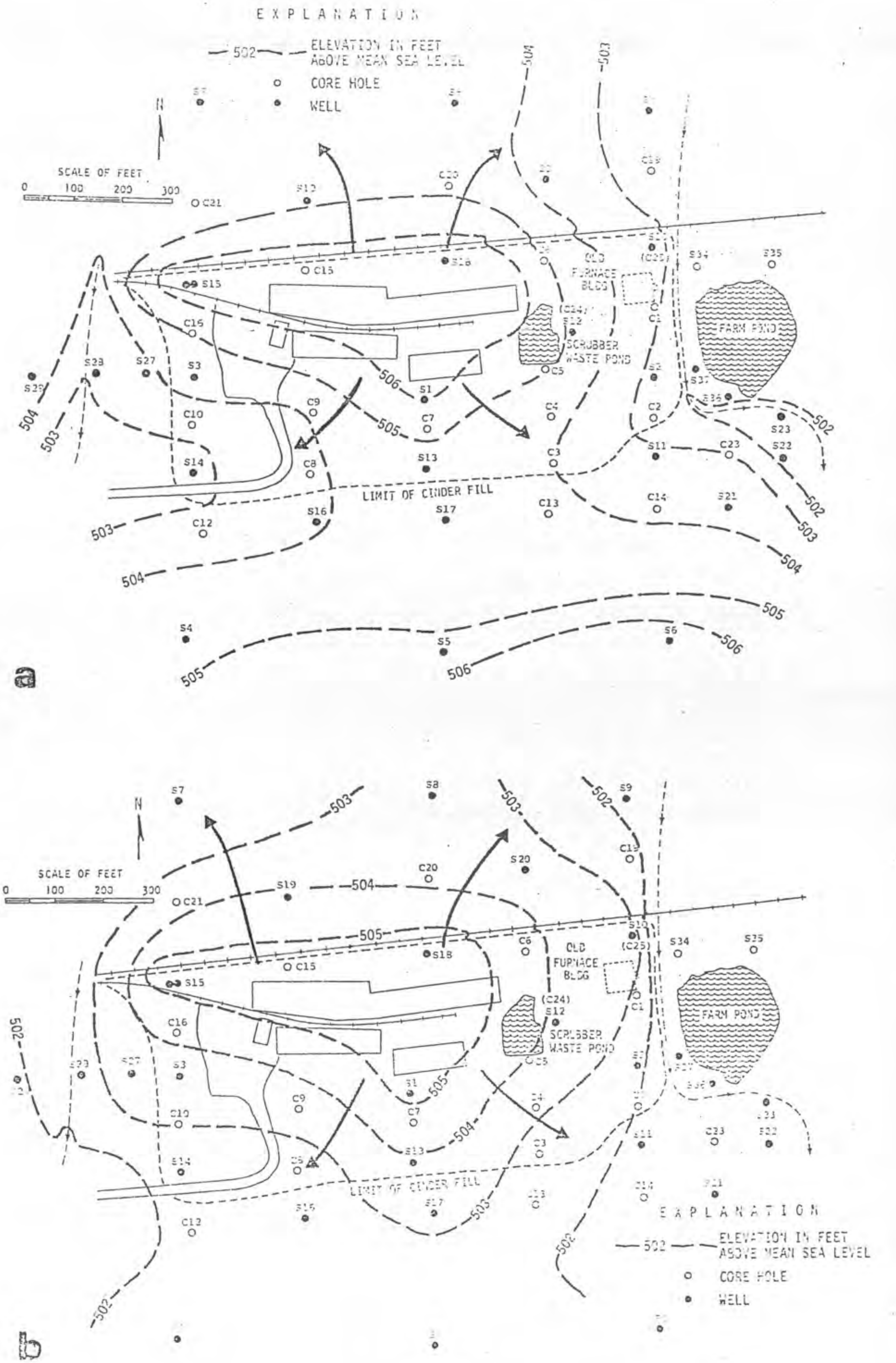


Figure 17. Water table contour maps for A) March, '75, and B) November, '75 - Site A

materials at the plant site, its topographic setting (higher than the surrounding land), and the liquid disposal activity of the plant all contribute to the development of this recharge mound.

Water level hydrographs for all deep wells at Site A are presented in figure 18. It should be noted that water levels in wells S-5D, S-6D, S-7D, and S-8D took approximately 15 months to stabilize. This was due to the relative impermeable nature of the materials these wells were completed in. Wells S-1D, S-2D, S-3D, S-4D, and S-9D were completed in sandier units and therefore were reflecting stabilized water levels within 1 or 2 months. Due to the slow recovery rates of some deep wells, they were not sampled monthly as were the shallow wells. The dots in figure 18 indicate when samples were collected. The decline in water levels after sampling is obvious in data from wells finished in the less permeable units. Maximum and minimum water levels for all deep wells are summarized in table 6.

Due to the problem of not having stabalized water levels in some of the deep wells for the period of record, monthly piezometric surface maps were not drawn. An estimated piezometric surface maps for deep wells is presented in figure 19. In general, water levels in the deep wells are higher than those in the shallow wells indicating a probable upward movement of water within the glacial drift sequence. In the immediate plant area, where the

Table 5. Range of water level flucuations in shallow wells - Site A

Well no.	LSD	Low			High			Flucuation
		Depth below land(ft)	MSL	Date	Depth below land(ft)	MSL	Date	
1-s	507.08	2.05	505.03	11-18-75	.73	506.35	3-20-75	1.32
2-s	507.83	6.10	501.73	7-13-76	4.15	503.68	1-9-75	1.95
3-s	505.60	2.80	502.80	10- 1-76	.22	505.38	3-20-75	2.58
4-s	506-87	4.64	502.23	10- 1-76	1.51	505.36	5-20-75	3.13
5-s	507.07	4.32	502.75	11-18-75	1.31	505.76	3- 2-76	3.01
6-s	510.51	9.43	501.08	10- 1-76	2.97	507.54	4-8-76	6.46
7-s	506.78	5.63	501.15	10- 1-76	2.36	504.42	3-2-76	3.27
8-s	506.13	2.75	503.38	7-29-76	2.38	504.75	3-2-76	.37
9-s	504.39	3.84	500.55	10- 1-76	1.78	502.61	4-8-76	2.06
10-s	504.16	1.34	502.82	8-12-75	.23	503.93	7-22-75	1.11
11	507.82	6.99	500.83	10- 1-76	4.51	503.31	4-8-76	2.48
12	508.87	5.52	503.35	7-13-76	4.05	504.82	7-22-75	1.47
13	507.00	3.29	503.71	11-18-75	2.25	504.75	7-22-75	1.04
14-s	504.45	2.79	501.66	10- 1-76	.88	503.57	7-22-75	1.91
15-s	508.92	4.89	504.03	10- 1-76	2.13	506.79	7-22-75	2.76
16	505.81	3.30	502.51	10- 1-76	1.53	504.28	4-8-76	1.77
17	505.89	2.89	503.00	10- 1-76	1.47	504.42	3-2-76	1.42
18	510.14	5.30	504.84	7-13-76	3.22	506.92	7-22-75	2.08
19	506.24	3.35	502.89	10- 1-76	1.38	504.86	3-2-76	1.97
20	504.98	2.21	502.77	10- 1-76	1.28	503.70	3-2-76	.93
21	509.04	7.93	501.11	10- 1-76	5.02	504.02	4-8-76	2.91
22	503.50	4.19	499.31	10- 1-76	1.54	501.96	3-2-76	2.65
23	502.64	2.60	500.04	10- 1-76	1.31	501.33	9-24-75	1.29
24	500.79	3.13	497.66	10- 1-76	.20	500.59	9-24-75	2.93
25	500.37	3.61	496.76	10- 1-76	.11	500.26	3-2-76	3.50
26	499.30	4.40	494.90	10- 1-76	.61	498.69	3-2-76	3.79
27	505.29	3.54	501.75	10- 1-76	1.31	503.98	3-2-76	2.23
28	503.82	3.05	500.77	10- 1-76	.22	503.60	4-8-76	2.83
29	505.59	5.12	500.47	10- 1-76	1.23	504.36	4-8-76	3.89
30	500.65	3.54	497.11	10- 1-76	.15	500.50	3-2-76	3.39
31	499.54	3.90	495.64	10- 1-76	1.10	498.44	4-8-76	2.80
32	498.44	3.32	495.12	10- 1-76	.13	498.31	4-8-76	3.19
33	497.92	3.83	494.09	10- 1-76	.36	497.56	4-8-76	3.47
36	503.47	4.13	499.34	9- 9-76	1.15	502.32	7-29-76	2.98
CHI-s	486.00	7.49	478.51	10- 1-76	1.96	484.04	5-20-75	5.53

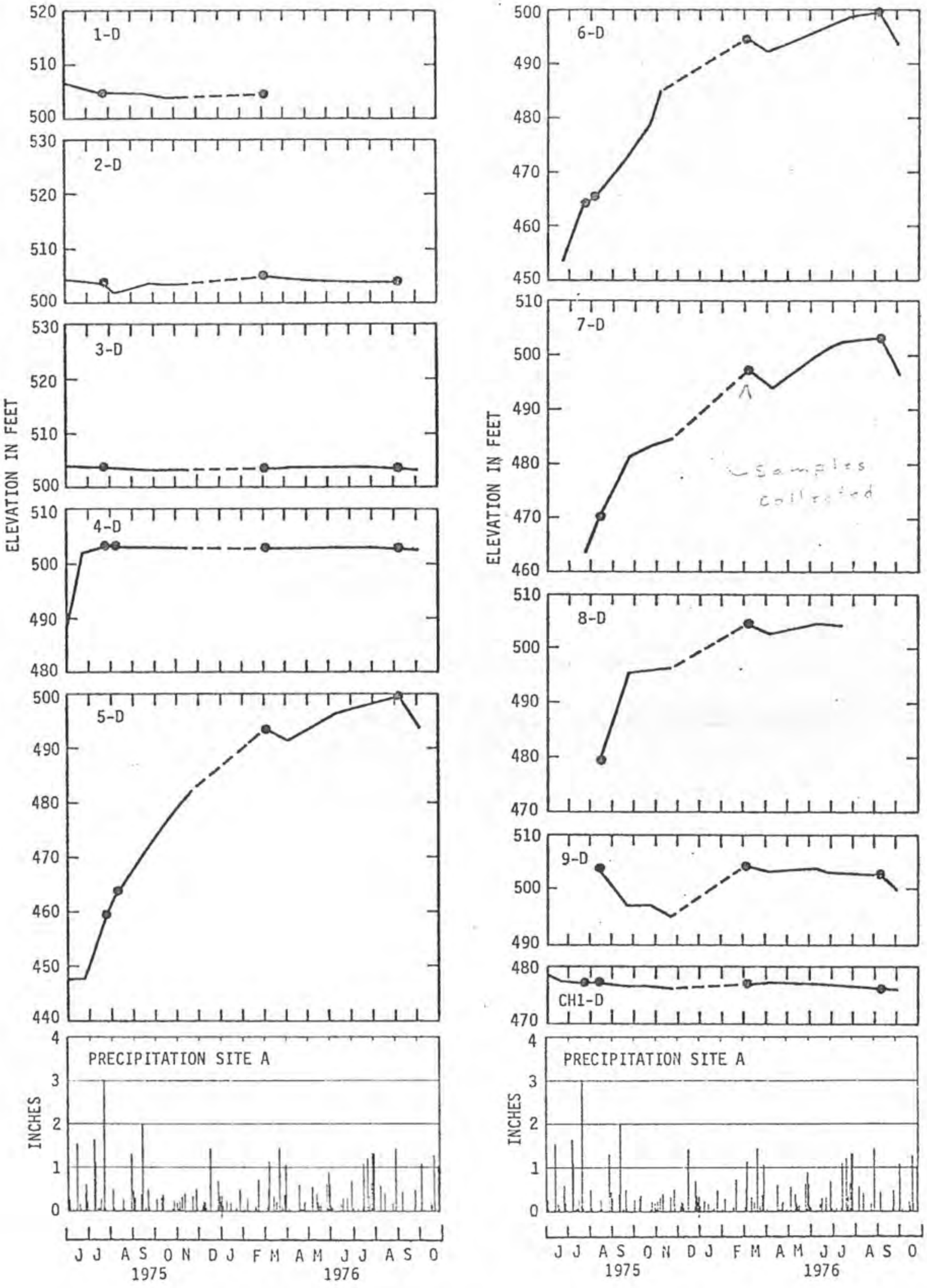


Figure 18. Water level hydrographs of deep wells - Site A

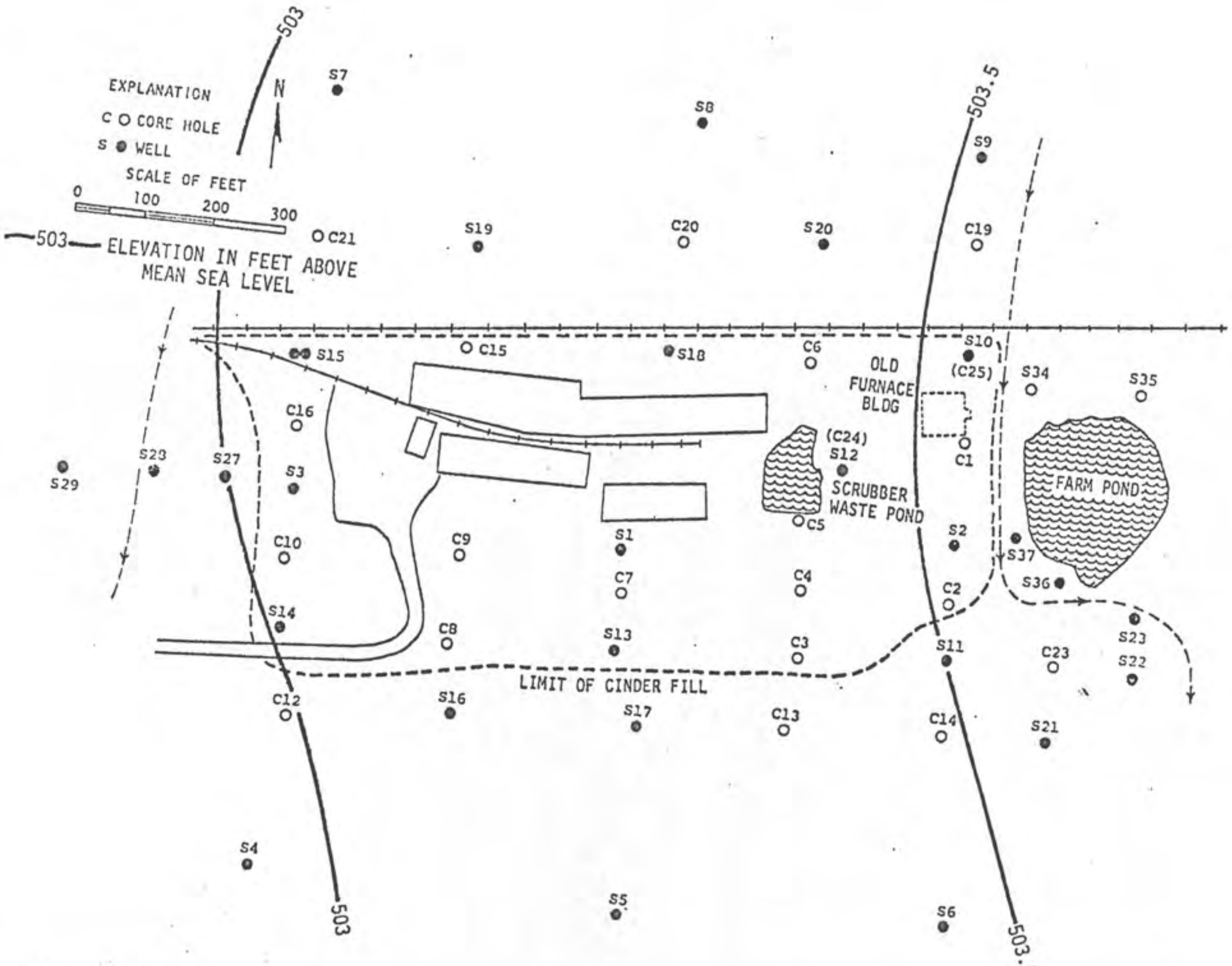


Figure 19. Estimated piezometric surface map of deep units – Site A

Table 6. Range of water level flucuations in deep wells - Site A

Well no.	LSD	Low			High			Flucuation
		Depth below land(ft)	MSL	Date	Depth below land(ft)	MSL	Date	
1-D	507.08	3.11	503.97	11-18-76	.87	506.21	5-20-76	2.24
2-D	507.83	4.50	503.33	1- 9-75	2.87	504.96	3- 2-76	1.63
3-D	505.60	3.98	501.62	1- 9-75	1.92	503.68	5-20-76	2.06
4-D	506.87	25.21	481.66	5-20-75	4.12	502.75	7-20-75	21.09*
5-D	507.07	59.40	447.67	5-20-75	7.61	499.46	9- 9-76	51.79*
6-D	510.51	56.75	453.76	6-18-76	10.96	499.55	9- 9-76	45.79*
7-D	506.78	43.22	463.56	7-22-75	3.60	503.18	9- 9-76	39.62*
8-D	506.13	26.72	479.41	8-13-75	1.58	504.55	6- 8-76	25.14*
9-D	504.39	8.70	495.69	11-18-75	+ .41	504.80	3- 2-76	9.11
CHI-D	486.00	9.56	476.44	10- 1-76	6.61	479.39	5-20-75	2.95

*Water levels not stabalized

shallow water levels are mounded, the movement of water in the shallow deposits probably is downward and horizontally while water in the deeper units probably is moving upward and horizontally.

Using Darcy's equation $v = PI$ where:

v = apparent or bulk velocity
P = permeability
I = hydraulic gradient

an average apparent rate of groundwater movement in the shallow deposits was calculated for the immediate plant area. The average rates of groundwater movement from the mounded area in March 1976 and November 1975 where 0.17 and 0.19 ft/day respectively. The actual or effective velocity is described by Hantush (19) as the apparent volume divided by the effective porosity of the soil or aquifer. The effective porosity is the portion of pore space in a saturated permeable material in which flow of water takes place. Not all of the pore space of a mterial filled with water is open for flow, since part of the voids are filled with water that is held in place by molecular and surface water tension forces.

The porosity of the aquifer materials (Hagerstown Formation) at Site A where measured to 0.32. Based on data presented by Todd (20), an effective porosity or specific yield of 0.10 was assumed.
$6\text{-}7 \times 10^{-4}$ cm/sec
Using this value, effective velocities of 1.7 and 1.9 ft/day or 620 to 690 ft/year were calculated for the mounded area of the plant.

These unexpected high rates of movement can be explained by the relatively steep hydraulic gradients developed beneath the plant complex. Similar calculations in areas removed from the influence

5×10^{-5} cm/sec

of the recharge mound resulted in average effective velocities of 0.15 to 0.40 ft/day or 55 to 145 feet per year.

A soil temperature survey was conducted at Site A by the Illinois State Geological Survey on April 16 and 17, 1975.

The 58 stations occupied in this survey are shown on figure 20. Temperature measurements were made in degrees Fahrenheit at a depth of 70 centimeters below land surface. Lines of equal temperature on a contour interval of one degree Fehrenheit are shown. A halo of high temperature was measured surrounding the smelter. The direction of shallow ground-water flow away from the smelter may be interpreted from lateral changes in the soil temperatures. Inferred lines of ground-water flow are shown on figure 20. Flow appears to be west to southwest, east to southeast and north from the site. The ground-water flow to the north discharges in the low ground immediately north of the railroad. The temperature survey indicates very little ground-water flow to the south of the site. Flow in this directions is restricted by the low swale just south of the plant property.

The shallow flow system interpreted from soil temperature measurements is similar to the potentiometric surface map of the shallow ground-water flow system constructed from water level measurements in shallow piezometers at this site (see figure 17).

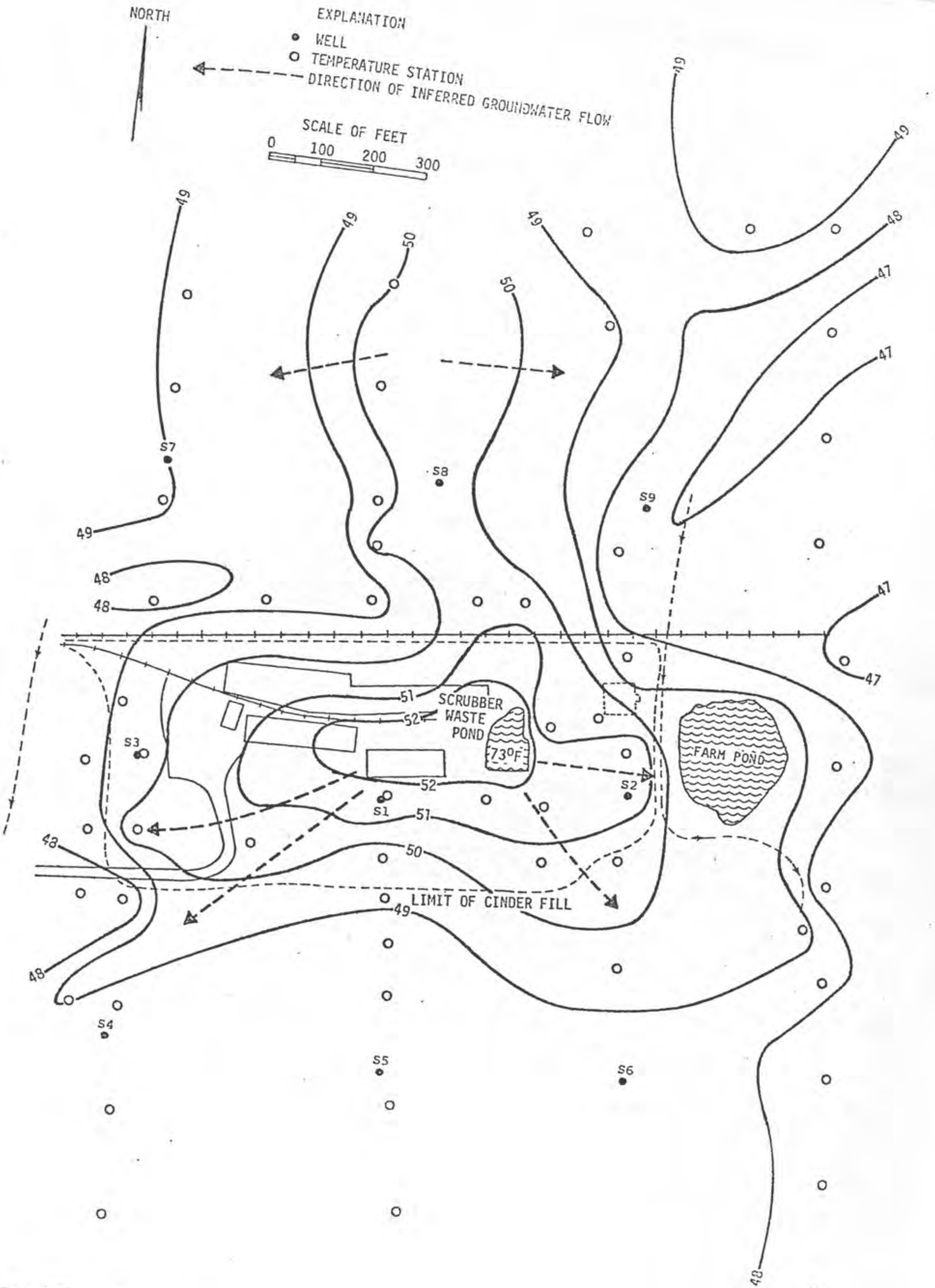


Figure 20. Soil temperature stations and results - Site A.

Chemical data

Aside fromproviding data for detailed geologic description, chemcial analysis of the core samples were conducted to define: (1) the vertical and horizontal migration patterns of chemical pollutants through the soil; and 2) the residual chemical buildup in soils in the vicinity of the pollution source. Results of chemical analysis conducted on soil core samples from site A are tabulated in Appendix C. Preliminary analyses of core samples during the early stages of the study indicated that four elements (zonc, cadmium, copper, and lead) were most likely to be carried into the soils and groundwater system beneath the plant property. As a result these elements were selected for routine analytical analyses.

Results of chemical analysis of core samples from the Site A control hole located approximately 3 miles south-south west of the plant, and samples from unaffected soil horizons beneath the plant property suggest that background concentrations for the 4 elements tested should be about 20 to 50 mg/l for zinc, .04 to 1.5 mg/l for cadmium, 10 to 30 mg/l for copper, and 10 to 40 mg/l for lead. There appears to be no significant chemical variation with depth or between geologic unit boundaries. Some zinc levels in isolated Pleistocene soils were higher.

To outline the limits of migration of these metals beneath the plant and give an indication of the effectiveness of the soils in retaining these metals, a series of cross sections showing zinc concentrations of the soil were prepared. The west to east cross sections are shown in figure 21. On the north side of the railroad tracks rather small quantities of zinc were found in the upper 3 to 5 feet of the soil profile (see 1-1 and 2-2). Most of the zinc introducted into this area probably was wind blown dust and ashes from the plant stack. The area of greatest accumulation and deepest penetration of zinc in the soil occurred immediately beneath the plant property (see 3-3', 4-4', 5-5', and 6-6'). Two principal sources of pollution, the cinders covering the plant property and the scrubber waste water, have resulted in large quantities of zinc moving into the soil profile. The effect of the scrubber waste water discharge is obvious in cross section 4-4'. Beneath well S-12 the depth of penetration (to the 100 mg/l boundary) is approximately 28 feet. However, it is interesting to note that lateral migration due to this activity has still been very limited. It also is worth noting that no significant lateral migration has taken place beyond the two drainage ditches bounding the plant on the west and east. Further south, beyond the limits of the cinder covered portion of the plant property, very limited zinc penetration has occurred (see 7-7' and 8-8').

The north-south cross sections shown in figure 22 also indicate that significant residual soil zinc concentrations are limited to the immediate area beneath the plant property.

Similar cross sections illustrating the buildup of cadmium, copper, and lead were prepared for this site. The general shapes of these cross sections are similar to those for zinc. The depth of penetration of cadmium is slightly less than that of zinc but considerably greater than that of copper and lead. Figure 23 shows the general buildup of cadmium in the soil for two cross sections through the plant property.

Figures 24 and 25 illustrate the same two cross sections

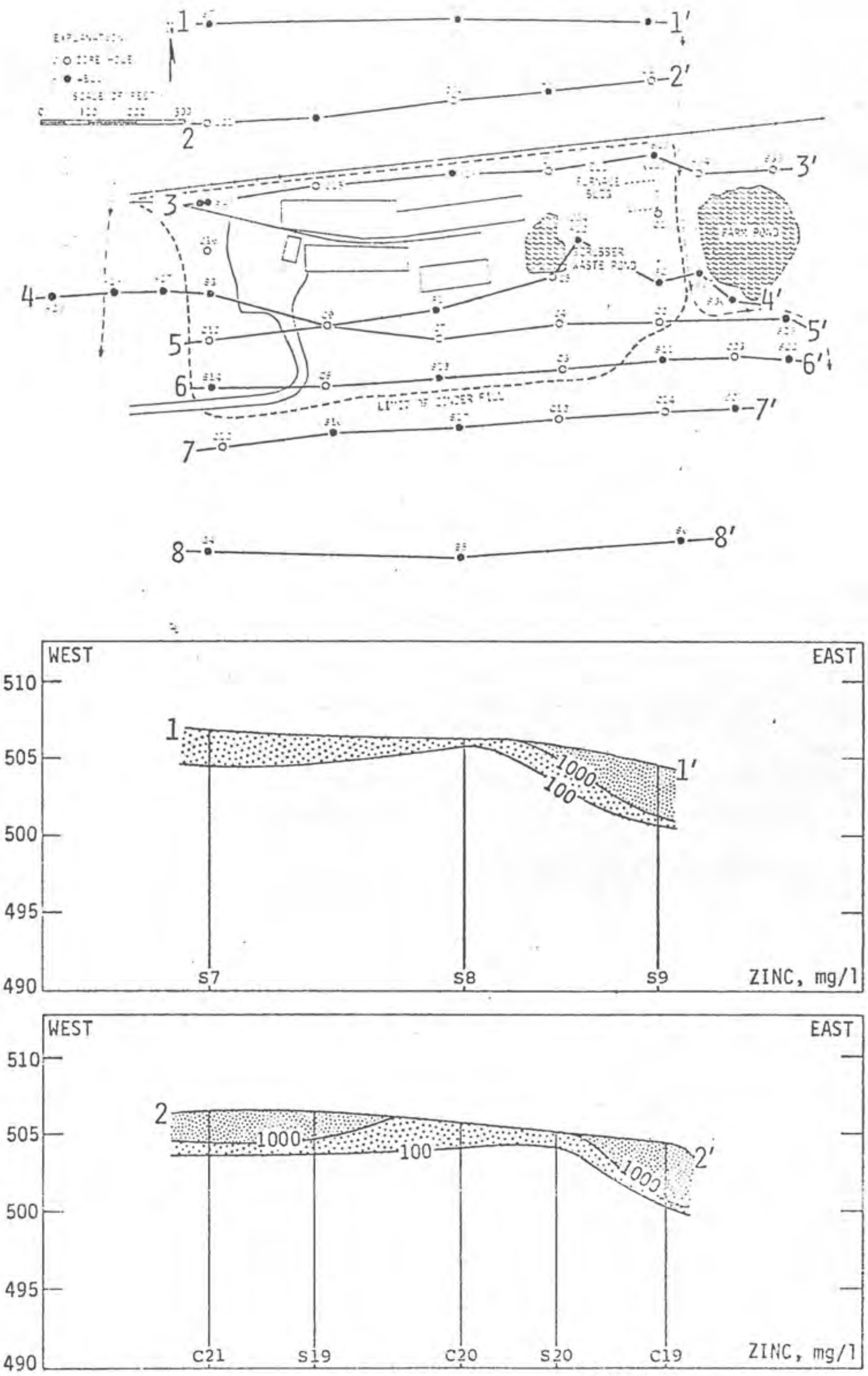


Figure 21. East-west soil zinc concentration profiles - Site A

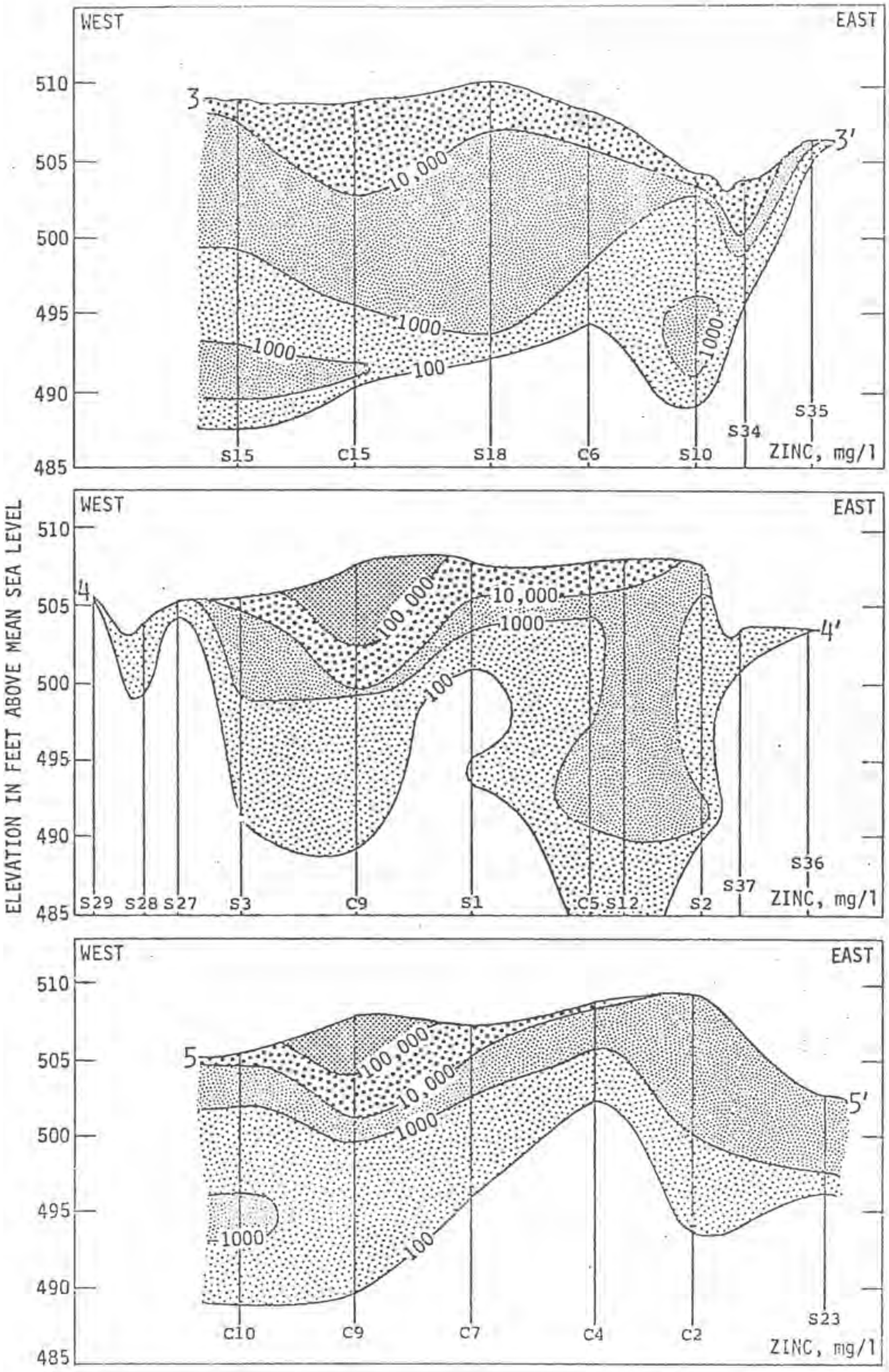


Figure 21. (Continued)

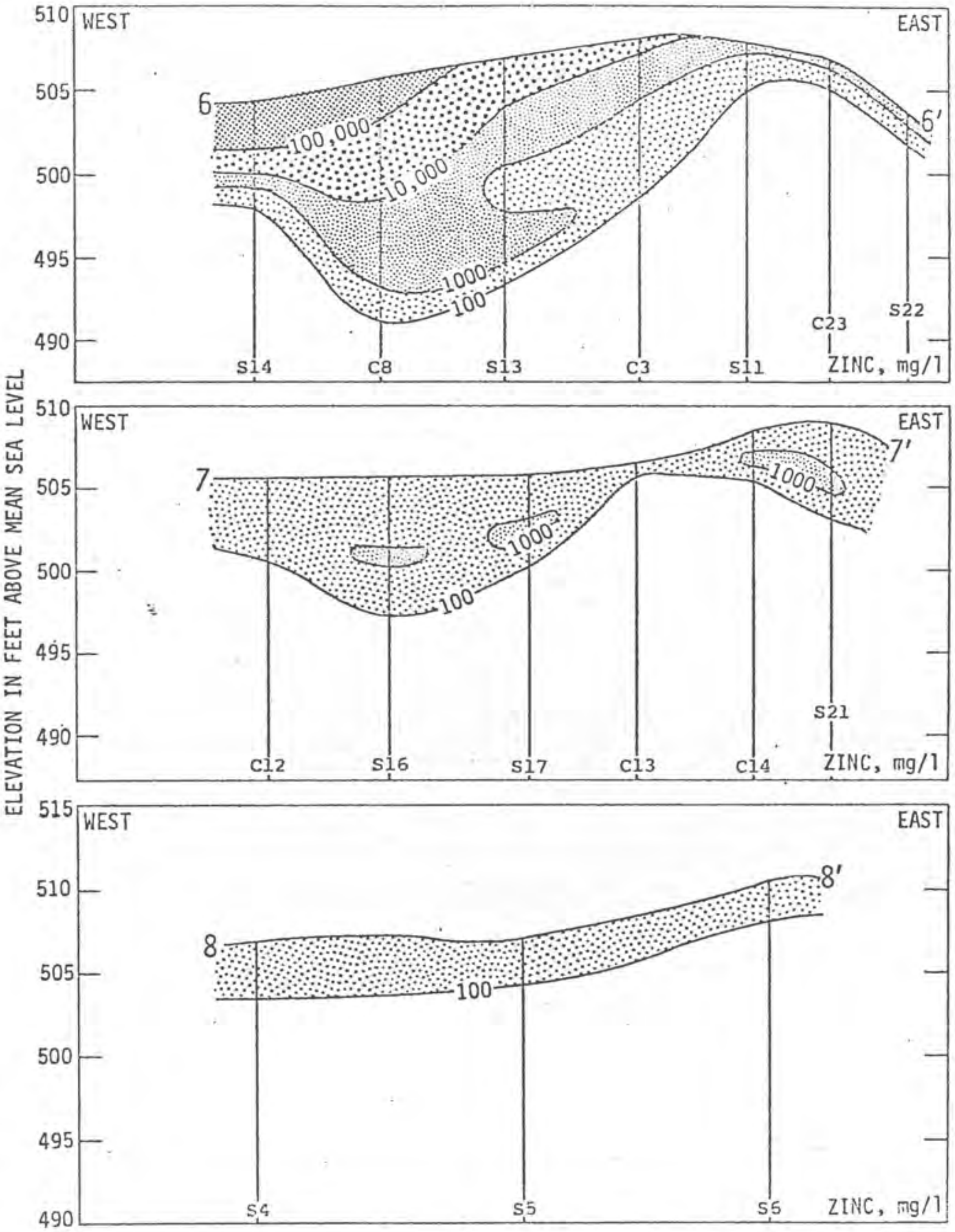


Figure 21. (Continued)

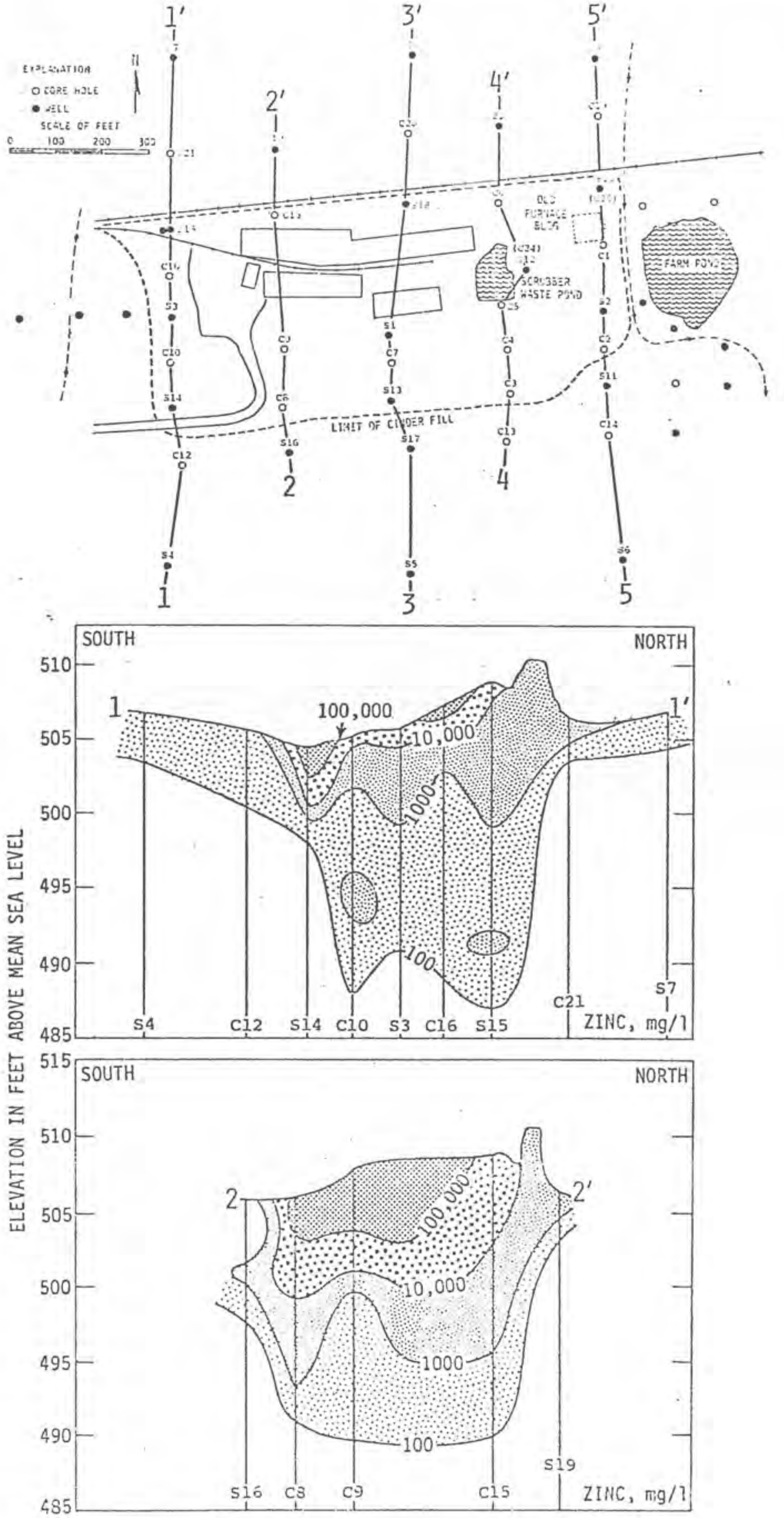


Figure 22. North-South Soil Zinc Concentration profile - Site A.

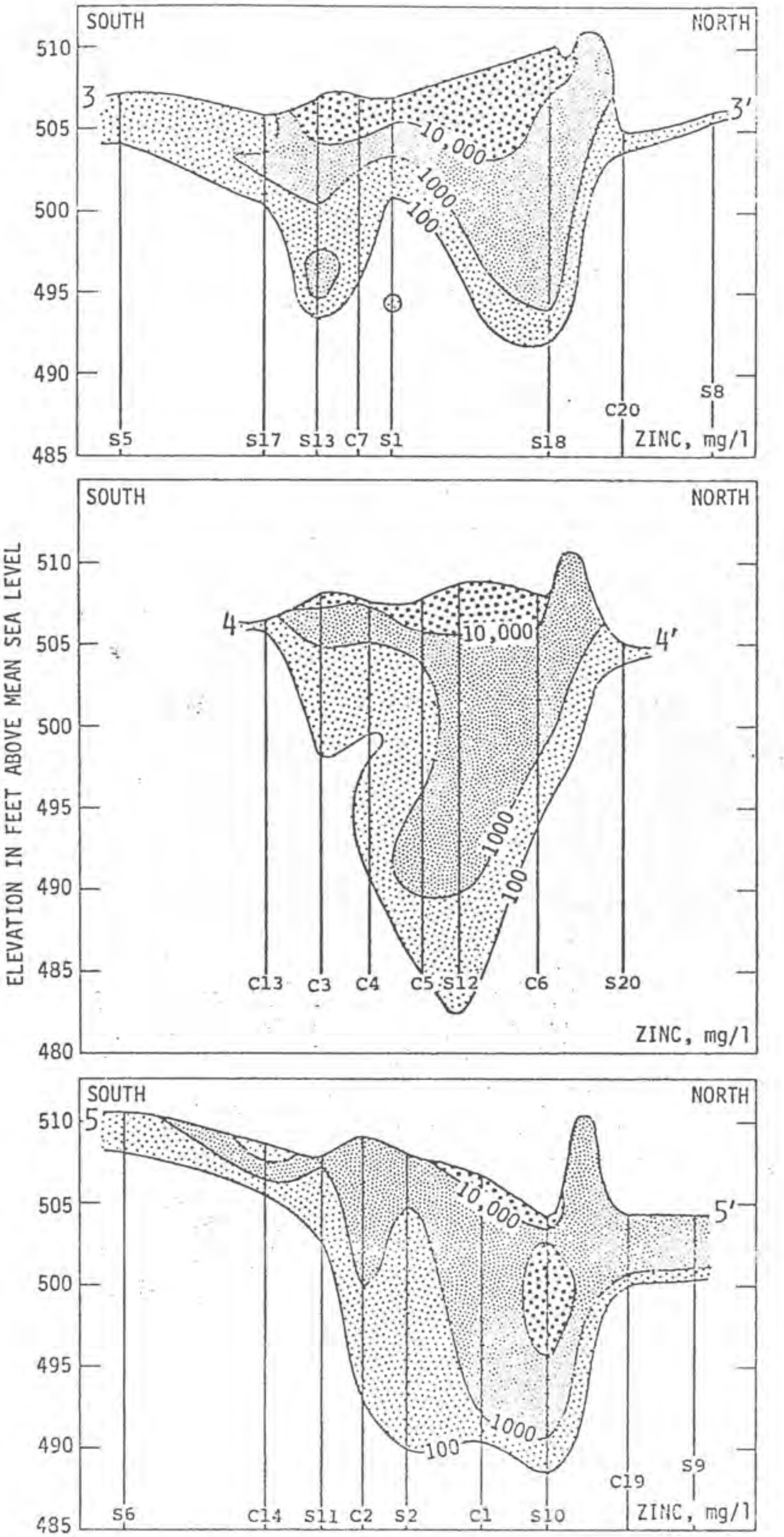


Figure 22. (Continued)

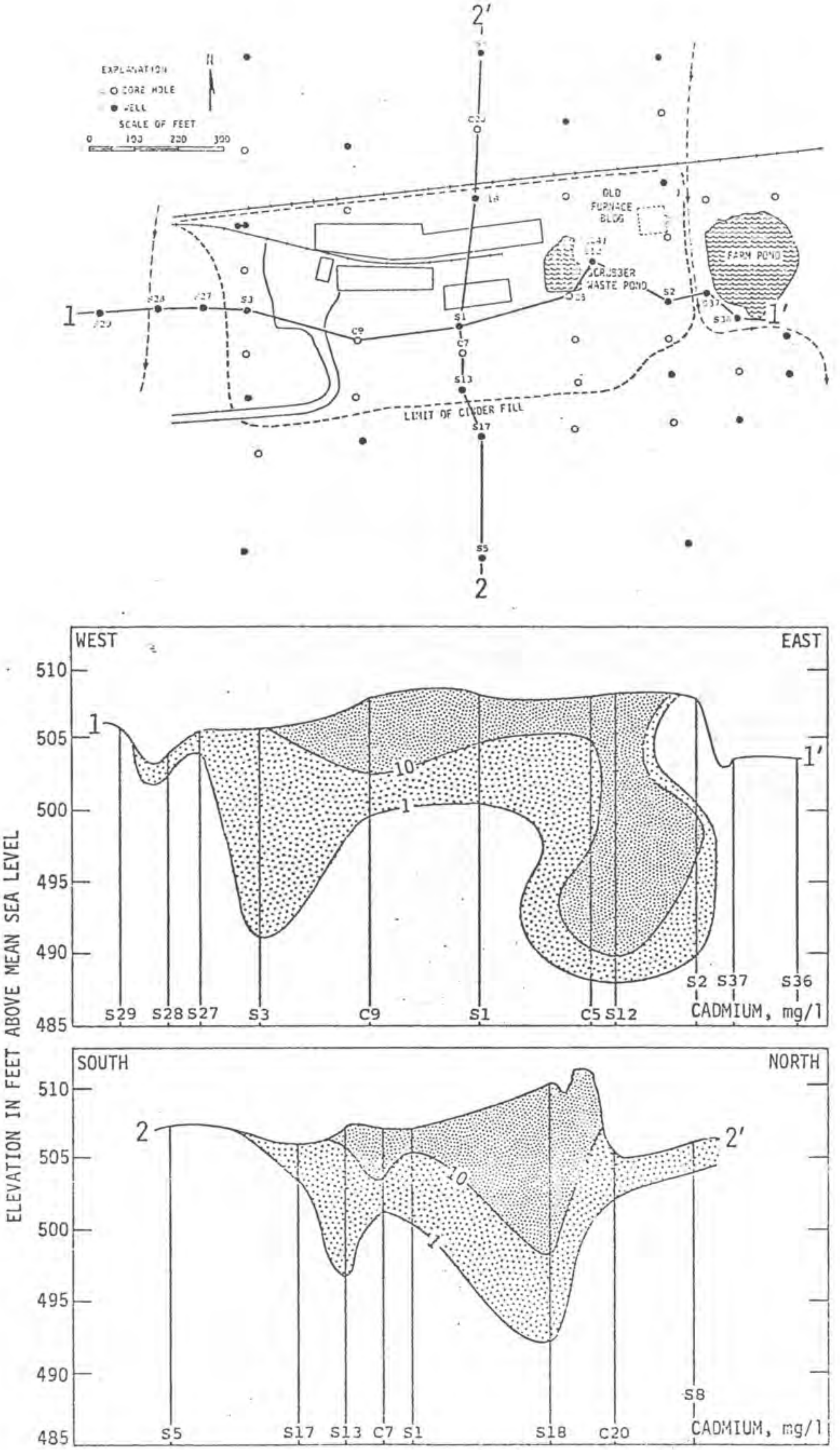


Figure 23. Soil cadmium concentration profiles - Site A

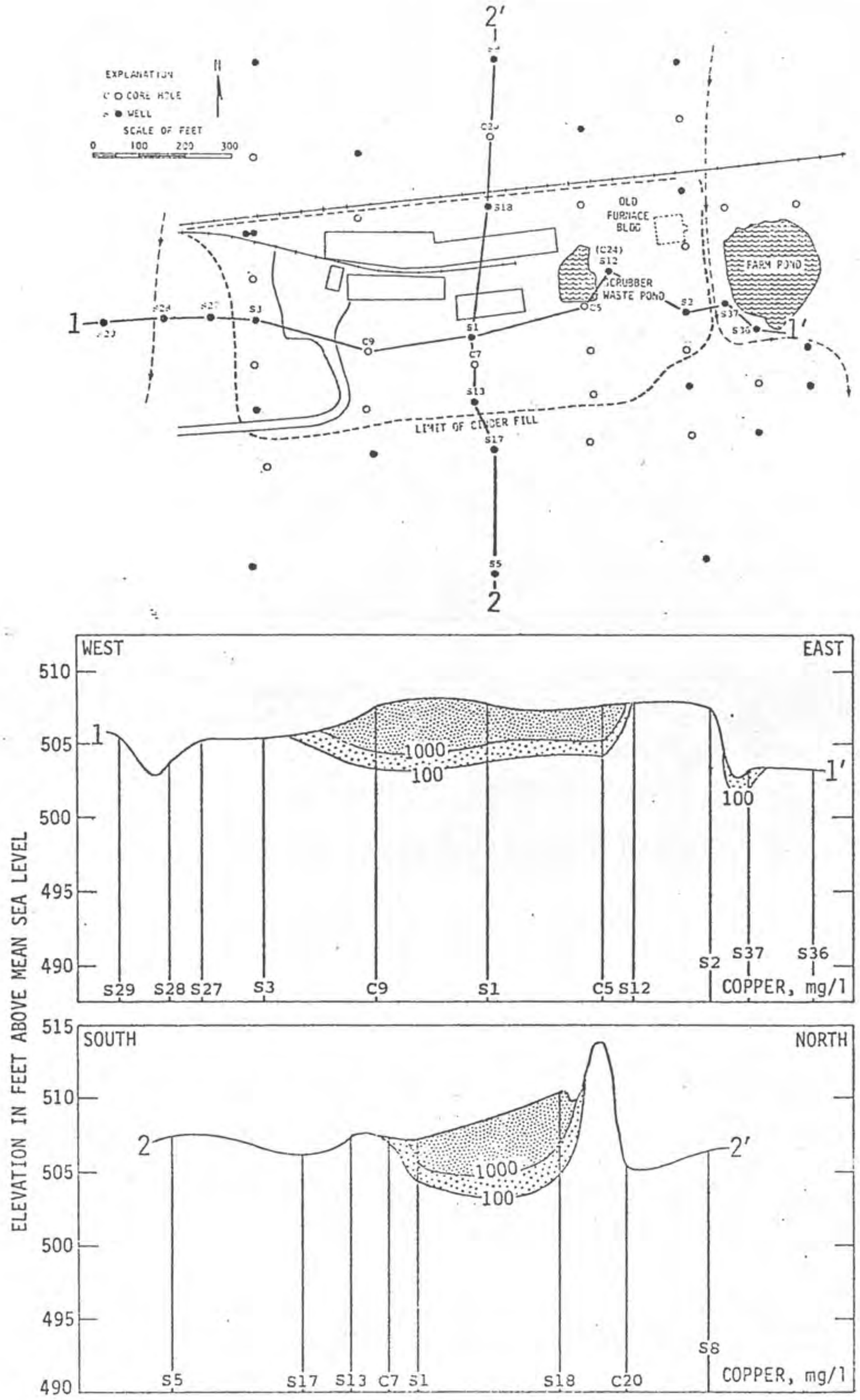


Figure 24. Soil copper concentration profiles - Site A

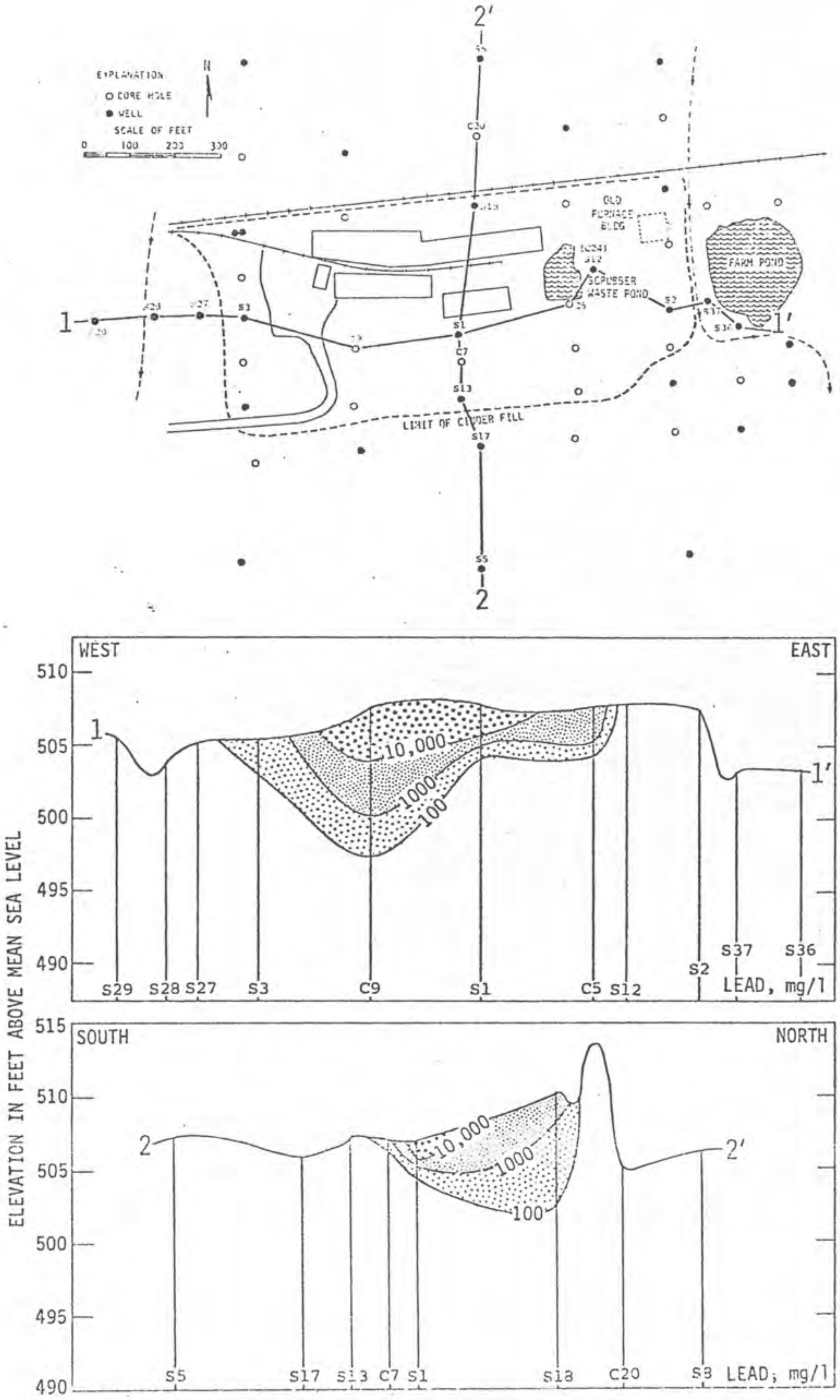


Figure 25. Soil lead concentration profiles - Site A

for copper and lead, respectively. The very shallow depths of penetration of these elements substantiates results of laboratory studies by Frost and Griffin (2) indicating the relative immobility of these metals. In general it was found that the areas of greatest penetration of the 4 elements traces, occurred beneath the scrubber waste water pit where a significant source of the metals, the scrubber waste water, is present, and the recharge into the soil system is greatest. In other areas removed from the pit the presence of the cinders becomes the dominant factor with lowland areas were ponded water accumulated secondary.

In addition to the direct percolation of metals rich water, at the plant site, a significant amount of metals rich surface water is running off the plant property and percolating into the stream beds draining the plant to the southwest and southeast. An accumulation of metals-rich cinder type sediments in the stream bed was noted. The retention of metals from the percolating water by the soil beneath the stream beds is illustrated in figure 26. From figure 26 it can be seen that the concentration of metals retained and depth of penetration decreases as the distance away from the plant site increases. The exact location of core sampling with respect to the centerline of the stream bed can account for significant variations in the recorded chemical constituents in the soil. Where possible, core sampling should be taken right in the center or bottom of the stream bed to obtain comparable results from hole to hole.

The mechanisms retaining the metals in the soil profile at site A predominantly are cation exchange and precipitation of insoluble metal compounds as a result of pH change. Cation exchange capacity

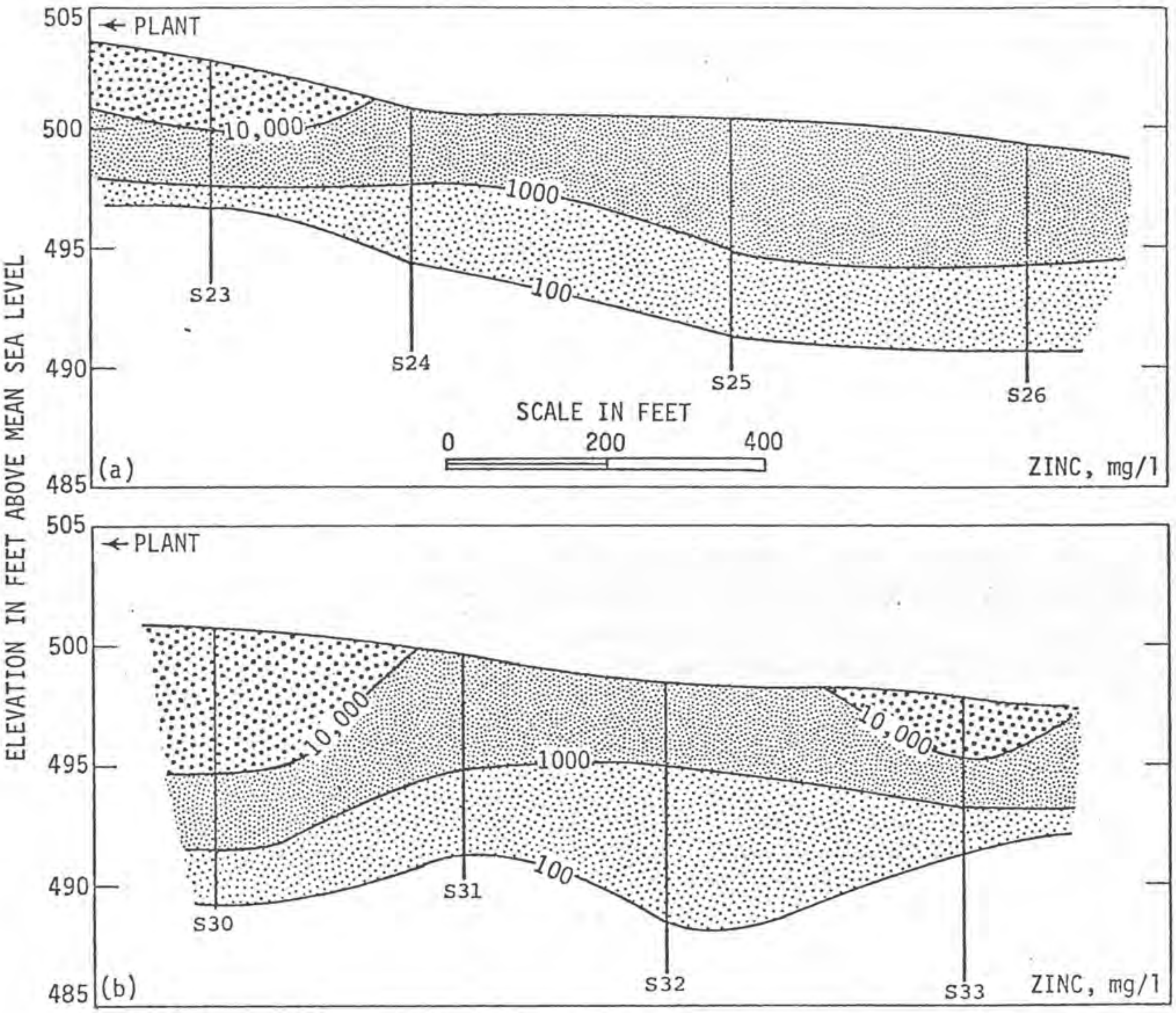


Figure 26. Streambed soil zinc concentration profiles - Site A

data generated indicate little variation in the retention capabilities of the upper geologic units, the silts, clays and tills. Therefore, as metals-rich water percolates downward through the soil profile the metals are exchanged preferentially in reverse order of their mobility.

Cation exchange capacities of soils measured at Site A range from about 4 to 10 meg/100 gram with the larger values occurring in the shallower soils. If zinc were transferred onto the available exchange sites of the soil, cation exchange could account for soil zinc concentrations up to about 3500 mg/l. This value could be higher according to some soil specialist as the measured C.E.C. may be lower than the original capacity of the soil. Some researchers maintain that the soil becomes "poisoned" in the presence of pollutants and true C.E.C. values can not be measured.

Aside from that possibility, three other factors can be used to explain the difference between the very high soil zinc concentrations shown in the upper part of the soil profiles and the values attributable to cation exchange:

1) Some of the very high values obtain for the surface and near surface samples actually are chemical results of cinder fill samples;
2) Immediately beneath the cinder fill, fine grained sediments from the cinders have been illuviated into the underlying soil also resulting in high zinc values of those samples; and
3) Soluble and insoluble salts of zinc and the other metals may be temporarily stored in the aerated zone waiting for eventual migration downward with later recharge events. This also results in higher zinc concentrations in soil samples from this horizon.

As the cation exchange capacity of the soil is exhausted and sufficient depth is reached to eliminate the three factors just noted, the metals buildup in the soil slowly continues to advance deeper into the soil profile. As this process occurs, calcium and magnesium are released into the water from the soil and the pH of the soil is lowered. When a depth is reached where the soil has not been leached, the pH increases, resulting in the formation of zinc precipitates, and a sharp break or decrease in soil zinc content. The alteration of soil pH in the upper geologic units was enhanced by the character of the infiltrating fluid. Samples of water collected after percolating through the cinder fill materials forming the sides of the disposal pit had measured pH values near 5. It can be assumed that the same pH was experienced by water filtering downward through the cinder fill covering the plant surface. It is suspected that sulphur contained in the cinders was dissolved to form a weak sulfuric acid thus creating the low pH and increasing the mobility of the zinc.

The conclusion pertaining to the mechanism of zinc and other metals fixation drawn from this field study are in agreement with the results of recent laboratory studies by Frost and Griffin (2). They conclude that increased removal of metals from solution occurs "with increasing pH values and with increasing concentrations of the heavy metal in solution".

Representative adsorption isotherms for Zn, Cu, and Cd developed by Frost and Griffin (2) are shown in Figure 27 . A marked increase in adsorption occurred for all three ions as the pH increased. The curves for Zn adsorption show a sharp increase in gradient at about 250 mg/l at pH 6.75 and 7.0, respectively. Similarly, the pH 7 curve for Cu adsorption had a sharp gradient increase at about 20 mg/l, as did the Cd curves at about 40 mg/l and 5 mg/l at pH6.5 and 7.0, respectively. A sharp change in gradient in an adsorption isotherm generally is viewed as initiation of precipitation.

Adsorption isotherms obtained for pure montmorillonite clays, at pH 5.0, developed by Frost and Griffin (2) is presented in Figure 28 . Curve A illustrates the amount of Cd, Zn, or Cu adsorbed by montmorillonite from pure $Cd(NO_3)_2$, $Zn(NO_3)_2$, or $Cu(NO_3)_2$ solutions that were adjusted to pH 5.0. Curve B illustrates the data obtained when using landfill leachate. Maximum adsorption occurred in the pure $Cd(NO_3)_2$, $Zn(NO_3)_2$, or $Cu(NO_3)_2$ solutions, whereas adsorption in the leachate was much lower because of competition by organics and other metals in solution, and organic complexing of the metals. The field situations discussed in this paper lie somewhere between these extremes, and probably closer to the pure solution than the leachate. In Griffins (21) studies montmorillonite adsorbed approximately 5 times more metals than other clays under similar conditions. It has already been noted that the soils at Site A are montmorillonite rich.

Precipitation also is an important mechanism for heavy-metal removal from solutions as is indicated by the removal of Cu, Zn, and Cd from solutions of varying pH and concentrations shown in Figure 27. Calculations based on solubility product ($K_{Zn(OH)_2} = 7 \times 10^{-18}$) indicated that at pH 7 $Zn(OH)_2$ is estimated to precipitate at a concentration of approximately 110 mg/l Zn. At pH 6.75,

$Zn(OH)_2$ solubility is estimated to be 290 mg/l Zn, and at pH 6.5 the Zn concentration is computed to be approximately 800 mg/l. Similar calculations of solubility product for $Cu(OH)_2$ ($_{Cu(OH)_2} = 1.6 \times 10^{-19}$) predicted that precipitation should be initiated at approximately 2 mg/l at pH 7 and 206 mg/l Cu at pH 6.

Calculations of the solubility product of Cd ($K_{Cd(OH)_2} = 6.5 \times 10^{-15}$) indicated that $Cd(OH)_2$ is much more soluble than either $Zn(OH)_2$ or $Cu(OH)_2$. However, the curves in Figure 25 are consistent with a mechanism of $CdCO_3$ formation: ($K_{CdCO_3} = 5.1 \times 10^{-12}$) will precipitate at Cd concentrations between 3 and 29 mg/l at pH 7 and between 29 and 290 mg/l Cd at pH 6.5.

Close examination of the data at site A indicate that the concentrations of zinc in the soil are highest in soils with a pH less than 6.5. Soil pH values as low as 3.4 were recorded and increased with depth to normal values around 7 to 8. Therefore, at low pH values, adsorption or cation exchange is the mechanism of heavy metal attenuation. The metals are adsorbed by the clays from solution as the liquid moves through the subsurface. As the pH increases, heavy metals not adsorbed by cation exchange are precipitated, thereby reducing concentrations of heavy metals in solution. Thus, pH controls the maximum concentration possible in solutions.

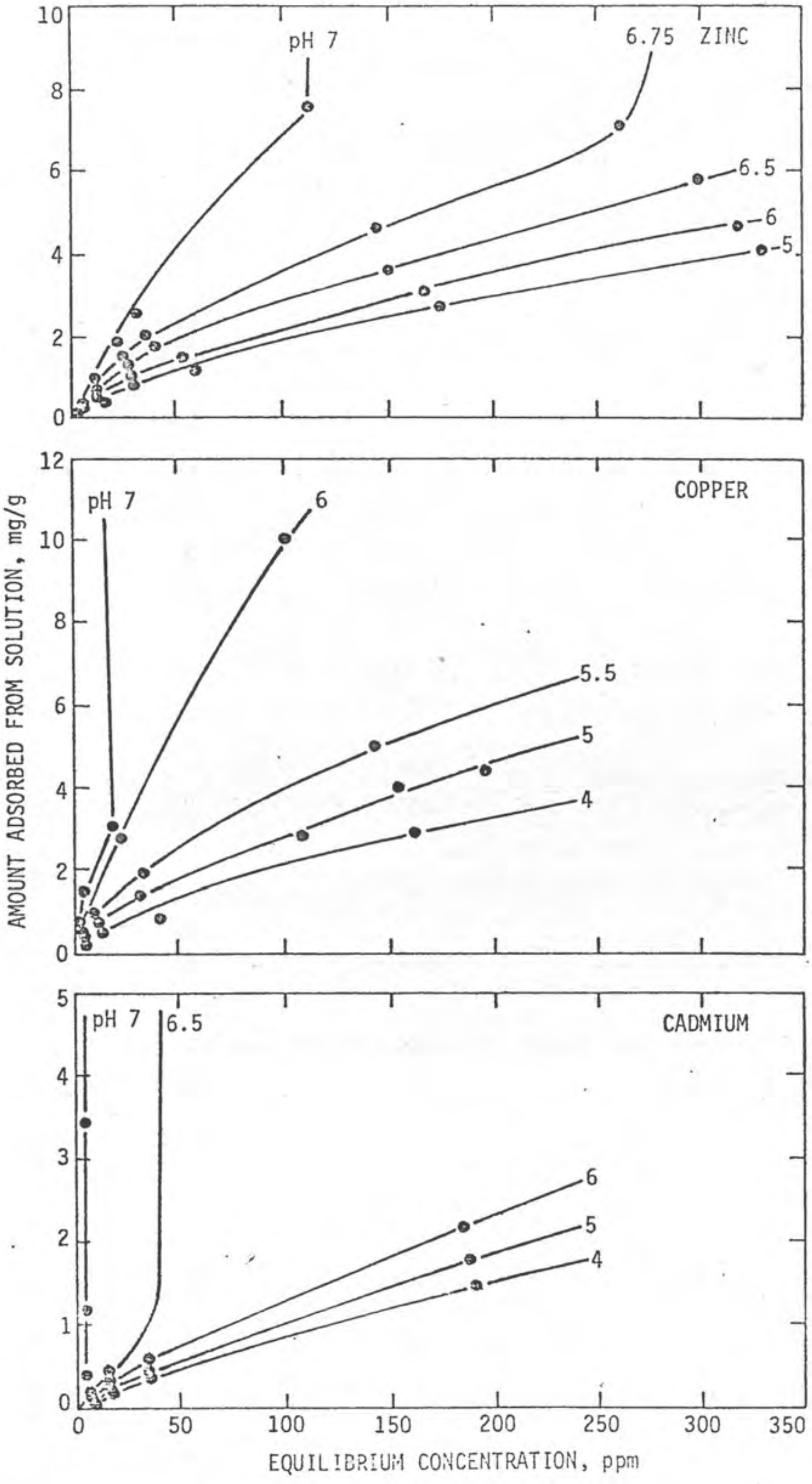


Figure 25 Representative adsorption isotherms for Zn, Cd, and Cu at various pH values (from Frost and Griffin, 1977)

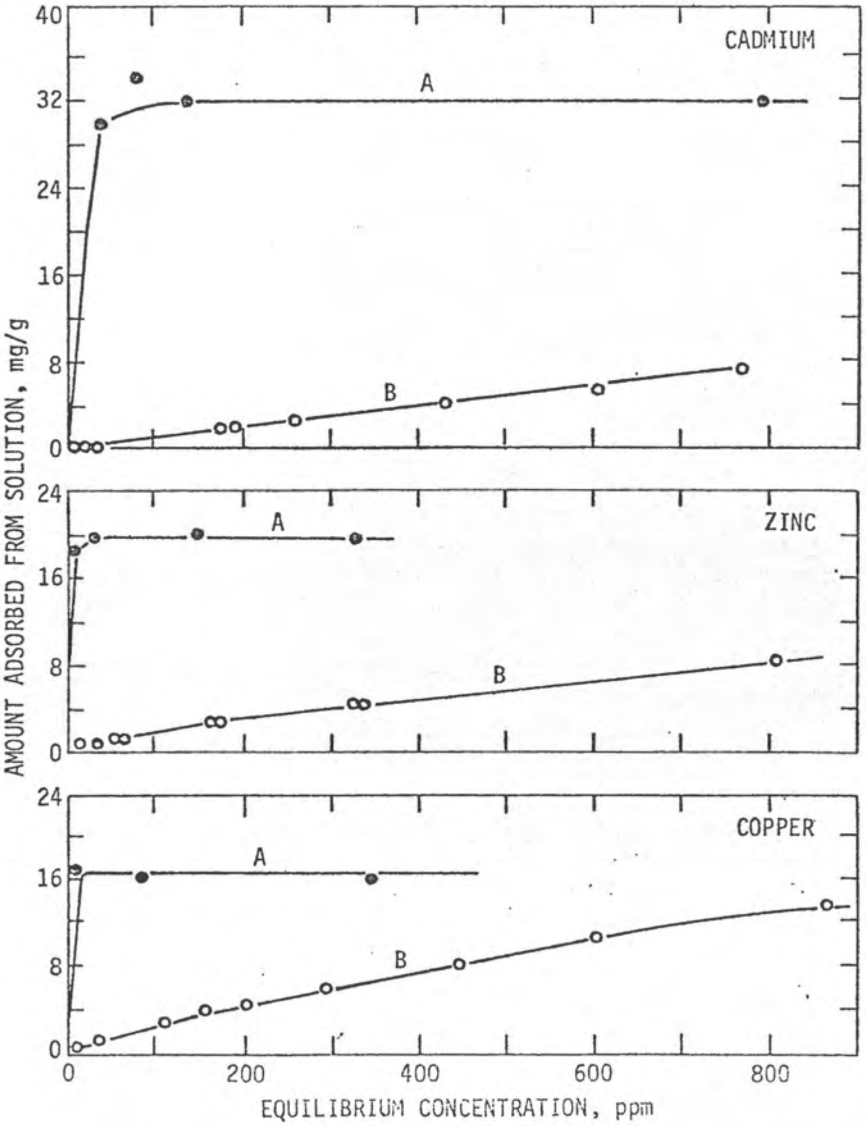


Figure 28. Adsorption isotherms for Zn, Cd, and Cu by montmorillonite (from Frost and Griffin, 1977).

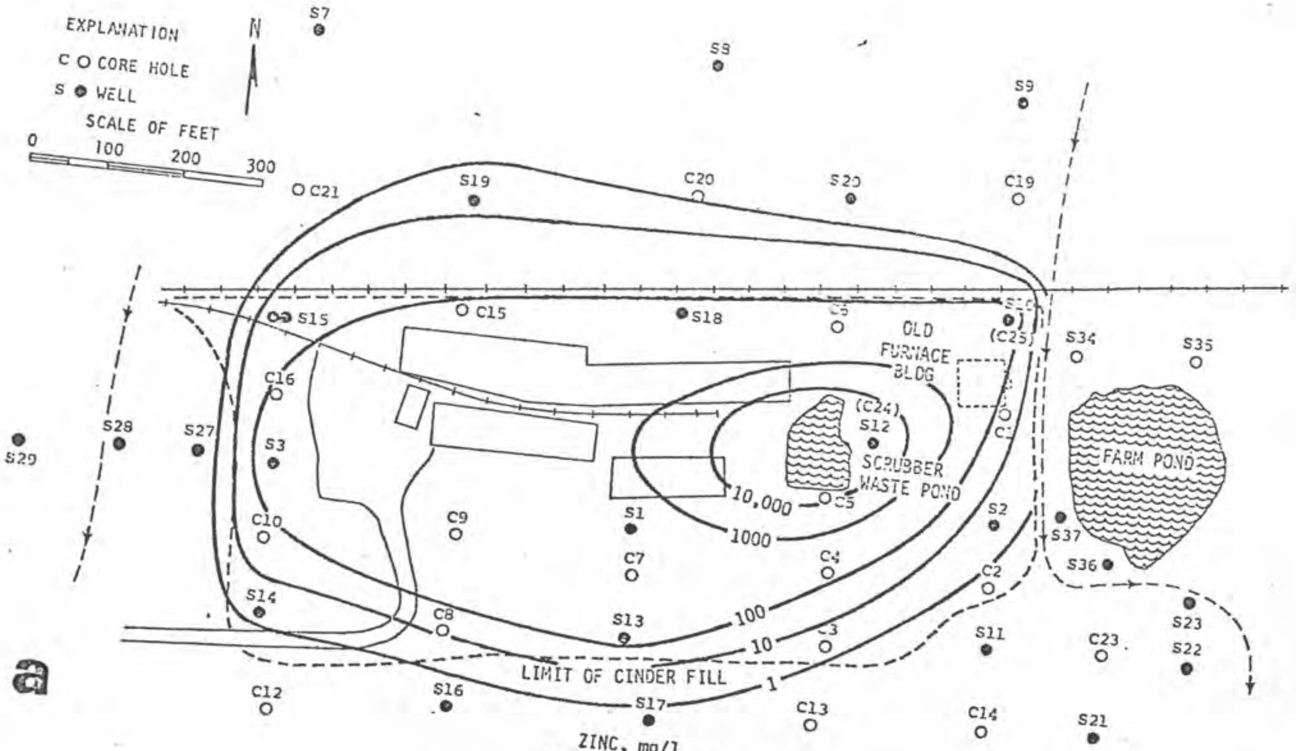
Results of chemical analysis of water samples collected from wells at site A are presented in table 7. All wells finished at the bedrock surface (S-1D through S-9D) produced water containing less than 0.5 mg/l zinc. The few isolated samples indicating higher zinc contents were determined not to be representative.

The zinc content of water collected from the shallow wells tapping the Hagarstown sand unit are illustrated in figures 29A and B. Figure 29A illustrating data for samples collected August 13, 1975 represents the minimum extent of shallow groundwater pollution and figure 29B illustrating data for samples collected September 9, 1976 represents the maximum extent of pollution. Due to the problems of not using a satisfactory sampling procedure and the unsuccessful attempt to detect well seal failures, further analysis of the water quality data generated probably is not worth while. As indicated earlier, the sampling procedure used in this study could account for as much as 40 to 80 percent of the fluctuations noted between sampling periods.

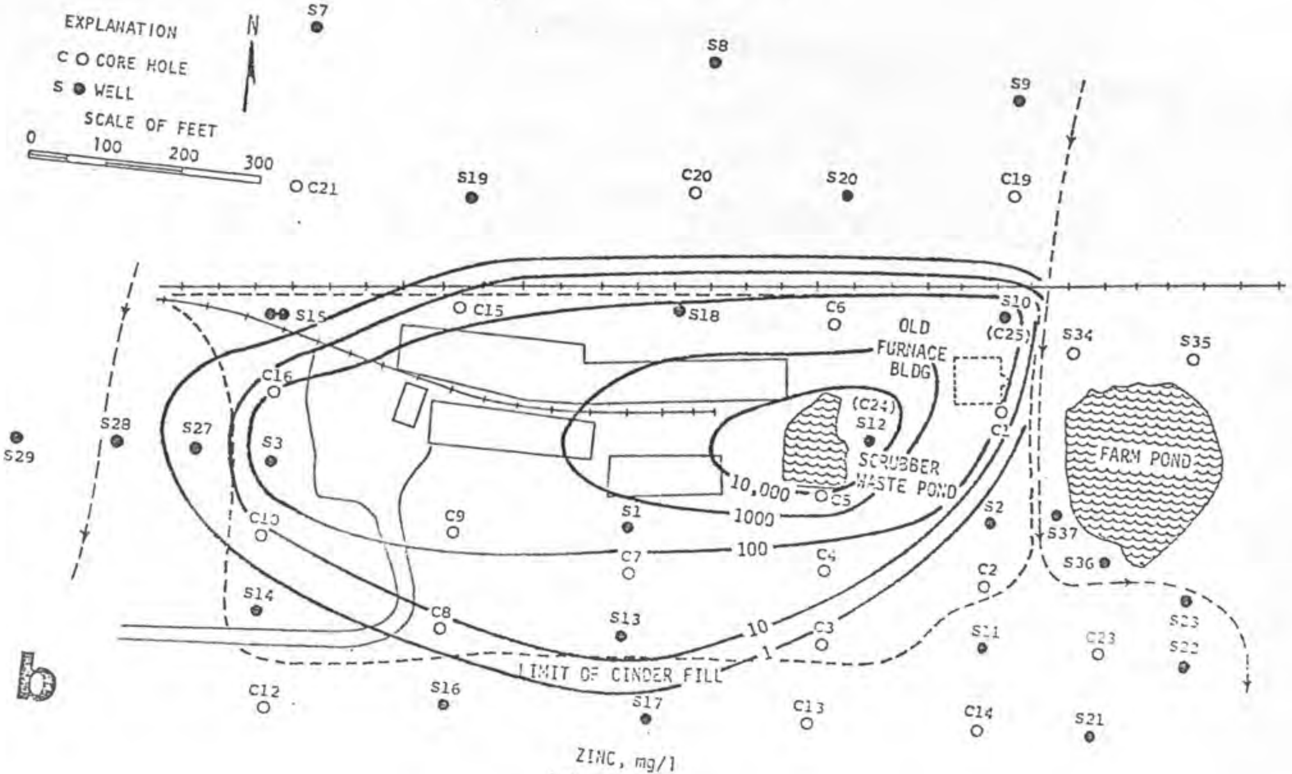
To better define the quality of water in an affected and unaffected area, water samples were collected from wells S-3S and S-6S for total mineral analysis. The results of these analysis and analysis of a water sample from the shallow control hole well indicate general agreement for S-6S (the unaffected area well) and SCH1-S. Increases in mineral constituents in the affected area well (S-3S) are obvious (see table 8).

Table 7. Water quality data - site A

				1975						1976		
	3-20	5-1	6-18	7-22	8-13	9-24	3-2	4-8	6-8	7-13	7-29	9-9
1-S	18.	15.		1.3	1.8							
1-D	.58	.51		<.5			<.5					
2-S	4.3	1.4		7.6	<.5			2.	<.5	11	<.5	5.7
2-D	.016	.15		<.5			<.5					
3-S	790.	660.	736	628	662		662.	720.	602.3	240.	476.	300.
3-D	.017	.72	<.5	25.8			.98					<.5
4-S			8.4	<.5	<.5		<.5	<.5	1.4		10.3	<.5
4-D			3.7	<.5	<.5		<.5					<.5
5-S			<.5	<.5	<.5		<.5	<.5	<.5	<.5	<.5	3.7
5-S				<.5	<.5		<.5					<.5
6-S			<.5	<.5	<.5		<.5	<.5	<.5	<.5	<.5	<.5
6-D			<.5	<.5	<.5		<.5					<.5
7-S				<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
7-D				<.5	<.5	<.5	<.5					<.5
8-S					<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
8-D						<.5	<.5					<.5
9-S					<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
9-D			<.5		<.5	<.5		<.5				<.5
10-S			207	293	350		50.3	363.			447.	196.
10-D									1.74	42.	224.	9.4
11				<.5	<.5		<.5	<.5	<.5	<.5	<.5	<.5
12			14,780	12,700	15,700		4000	12,476	15,300	15,600	21,580	15,600
13			6.2	10.9	16.9		33.8	500	<.5	<.5	<.5	156
14-S			<.5	<.5	<.5		<.5	<.5	3.2	<.5	<.5	4.2
14-D			<.5	<.5	<.5		<.5			<.5	<.5	4.8
15-S			<.5	20.5	<.5		<.5	10.6	2.0	50.	198.	18.
15-D			162.	144.	143.		12.9			110.	212.	87.
16			<.5	<.5	<.5		<.5	<.5	<.5	<.5	<.5	<.5
17			<.5	<.5	<.5		<.5	<.5	<.5	<.5	<.5	<.5
18			571.	566.	610.		353.7	585.	850.	170.	758.	342.
19					<.5	135.	.88	8.2	<.5	<.5	7.2	9.6
20					<.5	8.7	<.5	<.5	<.5	<.5	<.5	<.5
21						<.5		<.5	<.5	5.6	12.	<.5
22						<.5	<.5	<.5	<.5	<.5	<.5	<.5
23						308.	11.2	56.2	10.1	43.	103.	105.
24						<.5			<.5	<.5	<.5	<.5
25						<.5	.5	<.5	<.5	<.5	<.5	
26						<.5	.5	<.5	<.5	<.5	<.5	<.5
27						4.9	.5	<.5	<.5	<.5	13.1	<.5
28						<.5	.5	<.5	<.5	<.5	<.5	<.5
29						<.5	.5	<.5	<.5	<.5	<.5	<.5
30						<.5	.5	<.5	<.5	<.5	<.5	<.5
31						<.5	.5	<.5	<.5	<.5	<.5	<.5
32						<.5	.5	<.5	<.5	<.5	<.5	<.5
33						<.5	.5	<.5	<.5	<.5	<.5	<.5
36										<.5	<.5	<.5
37										<.5	<.5	
CH-IS							.5	<.5	3.1	<.5	<.5	<.5
CH-ID							.5					<.5



ZINC, mg/l
SEPTEMBER 9, 1976



ZINC, mg/l
AUGUST 13, 1975

Figure 29. Zinc content of water from shallow wells - Site A.

Table 8 Selected total mineral analyses data - Site A

		SCH1-S		S-6S		S-3S	
		mg/l	me/l	mg/l	me/l	mg/l	me/l
Iron(total)	Fe	2.3		4.7		0.0	
Manganese	Mn	.14		.44		21.01	
Calcium	Ca	96.4	4.81	33.5	1.67	2400	119.76
Magnesium	Mg	38.3	3.15	13.7	1.13	893	73.44
Strontium	Sr	.27	.01	.08		5.25	.12
Sodium	Na	75.4	3.28	81.9	3.56	389	16.92
Potassium	K	1.0	.03	0.6	.02	367	9.39
Ammonium	NH_4	0.1	.01	0.0	.00	156	8.64
Barium	Ba	<0.1		<0.1		<0.1	
Cadmium	Cd	.00		.00		1.19	.02
Chromium	Cr	.00		.00		.01	
Copper	Cu	.00		.00		.04	
Lead	Pb	<.05		<.05		<.05	
Lithium	Li	.01		.00		.15	
Nickel	Ni	<.05		<.05		2.8	.10
Zinc	Zn	.00		.04		750	22.95
Phosphate (filt)	PO_4	0.1		0.1		0.0	
Phosphate (unfilt)	PO_4	0.5		0.4		0.0	
Silica	SiO_2	15.8		13.2		33.1	
Fluoride	F	0.3		0.3		0.0	
Boron	B	0.0		0.1		0.5	
Nitrate	NO_3	0.5	.01	1.2	.02	223	3.59
Chloride	Cl	6	.17	20	.56	8300	234.06
Sulfate	SO_4	140.1	2.91	120.1	2.50	564.0	11.73
Alkalinity	(as $CaCO_3$)	404	8.08	166	3.32	40	.80
Hardness	(as $CaCO_3$)	398	7.96	140	2.80	9660	193.20
Total Dissolved Minerals		615		394		13802	

The data from S-3S was as expected and substantiates the solubility product calculations. The zinc concentration (750 mg/l) and pH (6.5) are in excellent agreement with the solubility of zinc hydroxide (800 mg/l at 6.5 pH).

These conclusions are borne out by the water quality data as well as the data from the soil cores. For example, the zinc concentration in piezometer 535 is 750 mg/l approximately the solubility of zinc hydroxide calculated at pH 6.5.

Evidence of cation ion exchange also is shown by the high concentrations of calcium (2400 mg/l) and magnesium (893 mg/l) present in this sample. The cation exchange positions in soils in this region of Illinois principally are filled with calcium and lesser amounts of magnesium. Grim (22) indicates that zinc is higher in the montmorillonite exchange series than Ca and Mg, and thus will replace these ions on the clay structure. According to Griffin (21), this process releases calcium and magnesium to the environment even when these are not part of the original waste stream.

Because of this phenomena, it is recommended that total mineral analysis be conducted on water samples from monitoring wells where cation exchange is likely to occur. Increases in one or more of these constituents (calcium or magnesium) could be an early warning of the eventual appearance of the more toxic metals. However, to properly interpret a series of samples the problem associated with collecting comparative samples must be solved.

In addition to the groundwater pollution study at this site. Dr. Bill Edwards of the Illinois State Natural History Survey conducted a preliminary study of the surface soils and vegetation species surrounding the site. Results of his work are presented in Appendix B. The findings of his work are summarized in the follow paragraph.

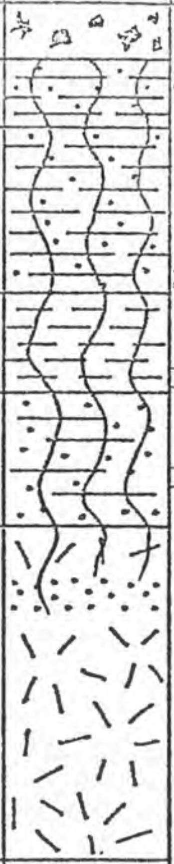
Levels of zinc in surface soils were high near the smelter at Site A and tended to decrease with distance from the smelter. Statistical modeling indicated that zinc is significantly conserved in soil organic matter. Consistantly high levels of zinc were detected in alluvial outwash soils high in organic matter for considerable distances below the smelter. The conclusion was drawn that erosion of surface soils high in zinc serves as a transport mechanism in the dispersion of zinc away from the smelter. The distribution, density, and productivity of wild plants and the planting of agricultural crops in the vicinity of the smelter were significantly related to the zinc status of surface soils. Chemical analyses of plants indicated: (1) that the zinc status of plants reflects, at least in part, the zinc status of their environments, (2) that different plants, even those growing in close association, evidenced quite different levels of zinc, and (3) that different parts of plants concentrate zinc at different rates. Although statistical analyses have not been completed, all observations that bear on findings of previously reported research on zinc-plant relationships are in general agreement with the earlier findings. The hypothesis is advanced that amino acids may be involved in the accumulation of zinc in plants against a concentration gradient with zinc in the soil solution, in the transport of zinc in the plant, and might also relate to conservation of zinc in soil organic matter.

Summary

The results of soil coring and water sampling of wells at Site A have defined the migration patterns of toxic metals from this site into the ground and shallow groundwater system. Cation exchange and precipitation of metals compounds as a result of the change in pH of the infiltrating fluid are the principal attenuating mechanisms influencing the metals movement.

The geologic setting at Site A has demonstrated the ability to contain high concentrations of toxic metals over an extended length of time. The desirability of this type of geology for disposal of similar types of pollutants has been clearly demonstrated.

The successful application of soil coring and water sampling from wells has proven the value of these techniques as research tools. The complimentary data generated from each technique are necessary to fully understand the fate of toxic metals migration.

No.	SITE A S-12 L.S. = 508.57			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5–2.0	FILL		–	–	–	–	–	–	–	–
2	3.5–4.0	PEORIA LOESS		28.5	–	–	–	0	47	10	43
3	5.0–5.5			–	–	–	–	0	3	72	25
4	6.0–6.5	ROXANA SILT (37-31-32)		–	–	–	–	5	42	29	29
5	7.5–8.0			–	–	–	–	–	–	–	–
6	8.0–8.5			–	–	–	–	1	37	30	33
7	9.5–10.0			–	–	–	–	–	–	–	–
8	10.6–11.3			22.0	–	–	–	2	30	35	35
9	11.5–12.0	BERRY CLAY (34-31-35)		–	–	–	–	1	29	34	37
10	12.0–12.5			–	–	–	–	1	30	44	26
11	13.5–14.0			15.3	–	–	–	3	43	15	42
12	14.0–14.5	HAGARSTOWN MEMBER (36-34-30)		–	–	–	–	3	31	34	35
13	14.5–15.0			–	–	–	–	1	41	33	26
14	15.0–15.5			17.4	–	–	–	–	–	–	–
15	15.5–16.0			–	–	–	–	–	–	–	–
16	16.0–16.5	GLASFORD FORMATION TILL (30-38-32)		–	–	–	–	4	34	36	30
17	16.5–17.0			–	–	–	–	3	48	32	30
18	17.0–17.5			–	–	–	–	5	28	32	40
19	18.0–18.5			–	–	–	–	–	–	–	–
20	19.2–19.8			–	–	–	–	6	32	39	29
21	20.5–21.0			–	–	–	–	–	–	–	–
22	21.5–22.0			–	–	–	–	9	28	44	28
23	23.0–23.5			–	–	–	–	–	–	–	–
24	23.5–24.0			–	–	–	–	1	12	52	36
25	26.0–26.5			–	–	–	–	–	–	–	–

S-121	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	57,000	24.	17.	14.	–	–
2	–	–	–	–	–	–	9,500	36.	18.	42.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	4,700	–	–	–	–	–
5	–	–	–	–	–	–	4,600	15.	43.	55.	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	7,800	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	8,900	32.	11.	14.	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	6,200	–	–	–	4.8	2.9
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	7,400	31.	15.	19.	4.9	3.7
15	–	–	–	–	–	–	3,700	29.	14.	7.9	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	1,200.	12.	17.	12.	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	190.	1.6	17.	9.6	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	290.	1.8	15.	7.6	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	150.	1.3	14.	10.	–	–

Site B

Site B also is a secondary zinc smelter located in south-central Illinois. As at Site A, this was a primary smelting operation processing zinc ore from about 1904 until 1962. It was then converted to a secondary smelting operation and currently is reprocessing selected scrap metals. Wastes from this smelter during the early years of operation were the same type of metals-rich ashes and cinders as at Site A. An area of approximately 38 acres at the plant site is covered with from 1 to 15 feet of these metals rich cinders.

In compliance with air pollution regulations, this industry installed an electric precipitator on their stacks in 1968. The precipitated particles are immediately recycled into the smelting process.

The suspected sources for groundwater pollution at this site were essentially the cinder fill material and stored scrap or junk on the plant property. Since this site is so similar to Site A, only a minimum amount of time and effort was spent in studying it. Therefore, a basic grid of 9 locations (22 wells) was established to form a basis for study. An additional 6 locations and wells eventually were constructed to permit more detailed metals migration definition (see figure 30). Total well and coring footages are about 1010 and 785 feet respectively.

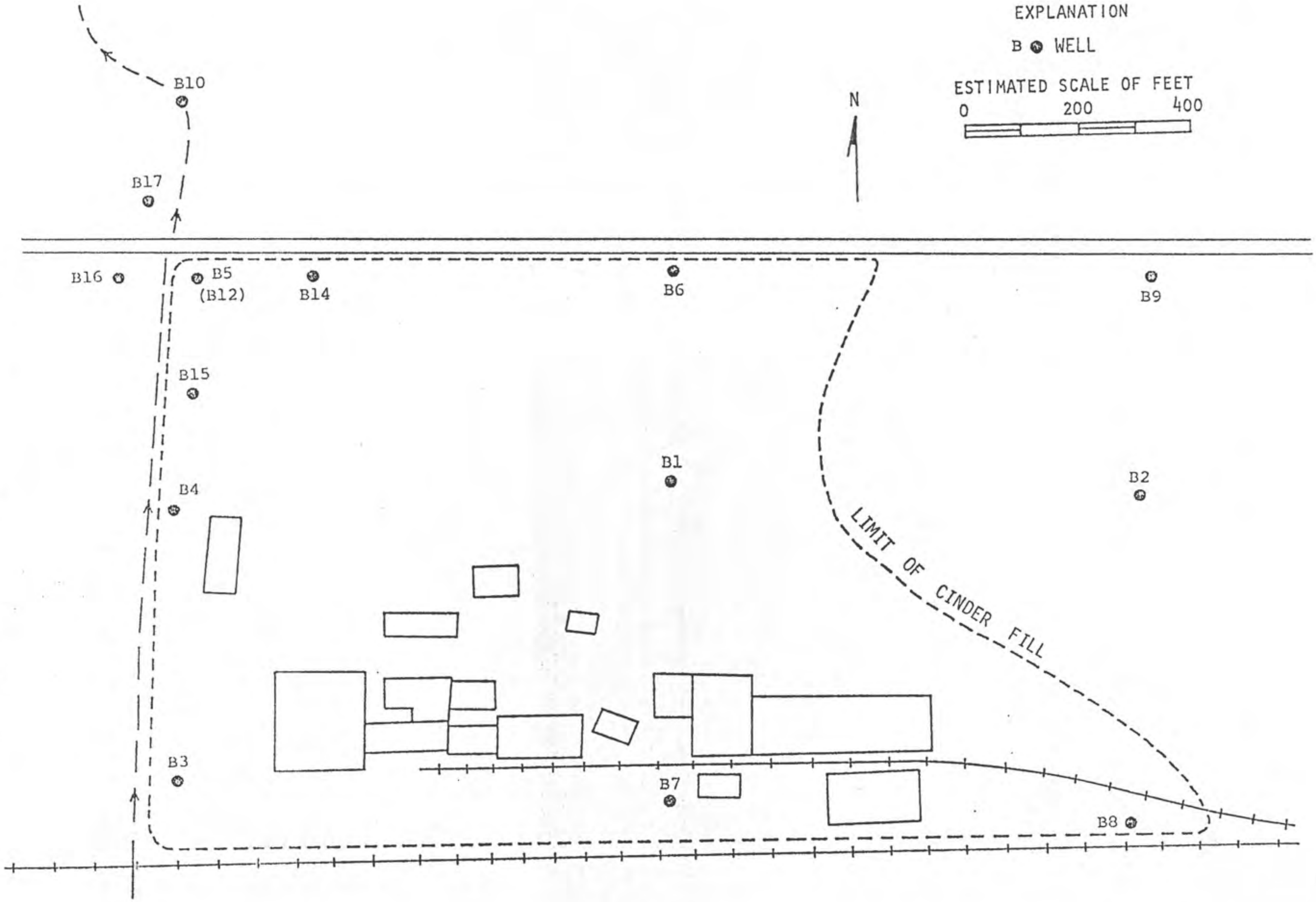


Figure 20. Location Map - Site B

Geology

The glacial drift at this site ranges in thickness from 40 to 65 feet, becoming thicker where the drift fills a northwest-southeast trending bedrock valley, (figures 31 A&E) The elevation of the Pennsylvanian bedrock ranges from greater than 410 feet above sea level in the southwest and northeast portions of the site to less than 390 feet in the valley to the northwest. The stratigraphic units are continuous across the site and tend to drape over the bedrock surface, gently dipping toward the valley (figures 32 & 33). Data from selected borings are included at the end of this site discussion. A complete tabulation of all data from all sites is available from N.T.I.S. Table 9 summarizes the textural and mineralogical information for each unit. A brief description of each stratigraphic unit follows:

Wisconsinan Stage

A) Peoria Loess (0-5 feet thick) - Massive, brown, clayey silt. Sand content is low. Expandable clay minerals make up over 80 percent of the clay fraction. Modern Soil developed in the Peoria; organic material and iron stains are common. This unit is leached.

B) Roxana Silt (3-8 feet thick) - Brownish-gray sandy silt. Sand content increases from about 18 percent at the top to about 28 percent at the base. Clay mineralogy similar to the overlying Peoria. The buried Farmdale Soil has developed in the Roxana which is leached and contains some organic material and abundant iron stains.

Sangamon Stage

Glasford Formation

C) Berry Clay Member (3-5 feet thick) - Brownish-gray and yellow-brown mottled sandy silty clay with some gravel. Sandier than the Roxana and may contain up to 50 percent sand. Clay mineralogy is similar to both the Peoria and Roxana. Considered an accretion-gley deposit. The buried Sangamon Soil is developed in the Berry; it is leached, iron stained, mottled, and contains some organic material.

STAGE	UNIT	AVERAGE TEXTURE	AVERAGE CLAY MINERALOGY (<2μ)	CARBONATE MINERALOGY (<2μ)
WISCONSINAN	PEORIA LOESS	(5-63-32) 28 samples	M 64% I 24.5% 8 samples	LEACHED
	ROXANA SILT	(16-57-27) 20 samples	M 80% I 12% 9 samples	LEACHED
SANGAMONIAN	BERRY CLAY MEMBER-GLASFORD FORMATION	(33-35-32) VARIABLE 19 samples	M 85% I 10% VARIABLE 19 samples	LEACHED
ILLINOIAN	HAGARSTOWN MEMBER-GLASFORD FORMATION	(41.5-29.5-29) VARIABLE 12 samples	M 72% I 18% 9 samples	LEACHED
	GLASFORD FORMATION TILL	(39-38-23) 35 samples	M 35% I 46% 39 samples	CONTAINS CARBONATES MAY BE LEACHED AT TOP
YARMOUTHIAN	LIERLE CLAY MEMBER-BANNER FORMATION	(21-37-42) 3 samples	M 58% I 24% 3 samples	LEACHED
KANSAN	BANNER FORMATION TILL	(29-42-29) Oxidized: (30-41-28) Unoxidized: (28-43-29) 115 samples	M 19% I 56% M (Ox.) 22% I (Ox.) 59% M (Unox.) 15% I (Unox.) 52% 102 samples	CONTAINS CARBONATES MAY BE LEACHED AT TOP
NEBRASKAN (?)	ENION FORMATION	(7-54-39) 51 samples	M 45% I 26.5% VARIABLE 45 samples	LEACHED
PENNSYLVANIAN SYSTEM	MODESTO FORMATION	(2.5-48-49.5) 14 samples	M 11% I 61% 10 samples	LEACHED

(5-63-32) = Average percentage of sand, silt, and clay excluding gravel.

M 64% = Average percentage of montmorillonitic (expandable) minerals in clay fraction (<2μ).

I 24.5% = Average percentage of illite in clay fraction.

Table 9. Textural and mineralogical data for stratigraphic units Site B

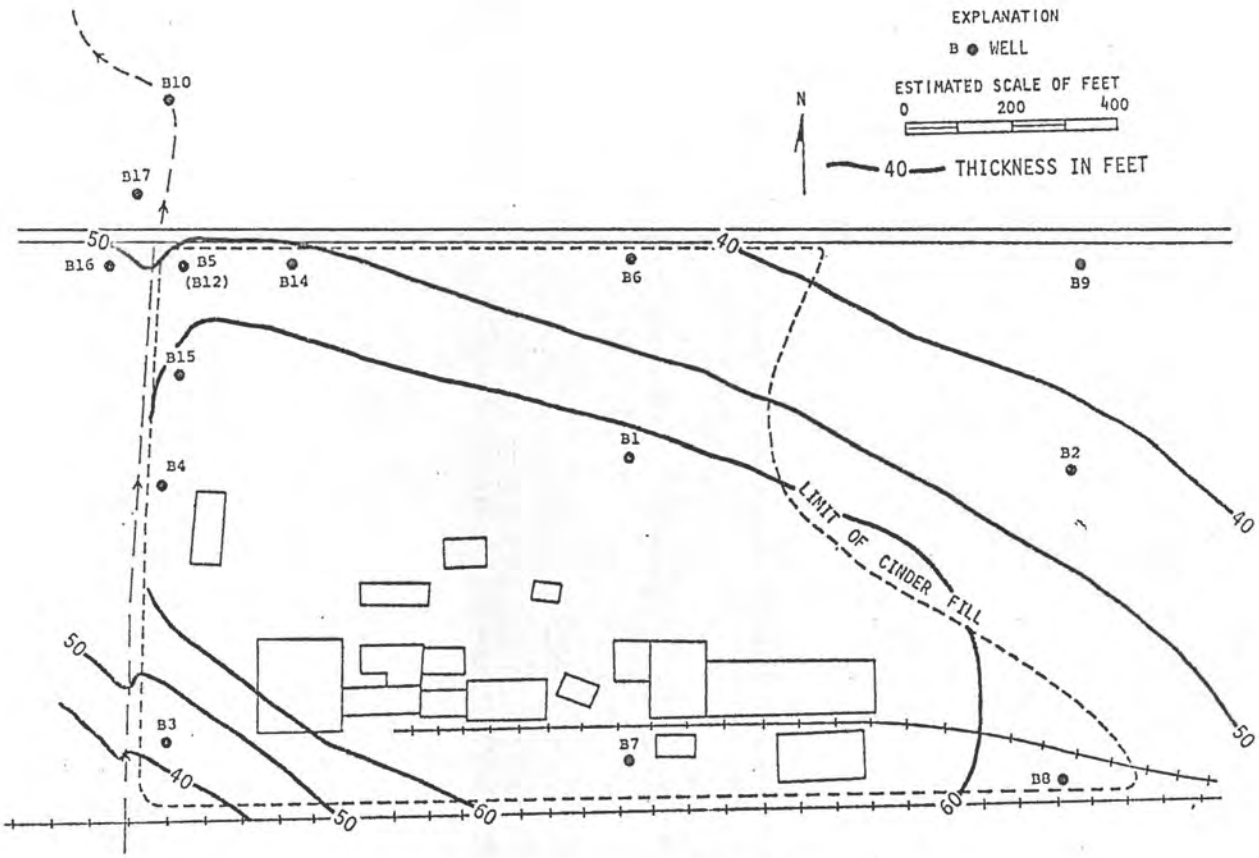


Figure 31A. Generalized drift thickness and bedrock surface maps - Site B

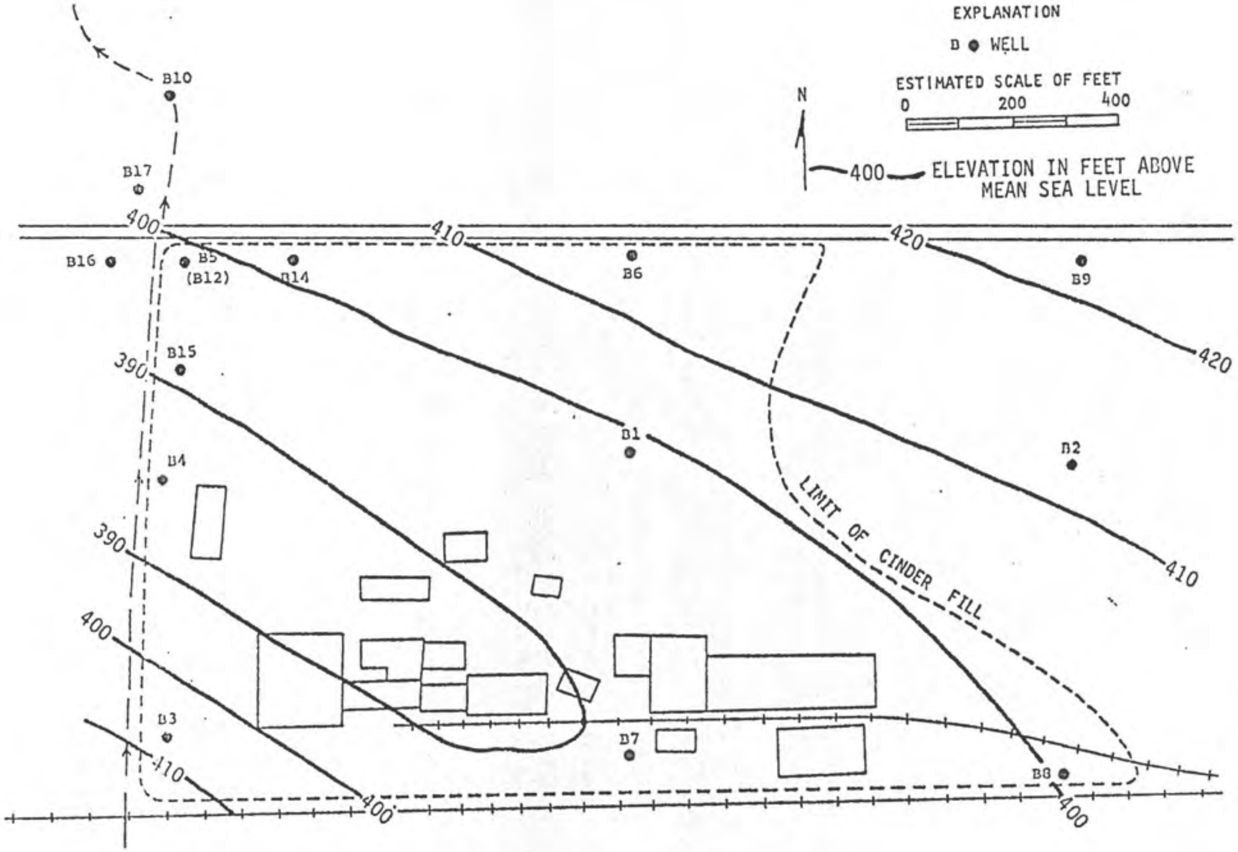

EXPLANATION
B ● WELL
ESTIMATED SCALE OF FEET
0
200
400
N
—400— ELEVATION IN FEET ABOVE MEAN SEA LEVEL
B10
B17
B16
B5
(B12)
B14
B6
B9
B15
B1
B2
B4
B3
B7
B8
LIMIT OF CINDER FILL
390
400
410
420

Figure 31B.

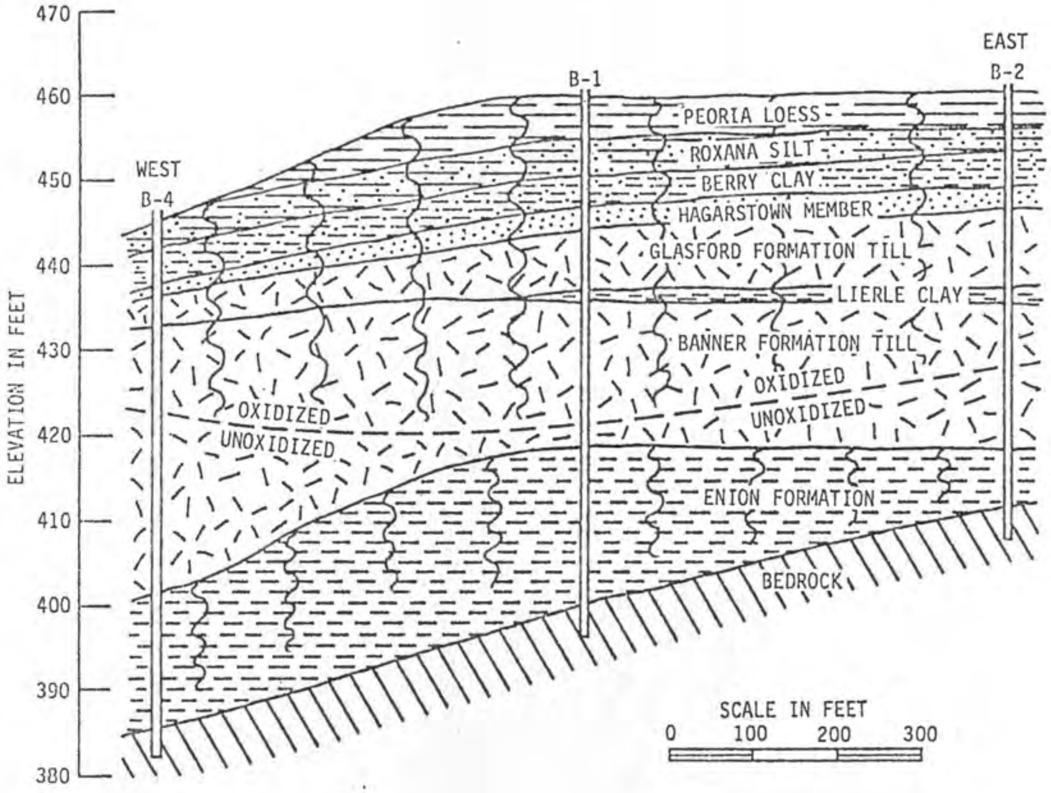


Figure 32. East-West stratigraphic cross-section - Site B

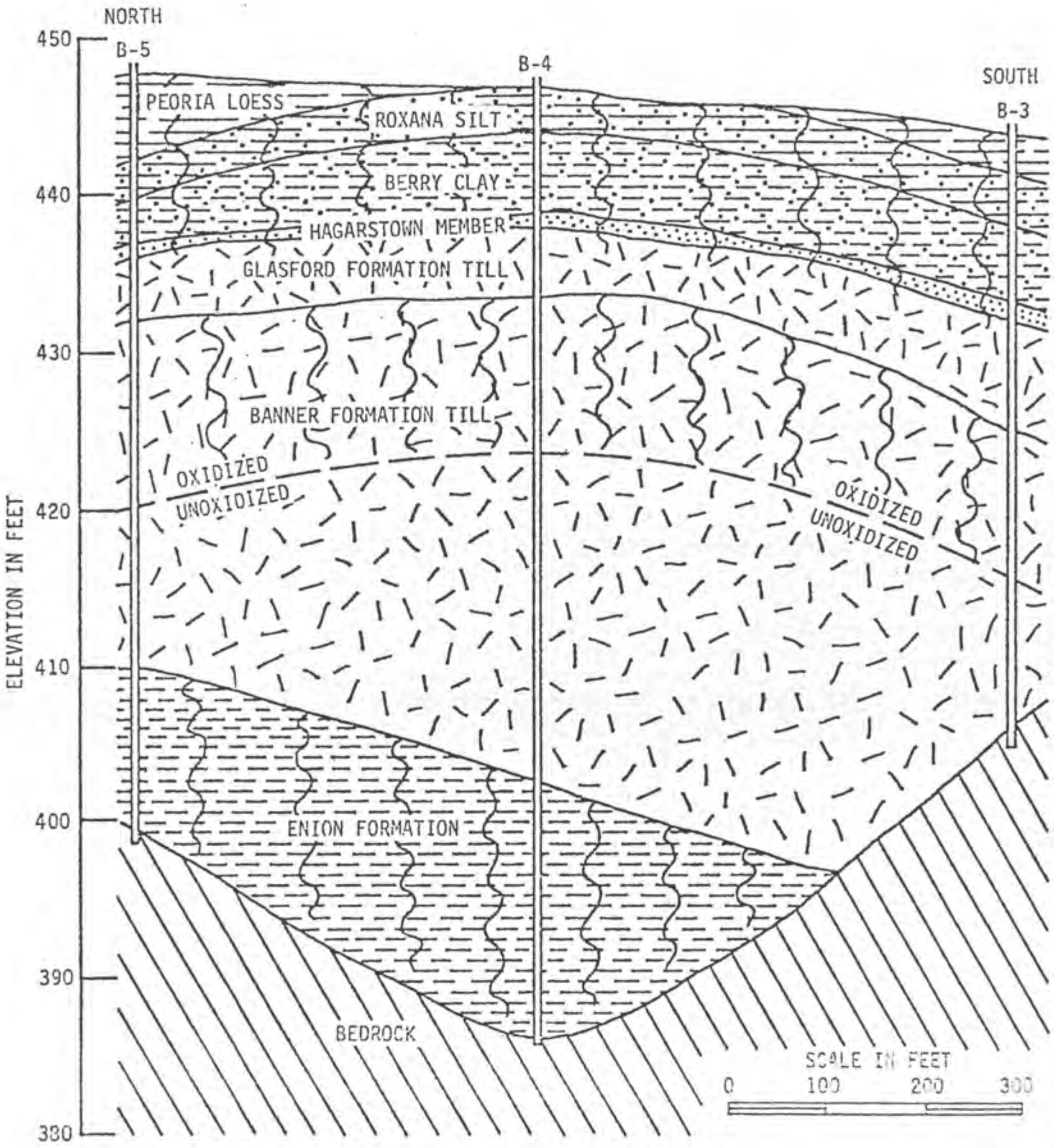


Figure 33. North-South stratigraphic cross-section - Site B

Illinoian Stage

D) Hagarstown Member (1-3 feet thick) - Thin, yellowish-brown silty sand to sandy till. Appears uniform in each boring but is variable in character from one boring to another, much more so than at Site A. In some borings, it is difficult to distinguish from the underlying Glasford Formation Till.

Sand content varies from hole to hole, but is typically over 30 percent and is similar to the underlying till. The percentage of expandable clay minerals is much higher than at Site A, whereas illite content is lower. This unit is leached and iron stained reflecting the development of the Sangamon Soil. The lithologic variability of this unit indicates an ablation origin related to the deposition of the underlying till even though not mineralogically similar.

E) Glasford Formation Till (0-10 feet thick) - Borwnish-gray to sandy silt till. Sand content typically over 30 percent. Illite content much higher and expandable clay content much lower than the overlying units. As at Site A, carbonates are present althouth the top of the till may be leached. Included in the till are sand lenses and sand coatings in joints. The till is thinner and more uniform in character than at Site A, and may represent only one glacial episode.

Yarmouthian Stage

Banner Formation

F) Lierle Clay Member (0-3 feet thick) - Thin, discontinuous brown to green sandy silty clay with a trace of gravel. X-ray data shows the Lierle to contain a high percentage of expandables and a relatively low percentage of illite. It is leached and the Yarmouth Soil is developed in this unit. An accretion gley.

Kansan Stage

G) Banner Formation Till (13-32 feet thick) - Oxidized brown sandy silt till over a lower, unoxidized, gray-brown clayey silt till. The entire till unit contains carbonates but the upper portion has been oxidized by the development of the Yarmouth Soil. Illite content is high and expandable clay content is low throughout the till unit (see Table 9). Texturally and mineralogically the till is fairly homogenous, although the oxidized till is slightly sandier with a greater proportion of expandables and illite than the unoxidized till (see Table 9). Composition of the till appears to relate to the material it rests on in each boring, suggesting local incorporation. Till thickness ranges from 13 to 32 feet. The upper, oxidized zone is 7 to 18 feet thick, while the lower, unoxidized portion varies in thickness from 0 to 22 feet.

Nebraskan Stage

H) Enion Formation (0-22 feet thick) - Dark olive-brown to brown and gray silts and clays of varying thickness. Thickness of this deposit appears to be related to the bedrock valley beneath the site (Fig.34). Sand content is generally less than 10 percent. Expandable clay minerals are typically more abundant than illite, but the mineralogy varies from hole to hole. The sequence is leached with localized mottling and iron stains at the top of the unit reflecting soil formation.

This interval appears to represent post Pennsylvanian, pre Kansan quiet-water sedimentation. The absence of carbonates suggests a long period of soil formation prior to invasion of Kansan glaciers. The unit is therefore assigned to the Enion Formation of Nebraskan age.

Pennsylvanian System

Modesto Formation - Bedrock consisting of greenish-gray shale with abundant mica. Data is limited because drilling was usually terminated at the top of bedrock.

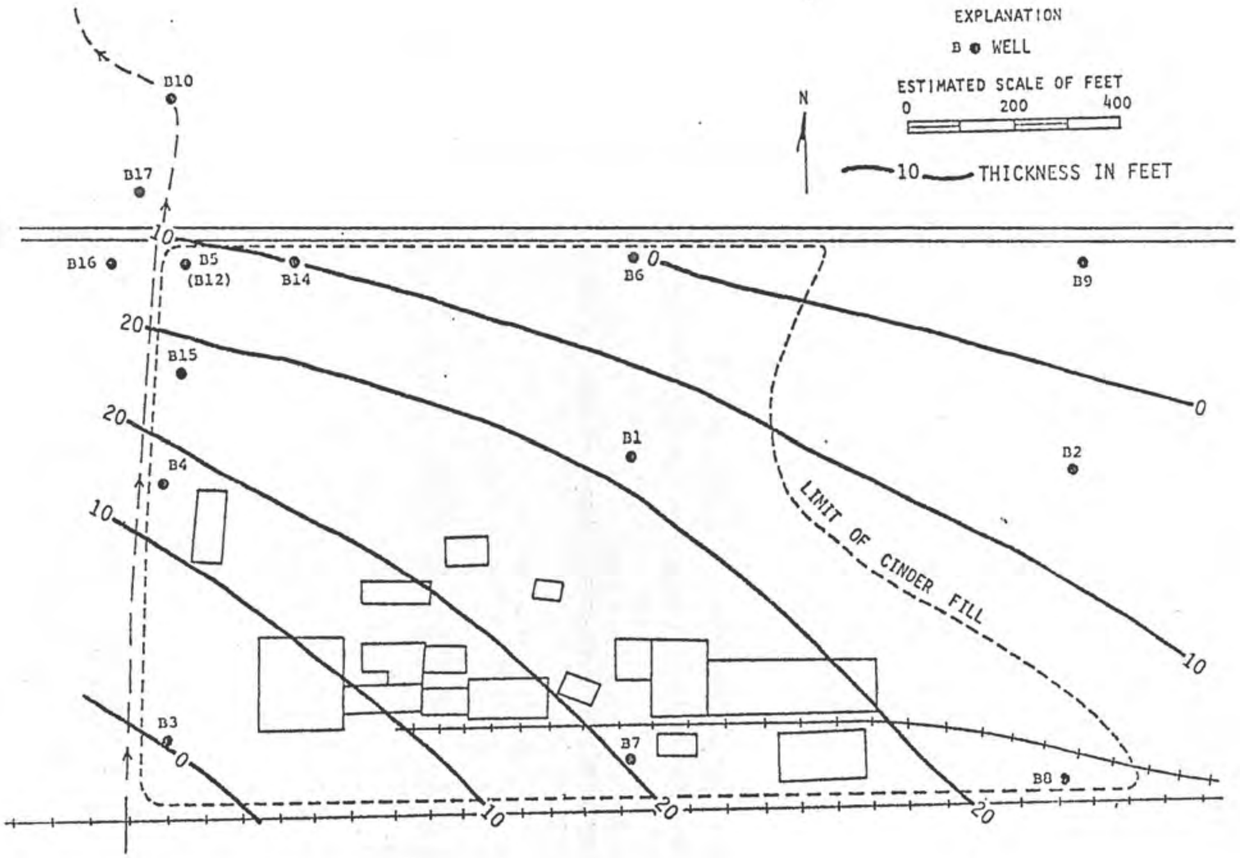


Figure 34. Thickness of Enion Formation - Site B

Available information suggests little montmorillonite and abundant illite (Table 9). The shale is leached and fine-grained, with very little sand.

Five soil profiles were identified in the glacial record at Site B. In addition to the four soils found at Site A - Yarmouth, Sangamon, Farmdale, and Modern - the Afton Soil is developed in the Enion Formation.

Inasmuch as the upper four units are thin and contain three soil profiles, the glacial drift is leached from the surface to a depth of 10 to 22 feet. The zone of leaching typically extends into the Hagarstown or Glasford Formation Till.

Hydrology

Based on the geologic description of Site B, the only aquifer of significance at this site is the Hagerstown member, a 1 to 3 foot thick sand unit. This unit occurs at depths from 6 to 10 feet and offers the only significant permeable zone that could allow for lateral groundwater movement away from the site.

Due to the similarity of geologic units at Sites A and B, no pumping test was conducted at Site B. The coefficient of transmissibility of the sand unit was assumed to be the same as at Site A, 285 gpd/ft. This results in an average coefficient of permeability of about 145 gpd/ft.

Water level hydrographs for all shallow wells at Site B are presented in figure 35. Also included is a graph of precipitation for the period of record. The hydrographs for wells B-1S, B-2S, B-6S, B-7S, B-8S, B-9S, and the two control holes indicate that these upland wells particularly are responsive to precipitation. Wells B-3S, B-4S, and B-5S located along the creek draining the plant site are in lowland settings and therefore subject to less variation in water levels. Maximum and minimum water levels for the shallow wells are summarized in table 10.

Water table contour maps were drawn for each round of water level measurements made. Figure 36 A and B for March 1975 and October 1976 illustrate the high and low water table configurations respectively. In both instances the principal direction of groundwater movement is to the west and north. This coincides with the surface drainage patterns established by the land surface topography.

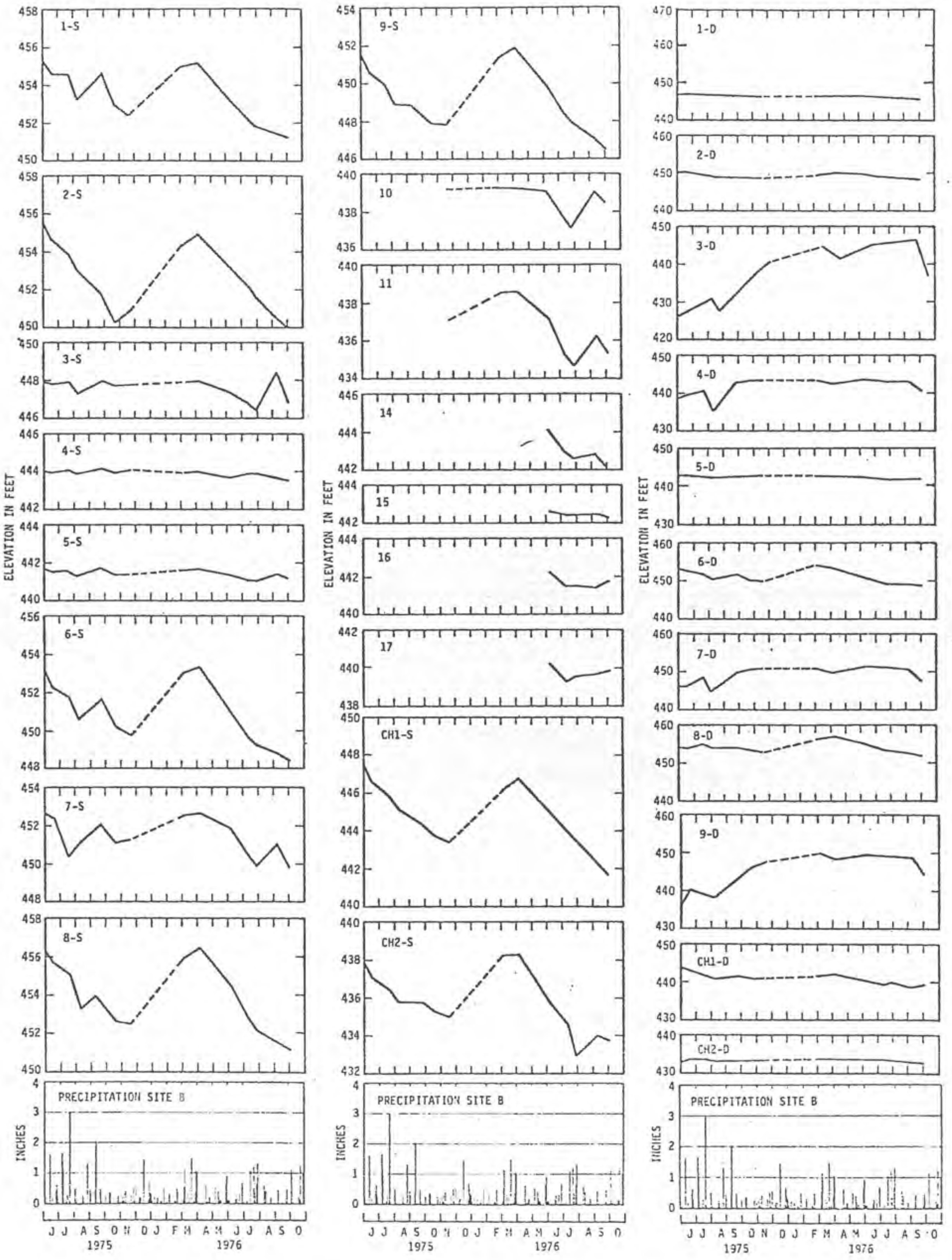
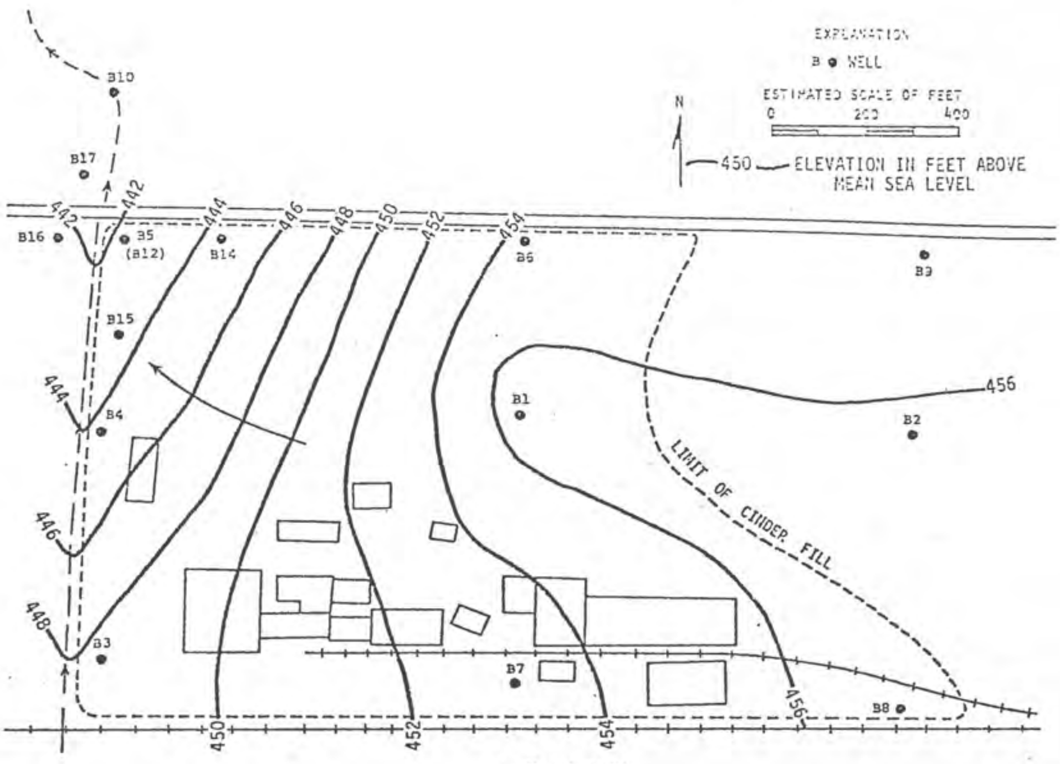
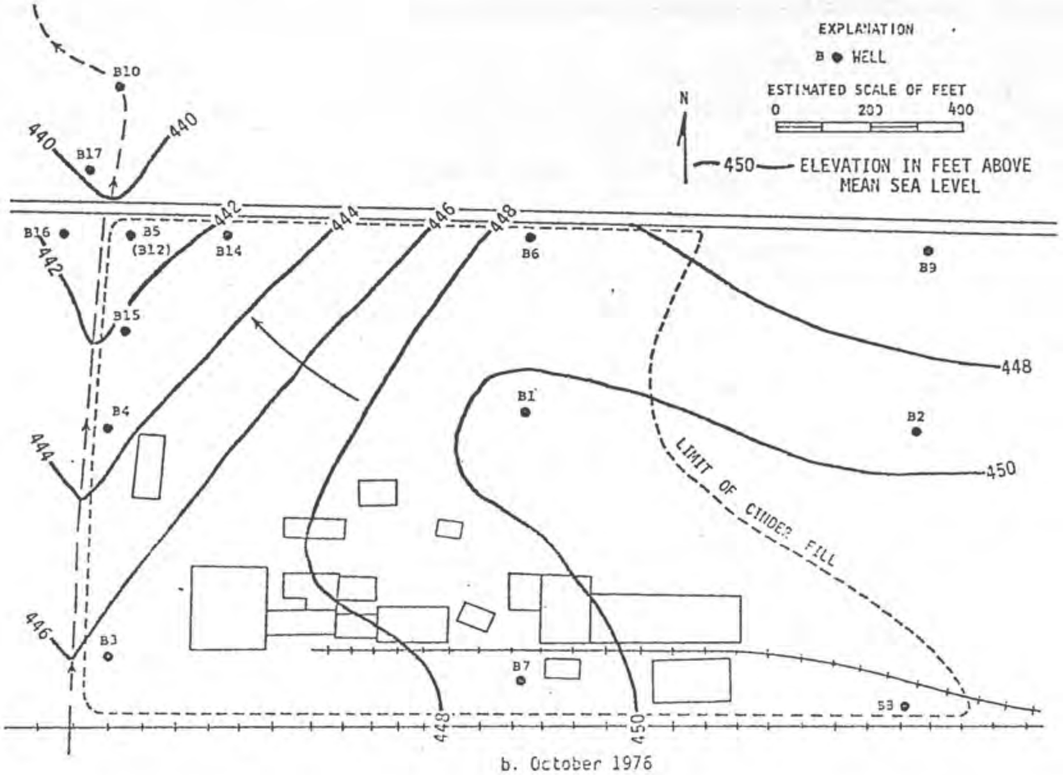


Figure 35. Water level hydrographs of shallow and deep wells - Site B



a. March 1974



b. October 1976

Figure 36. Water table contour maps for A) March, 75, and B) October, 76 - Site B

Table 10. Range of Water Level Flucuations in Shallow Wells - Site B

		Low			High			
Well No.	LSD	Depth Below Land (ft)	MSL	Date	Depth Below Land (ft)	MSL	Date	Flucuation
1-S	457.36	6.16	451.20	10-1-76	0.99	356.37	3-19-75	5.17
2-S	459.38	9.41	449.97	10-1-76	2.01	457.37	3-19-75	7.40
3-S	449.93	3.49	446.44	7-30-76	1.56	448.37	9-9-76	1.93
4-S	446.59	3.06	443.53	10-1-76	1.90	444.69	4-23-75	1.16
5-S	447.55	6.50	441.05	7-30-76	5.44	442.11	3-19-75	1.06
6-S	455.83	7.65	448.18	10-1-76	1.21	454.62	3-19-75	6.44
7-S	455.54	5.70	449.84	10-1-76	2.12	453.42	3-19-75	3.58
8-S	457.88	6.81	451.07	10-1-76	0.20	457.68	3-19-75	6.61
9-S	455.67	9.15	446.52	10-1-76	2.91	452.76	5-1-75	6.24
10	440.27	3.08	437.19	7-30-76	0.98	439.29	3-2-76	2.10
11	438.79	4.10	434.69	7-30-76	0.13	438.66	4-6-76	3.97
14	452.07	9.95	442.12	10-1-76	9.16	442.91	7-13-76	0.79
15	448.42	6.16	442.26	10-1-76	5.79	442.63	6-8-76	0.37
16	446.30	4.78	441.52	7-30-76	3.86	442.44	9-9-76	0.92
17	444.77	5.35	439.42	7-13-76	4.44	440.33	6-8-76	0.91
CH1-S	452.00	10.34	441.66	10-1-76	3.26	448-74	4-23-76	7.08
CH2-S	445.00	12.09	432.91	7-30-76	6.36	438.64	5-1-76	5.73

Water level hydrographs for all deep wells at Site B are presented in figure 35. There are two complicating factors that should be kept in mind when looking at the deep well water levels. The lack of stabilization of water levels with time was an apparent problem in Wells B-3D, B-4D, B-7D, and B-9D. Wells B-3D thru 13-8D were constructed using the multi-well technique (placement of several wells of different depths in one bore hole) discussed earlier. Observations of water levels with time and the response of shallow water levels while pumping deep wells indicate that the seals between well screens in Wells B-6 and B-8 were leaking. The water levels measured in the deep wells were therefore more representative of shallow water levels. Maximum and minimum water levels of the deep wells are summarized in table 11.

However, an estimated piezometric surface map for the deep wells is presented in figure 37. In general, water levels in the deep wells are lower than those in the shallow wells indicating a probable downward movement of water within the drift section.

Applying Darcy's equation as at Site A, an average apparent rate of groundwater movement in the shallow deposits for October and March are 0.10 and 0.20 ft/day, respectively. Using the same effective porosity or specific yield as at Site A, effective velocities of 1.0 to 2.0 ft/day or about 365 to 730 ft/year were calculated. These velocities also are fairly high due to the steep hydraulic gradients present in the shallow drift materials.

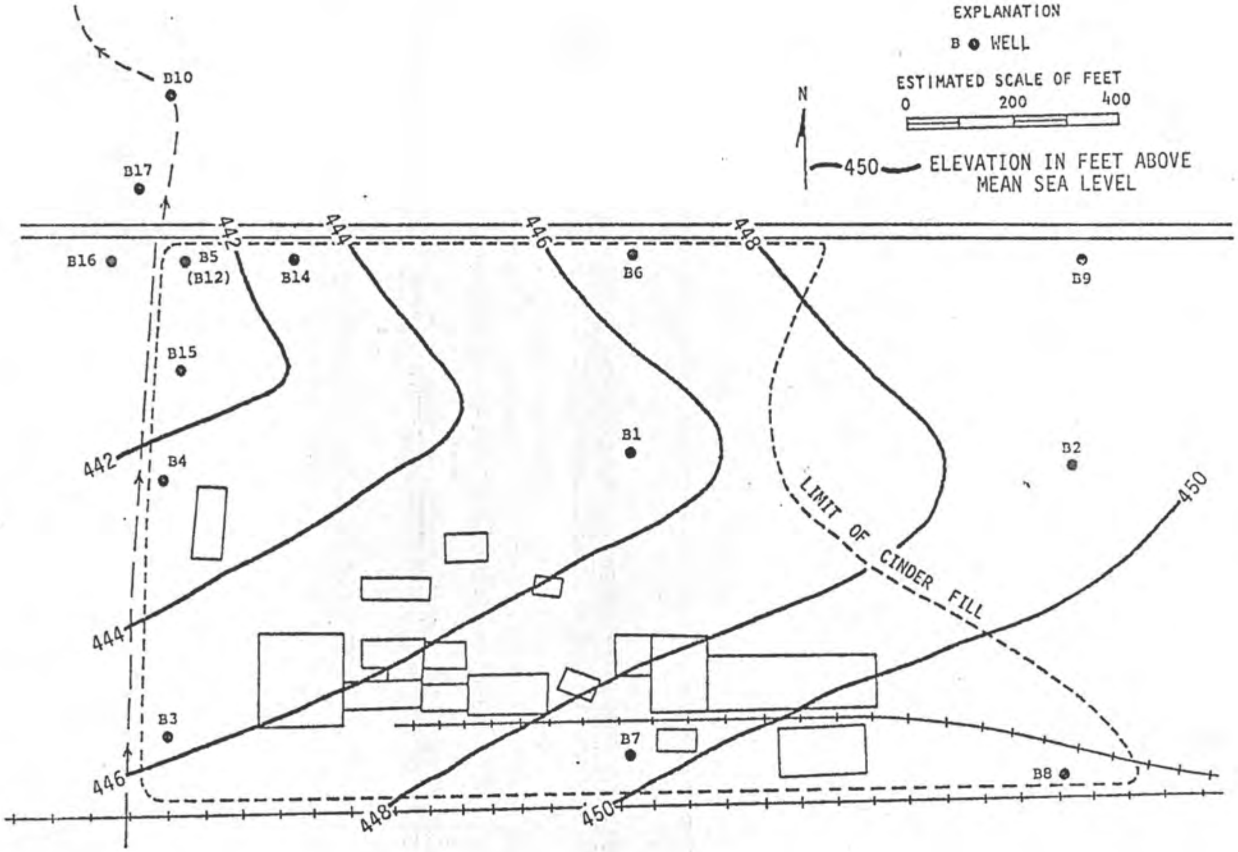


Figure 37. Estimated piezometric surface map of deep units – Site B

Table 11. Range of Water Level Flucuations in Deep Wells - Site B

Well No.	LSD	Low			High			Flucuation
		Depth Below Land(ft)	MSL	Date	Depth Below Land(ft)	MSL	Date	
1-D	457.36	11.70	445.66	10-1-76	10.31	447.05	5-20-75	1.39
2-D	459.38	22.54	436.84	2-13-75	8.98	450.40	3-19-75	13.56*
3-D	449.93	34.20	415.73	2-13-75	4.29	445.64	7-30-76	29.91*
4-D	446.59	11.83	434.76	4-23-75	2.93	443.66	3-2-76	8.90
5-D	447.55	6.06	441.49	7-29-75	4.79	442.76	3-19-75	1.27
6-D	455.83	7.55	448.28	10-1-75	1.43	454.40	3-19-75	6.12**
7-D	455.54	52.71	402.83	2-13-76	4.34	451.20	6-8-76	48.37*
8-D	457.88	8.05	449.83	4-23-75	1.07	456.81	4-6-76	6.98**
9-D	455.67	28.23	427.44	5-1-75	5.69	449.98	3-2-76	22.54*
CH1-D	452.00	12.65	439.35	10-1-76	6.14	445.86	5-1-75	6.51
CH2-D	445.00	14.19	430.81	4-23-75	11.25	433.75	3-2-76	2.94

*Water levels not stabilized.

**Leakage between shallow and deep wells noted.

A soil temperature survey at Site B was conducted by the Illinois State Geological Survey on July 11, 1975.

The 50 stations occupied in this survey are shown on figure 38. Temperature measurements could not be made in much of the western part of the area because of a thick cover of cinders on the land surface. Temperature measurements were made in degrees Fahrenheit at a depth of 70 centimeters below land surface. Lines of equal temperature on a contour interval of two degrees Fahrenheit are shown on figure 38. High temperatures were measured in the vicinity of the buildings. Based on the variation in soil temperatures across the area, the interpreted direction of groundwater flow is northward for the eastern part of the area and north to northwestward for the western part of the area. This compares favorable with the directions of groundwater flow determined from water level data (see figure 34).

The ground in the eastern part of the area is covered by vegetation and solar heating effects appear to be uniform. The land surface in this area slopes to the north. The increase in soil temperatures from 72° F south of the railroad tracks to 76° F north of the highway is apparently caused by the transport of heat northward by ground water flowing downslope in the shallow ground-water flow system.

Vegetation was mainly absent in the western part of the site. Land surface cover in this area ranged from bare ground to various thicknesses of cinders and other refuse. The variation in the solar heating of this area makes soil temperature measurements unreliable for interpretation of shallow ground-water flow.

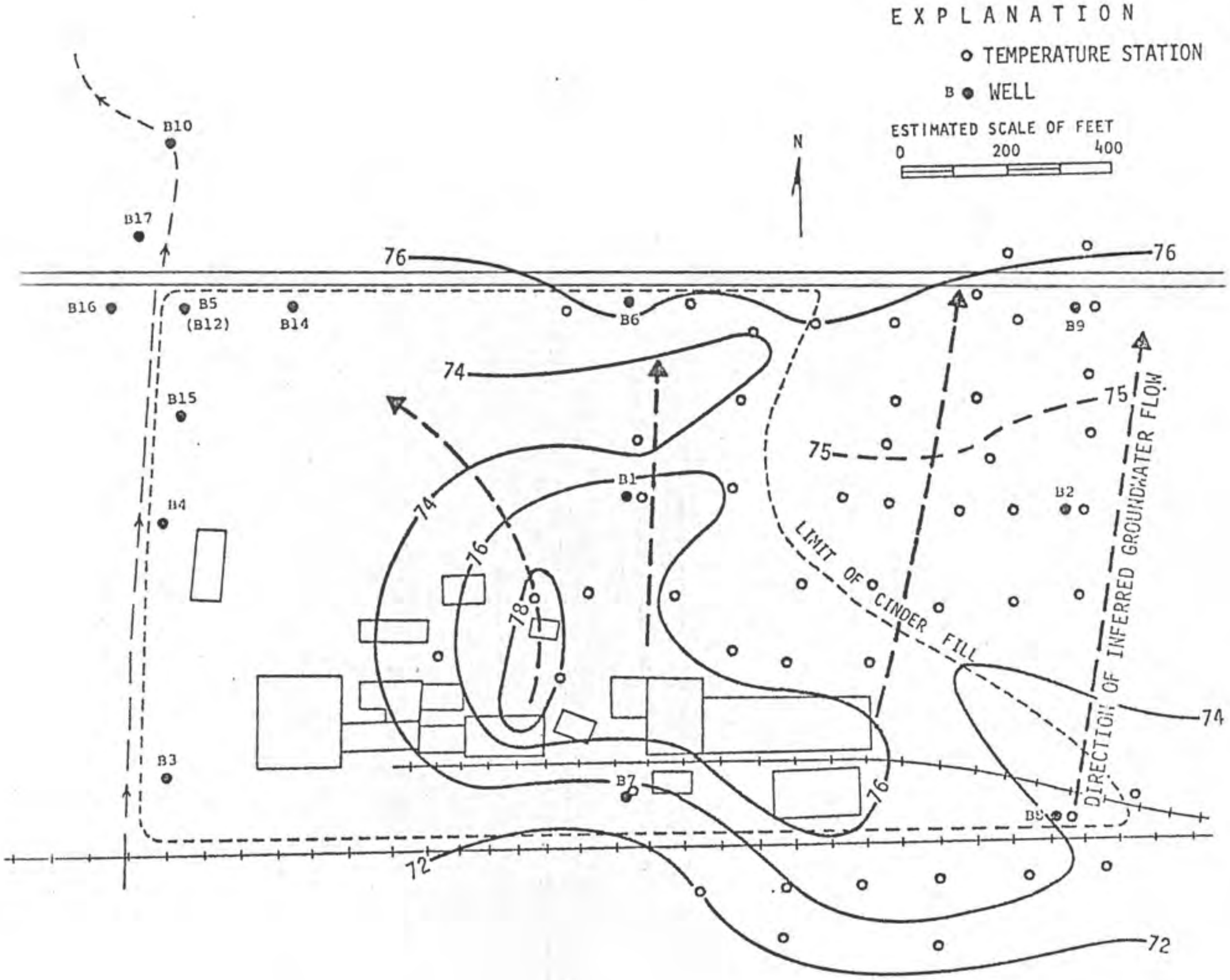


Figure 38. Soil temperature stations and results - Site B

Chemical Data

Results of all chemical analysis conducted on soil core samples from Site B are tabulated in Appendix C. Based on the experience gained at Site A zinc determinations were made for all holes and multi-element analysis were run for only those holes where high zinc levels were detected (B-5,14,15,16, and 17).

Data from the 2 control holes located about 1 1/2 miles southwest of the site and unaffected parts of the cores at site B indicate that background concentrations for zinc range from 20 to 50 mg/l, cadmium from <.02 to .20 mg/l, copper from 5 to 20 mg/l, and lead from 7 to 20 mg/l. These values are very comparable with those found at site A and as at site A there was little variation in background levels with depth.

To outline the limits of migration of zinc beneath this site a series of cross section showing zinc concentrations in the soil were developed. Figures 39 and 40 illustrate the east-west and north-south cross sections through the plant property respectively. Penetration of zinc into the soil profile is limited to those areas overlain by cinder fill. The depth of penetration varies from the near surface in the northeast portion of the plant property to a maximum of about 15 feet in the vicinity of B-5. In an effort to delineate the horizontal limits of zinc penetration around B-5, four core holes and wells were constructed surrounding it. Based on the results from these core holes it appears very likely that B-5 is an anomoly. From conversation with the plant manager, it was learned that B-5 is located at the site of an old entrance to the plant property. Over the course of the last 30 years several types of disruptive construction type activities have taken place in this area. The plant entrance road was closed and pilings were installed along the highway to support an extension of the [illegible] the north boundry of the plant site.

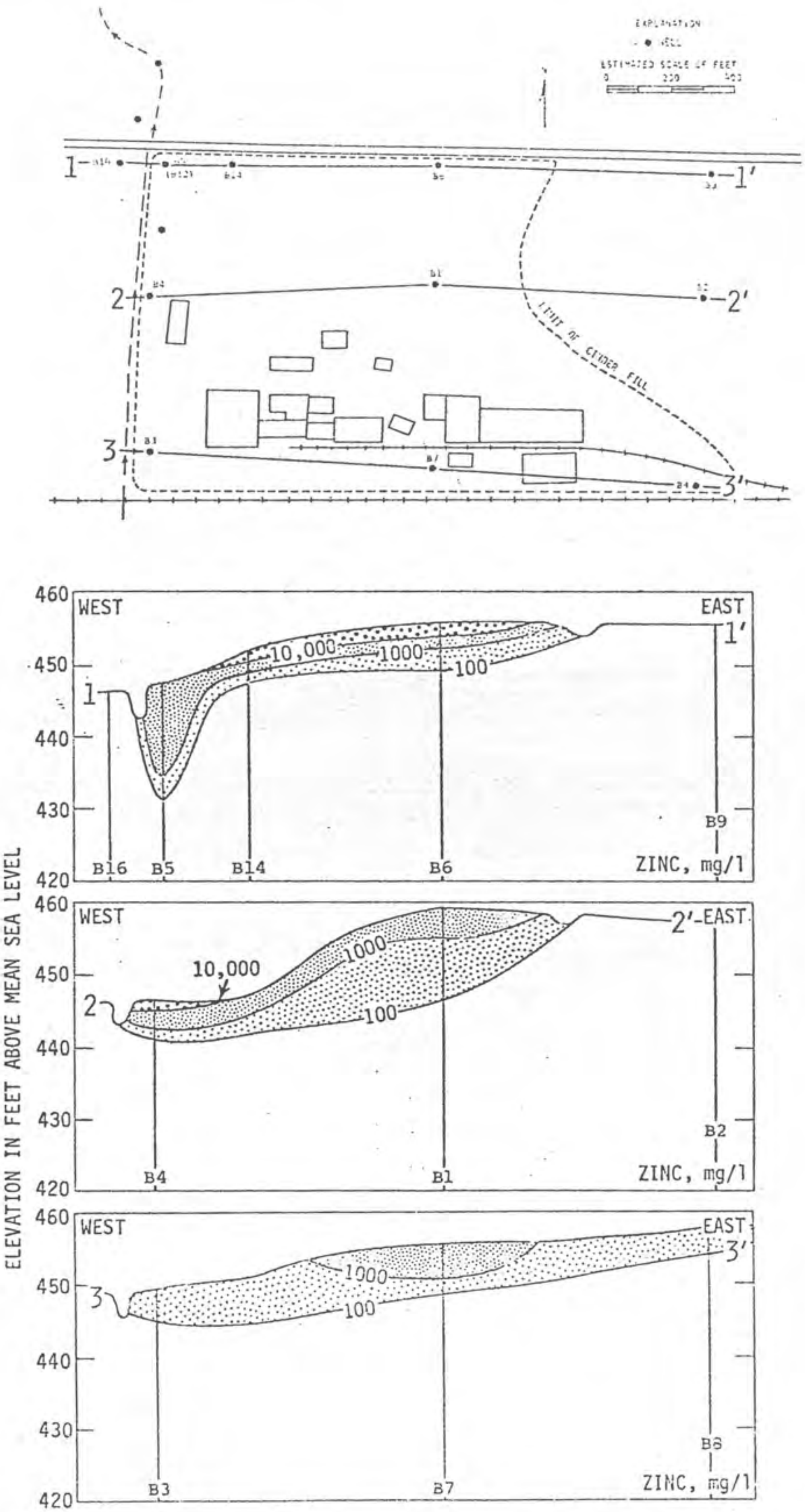


Figure 39. East-West soil zinc concentration profiles
Site B

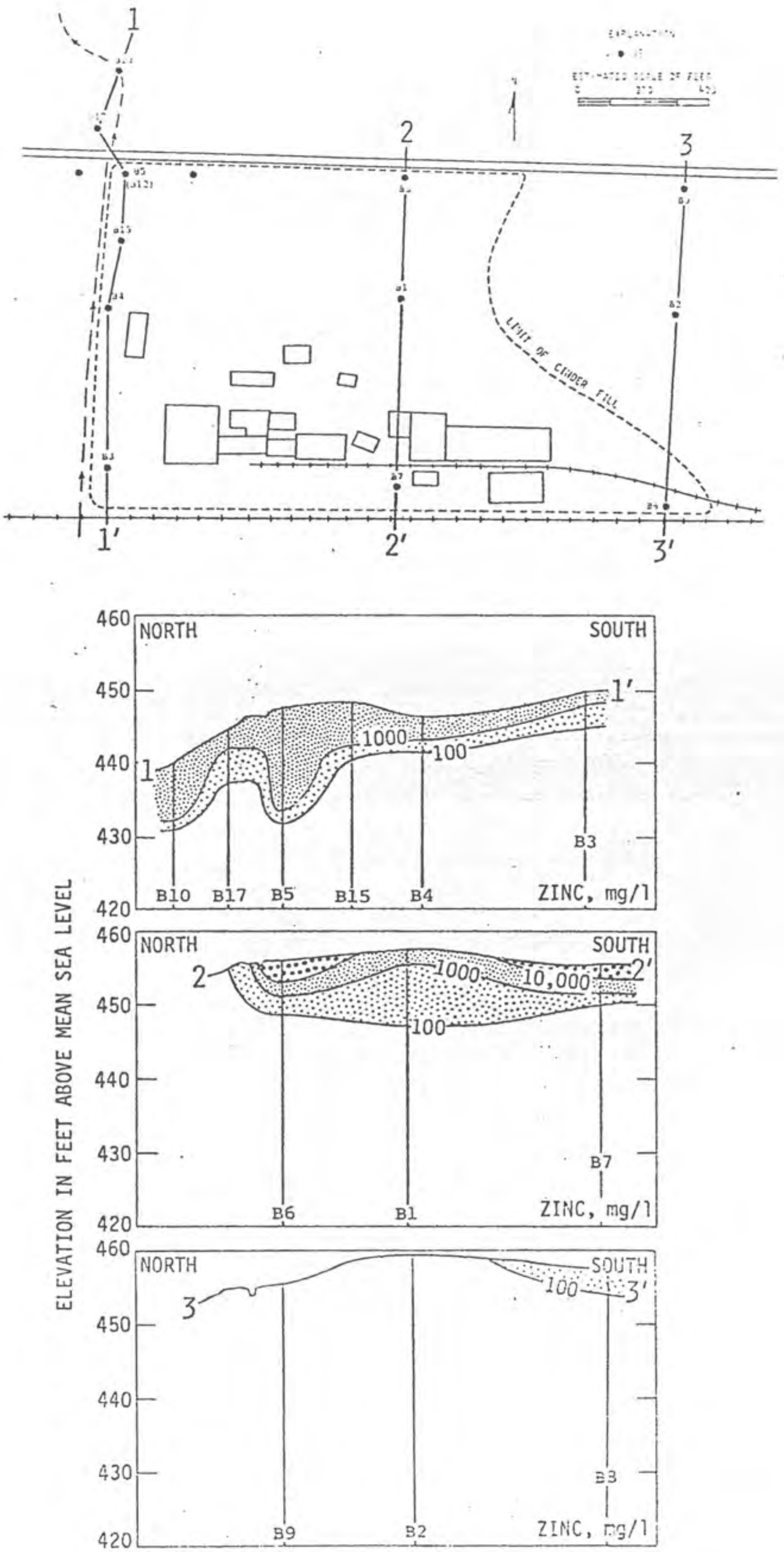


Figure 40. North-South soil zinc concentration profiles
Site B

An east-west water main also was installed across the old roadway and according to the plant manager metals-rich cinders were used as fill and introduced into the ground to a depth of about 10 feet.

Aside from the anomolous area around B-5, the maximum depth of zinc penetration on the plant property was about 11 feet. As at Site A no significant lateral migration of zinc was detected beyond the limits of the plant property. Site B has greater surface relief than Site A and is drained considerably better. As a result, there is less recharge occurring through the cinder fill and thus less migration of metals-rich water into the soil. However, there is more metals-rich surface water runoff resulting in higher soil zinc concentrations in the soils beneath the creek bed draining the plant property to the north (see figure 42). In figure 41, the zinc penetration profile between B-17 and B-10 have purposely not been connected. B-17 is located on the stream bank about 30 feet from the stream bed and as discussed before is not representative of zinc concentrations that would be expected in the soils directly beneath the creek. The differences in values at B-17 as opposed to B-10 and B-11 illustrate the limited horizontal migration of zinc away from the creek valley.

No cross sections are presented indicating the degree of migration and soil retention for cadmium, copper, and lead for Site B. By inspection, it is obvious that the same general relationships exist between these metals and zinc as at Site A. Sinilarly, the same mechanisms controlling the movement of the metals within the soil profile at Site A also are acting at this site.

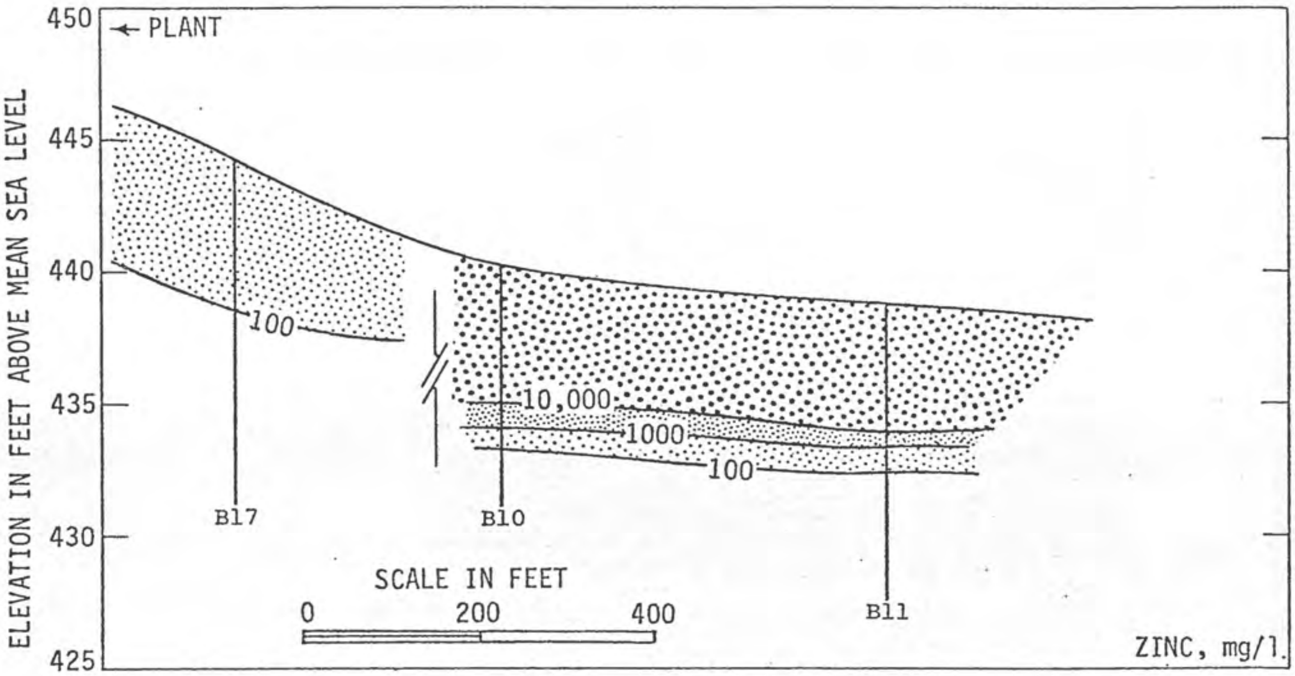


Figure 41. Streambed soil zinc concentration profile - Site B

Results of chemical analysis of water samples collected from wells at Site B are presented in table 12. All wells finished at the bedrock surface (B-1D through B-9D) produced water containing less than 0.5 mg/l zinc. One sample from well B-6D contained 7.8 mg/l zinc but probably was not a representative sample.

Aside from a few nonrepresentative zinc contents ranging from 1.6 to 10 mg/l for water from the shallow wells, only one well, B-5S, consistantly produced water having any significant zinc concentrations. The initial two samples having 110 and 140 mg/l zinc concentrations still could have been reflecting the effects of pollutants introduced during the drilling process. The remaining samples varied from .66 to 45.5 mg/l zinc and probably were a result of varying sampling procedures. No total mineral analysis were run on water samples collected at Site B. Table 13 gives results of total mineral analyses from the shallow and deep control hole wells.

Table 12. Water quality data - Site B

			1975							1976		
	2-13	3-19	6-18	7-21	8-11	11-18	3-2	4-6	6-8	7-13	7-30	9-9
1-S	.39	.11	<.1	<.5	<.5	<.2	<.5	<.5	.25	10.	<.5	<.5
1-M	.25	.007	<.1				<.5					
1-D		.019	<.7	<.5	<.5	<.2	<.5					<.5
2-S	.056	.034	<.4	<.5	<.5	<.2	<.5	2.7	<.5	<.5	<.5	<.5
2-D	.013	.019	0.7	<.5	<.5	<.2	<.5					<.5
3-S		.044	<.3	<.5	<.5	<.2	<.5	<.5	<.5	<.5	<.5	<.5
3-D		.018	<.4	<.5	<.5		<.5					<.5
4-S		.020	<.1	<.5	<.5	<.2	<.5	<.5	<.5	<.5	<.5	<.5
4-D		.017	<.3	<.5	<.5		<.5					<.5
5-S	110.	140.	29.5	27.1	8.4	8.0	.66	32.5	6.1	11.5	41.6	45.5
5-D	.16	.041	<.1	<.5	29.2	0.4	<.5	<.5				
6-S	1.1	.047	<.1	<.5	<.5	<.2	<.5	<.5	<.5	<.5	<.5	<.5
6-M	.25	.089	<.1				<.5	3.6				
6-D	.23	.023	<.1	<.5	<.5		<.5	7.8				<.5
7-S		.17	<.1	<.5	<.5	<.2	<.5	<.5	<.5	<.5	<.5	<.5
7-M		.039	<.1		<.5		<.5					
7-D		.011	<.1	<.5	<.5		<.5					<.5
8-S		.019	<.5	<.5	<.5	0.2	<.5	4.	<.5	<.5	<.5	<.5
8-M		.21	<.1				<.5					
8-D												<.5
9-S		.012	<.1	<.5	<.5	1.1	<.5	3.	<.5	<.5	<.5	<.5
9-D		.01	<.1	<.5	<.5		<.5					<.5
10						1.6	<.5	3.	<.5	<.5	<.5	<.5
11						4.7	<.5	<.5	<.5	<.5	<.5	<.5
14									<.5	<.5	<.5	<.5
15									<.5	<.5	<.5	<.5
16									2.2	<.5	<.5	<.5
17									<.5	<.5	<.5	<.5
CH1-S				<.5	<.5	0.5	<.5	<.5	<.5	<.5	<.5	
CH1-D				<.5	<.5	0.7	<.5					<.5
CH2-S				<.5	<.5	0.3	<.5	<.5	<.5	<.5	<.5	<.5
CH2-D				<.5	<.5	0.3	<.5					<.5

Table 13. Selected Total Mineral Analysis Data - Site B

		mg/l	me/l	mg/l	me/l
Iron (total)	Fe	90		1.7	
Manganese	Mn	3.80		.07	
Calcium	Ca	72.0	3.59	80.0	3.99
Magnesium	Mg	24.9	2.05	33.2	2.73
Strontium	Sr	.36	.01	.13	
Sodium	Na	169.	7.35	60.2	2.62
Potassium	K	2.0	.05	0.4	.01
Ammonium	NH_4	0.7	.04	tr	tr
Barium	Ba	0.3		<0.1	
Cadmium	Cd	.00		.00	
Chromium	Cr	.00		.00	
Copper	Cu	.00		.00	
Lead	Pb	<.05		<.05	
Lithium	Li	.01		.00	
Nickel	Ni	<.05		<.05	
Zinc	Zn	.00		.00	
Phosphate (filt)	PO_4	0.0		0.0	
(unfilt)	PO_4	3.4		0.1	
Silica	SiO_2	16.6		20.2	
Fluoride	F	0.9		0.4	
Boron	B	0.2		0.0	
Nitrate	NO_3	0.3	tr	18.2	.29
Chloride	Cl	130	3.67	10	.28
Sulfate	SO_4	8.6	.18	149.3	3.11
Alkalinity	(as $CaCO_3$)	460	9.20	286	5.72
Hardness	(as $CaCO_3$)	282	5.64	336	6.72

Total Dissolved Minerals	698		543

Summary

The results of work conducted at Site A are directly applicable to the understanding of metals migration at this site. Cation exchange and precipitation are the principal attenuating mechanisms. The geology is similar and therefore desirable for this type of waste disposal activity. The topography of this site is steeper resulting in better drainage and less downward migration of the metals.

The ability to define the migration patterns of the metals with fewer core holes and peizometers attest to the similarity of the sites and knowledge gained at Site A.

✓

Site C

Site C is a petroleum base-chlorinated hydrocarbon plant producing pesticides, adhesives, resins, and other associated products. It is located in east-central Illinois and has been in operation since the late 1930's. Wastes from the plant principally are in liquid form and are stored in surface pits or lagoons. Since September 1965, a deep disposal well has been used to dispose of most of the waste generated (injection averages about 400,000 gallons per day). Prior to that time, waste discharges into drainage ditches and a nearby stream were common.

Waste water from the plant varies in mineral content daily and ranges from 11,140 to 27,479 mg/l sodium hydroxide, 78,980 to 149,500 mg/l sodium chloride, and 111,600 to 209,500 mg/l total dissolved minerals. No organic analyses of the waste water are available. The concentrations given above periodically are diluted with surface runoff water from the plant property that is required to be retained, treated, and disposed of along with the process waste water.

According to verbal reports from farmers in the area of the plant, occurrences of gross pollution have been experienced in the past, primarily in the form of surface water pollution. Evidence of contaminated surface water flow from the plant into nearby fields is present as portions of some fields remain sterile. Also, a few animal deaths and frequent fish kills in nearby streams reportedly have occurred in the past due to pollution from the plant. The frequency of such occurrences has been reduced dramatically since the deep disposal wells went into operation in 1965.

As noted earlier in this report, permission to core test and install monitoring wells on plant property at Site C was denied by the industrial officers. Due to the completely different nature of the potential pollution source and total cooperation offered by owners of surrounding farm lands an abbreviated study was undertaken at this site. Although scientifically limited in tracing the migration of pollutants thru the soil, the experience gained in sampling for this type of pollutant have justified the time and money spent at this site.

A total of 8 wells at 8 locations were completed around Site C. Core samples, including bedrock core samples at 3 of the eight sites, also were taken (see figure 42). Total well and core sampling footages are about 186 and 342 feet, respectively.

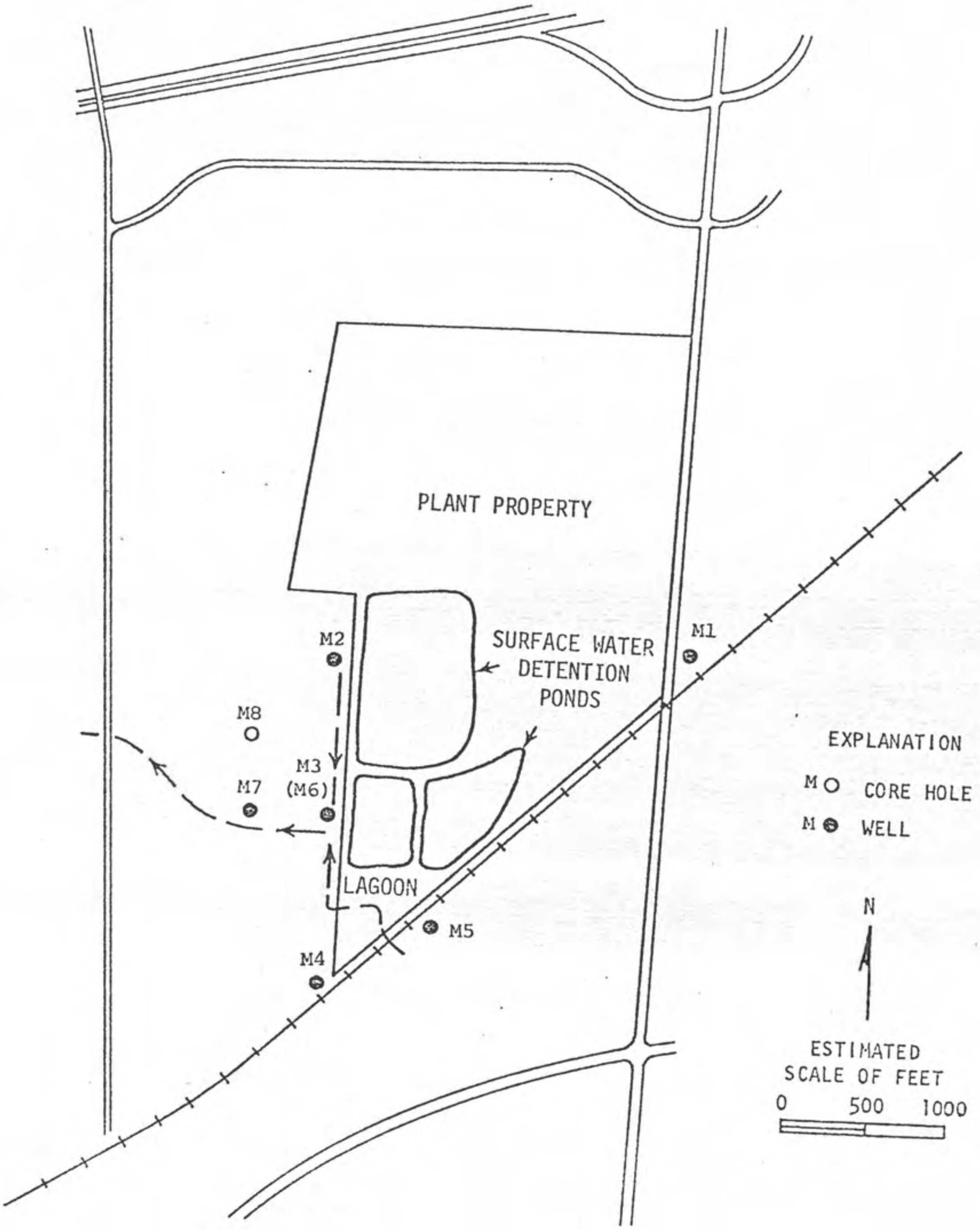


Figure 42. Location Map - Site C

Geology

The glacial drift at site C varies from 6 to 38 feet thick, becoming thicker to the west (figure 43A). The rapid thickening to the west is related to the bedrock surface which drops off quickly at the western edge of the site (figure 43B). The bedrock elevation slopes from 624 feet above sea level on the east to 576 feet on the west. The stratigraphic units are generally flat lying, but vary considerably in thickness across the site. Figure 44 is an east-west cross section which illustrates the relationship between the bedrock surface and the glacial materials. Data from selected borings are included at the end of this site discussion. A complete tabulation of data is available from N.T.I.S. A description of each of stratigraphic unit follows:

Wisconsinan Stage

A) Peoria Loess (2-6 feet thick) - Brownish-gray organic silt. Sand content averages 14 percent, but varies from 5 to 24 percent. Montmorillonite averages 45 percent and illite 34 percent of clay mineral fraction. Consists of wind-blown deposits during and following Woodfordian glaciation. Evidence of Modern Soil includes iron and manganese stains, organic material, and absence of carbonates.

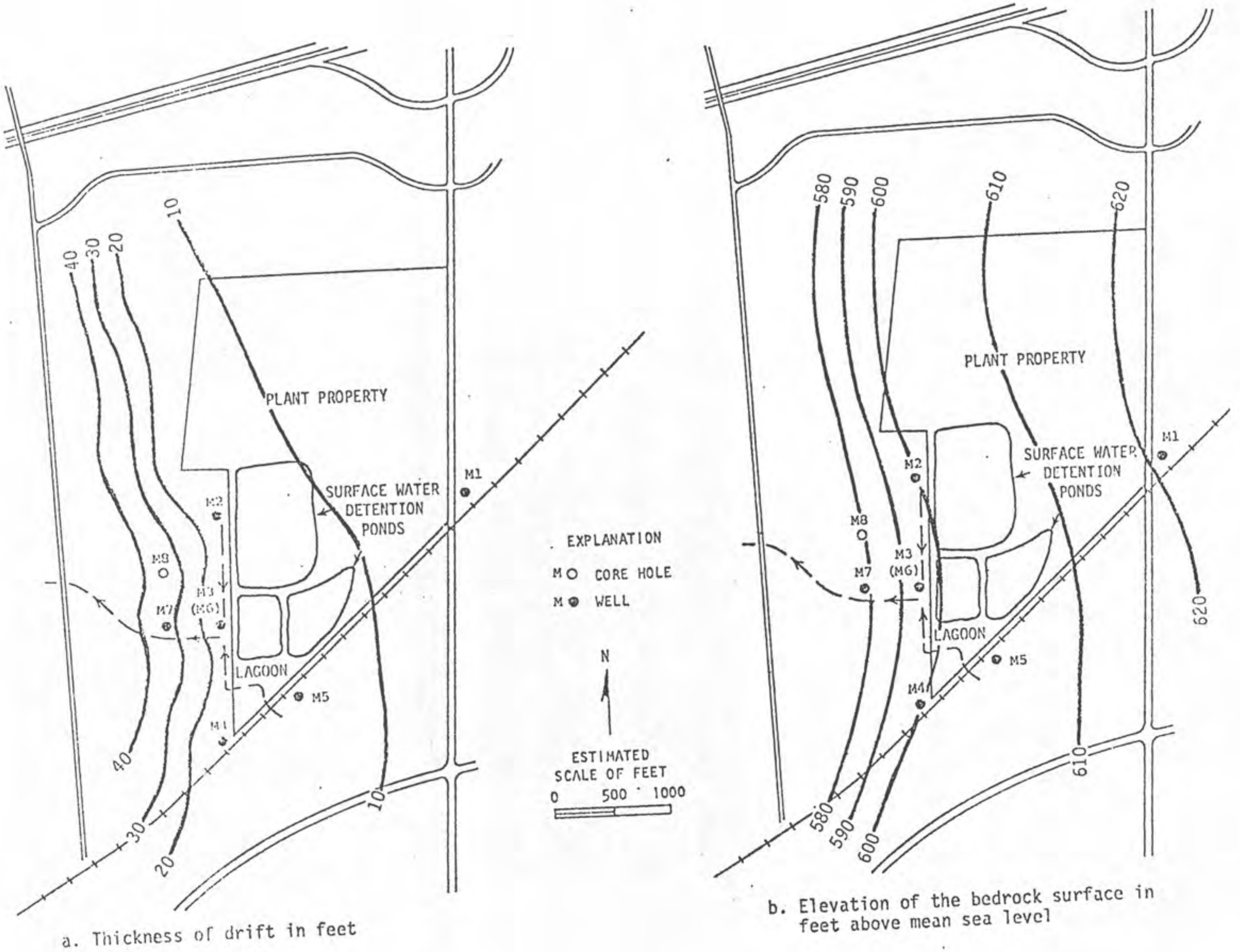
B) Roxana Silt (0-3 feet) - Dark brown silt. In some places it is hard to distinguish from the overlying Peoria Loess or underlying Berry Clay. Sand content averages 20 percent but is variable. No mineralogical data is available. Consists of wind-blown deposits mixed with the underlying material. Contains Farmdale Soil and the lower portion of the Modern Soil. It is leached and contains iron stains and organic material.

Sangamonian Stage

Glasford Formation

C) Berry Clay Member (0-4 feet thick) - Brownish gray silty clay with

Figure 43. Generalized drift thickness (A) and bedrock surface elevation (B) maps - Site C



a. Thickness of drift in feet

b. Elevation of the bedrock surface in feet above mean sea level

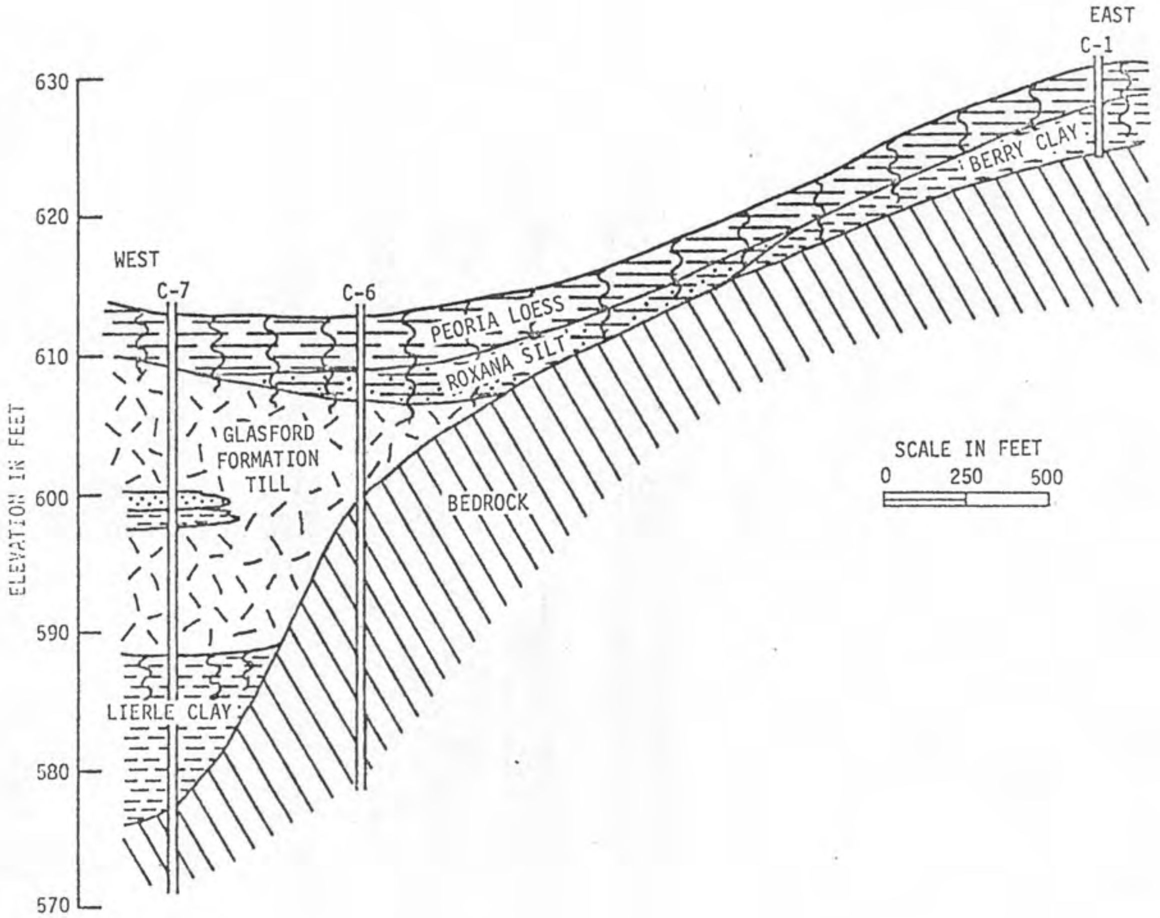


Figure 44. East-West stratigraphic cross-section Site C.

a trace of gravel. Sand content averages 30 percent but is variable. No mineralogical data is available. Considered an accretion gley deposit. Contains the Sangamon Soil, is leached and contains organic material and iron and manganese stains. Mottling increases with depth indicating strong weathering.

Illinoian Stage

D) Glasford Till Member (0-21 feet) - Dark gray to yellowish-brown sandy glacial till with some gravel. Sand content somewhat variable but averages 35 percent. Mineralogical data indicate average montmorillonite content of 13 percent and average illite content of 59 percent. Evidence of the Sangamon Soil is present. It is leached and mottled at the top; iron stains are abundant, especially along joints. Carbonates are present with depth. Some interbedded silts and sands. Lower portion dark gray to olive brown sandy till; contains carbonates, pebbles, and fragments of Lierle Clay and bedrock.

Yarmouthian Stage

Banner Formation

E) Lierle Clay Member (0-11 feet) - Gray to olive gray silty clay. Contains rock fragments and some thin stratification. Texture variable. Montmorillonite averages 25 percent and illite 28 percent of clay fraction. Evidence of Yarmouthian Soil includes iron stains and absence of carbonates.

Pennsylvanian System

Mattoon Formation - Bedrock consisting of fine-grained micaceous sandstone and siltstone. Some shale locally present. Bedrock is leached.

Hydrology

Based on the geologic description of this site, there is no significant aquifer in the glacial materials above bedrock. However, there is a sandstone unit in the upper Pennsylvanian age rocks that is used locally as a source for small domestic type water supplies. In addition, there appeared to be a relatively permeable zone at the drift-bedrock interface at most locations. Lateral movement of water in this zone and the underlying sandstone unit appeared most likely.

To explore the possible conveyance of pollutants at the drift-bedrock interface 5 wells were finished just above the rock. Water level hydrographs for these wells, the shallow control hole, and precipitation data are presented in figure 45. All wells appeared to be very responsive to fluctuations in precipitation.

Water table contour maps were drawn for each round of water level measurements made. Figures 46 A and B illustrate the high and low water table configurations for March 1976 and October 1976 respectively. In both instances the direction of groundwater movement in the shallow drift is to the west.

Two wells, M3-D and M-7 were completed in the deeper lying sandstone units. Water level hydrographs for these wells and the deep control hole well also are shown in figure 45. The general shape of these hydrographs are very similar to those for the shallow wells suggesting that they probably are hydraulically interconnected. Maximum and minimum water levels for all wells at Site C are summarized in table 14.

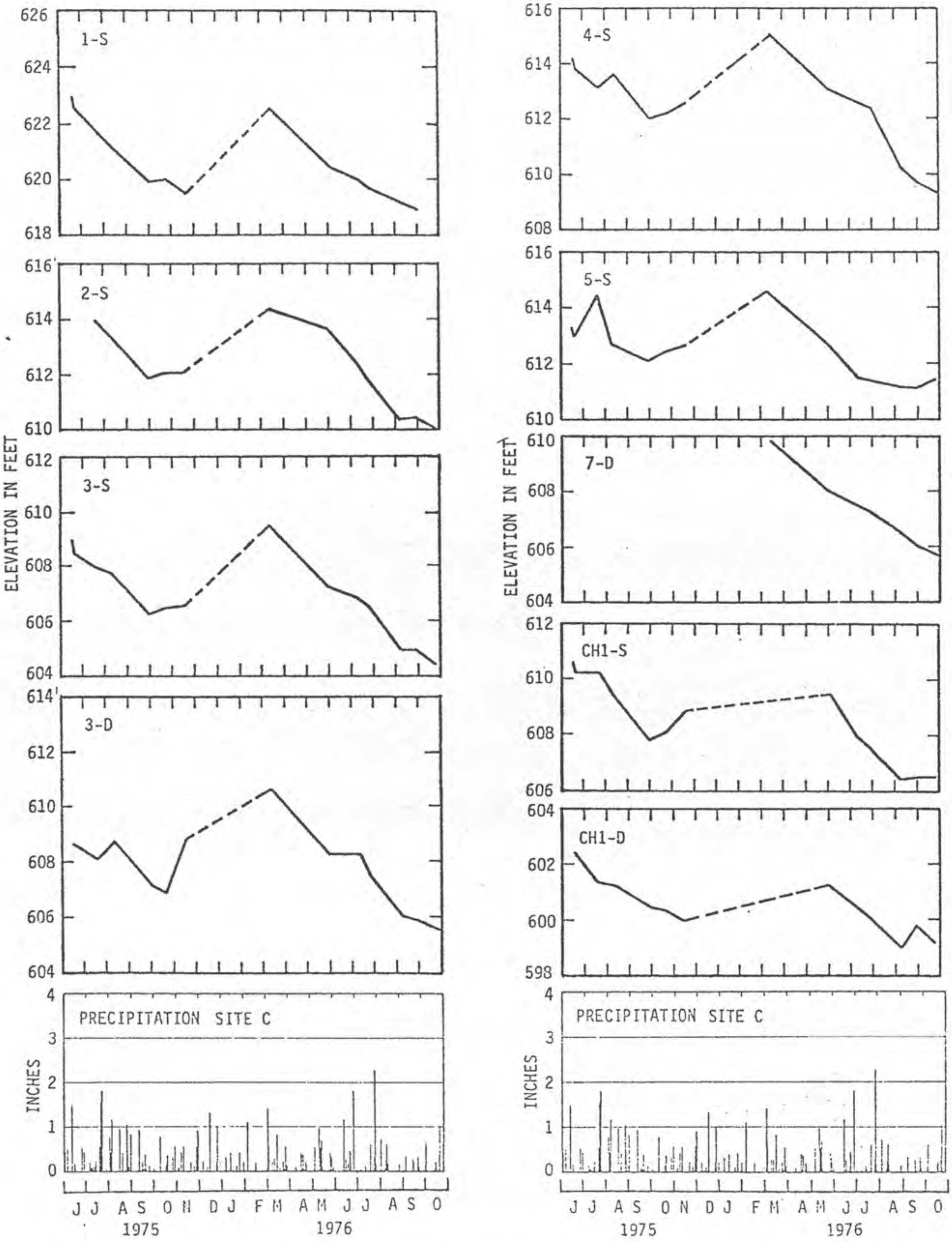
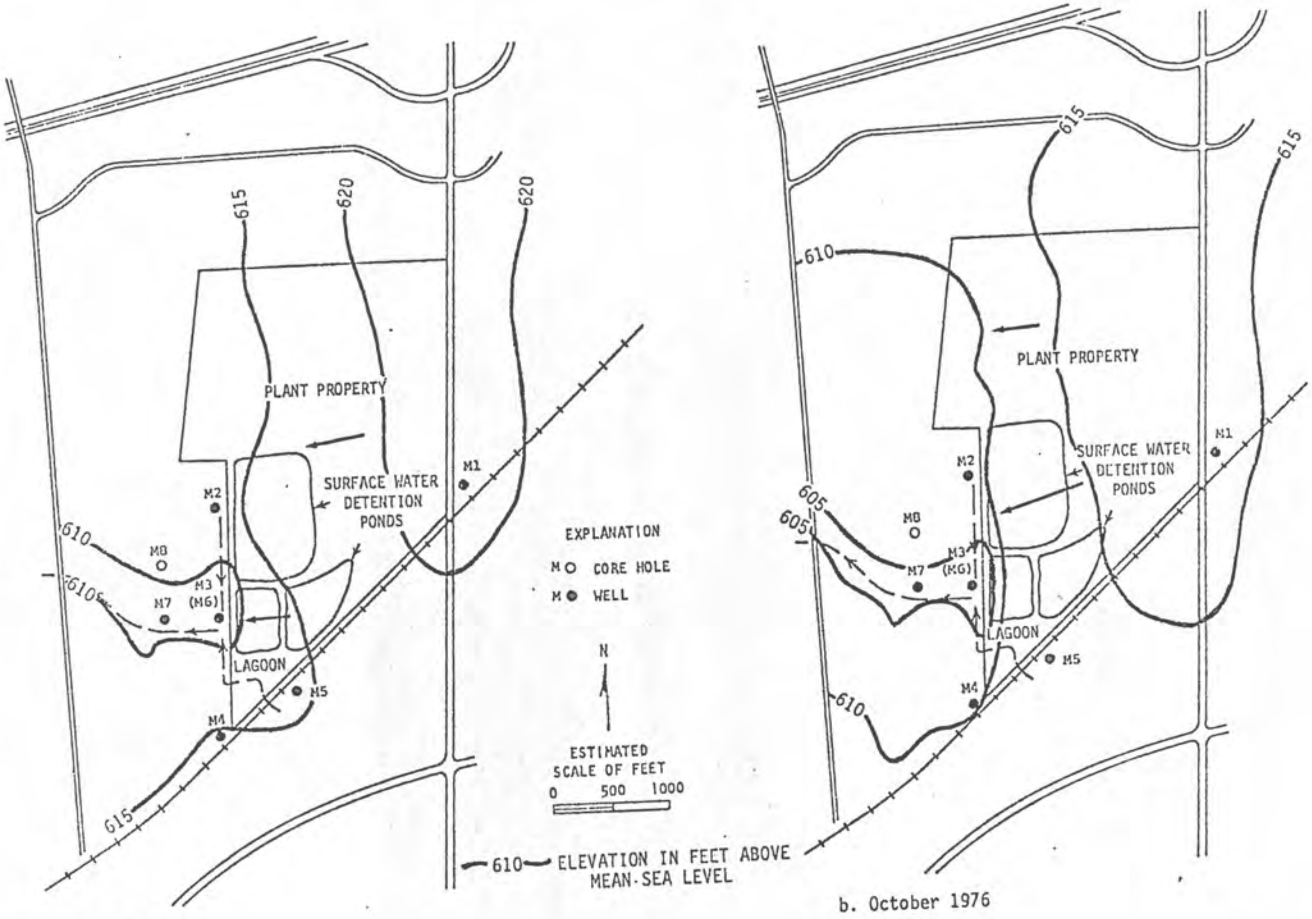


Figure 45. Water level hydrographs of all wells - Site C



a. March 1976

b. October 1976

Figure 46. Water table contour maps for A) March, 76, and B) October, 76 - Site C

Due to the limited extent of investigations at site C no attempts were made conduct a pumping test or determine rates of groundwater movement.

Table 14. Water Level Fluctuations in All Wells - Site C

		Low			High			
Well No.	L.S.D.	Depth Below Land (ft)	MSL	Date	Depth Below Land (ft)	MSL	Date	Fluctuation
1-S	627.78	8.88	618.90	10-1-76	4.76	623.02	6-17-75	4.12
2-S	615.30	5.34	609.96	10-27-76	0.98	614.32	3-12-76	4.36
3-S	611.26	6.82	604.44	10-27-76	1.88	609.38	3-12-76	4.94
3-D	611.26	5.79	605.47	10-27-76	0.71	610.55	2-12-76	5.08
4-S	614.78	5.38	609.40	10-27-76	-0.24	615.02	3-12-76	5.62
5-S	615.87	4.78	611.09	9-10-76	1.21	614.66	3-12-76	3.57
7-D	608.76	3.03	605.73	10-27-76	-1.00	609.76	3-12-76	4.03
CH1-S	615.00	8.57	606.43	9-10-76	4.37	610.63	6-17-75	4.20
CH1-D	615.00	16.79	598.21	10-27-76	12.50	602.50	6-17-76	4.29

Chemical Data

Organic analysis of waste water from the aerated lagoon on the plant property were conducted by the Illinois Environmental Protection Agency. The three primary compounds they detected in the waste were benzene hexachloride, heptachlor, and heptachlor expoxide. Specific research was conducted for these compounds in the core and water samples analyzed by the Natural History Survey and Environmental Research Laboratories. No evidence of these or any other chlorinated hydrocarbon compounds was found.

The presence of dieldrin and various forms of chlordane were detected in surface samples at M-3 and M-4. Both sites are in cultivated fields and the detected compounds were found only in the upper 18 inches. It is quite possible that the presence of these compounds is due to agricultural applications and should not be attributed to pollution from the chemical plant.

Results of inorganic analysis of water samples at Site C are presented in table 15. Total mineral and chloride concentrations presented in the table indicate that wells M-2 (950 mg/l TDS), M-3S (1328 mg/l TDS), and M-4 (5188 mg/l TDS) appear to be affected by the highly mineralized waste water at the plant. Wells M-1 (108 mg/l TDS), M-3D (653 mg/l TDS), M-5(403 mg/l TDS), and M-7 (290 mg/l TDS) apparently are not affected.

Due to the lack of access to the plant property no further work was carried out at this site. The limited data generated is not adequate to define the limits of migration of pollutants from the plant site. However, definite evidence of inorganic pollutants were detected in water samples from wells west of the plant the direction of shallow groundwater movement. Visual evidence of organic pollutants

TABLE 15

TOTAL MINERAL ANALYSIS DATA - SITE C

Well No.		M-1		M-2				M-3S				M-3D			
Date		6-2-76		10-3-75		6-2-76		10-3-75		6-2-76		10-3-75		6-2-76	
		mg/l	me/l	mg/l	me/l	mg/l	me/l	mg/l	me/l	mg/l	me/l	mg/l	me/l	mg/l	me/l
Iron(total)	Fe	1.9		5.2		0.1		2.8		0.0		5.5		Tr.	
Manganese	Mn	.61		2.83		.03		6.11		.00		2.26		.12	
Calcium	Ca	8.0	.40	153.	7.66	104.0	5.19	216	10.78	158.0	7.88	125.	6.25	75.2	3.75
Magnesium	Mg	6.3	.52	82.9	6.82	82.8	6.81	104	8.62	101.2	8.32	39.3	3.23	31.3	2.57
Strontium	Sr	.09		.43	.01	.30	.01	.43	.01	.27	.01	.25	.01	.20	
Sodium	Na	7.1	.31	71.	3.09	70.7	3.08	94.	4.09	77.0	3.35	49.7	2.16	45.9	2.00
Potassium	K	0.5	.01	1.8	.05	1.8	.05	3.0	.08	2.2	.06	4.1	.10	3.5	.09
Ammonium	NH_4	Tr.	Tr.	0.1	.01	Tr.	Tr.	0.0	.00	Tr.	Tr.	0.0	.00	Tr.	Tr.
Barium	Ba	<0.1		0.3		<0.1		0.3		<0.1		0.2		<0.1	
Cadmium	Cd	.00		.00		.00		.00		.00		.00		.00	
Chromium	Cr	.00		.00		.00		.00		.00		.00		.00	
Copper	Cu	.01		.00		.00		.00		.00		.00		.00	
Lead	Pb	<.05		<.05		<.05		<.05		<.05		<.05		<.05	
Lithium	Li	.01		.02		.01		.03		.02		.04		.03	
Nickel	Ni	<.05		<.05		<.05		<.05		<.05		<.05		<.05	
Zinc	Zn	.01		5.4	.17	.00		3.5	.11	.00		.08		.00	
Phosphate(filt)	PO_4	0.0		0.0		0.0		0.0		0.0		0.0		0.0	
Phosphate(unfilt)	PO_4	0.0		0.2		-		0.0		-		0.4		0.0	
Silica	SiO_2	16.7		9.4		7.2		9.7		5.2		15.9		10.7	
Fluoride	F	0.1		0.2		0.2		0.2		0.1		0.2		0.2	
Boron	B	0.0		0.1		0.1	.00	0.1		0.0		0.1		0.1	
Nitrate	NO_3	9.0	.14	1.1	.02	0.1	8.97	1.1	.02	0.3	.00	0.9	.01	0.4	.01
Chloride	Cl	10	.28	330	9.30	318	1.43	545	15.37	485	13.70	21.	.59	20	.56
Sulfate	SO_4	37.6	.78	85.6	1.78	68.7		96.5	2.01	100.0	2.08	133.1	2.77	78.0	1.62
Alkalinity (as $CaCO_3$)		2	.04	332	6.64	240	4.80	320	6.40	196	3.92	426	8.52	316	6.32
Hardness (as $CaCO_3$)		46	.92	724	14.48	600	12.00	970	19.40	810	16.20	474	9.48	316	6.32
Total Dissolved Minerals		108		950		771		1328		1104		653		468	

TABLE 15

TOTAL MINERAL ANALYSIS DATA - SITE C (cont.)

Well No.		M-4				M-5				M-7		MCH1-S		MCH1-D	
Date		10-3-75		6-2-76		10-3-75		6-2-76		6-2-76		6-2-76		6-2-76	
		mg/l	me/l	mg/l	me/l	mg/l	me/l	mg/l	me/l	mg/l	me/l	mg/l	me/l	mg/l	me/l
Iron(total	Fe	7.8		4.1		2.1		0.0		0.0		0.2		0.3	
Manganese	Mn	14.10		3.20		1.13		.00		.00		.00		.04	
Calcium	Ca	840.	41.92	700	34.93	67.6	3.37	56.4	2.81	31.6	1.58	48.0	2.40	28.8	1.44
Magnesium	Mg	337.	27.68	302	24.87	34.1	2.80	33.0	2.71	26.5	2.18	17.5	1.44	23.3	1.92
Strontium	Sr	1.51	.03	1.4	.03	.18		.16		.10		.50	.01	.09	.00
Sodium	Na	460.	20.01	404	17.57	32.8	1.43	30.2	1.31	39.1	1.70	58.4	2.54	57.9	2.52
Potassium	K	4.6	.12	5.0	.13	2.5	.06	1.7	.04	1.4	.04	0.9	.02	2.8	.07
Ammonium	NH_4	0.1	.01	0.1	.01	0.1	.01	Tr.	Tr.	Tr.	Tr.	0.1	.01	0.1	.01
Barium	Ba	0.9		<0.1		0.3		<0.1		<0.1		<0.1		<0.1	
Cadmium	Cd	.00		.00		.00		.00		.00		.00		.00	
Chromium	Cr	.00		.00		.00		.00		.00		.00		.00	
Copper	Cu	.02		.02		.00		.00		.00		.00		.01	
Lead	Pb	<.05		<.05		<.05		<.05		<.05		<.05		<.05	
Lithium	Li	.06		.06		.02		.01		.02		.00		.01	
Nickel	Ni	<.05		<.05		<.05		<.05		<.05		<.05		<.05	
Zinc	Zn	.13		.02		.02		.00		.00		.00		.00	
Phosphate(filt)	PO_4	0.0		0.0		0.0		–						0.0	
Phosphate(unfilt)	PO_4	0.0		0.0		0.1		0.0		0.0		0.1		0.0	
Silica	SiO_2	8.7		7.7		10.1		6.8		7.8		11.9		2.5	
Fluoride	F	0.2		0.1		0.2		0.2		0.1		0.2		0.2	
Boron	B	0.1		0.0		0.1		0.1		0.1		0.1		0.1	
Nitrate	NO_3	1.6		0.6	.01	1.3	.02	0.0	.00	0.0	.00	0.2	.00	0.4	.01
Chloride	Cl	3025.	85.31	2650	74.73	19	.54	12	.34	9	.25	16	.45	14	.39
Sulfate	SO_4	31.6	.66	29.8	.62	48.8	1.02	46.5	.97	36.4	.76	65.6	1.36	78.0	1.62
Alkalinity	(as $CaCO_3$)	208	4.16	132	2.64	302	6.04	282	5.64	228	4.56	228	4.56	194	3.88
Hardness	(as $CaCO_3$)	3480	69.60	2990	59.80	308	6.16	276	5.52	188	3.76	192	3.84	168	3.36
Total Dissolved Minerals		5188		4203		403		380		290		360		340	

also were noted in fields west of the plant. It appears that the glacial materials are retarding the migration of the organic pollutants while the more mobile inorganic pollutants are migrating through the soil materials. No evidence of either type of pollutant was detected in water or core samples from the underlying bedrock aquifer.

Results

The study conducted at this site did not permit defining the limits of hydrocarbon migration into the soil. Had access to the plant property been granted, a better understanding of the interaction between the soils and hydrocarbon compounds could have been accomplished.

The experience gained in core sampling for hydrocarbon type pollutants should be of value to other studies of this type. Also, the difficulty experienced in trying to identify possible hydrocarbon compounds in the laboratory and show that they are in fact a result of disposal activities and not naturally occurring compounds in the soil should be noted. This problem alone should be reason enough to not conduct studies unless access to the pollution source can be obtained. Had that been the case in this study, direct comparison of peaks on the gas chromatograph could have been made and indentification of those compounds would have been simpler.

While no evidence of organic pollutant movement was detected, information is not sufficient to show to what extent soils have retained the organic pollutants.

Site D

Site D is secondary zinc smelter located in north-central Illinois. It was a primary smelting facility from 1906 until 1971 when it was converted to secondary smelting operations. Wastes from the plant principally have been in the form of metals-rich cinders as at Sites A and B. There currently is a 40 foot high pile of cinders covering about 12 acres in the southeast portion of the plant property. A 1 to 5 foot thick layer of cinders also cover the remaining 90 acres of the plant complex.

This site was selected because it lies along the Illinois River in an alluvial sand and gravel setting. It also is compatable with Sites A and B with regard to the pollution source (zinc) and period of operation. A limited number of core holes and wells were constructed at this site. A total of 7 core holes and 14 wells at the 7 sites were constructed (see figure 47). Total well and coring footages are about 347 and 185 feet respectively.

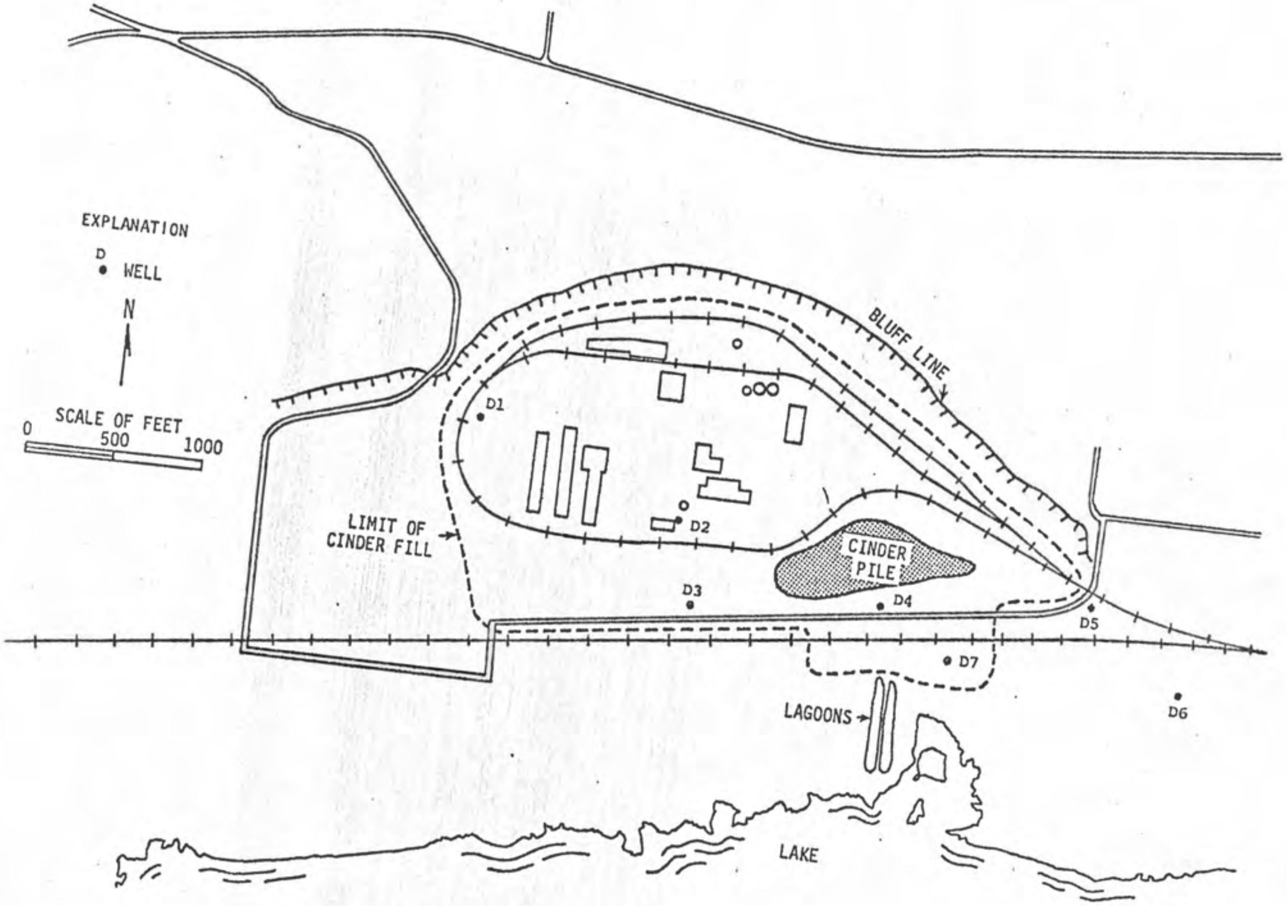


Figure 47. Location map - Site D

Geology

The stratigraphic units at Site D differ markedly from those at the other locations. Site D is situated on a low level outwash terrace at the edge of the Illinois River floodplain. The outwash (Henry Formation) varies in character and thickness across the site. At the eastern edge of the property, the Henry Formation is overlain by predominately swamp deposits (Grayslake Peat). Figure 48 is a cross-section which illustrates the nature of the deposits at the site. Date for selected borings are included at the end of this site discussion. A complete tabulation of data for all sites is available through N. T. I. S. No textural or mineralogical analyses were run of the samples collected at this location. Bedrock was not encountered in any of the borings, so the exact thickness of the unconsolidated sediments is unknown. However, available data suggest that the unconsolidated materials are 50 to 100 feet thick, and thinning eastward. The stratigraphy developed during this investigation corresponds with previous work in the area by Willman (23). A brief description of the stratigraphic units follows:

Holocene Stage

A) Grayslake Peat (0-20 feet thick) - Recent accumulation of peat, marl, and muck locally interbedded with silt and silty sand. Light gray to dark gray to black in color; organic material including wood fragments is abundant. Contains carbonates except at the surface. Represents accumulation of organic material in a wet, poorly drained environment. Silt loam at the base overlying the Henry Formation may represent transition from alluvial to swampy environment.

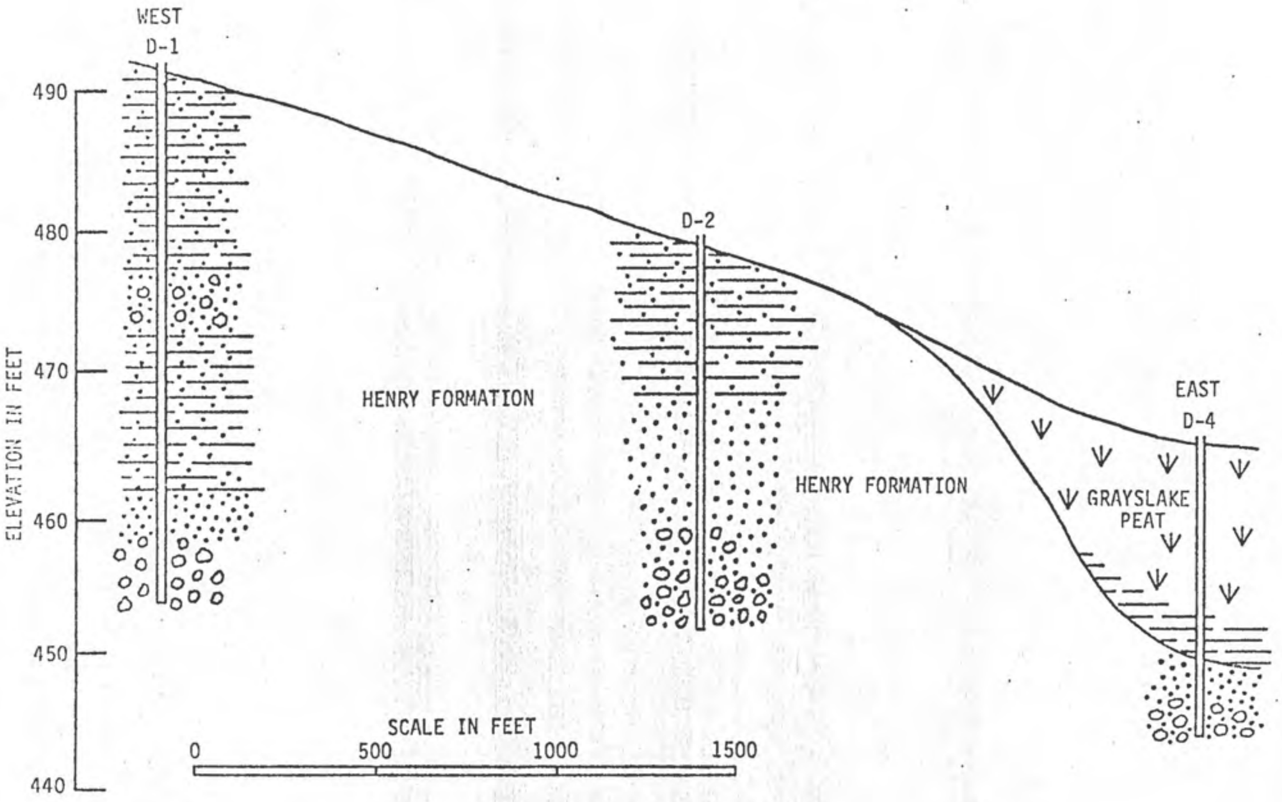


Figure 48. Stratigraphic cross-section - Site D

Wisconsinan Stage

B) Henry Formation (3-38 feet thick) - Interbedded clay, silt, sand, and gravel. Predominantly silt and clay in upper portion (see figure 48); probably contains slopewash from adjacent bluffs, especially the western part of site. Considerable variation in texture vertically and laterally (see figure 48). Typically becomes coarser with depth; sand and gravel predominant. Contains carbonates except where leached at the surface. Deposited by meltwaters from the Wisconsinan glaciers carrying sediment down the Illinois River Valley. Contains poorly developed Modern Soil; has probably been disturbed by man's activity. It is at the surface in the western portion of Site D and underlies Unit A in the eastern part of the site.

Hydrology

Based on the geologic description of this site, it is obvious that there is a thick permeable sand and gravel deposit associated with the Illinois River lowlands. Two wells owned by the industry are capable of yielding in excess of 500 gallons per minute each.

To determine the hydraulic characteristics of this aquifer a pumping test using 1 observation well (D-4D) was conducted on August 31, 1976. To allow for a larger pumping rate during the test, an 8-inch diameter well (T.W.1) was constructed 8 feet east of D-4D. The well was 32 feet deep and equipped with 10 feet of 7 slot (0.007 inch) wire wound screen. The well penetrated the top 10 feet of the aquifer.

The well was pumped at a constant rate of 30 gallons per minute for a period of 135 minutes and allowed to recover for a period of 80 minutes. Water level measurements or drawdown data for T.W.1 and D-4D are presented in figure 49.

Analysis of these data were complicated due to the following: 1) the low pumping rate relative to the well diameter (effects of stored water in the casing); 2) most theoretical solutions for type curves require the assumption that flow is uniform through all sections of the well screen. Under ordinary circumstances this assumption is not critical, but in this case cannot be accepted due to the closeness of the observation well; and 3) the production well (T.W.1) is partially penetrating at only 17.2 percent and this low a percentage does not appear in tables of well functions found in the literature.

To solve for the above situation, type curves were generated to fit the field conditions. A modified form of a computer program

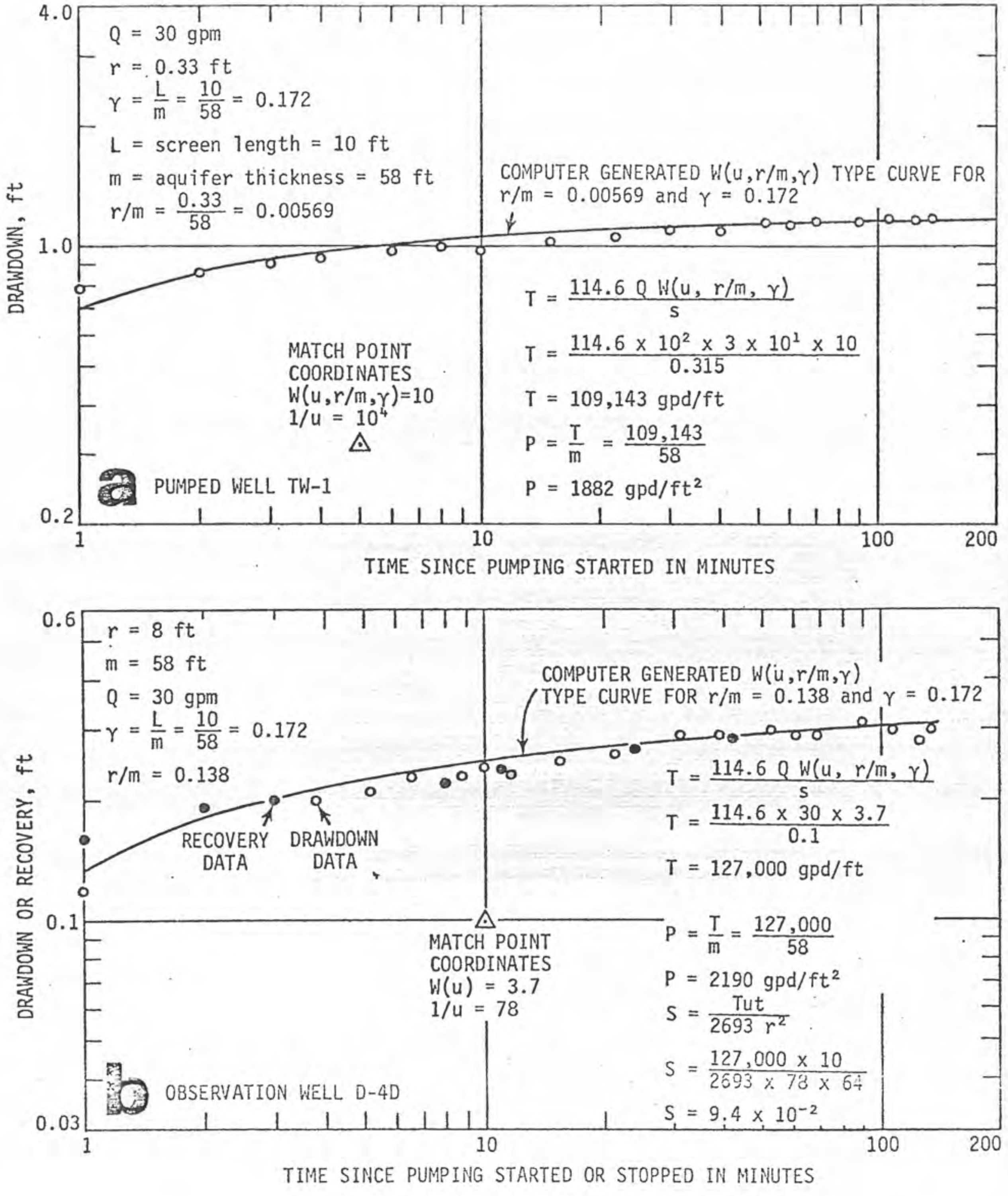


Figure 47. Pumping test data for well T.W.1 - Site D

given by Prickett and Lonnquist (24) was used. Their program was modified to operate in a vertical cross section with radial symmetry about the center of the production well. The program also was transformed to yield a nondimensional well function. The well function for nonleaky aquifers, $W(u)$ used at site A is an example of a mathematically generated type curve. The well function generated in this case is termed $W(u,\frac{r}{m}, \gamma)$ since the drawdown also is a function of the ratios of observation well distance to the aquifer thickness (r/m) and the production well screen length to the aquifer thickness $(\frac{L}{m})$.

Figures 49 A&B show the resulting type curve analyses for the pumped well and observation well, respectively. Since the effective radius of the pumped well is unknown, results of analysis from the pumped well data are considered only an approximation. The accepted computed coefficients of transmissivity, permeability, and storage coefficient are 127,000 gpd/ft, 2,190 gpd/ft^2, and .094, respectively.

The computed storage coefficient is unexpectedly high. This could be due to some leakage from materials overlying the defined aquifer. Another possible explanation is the presence of the cinder pile next to the pumping test site. Lowering of water levels due to pumpage may allow additional compaction of the aquifer materials under the weight of the cinder pile and an apparently higher storage coefficient value would result.

In an effort to detect any possible shallow groundwater pollution at this site, a series of wells were constructed about 5 to 10 feet below the water table surface and another series of wells were installed about 10 to 15 feet below that. Water level hydrographs for the shallow and deep wells are presented in figure 50.

Water table contour maps were drawn for each round of water level measurements made. Figures 51 A and B illustrate the high and low water table configurations for June 1976 and October 1976, respectively. The general direction of groundwater movement is to the south toward the back water lake, and the Illinois River.

Water levels in the deeper wells varied in response to precipitation in a fashion similar to the shallow wells. At wells D-1 and D-2 the vertical movement of water in the drift materials is downward. At all other sites, those closer to the river, the direction of vertical movement is upward. Maximum and minimum water levels for all wells at site D are summarized in table 16.

To determine the average apparent rate of groundwater movement Darcy's equation was applied as at site A. The average rates of movement for June and October 1976 were 4.60 and 3.54 ft/day, respectively. Based of data presented by Todd (20), an effective porosity or specific yield of .20 was assumed for the aquifer materials. Using this value, effective velocities of 23 and 18 ft/day were calculated. These relatively high rates of groundwater movement were to be expected in a permeable sand and gravel aquifer of this type.

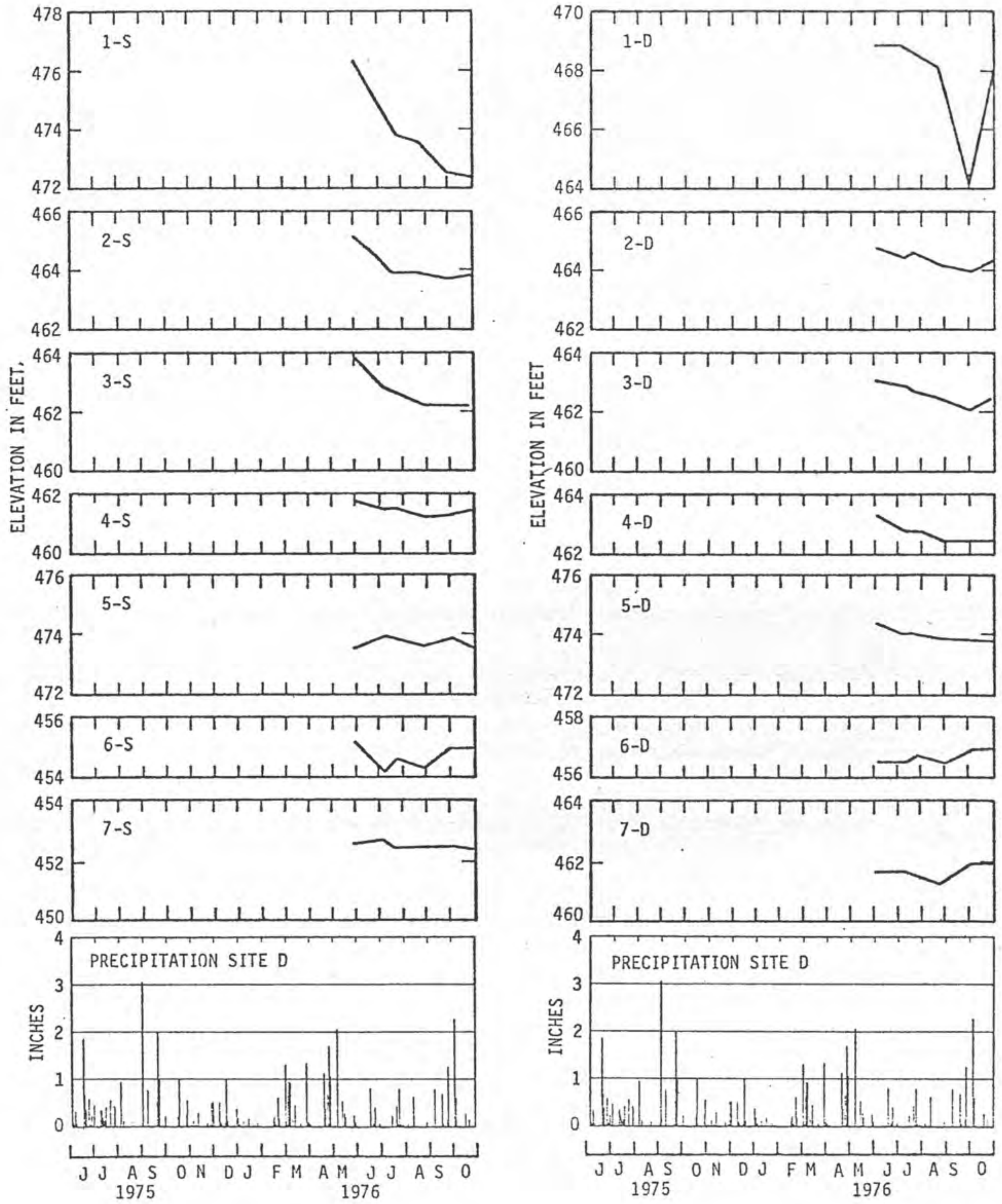
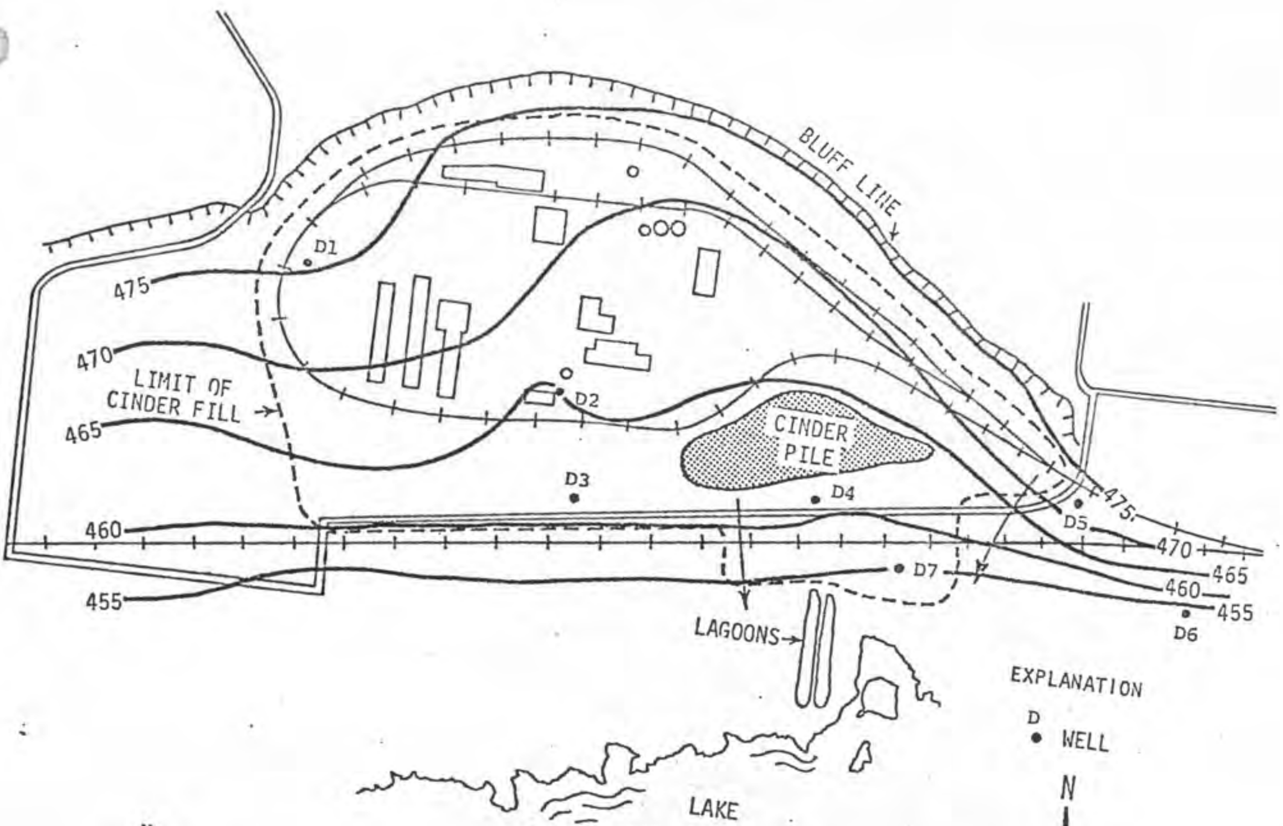


Figure 50. Water level hydrographs for all wells - Site D

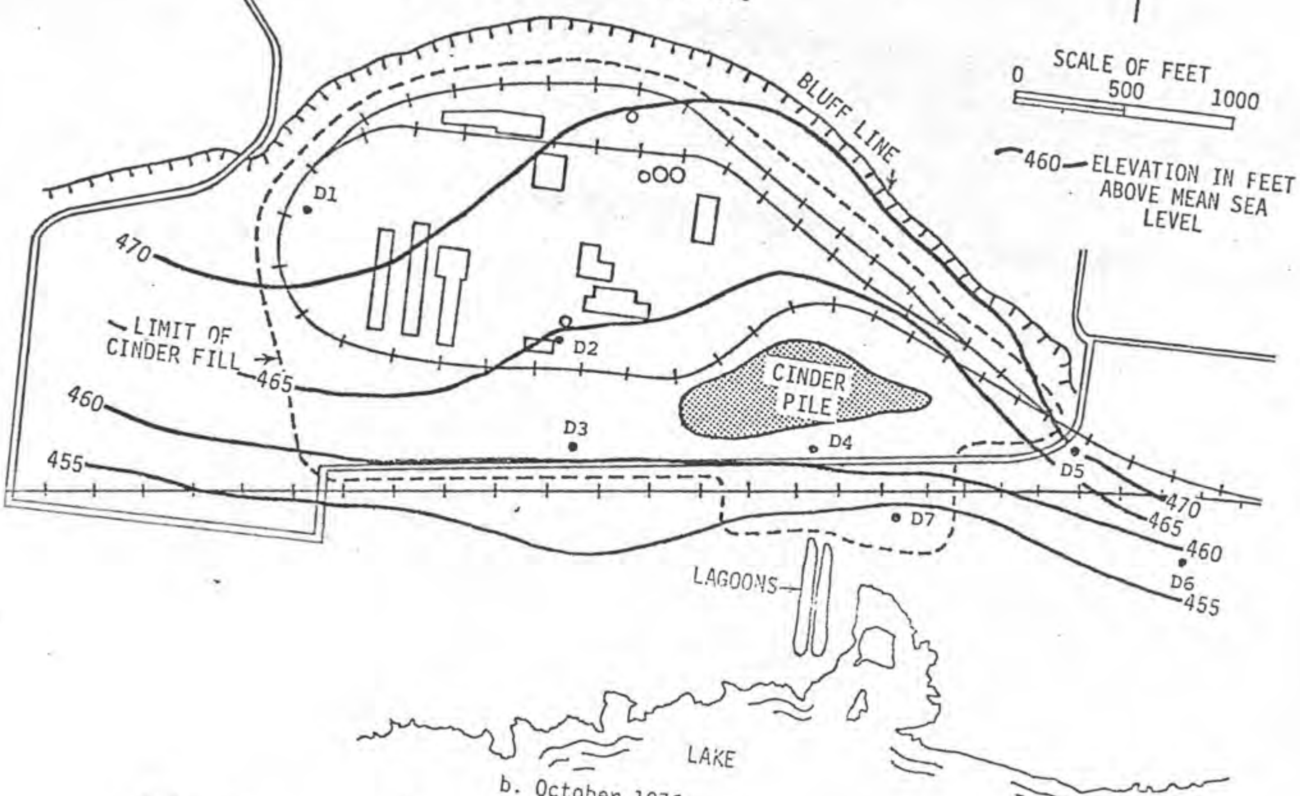
TABLE 16

RANGE OF WATER LEVEL FLUCTUATIONS IN ALL WELLS - SITE D

		Low			High			
Well No.	L.S.D.	Depth Below Land(ft.)	MSL	DATE	Depth Below Land(ft.)	MSL	Date	Fluctuation
1-S	490.98	18.54	472.44	10-26-76	14.56	476.42	6-1-76	3.98
1-D	491.04	26.95	464.09	9-29-76	22.20	468.84	7-8-76	4.75
2-S	478.92	14.81	464.11	9-29-76	13.32	465.60	6-1-76	1.49
2-D	478.76	14.91	463.85	9-29-76	13.02	464.74	6-1-76	1.89
3-S	469.58	7.35	462.23	8-24-76	5.68	463.90	6-1-76	1.67
3-D	469.88	7.90	461.98	9-29-76	6.92	462.96	6-1-76	0.98
4-S	464.82	3.50	461.32	9-29-76	3.02	461.80	6-1-76	0.48
4-D	464.66	2.29	462.37	9-29-76	1.41	463.15	6-1-76	0.78
5-S	473.56	0.08	473.48	6-1-76	-0.35	473.91	7-8-76	0.43
5-D	473.65	-0.19	473.84	10-26-76	-0.79	474.44	6-1-76	0.60
6-S	456.29	2.04	454.25	7-8-76	1.00	455.29	6-1-76	1.04
6-D	456.37	-0.03	456.40	8-25-76	-0.49	456.86	10-26-76	0.46
7-S	467.29	14.98	452.31	10-26-76	14.67	452.62	7-8-76	0.31
7-D	467.08	5.74	461.34	8-25-76	5.08	462.00	10-26-76	0.66



a. June 1976



b. October 1976

Figure 51. Water table contour maps for A) June, 76, and B) October 76 - Site D

A soil temperature survey was made at Site D on April 14 and 21, 1976. The location of the 44 stations is shown on figure 52. All temperature readings were corrected to the April 14 data. The soil temperatures were measured at a depth of 70 cm. and corrected for depth to the water table by methods given in Cartwright (1974). Line of equal temperature on a contour interval of two degrees Fahrenheit are shown on figure 52. High soil temperatures were measured surrounding the complex of industrial buildings. High soil temperatures were also measured in low ground south of the high mound of cinders, and are caused by ground-water discharge. At the season of the year when the soil temperature measurements were made, a warm anomaly is expected in areas of ground-water discharge. Ground-water discharge in the vicinity of the cinder pile may be receiving contributions from the regional flow system as well as from ground water locally mounded in the cinder pile. Ground-water discharge from the cinder pile may be highly contaminated.

Inferred direction of ground-water flow for the study area interpreted from the soil temperature is southward toward the lake. This also agrees favorably with the direction of groundwater determined from water level data (see figure 51).

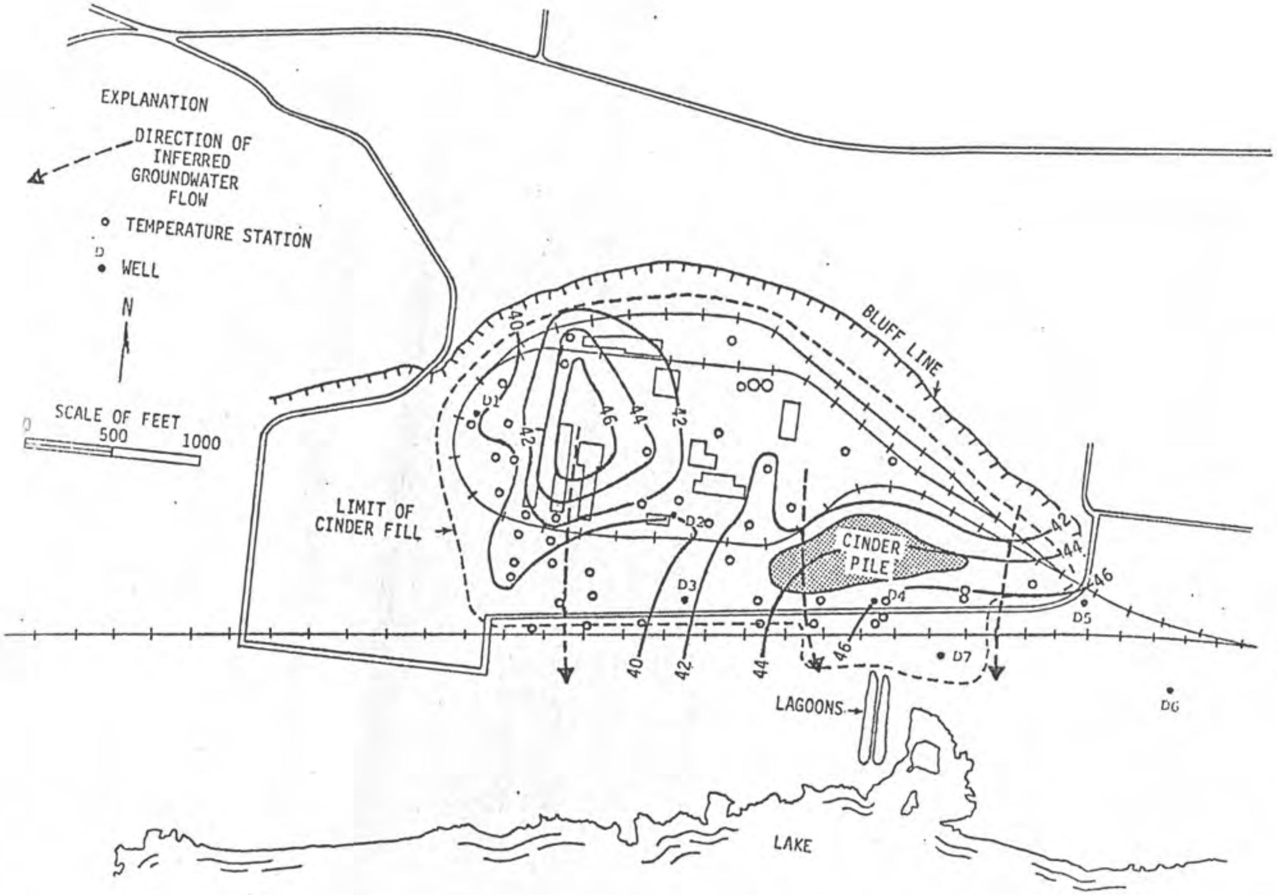


Figure 52. Soil temperature stations and results - Site D.

Chemical Data

Aside from providing data for geologic interpretation, chemical analyses of the core samples were conducted to define the migration characteristics of the suspected pollutants through the sandy soil and the effectiveness of these soils to retain the metal pollutants. Results of all chemical analysis conducted on the soil core samples are tabulated in Appendix C. As at sites A and B four elements, zinc, cadmium, copper, and lead routinely were determined.

No control hole was constructed at this site due to the limited time and money available. However, data from the lower segments of all holes at this site suggests that the background concentrations found in the control holes at sites A and B also are valid at this site. Zinc concentrations in the lower portions of the seven core holes ranged from about 13 to 75 mg/l, cadmium from <0.6 to .90 mg/l, copper from about 10 to 25 mg/l, and lead from <4.0 to 90 mg/l.

The number and location of core holes at this site were not adequate to define the limits of horizontal migration of the metals in the soil. However, the vertical migration patterns are very similar to those encountered at sites A and B.

Holes D-1, D-2, and D-3 are located on relatively upland portions of the plant complex. Zinc concentrations in excess of 10,000 mg/l were present in the cinder fill material at the surface. Below the fill, zinc concentrations generally decrease downward through the soil profile in which carbonates have been leached. Cation exchange is the major mechanism of attenuation in this interval.

Below the zone of leaching, carbonates are present, and pH is presumed to be about 7 to 8. The increase in soil pH causes precipitation to be an important factor in attenuation and is reflected by an increase in zinc concentrations. Examination of the core samples indicates accumulations of zinc carbonate in samples with extremely high zinc levels.

The clays present in the fine-grained surfical geologic material is responsible for a rapid decrease in zinc concentrations just below the cinder fill material, just as at sites A and B. However, the Henry Formation becomes coarse grained with depth, and appears to be less effective in attenuating zinc movement by cation exchange. However, the zinc concentrations drop off quickly to background levels below a depth of 16 to 17 feet due to the combined action of cation exchange and precipitation.

Holes D-4, D-5, and D-7 also are similar to each other. At each of these locations the fill materials are underlain by the Grayslake Peat and migration into these highly organic materials is minimal. Information for hole D-4 indicates that in addition to cation exchange, soil pH also is a major factor contributing to attenuation. Hole D-6 is a lowland swampy area with the Grayslake Peat at the surface and extending to a depth of about 19 feet. The repeated inundation of this location with high metal content surface water has resulted in zinc migration to a depth of about 6 feet into the peat. In other studies conducted by the State Water Survey, analysis of the lake bottom sediments south of the plant indicate that large quantities of heavy metals have left the plant site by surface water mechanisms (see table 17). Results of that study indicate that surface water inundated D-6 periodically

Table 17. Trace Elements Cencentration (mg/l) In Bottom Sediment From the back Water Lake South of Site D.

Sample No.	Depth (inches)	Pb	Zn	Cd	Cu
LDP	0-3	141	5000	52	128
LDP	3-6	119	5000	34	119
LDP	6-9	183	4100	104	130
LDP	9-12	211	3400	116	109
LDP	12-15	42	348	6	47

had high metal contents. In addition the metals content of the lakebottom sediments can be compared with the stream bottom sediments at Sites A and B.

Vertical migration of cadmium at each location was very similar to that of zinc. Copper and lead above assumed background levels were limited to the fill materials indicating little or no vertical migration of these metals into the underlying soils.

The mechanisms retaining the metals in the soil profile at this site are the same as at Sites A and B. Since no cation exchange capacities were determined for core samples at this site, no comparisons can be made concerning the relative effectiveness of the sandy soils versus the clays, silts, and tills. Results of many laboratory studies suggest that the sandy soils would be less effective as an exchange material, although, it would be very difficult to substantiate these results from the data collected in this study. However, there does appear to be obvious evidence of the high exchange capability of the organic materials at this site.

Results of chemical analyses of water samples collected from wells at Site D are presented in table 18. All deep wells, those finished 15 to 20 feet into the aquifer, produced water containing less than 0.5 mg/l zinc. Wells D-1S and D-4S produced water containing from <0.6 to 16.6 mg/l zinc and <0.5 to 69.5 mg/l zinc respectively. As discussed earlier, a large portion of this large variation in zinc content may be a result of our sampling protocol. In addition the close proximity of D-4S to the cinder pile and the probable resulting highly mineralized water may have affected the well seal. If the first sample (6-1-76) had been affected by the drilling process, the well seal failure theory would explain the results of the remaining samples.

Table 18. Water Quality data - Site D.

Site D

	1976			
	6-1	7-8	7-27	8-25
1S	0.3	13.	16.6	2.7
1D	<.5	<.5	<.5	<.5
2S	<.5	<.5	<.5	<.5
2D	<.5	<.5	<.5	<.5
3S	<.5	<.5	<.5	<.5
3D	<.5	<.5	<.5	<.5
4S	69.5	<.5	4.6	12.1
4D	<.5	<.5	<.5	<.5
5S	<.5	<.5	<.5	<.5
5D	<.5		<.5	<.5
6S	<.5	<.5	<.5	<.5
6D	<.5	<.5	<.5	<.5
7S				
7D	0.3		<.5	<.5

Results

The work conducted at this site was limited in scope but provided a basic understanding of metals migration in this type of environment. The site was selected because it is a sandy environment that poses core sampling problems not encountered at the other sites and the effectiveness of sandy soils to retain metals is reportedly low.

The core sampling problems (heaving sand, grain size segregation) associate with the geologic environment hindered the collection of good continuous core samples. Instead, samples collected from the sandy intervals were somewhat segregated with the fines on top and coarser materials below.

The relatively shallow penetration depth of metals concentrations was somewhat surprising. The silty surface materials overlying the sand aquifer and highly organic peat deposits appear to be retaining significant quantities of the metals pollutants. The fact that no large amounts of zinc were found in the aquifer indicates that it has either not entered the aquifer or is entering it at such a slow rate compared to the regional flow system that it is undetectable.

Sufficient data was not generated to indicate that this type of geology is desirable for waste disposal activities of this type. It still appears to be somewhat suspect for these types of pollutants and probably not desirable at all for more mobile types of polutants.

Section X

Applicability of Methodologies

Geologic suitability

In addition to the drilling at sites A, B, C, and D, more information was desired to provide a better understanding of the regional Pleistocene stratigraphy in the study areas and the general suitabiligy of coring as a monitoring technique. Therefore, four additional borings for stratigraphic control were made. The locations of these stratigraphic control holes (sites E, F, G, and H) are shown on Figure 9. Sites E, F, G, and H are presented in tables 19-22.

The information obtained from the stratigraphic control borings indicates that, in general, the units encountered at sites A, B, and C are fairly continuous across south-central Illinois. Typically, Wisconsinan loess overlies Illinoian and Kansan tills and related depostis. In addition to the Modern Soil, at least three buried soils are identified in the study areas.

At sites F and H, a thick sequence of water-laid sediments overlies the Glasford Formation Till. This interval, termed the Pearl Formation, consists of a few feet of fine-grained sediments at the top, several feet of sandy materials, and a thick silt at the base. This unit is thought to represent water-laid deposits following and probably related to the last episode of Illinoian glaciation. The Sangamon Soil is developed in the upper portion of the Pearl Formation. The time interval represented by the Pearl Formation may be at least partially equivalent to the time represented by the Berry Clay and Hagarstown Members of the Glasford Formation at sites A and B.

Two stratigraphic units were noted in the boring at site F which were not identified in any other borings. The Glasford Formation Till is underlain by 17 feet of predominantly fine-grained sediments termed the Petersburg Silt.

	SITE E L.S. = 525			Grain Size				X-Ray Data					
No.	Depth of Sample (ft)	Unit Description	Graphic Log	Gvl %	Sd %	St %	Cl %	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec
1	0.8-1.0	PEORIA LOESS (4-48-48)		0	4	43	53	.75	60	21	19	N.D.	N.D.
2	1.8-2.0			0	3	49	48	1.0	77½	13½	9	N.D.	N.D.
3	3.7-3.9			0	4	53	43	1.4	85	10	15	N.D.	N.D.
4	4.8-5.0	ROXANA SILT (23-44-33)		1	22	43	35	.93	87	7½	5½	N.D.	N.D.
5	8.2-8.4			1	24	45	31	.94	84½	9	6½	N.D.	N.D.
6	9.3-9.5	BERRY CLAY (27-35.5-37.5)		2	29	33	38	1.8	62	27½	10½	N.D.	N.D.
7	10.7-10.9			1	25	38	37	1.6	76½	16½	7	N.D.	N.D.
8	11.8-12.0	GLASFORD FORMATION TILL (34-39-27)		1	28	38	34	1.9	59½	30	10½	N.D.	N.D.
9	12.4-12.6			1	41	29	30	3.75	18	69	13	N.D.	16
10	13.8-14.0			3	41	31	28	3.4	12½	73	14½	21	34
11	14.7-15.0			5	42	31	27	3.76	23	65½	11½	54	42
12	15.7-16.0			–	–	–	–	2.82	21½	63½	15	49	36
13	17.2-17.5			–	–	–	–	2.31	17	64½	18½	50	28
14	19.7-20.0			1	55	31	14	1.65	12	62½	25½	29	23
15	20.7-21.0			–	–	–	–	1.42	8	62½	29½	46	23
16	22.7-23.0			–	–	–	–	1.36	13	58½	28½	30	18
17	24.7-25.0			4	34	41	25	1.07	6	58	36	21	13
18	26.7-27.0			–	–	–	–	1.19	27½	46½	26	24	16
19	28.7-29.0			–	–	–	–	1.55	20½	55½	24	19	11
20	31.0-31.3			3	30	44	26	1.4	25	51	24	8	14
21	32.5-32.8			–	–	–	–	1.0	35	39	26	12	10
22	34.0-34.3			–	–	–	–	1.21	38½	39½	22	18	16
23	35.7-36.0			–	–	–	–	1.24	39	39½	21½	16	19
24	36.7-37.0			1	19	51	30	1.03	35	39½	25½	16	12
25	38.7-39.0			–	–	–	–	.97	36	38	26	12	15
26	40.0-40.3			2	20	47	33	.96	34½	38½	27	11	14
27	41.7-42.0	LIERLE CLAY (30-30-40)		1	24	33	4[illegible]	.78	59½	22	18½	N.D.	N.D.
28	43.7-44.0			3	36	27	37	.96	40	35½	24½	N.D.	N.D.
29	44.7-45.0	BANNER FORMATION TILL (29-42-29)		1	32	38	30	1.2	24	49½	26½	N.D.	N.D.
30	46.7-47.0			3	26	46	28	1.3	20	53	27	17	9
31	48.7-49.0			–	–	–	–	2.48	18	72½	19½	63	24
32	50.0-50.3			2	26	47	27	1.4	18	56	26	34	12
33	51.7-52.0			–	–	–	–	1.7	22	56	22	19	16
34	52.7-53.0			3	25	42	33	1.65	12	62½	25½	29	18
35	54.0-54.3	BEDROCK		–	–	–	–	.94	38	36	26	N.D.	N.D.
36	55.7-56.0			0	2	55	43	2.4	4½	75	20½	N.D.	N.D.

Table 19. Textural and Mineralogical Data - Site E

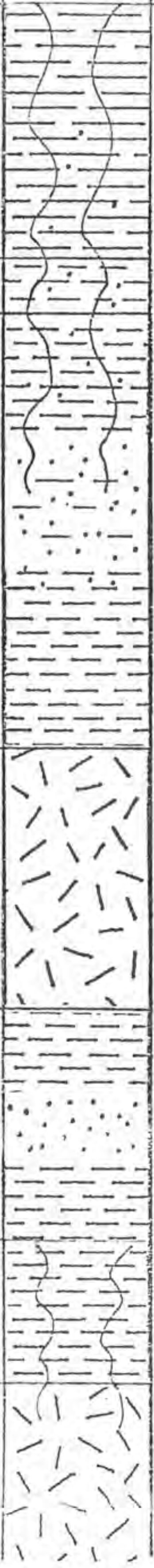
SITE F L.S. = 435				Grain Size				X-Ray Data					
No.	Depth of Sample (ft)	Unit Description	Graphic Log	Gvl %	Sd %	St %	Cl %	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec
1	0.1-0.5	PEORIA LOESS (13-57-30)		1	7	64	29	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
2	0.5-1.0			1	3	67	30	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
3	1.0-1.5			2	3	76	21	1.3	18	54½	27½	N.D.	N.D.
4	1.5-2.0			0	17	60	23	1.16	24½	48	27½	N.D.	N.D.
5	2.0-2.5			0	15	43	42	1.2	57	28	15	N.D.	N.D.
6	3.0-3.5			0	16	47	37	1.9	74	19½	6½	N.D.	N.D.
7	5.5-6.0			0	31	40	29	1.7	75	18	7	N.D.	N.D.
8	6.5-7.0			0	13	59	28	2.0	61½	29	9½	N.D.	N.D.
9	7.0-7.5	ROXANA SILT		0	32	38	30	1.09	61	24	15	N.D.	N.D.
10	8.0-8.5	PEARL FORMATION		0	3	71	26	.73	41	30½	28	N.D.	N.D.
11	8.5-9.0			2	2	65	33	.84	25	42	33	?	12
12	9.0-9.5			1	3	63	34	.80	29	39	32	N.D.	N.D.
13	9.5-10.0			2	2	62	36	1.0	20	48	32	N.D.	12
14	10.5-11.0			10	26	39	35	1.3	13	58	29	N.D.	N.D.
15	11.5-12.0			15	60	12	28	1.4	11½	60½	28	N.D.	?
16	12.5-13.0			25	55	20	25	1.2	19½	51½	29	N.D.	N.D.
17	13.5-14.0			16	65	11	24	1.3	13½	57	29½	N.D.	N.D.
18	16.0-16.5			26	51	28	21	1.5	16½	58	25½	N.D.	N.D.
19	17.5-18.0			17	65	11	24	1.5	17½	57	25½	N.D.	N.D.
20	19.5-20.0			3	43	35	22	1.6	7½	65½	27	N.D.	N.D.
21	22.0-22.5			11	41	32	27	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
22	22.5-23.0			0	1	74	25	1.42	25	51	24	N.D.	8?
23	23.5-24.0			0	17	70	13	1.27	18	54	28	?	12
24	25.5-26.0			0	1	84	15	1.95	9	68	23	?	22
25	26.5-27.0			0	0	80	20	1.56	8½	64	27½	21	22
26	28.5-29.0	GLASFORD FORMATION TILL (16-51-33)		11	17	49	34	.97	3	57½	39½	15	?
27	29.5-30.0			29	10	50	40	.81	9	50	41	20	13
28	30.5-31.0			4	17	52	31	.86	15½	47½	37	16	15
29	31.5-32.0			1	16	51	33	.90	10½	51½	38	9	10
30	33.5-34.0			2	17	51	32	.84	9½	50½	40	7	12
31	34.5-35.0			1	11	51	38	.70	22	40	38	9	12
32	35.5-36.0			1	15	53	32	1.18	18	52½	29½	18	12
33	37.0-37.5			0	96	0	4	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
34	38.5-39.0			2	28	50	22	.76	19½	43	37½	9	?
35	39.5-40.0	PETERSBURG SILT		0	3	84	13	.92	12	51	37	13	?
36	41.5-42.0			0	2	81	17	.85	13½	48½	38	8	13
37	43.5-44.0			0	1	43	56	.95	15	50	35	9	17
38	48.5-49.0			0	74	19	7	1.06	7	56½	36½	?	N.D.
39	50.5-51.0			0	82	11	7	.80	12½	48	39½	12	11
40	53.5-54.0			0	81	10	9	1.00	11	53½	35½	?	7
41	55.5-56.0			0	2	59	39	.905	17	48	35	8	8
42	56.0-56.5			0	1	43	56	.95	17	49	34	7	11
43	56.5-57.0	LIERLE CLAY (5-36-59)		1	5	47	48	1.17	22	49½	28½	8	9
44	57.5-58.0			0	2	35	63	1.28	24	50	26	?	?
45	58.0-58.5			0	4	35	61	1.59	13½	61	25½	N.D.	N.D.
46	58.5-59.0			0	5	32	63	1.49	14½	59	26½	N.D.	27
47	59.5-60.0			6	7	32	61	1.17	31	44	25	N.D.	N.D.
48	60.0-60.5	BANNER FORMATION TILL		0	4	66	20	.68	39½	30½	30	N.D.	N.D.
49	60.5-61.0			0	5	46	49	.48	44	23½	32½	N.D.	N.D.
50	61.5-62.0			2	25	52	23	.865	24	43	33	9	12
51	62.5-63.0			1	24	51	25	.77	18	44	38	9	N.D.

Table 20. Textural and Mineralogical Data - Site F

No.	SITE F L.S. = 435			Grain Size				X-Ray Data					
	Depth of Sample (ft)	Unit Description	Graphic Log	Gvl %	Sd %	St %	Cl %	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec
52	63.5-64.0	BANNER (21-54-25)		0	24	51	25	.77	17½	42	40½	14	N.D.
53	64.5-65.0			2	11	63	26	.65	13½	42½	44	N.D.	10
54	65.5-66.0			3	26	52	22	.86	16½	47	36½	9	12
55	66.5-67.0			1	24	52	24	.72	18½	42½	39	N.D.	11
56	67.5-68.0			7	25	50	25	.77	21	42½	36½	8	11
57	68.5-69.0			3	26	46	28	.78	19	43½	37½	N.D.	N.D.
58	70.5-71.0	HARKNESS SILT (3-38-59)		0	4	38	58	1.03	20½	48½	31	?	10
59	71.5-72.0			0	5	46	49	1.18	27	46½	26½	9	13
60	73.5-74.0			0	0	38	62	1.39	29½	47½	23	43	30
61	74.5-75.0			0	0	37	63	1.61	35½	45½	19	48	35
62	77.5-78.0			0	0	34	66	1.54	34½	45½	20	49	30
63	79.5-80.0			0	6	37	57	1.51	18½	56½	25	54	29
64	81.5-82.0			0	0	34	66	1.57	14½	60	25½	65	49
65	83.5-84.0			0	1	36	63	1.58	18	57½	24½	47	35
66	85.5-86.0			0	5	38	57	1.89	17½	61	21½	60	48
67	87.5-88.0			0	7	39	54	1.54	18	57	25	61	43
68	89.5-90.0	PENNSYLVANIAN BEDROCK		0	22	45	33	1.21	27	47	26	41	42
69	90.5-91.0			0	37	21	42	1.27	27	48	25	46	26
70	91.5-92.0			0	48	30	22	.96	26	44	30	?	?
71	92.0-92.5			5	39	43	18	.70	7½	47½	45	10	5

Table 20. Textural and Mineralogical Data - Site F (continued)

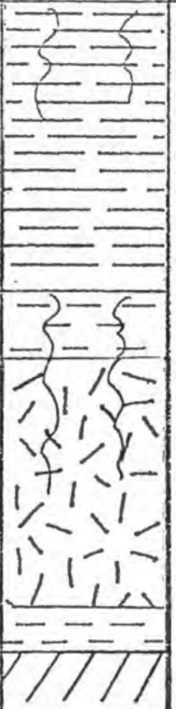
SITE G L.S. = 510				Grain Size				X-Ray Data					
No.	Depth of Sample (ft)	Unit Description	Graphic Log	Gvl %	Sd %	St %	Cl %	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec
1	0.5-0.8	PEORIA LOESS (2-60-38)		1	5	68	27	–	–	–	–	N.D.	N.D.
2	1.5-2.0			0	1	54	45	–	72½	19½	8	N.D.	N.D.
3	2.5-3.0			–	–	–	–	–	76	18½	5½	N.D.	N.D.
4	3.5-4.0			0	1	58	41	–	77	16½	6½	N.D.	N.D.
5	4.5-5.0			–	–	–	–	–	65	21	14	N.D.	N.D.
6	5.5-6.0			–	–	–	–	–	66	21	13	N.D.	N.D.
7	6.5-7.0			–	–	–	–	–	61½	22½	16	N.D.	N.D.
8	7.5-8.0			0	10	61	29	–	54	27	19	N.D.	N.D.
9	8.5-9.0	ROXANA SILT (11-59-30)		0	13	57	30	–	51	28½	20½	N.D.	N.D.
10	9.0-9.5			0	11	55	34	–	47½	32	20½	N.D.	N.D.
11	11.5-12.0	GLASFORD FORMATION TILL (31.5-36.5-32)		7	25	32	43	–	–	–	–	N.D.	N.D.
12	13.5-14.0			2	31	36	33	–	33½	44	22½	N.D.	N.D.
13	15.5-16.0			2	33	38	29	–	–	–	–	N.D.	N.D.
14	16.5-17.0			3	32	38	30	–	9½	63	27½	N.D.	11
15	17.5-18.0			4	32	35	33	–	6½	62½	31	N.D.	10
16	18.5-19.0			4	35	35	30	–	4½	68½	27	19	20
17	19.5-20.0			6	34	36	30	–	10	69	21	13	19
18	20.5-21.0			7	30	44	26	–	10	69	21	27	17
19	22.0-22.5			–	–	–	–	–	7½	72½	20	25	24
		PENNSYLVANIAN SANDSTONE											

Table 21. Textural and Mineralogical Data - Site G

No.	SITE H L.S. = 670			Grain Size				X-Ray Data					
	Depth of Sample (ft)	Unit Description	Graphic Log	Gvl %	Sd %	St %	Cl %	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec
1	0.5-1.0	PEORIA LOESS (10-54-36)		1	8	64	28	–	–	–	–	–	–
2	1.5-2.0			1	7	58	35	–	–	–	–	–	–
3	2.5-3.0			1	15	40	45	2.2	85½	11	3½	–	–
4	4.0-4.5	ROXANA SILT		1	6	62	32	1.2	77½	14½	8	–	–
5	4.5-5.0	PEARL FORMATION		5	34	39	27	1.15	70½	18½	11	–	–
6	6.5-7.0			5	40	35	25	–	76½	13½	10	–	–
7	8.5-9.0			25	36	37	27	–	79	12	9	–	–
8	10.5-11.0			10	61	10	29	–	29½	46	24½	–	–
9	12.5-13.0			8	69	13	18	1.4	19½	54	26½	–	–
10	14.5-15.0			29	61	17	22	3.0	13	71	16	–	–
11	32.5-33.0			1	19	69	12	1.77	10½	65	24½	27	30
12	34.5-35.0	GLASFORD FORMATION TILL (44-37-19)		8	45	33	22	2.7	12	71	17	27	32
13	35.5-36.0			11	43	36	21	2.0	13½	65	21½	32	21
14	36.5-37.0			12	56	28	16	2.2	13	66	21	30	27
15	37.5-38.0			9	50	31	19	2.2	12	67	21	30	29
16	40.5-41.0			16	69	22	9	2.0	11½	66½	22	30	26
17	42.0-42.5			10	49	40	11	2.125	8	70	20	30	27
18	44.5-45.0			10	18	55	27	2.18	20	61	19	24	20
19	45.5-46.0			9	23	50	27	2.34	22½	60½	17	18	16
20	47.0-47.5	LIMESTONE BEDROCK		37	15	39	46	–	32	55	13	136	12

Table 22. Textural and Mineralogical Data - Site H

Texturally, this unit varies from a silty clay to silt to sand. The Petersburg Silt is thought to represent proglacial sedimentation in advance of the earliest Illinoian glaciation.

Similarly, the Glasford Formation Till at site F is underlain by a thick silt interval. This unit, termed the Harkness Silt Member of the Banner Formation is fairly uniform in texture and mineralogy. It also is thought to represent proglacial sedimentation prior to Kansan glaciation.

Deposits of Kansan age have been identified at all locations except sites D and G. The presence of Kansan till and related deposits at site F, near the southern boundary of Illinoian glaciation, would seem to suggest that Kansan glaciation was nearly as extensive as Illinoian glaciation.

The original intent in constructing these additional stratigraphic borings was to determine what portions of Illinois would be similar in their capabilities to retaining pollutants as were Sites A, B, and C. These borings were completed before the study at Site D was started. The data collected indicates that we were successful in selecting areas of similar geologic development and they probably would react to the disposal of waste in manners similar to that at Sites A, B, and C. This suggests that there may be as much as 1/5 of the State of Illinois that could be suitable as disposal areas of similar types of wastes.

However, the study at site D, an assumed poor geologic regime for disposal of the same type of waste, suggests that even the sandy soil regime did a respectable job in retaining the metals. This probably was a combined result of the silty surface materials, silty sand, and large amount of iron oxide present at this site.

The experience gained at the four study sites and stratigraphic holes indicates that soil coring can be a very helpful research tool in any type of geology. However, proper geologic interpretation and a competant understanding of soil chemistry is necessary to make use of this technique. Without the expertise of a geologist and soil chemist the merits of collected soil cores are very limited.

Use of Coring Technique in Courts

Our experience in courts is very limited. All problems dealing with earth materials, and the water contained in these materials, do not have clear-cut resolutions. Instead, they frequently are a matter of degree. Our limited experience in court suggests that, to a large extent, the skill of the attorneys in dealing with scientific matters (especially earth science) has been the overriding factor in the outcome.

Nevertheless, we feel that the approach used in this study is scientifically sound, and should withstand tests in court. There are, however, two drawbacks to this technique which may present some problems. First, this is a new method, and there is a general lack of background data essential for comparative purposes. Second, being a new method there is the lack of previous experience and court tests; "standard" techniques hold up much better in court.

Cost Analysis

One of the goals of this project was to develop effective investigative and monitoring techniques for detecting and evaluating the extent of ground water pollution from surface toxic waste disposal activities. In addressing this issue, the effectiveness and the costs of investigative and monitoring techniques must be considered. The following information indicates the costs of the two principle techniques employed in the project; 1) collecting core samples for analysis, and 2) installing peizometers for collecting water samples.

At site A, approximately 1454 linear feet of core sample from 59 different locations was completed at a cost of about $9835. The cost breakdown per hole is given in table 23. It should be noted that the footage charges at the top of this table were established by contract in November, 1974. As the project and coring continued into the summer of 1976, an agreement was made with drilling contractor to pay on a hourly basis for additional work (see holes S34-S37 and C24 and C25). The average cost per foot for these holes was $5.39, or slightly below the minimum contract footage charge.

At site B, approximately 785 linear feet of core sample from 18 different locations was completed at a cost of about $4618. The cost breakdown per hole is given in table 24. As a site A, holes B14-B17 were drilled in the summer of 1976 and payed for on an hourly basis. The average cost per foot of these holes was $4.22, again lower than the total average of $6.33 per foot.

At site C, due the nature of the pollutants being studied and the precautions taken to insure that samples were not polluted

TABLE 23 CORING AND SAMPLING COSTS (SITE A)

No.	Total footage charged to unit price per foot $5.50	$6.50	$7.50	$8.50	$9.50	Total cost	Total footage	Average Cost per foot
S-1	21.9	26.8	11.0	4.8	--	$467.36	64.5	$7.25
S-2	25.7	8.1	25.7	--	--	432.33	59.5	7.25
S-3	11.2	19.0	29.5	14.4	--	585.43	74.1	7.90
S-4	22.0	22.0	16.0	9.0	--	469.69	69.0	6.81
S-5	23.5	23.5	13.0	2.0	--	406.08	62.0	6.54
S-6	20.5	25.5	14.0	8.0	--	459.54	68.0	6.75
S-7	30.0	15.0	15.0	11.0	--	475.78	71.0	6.70
S-8	15.0	15.0	35.0			452.46	65.0	6.96
S-9	13.0	17.0	27.5			398.21	57.5	6.93
S-10	10.0	3.0	--	--	--	84.46	13.0	6.49
S-11	12.5	--	--	--	--	78.33	12.5	6.26
S-12	15.0	1.5	--	--	--	104.89	16.5	6.36
S-13	15.0	--	--	--	--	93.99	15.0	6.27
S-14	17.0	2.0	--	--	--	121.04	19.0	6.37
S-15	18.7	--	--	--	--	116.64	18.7	6.24
S-16	12.5	3.0	--	--	--	100.12	15.5	6.46
S-17	13.0	4.5	--	--	--	114.15	17.5	6.52
S-18	14.0	5.0	--	--	--	120.99	19.0	6.37
S-19	12.5	--	--	--	--	75.34	12.5	6.03
S-20	14.0	--	--	--	--	85.04	14.0	6.07
S-21	15.0	--	--	--	--	92.46	15.0	6.16
S-22	10.0	--	--	--	--	60.75	10.0	6.08
S-23	10.0	--	--	--	--	60.75	10.0	6.08
S-24	10.0	--	--	--	--	59.95	10.0	6.00
S-25	11.5	--	--	--	--	69.37	11.5	6.03
S-26	11.0	--	--	--	--	65.48	11.0	5.95
S-27	15.0	--	--	--	--	89.01	15.0	5.93
S-28	10.0	--	--	--	--	61.13	10.0	6.11
S-29	17.5	--	--	--	--	102.38	17.5	5.85
S-30	12.5	--	--	--	--	74.11	12.5	5.93
S-31	12.5	--	--	--	--	75.64	12.5	6.05
S-32	15.0	--	--	--	--	91.31	15.0	6.09
S-33	14.5	--	--	--	--	86.64	14.5	5.98
S-34		@$40/hr	3.3 hr			136.95	23.0	5.95
S-35			2.8 hr			115.88	18.0	6.44
S-36			2.4 hr			101.17	24.0	4.22
S-37			2.4 hr			101.17	24.0	4.22
C-1	15.0	2.5	--	--	--	132.96	17.5	7.60
C-2	16.3	--	--	--	--	122.71	16.3	7.53
C-3	12.5	2.5	--	--	--	117.29	15.0	7.82
C-4	15.0	--	--	--	--	114.79	15.0	7.65
C-5	15.0	--	--	--	--	114.79	15.0	7.65
C-6	15.0	2.5	--	--	--	132.96	15.0	8.86
C-7	12.5	--	--	--	--	99.13	12.5	7.93
C-8	16.5	--	--	--	--	124.19	16.5	7.53
C-9	20.0	--	--	--	--	146.12	20.0	7.30
C-10	15.9	--	--	--	--	117.83	15.9	7.41
C-12	17.0	--	--	--	--	123.88	17.0	7.29
C-13	13.4	--	--	--	--	[illegible].84	13.4	7.[illegible]

Table Coring and Sampling Costs (Site A) - cont.

C-14	14.5	--	--	--	--	111.37	14.5	7.68
C-15	19.0	--	--	--	--	134.49	19.0	7.08
C-16	14.0	2.5	--	--	--	124.77	16.5	7.56
C-19	15.0	--	--	--	--	112.88	15.0	7.53
C-20	15.0	--	--	--	--	112.63	15.0	7.51
C-21	17.5	--	--	--	--	127.43	17.5	7.28
C-23	15.5	--	--	--	--	116.10	15.5	7.49
C-24		@$40/hr	3.5 hr			145.39	25.0	5.82
C-25			3.7 hr			153.81	27.0	5.70
SCH-1	23.5	24.5	34.8	--	--	558.69	82.8	6.74
Total						9835.07	1454.2	6.76

TABLE 24 CORING AND SAMPLING COSTS (SITE B)

	Total footage charged to unit price per foot							
No.	$5.50	$6.50	$7.50	$8.50	$9.50	Total cost	Total footage	Average Cost per foot
B-1	14.0	16.0	30.4	--	--	$ 455.34	60.4	$ 7.56
B-2	18.0	18.0	16.5	--	--	339.75	52.5	6.47
B-3	12.0	18.0	10.7	--	--	263.25	40.7	6.47
B-4	14.0	31.1	15.0	--	--	391.65	60.1	6.52
B-5	11.0	21.0	20.3	--	--	349.25	52.3	6.68
B-6	14.0	16.0	13.0	--	--	278.50	43.0	6.48
B-7	11.5	29.5	25.0	--	--	442.50	66.0	6.70
B-8	19.0	23.0	13.0	--	--	351.50	55.0	6.39
B-9	15.0	15.0	16.0	--	--	309.19	46.0	6.72
B-10	12.1	--	--	--	--	73.14	12.1	6.04
B-11	9.5	--	--	--	--	57.42	9.5	6.04
B-12	9.5	--	--	--	--	57.42	9.5	6.04
B-14		@$40/hr	2.4 hr			101.17	24.0	4.22
B-15			2.4 hr			101.17	24.0	4.22
B-16			2.5 hr			105.39	25.0	4.22
B-17			2.5 hr			105.39	25.0	4.22
BCH-1	16.0	20.5	15.0	--	--	333.75	51.5	6.48
BCH-2	15.0	18.0	39.5	--	--	501.88	72.5	6.92
Totals						4617.66	729.1	6.33

during the coring process, all work was paid for on an hourly basis. Holes M1-M5 were drilled in the summer of 1975 at $40 per hour. Holes M6-M8 were drilled in the summer of 1976 and the local union insisted on having a local operator present. This resulted in an hourly charge of $62 per hour. A total of approximately 324 linear feet of core sample from 9 different locations was completed at a cost of about $5190 (see table 25). The average cost per foot at this site was $16.01.

At site D the coring and well installations were done by the principle investigator and 2 employees of the Illinois State Geological Survey using a trailer mounted Mobile B30S drilling rig. To obtain comparable cost numbers, the salary and travel expenses of the principal investigator were not included in cost calculations. His expenses are not included in the costs at sites A and B. The work at site D took 2 weeks or 10 working days to complete. Two-thirds of this time can be charged against coring. The costs of coring was calculated as follows:

Salaries:
2 men @ $60/day each x 6 2/3 days = $800
Per diem:
2 men @ $15/day each x 6 2/3 days = 200
Lodging:
2 men @ $15/night each x 5 1/3 nts = 160

Sub total	$1160
sample bottles	70
Total	$1230

TABLE 25. CORING AND SAMPLING COSTS (SITE C)

No.	Hours @$40/hr	Total cost	Total footage	Average Cost per foot
M-1	3.0 hours	124.21	9.5	13.07
M-2	13.0 hours	526.51	16.0	32.91
M-3	8.0 hours	326.13	27.0	12.08
M-4	4.0 hours	167.66	16.5	10.16
M-5	3.5 hours	148.04	16.5	8.97
M-6	18.8 hours*	1163.14	71.0	16.38
M-7	15.2 hours*	945.26	57.7	16.38
M-8	16.9 hours*	1048.47	64.0	16.38
MCHI	17.5 hours	741.36	46.0	16.11
Totals		5190.78	324.2	16.01

*hourly rate $62

A total of about 128 linear feet of core sample was collected at 7 different locations for approximately $1230 or $9.57 per foot. The higher footage cost for site D as compared with the costs at sites A and B probably are the result of 3 factors combined. 1) The drilling rig used was just barely adequate for the task and the work progressed somewhat slowly. 2) The 3 man crew had never worked together before and some time was lost at the initial stage due to becoming familiar with the rig and each other, and 3) The sandy nature of this site and particularly the sand heaving up into the augers presented problems not encountered at the other sites. This also resulted in lost time.

The cost of routine sample coring, using a professional drilling crew, as at sites A and B probably can be considered representative of 1974 costs. In planning future work, adjusting the $6.50 to $7.00 per foot price to current dollars would appear reasonable. In instances where special problems are present, such as at site C, cost projections would be very difficult.

The costs associated with constructing peizometers at the four sites also need to be considered to make any comparative studies. At site A 49 wells totaling about 1309 feet in depth were constructed for a total cost of about $6182 or an average cost of $4.72 per foot (see table 26). At site B 32 wells totaling about 1010 feet in depth were constructed for a total cost of about $5824 or an average cost of $5.77 per foot (see table 27). At site C 9 wells totaling about 186 feet in depth were constructed for about $1885 or $10.11 per foot (see table 28) At site D 14 wells totaling 336 feet in depth were constructed for about $790 or $2.35 per foot.

The average cost per foot at sites A and B probably are most

TABLE 26. OBSERVATION WELL INSTALLATION COSTS (SITE A)

			Cost				
			Materials				
Well number	Total footage	Total labor time (hrs)	Well	Pumping	Labor at $40/hr	Total for wells	Cost Per Foot
S1-S,M,D	110	21.5	173.80	70.66	860.00	1104.06	10.04
S2-S,M,D	116	10.75	148.38	71.86	430.00	650.24	5.61
S3-S,M,D	108	17.0	134.72	68.26	680.00	882.98	8.18
S4-S,D	86	4.0	61.53	32.71	160.00	254.24	2.96
S5-S,D	77.5	3.0	61.92	30.25	120.00	212.17	2.74
S6-S,D	82	4.5	63.08	31.99	180.00	275.07	3.35
S7-S,D	92	4.5	60.57	20.53	180.00	261.10	2.84
S8	80.5	4	61.43	33.07	160.00	254.50	3.16
S9	75	4.5	56.64	29.52	180.00	266.16	3.55
S10	13.5	2.0	12.52	7.66	80.00	100.18	7.42
S11	13.5	.75	12.52	7.66	30.00	50.18	3.72
S12	18.0	.75	15.49	8.96	30.00	54.45	3.03
S13	16.5	.75	14.50	8.53	30.00	53.03	3.21
S14-S,D	28.5	2.25	38.03	15.74	90.00	143.77	5.04
S15-S,D	30.5	1.5	27.35	15.71	60.00	103.06	3.38
S16	17.0	1.0	14.83	8.67	40.00	63.50	3.74
S17	15.0	1.0	25.18	8.87	40.00	74.05	4.94
S18	16.0	1.0	25.84	9.16	40.00	75.00	4.69
S19	12.3	1	12.50	7.60	40.00	60.10	4.89
S20	13.5	2	13.51	8.09	80.00	101.60	7.53
S21	15	1	14.50	8.53	40.00	63.03	4.20
S22	10	1	11.20	7.08	40.00	58.28	5.83
S23	10	1	10.87	6.93	40.00	57.80	5.78
S24	10	1	10.87	6.93	40.00	57.80	5.78
S25	11.5	1	11.86	7.37	40.00	59.23	5.15
S26	11	1	11.53	7.21	40.00	51.75	4.70
S27	15	1	14.17	8.38	40.00	62.55	4.17
S28	10	1	10.87	6.92	40.00	57.79	5.78
S29	17.5	1	15.82	9.11	40.00	64.93	3.71
S30	12.5	1	12.52	7.66	40.00	60.18	4.81
S31	12.5	1	12.52	7.66	40.00	60.18	4.81
S32	15	1	14.17	8.38	40.00	62.55	4.17
S33	14.5	1	13.84	8.24	40.00	62.08	4.28
S36	11	1	71.72	14.46	40.00	126.18	11.47
S37	12	1	71.72	14.46	40.00	126.18	10.52
SCHI-S,D	100	6.0	89.17	36.92	240.00	366.09	3.66
Totals	1308.8	104.25	1371.12	641.21	4170.00	6182.33	4.72

TABLE 27. OBSERVATION WELL INSTALLATION COSTS (SITE B)

Well number	Total footage	Total labor time (hrs)	Cost				
			Materials		Labor at $40/hr	Total for wells	Cost Per Foot
			Well	Pumping			
B1-S,M,D	118	17.0	159.84	72.75	680.00	912.59	7.73
B2-S,D	67	7.5	84.76	27.20	300.00	411.96	6.15
B3-S,D	61	4.0	113.57	25.49	160.00	299.06	4.90
B4-S,D	78	10.0	129.02	30.39	400.00	559.41	7.17
B5-S,D	57	7.0	113.56	24.30	280.00	417.86	7.33
B6-S,M,D	88	8.5	130.19	37.17	340.00	507.36	5.77
B7-S,M,D	133	8.75	196.61	50.82	350.00	597.43	4.49
B8-S,M,D	112	7.0	148.19	44.28	280.00	472.47	4.22
B9-S,D	58	4.0	44.60	23.66	160.00	228.26	3.94
B10	14	--	12.39	4.84	----	17.23	1.23
B11	11	--	9.73	3.81	----	13.54	1.23
B14	15	1	71.72	14.46	40.00	126.18	8.41
B15	14	1	71.72	14.46	40.00	126.18	9.01
B16	13	1	71.72	14.46	40.00	126.18	9.71
B17	12.5	1	71.72	14.46	40.00	126.18	10.09
BCHI-S,D	67	7.75	125.83	27.24	310.00	463.07	6.91
BCH2-S,D	91	8.0	68.50	30.98	320.00	419.48	4.61
Totals	1009.5	93.5	1623.67	460.77	3740.00	5824.44	5.77

TABLE 23. OBSERVATION WELL INSTALLATION COSTS (SITE C)

			Cost				
			Materials				
Well number	Total footage	Total labor time (hrs)	Well	Pumping	Labor at $12.50/hr	Total for wells	Cost Per Foot
M1	10	5.0	102.49	8.30	62.50	110.79	11.08
M2	20	5.0	115.19	15.80	62.50	130.99	6.55
M3-S,D	50	10.0	238.28	36.70	125.00	274.98	5.50
M4	17.5	5.0	110.82	13.33	62.50	124.15	7.09
M5	17.5	5.0	110.82	13.33	62.50	124.15	7.09
M7	55	5	90.20	39.25	174.00*	303.45	5.52
MCHI-S,D	17.5	10.0	264.06	52.11	125.00	316.17	18.07
Totals	186.5	45	1031.86	178.82	674.00	1884.68	10.11

* 3/hr @ $50/hr
2/hr @ 7.50 x 1.6/hr

representative of 1974 costs for constructing small-diameter (2-inch) PVC peizometers. The higher cost per foot at site C is a result of using black iron pipe, requiring more time to put together and install, and the extreme precautions carried out during installation. The apparent low costs at site D may be the result of underestimating the time involved in installation. More likely, the sandy nature of the materials at this site made well installations simpler. In planning for future projects adjusting the $5.00 to $6.00 cost per foot to current dollars would appear reasonable.

In attempting to evaluate the relative merits of soil sampling versus well installation and water sampling, you also should consider the costs of analytical work and the results obtained. During the course of this study the analysis of soil samples for the 4 elements of interest, zinc, cadmium, copper, and lead, ran about $12.00. If a single element assay was made it ran about $7.00. Analysis of water samples for the same 4 elements using electric analytical techniques ran about $7.00. Single element assays ran about $5.00.

Using the cost figures generated in this study some comparisons can be made. Assume that a 30 foot deep core and well is constructed. The cost of coring would be about $7.00/ft x 30 feet or $210. If analysis were made for every other 0.5 foot segment a total of 30 samples at $7.00 each for the four elements would cost about $210. The 30 foot deep well at $6.00/ft would cost about $180. If water samples were collected monthly for one year and analyzed for the 4 elements of interest, the analytical work would cost about $84. The total costs of coring and analysis would be about $420 versus $264 for a well and one year of sampling and analysis.

Depending on the type of waste to be disposed of or monitored, soil sampling may prove to be more effective even though more costly. If a research type project is being conducted, coring would prove to be most useful. The coring and analysis of the core samples give a better understanding of the phenomena that are taking place in the soil. However, due to the costs, coring may not be practical as a routine monitoring technique.

Based on the results of this study we recommend:

1) Coring and soil analysis be used in research type projects or when the toxicity of a waste product warrants the additional expenditure.

2) A limited number of core holes and soil sampling would be adviseable to evaluate a proposed disposal site. A better understandingof the soils interaction with the waste product is gained. Geologic interpretation of the core samples also provides better information for design and location of monitoring wells.

3) Routine monitoring of most disposal sites should be accomplished using wells located and designed based on preliminary coring analysis. Periodic coring and soil analysis may be worthwhile to substantiate original soil effectiveness assumptions.

SECTION XI

INTERDISCIPLINARY EVALUATION

The original proposal for this project indicated that the study would be an interdisciplinary effort. Technologies from the fields of groundwater hydrology, geology, agronomy, chemistry, and geophysics were to be employed. In addition, as the project progressed, infrared areal photography was flown in hopes that it could be used as a tool in tracing groundwater pollution. All of these disciplines were employed during the course of the study. However, the extent to which all of them were applied to the principal goals of the study falls short of a true multidisciplinary study in the opinion of the principal investigator.

Aside from the areal photography and the botanical and plant pathology work conducted by Dr. Edwards, the remaining work is directly related to goals of the study. However, it is not likely that very many persons would consider groundwater hydrology and geology as two independent disciplines. The geophysical efforts also clearly are tools for or types of geologic study.

The other discipline mentioned in the proposal is chemistry. Although a separate discipline, chemistry traditionally has been a supportive discipline in studies of this type. The goal of the original proposal to put together a working multidisciplinary study group was not obtained. Instead, a central core consisting of a hydrologist, geologists, and a chemist developed and contributed most toward the stated objective of the project.

A study of interdisciplinary research is being conducted at the University of Washington. Preliminary findings of that study presented by Mar, Newell, and Saxberg (25) seem to describe the development and fate of the multidisciplinary approach in this study.

The development of a multi-disciplinary group usually is the result of:

- A charismatic leader: He/she has the ability to attract and persuade others to join.
- Senior leader: Team members join because they feel they can gain prestige or knowledge from a recognized leader.
- A common enemy: A group faces common problems such as lack of recognition or resources, and feels that together they can solve these dilemmas.
- A common subject or client: Needs of client or subject overwhelm personal differences and a group comes together on a common problem.

In each of these cases, a driving force exists that can temporarily hold a team together until adequate communication and understanding develop to form a permanent bond for the group.

In the case of a strong leader, a group may be formed from the force of submission rather than positive interdisciplinary cooperation. These groups generally result in faster group cohesion, but do not guarantee interdisciplinary group productivity. The common enemy or target approach seems to be the most productive since a common concern can dominate individual differences.

The problems associated with interdiciplinary studies almost always are people problems. Personal prejudices and bigotry, both on a personal and discipline basis, often are too strong to overcome. The need to develop concepts concerning the dominate discipline yet not necessarily every discipline results in jealousies among team members. The "inequitable" distribution of research funds in the eyes of supportive or less dominant disciplines also creates problems.

Probably the greatest one single stumbling block to successful interdisciplinary research is communication. Each discipline has developed its own sophisticated jargon to a state that a novice cannot understand the nomenclature much less the concepts. When scientist from several disciplines attempt to discuss a topic, it may take up to a year for individuals from different disciplines to gain sufficient command of each others jargon to conduct meaningful dialogue.

Constructive communication requires a long period of interchange that seems scientifically unproductive. Individuals that master an encounter with one discipline seem more effective in the next encounter with another discipline. There seems to be an increase in tolerance and patience as more interdisciplinary experience is obtained. On the other hand, individuals who are committed to academic specialization have grave difficulties participating in interdisciplinary efforts. Disciplines themselves may inherently have some intolerance of other disciplines; in fact, segments within the same discipline may claim superiority, excellence, or intellectual distinction over others.

Based on the experience gained in this study, three general recommendations are made concerning interdisciplinary research:

1) The dominant roles of the appropriate disciplines and lesser roles of others should be understood clearly by members of all disciplines before an agreement to enter

into a group effort is made.

2) Each discipline should take an active part in the planning and budgeting of a project to minimize future conflicts and misunderstandings.

3) If successful teams or groups have been formed, the likelyhood of future success is much greater than with new formed groups. They should therefore be given greater consideration by funding agencies if economic use of research funds are desired.

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APPENDIX A

VOLCLAY®

6 June 1975

State Water Survey
P. O. Box 232
Urbana, Illinois 61801

Attention: Mr. Bill Walker

SUBJECT: Bentonite

Dear Mr. Walker:

In the field verification study of hazardous material migration and resultant groundwater pollution the need for an effective monitoring system is an important requirement. The data collection of groundwater samples from piezometer-tube observation wells, at various depths, is one method being used to quantitatively evalute the rate of movement and migration of hazardous chemicals through earth materials.

The use of observation wells to evaluate the horizontal or vertical movement of hazardous waste from a disposal site requires well placed monitoring stations. "Each observation well must be screened opposite that layer under observation and isolated from all others with casing and cement grout or bentonite, from the top of the screen to land surface." This isolation of the screen, insures that the sample water taken is representative of the groundwater at that depth. If the screen is not well packed, surface water or groundwater from the above soil stratas may migrate down the casing of the observation well rendering the results erroneous.

An improperly packed observation well can be caused by the bentonite not swelling properly or, breaking down with time. Bentonite swells to approximately 13-15 times its original dry volume when hydrated with fresh water. However, the unique swelling of bentonite can be retarded and reversed.

When bentonite is introduced into water that has a total hardness level greater than 450 ppm it begins to loose its efficient swelling characteristics. Bentonite looses (more than 50%) its swelling properties when introduced into a contaminated environment that has a dissolved salt content or heavy metal ion content greater than 1000 ppm.

Continued..........

AMERICAN COLLOID COMPANY/5100 SUFFIELD COURT/SKOKIE, ILLINOIS 60076
PHONE 312/583-0400 TWX 910-223-0738 TELEX 724-413

Water Sample Analysis

The industrial waste sample from Sandoval, Illinois was tested for the amount of dissolved solids, conductivity, and free swell. The results are as follows:

Project No. 5642, Sandoval, Illinois

1. Total dissolved solids	125,000 ppm
2. Conductivity	Over 1,000 micro mhos
3. Free swell	2
4. Loss of free swell	95.5%

Recommendation

Because of the high contamination of the sample liquid, we recommend that no natural sodium bentonite be used as a screen pack. Natural bentonite, when introduced into this type of contaminated environment, will not provide the proper seal within the observation well.

Contaminated Waters

Natural sodium bentonite can be used as a well-pack when the groundwater has a total hardness level lower than 450 ppm and a dissolved salt content or heavy metal content lower than 1,000 ppm.

If a monitoring well is packed with natural sodium bentonite and the total hardness and contaminant level of the groundwater is greater than the amount specified above, natural sodium bentonite will not swell to its maximum efficiency. In fact, it will eventually start to degrade and shrink in size loosing whatever pack was initially there.

When soluble contaminants exist in the groundwater in quantities geater than 1000 ppm, the ions from the contaminants will decrease the swelling characteristics of natural sodium bentonites. What happens is dissolved salt ions with a strong positive charge is attracted to the negatively charged bentonite. This phenonoma effects a breakdown by short circuiting the swell characteristics of the bentonite particle.

Volclay Saline Seal-100 is a natural sodium bentonite that has been specially treated to make it immune to attack, by water solvable chemicals. The additives that make Saline Seal-100 resistant to chemical breakdown are propritary in nature (currently pending patent approval).

Continued..........

Volclay Saline Seal-100 can be effectively used to impound highly contaminated industrial waste. An important design criteria for a successful seal using Saline Seal is to prehydrate and thoroughly saturate the Saline Seal with fresh water prior to the introduction of contaminated waste.

This can be effectively done when Volclay Saline Seal is applied as a soil admixture in an open environment; such as an open lagoon. However, in using Saline Seal slurry as an observation well-pack the main problem is a technical one. The main problem is how to mechanically place Saline Seal slurry between the outside wall of the observation well and the surrounding soil surface.

The Volclay Saline Seal 100 slurry will not degrade when introduced into the Sandoval, Illinois observation wells. However, the technical requirements of providing a tight observation well-pack by the slurry method can be questioned. There is no sure method of providing a good seal within an observation well by the slurry method.

In a non-contaminated environment dry bentonite pellets can be dropped down the observation wall. Once in contact with fresh water the bentonite swells many times its original dry volume providing a good observation well-pack.

This is not the case when dry bentonite is dropped down an observation well located in a highly contaminated environment; such as the one found at Sandoval, Illinois. Here, the groundwater is saturated with highly contaminated waste. Using dry natural sodium bentonite or dry Saline Seal-100 in such a contaminated environment would not provide the desired observation well-pack.

Alternatives

When using natural sodium bentonite or Saline Seal-100 to pack and seal obserrvation wells around a hazardous waste disposal site, four basic criterias should be considered.

1. The type of contaminated waste being disposed of.
2. The concentration of the contaminated waste.
3. The location of the observation wells in refercance to the disposal site.
4. The porosity of the soil and the length of time the hazardous waste has saturated that soil.

Continued...........

Ideally the observation wells should be placed in a noncontaminated environment; prior to the disposal of the hazardous waste. We would then recommend the use of Volclay Saline Seal-100 as the observation well-pack. The Saline Seal could be applied in a dry form and hydration could occur without hinderance from groundwater contaminants. The observation well would be properly sealed with a contaminant resistant bentonite that would not breakdown when strong contaminants are introduced. Groundwater samples gathered from such an observation well would represent the desired isolated layer.

Respectfully,

Mark T Bertane

Mark Bertane
American Colloid Company

MB/slc

APPENDIX B

APPENDIX B

(Preliminary Draft)

A Preliminary Appraisal of Possible Relationships Between Vegetation and Zinc in Surface Soils *

by

Wm. R. Edwards

Illinois State Natural History Survey
Urbana, Illinois

March 1977

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*Funded in part by USEPA No. R 8032 16-01-2.

Abstract: Levels of zinc in surface soils were high near the smelter at Site A and tended to decrease with distance from the smelter. Statistical modeling indicated that zinc is significantly conserved in soil organic matter. Consistently high levels of zinc were detected in alluvial outwash soils high in organic matter for considerable distances below the smelter. The conclusion was drawn that erosion of surface soils high in zinc serves as a transport mechanism in the dispersion of zinc away from the smelter. The distribution, density, and productivity of wild plants and the growing of agricultural crops in the vicinity of the smelter were significantly related to the zinc status of surface soils. Chemical analyses of plants indicated (1) that the zinc status of plants reflects, at least in part, the zinc status of their environments, (2) that different plants, even those growing in close association, evidenced different levels of zinc, and (3) that different parts of plants concentrate zinc at different rates. Although statistical analyses have not been completed, all observations that bear on findings of previously reported research on zinc-plant relationships are in general agreement with the earlier findings. The hypothesis is advanced that amino acids may be involved in the accumulation of zinc in plants against a concentration gradient with zinc in the soil solution, in the transport of zinc in the plant, and in conservation of zinc in soil organic matter.

Frontispiece

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Fig.15. Zone II. Foreground dense stand of stunted *Amaranthus hybridus*, *Panicum dichotomiflorum*, *Agrostis hyemalis*, and scattered *Apocynum cannabinum*; clumps of *Andropogon gerardi* in foreground; *A. virginicus* in background.

Fig.16. Close-up of tallgrass prairie zone showing interspersion of *Amaranthus hybridus*.

Fig.17. Zone III. *Sorghastrum nutans* and *Andropogon gerardi*

LIST OF TABLES

INTRODUCTION

On 21 July 1974 a research grant was tendered the Illinois State Water Survey, through the University of Illinois, at Urbana, by the U.S. Environmental Protection Agency (USEPA No. R 8032 16-01-2). The title of said grant was "Field Verification of Industrial Hazardous Material Migration from Land Disposal Sites". The original principal investigator for the grant was Mr. William H. Walker and the completion date was specified as 21 January 1977.

> "The primary purpose of this study was to develop effective investigative and monitoring techniques for detecting and quantitatively evaluating the extent of groundwater pollution from surface toxic waste disposal activities. The study also was designed to field verify the effectiveness of glaciated region soils and associated surface deposits in retaining specific hazardous chemicals.
>
> "Special emphases were placed on defining: 1) the vertical and horizontal migration patterns of chemical pollutants through the soil and shallow aquifer systems: 2) the residual chemical buildup in soils in the vicinity of pollution sources and their long-term potential for localized groundwater pollution. In accomplishing these goals, an understanding was developed for the practical aspects of core drilling, soil sampling, piezometer installation and collecting water samples.

> "In addition to the principal purposes of this study, an evaluation of the merits and problems associated with multi-disciplinary studies was made" (James Gibb 1977, personal communication).

Of primary concern was the migration and extent of pollution of ground and surface waters by zinc at smelter sites. In an attempt to broaden the ecological perspective of the possible consequences of zinc pollution at smelter sites, limited funds were made available from the grant for collection of preliminary data to be examined for possible indications that patterns of distribution, size, abundance, and productivity of the plants occurring in the vicinity of zinc smelters reflect the zinc status of their environment. It should be emphasized that under this grant the work on vegetation was entirely preliminary in nature and in no way definitive.

In all, migration of zinc and extent of pollution of surface and groundwaters by zinc were studied at four smelter sites in Illinois. Of necessity, field work on the vegetation portion of the project was limited to one site but a second zinc smelter was visited by this writer several times during the course of field work. The two sites were outwardly similar.

The vegetative study was conducted at a smelter, Site A, located in south-central Illinois. The exact location of Site A and the name of the corporation operating the smelter will remain unspecified in accordance with provisions set forth in the grant.

OBJECTIVES OF THE VEGETATIVE STUDY

1. To prepare generalized maps of the vegetation in fields within about 800 m of the zinc smelter on Site A.
2. To determine whether different plant species reflected the zinc status of their environments in terms of:
    a. Where they occurred
    b. Levels of zinc found in their tissues
3. To relate observations made on zinc-vegetation relationships at Site A to previous investigations of zinc and to accepted concepts of plant ecology.

CONCEPT OF THE VEGETATIVE STUDY

Even the most casual observer is struck by the impoverished and stressed appearance of vegetation near old zinc smelters. The vegetation there is highly patterned and suggests adverse long-term responses associated with smelting operations.

The primary purpose of the vegetative work at Site A was to prepare a series of vegetative maps that would describe and record the locations of the various plant communities that are responsible for the unique appearance of the area. This objective was based on the concept that plants occur in communities that have definable boundaries in time and space and express some characteristic species composition, uniformity of structure, and semblance of social organization.

In practice however, it is possible to recognize the existence of communities in only the broadest possible context. The problem is that in most instances changes in vegetation result primarily from relatively gradual changes in the frequency, dispersion, size, and dominance of different species. Therefore, attempting to define plant communities becomes a largely arbitrary and relatively meaningless process.

Alternative to the concept of the plant community is the view that plants are neither distrubuted as communities nor distributed at random in space or time, either as species or as individuals. In the latter view, vegetation reflects a combination of variations in the environment and the history of events that have conditioned the particular site. Vegetation is viewed as a continuum in which plants tend to occur along an n-dimensional set of environmental gradients dependent on their access to favorable sites and their relative competitive advantage with respect to other plants of the same and of other species.

The utility of the continuum concept is not only that it better expresses how plants are dispersed but that it also provides the basis for complex environmental analyses, modeling of ecological systems, and the identification and description of limiting factors.

The second purpose of the vegetative study was to make a preliminary assessment of zinc as a variable factor (dimension) affecting the status of different species of plants on Site A. Of primary concern was how such parameters as the abundance (occurrence) and site (productivity) of different species related to the zinc status of the soil and of the plants themselves. It was recognized that responses to levels of zinc would be to some degree obscured by the status of other elements and ions and to factors relating to past disturbance, succession, and competition.

The ideal study would have involved an extensive series of detailed chemical analyses of soils and vegetation for 15-20 elements plus measurement of as many other environmental and plant parameters as possible over an extensive sample of points. These data would then have been subjected to multivariate or discriminate function analyses. The scope and cost of such an appraisal were beyond the resources of the overall project. As a result, it was necessary to limit this phase of the study to the zinc status of dominant plants and of the surface soils on which they were growing for a sample of points arbitrarily selected in the more characteristic habitats on the study area. Surface soils were also sampled for zinc along the major waterways draining the study area.

BACKGROUND

Environmental Distribution of Zinc

Traces of zinc are found throughout the environment. Nine of twelve isotopes of zinc are known; the isotopes 64, 66, 67, 68, and 70 are stable; zinc is often used in tracing experiments (Prasad 1966). The origin of zinc in the soil is thought to be 99.5 percent from degradation of igneous and shale rocks during soil formation and 0.5 percent from rapid neutron capture (Bowen 1966). Zinc comprises 70 ppm of igneous rocks, where it is associated with sulfides in the mineral sphalerite or zinc bende (Sauchelli 1969); it also comprises approximately 95 ppm of shales depending on their organic content, 16 ppm of sandstones, 20 ppm of limestones, and 40 ppm of coal (Bowen 1966). Zinc is associated with the micaceous and chlorite components in shale (Wedepohl 1972). Dry soil ranges from 10 to 300 ppm zinc, whereas undried samples contain 0.1 to 0.3 ppm (Bowen 1966). Van Reen (in Prasad 1966) reported 15 ppm Zn in water to be the threshold of taste. Bowen wrote that river and sea water both have an average 0.01 ppm zinc and that air contains less than 0.07 $\mu g/m^3$ (5.4×10^{-5} ppm). Dust accumulating on surface areas was found to deposit 24 mg/m^2 of zinc per year (Hewitt 1966).

Most of the zinc in soils occurs in primary minerals and in clays formed secondarily from parent materials (Bowen 1966). Viets (in Prasad 1966) states that the upper soil horizons contain more zinc than do subsoils. Studies by Hibbard (1940) demonstrated zinc accumulation in the upper horizons of forest soils. He reasoned that absorption of zinc from subsoils by roots and subsequent fixation of zinc by topsoils from decaying organic matter and dust caused the accumulation.

Fertilizers contain zinc in the following amounts: rock phosphate, 50-1000 ppm, superphosphate, 50-1000 ppm, and potassium salts, 0-10 ppm (Tenny and Stanley 1971). The commercial rearing of livestock results in large quantities of manure that contain significant amounts of zinc. Benenati (1974) reported that 81.9 percent of the zinc ingested by animals was excreted in their feces.

Major sources of zinc pollution are zinc smelting operations and zinc mine wastes. Strojan's (1975) investigation of zinc distribution in a forest soil community revealed 26,000 ppm zinc in the organic litter layer at a 1-km distance from the smelter. In a similar study in Oklahoma, zinc ranged from 2,680 to 26,150 ppm in the top 15 cm of soil within 1-km of the smelter (Benenati 1974). Zinc tip waste materials were reported by Weston et al. (<u>in</u> Goodman et al. 1965) to contain up to 6 percent (60,000 ppm) zinc.

Zinc-Plant Relationships

Uptake by Plants

Zinc forms chelates with cysteine, EDTA, gluconic acid, glycine, mercaptoacetic acid, and mercaptoethylamine, the EDTA-Zn complex being the most stable. The uptake of zinc by plants is influenced by concentrations of other nutrients in the soil, pH, and the organic matter content of the soil. Plants utilize chelated forms of zinc (Viets in Prasad 1966) -- ZnO, $Zn_3 (PO_4)_2$, $ZnCO_3$, and $ZnSO_4$ (Boawn et al. 1960).

Youngdahl (1975) found that a high concentration of phosphorus in water cultures increased the zinc found in the ethanol-soluble fraction of the cell walls. Thus, phosphate-induced binding of zinc to cell walls may reduce zinc available for transport to the upper plant and cause zinc deficiency. In contract, low concentrations of phosphorus increased zinc concentrations in all plant parts (Faurisi 1974). Similarly, low zinc levels increased phosphorus in all plant parts. Faurisi found that the influence of phosphorus on zinc uptake was operable at 20/15° C and 30/25° C but that a high zinc concentration decreased phosphorus concentrations only at the warmer temperature.

Zinc uptake is lowered by high phosphate levels in the soil. Viets (in Prasad 1966) reported that phosphate preceipitates zinc as $Zn_3 (PO_4)$ and thus renders it unavilable to the plant.

Sauchelli (1969) stated that the presence of nitrates, chlorides, and sulfates increased the availability of soil zinc as a result of the soluble compounds formed. In comparison to other metal nutrients, Bowen (1966) found the following mineral uptake affinities in kale: Mn> Ca> Zn> Mg> Cu. Increases in soil calcium were reported to increase zinc uptake (Houston 1974). However, magnesium ions decrease zinc uptake via absorption of available zinc (Sauchelli 1969).

The amount of organic matter and clay in soil is positively related to the uptake of zinc (Houston 1974). Zinc is thought to be chelated to organic matter, occupying three sites in the humic acid molecule (Randhawa and Broadbent 1965, Bowen 1966, Prasad 1966). Before being available to the plant, zinc must be leached from humus and clay materials under acidic conditions.

Thorne (1957), Boawn et al. (1960), Bowen (1966), and Viets (_in_ Prasad 1966) reported that availability of zinc to plants was optimal at pH 5 or lower. As pH decreases from reduction of soil organic matter and subsequent release of organic acids (Kee and Bloomfield 1962, Bowen 1966), zinc becomes more available.

Zinc uptake decreases substantially when lime is applied to the soil (Bowen 1966, Viets _in_ Prasad 1966, Sauchelli 1969). Wehrenberg (1956) cited evidence of zinc exchanging with calcium in carbonate rocks. Furthermore, Viets (_in_ Prasad 1966) reported precipitation of zinc as the hydroxide, carbonate, phosphate, and calcium or magnesium zincates at pH 6 or higher.

Few correlations apparently exist between the zinc content of soil and the zinc status of plants growing on it (Viets _in_ Prasad 1966, Onochie 1970). However, Schueneman (1974) found that zinc concentrations and zinc uptake in plants increased with soil concentrations of zinc, except in soils of lowest organic content. Boawn et al. (1960) reported the same but observed that each additional increment of zinc in fertilizer had a smaller effect onzinc uptake. (See section on Toxicity and Tolerance).

In summary, soil factors that enhance zinc uptake by plants are decreased phosphorus and phosphate concentrations, increased concentrations of [illegible], increased calcium concentrations, decreased magnesium concentrations, decreased pH, and increased organic matter.

Both plant leaves and roots may absorb zinc in water-soluble or exchangeable forms (Bowen 1966, Sauchelli 1969). That zinc is transported via a carrier mechanism is supported by the few naturally chelated derivatives that have been found in plant sap (Bowen 1966). Bowen's data on zinc uptake by kale demonstrated a large concentration gradient between zinc in soil solution (0.02 ppm) and zinc in kale leaves (0.2 ppm).

Absorption of nutrients occurs through unicellular root hairs located behind the growing root tip (Bowen 1966, Viets *in* Prasad 1966). Zinc ions may diffuse intracellularly but the xylem appears the main region of transport. Isarangkura's (1974) work displayed greater absorption of zinc by younger corn leaves than by older leaves.

Concentrations in Plant Tissues

Although zinc is found throughout the plant (Sauchelli 1969), higher concentrations are found in the meristematic regions (Bradshaw et al. *in* Goodman et al. 1965. Bowen (1966) observed that zinc content of roots slightly exceeded that in shoots. Sauchelli (1969) found that zinc content decreases from roots to shoots, to leaves, and to fruits. However, Isarangkura (1974), when applying zinc to the foliage and roots of two varieties of corn from emergence to anthesis, found the highest amount of zinc accumulated in the shoots (6 mg/ plant). Viets (*in* Prasad, 1966) reported zinc concentrated in seeds in sufficient amounts to produce small seedlings. Tomato seeds under normal nutrient conditions contained 56 ppm zinc whereas those under deficient conditions contained 21 ppm (Bowen and Cawse 1962).

Faurisi (1974) demonstrated that tomato and orange fruits increase in dry weight in response to increased zinc concentrations in cultural solutions (1.0 to 5.0 µm).

Physiological Function in Plants

The principal physiological function of zinc is to catalyze certain enzymatic activity. Of primary importance is the association of zinc with the enzyme tryptophan desmolase in converting tryptophan to auxin (indolacetic acid) (Tsui 1948, Spector 1956, Orten *in* Prasad 1966). A second major role of zinc is in the formation of the zinc prosthetic group for carbonic anhydrase, which is responsible for the degradation of bicarbonate (Thorne 1957, Prasad 1966).

Investigations have suggested zinc's role in additional enzymatic reactions. For instance, zinc may be required by triose phosphatase in splitting 1,6-diphosphofrudose in gylcolysis (Kai Li *in* Prasad 1966). Youngdahl (1975) reported that in corn the concentration of zinc in hydroponic cultures was correlated with the activity of the enzymes ribonuclease and acidphosphatase. Wegner and Romano (1963) analyzed the stimulatory effect of zinc on RNA synthesis (in *Rhizopus nigricans*) and postulated that increased RNA synthesis and activity were caused by the increased synthesis of purines, pyrimidines, and nucleotides, or by increased stability of the RNA molecule. In the fungus *Aspergillus niger*, zinc may be a co-factor for c-AMP in the regulation and development of citric acid fermentation (Wold 1974). Wold further concluded that a capacity for citric acid accumulation could have evolved because of its ability to solubilize zinc and other metals from otherwise unavailable soil complexes.

In plants, zinc catalyzes processes of cellular oxidation, is vital for the transformation of carbohydrates, regulates the consumption of sugars, increases the source of energy for the production of chlorophyll, aids in the formation of auxins, and promotes water absorption (Sauchelli 1969).

Requirements

Zinc requirements depend on both the size and species of the organism. Quantities of zinc required from nutrient solutions (mg/l, ppm) for several groups of bacteria and plants are: bacteria, 0.1; fungi, 0.2-2.0; green algae, 0.0005-0.06; and angiosperms, 0.02 (Bowen 1966). Viets et al. (1961) reported that, for good yield, field crops required from 0.1 to 0.25 pounds of zinc per acre.

Zinc Deficiency in Plants

Although zinc deficiency may be found locally throughout the world, Australia, New Zealand, Central and South Africa, Brazil, and western Europe display it most notably (Bowen 1966, Viets *in* Prasad 1966). With increased crop productions, zinc deficiency has been reported in 32 states of the U. S. (Viets *in* Prasad 1966, Sauchelli 1969). The importance of zinc in sprays and fertilizers has only been recognized since 1931 (Sauchelli 1969).

Zinc deficiency prevails on neutral to basic soils, on acid leached soils and on strongly acidic peat soils (Viets *in* Prasad 1966). Rarely are deficiencies manifested on either podzolic or black prairie soils. Viets also concluded that zinc deficiency is more prevalant in climates of high light intensity and elevated temperature. In warm climates, blue and ultraviolet light may destroy auxin (Viets *in* Prasad 1966). Another contributor to zinc deficiency, according [illegible] ([illegible]), is high concentrations of phosphorus that increase the amount of zinc bound to cell walls. Such binding may reduce zinc transport to the upper plant and thereby cause a deficiency. Boawn et al. (1960) found that excess phosphate caused deficiency by forming the insoluble precipitate $Zn_3 (PO_4)_2$. Another inducement of zinc deficiency is a small root system resulting from inadequate soil nitrogen (Viets *in* Prasad 1966). Viets (1961) wrote that the immobility of zinc in soil requires roots to grow toward it, and also mentioned that increased salinity, lack of soil aeration, lack of soil water, poor availability of other nutrients, nematodes, root pathogens, and pesticides contributed to deficiency.

Visible symptoms of zinc deficiency are attributed in most instances to the lack of auxin. Interveinal chlorosis of leaves also occurs (Spector 1956, Bowen 1966, Viets *in* Prasad 1966, Sauchelli 1969). Spector reported that in monocots chlorosis of upper leaves appears first whereas in dicots the lower leaves are first affected. Failure of internode elongation due to lack of auxin results in stunting and rosetting. Due to a delay in the life-cycle completion, reproduction is impaired (Hewitt 1966, Viets *in* Prasad 1966, Underwood 1971).

Detailed investigations by Thorne (1957) and Underwood (1971) linked zinc deficiency to reduced carbohydrate metabolism in both fungi and higher plants. Isarangkura (1974) found zinc-deficient corn leaves to have carbon dioxide assimilation rates of 7 to 32 mg/dm^2/leaf/hr, whereas normal corn leaves had rates of 47 mg/dm^2/leaf/hr. Concentrations of reducing-and-total sugar were also reduced for the zinc-deficient corn plant. A cytological examination of zinc-deficient plants by Thorne (1957) revealed small tumors on roots, decreased numbers of chloroplasts, chloroplasts filled with oil droplets, the absence of starch grains, the presence of broad transversely divided palisade cells, the accumulation of tannis and phenols in leaves, calcium oxalate crystals in leaves and buds, and the lack of meristematic activity in roots and cambium.

Sensitivity to zinc varies among plants. Good indicators of deficient conditions are citrus fruit trees, corn, beans, and onions (Viets et al. 1954, Viets *in* Prasad 1966). The sensitivity of the fungus *Aspergillus niger* to zinc is sufficient to be used in bioassays of zinc availability in soil (Viets *in* Prasad 1966).

Zinc

Toxicity and Tolerance in Plants

Zinc toxicity is rare, and found only near zinc mines (Underwood 1971). Camp (1974) reported 0.06 mg/l (6 ppm) zinc as toxic to the alga *Selenastrum capricornutum*.

Zinc toxicity is exemplified by retarded or inhibited growth (Camp 1974, Faurisi 1974). Ambler (1969) reported excess zinc to induce iron chlorosis. The toxicity to *Selenastrum capricornutum* was greater at 29° than at 24° or 19°C (Camp 1974). Furthermore, using light and dark bottles, Camp (1974) found zinc toxicity to affect photosynethesis but not respiration. The mechanism of toxic action is competitive interference with other catalytic metals and complexation with reactive groups of enzymes (Bowen 1966, Kai Li *in* Prasad 1966). The combination of zinc with essential metabolites may also induce toxic effects (Bowen 1966).

Benenati (1974) studied the zinc content of wheat adjacent to an Oklahoma smelter. The average zinc content of the wheat (ppm dry weight) was inversely related to the distance from the smelter and directly related to the soil content of zinc. The level of zinc in this wheat was five times greater than the range of 18.3

to 19.4 ppm found in normal wheat.

Benenati's investigation of an adjacent pasture showed that vegetative variety and diversity decreased with closeness to the smelter. The height of alfalfa (Medicato sativa) was negatively correlated with zinc content of the soil. Pasture plants increased in zinc content over the growing season. Forbs was found to contain higher metallic concentrations than the native grasses (Andropogan scoparius, Panicum virgatum, and Sorghastrum nutans). Benenati prepared a diagram modeling zinc influx in a bermuda pasture system over the next 1,000 years. Bradshaw et al. (in Goodman et al. 1965) found the grass Agrostis tenuis growing on waste from old zinc mines. An investigation using Zn showed an accumulation of zinc in all root meristematic regions. Bradshaw 1965 et al; speculated that zinc may be rendered innocuous by complexation with other compounds.

Zinc tips (dumps of wastes from zinc mining and smeltering operations) in Britain's Swansea Valley were studied by Weston et al. (in Goodman et al. 1965), where up to 6 percent (60,000 ppm) zinc was recorded. Along protected slopes, Bryum was capable of growing on zinc tip soils. Agrostis, Holcus, and Molinia were found growing along the waterline of a slag-contaminated pond. Soil enrichment of the tips using NPK fertilizer, lime, and sewage sludge resulted in improved plant growth, although plants remained small and chlorotic. In experiements in which cellulose film was buried in untreated tip soils for 10 weeks only a few fungal hyphae developed suggesting reduced microbal activity in high zinc soil environments.

Although metallic tolerance is not restricted to the Gramineae, species of this family become adapted to excess zinc and appear to be partially dependent on the excess (Bradshaw et al. in Goodman et al. 1965, Hewitt and Smith 1975). Bradshaw reported that metallic tolerance is linked to several genes in <u>Agrostis tenuis</u> and one gene in <u>Festuca ovina</u>. Fungi are also tolerant.

Zinc-Animal Relations

Uptake by Animals

Zinc uptake is accomplished by primitive animals via diffusion of aqueous zinc through outer membranes. Multicellular invertebrates may absorb ionic zinc through a permeable integument or through the gut. Within the body of invertebrates, the ions are absorbed by Malpighian tubules. In warm blooded vertebrates obtain zinc principally via ingestion. Uptake of zinc is accomplished through permeable skins in amphibians and through gills in fish (Bowen 1966). Zinc ions are absorbed through the gut of vertebrates. In man the duodenum is the main area of absorption (Underwood 1971). Pearson et al. (1966) found that zinc was accumulated by the intestinal mucosa against a concentration gradient. However, zinc movement was slow from the mucosa to the inner fluids.

Various factors apparently influence the absorption of zinc through the gut. Stake (1974) observed that under conditions of lactation in ruminants absorptive ability of the intestine for zinc was increased. Stake's work supported the concept of zinc regulation at the tissue level and that levels of zinc in tissues were closely correlated with protein deposition. Similarly, vitamin D intake indirectly increases zinc absorption by increasing skeletal growth and calcification (Underwood 1971). Phytate, $C_6H_6(OPO_3H_2)_6$, an organic acid of plant proteins complexes with zinc to form nonabsorbable zinc-phytate in the digestive tract thus limiting zinc absorption in the gut. (Oberleas et al. <u>in</u> Prasad 1966). High concentrations of calcium and copper in the gut interfere with absorption of zinc in pigs, cats, and birds (Underwood

1971). Inhibition of absorption of zinc by nitrogen and cyanide under in-vitro conditions was reported by Pearson et al. (in Prasad 1966). However, excess cupric ions and 2,4-dintrophenol had no effect on zinc uptake in Pearson's studies.

In man, less than 5 percent of ingested zinc is absorbed by the gut and the remainder is largely eliminated in the feces (Spector 1956, Bowen 1966, Underwood 1971). Benenati reported that pasture animals absorbed 19.1 percent and excreted 81.9 percent of the zinc they injected. Spector (1956) reported 100 μg/kg body weight of zinc lost daily through human feces and 18 μg/g body weight lost in the urine; Underwood (1971) found that 1.15 ± 0.30 μg/g zinc was lost through perspiration. In acute cases of porphyria, lead poisoning, and rheumatic fever, increased levels of urinary zinc are observed. The zinc is excreted as the zinc-coproporphyrin complex and is thought to function in increasing water solubility and excretion of porphyrins (Orten in Prasad 1966).

After entering the bloodstream, zinc is most rapidly accumulated in the pancreas, spleen, liver, and kidney (Spencer et al. in Prasad 1966). Underwood (1971) reported zinc to be up slowly and firmly bound by the skeletal and central nervous systems. Zinc in hair and feathers is also unavailable as a tissue reserve (Strain and Pories in Prasad 1966). Tissue reserves of zinc are in the pancreas, spleen, liver, kidney, muscles, and red blood cells (Spencer et al. in Prasad 1966, Underwood 1971).

Studies of fetal metabolism have shown a rapid transport of zinc across the placenta. Pregnant mice, when injected with labeled zinc 2 hours before birth, produced offspring with labeled zinc incorporated in their livers and bones (Underwood 1971).

Concentrations

In humans the choroid is the tissue highest in zinc, according to Underwood (1971), although its function there is unknown (Table 1). Underwood further reported that zinc is present in significant amounts in male sex organs and secretions. He suggested that 5 percent of this zinc exists in conjunction with carbonic anhydrase. High accumulations of zinc are found in snake venom (Bowen 1966, Underwood 1971).

Hair and feathers indicate the status of zinc in mammals and birds (Strain and Pories in Prasad 1966, Hanson 1976). Analysis of human hair revealed higher zinc levels in women's hair than men's and a seasonal variation of zinc levels in the hair of men. Low levels of zinc in hair were observed in humans with arteriosclerosis (Strain and Pories in Prasad 1966, Underwood 1971). Underwood (1971) concluded that zinc may be involved in the repair of arterial walls.

Physiological Functions in Animals

Zinc functions as catalyst for various enzymes. Specifically, carbonic anhydrase requires a zinc prosthetic group. Keilen and Mann (1940) isolated and purified carbonic anhydrase containing 0.33 percent zinc. Other metaloenzymes requiring zinc include alcohol dehydrogenase (ADH), lactate dehydrogenase (LDH), malate dehydrogense (MDH), lactate-cytochrome-c-reductase, glyceraldehyde-3 phosphate dehydrogenase, alkaline phosphatase, carboxypeptidase, neutral protease, and aldolase (Spector 1956, Kai Li in Prasad 1966, Underwood 1971). Another function of zinc reported by Underwood (1971) is the control of ribonuclease activity at the cellular level.

The association of zinc with enzymes makes it pertinent to metabolism, and thus to nutrition, reproduction, and growth. Although Orten (in Prasad 1966) indicated the role of zinc in the endocrine system to be unknown, Haumont and McLean, in the same text, suggested it acted with the enzymes and hormones of bone calcification. Underwood (1971) reported similar actions for zinc. Orten (in Prasad 1966) reported the association of zinc and the hormones adrenocorticotropin, glucagon, and insulin. Active insulin levels are regulated by zinc, according to Voisin (1959). Primary and secondary sex characteristics of males are dependent on adequate amounts of zinc (Prasad 1966). Prasad's study of zinc deficiency in Middle East males showed improved growth and gonadal development and the appearance of secondary sex characteristics after zinc supplementation.

Studies of man and other animals by Pories and Strain (in Prasad 1966) demonstrated the importance of zinc in promoting healing of wounds. Persons with burns showed decreased zinc levels in the hair, substantiating the need of the element at the healing sites. Similar data on zinc levels in hair exist for subjects with arteriosclerosis.

Wendt et al. (in Prasad 1966) claimed that ingestion of alcohol caused the liberation of zinc and various apoenzymes from the human myocardium. Studies suggested an altered cellular metabolism of the heart upon repeated alcohol consumption. The regulation of zinc levels by the liver is also affected by alcohol. Alcoholic cirrhosis is characterized by a low serum level of zinc and increased urinary zinc (Prasad 1966).

Zinc Deficiency In Animals

The normal zinc intake for a 70 kg man is 10-15 mg/day; deficient levels may be 3-4 mg/day. For a 0.3-kg rat, 0.02-0.04 mg is a normal daily intake, while 0.016 mg is a deficient amount (Bowen 1966).

Zinc deficiency has been diagnosed in man and other vertebrates. Prasad (1966) studied Egyptians exhibiting dwarfism, hypogonadism, and iron-deficient anemia. He attributed these symptoms to the lack of zinc. Underwood (1971) reported retardation of human growth accompanied by depressed appetite and impared nutrient utilization as a result of inadequate dietary zinc. Bone growth in particular is hindered. Hyperkeratinization (keratogenesis) of the epithelial cells occurs under zinc insufficiency. As a result, skin follicles degenerate; birds show poor feathering and dermatitis; mammals display sparse hair coverings; fibers of sheep wool are crimpless, thin, and loose; horns are spongy and hemorrhagic (Luecke in Prasad 1966, Underwood 1971); and wounds heal slowly (Pories and Strain in Prasad 1966, Underwood 1971). Underwood reported that the learning behavior of rats declined under conditions of inadequate dietary zinc. Sexual and reproductive functions are particularly sensitive to inadequate levels of zinc. Lack of zinc hinders sexual development of males and disrupts spermatogenesis. Underwood (1971) reported the need of zinc in sperm maturation and in survival in germinal epithelium. Female rats subjected to severe zinc deficiency in the diet often displayed infertility or had difficult births with extreme bleeding (Underwood 1971). Avian eggs with low levels of zinc show reduced hatchability and embryonic abnormalities (Underwood 1971).

Examination of tissues from zinc-deficient organisms indicate the impaired synthesis of proteins and nucleic acids and impaired carbohydrate metabolism. Underwood (1971) also reported that hormone production and activities decreased as a consequence of zinc deficiency.

Parzyck's (1974) research on pregnant rats fed a zinc-deficient diet revealed susceptibility to toxic effects of cadmium. The mechanism, as proposed by Leber (1974), is the competition between zinc and cadmium for amino acid substrates.

Zinc Toxicity in Animals

Van Reen (*in* Prasad 1966) concluded that more than 0.25 percent zinc in the diet was toxic. He also reported that inhalation of dusts and fumes high in zinc and contact of zinc or zinc salts with the skin caused adverse reactions. Bowen (1966) showed 50 mg of zinc per day to be toxic and 150 mg to be lethal to a 0.3-kg rat.

Toxic levels of zinc depress animal growth (Bowen 1966, Van Reen *in* Prasad 1966, Underwood 1971). Zinc induces anemia by interference with iron (Underwood 1971). In ruminants, Underwood (1971) reported high zinc levels to be detrimental to microorganism. Excess zinc in the rumen delays physiological action of insulin (Voisin 1959) and prolongs hypoglycemia (Underwood 1971). The activity of insulin may be reduced by the binding of zinc to that hormone (Cunningham 1951). The mechanism of zinc toxicity is competitive interference with other metallic activators and complexation with hormones and reactive groups of substrates (Bowen 1966).

Dietary levels of minerals and vitamins affect the relative toxicity of zinc. Thawley's (1975) investigation on rats showed that zinc toxicity (0.5 percent of diet) increased when dietary calcium levels were low (0.1 percent). Zinc toxicity also increases when levels of vitamin D increased to excess (50,000 IU/kg of feed). Furthermore, zinc and lead interacted to alleviate the toxic effects of zinc. Zinc and cadmium acted to reduce blood hemoglobin and copper levels in the liver and kidney (Thawley 1975).

Toxicity of zinc in a forest soil community adjacent to a Pennsylvania zinc smelter was reported by Strojan (1975). Areas 1, 6, and 40 km from the plant site were studied, the 40-km areas served as a control. The 1-km area contained 26,000 ppm zinc in the second organic litter (A_2) layer. Both the 1-km and 6-km areas exhibited lowered microarthropod diversity and numbers; the Oribatid mites decreased the most, Collembola the least. Pitfall traps revealed that for the macroarthropods, beetles decreased the most. Soil respiration, as indicated by carbon dioxide evolution, was significantly lower near the smelter. Decomposition rates of leaf fall, as judged from litter bags, were also lower near the smelter. Strojan concluded that high zinc levels retarded decomposition and mineral recycling by decreasing the animal populations in the soil.

Similarly, Benenati (1974) assessed the effects of an Oklahoma zinc smelter over a 7-mile radius. Decreased productivity, altered floristic composition, and lowered species diversity were evident. Collections of forage and water contained enough zinc and other metals to be detrimental to livestock.

METHODS

The Study Area

The study area at Site A was limited primarily to fields within 600-800 m of the zinc smelter. Fields were defined by the [illegible] by such factors as roads and farm lanes, the railroad, fences, interspersion of agricultural crops, and other human activities.

Fields were classed as "agricultural"--those currently being farmed-- or "successional"-- those not being farmed. The latter showed numerous effects of past farming or pasturing but were dominated by "wild" plants as opposed to planted crops of cereal grains, row crops, and forage plants that dominated the agricultural fields.

In general, land less than 300-500 m from Site A is so eroded and impoverished or "poisoned", or both, that it is no longer farmed on a regular basis and in most instances was characterized as successional. Fields more than about 800 m from the smelter complex appeared normally productive, or nearly so, for crops such as corn (*Zea mays*), soybeans (*Glycine max*), wheat (*Triticum aestivum*), and grain sorghum (*Sorghum vulgare*). Several fields 300-500 m from the smelter show apparently unsuccessful attempts at cropping over the last 1-3 years.

Because the land near the smelter has little or no present value for agriculture, several fields have been used for dumping refuse and rubble. There is also an old automotive junkyard and salvage operation on about 10 acres just southwest of the plant.

Although fields at Site A dominated by wild plants have been termed successional, their vegetative pattern is considerably different from that characteristic of abandoned agricultural land in south-central Illinois. Successional patterns evident near Site A will be described later in this report.

Cover Mapping

Maps of the vegetation at Site A were prepared using aerial infra-red photographs to delineate patterns of aspect dominance within individual fields. Vegetative pattern was described on the basis of observations made in the individual fields with the use of the aerial photos for reference. Nomenclature follows Jones (1963). Identifications of plant specimens were referenced against type specimens in the herbarium of the Illinois Natural History Survey, Urbana. The identifications of several questionable specimens were verified by Dr. Robert A. Evers, former curator of the herbarium, now retired.

Sampling

In theory, an experiment is designed to provide a sample adequate to test some chosen hypothesis. Normally, the design involves a form of random or stratified random sampling. In typical practice, however, the entire study, including the hypothesis, is reduced to accommodate the funds available. The vegetative study reported here was no exception.

The number of dominant vegetative types was large, and their spatial distribution such that any truly random sampling of soils and vegetation did not appear practical. The limited time available for sampling made it impractical to undertake any extensive series of complex chemical analyses of soils and plant tissues.

Sampling proceeded on the basis of a quasi-stratification by individual fields. Within fields, sampling zones were selected arbitrarily on the basis of dominant vegetation. Important species of plants were identified in each field and at least one sample was taken to include each important species in each field. If a particular species was dominant over relatively large areas or diverse parts of a field, as many as 5-6 samples were taken at distant or representative, or both, points over the field.

The number of samples taken in a field was largely a function of the number of dominant species and unique vegetative situations apparent in that field. The number of samples of a given species depended on the number of fields in which it occupied a relatively conspicuous position and on its distribution within these fields. Common species were sampled both as dominants and on the basis of their occurrence in samples dominated by other species. Although the selection of sites for sampling was arbitrary, common species were sampled under a considerable range of conditions occurring over the study area.

For the majority of herbaceous species encountered in successional fields, a sample consisted of all living, rooted green plants occurring within five quadrats 25 x 25 m in size within a relatively uniform stand dominated by some particular species. In most instances of sampling, annual plants were pulled from the soil, were separated by species and counted, and their numbers were recorded by species. After counting, loose dirt was shaken from roots and the plants were placed one species per sample in paper bags. All bags were labeled as to site, field, sample numbers, species of plant, numbers of plants, and date.

In the case of the larger weedy forbs, perennial grasses, and woody plants, sampling consisted merely of the collection of about 1 kg of leaf and stem materials. These too were placed in labeled paper bags.

After collection, the bagged plant materials were dried for 5-8 days at about 50^0 C in a forced-air oven and then stored in large (approximately 75 x 100 cm) sealed plastic bags to which napthalene crystals had been added as a larvicide.

The problem of obtaining estimates of productivity and mean sizes for the samples containing known numbers of annual plants was complicated by adherence of soil to the plant roots. The procedure used was to weigh the bags containing the dried plant materials to obtain gross weights. Plants were removed and the empty bags were weighed. After 3-10 g of the plant material from each sample had been saved for chemical analysis, the remainder was ashed and the resulting substance, principally soil materials, was weighed. The net dry weight of plant material for each species for each sample was then estimated as gross weight of bag and contents, minus weight of the bag, and minus weight of soil material remaining after ashing. Any loss of weight through plant ash was considered a negligible bias that would be relatively constant among samples for a species and proportionate to the amount of plant material for that species in the sample.

The 2 to 10-g samples of plant tissues were finely chopped in a "Waring Blender" and stored in polyethylene bags for future chemical analysis.

Surface soils were sampled from within each quadrat after plant materials had been removed. Soil samples typically consisted of about nine cores, 5 cm deep and 2.5 cm in diameter, removed with a soil sampling probe from each of the five quatrats that comprised a sample. Reference soils for samples of woody vegetation and perennial grasses and forbs were obtained in close proximity to the individual plants sampled and within what was considered their probable rooting zones. After collection, soil samples were placed in a forced-air oven where they were dried for 5-8 days at 50^0 C. Soil materials were collected and stored in plastic containers and covered with polyethylene lids.

After drying, soil samples were hand-ground, sieved through a 20-mesh (841-µm opening) screen, tumbled for 20-30 minutes to assure thorough mixing, returned to their original containers, and sealed for future chemical analysis. Materials not passing through the screen were discarded.

Chemical Analyses

Plant tissue and soil samples were analyzed for zinc by the Environmental Research Analytical Laboratory, University of Illinois, Urbana, under the supervision of Dr. A. M. Hartley. The pH of soil samples was determined under the author's supervision in a laboratory of the Section of Wildlife Research, Illinois Natural History Survey, Urbana, according to the procedure of Peech (1965).

Statistical Analyses

Multivariate and discriminant function analyses were performed by digital computer facilities of the University of Illinois, Urbana. Two-factor regression and correlation analyses were performed by hand using computer facilities of the Illinois Natural History Survey.

FINDINGS

Zinc in Surface Soils

Levels of zinc in samples of surface soils collected in the vicinity of the smelter at Site A ranged as high as 78,000 ppm--nearly 8 percent zinc (Fig. 1). In general, levels of zinc in upland surface soils were high near the smelter and decreased with distance from the smelter. Levels of zinc in soil samples collected beyond the apparent influence of the smelter were in the range of 25-80 ppm (Table 2). Two upland soil samples taken approximately 2 km north of the smelter contained 160 and 200 ppm zinc. Two samples taken about 6.8 km northeast of the smelter contained 27 and 28 ppm zinc. The levels of zinc in upland surface soils at Site A were in keeping with levels of zinc in surface soils reported by other workers (Strojan 1975, Benenati 1974, Weston et al. in Goodman et al, 1965).

Consistently high levels of zinc were detected in alluvial soils high in organic matter sampled in outwash areas near the smelter and on floodplains along the small intermittent streams that drain surface water from the site (Fig. 1). Relatively high levels of zinc were detected in alluvial deposits for a considerable distance downstream from the smelter (Table 3).

The levels of zinc in upland surface soil samples from Site A were examined as dependent variables in a multiple correlations program model, with (1) distance of the sample location from the smelter, (2) sample pH, and (3) percent soil organic matter as independent variables. Data from 129 soil samples were included in the analysis. Although the multiple correlation coefficient from this analysis was only r = 0.442, it was highly significant ($F_{3,125}$ = 3.559; Ref F^{3}_{125}0.02 = 2.358). However, only about 20 percent of the variability observed in zinc levels in upland surface soils at Site A was accounted for in the three-element model. Thus, the pattern of zinc distribution at Site A is clearly not a simple function of distance, although distance was indicated as one significant factor.

The analysis indicated that the level of zinc was significantly associated with the level of soil organic matter. Zinc was also significantly associated with pH. This finding may derive from an association between pH and soil organic matter relating to the exchange capacity of the organic matter and its ability to hold cations.

The conclusion drawn from the preceding observations and analysis is that zinc is significantly conserved in surface soils by soil organic matter. Bowen (1966) was of the opinion that most zinc in soils occurs in primary minerals and in clays derived from parent materials. Viets (<u>in</u> Prasad 1966) concluded that the upper soil horizons hold more zinc than do subsoils. Hibbard (1940) early demonstrated the accumulation of zinc in the upper horizons of forest soils and reasoned that it derived from decaying organic matter. Strojan (1975) found high levels (26,000 ppm zinc) in the organic litter layer of a forest soil 1 km from a smelter.

Corollary to the conclusion that zinc is conserved in soil organic matter is the hypothesis that the erosion of surface soils, which results in a "loss" of organic matter, would effect a transport and dispersion of zinc away from the smelter site. At Site A most erosion is the result of the impact of rain on bare soil and subsequent transport of suspended soil particles by surface water. The accumulation of zinc in high organic alluvial soils near, and particularly downstream from the smelter supports the hypotheses of movement of zinc in suspended soil organic matter.

The pattern of zinc in surface soils observed at Site A leaves little doubt that the smelter has been a locally significant source of zinc pollution. It further appears that zinc released by the smelter tends to be concentrated and conserved in the organic fraction of surface soils. Although zinc complexed with organic matter and with clay minerals is relatively immobile, there has been movement of complexed zinc away from the smelter as a consequence of erosion and run-off of surface water. Considering the residual levels of zinc in the surface soils at Site A, additional downstream movement of zinc can be expected with each rain that is sufficient to put exposed soil in suspension, causing erosion and run-off of suspended material.

Vegetative Zones

Surfaces at Site A were broadly classed as areas of erosion (uplands) and areas of alluvial deposition (lowlands). The upland soils near the smelter are severely eroded into the "B" horizon. The degree of erosion on comparable slopes tends to decrease with distance from the smelter.

Previously, it was pointed out that vegetative zones and communities are not clearly defined. However, some generalizations relative to pattern appear warranted by the distribution of plants growing in relation to the zinc smelter at Site A.

The dominant species at Site A are those characteristic of many eroded, disturbed, low-fertility situations in south-central Illinois. However, their pattern and spatial relations appear unique. In effect, vegetation at Site A suggests a modification of a secondary successional sere in which distance from the smelter replaces time in successional perspective (Fig. 2).

Time did not permit a comprehensive taxonomic investigation of the flora of Site A and comparable nearby habitats. However, Table 4 presents a list of plants compiled by the author. Many, but not all, species identifications were verified by comparison with specimens on file in the herbarium of the Illinois State Natural History Survey, Urbana. Although many of the more common plants of the area are included, this list is far from complete. However, it does give a general picture of the flora of the region.

Zone 0: Bare Ground

Near the smelter and particularly in areas of alluvial outwash are areas essentially devoid of rooted emergent vegetation (Fig. 3). Such areas were classed as Zone 0.

Zone I: Amaranthus-Panicum

Vegetation on upland sites near the smelter is very sparse. Extensive spots are bare or nearly so. Plant species diversity in Zone I is low and is characterized by the weedy annual grass Panicum dichotomiflorum and the weedy annual forb Amaranthus hybridus. P. dichotomiflorum tends to colonize areas of completely bare soil whereas A. hybridus tends to establish in tiny spots where bits of organic debris have collected.

The first, or Amaranthus-Panicum, zone is characterized by dense populations of tiny individuals of the two dominant species (Figs. 4-8). Densities in excess of 5,000 plants per m^2 were common in Zone I near the smelter. In such situations quadrats often contained no individuals more than 10 cm tall and few quadrats contained any individuals more than 20 cm tall. Productivity in the Amaranthus-Panicum zone near the smelter was in the range of 120-150 g/m^2. Regardless of their small size, individuals of both

A. hybridus and *P. dichotomiflorum*, which survived until fall, produced an abundance of normal-appearing seed.

Farther from the smelter the sizes and productivities of *A. hybridus* and *P. dichotomiflorum* increased, although both remained stunted in comparison with size of similar individuals observed away from Site A. Increases in size and productivity were accompanied by decreases in density.

Solanum carolinense and *Apocynum cannabinum* represent the only other genera represented with any significant frequency in the *Amaranthus-Panicum* zone.

At Site A the *Amaranthus-Panicum* zone was present and occupied the same general area all three summers when the vegetation was examined (1974-76). This distribution is in definite contrast to the successional status typical of *A. hybridus* and *P. dichotomiflorum* on uplands away from Site A where those species tend to colonize on bare soil after disturbance and in corn (*Zea mays*) and soybean (*Glycine max*) fields. In disturbed sites, *A. hybridus* typically occurs the first growing season after disturbance. Dominance by *P. dichotomiflorum* is also greatest during the first year but tends to be present in greatly reduced numbers for 2-3 additional years (Wm. R. Edwards, unpublished data).

The general pattern of *A. hybridus* and *P. dichotomiflorum* suggests that their zone of dominance at Site A will probably persist for some time.

Zone Ia: Spartina Flats

Zone Ia might be best termed "Spartina Flats." These are poorly drained spots of recently deposited alluvium containing considerable sand, silt and organic matter. The alluvium was derived [illegible] from erosion of adjacent uplands. The Spartina flats, as the name implies, are dominated by *Spartina pectinata* (Fig. 5). They tend to occur on otherwise bare areas or as a transition between bare ground and the vegetation of Zone I near the smelter and along the drainageways in Zones II and III farther from the smelter. In such situations standing water is present during most of the spring and for periods of 3-10 days after moderate to heavy rains. Soils tend to stay wet or damp for extended periods. Much of the distribution of *Spartina* appears to relate primarily to alluvial soils and to drainage. These soils tend to have a salty taste.

In a few spots where water stands for more prolonged periods one finds occasional small clumps of *Typha latifolia* associated with the *Spartina*. Except for an occasional *Amaranthus*, *Spartina* stands tend to be monospecific.

Zone II: *Amaranthus*-*Panicum*-*Agrostis*-"Plus"

Starting perhaps 80 m from the smelter in areas slightly less eroded and having slightly less surface drainage, the weedy annual grass *Agrostis hyemalis* is detected in increasing numbers and forms what amounts to a second zone--the *Amaranthus*-*Panicum*-*Agrostis* zone (Figs. 9-10). In Zone II the rush *Juncus tenuis* is common along furrows, paths and wheel traces where the soil is compacted and where water tends to stand after a rain. Also to be found in Zone II, principally in poorly drained spots, are colonies of moss (*Polytrichium* spp.) that are 5-25 m or larger in diameter.

As with the *Amaranthus* and *Panicum*, the abundance, size, and productivity of *Agrostis* tend to increase with distance from the smelter, but it too tends to be smaller and less productive than when found in habitats away from Site A.

In Zone II both *Amaranthus* and *Panicum* tended to be larger and [illegible] and density when growing in close association with *A. hyemalis*.

The area dominated by *A. hyemalis* appeared essentially the same in all three summers of observation. Here again, the observed pattern suggests that the dominance of *A. hybridus*, *P. dichotomiflorum*, and *A. hyemalis* will probably persist for a considerable number of years in the absence of further physical disturbance.

In south-central Illinois *A. hyemalis* is a characteristic dominant on poorly drained low-fertility soils during second and third seasons after abandonment, following cropping for corn or soybeans. It is usually present in reduced numbers for several additional years. In many respects, it replaces *P. dichotomiflorum* in the sere. The pattern of *A. hyemalis* on Site A suggests that of a replacement, but here the pattern is a replacement in space as opposed to its usual position as a replacement in a time sere of secondary succession.

The extent of erosion in Zone II is demonstrated by the presence of numerous mounds (Figs. 11-13). Where roots have inhibited soil erosion, trees and deep-rooted perennial herbs persist on mounds rising 25-35 cm above the adjacent soil.

Scattered through Zone II is an assortment of perennial herbs and woody plants that probably represent relics of the community that gave way to the one now dominated by *A. hybridus*, *P. dichotomiflorum*, and *A. hyemalis*.

On the nearly level upland portions of Zone II one finds scattered clumps of *Andropogon gerardi* and *Sorghastrum nutans* (Figs. 14-15). Although these may represent colonizing species, it is more likely that they represent relics of the prairie that originally vegetated uplands of the area. Also present on the uplands in Zone II are numerous gnarled, stunted, dead, and dying *Crataegus* spp., *Malus* spp., and *Gleditsia triacanthos* (Figs. 11-12). The presence of these thorny species suggests heavy pasturing over an extended period in the past. Old fence posts support the premise of a past history of grazing.

Although no trees were aged, from their appearance it is probable that they were established prior to, or relatively soon after, the smelting of zinc was initiated. The impression one gains in viewing the erosion and vegetation in Zones I and II is that present conditions reflect a combination of toxic effects of zinc and prolonged overgrazing.

Other tree species present in Zone II included *Sassafras albidum*, *Populus deltoides*, *Quercus imbricaria*, and *Diospyros virginiana*. Other flowering plants observed in Zone II included *Xanthium commune*, *Asclepias tuberosa* (specimen was a particularly vibrant, deep orange in color), *Verbena hastata*, *Baptisia leucantha*, *Solanum carolinense*, *Asclepias hirtella*, *Apocynum cannabinum*, *Festuca elatior*, *Agrostis alba*, *Rubus flagellaris*, *Asparagus officinalis*, and *Vitis* spp. One area of tight soils is being extensively invaded by *Campsis radicans*.

Zone III: Tallgrasses

Zone III is dominated by the native perennial grasses *Andropogon virginicus*, *A. gerardi*, and *Sorghastrum nutans*. Of these, *S. nutans* is far more abundant and extensively distributed (Fig. 16).

A. virginicus appeared to occupy a somewhat transitional position between Zone II and dense stands of *S. nutans*; however, patterning of the tallgrasses was complex. In places *A. virginicus* occurred in almost pure stands all three summers, in places it occurred in mixed stands with *S. nutans* all three summers. In situations where *A. virginicus* was observed to increase, it was apparent that an attempt had been made to farm the field within the past 3-5 years (see description of Zone V), and the role of *A. virginicus* in community development was in keeping with its typical role in old field succession. The appearance of sites where *A. virginicus* was successional suggested higher fertility and less erosion than where it held a transitional position between Zone II and *S. nutans*. The latter position very probably related to some environmental gradient as opposed to a time sere.

Sorghastrum nutans occurred extensively in dense mixed stands with *A. virginicus*, in dense stands alone, in open mixed stands with *A. gerardi*, and in scattered clumps. Fairly dense stands of tallgrasses including *S. nutans* did not, however occur closer than about 250 m from the smelter. The best stands of *S. nutans* began about 400 m from the smelter. The closest individual clumps of *S. nutans* were perhaps 150 m from the smelter.

The closest individual clumps of *A. gerardi* were about 100 m from the smelter, with the better stands perhaps 400 m away. *A. gerardi* tended to occur primarily in scattered clumps and mixed open stands with *S. nutans*. It tends to occupy more mesic sites than *S. nutans* but less wet sites than *Spartina pectinata*. It is probable that *A. gerardi* was to a degree limited in its distribution and abundance by the somewhat droughty nature of the area soils.

The tallgrass zone located southwest of the smelter supports probably the best and most extensive relic stand of *S. nutans* in Illinois today. Only two forbs, *A. hybridus* and *Baptisia leucantha*, [illegible] tallgrass zone. Only *A. hybridus* was common

(Fig. 17). There is no ready explanation for the lack of forbs in Zone III. Perhaps the lack of forbs in the tallgrass zone relates to a long history of heavy grazing and frequent burning, but other areas in the region have suffered both and exhibit far greater diversity. The railroad, which passes through Site A, is frequently burned and supports numerous prairie forbs in relatively close proximity to the smelter.

Zone IV: Swamp

Just northeast of the smelter is a swampy area dominated by buttonbush (*Cephalanthus occidentalis*). This area appears to have derived from the partial blocking of an old watercourse by the railway. Limited channelization of this watercourse was effected in late 1974 or early 1975 in the vicinity of the smelter both north and south of the railroad. Channelization resulted in extensive destruction of buttonbush and drainage of the swamp. This habitat will change markedly in the next several years.

Zone V: Wooded Waterways

This zone is comprised of vegetation associated with the watercourse that passes immediately east of the smelter. The woody vegetation of Zone V is dominated by *Populus deltoides*, *Salix nigra*, *Quercus palustris*, *Platanus occidentalis*, and *Ulmus americana*. On better-drained sites one finds *Quercus imbricaria*, *A. alba*, *Prunus* spp., *Gleditsia triacanthos*, *Sassafras albidum*, *Diospyros virginiana*, *Crataegus* spp., *Malus* spp., *Sambucus canadensis*, *Rubus* spp., *Rhus radicans*, and *Symphoricarpos orbiculatus*. Evidence of the past presence of a homesite is indicated by two large old scotch pine (*Pinus sylvestris*), a rapidly spreading clone of *Populus alba*, and a small clone of *Catalpa bignonioides*. Open areas in Zone V, depending on their past history of disturbance, proximity to the smelter, soil type, and drainage, support herbaceous plants discussed for Zones I, Ia, II, III, and VI, plus *Cuscuta* spp.

Zone VI: Recently Disturbed

Vegetation in the zones I through V reflect, in most instances, responses to factors that have operated over an extended period of years. The result is that vegetative patterns in those zones suggest a relatively high degree of temporal stability. In contrast to such stable-appearing situations is the vegetation in areas where soils have recently been disturbed in unsuccessful attempts at farming. The later situations have been designated as Zone VI. In general, Zone VI situations occur at least 350 m from the smelter in places where erosion has been compartively light.

Common plants observed in Zone VI included *Amaranthus hybridus*, *Panicum dichotomiflorum*, *Agrostis hyemalis*, *Andropogon virginicus*, *Eupatorium serotinum*, *Ambrosia artemisiifolia*, *Verbena hastata*, *Juncus tenuis*, *Solanum carolinense*, *Trifolium pratense*, and *Bidens coronata*.

The basic vegetative pattern observed in Zone VI was a successional conversion of annuals to a *Eupatorium*-dominated community on better sites and to *Andropogon virginicus* on the intermediate sites. Zone II vegetation occupies the poorest sites in Zone VI and will probably persist for fairly long periods of time. *A. artemisiifolia* was an important annual on the better sites in 1975 but was greatly reduced in 1976.

Average sizes and productivities of *Amaranthus hybridus*, *Panicum dichotomiflorum* and *Agrostis hyemalis* were greater, and densities less, in Zone VI than in Zones I and II, particularly in 1975 and on the better Zone VI soils. In 1976 the first two of those species were generally reduced in size, productivity, and density in Zone VI, again particularly on the better soils.

In summer 1975 the most fertile portions of Zone VII were dominated by red clover (*Trifolium pratense*) apparently seeded in 1974. Associated herbs in 1975 included *Ambrosia*, *Amaranthus*, *Xanthium*, *Bidens*, *Agrostis*, *Panicum*, and *Juncus*. These species were much reduced in numbers in 1976, when they tended to be replaced by *Eupatorium*, *Erigeron annuus*, *E. strigosus*, *E. canadensis*, *Solidago* spp., and *Lactuca*. *Agrostis*, too, was more prevalent in 1976. This pattern is more or less typical of early secondary succession in south-central Illinois.

Zone VII: Railroad Right-of-Way

The railroad right-of-way passing east-west immediately north of the smelter defines Zone VII. Beyond about 100 m from the smelter, vegetation is dominated by a diverse admixture of native prairie forbs, grasses, and Eurasian weeds. In wet sites nearer the plant, *Spartina* tends to dominate mesic areas of alluvial soils. No attempt was made to compile a comprehensive listing of species present along the right-of-way over the growing season. However, the following plants are common and characteristic away from the smelter in Zone VII: *Amaranthus*, *Amorpha canescens*, *Arctium minus*, *Asclepias tuberosa*, *Asparagus*, *Aster novae-angliae*, *Baptisia leucantha*, *Cassia fasciculata*, *Cuscuta*, *Diospyros virginiana*, *Eryngium yuccifolium*, *Geranium maculatum*, *Helianthus grosseserratus*, *Lactuca*, *Lespedeza capitata*, *Liatris aspera*, *L. pycnostachya*, *Mirabilis nyctaginea*, *Panicum virgatum*, *Potentilla simplex*, *Rhus glabra*, *Rosa carolina*, *Rudbeckia hirta*, *Silphium lacineatum*, *S. terebinthinaceum*, *Solidago* nemoralis, Sorghastrum nutans, Sporobolus heterolepus, Tradescantia subaspera, T. virginica, Tripsaicum dactyloides, and Yucca filamentosa. In fact, most of the species listed in Table 4, plus numerous others, probably occur along the right-of-way within 1-2 miles of the smelter.

Zone VIII: Cropland

Principal agricultural crops grown in the fields surrounding the smelter included wheat, red clover, soybeans, sorghum, and corn in that approximate sequence of proximity to the smelter. In general, wheat was being planted in fields having higher levels of zinc in surface soils than were the other crops. This pattern of crops very probably reflected past successes and failures of local farmers in growing those crops on the zinc-polluted soils near the smelter.

Cropping success was obviously not uniform with respect to the distance from the smelter in those wheat and soybean fields nearest the smelter. Stands of wheat and soybeans nearest the smelter tended to be sparse and stunted. Yields were virtually nil in spots and harvest was not even attempted in such situations. Parts of several fields suggested recent abandonment after unsuccessful attempts at cropping. Soil tests revealed consistently higher levels of zinc in places where stands were thin and plants stunted than in parts of the same fields where the densities and sizes of crops looked more normal. Critical levels for zinc appeared to be about 1,200 ppm for wheat, a little less for soybeans, 600 ppm for sorghum, and a little less for corn.

The pattern of cropping at Site A and the productivity of crops within individual fields clearly suggested that levels of zinc were significantly related to crop production for at least 500 and probably more than 800 m from the smelter.

Although the models used in the preliminary analyses do not constitute a test, it is possible that massive applications of lime and fertilizers in connection with a program of growing forage plants to restore soil organic matter might, in time, reclaim for crop production some of the polluted and impoverished land near the smelter at Site A. The key would seem to be to restore high levels of organic matter. Sweet clover (Melilotus officinalies) and the tall native prairie grasses would be worth trying in such a program.

The general pattern of upland vegetation at Site A is for the so-called "colonizing" plants typical of early secondary succession on low-fertility sites in south-central Illinois to annually dominate areas where concentrations of zinc are relatively high and levels of pH and organic matter are relatively low in surface soils. Plants typical of later stages of the sere tend to occupy areas lower in zinc but higher in pH and organic matter. This pattern of plants leads to the hypothesis that plants are distributed in both space and time along complex dynamic environmental gradients.

Plants occurring on moist alluvial soils and other mesic sites generally appeared more tolerant of high concentrations of zinc than did the plants typical of drier upland sites. Notable examples observed at Site A include Spartina pectinata, Populus deltoides, Cephalanthus occidentalis, Typha latifolia, Salix nigra, Campsis radicans, and Apocynum cannabinum. It is possible that factors associated with the generally high levels of soil organic matter and pH of the mesic sites might somehow offset the potentially toxic effects of zinc. However, a more logical possibility is that as a result of the tendency for organic matter to conserve and concentrate zinc, and a wide variety of other elements, over periods of evolutionary time organisms associated with high organic alluvial soils have been sufficiently exposed to evolve relative tolerance to high levels of zinc and, presumably, other elements as well.

Weeds of Corn, Sorghum, and Soybean Fields

The weed populations of corn and soybean fields near the smelter appeared to be largely a function of soil moisture conditions plus the success of weed control in the individual field. Some fields were essentially "clean"; others were fairly weedy. Common weeds of corn, sorghum (*Sorghum vulgare*), and soybean fields at Site A include: *Amaranthus hydridus*, *Ambrosia artemisiifolia*, *Asclepias syriaca*, *Ipomoea hederacea*, *Xanthium commune*, *Solanum carolinense*, *Panicum dichotomiflorum*, and *Digitaria* (2 species). Because of the nature of chemical weed control, weedy grasses tended to be more prevalent in corn and sorghum and weedy forbs to be more abundant in soybeans.

Weeds of Wheat Fields

Weeds tended to be more prevalent in wheat (*Triticum aestivum*) than in row crops, probably because chemical weed control is not practical in wheat fields as it is in row crops. Common weedy forbs of wheat fields at Site A include: *Ambrosia artemisiifolia*, *Amaranthus hybridus*, *Cirsium vulgare*, and *Digitaria* spp. Frequently seeded in the wheat are *Trifolium pratense*, *T. hybridum*, *Agrostis alba*, and *Phleum pratense*. *Melilotus* spp. often appeared as a volunteer in wheat fields. In areas closer to Site A where soils were less conducive to wheat and the forage grasses and legumes, one finds an increased incidence of such weedy plants as *Amaranthus hybridus*, *Panicum dichotomiflorum*, *Agrostis hyemalis*, *Plantago pusilla*, *Bromus secalinus*, *Juncus* spp., *Solanum carolinense*, and *Xanthium commune*.

It was quite apparent that many weedy forbs and grasses were at a competative disadvantage on the better sites.

Discrimination of Community Type

The previously discussed relationships of the levels of zinc, pH, and organic matter in surface soils as they related to distance from the smelter, and the occurrence of vegetative and land-use zones as they appeared to relate to distance from the smelter, lead to the hypothesis that zinc, pH, and organic matter were significant in land use and in community development at Site A. This hypothesis was tested by discriminate function analysis using zinc, pH, and organic matter as discriminating parameters. Classes were based on the vegetative type or land use at the various sample locations. Classes included (1) bare ground, (2) Amaranthus hybridus or Panicum dichotomiflorum, or both, (3) A. hybridus or P. dichotomiflorum, or both, with Agrostis hyemalis, (4) perennial tallgrasses, (5) plants associated with alluvial deposits, and (6) cropland. Data for 128 sample locations were used in this analysis.

The preliminary discriminate function analysis revealed that levels of zinc, organic matter, and pH were all significantly associated with vegetative pattern and land use at Site A. The nature of the separation of the six variables along the three gradients is suggested in Table 5. Unfortunately, this aspect of the analysis had not been completed in time for inclusion in this report but will be included in the final draft of the manuscript being prepared on this study.

Size, Density, Productivity, Diversity, and Competition

The analyses of relationships between the densities, sizes, [illegible] of different plant species to the levels of [illegible] in their associated surface soils have not been accomplished. However, inspection of tabulated data suggests some interesting possibilities.

In general, size and productivity appeared inversely related to density and also to the levels of zinc. These relationships indicate the increasing significance of competition to population regulation as physical factors become less limiting. The phenomenon of density being inversely related to fertility was previously observed during the author's study of fertility in relation to secondary succession (Edwards 1975). The observation at Site A appeared to support the contention of the previous study that plants are distributed along environmental gradients (occupy "realized niches") on the basis of competition with other plants having access to those gradients.

Benenoti (1974) reported that the height of alfalfa (Medicago sativa) was inversely related to soil zinc. He also observed that on his study area in Oklahoma, plant species diversity increased with distance from the smelter. Although species diversity tended to increase with distance at Site A, the species composition in the tallgrass zone was restricted primarily to three species--Sorghastrum nutans, Andropogon gerardi, and Amaranthus hybridus, with Spartina pectinata along the floodplain. Presumably, A. hybridus was filling the forb niche in that prairie grassland because of high levels of soil zinc. Although prairie forbs were common and diverse in suitable habitats away from the smelter at Site A, they were largely restricted to the railroad right-of-way on the study area, where their numbers were not striking as they were farther away. Several exceptional prairie remnants occur only 2-3 miles east and west of [illegible] right-of-way.

Zinc in Plant Tissues

Four different types of chemical analyses of plants were performed: (1) total plants, (2) aboveground parts, (3) leaves and green twigs, and (4) grains (seeds). To a large degree the tissues analyzed depended on the size of the species of plant analyzed. Small plants, regardless of species, were analyzed in total. The larger, more deeply rooted annuals and perennials had only their aboveground parts analyzed. Only leaves and green twigs of woody plants were analyzed whereas only grain was analyzed for the wheat and feed grains.

Although the statistical analyses are incomplete and preliminary, several distinct patterns appear to be emerging relative to the differences in the levels of zinc in tissues of different species of plants and to the differences of zinc in soil samples (Tables 6-13).

Several types of differences in the levels of zinc in plants were considered: (1) levels of zinc in individual plants of the various species as they relate to levels of zinc in surface soils and to distance from the smelter, (2) differences in levels of zinc among different species of plants, and (3) differences in levels of zinc in different parts of plants.

One of the disappointing aspects of the study was that funds did not permit assays of soils and plant tissues for elements other than zinc. Much could have been learned from such analyses.

Not surprisingly, the levels of zinc in plant tissues tended to reflect the levels of zinc in the surface soils in which they were growing. This relationship was clearly demonstrated by regression analysis of the log of the level of zinc in grain samples (Table 13) with the level in associated soil samples for both wheat ($\underline{r}_{11} = 0.924$) and soybeans ($\underline{r}_{11} = 0.926$). However, the association for sorghum

(r_{12} = 0.442) was considerably weaker. This association between sorghum and zinc may have been due to the limited range of variation of soil zinc for the sorghum samples. Not enough samples of corn were available to test. The correlation of plant zinc with soil zinc is suggested for other species but the grain samples offered the best possibilities for preliminary testing.

The observation that the level of zinc in wheat is directly related to the levels of zinc in soils and inversely related to distance from the smelter at Site A was similar to that reported by Benenoti (1974) for wheat grown near a smelter in Oklahoma.

In the present study, the levels of zinc in wheat ran as high as 550 ppm. The highest was approximately 10-15 times the level of zinc in samples of wheat from control points (Table 13). This ratio was considerably greater than was observed by Benenoti (1974), who reported that wheat growing near a smelter in Oklahoma contained 5 times the zinc of normal wheat. Benenoti (1974) reported zinc in normal wheat to be in the range of 18.3-19.4 ppm whereas control samples of wheat obtained in southcentral Illinois were in the general range of 28 to 44 ppm. Whether the samples from the two states are really different is not known; however, Illinois soils and wheat may, in general, contain more zinc than Oklahoma soils and wheat.

As was reported earlier, different species of plants tended to be associated with different levels of soil zinc. As one might expect, different species of plants appeared to exhibit different levels of zinc in their tissues (Tables 6-13). These differences undoubtedly reflected, in part, the different zinc status of their environments. However, plants that tended to occur together, such as <u>Amaranthus hybridus</u> and <u>Panicum dichotomiflorum</u>, appeared to concentrate zinc in their tissues [illegible] different rates. This phenomenon will be ascribed in the near future by comparing levels of zinc among individuals of those species collected from the same sampling points.

One measure of the differences in rates of accumulation of zinc by plants of different species was evident in the comparison of the regression coefficient ($\underline{b}_{w}$ = 0.550) for the relationship between the log of zinc in surface soil samples ($\underline{X}$) with the log of zinc in the grains ($\underline{Y}$) of wheat. This relationship was quite different ($\underline{t}_{18}$ 0.01 = 2.88) from that shown by the respective regression coefficient ($\underline{b}_{s1}$ = 0.252) for soybeans. The regression coefficient for sorghum ($\underline{b}_{s2}$ = 0.269) did not, however, differ from that for soybeans. The above observations lead to the hypothesis that different rates of accumulation of zinc were somehow associated with relative zinc tolerances of different plant species.

In contrast to the generally high levels of zinc in the leaves and green twigs of *Populus* and *Salix* were the relatively low levels of zinc in the leaves and stems of *Cephalanthus occidentalis*, Campsis radicans, and in the leaves of the perennial prairie grasses, particularly Spartina. These relatively low levels were associated with the high levels of soil zinc (Table 10, 12).

Although the preliminary analyses strongly suggested species-related differences in the rates of accumulation of zinc, it was also clear that assays of samples of tissue from total plants consistently ran far higher in zinc than assays of samples that consisted only of leaves and stems, and for the samples of grain (Table 6). Samples of leaves and green twigs were also high in zinc for *Populus deltoides* and *Salix nigra* (TAbles 6, 12). Thus, for plants sampled on the study area at Site A, zinc appeared to have been concentrated at different rates in different parts of the plants.

On the possibility that this latter phenomenon was the consecuence of zinc in soil particles and dust adhering to the plants, in 1976 a series of plant samples was collected and gently washed in distilled water prior to chemical analysis. The results of the analyses in 1976 were in close agreement with the findings in 1975.

The data obtained on this study are in agreement with those of Sauchelli (1969), who found zinc throughout the plant; of Bradshaw et al. (in Goodman et al. 1965), who found higher concentrations of zinc in meristematic tissues; and of Bowen (1966), who observed zinc content of roots to slightly exceed that for shoots. Isarangkura (1974) found greater absorption of zinc by younger than by older leaves of corn.

Thus, it appears that zinc tends to be concentrated in the primary growth zones of plants--areas where proteins are being synthesized at high rates.

The three annuals that tended to occupy the highest zinc soils and to have the highest levels of zinc in their tissues (*Amaranthus hybridus*, *Panicum dichotomiflorum*, and *Agrostis hyemalis*) frequently evidenced higher levels of zinc than their respective associated soils (Tables 7-9). The higher levels of zinc in plants than in the soils imply that those plants have a significant capacity to concentrate and hold zinc against a concentration gradient. Bowen (1966) reported a steep gradient between zinc in soil solution, 0.02 ppm, and zinc in the leaves of kale (*Brassica kaber*)(0.2ppm).

A possible explanation of the phenomenon of zinc being concentrated in growth areas of roots and shoots of plants is that, in living plants, zinc complexes with amino acids, which serve as carriers. The observed high levels of zinc associated with soil organic matter would be a logical consequence of accumulation of zinc by plant roots. These two observations suggest that zinc conserved in soil organic matter is fixed by plant roots--perhaps during protein synthesis.

Hanson (1976) reported a wide variety of elements associated with the proteins of feathers of blue and snow geese (Anser Caerulescens) and that the levels of such elements reflect their availability in the individuals' respective environments.

If the previous hypothesis of zinc fixation during synthesis of proteins is correct, how does one explain differential levels of zinc in the aboveground parts of different plants? The logical rationale is that we sampled different tissues of the different species and that the tissues sampled were at different stages of growth and development. Thus, their levels of proteins were different, or that different plants synthesize proteins at different rates, in different amounts, or of a different type, or a combination of these factors. This phenominon offers intriguing possibilities for future research.

DISCUSSION

In general, levels of zinc in surface soils and the degree of erosion both decrease with distance from the smelter at Site A. Plant communities at Site A tend to have low species diversity, but diversity tends to increase with distance from the smelter. Productivity also tends to increase with distance from the smelter. Communities nearest the smelter are dominated by species that colonize disturbed sites of low fertility in south-central Illinois. Communities occurring at successively greater distances from the smelter are dominated by plants normally associated with successively later stages in secondary successional series typical for south-central Illinois. The level of zinc in surface soil samples was significantly related to the plant species that were growing on the samples.

The conclusion is drawn that there have been serious long-term effects from zinc smelting on the soils and vegetation at Site A. High levels of zinc have probably led to decreased productivity and altered composition of plant species. As a consequence, the community apparently became increasingly vulnerable to overgrazing, erosion, and loss of nutrients -- the result being a cycle of increasing impoverishment.

The occurrence of different plant species in relation to levels of zinc in surface soils plus the different levels of zinc in the tissues of different plants indicates that different plants have different tolerances for zinc and different capacities to accumulate zinc.

Observations made at Site A are in agreement with Weston et al.

(in Goodman et al. 1965) who reported Agrostis tenuis and Bryum on zinc tip soils in Britain. Fertilization of those zinc tip soils resulted in improved plant growth although the plants remained small and chlorotic. Bradshaw et al. (in Goodman et al. 1965) found metal tolerance to be a genetic characteristic of Agrostis tenuis and Festuca ovina. The importance of Agrostis (A. hyemalis) at Site A has been detailed. Festuca elatior has shown promise in attempts to reclaim an area northwest of the smelter for use as a village park. Thus, the vegetative pattern at Site A suggests a combination of zinc and fertility gradients in relation to differential zinc tolerance of species having access to those gradients.

Zinc tolerance is very probably a genetic characteristic of the individual plant species. Bradshaw (in Goodman et al. 1965) reported metallic tolerance to be linked to several different genes in Agrostis tenuis and to one gene in Festuca ovina. Different species of both these genera were common in relative proximity to the smelter at Site A, suggesting that relative tolerance exists above the species level - at least in those two genera.

The vegetative pattern suggests that at Site A successional species occupy positions in space relative to some complex system of environmental gradients as opposed to their normal position in a time sequence of vegetational development.

In effect, zinc pollution has induced negative succession. If zinc is still accumulating, the process of negative succession will presumably continue and be evident at progressively greater distances from the smelter. If the amount of zinc in the environment is holding at a relatively constant level as a result of "new" zinc emissions being controlled at the smelter and "old" zinc being conserved in clay and organic matter, the present pattern of vegetation may persist with relatively minor change. If the zinc is being vectored away from the site faster than it is accumulating, succession would be expected to proceed in a more typical fashion. It is obvious at Site A that the zinc status of soils and vegetation are mutually dependent.

Observations at Site A and elsewhere make it clear that there are physical and chemical bases involved in plant succession and the development of vegetation. Moreover, events that induce succession are not inevitably undirectional $\frac{1}{M}$ and thus succession is not inevitably undirectional $\frac{1}{M}$ as Gleason (1926) pointed out so many years ago.

In recent years the concept of distribution of plants along environmental gradients has achieved general acceptance by ecologists (Whitaker 1951, 1953, 1957; Curtis and McIntosh 1951; Curtis 1955, 1959). This may be the first time, however, that succession has been directly linked to gradients.

In a previous study of the roles of soil fertility and competition in secondary succession in south-central Illinois (Edwards 1975), this writer concluded that plants are distributed in relation to environmental gradients on the basis of competition. The plant species observed at, and in close proximity to, Site A make it clear that a diverse array of species have potential access to the study area. The number of species having access to a given place or zone is undoubtedly far greater than the number of species actually present. This implies that some form of exclusion may be in operation.

At the higher levels of soil zinc where only colonizing species exist, their presence or absence may well reflect direct effects on such species as *Panicum dichotomiflorum* and *Amaranthus hydridus*. This condition is no doubt greatly complicated by erosion and the resulting low fertility. As zinc decreases and fertility increases, colonizing species are replaced by other species. Size-density relationships indicate that replacement occurs on the basis of competition. This statement, of course, is hypothesis, not fact. However, it is a hypothesis that can and should be tested in a controlled environment.

At distances greater than about 400 m from the smelter, soils support crops typical of the region. Although no attempt was made to estimate crop yields, it appeared that beyond 600 yards crop production was in the normal range. However, at distances less than about 400 m, wheat and soybeans were definitely reduced in size, density, and yield. Neither corn nor sorghum was planted less than about 500 m from the smelter in 1975 when most of our field study was done.

One consequence of zinc-related impoverishment at Site A has been an almost complete loss of value of the land for agricultural production within about 400 m of the smelter. As typical of "worthless" land, much of the area now serves as a junkyard and a place to dump rubble and trash.

A tract of approximately 20 acres near the smelter has been acquired for a village park. This tract has been seeded to fescue (*Festuca elatior*) with fair initial success of establishment, although near the smelter the stand is thin and a sod appears slow in forming. Although a park is definitely a move in the right direction, much of the seeded tract will probably be slow to develop a sod sufficiently strong to support the level of use typical of village parks.

Management of lands subject to zinc pollution in the vicinity of smelters is a problem. Although the problem was not attacked directly on this study, several observations made at Site A have potential significance for managing these lands.

Because zinc is concentrated and conserved in soil organic matter, there is probably no efficient method of removing zinc from the soil. Cropping can remove some zinc annually but, in a 4-5 month growing season, zinc from air-borne emissions will in many places concentrate faster than it can be removed by cropping. Beyond that, extensive areas near smelters are already too toxic for growing agricultural crops. The obvious approach to controlling zinc pollution is to try to contain zinc emissions at their source.

Plants of moist environments appear better adapted to high levels of zinc in surface soils than plants from more xeric habitats. In general, plants from moist environments should be tried first in attempts to revegetate zinc-polluted areas. Those native plant species that currently demonstrate the best rates of survival at a given site should obviously be tried first. It is unfortunate that much of the upland area surrounding smelters may be too dry to support moist-site vegetation.

A second attribute that might be associated with zinc tolerance is salt tolerance. Salt-tolerant plants should be evaluated as possible species to use in reclaiming zinc-polluted areas. Deep rootedness is probably a third desirable characteristic of plants for use in reclamation of zinc-polluted areas.

In appraising the flora available for use in reclamation of land polluted by zinc, one is impressed by the potential range of adaptations and tolerances of prairie plants. Drought and moisture tolerances, deep rootedness, and salt tolerance are all characteristics of prairie flora. Any experimental reclamation should feature prairie plants that appear to possess natural adaptations to particular site conditions.

Extreme erosion of surface soils may constitute a major factor in retarding reestablishment of vegetation in zinc-polluted areas. In geologically "old" soils the basic difficulty is loss of nutrients contained in organic matter in the surface soils that has been removed through erosion. Natural development of vegetation must proceed on the basis of building up nutrient-conserving organic matter in the soil. The problem is how to rebuild soil organic matter rapidly. One obvious experimental approach is to incorporate sewage sludge into the upper 10- to 20-cm soil layer and then seed a variety of what appear to be site-adapted plants selected from our native prairie flora.

It should be recognized that many plants growing in high zinc soils are probably under considerable stress and cannot tolerate much additional stress and disturbance from such factors as grazing or trampling. Man's use of areas subjected to heavy zinc pollution should probably be minimal. A further value of using natural vegetation to reclaim pollution-ravaged areas is the resultant benefit to wildlife where such areas are left relatively undisturbed.

Because of the extreme long-term effects of zinc pollution apparent in the immediate vicinity of smelters, plus the difficulties inherent in reclaiming such areas, a sanitary landfill might be a desirable prereclamation use of a zinc polluted site.

During landfilling, zinc in surface soils would be redistributed at relatively low concentrations through a deep profile. By containing further pollution at the smelter, surface reclamation should proceed at rates near normal for comparable landfill sites. Establishing sanitary landfills at smelter sites would help to minimize the loss of agricultural land to landfills.

Thus, zinc-polluted areas could accommodate several consecutive uses - sanitary landfills, disposal of sewage sludge by soil incorporation, and ultimately the development of wildlife habitat.

Another way to detoxify soil environments high in zinc might be to saturate them with an element of similar valance, such as calcium, by heavy application of agricultural limestone. However, a probable adverse consequence of heavy liming of zinc-degraded soils would be reduced availability of phosphorus to plants. Phosphorus is typically in critical short supply in the soils of south-central Illinois, particularly heavily eroded soil, and could quickly become even more limiting to plant growth after liming unless phosphate fertilizers were also added. Phosphate fertilizers tend to be high in cadmium (Friberg et al. 1971) $\frac{1}{M}$ thus the stage could be set for a second level of toxification. (High levels of cadmium also occur in sewage sludge).

The conservation of zinc in surface soils and zinc-plant relationships observed at Site A represent phenomena that undoubtedly are not peculiar to zinc. Soil organic matter has long been recognized as a reservoir for a wide variety of elements. Research is increasingly demonstrating that heavy metals typically occur at elevated levels in surface soils in association with humic substances, that heavy metals enter and accumulate in plant roots, and that they are subsequently [illegible] into leaves and shoots.

(Friberg et al. 1971, Friberg and Vostal 1972, Allaway and Davies 1971, Bagle and Doss 1967, Rolf and Haney 1975, Alberts et al. 1974, Shocklette 1965, Gish and Christenson 1973, Ruhling and Tyler 1968, Dedolph et al. 1970, Lagerwerff and Specht 1970). These and other studies indicate high levels of heavy metals in soils and plants in the vicinities of mines, smelters, and other point sources. Differential rates of tolerance and accumulation by plants are noted for a variety of heavy metals in the above and other studies.

Because elements such as zinc, cadmium, mercury, and lead behave much the same way in soil-plant systems, one would expect the principles of managing soils for toxic levels of one problem metal to be generally applicable to problem areas where other metals are involved. Experimental approaches suggested here for managing areas polluted by zinc should be applicable to the development of experimental management programs for areas around mines and smelters adversely affected by toxic accumulations of other metals. The general concept of zinc management presented here is potentially suited to managing for a variety of pollutants.

In reviewing the literature covering research on zinc and other heavy metals as environmental pollutants, one is surprised at the relatively little attention that has been paid natural accumulations of problem elements in organic matter, and also with clays, and how such elements are exchanged and concentrated in plants as steps in the cycling of those elements through natural systems. Research on heavy metals in natural systems is particularly appropriate to any decisions as to what normal or safe limits of heavy metals might be. Soil-plant-metal relationships constitute an area of research that warrants considerable attention.

Suggestions on Study Design

The lack of funds to accomplish the objectives desired by this investigator was a primary problem on the vegetative phase of the overall study. Those objectives proved considerably broader than those of Mr. William H. Walker, the original principal investigator for USEPA No. R 8032 16-01-2. Mr. Walker's purpose was to obtain a cover map of the study area that would define and describe the different vegetative and land-use zones.

Although the primary objective of the overall project was to study zinc in relation to groundwater, it was unfortunate that no plant ecologist was consulted during the design phase. The study site offers almost unlimited possibilities for the study of both basic ecological relationships among plants and of the effects of zinc pollution on the development and dynamics of plant communities. The key elements in such studies are chemistry and systems modeling by computer--both are expensive, particularly the large numbers of chemical analyses of soils and plant tissues.

The study site is an exceptional place to obtain real date for the development of systems models. One cannot stress strongly enough the potential value of funding basic ecological research on the vegetation at Site A! More samples are needed $\frac{1}{M}$ for more species, more sites, and more chemical analyses of more potentially significant elements. There is an immediate need for funds to complete the statistical analyses of the available data.

This report deals with analyses of data from pooled samples. It is now clear that in any future work, samples should not be pooled but be discrete with respect to chemical parameters of soil samples taken at the sites of individual plants.

Hypotheses derived from statistical modeling of field data should be tested experimentally under controlled environmental conditions in the laboratory, greenhouse, or environmental chamber.

Although it may be possible to structure ecological studies of the type that can and should be undertaken in the future at Site A in 3-year projects, it should be recognized that the potential for such research is so broad that it should not be attempted in a single 3-year study. Funding agencies should be prepared to think in terms of supporting a series of consecutive projects the nature of which would be dictated, at least in part, by the findings of preceding projects. Agencies should also think in terms of simultaneously supporting several complementary projects. It should also be recognized that research agencies such as the Natural History Survey have very limited financial resources available to support independent research of this type.

Acknowledgments

Pamela Clark and Tim Duez assisted in the collection of soil and vegetative samples at Site A in 1975. Pat O'Brien Mackey helped process the field samples collected in 1975, assisted in chemical analysis, tabulated data, and was responsible for the review of literature on zinc. Sara Stevenson and Joan Macuszek assisted in the preparation of samples, chemical analyses, and data tabulation. Joan Macuszek also assisted in the collection and preparation of samples at Site A in 1976. Larry Farlow[1] photographed vegetation at Site A. Stephen P. Havera[1] and John A. Schleicher[2] were consulted on statistical procedures. Drs. Harold C. Hanson[1] and Robert L. Jones[3] were consulted on the interpretation and significance of findings. Helen C. Schultz[1] and Dr. Glen C. Sanderson[1] read and edited preliminary drafts of this manuscript. Chemical analyses of soil and vegetative samples were under the general supervision of Dr. Arnold M. Hartley[4].

Primary support for the vegetative portion of this study was provided by the Illinois State Natural History Survey, Urbana. Funds amounting to approximately $3,000 provided by USEPA Grant No. R 8032 16-01-2 to the Illinois State Water Survey were used to support Ms. Clark and Mr. Duez during the summer of 1975. Mrs. Mackey and Ms. Macuszek were students at Eastern Illinois University and Ms. Stevenson was a student at Augustana College. These ladies worked at no charge to the project during internships required by their respective schools.

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[1] Illinois State Natural History Survey

[2] Illinois State Geological Survey

[3] University of Illinois, Department of Agronomy

[4] University of Illinois, Institute for Environmental Studies

Table 1. Zinc in ppm in selected animal tissues, fluids, and cellular components.

Tissue	Zn, ppm	Additional Comments	Reference
Kidney (mammalian)	210	Zinc is concentrated in the cortex.	Bowen 1966, Underwood 1971
Muscle (mammalian)	180	In red muscles, zinc is concentrated in myofibrils and the nuclei fraction.	Bowen 1966, Underwood 1971
Hair (mammalian)	170		Bowen 1966
Liver (mammalian)	130		Bowen 1966
Heart (mammalian)	110		Bowen 1966
Lung (mammalian)	62		Bowen 1966
Brain (mammalian)	46		Bowen 1966
Skin (mammalian)	13	More zinc is found in the epidermis than in the dermis.	Bowen 1966, Underwood 1971
Feathers	8-140		Strain & Pories *in* Prasad 196
Blood (crustacean)	6.5		Bowen 1966
Blood (nematode)	9		Bowen 1966
Blood (insect)	11		Bowen 1966
Blood (human)	6.5		Bowen 1966
Plasma	1.6	Zinc is associated with serum albumin and globulins	Bowen 1966, Underwood 1971
Red cells	12.3	Zinc is associated with carbonid anhydrasa. 8.9×10^6 atoms Zn per redblood cell. White blood cells and platelets also contain zinc.	Bowen 1966, Underwood 1971
Nuclei	3-140 (n=3)		Bowen 1966

Table 1.- continued.

Table 1. Continued - page 2.

Nuclear DNA	95 (n=1)		Bowen 1966
Mitochondria	39 (n=1)		Bowen 1966
Milk	3-5	Colostrium contains 3-5 times the amount of zinc as milk.	Bowen 1966, Picciano 1974
Semen (1st fraction)	2930	The zinc content is calculated on a dry weight basis.	Underwood 1971

Table 2. Levels of zinc in upland surface soil samples (#) from control points away from Site A. *

		Degree					Degree		
#	Range	Bearing	Zinc	Direction	#	Range	Bearing	Zinc	Direction
46	6.3km	36	27	NE	85	31km	267	63	W
47	6.8km	36	28	NE	87	37km	266	79	W
48	2.4km	0	160	N	111	2.7km	228	150	SW
49	2.4km	0	200	N	122	5.1km	224	51	SW
33	8.2km	233	69	SW	177	12.5km	296	27	NW
34	3.7km	245	52	SW					

* Range from smelter to sample point in kilometers; bearing from smelter; zinc in ppm.

Table 3. Levels of zinc in samples of alluvial soils receiving surface water drainage from Site A. *

		Degree					Degree		
#	Range	Bearing	Zinc	Direction	#	Range	Bearing	Zinc	Direction
14	85	195	20000	S	110	680	150	15000	SE
16	85	190	31000	S	112	180	72	39000	E
28	460	122	24000	S	113	890	217	9600	SW
33	610	118	7900	S	115	560	226	43000	SW
35	560	233	5500	SW	117	730	157	12000	SE
62	200	52	6500	NE	139	470	232	16000	SW
67	300	49	6400	NE	140	5270	224	1500	SW
69	150	350	66000	NW	144	490	232	59000	SW
71	320	2	10000	N	145	290	108	15000	E
80	270	45	16000	NE	147	560	235	4600	SW
90	2950	227	1900	SW	160	420	238	78000	SW
92	190	60	15000	NE	161	420	275	6100	W
107	1085	210	6500	SW	168	490	228	12000	SW
108	950	217	8300	SW	189	3565	105	2500	SE

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* Range from smelter to sample point in meters; bearing from smelter; zinc in ppm.

Table 4. Some plants common to waste places, old fields, pastures, and rights-of-way in south-central Illinois.

Acalypha rhomboidea

A. virginica

Acer negundo

A. saccharinum

Achillea millefolium

Agrostis alba

A. hyemalis

Allium vineale

Alopecurus carolinianus

Alnus serrulata

Amaranthus hybridus

Ambrosia artemisiifolia

A. bidentata

Amorpha canescens

Andropogon gerardi

A. scoparius

A. virginicus

Apocynum cannabinum

Arctium minus

Aristida dichotoma

A. longespica

Asclepias hirtella

A. incarnata

A. syriaca

A. tuberosa

A. verticillata

Asparagus officinalis

Aster novae-angliae

A. pilosus

Avena fatua

Baptisia leucantha

Bellis perennis

Betula nigra

Bidens spp.

Brassica nigra

Bromus commutatus

B. secalinus

B. tectorum

Campanula americana

Campsis radicans

Capsella bursa-pastoris

Cardamine arenicola

Carex spp.

Carya spp.

Cassia fasciculata

Catalpa bignonioides

Celtis occidentalis

Cephalanthus occidentalis

Chenopodium album

Cicuta maculata

Cirsium arvense

C. vulgare

Claytonia virginica

Commelina communis

Convolvulus arvensis
Cornus florida
C. racemosa
Crataegus spp.
Crotolaria sagittalis
Croton monanthogynus
Crotonopsis elliptica
Cuscuta spp.
Cyperus spp.
Datura stramonium
Daucus carota
Desmodium spp.
Dianthus armeria
Digitaria ischaemum
D. sanguinalis
Diodea teres
Diospyros virginiana
Dodecatheon media
Echinochloa crusgalli
Eleocharis spp.
Epilobium angustifolium
Equisetum arvense
E. Hyemale
Erechtites hieracifolia
Erigeron annuus
E. canadensis
E. strigosus
Eryngium yuccifolium
[illegible]
Euphorbia corollata
Festuca elatior
Fragaria virginiana
Fraxinus lanceolata
Geranium maculatum
Geum canadense
G. vernum
Gleditsia triacanthos
Glycine max
Gnaphalium purpureum
Helianthemum bicknellii
Helianthus grosseserratus
Heliopsis helianthoides
Hordeum jubatum
H. mutilum
H. pusillum
Hypericum drummondii
H. perforatum
Ipomoea hederacea
I. pandurata
Juglans nigra
Juncus tenuis
J. torreyi
Juniperus virginiana
Kuhnia eupatorioides
Lactuca canadensis
L. scariola
Lepidium densiflorum
L. virginicum

Lespedeza capitata
L. cuneata
L. striata
L. stipulacea
Liatris aspera
L. pycnostachya
Lithospermum arvense
L. canescens
Lonicera japonica
Ludwigia alternifolia
Maclura pomifera
Malus spp.
Malva neglecta
Medicago lupulina
M. sativa
Melilotus alba
M. officinalis
Mikania scandens
Mirabilis nyctaginea
Monarda fistulosa
Morus alba
Oenothera biennis
O. pilosella
Oxalis dillenii
O. stricta
Panicum dichotomiflorum
P. huachucae
P. virgatum
Paspalum circulare

Pastinaca sativa
Penstemon spp.
Petalostemum purpureum
Phleum pratense
Phlox pilosa
Phragmites communis
Physalis spp.
Phytolacca americana
Plantago aristata
P. pusilla
P. rugelii
Platanus occidentalis
Poa annua
P. compressa
P. pratensis
Polygala sanguinea
Polygonum aviculare
P. pensylvanica
P. persicaria
Populus alba
P. deltoides
Portulaca oleracea
Potentilla simplex
Prunus spp.
Pycnanthemum flexuosum
Pyrus communis
Quercus spp.
Ranunculus spp.
Ratibida pinnata

Rhus glabra

R. radicans

Rosa carolina

Rosa multiflora

Rubus allegheniensis

R. flagellaris

R. occidentalis

Rudbeckia hirta

Ruellia humilis

Rumex acetosella

R. altissimus

R. crispus

Salix nigra

Sambucus canadensis

Saponaria officinalis

Sassafras albidum

Scirpus spp.

Scutellaria latifolia

Senecio plattensis

Setaria faberi

S. viridis

Silphium lacineatum

S. perfoliatum

S. terebinthinaceum

Sisyrinchium albidum

Smilacina racemosa

Smilax hispidus

Solanum carolinense

[illegible]

S. hirtella

S. juncea

S. media

S. nemoralis

S. rigida

S. ulmifolia

Sonchus aspera

S. oleraceus

Sorghastrum nutans

Sorghum halepense

S. vulgare

Spartina pectinata

Sporobolus heterolepis

Stachys arenicola

Stellaria media

Strophostyles spp.

Symphoricarpos orbiculatus

Taraxacum officinale

Teucrium canadense

Tradescantia subaspera

T. virginica

Tragopogon dubius

Tridens flavus

Trifolium hybridum

T. pratense

T. repens

Tripsacum dactyloides

Triticum aestivum

Typha latifolia

Ulmus americana

U. rubra

Vaccineum arboreum

Verbascum blattaria

V. thapsus

Verbena hastata

Vernonia missurica

Veronica peregrina

Viburnum spp.

*Viola papilonace*a

Vitis cinerea

V. vulpina

Xanthium commune

Yucca filamentosa

Zea mays

Table 5. Ranking of classes of vegetative type and land use with respect to mean levels of zinc, pH, and organic matter in surface soils.*

Land use or Vegetation Class	ppm Zinc	pH	% OM	n
Alluvial Outwash	19,130 (1)	6.07 (1)	7.9 (2)	21
Bare Upland	10,430 (2)	5.13 (6)	5.1 (6)	8
Amaranthus-*Panicum*	5,340 (3)	5.67 (3)	6.9 (3)	30
Amaranthus-*Panicum*-*Agrostis*	2,380 (5)	5.30 (5)	6.3 (4)	25
Tallgrasses	3,030 (4)	5.65 (4)	8.1 (1)	14
Cropland	1,030 (6)	5.94 (2)**	5.6 (5)	30

* Rankings are in parentheses.

** Undoubtedly reflects application of agricultural limestone.

Table 6. Mean and maximum relationships of zinc in tissues and associated soil samples for several common wild and agricultural plants collected in the vicinity of Site A.*

Plant Species	Sample Size	Maximum Zinc Found in Plant Tissues	Maximum Zinc in Associated Soils	$\bar{x}$ Zinc in Plants of Type from Site "A"	$\bar{x}$ Zinc in Soils Associated with Type Plants from Site "A"	Ratio of $\bar{x}$ Zinc in Plants to $\bar{x}$ Zinc in Associated Soils
Wild Plants						
Spartina pectinata (a)	4	540	66000	330	26780	0.012
Amaranthus hybridus (b)	44	22000	59000	9260	6320	1.466
Panicum dichotomiflorum (b)	42	10000	18000	2500	3150	0.794
Agrostis hyemalis (b)	23	4900	3200	4900	1400	2.275
Andropogon virginicus (a)	7	260	15000	159	3300	0.048
" " (b)	7	1000	2200	631	1227	0.515
A. gerardi (a)	4	220	1600	130	1120	0.118
Sorghastrum nutans (a)	5	840	7300	390	4740	0.082
Eupatorium serotinum (a)	6	1700	2200	1270	1310	0.969
Populus deltoides (c)	8	4700	7900	2740	21440	0.128
Agricultural Plants						
Triticum aestivum (d)	7	550	6200	270	2620	0.104
Glycine max (d)	9	220	1900	130	860	0.155
Sorghum vulgare (d)	11	220	800	75	480	0.157

* Zinc in ppm; (a) total plant assayed, (b) aboveground parts assayed, (c) leaves and green twigs assayed, and (d) seed assayed.

Table 7. Levels of zinc in Amaranthus hybridus and associated soil samples (#) from Site A and a nearby control (c).*

#	Tissue	Soil	#	Tissue	Soil	#	Tissue	Soil
1	12000	560	75	14000	5300	143	12000	1200
2	10000	3200	77	4900	7800	144	22000	59000
6	1400	11000	78	20000	2100	146	13000	1600
9	12000	800	79	6500	7800	153	4900	8500
12	9100	1900	81	13000	9100	157	20000	3300
13	13000	12000	82	11000	5500	159	670	1700
16	2000	31000	91	1600	2200	168	700	12000
30	17000	2000	97	1200	22000	170	17000	1400
35	8000	5500	101	3900	1100	180	2700	1300
38	21000	250	104	1900	2100	181	7000	980
54	15000	4000	125	9100	1300	182	1200	600
55	17000	1600	129	16000	1700	184	6800	400
62	3600	6500	130	16000	6200	186	7600	2200
72	4000	6800	141	3000	980	187	14000	1500
73	9500	18000	142	1300	2000	177c	94	27

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* Zinc in ppm.

Table 8. Levels of zinc in the weedy grass <u>Panicum dichotomiflorum</u> and associated soil samples (#) from Site A.*

#	Tissue	Soil	#	Tissue	Soil	#	Tissue	Soil
2	10000	3200	79	2400	7800	129	1600	1700
5	1900	5800	81	1900	9100	141	4300	930
15	2700	2100	82	620	5500	142	2800	2000
19	1600	1100	88	690	1000	149	2300	1300
31	700	1300	93	650	910	154	1900	1200
54	2500	4000	94	380	1600	157	5700	3300
55	1100	1600	95	300	1200	158	3300	3600
62	1500	6500	96	800	900	170	2500	1400
66	3400	2800	99	1000	2200	172	2900	6300
72	4800	6800	101	360	1100	180	7100	1300
73	4200	18000	104	300	2100	181	1700	980
74	3000	1200	109	3500	1400	185	4200	6000
75	4200	5300	119	550	733	186	5500	2200
78	2700	2100	125	1500	1300	187	3800	1500

* Zinc in ppm.

Table 9. Levels of zinc in the weedy grass <u>Agrostis hyemalis</u> and associated soil samples (#) from Site A'.*

#	Tissue	Soil	#	Tissue	Soil
1	2600	560	119	2300	733
2	4600	3200	125	2800	1300
9	2500	800	129	4900	1700
19	3700	1100	143	2800	1200
25	13000	1400	146	2900	1600
30	2600	2000	149	3300	1300
55	4600	1600	154	2000	1200
58	1500	3700	159	3200	1700
83	1500	1000	180	3100	1300
93	1100	910	181	2200	980
94	1200	1600	184	3800	400
96	1000	900			

* Zinc in ppm.

Table 10. Levels of zinc in several common grasses and associated soil samples (#) from Site A and nearby controls (c). *

Species	#	Tissue	Soil	#	Tissue	Soil
Andropogon virginicus	21	120	1400	88	1000**	1000
" "	60	90	1100	93	540**	910
" "	92	100	15000	96	600**	900
" "	131	100	1400	109	320**	1400
" "	146	180	1600	141	730**	980
" "	165	260	1400	143	830**	1200
" "	167	260	1200	186	400**	2200
" "	178c	11	27			
A. gerardi	8	220	1600	11	99	1500
" "	9	100	800	188	110	570
Sorghastrum nutans	23	130	3900	136	840	7300
" "	59	130	7300	177	310	1200
" "	106	530	4000			
Spartina pectinata	16	490	31000	69	540	66000
" "	35	190	5500	147	90	4600
Aristida spp.	58	600	3700			
Festuca elatior	153	2800	8500			

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* Zinc in ppm.

** Assay of total plants--young individuals in first season of development. All other tissue analyses listed in this table are of aboveground parts of plants in second or later year of development.

Table 11. Levels of zinc in several common weedy forbs and associated soil samples (#) from Site A and a nearby control (c). (Zinc in ppm.)

Species	#	Tissue	Soil
Ambrosia artemisiifolia	26	1000	1600
" "	109	1300	1400
" "	127	3100*	1400
Apocynum cannabinum	16	540	31000
" "	72	200	6800
Asparagus officinalis	4	2100	16000
Aster pilosus	109	1200	1400
Cuscuta spp.	81	140	(9100)
Eupatorium serotinum	60	1100	1100
" "	97	1200	1100
" "	103	1200	1100
" "	105	1100	940
" "	114	1300	2200
" "	127	1700	1400
Verbena hastata	26	570	1600
" "	132	300	1200
Trifolium pratense	26_c	720	1600
" "	128	290	1000
" "	177	36	27

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* Including roots. All other analyses in this table are of above-ground plant parts only.

Table 12. Levels of zinc in leaves and twigs of several common woody plant species and associated soil samples (#) from Site A. *

Species	#	Tissue	Soil
Campsis radicans	126	180	4200
Cephalanthus occidentalis	80	210	16000
Populus deltoides	28	2000	24000
" "	33	4700	79000
" "	61	3500	1600
" "	67	2400	6400
" "	92	2300	15000
" "	112	2200	39000
" "	122	3300	4500
" "	142	1500	2000
Quercus palustris	138	190	1600
Salix nigra	18	1300	3100
Sassafras albidum	105	680	940

* Zinc in ppm.

Table 13. Levels of zinc in wheat, soybean, grain sorghum, corn, and associated soil samples (#) from Site A and nearby control areas (c).*

WHEAT			SOYBEANS			SORGHUM			CORN		
#	Grain	Soil	#	Grain	Soil	#	Grain	Soil	#	Grain	Soil
20	86	1200	22	120	1100	36	36	800	182	52	600
89	270	1200	24	135	1000	37	69	280	183	52	1100
100	80	710	29	110	360	38	57	250	177_c	40	27
104	320	2100	32	220	1900	39	38	440			
148	170	3500	41	160	1200	43	220	540			
150	420	3400	42	99	500	44	85	730			
151	550	6200	48	75	160	45	67	450			
33_c	32	69	51	170	1000	49	56	200			
84_c	38	59	53	120	560	50	40	550			
85_c	44	63	46_c	63	28	52	50	310			
87_c	28	79	177_c	64	27	175	110	700			
						47_c	30	28			

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* Zinc in ppm.

Fig. 1. Levels of zinc in samples of surface soils plotted with respect to the smelter at Site A.

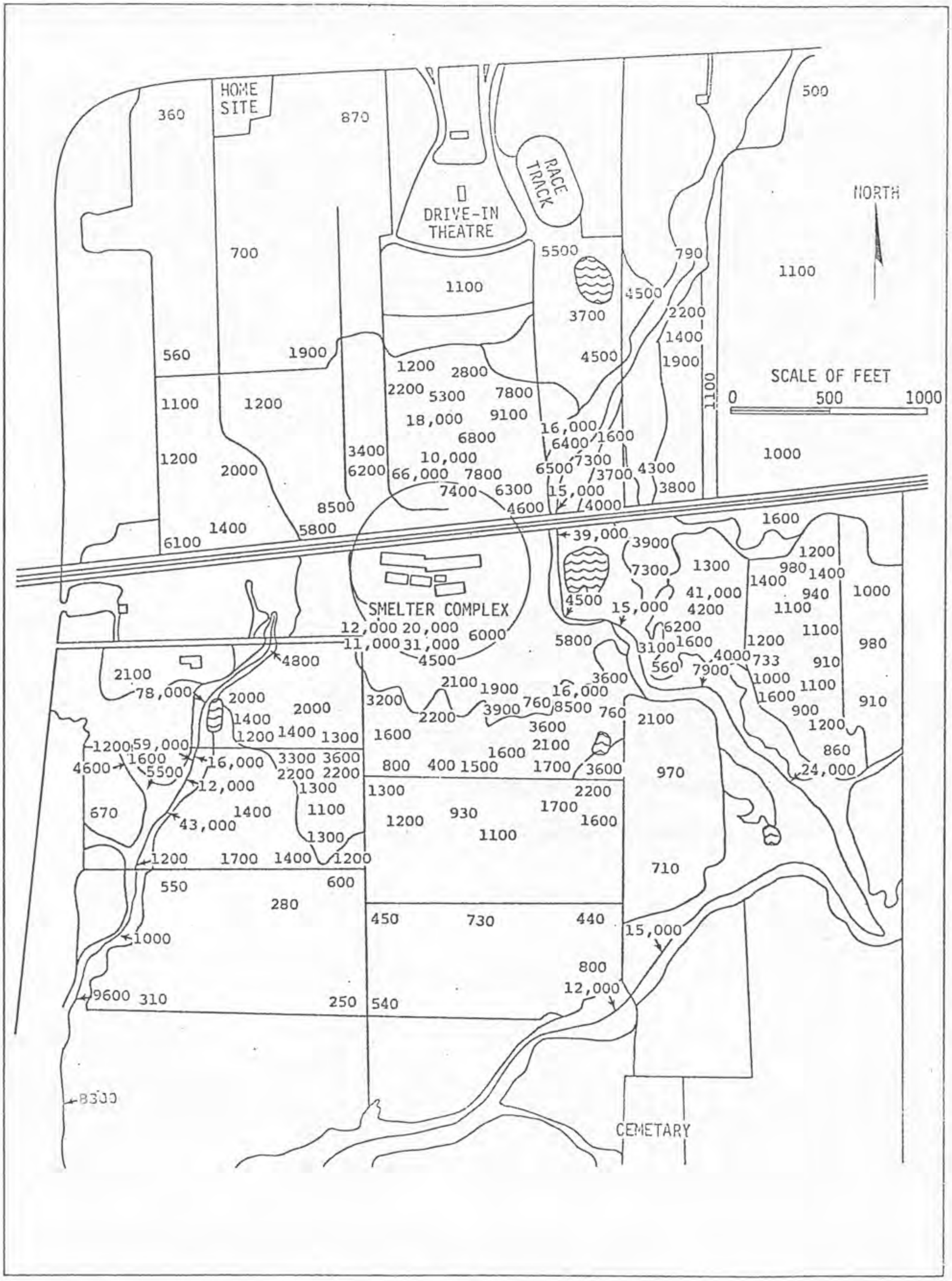

Figure 1. Level of zinc in samples of surface soils plotted with respect to the smelter at Site A.

Fig. 2. Major vegetative zones present on the study area at Site A.

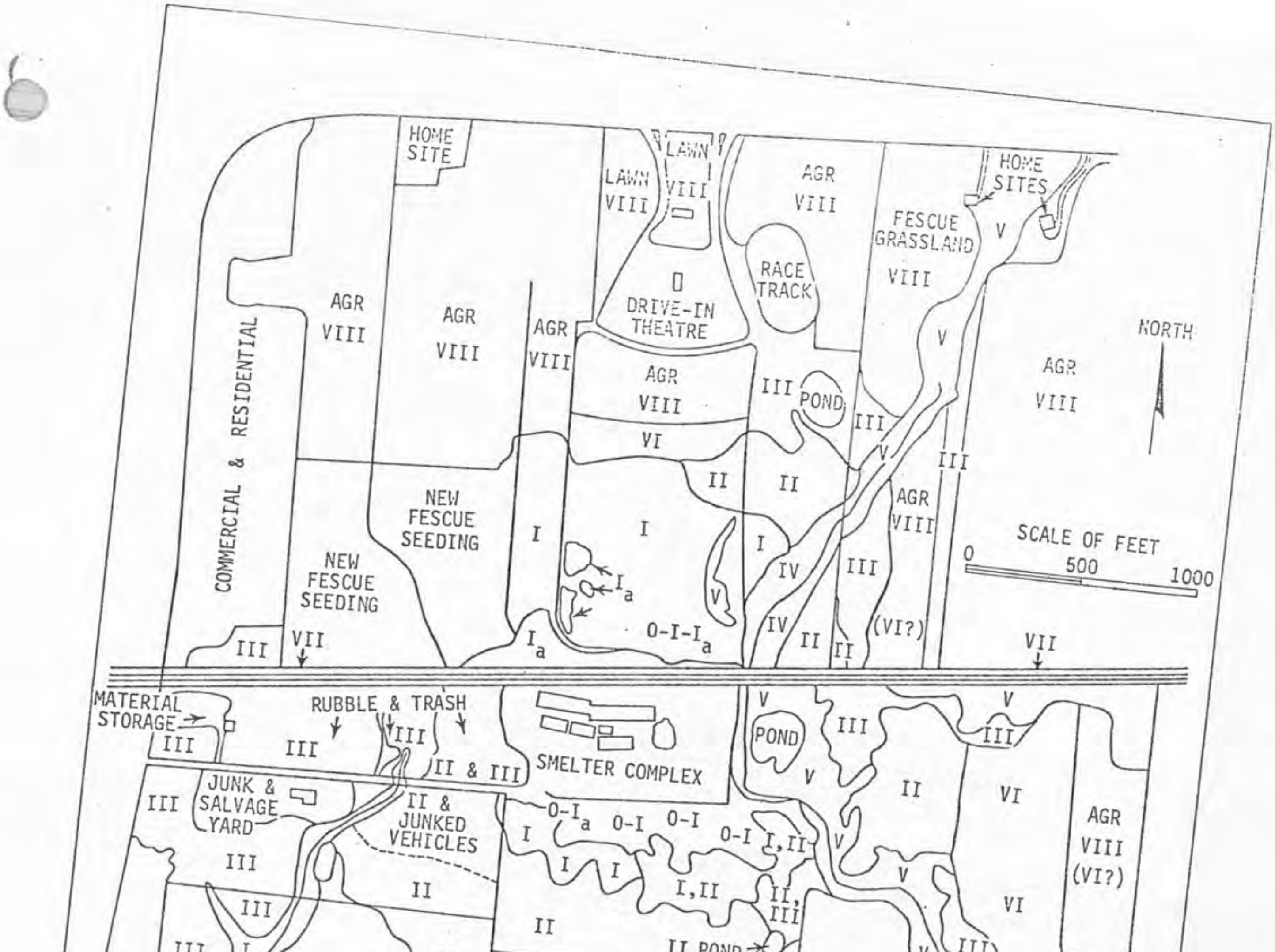

Figure 2. Major vegetative zones present on the study area at Site A.

Fig. 3. Zones O and Ia. Bare area of alluvial outwash with occasional Apocynum cannabinum; Spartina pectinata in background.

Fig. 4 . Zone I. Sparse stand of stunted *Panicum dichotomiflorum*.

Fig. 5 . Zone I. Relatively dense stand of *Panicum dichotomiflorum*.

Fig. 6 . Zone I. Mixed stand of *Amaranthus hybridus* and *Panicum dichotomiflorum* (with a few seed heads from nearby *Agrostis hyemalis*).

Fig. 7 . Zone I. Dense stand of stunted *Amaranthus hybridus*.

Fig. 8 . Zone I. Medium stand of <u>Amaranthus hybridus</u>.

Fig. 9 . Zone II. Mixed stand of stunted Amaranthus hybridus, Panicum dichotomiflorum, and Agrostis hyemalis.

Fig. 10 . Zone II. Mixed stand of *Panicum dichotomiflorum* and *Agrostis hyemalis*.

Fig. 11 . "Hump" dominated by *Asparagus officinalis* with *Sambucus canadensis* and *Amaranthus hybridus*; stressed *Crataegus* spp. and *Malus* spp. in the background.

Fig. 14 . "Hump" dominated by *Baptisia leucantha* with *Panicum dichotomiflorum* and *Amaranthus hybridus*; stressed *Crataegus* spp. and *Malus* spp. in the background.

Fig. 13. Zonation in eroded area around old apple (*Malus* spp.) tree; foreground mixed *Panicum dichotomiflorum* with some *Amaranthus hybridus*; dense *A. hybridus* around tree, taller individuals nearer tree; clump of *Asparagus officinalis* on left side of tree.

Fig. 14. Transition. Zone I in foreground dominated by *Amaranthus hybridus* and *Panicum dichotomiflorum*. Zone II in midground; tall clumps in left center are *Andropogon gerardi* and *Sorghastrum nutans*; light gray area is *Agrostis hyemalis*; dark grass behind the *Agrostis* is *Andropogon virginicus*.

Fig. 15. Zone II. Foreground, dense stand of stunted *Amaranthus hybridus*, *Panicum dichotomiflorum*, *Agrostis hyemalis*, and scattered *Apocynum cannabinum*; clumps of *Andropogon gerardi* in foreground; *A. virginicus* in background.

Fig. 16 . Close-up of tallgrass prairie zone showing interspersion of Amaranthus hybridus.

Fig. 17 . Zone III. *Sorghastrum nutans* and *Andropogon gerardi* grassland.

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APPENDIX C

Appendix C

Field Dispersivity Experiment

By

T. A. Prickett

Illinois State Water Survey

Urbana, Illinois

During the course of study at Site D an 8-inch diameter test well was constructed and a pumping test run to determine the aquifer characteristics. This well and well D-4D provided an excellent opportunity to conduct a field dispersivity experiment. Although not directly applicable to this study, the development of field values of dispersivity is needed to understand the movement of other types of pollutants through the ground.

According to Bear (1972) dispersion and diffussion is an irreversible process in which fluids mix with one another as flow takes place. In addition to inhomogeneity on the microscopic scale, there also may be inhomogeneity on a larger scale due to variations in hydraulic conductivity from one part of the flow regime to the next. This inhomogeneity adds to the dispersion process. Finally, if turbulent flow exits, which it probably does in the vicinity of pumped wells, additional mixing may take place.

Diffusion is the mixing process that takes place on a molecular scale even in the absence of flow. Because molecular diffusion is time dependent, its overall effect in transport processes is significant only at low flow velocities. In cases where high velocities are experienced such as around a pumped well diffusion can be ignored. Therefore, separation of dispersion and diffusion was neglected in the experiment below.

An experiment was conducted to determine the dispersity of the aquifer using chloride enhanced total dissolved mineral (TDM) content as a tracer. As discussed in the text an 8-inch diameter test well (T.W.1) was constructed 8 feet east of D-4D and a controlled pumping test was run to determine aquifer characteristics. Immediately after the recovery portion of the pumping test, one thousand gallons, with TDM of 1,835 mg/l was injected into T.W.1 at an average rate of 83 gpm by gravity drainage from a tank truck. An analysis of a water sample taken during the pumping test indicate that the resident groundwater TDM before injection was 749 mg/l. After injection was completed, well T.W.1 was pumped at the rate of 30 gpm for 90 minutes. During this 90 minute pumping period, water samples were collected at regular intervals for TDM determiniations. The total length of pumping during this process was sufficient to purge all the injected water from the aquifer. A graph of TDM content of the pumped water expressed as a ratio of that of the injected water is given in Figure 1. The TDM content of the pumped water immediately begins to decline from the moment pumping commences. The primary reason the water initially does not come back at the injection concentration is the effects of dispersion.

In the following analysis, all of the above processes which could cause a change in TDM content of the flowing fluid are considered together as one mixing coefficient (dispersivity).

The calculating of a dispersivity coefficient is based on the radially symmetrical flow model developed by Prickett and Lonnquist (1971). This flow model provides head distributions for the injection pumping scheme by applying the hydraulic coefficients and pumped well characteristics calculated from the controlled pump test. By using Darcy's Law, and assuming a porosity of 0.22, this model also provides the velocity distributions for the injection-pumping scheme. Secondly,

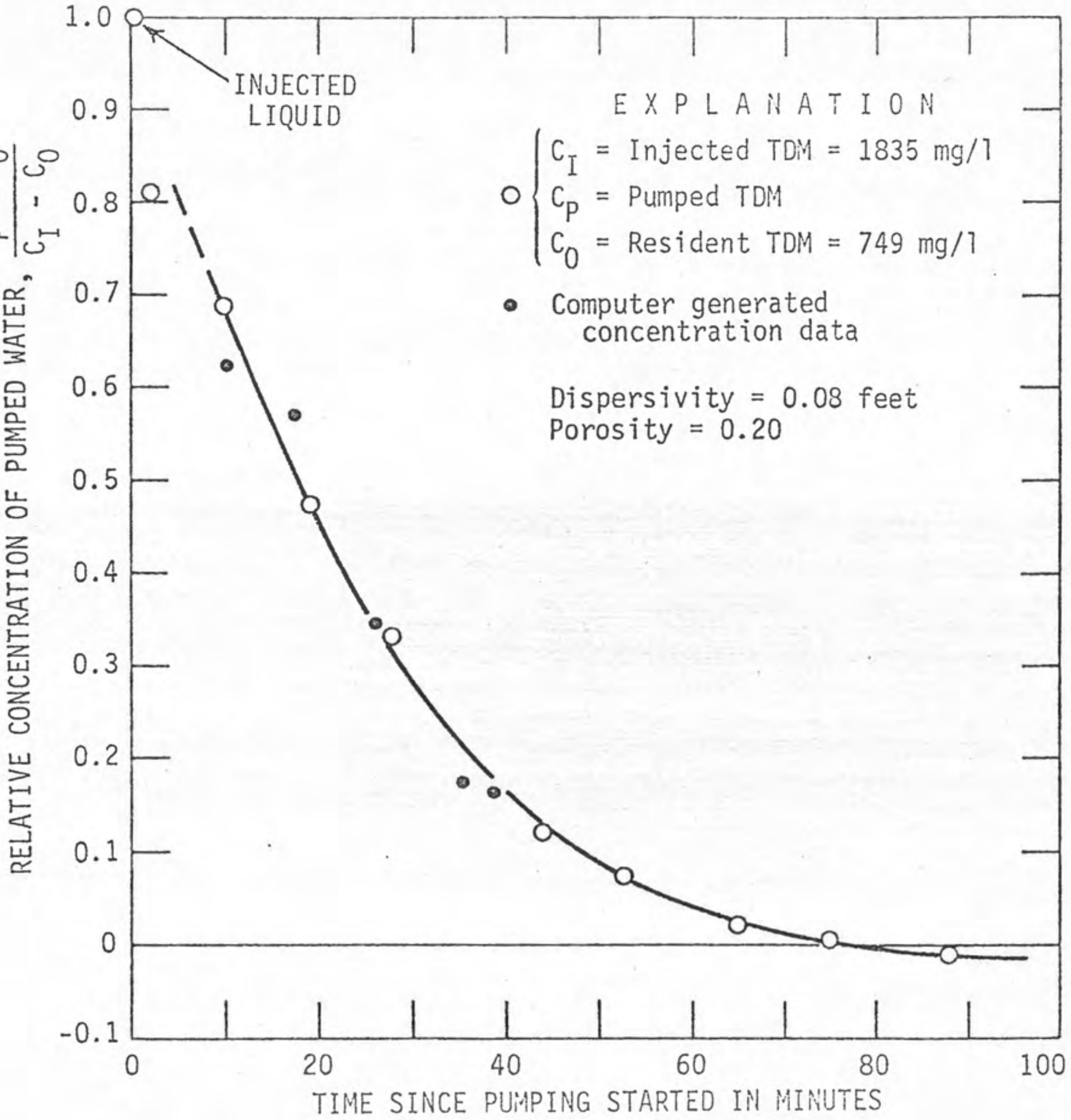

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
RELATIVE CONCENTRATION OF PUMPED WATER, $\frac{C_P - C_0}{C_I - C_0}$
0
20
40
60
80
100
TIME SINCE PUMPING STARTED IN MINUTES
INJECTED LIQUID
EXPLANATION
○ C_I = Injected TDM = 1835 mg/l
C_P = Pumped TDM
C_0 = Resident TDM = 749 mg/l
● Computer generated concentration data
Dispersivity = 0.08 feet
Porosity = 0.20

Figure 1

a random-walk model, developed at the Water Survey, was used in conjunction with this flow model to trace the movement of the injected water as it flows into the aquifer, mixes with the resident groundwater and is pumped out. The random-walk model is a particle tracer wherein computer generated particles are moved from place to place according to the velocity distribution given by the flow model. A random component of velocity is added to the flow model velocity distributions to account for dispersion. The magnitude of these random velocity components is directly proportional to the dispersivity coefficient.

The total scheme using the marker particles is to generate a uniform number of particles entering the injection well during the period of injection, allowing particles to move in response to the flow, and then count the particles as they are then removed from the pumped well in time. The time distribution of the number of particles removed during the pumping part of the test is directly related to the chemical content of the pumped water as shown in Figure The aquifer dispersivity is calculated by adjusting the random velocity components of the model so that the chemical concentration curve from the model matches that developed from the field sampling and analyses.

Figure 1 illustrates the agreement between the computer model and field concentration curves for the pumping part of the test. An aquifer dispersivity of .080 feet was calculated. It should be mentioned here that dispersivity has a directional component depending on the direction of the flow. For instance in two dimensional flow, dispersion is greater in the direction of flow and less perpendicular to the flow. The usual procedure involves calculating two aquifer dispersivities in those two directions. However, since [illegible] was only partially penetrating the aquifer, there three dimensional flow and three dispersivities involved. Adequate information is not available to assess the three dimensional situation involved in this experiment and the calculated dispersivity is a lumped parameter representing the combination of the true three-dimensional situation.

In the course of adjusting the various coefficients in the computer model, it became apparent that the calculated dispersivity coefficient was somewhat sensitive to changes in model coefficients. Assumptions concerning porosity, hydraulic conductivity, injection rate, model generated heads and time-increment discretization effected the calculated dispersivity. Under the conditions of the experimental test, however, the calculated dispersivity is considered adequately defined. However, in future tests of this sort, it is suggested that a fully penetrating well be specified, that positive control be maintained on the injection rate, and that geologic data be available for the total thickness of the aquifer involved.

Bear, Jacob. Dynamics of fluids in porous media. American Elsevier Publishing Co., Inc., New York, New York, 1972. 764 pp.

Prickett, T.A. and C.G. Lonnquist. Selected Digital Computer Techniques For Aquifer Evaluation. Bulletin 55, Illinois State Water Survey, Urbana, Illinois, 1971. 62 pp.

Abbreviations and Symbols

W	moisture content	Cal	calcite
Gs	specific gravity	Dol	dolomite
Gvl	gravel	cts/sec	counts per sec
Sd	sand	Zn	zinc
St	silt	Cd	cadmium
Cl	clay	Cu	copper
DI	diffraction index	Pd	lead
M	montmorillonite	CEC	cation exchange capacity
I	illite	N.D.	not detectable
C-K	Chlorite-Kaolinite		

≋ Soil developed

⁘ Sand

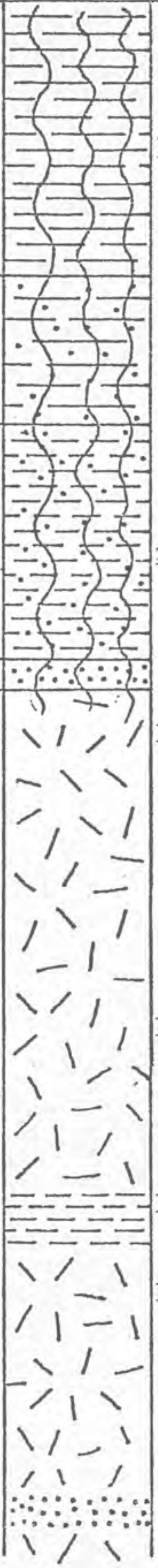
☰ Silt

▤ Clay or accretion gley

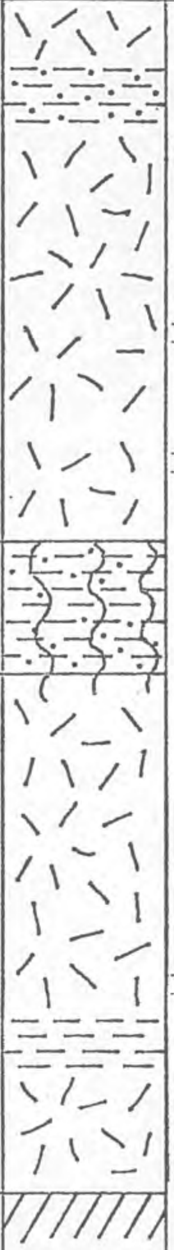
⁙ Till

▨ bedrock

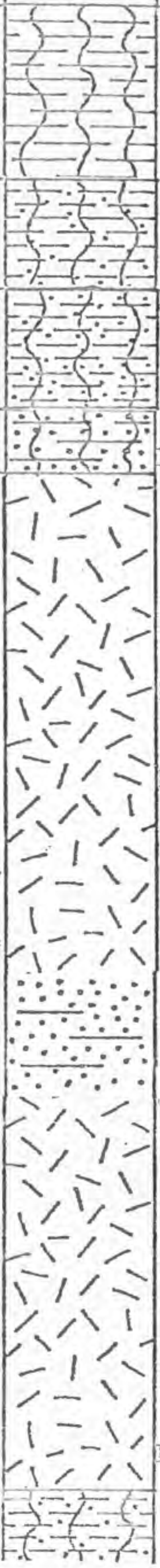
(3-24-73) average percent sand-silt-clay excluding gravel

No.	SITE A S-1 L.S. = 507.08			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0-1.0	PEORIA LOESS (3-58-39)		–	–	–	–	–	–	–	–
2	1.0-2.0			–	–	–	–	–	–	–	–
3	2.0-2.5			–	–	–	–	0	2	63	35
4	2.5-3.0			–	–	–	–	–	–	–	–
5	3.0-3.5			31.8	2.66	.78	93	–	–	–	–
6	3.5-4.0			–	–	–	–	1	4	49	47
7	4.0-4.5			–	–	–	–	1	4	59	37
8	5.0-5.5			–	–	–	–	0	3	60	37
9	5.5-6.0			–	–	–	–	–	–	–	–
10	6.0-6.5	ROXANA SILT (20-49-31)		–	–	–	–	3	34	40	26
11	6.5-7.0			–	–	–	–	–	–	–	–
12	7.0-7.5			–	–	–	–	0	10	55	35
13	7.5-8.0			–	–	–	–	–	–	–	–
14	8.0-8.5			–	–	–	–	0	15	53	32
15	8.5-9.0	BERRY CLAY (28-28-44)		–	–	–	–	–	–	–	–
16	9.0-9.5			–	–	–	–	0	25	29	46
17	9.5-10.0			–	–	–	–	–	–	–	–
18	10.0-10.5			–	–	–	–	1	24	29	47
19	10.5-11.0			25.5	2.66	.69	98	–	–	–	–
20	11.0-11.5			–	–	–	–	1	23	28	49
21	11.5-12.0			–	–	–	–	–	–	–	–
22	12.0-12.5			–	–	–	–	1	40	27	33
23	12.8-13.3	HAGARSTOWN		–	–	–	–	1	51	31	18
24	14.0-14.5	GLASFORD FORMATION TILL (30-41-29)		–	–	–	–	2	34	34	32
25	14.5-15.0			12.3	–	–	–	–	–	–	–
26	15.2-15.7			–	–	–	–	7	36	34	30
27	15.7-16.2			–	–	–	–	5	35	37	28
28	16.2-16.7			–	–	–	–	–	–	–	–
29	16.7-17.2			–	–	–	–	6	35	34	31
30	17.2-17.7			–	–	–	–	–	–	–	–
31	17.7-18.2			–	–	–	–	6	34	36	30
32	18.2-18.7			–	–	–	–	–	–	–	–
33	18.7-19.2			–	–	–	–	16	30	37	33
34	19.2-19.7			–	–	–	–	–	–	–	–
35	19.7-20.2			13.4	–	–	–	–	–	–	–
36	20.5-21.0			–	–	–	–	13	31	38	31
37	21.0-21.5			–	–	–	–	3	23	37	40
38	22.0-22.5			–	–	–	–	3	31	42	27
39	23.2-23.7			–	–	–	–	3	32	38	30
40	24.0-24.5			–	–	–	–	4	31	38	31
41	24.5-25.0			12.3	2.70	.33	126	–	–	–	–
42	25.0-25.5			–	–	–	–	1	14	53	33
43	26.3-26.8			–	–	–	–	4	28	42	30
44	26.8-27.3			12.3	2.70	.33	126	–	–	–	–
45	27.3-27.8			–	–	–	–	1	19	48	33
46	28.3-28.8			–	–	–	–	6	29	40	31
47	29.0-29.5			–	–	–	–	5	29	40	31
48	30.3-30.8			–	–	–	–	3	31	37	32
49	31.3-31.8			–	–	–	–	5	33	37	30
50	31.8-32.3			–	–	–	–	–	–	–	–
51	32.3-32.8			–	–	–	–	7	53	27	20
52	32.8-33.1			–	–	–	–	–	–	–	–

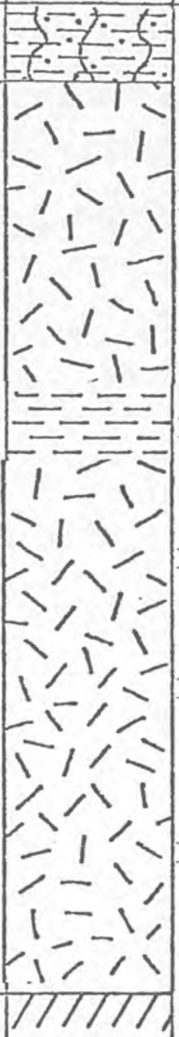
S-1	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	25,000	–	–	16,000	–	–
2	–	–	–	–	–	–	22,000	–	–	93.	–	–
3	1.10	80½	12	7½	N.D.	N.D.	2,300	–	–	16.	–	–
4	–	–	–	–	–	–	2,200	–	–	21.	–	–
5	–	–	–	–	–	–	—	–	–	–	–	–
6	1.75	82½	12½	5	N.D.	N.D.	470	–	–	14.	–	–
7	1.82	88½	8½	3	N.D.	N.D.	—	–	–	–	–	–
8	1.44	92	5½	2½	N.D.	N.D.	94	–	–	16.	–	–
9	–	–	–	–	–	–	42	–	–	12.	–	–
10	1.29	91	6	3	N.D.	N.D.	38	–	–	13.	–	–
11	–	–	–	–	–	–	44	–	–	7.9	–	–
12	1.33	91	6	3	N.D.	N.D.	44	–	–	7.4	–	–
13	–	–	–	–	–	–	57	–	–	10.	–	–
14	1.22	90	6½	3½	N.D.	N.D.	53	–	–	9.8	–	–
15	–	–	–	–	–	–	110	–	–	17.	–	–
16	1.24	89½	7	3½	N.D.	N.D.	55	–	–	9.9	7.4	10.0
17	–	–	–	–	–	–	55	–	–	15.	–	–
18	1.24	88½	7½	4	N.D.	N.D.	84	–	–	16.	–	–
19	–	–	–	–	–	–	—	–	–	–	–	–
20	1.35	86½	9	4½	N.D.	N.D.	53	–	–	12.	–	–
21	–	–	–	–	–	–	62	–	–	9.8	–	–
22	1.42	84	11	5	N.D.	N.D.	240	–	–	14.	–	–
23	1.90	38	45½	16	N.D.	N.D.	220	–	–	8.4	6.0	4.5
24	–	23½	57½	19	10	15	52	–	–	11.	–	–
25	–	–	–	–	–	–	47	–	–	8.9	–	–
26	1.94	26	55	19	25	20	—	–	–	–	–	–
27	2.12	40	45½	14½	36	21	43	–	–	8.3	–	–
28	–	–	–	–	–	–	37	–	–	7.8	–	–
29	2.42	31½	53½	15	24	25	47	–	–	9.8	–	–
30	–	–	–	–	–	–	55	–	–	10.	–	–
31	1.50	24	52½	23½	37	23	64	–	–	9.8	–	–
32	–	–	–	–	–	–	53	–	–	8.8	–	–
33	1.22	21	51	28	27	18	45	–	–	9.3	–	–
34	–	–	–	–	–	–	56	–	–	9.7	–	–
35	–	–	–	–	–	–	42	–	–	8.6	–	–
36	1.21	31	44	24½	32	27	—	–	–	–	–	–
37	.93	75½	14½	10	N.D.	N.D.	—	–	–	–	–	–
38	1.21	53½	30	16½	37	29	—	–	–	–	–	–
39	1.26	42	38	20	40	23	46	–	–	10.	–	–
40	1.07	29	44	27	27	25	—	–	–	–	–	–
41	–	–	–	–	–	–	—	–	–	–	–	–
42	.75	70	16	14	N.D.	N.D.	—	–	–	–	–	–
43	1.17	42½	36½	21	31	37	38	–	–	11.	–	–
44	–	–	–	–	–	–	—	–	–	–	–	–
45	1.00	50	30	20	26	20	—	–	–	–	–	–
46	1.13	40	38	22	23	30	—	–	–	–	–	–
47	1.04	43	34½	22½	24	29	36	–	–	11.	–	–
48	1.21	32	44	24	26	36	—	–	–	–	–	–
49	1.27	9½	59½	31	40	N.D.	48	–	–	11.	–	–
50	–	–	–	–	–	–	46	–	–	11.	–	–
51	–	–	–	–	–	–	28	–	–	7.0	–	–
52	–	–	–	–	–	–	36	–	–	8.4	–	–

No.	SITE A S-1 L.S. = 507.08			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
53	33.1-33.6	GLASFORD FORMATION TILL		–	–	–	–	3	34	37	29
54	34.1-34.6			–	–	–	–	0	19	42	39
55	35.1-35.6			–	–	–	–	0	19	35	46
56	36.1-36.6			–	–	–	–	0	18	38	44
57	37.0-37.5			–	–	–	–	3	20	46	34
58	38.0-38.5			–	–	–	–	5	27	47	26
59	39.0-39.5			–	–	–	–	7	27	45	28
60	39.5-40.0			–	–	–	–	–	–	–	–
61	40.0-40.5			–	–	–	–	2	26	48	26
62	41.0-41.5			12.8	2.70	.39	121	–	–	–	–
63	42.3-42.8			–	–	–	–	2	24	46	30
64	43.3-43.8			–	–	–	–	1	27	47	26
65	44.3-44.8			–	–	–	–	1	19	55	26
66	45.5-46.0			15.5	2.70	.39	121	–	–	–	–
67	46.0-46.3			–	–	–	–	–	–	–	–
68	46.3-46.8			–	–	–	–	4	28	58	14
69	48.1-48.6	LIERLE CLAY (21-40-39)		–	–	–	–	5	28	47	25
70	48.6-49.1			–	–	–	–	2	27	45	34
71	49.1-49.6			–	–	–	–	1	20	36	44
72	50.1-50.6			–	–	–	–	–	–	–	–
73	51.2-51.7	BANNER FORMATION TILL (27-43-30)		–	–	–	–	2	28	34	38
74	52.2-52.7			–	–	–	–	4	29	41	30
75	53.2-53.7			–	–	–	–	4	29	40	31
76	54.2-54.7			–	–	–	–	3	29	43	28
77	54.7-55.2			–	–	–	–	–	–	–	–
78	55.2-55.7			–	–	–	–	14	28	46	26
79	56.2-56.7			–	–	–	–	5	31	47	22
80	56.7-57.2			–	–	–	–	–	–	–	–
81	57.2-57.7			–	–	–	–	5	29	46	25
82	58.0-58.5			18.0	2.70	.49	113	10	36	41	23
83	58.5-59.0			–	–	–	–	–	–	–	–
84	59.0-59.5			–	–	–	–	0	6	37	57
85	59.5-60.0			–	–	–	–	4	32	35	33
86	61.7-62.2			–	–	–	–	2	22	41	37
87	62.2-62.7			–	–	–	–	8	21	44	35
88	62.9-63.4			–	–	–	–	2	21	45	34
89	66.0	BEDROCK		–	–	–	–	–	–	–	–

S-1	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
53	1.25	41	38½	20½	17	22	40	–	–	11.	–	–
54	.85	75½	13½	11	N.D.	N.D.	–	–	–	–	–	–
55	.86	82½	10	7½	N.D.	N.D.	–	–	–	–	–	–
56	.71	80	10½	9½	N.D.	N.D.	20	–	–	18.	–	–
57	.91	64½	20½	15	18	19	–	–	–	–	–	–
58	.99	45½	32½	22	11	31	–	–	–	–	–	–
59	1.16	50½	31½	18	12	30	–	–	–	–	–	–
60	–	–	–	–	–	–	46	–	–	17.	–	–
61	.96	48½	30½	21	16	24	–	–	–	–	–	–
62	–	–	–	–	–	–	–	–	–	–	–	–
63	.98	35	39	26	10	21	42	–	–	14.	–	–
64	.93	56½	25½	18	N.D.	N.D.	–	–	–	–	–	–
65	.94	72½	16	11½	N.D.	N.D.	–	–	–	–	–	–
66	–	–	–	–	–	–	–	–	–	–	–	–
67	–	–	–	–	–	–	34	–	–	14.	–	–
68	1.19	40	38½	21½	24	N.D.	34	.12	–	11.		
69	1.27	39½	39½	21	18	25	34	.20	–	13.	–	–
70	.99	61½	23	15½	N.D.	24	–	–	–	–	–	–
71	.90	81	11	8	N.D.	N.D.	24	.20	–	24.	–	–
72	–	–	–	–	–	–	24	.20	–	16.	–	–
73	1.37	21	53	26	20	20	62	.20	–	15.	–	–
74	1.47	18	56	26	46	21	–	–	–	–	–	–
75	1.56	16	59	25	44	19	58	.10	–	12.	–	–
76	1.46	18	56½	25½	51	20	54	.20	–	11.	–	–
77	–	–	–	–	–	–	52	.22	–	11.	–	–
78	1.62	12½	62	25½	43	13	50	–	–	12.	–	–
79	1.43	6	64	30	62	22	44	–	–	11.	–	–
80	–	–	–	–	–	–	33	.20	–	7.4	–	–
81	1.38	13½	58½	28	61	22	–	–	–	–	–	–
82	1.42	14½	58½	27½	24	10	–	–	–	–	–	–
83	–	–	–	–	–	–	64	–	–	15.	–	–
84	1.60	10	63½	26½	76	19	70	–	–	10.	–	–
85	1.63	8	65½	26½	84	31	20	–	–	3.	–	–
86	1.07	14	53	33	37	20	58	–	–	13.	–	–
87	1.06	11½	54½	34	43	19	–	–	–	–	–	–
88	.98	12½	52	35½	30	19	32	–	–	7.	–	–
89	.50	3	41½	55½	17	13	130	–	–	30.	–	–

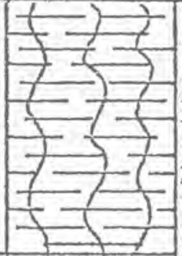
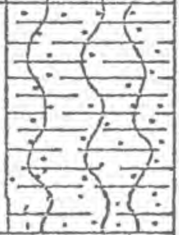
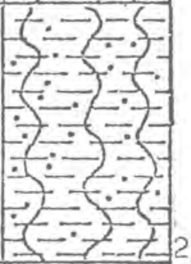
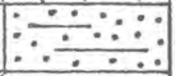
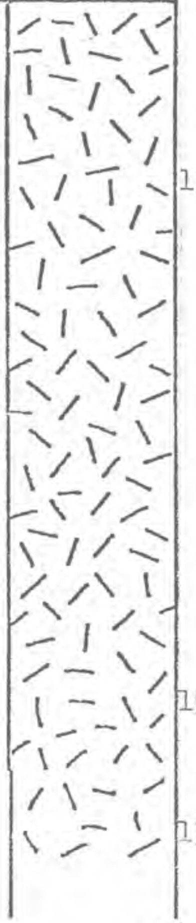
	SITE A S-3 L.S. = 505.60			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (4-58-38)		–	–	–	–	–	–	–	–
2	1.4-1.7			–	–	–	–	–	–	–	–
3	1.7-2.2			–	–	–	–	0	3	55	42
4	2.2-2.7			–	–	–	–	–	–	–	–
5	2.7-3.2			–	–	–	–	0	4	61	35
6	3.7-4.2	ROXANA SILT (12-57-31)		–	–	–	–	3	11	59	30
7	4.3-4.8			–	–	–	–	–	–	–	–
8	4.8-5.3			–	–	–	–	1	12	56	32
9	5.3-5.9			–	–	–	–	1	8	57	35
10	6.4-6.9	BERRY CLAY (34-33-33)		–	–	–	–	2	26	40	34
11	7.7-8.2			–	–	–	–	2	39	30	31
12	8.7-9.2			–	–	–	–	1	41	29	30
13	10.0-10.6			–	–	–	–	1	36	29	35
14	10.6-11.1	HAGARSTOWN		–	–	–	–	2	44	30	26
15	11.1-11.6			18.2	2.70	.47	114	–	–	–	–
16	11.6-12.1	GLASFORD FORMATION TILL (30-40-30)		–	–	–	–	3	33	35	32
17	12.6-13.1			–	–	–	–	3	31	37	32
18	13.6-14.1			–	–	–	–	3	31	38	31
19	14.6-15.1			–	–	–	–	5	33	37	30
20	15.1-15.6			–	–	–	–	–	–	–	–
21	15.6-16.1			–	–	–	–	4	33	36	31
22	16.5-17.0			–	–	–	–	5	33	37	30
23	17.5-18.0			12.4	2.70*	.33	127	–	–	–	–
24	18.5-19.0			–	–	–	–	4	32	38	30
25	19.6-20.1			–	–	–	–	5	30	37	33
26	21.0-21.5			13.4	2.70*	.35	125	–	–	–	–
27	21.5-22.0			–	–	–	–	4	32	36	32
28	23.7-24.2			–	–	–	–	6	32	36	32
29	24.7-25.2			–	–	–	–	4	33	37	30
30	25.2-25.7			–	–	–	–	–	–	–	–
31	26.0-26.5			–	–	–	–	4	33	40	27
32	28.7-29.2			–	–	–	–	3	30	40	30
33	29.7-30.2			–	–	–	–	6	55	25	20
34	30.2-30.7			–	–	–	–	3	63	19	18
35	30.7-31.2			–	–	–	–	1	72	14	15
36	32.3-33.1			–	–	–	–	3	55	28	17
37	33.7-34.2			–	–	–	–	5	32	38	30
38	34.2-34.8			–	–	–	–	–	–	–	–
39	34.8-35.3			–	–	–	–	3	30	42	28
40	35.4-35.9			–	–	–	–	3	32	39	29
41	36.0-36.5			9.6	2.70*	.28	131	–	–	–	–
42	36.7-37.2			–	–	–	–	3	26	40	34
43	37.7-38.2			–	–	–	–	7	33	39	28
44	38.7-39.2			–	–	–	–	3	34	39	27
45	39.7-40.2			–	–	–	–	3	30	45	25
46	40.7-41.2			–	–	–	–	2	22	50	28
47	41.7-42.2			–	–	–	–	2	20	54	26
48	42.7-43.2			–	–	–	–	4	32	40	28
49	43.5-44.0			11.3	2.70*	.33	127	–	–	–	–
50	44.2-44.7			–	–	–	–	2	22	46	32
51	44.7-45.2	LIERLE CLAY		–	–	–	–	5	33	39	28

S-3|	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	15,000	–	–	–	–	–
2	–	–	–	–	–	–	2,800	8.0	71.	250.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	2,700	–	–	–	–	–
5	1.5	86	10	4	N.D.	N.D.	–	–	–	–	–	–
6	0.7	88	6	6	N.D.	N.D.	–	–	–	–	–	–
7	–	–	–	–	N.D.	N.D.	1,700	4.8	27.	23.	–	–
8	0.9	93	4	3	N.D.	N.D.	1,200	–	–	–	–	–
9	1.6	86	10	4	N.D.	N.D.	1,200	3.6	21.	20.	–	–
10	1.2	86	9	5	N.D.	N.D.	580	–	–	–	–	–
11	0.9	79	12	9	N.D.	N.D.	324	–	–	–	–	–
12	0.8	65	19	16	N.D.	N.D.	490	–	–	–	–	–
13	0.8	78	12	10	N.D.	N.D.	620	0.8	27.	22.	–	–
14	1.9	29	52	19	N.D.	N.D.	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	2.1	25	57	18	11	22	600	–	–	–	–	–
17	2.0	30	52	18	13	29	410	2.3	34.	24.	–	–
18	1.9	28	53	19	15	35	–	–	–	–	–	–
19	1.2	27	47	26	29	22	–	–	–	–	–	–
20	–	–	–	–	–	–	37.	.12	28.	23.	–	–
21	1.2	22	49	29	20	34	–	–	–	–	–	–
22	1.2	23	49	28	34	29	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	1.1	25	46	29	31	21	–	–	–	–	–	–
25	1.1	18	50	32	30	25	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	1.2	19	51	30	36	30	–	–	–	–	–	–
28	1.1	19	50	31	36	25	–	–	–	–	–	–
29	1.1	23	47	30	42	20	–	–	–	–	–	–
30	–	–	–	–	–	–	40	–	–	–	–	–
31	1.2	27	47	26	34	24	–	–	–	–	–	–
32	1.0	38	37	25	22	14	–	–	–	–	–	–
33	0.9	33	39	28	30	32	–	–	–	–	–	–
34	1.2	30	45	25	31	24	–	–	–	–	–	–
35	1.4	28	48	24	28	24	–	–	–	–	–	–
36	1.3	27	48	25	30	31	26.	–	–	–	–	–
37	1.3	20	53	27	21	22	–	–	–	–	–	–
38	–	–	–	–	–	–	27.	–	–	–	–	–
39	1.1	24	48	28	21	22	–	–	–	–	–	–
40	1.2	26	48	26	24	31	–	–	–	–	–	–
41	–	–	–	–	–	–	33.	–	–	–	–	–
42	1.0	12	53	35	24	N.D.	–	–	–	–	–	–
43	1.1	28	45	27	23	23	–	–	–	–	–	–
44	1.4	29	48	23	30	16	17.	–	–	–	–	–
45	1.4	30	47	23	22	26	–	–	–	–	–	–
46	1.1	28	45	27	17	23	–	–	–	–	–	–
47	1.1	25	47	28	29	26	48.	–	–	–	–	–
48	1.2	31	44	25	32	21	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–
50	1.1	45	34	21	27	26	–	–	–	–	–	–
51	1.4	13	59	28	35	21	–	–	–	–	–	–

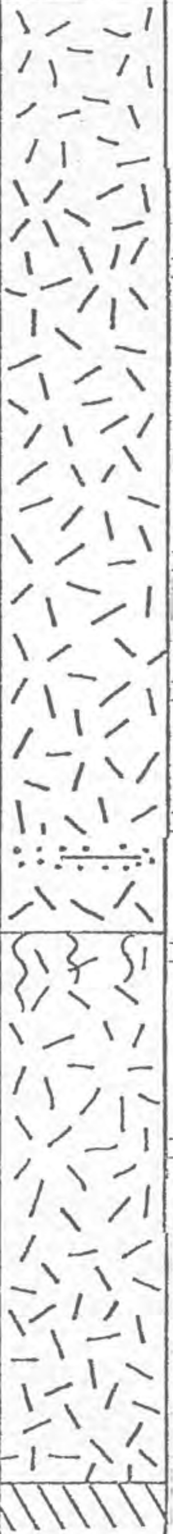
	SITE A S-3 L.S. = 505.60			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
52	45.7-46.2	LIERLE CLAY		–	–	–	–	2	17	52	31
53	46.2-46.7			17.9	2.70*	.52	111	–	–	–	–
54	46.7-47.2	BANNER FORMATION TILL (24-45-31)		–	–	–	–	1	19	39	42
55	47.7-48.2			–	–	–	–	1	25	47	28
56	49.7-50.2			–	–	–	–	5	28	42	30
57	50.5-50.9			11.7	2.70*	.33	127	–	–	–	–
58	50.9-51.4			–	–	–	–	9	30	41	29
59	51.7-52.2			–	–	–	–	5	28	41	31
60	52.7-53.2			–	–	–	–	4	29	43	28
61	53.7-54.2			–	–	–	–	3	28	46	26
62	54.7-55.2			–	–	–	–	4	31	44	25
63	55.7-56.2			–	–	–	–	1	5	68	27
64	56.7-57.2			14.2	2.70*	.35	125	–	–	–	–
65	57.7-58.2			–	–	–	–	7	21	45	34
66	58.7-59.2			–	–	–	–	3	21	47	32
67	59.2-59.7			–	–	–	–	–	–	–	–
68	59.7-60.2			13.7	2.70*	.39	122	–	–	–	–
69	60.7-61.2			–	–	–	–	2	22	44	34
70	61.7-62.2			–	–	–	–	3	21	45	34
71	62.7-63.3			–	–	–	–	5	21	45	34
72	63.3-63.8			14.4	2.70*	.35	125	–	–	–	–
73	63.8-64.3			–	–	–	–	2	20	48	32
74	64.8-65.3			–	–	–	–	2	22	44	34
75	65.8-66.3			–	–	–	–	3	21	44	35
76	66.5-67.0			–	–	–	–	3	19	45	36
77	67.0-67.5			14.8	2.70*	.37	123	–	–	–	–
78	67.7-68.2			–	–	–	–	2	19	55	26
79	68.6-69.1			–	–	–	–	14	17	47	36
80	69.7-70.2			–	–	–	–	4	18	56	26
81	73.1-73.6			–	–	–	–	–	–	–	–
82	73.6-74.0	BEDROCK		–	–	–	–	–	–	–	–

*Estimate

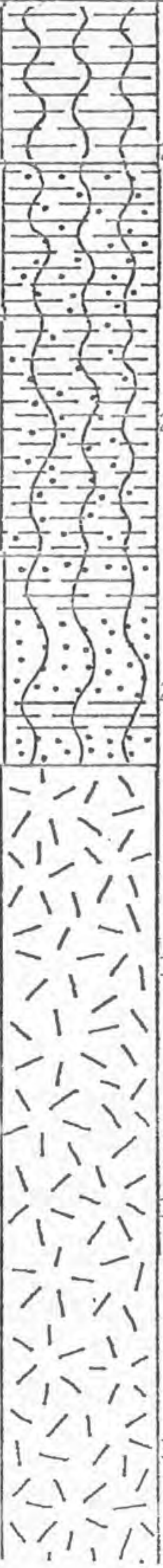
S-31	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
52	0.9	45	32	23	14	10	–	–	–	–	–	–
53	–	–	–	–	–	–	–	–	–	–	–	–
54	1.4	21	53	26	N.D.	N.D.	–	–	–	–	–	–
55	1.5	28	50	22	N.D.	N.D.	–	–	–	–	–	–
56	1.4	14	58	38	61	–	–	–	–	–	–	–
57	–	–	–	–	–	–	–	–	–	–	–	–
58	–	–	–	–	47	–	–	–	–	–	–	–
59	–	–	–	–	47	–	–	–	–	–	–	–
60	–	–	–	–	52	–	–	–	–	–	–	–
61	–	–	–	–	52	–	–	–	–	–	–	–
62	–	–	–	–	55	–	–	–	–	–	–	–
63	–	–	–	–	20	–	–	–	–	–	–	–
64	–	–	–	–	–	–	–	–	–	–	–	–
65	–	–	–	–	33	–	–	–	–	–	–	–
66	–	–	–	–	36	–	–	–	–	–	–	–
67	–	–	–	–	–	–	59.	–	–	–	–	–
68	–	–	–	–	–	–	–	–	–	–	–	–
69	–	–	–	–	–	–	–	–	–	–	–	–
70	–	–	–	–	–	–	–	–	–	–	–	–
71	–	–	–	–	–	–	57.	–	–	–	–	–
72	–	–	–	–	–	–	–	–	–	–	–	–
73	1.4	17	56	27	28	19	–	–	–	–	–	–
74	–	–	–	–	–	–	–	–	–	–	–	–
75	1.4	20	54	26	30	15	–	–	–	–	–	–
76	1.0	10	53	37	N.D.	N.D.	–	–	–	–	–	–
77	–	–	–	–	–	–	–	–	–	–	–	–
78	1.0	14	52	34	30	22	–	–	–	–	–	–
79	0.9	11	52	37	18	15	45.	–	–	–	–	–
80	1.0	15	51	34	20	16	–	–	–	–	–	–
81	0.8	8	50	42	N.D.	20	–	–	–	–	–	–
82	0.5	3	43	54	N.D.	N.D.	–	–	–	–	–	–

No.	SITE A S-4 L.S. = 506.87			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0-0.5	PEORIA LOESS (5-61-34)		–	–	–	–	0	6	71	23
2	0.5-1.0			–	–	–	–	1	7	71	22
3	1.5-2.0			34.9	–	–	–	0	3	55	42
4	2.0-2.5			–	–	–	–	0	2	50	48
5	3.5-4.0			28.3	–	–	–	1	1	54	45
6	4.0-4.5			–	–	–	–	0	9	64	27
7	4.5-5.0			–	–	–	–	0	10	64	26
8	5.5-6.0	ROXANA SILT (28-43-29)		–	–	–	–	0	17	58	25
9	6.0-6.5			–	–	–	–	1	17	57	26
10	6.5-7.0			–	–	–	–	1	15	57	28
11	7.0-7.5			–	–	–	–	0	35	34	31
12	8.5-9.0			–	–	–	–	0	41	22	37
13	9.0-9.5			–	–	–	–	1	39	27	34
14	9.5-10.0			–	–	–	–	0	32	34	34
15	10.0-10.5	BERRY CLAY (32-40-28)		–	–	–	–	2	31	37	32
16	10.5-11.0			–	–	–	–	1	32	35	33
17	11.0-11.5			–	–	–	–	6	35	46	19
18	11.5-12.0			–	–	–	–	2	33	34	33
19	12.0-12.5			–	–	–	–	3	30	45	25
20	12.5-13.0			–	–	–	–	1	31	40	29
21	13.0-13.5			–	–	–	–	2	31	59	10
22	13.5-14.0			23.7	–	–	–	1	32	35	33
23	14.0-14.5	HAGARSTOWN		–	–	–	–	6	9	56	25
24	15.0-15.5			–	–	–	–	9	25	53	22
25	15.5-16.0	GLASFORD FORMATION TILL (32-42-26)		–	–	–	–	3	25	53	22
26	16.0-16.5			–	–	–	–	5	34	38	28
27	18.0-18.5			–	–	–	–	5	31	41	28
28	18.5-19.0			–	–	–	–	3	33	39	28
29	19.0-19.5			–	–	–	–	6	43	34	23
30	20.5-21.0			13.0	–	–	–	3	34	38	28
31	21.5-22.0			–	–	–	–	3	40	32	28
32	22.0-22.5			–	–	–	–	3	38	34	28
33	22.5-23.0			–	–	–	–	4	60	13	27
34	24.0-24.5			–	–	–	–	4	33	40	27
35	24.5-25.0			–	–	–	–	5	29	42	29
36	25.0-25.5			–	–	–	–	9	29	45	26
37	25.5-26.0			–	–	–	–	7	29	43	28
38	26.0-26.5			–	–	–	–	5	32	43	25
39	26.5-27.0			–	–	–	–	2	29	44	27
40	27.0-27.5			–	–	–	–	6	33	44	23
41	28.0-28.5			–	–	–	–	3	35	39	26
42	28.5-29.0			–	–	–	–	6	31	44	25
43	29.0-29.5			–	–	–	–	5	29	42	29
44	29.5-30.0			–	–	–	–	4	27	44	29
45	30.0-30.5			–	–	–	–	4	34	39	27
46	30.5-31.0			15.7	–	–	–	7	30	45	25
47	31.0-31.5			–	–	–	–	5	30	45	25
48	32.5-33.0			–	–	–	–	5	32	43	25
49	33.0-33.5			–	–	–	–	3	32	42	26
50	33.5-34.0			13.8	–	–	–	6	32	40	28
51	34.0-34.5			–	–	–	–	4	37	39	24

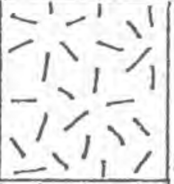
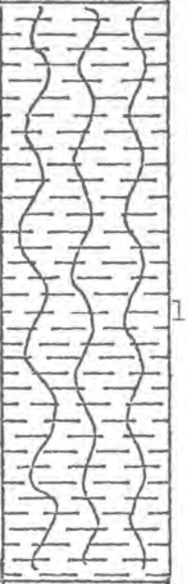
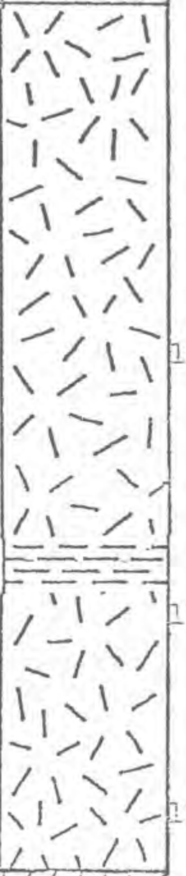
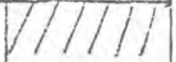
S-4	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	270.	.46	5.2	18.	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	40.	.36	12.	11.	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	27.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	13.	<.12	9.8	9.7	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	10.	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	46.	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	53.	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	43.	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–
42	–	–	–	–	–	–	–	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	–	–	–	–	–	–	–	–	–	–	–	–
46	–	–	–	–	–	–	–	–	–	–	–	–
47	–	–	–	–	–	–	–	–	–	–	–	–
48	–	–	–	–	–	–	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–
50	–	–	–	–	–	–	–	–	–	–	–	–
51	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A S-4 L.S. = 506.87			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
52	35.5-36.0	GLASFORD FORMATION TILL		–	–	–	–	5	32	41	27
53	36.0-36.5			–	–	–	–	8	31	42	27
54	36.5-37.0			–	–	–	–	3	32	42	26
55	37.0-37.5			–	–	–	–	3	32	43	25
56	37.5-38.0			–	–	–	–	5	31	42	27
57	38.0-38.5			–	–	–	–	5	32	41	27
58	38.5-39.0			–	–	–	–	3	32	43	25
59	40.0-40.5			14.7	–	–	–	4	32	42	26
60	40.5-41.0			–	–	–	–	5	31	43	26
61	41.0-41.5			–	–	–	–	11	31	41	28
62	41.5-42.0			–	–	–	–	3	33	41	26
63	42.0-42.5			–	–	–	–	3	32	40	28
64	42.5-43.0			–	–	–	–	5	32	41	27
65	43.0-43.5			–	–	–	–	2	30	45	25
66	43.7-44.0			–	–	–	–	2	32	40	28
67	44.0-44.5			–	–	–	–	5	31	42	27
68	44.5-45.0			12.6	–	–	–	4	32	40	28
69	45.0-45.5			–	–	–	–	5	31	42	27
70	47.0-47.5			–	–	–	–	3	32	40	28
71	51.0-51.5			–	–	–	–	4	31	42	27
72	51.5-52.0			13.2	–	–	–	6	31	41	28
73	52.0-52.5			–	–	–	–	6	33	40	27
74	53.5-54.0			–	–	–	–	4	30	42	28
75	54.0-54.5			–	–	–	–	3	30	44	26
76	54.5-55.0			14.2	–	–	–	2	29	42	29
77	56.0-56.6			–	–	–	–	3	38	41	21
78	57.5-58.0			–	–	–	–	6	36	39	25
79	58.0-58.5			–	–	–	–	6	33	40	27
80	58.5-59.0	BANNER FORMATION TILL (20-45-33)		18.0	–	–	–	1	16	55	29
81	59.0-59.5			–	–	–	–	2	20	52	28
82	59.5-60.0			–	–	–	–	1	17	55	28
83	60.5-61.0			–	–	–	–	1	11	61	28
84	61.0-61.5			–	–	–	–	2	27	41	32
85	61.5-62.0			–	–	–	–	2	24	45	31
86	63.0-63.5			13.9	–	–	–	3	21	44	35
87	63.5-64.0			–	–	–	–	3	22	45	33
88	64.0-64.5			–	–	–	–	3	21	45	34
89	64.5-65.0			–	–	–	–	2	22	46	32
90	65.0-65.5			–	–	–	–	3	22	44	34
91	65.5-66.0			–	–	–	–	2	22	46	32
92	66.0-66.5			–	–	–	–	3	21	45	34
93	66.5-67.0			–	–	–	–	1	21	45	34
94	67.0-67.5			–	–	–	–	5	20	48	32
95	67.5-68.0			–	–	–	–	2	19	51	30
96	68.0-68.5			–	–	–	–	4	19	48	33
		BEDROCK									

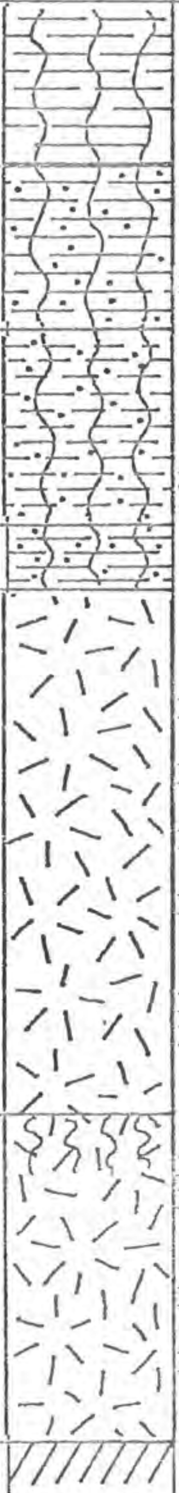
S-4	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
52	–	–	–	–	–	–	–	–	–	–	–	–
53	–	–	–	–	–	–	–	–	–	–	–	–
54	–	–	–	–	–	–	–	–	–	–	–	–
55	–	–	–	–	–	–	–	–	–	–	–	–
56	–	–	–	–	–	–	–	–	–	–	–	–
57	–	–	–	–	–	–	–	–	–	–	–	–
58	–	–	–	–	–	–	–	–	–	–	–	–
59	–	–	–	–	–	–	–	–	–	–	–	–
60	–	–	–	–	–	–	–	–	–	–	–	–
61	–	–	–	–	–	–	–	–	–	–	–	–
62	–	–	–	–	–	–	–	–	–	–	–	–
63	–	–	–	–	–	–	–	–	–	–	–	–
64	–	–	–	–	–	–	–	–	–	–	–	–
65	–	–	–	–	–	–	–	–	–	–	–	–
66	–	–	–	–	–	–	–	–	–	–	–	–
67	–	–	–	–	–	–	–	–	–	–	–	–
68	–	–	–	–	–	–	–	–	–	–	–	–
69	–	–	–	–	–	–	–	–	–	–	–	–
70	–	–	–	–	–	–	–	–	–	–	–	–
71	–	–	–	–	–	–	–	–	–	–	–	–
72	–	–	–	–	–	–	–	–	–	–	–	–
73	–	–	–	–	–	–	–	–	–	–	–	–
74	–	–	–	–	–	–	–	–	–	–	–	–
75	–	–	–	–	–	–	–	–	–	–	–	–
76	–	–	–	–	–	–	–	–	–	–	–	–
77	–	–	–	–	–	–	–	–	–	–	–	–
78	–	–	–	–	–	–	–	–	–	–	–	–
79	–	–	–	–	–	–	–	–	–	–	–	–
80	–	–	–	–	–	–	–	–	–	–	–	–
81	–	–	–	–	–	–	–	–	–	–	–	–
82	–	–	–	–	–	–	–	–	–	–	–	–
83	–	–	–	–	–	–	–	–	–	–	–	–
84	–	–	–	–	–	–	–	–	–	–	–	–
85	–	–	–	–	–	–	–	–	–	–	–	–
86	–	–	–	–	–	–	–	–	–	–	–	–
87	–	–	–	–	–	–	–	–	–	–	–	–
88	–	–	–	–	–	–	–	–	–	–	–	–
89	–	–	–	–	–	–	–	–	–	–	–	–
90	–	–	–	–	–	–	–	–	–	–	–	–
91	–	–	–	–	–	–	–	–	–	–	–	–
92	–	–	–	–	–	–	–	–	–	–	–	–
93	–	–	–	–	–	–	–	–	–	–	–	–
94	–	–	–	–	–	–	–	–	–	–	–	–
95	–	–	–	–	–	–	–	–	–	–	–	–
96	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A S-5 L.S. = 507.07			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS (5-61-34)		–	–	–	–	2	8	71	21
2	1.5-2.0			–	–	–	–	0	3	63	34
3	2.0-2.5			–	–	–	–	0	4	54	42
4	3.5-4.0			–	–	–	–	0	5	60	35
5	4.0-4.5			25.7	–	–	–	0	5	59	36
6	4.5-5.0	ROXANA SILT (17-53-30)		–	–	–	–	0	14	57	29
7	5.5-6.0			–	–	–	–	2	17	52	31
8	6.0-6.5			–	–	–	–	0	15	52	33
9	6.5-7.0			–	–	–	–	1	17	54	29
10	7.0-7.5			–	–	–	–	1	23	52	25
11	7.5-8.0	BERRY CLAY (31-35-34)		–	–	–	–	0	32	36	31
12	8.0-8.5			–	–	–	–	1	28	38	34
13	8.5-9.0			–	–	–	–	1	31	35	34
14	9.0-9.5			23.9	–	–	–	2	30	31	39
15	9.5-10.0			–	–	–	–	1	31	36	33
16	10.0-10.5			–	–	–	–	1	12	53	35
17	10.5-11.0			–	–	–	–	3	32	35	33
18	11.0-11.5			–	–	–	–	2	34	31	35
19	11.5-12.0	HAGARSTOWN MEMBER (47-32-21)		–	–	–	–	1	40	35	25
20	12.0-12.5			–	–	–	–	3	41	34	25
21	13.0-13.5			–	–	–	–	8	55	28	17
22	13.5-14.0			–	–	–	–	3	49	35	16
23	14.0-14.5			20.1	–	–	–	8	45	34	21
24	14.5-15.0			–	–	–	–	3	44	33	23
25	15.0-15.5			–	–	–	–	2	53	30	17
26	15.5-16.0	GLASFORD FORMATION TILL (31-41-28)		–	–	–	–	6	42	33	25
27	16.0-16.5			–	–	–	–	4	41	38	21
28	16.5-17.0			–	–	–	–	3	32	46	22
29	18.0-18.5			–	–	–	–	3	33	39	28
30	18.5-19.0			–	–	–	–	4	34	41	25
31	19.0-19.5			–	–	–	–	3	34	40	26
32	20.0-20.5			13.0	–	–	–	22	29	44	27
33	20.5-21.0			–	–	–	–	5	32	41	27
34	21.0-21.5			–	–	–	–	3	32	41	27
35	21.5-22.0			–	–	–	–	8	31	39	30
36	22.0-22.5			–	–	–	–	5	28	43	29
37	22.5-23.0			–	–	–	–	4	33	40	27
38	23.0-23.5			–	–	–	–	4	34	38	28
39	23.5-24.0			–	–	–	–	4	29	40	31
40	24.0-24.5			12.5	–	–	–	5	31	43	26
41	24.5-25.0			–	–	–	–	5	32	41	27
42	25.5-26.0			–	–	–	–	5	31	42	27
43	26.0-26.5			–	–	–	–	7	31	44	25
44	26.5-27.0			–	–	–	–	5	31	41	28
45	27.0-27.5			–	–	–	–	7	35	39	26
46	29.0-29.5			–	–	–	–	4	33	40	27
47	29.5-30.0			–	–	–	–	3	28	43	29
48	30.0-30.5			17.6	–	–	–	5	27	42	31
49	30.5-31.0			–	–	–	–	2	23	49	28
50	31.0-31.5			–	–	–	–	3	29	43	28
51	31.5-32.0			–	–	–	–	4	25	46	29

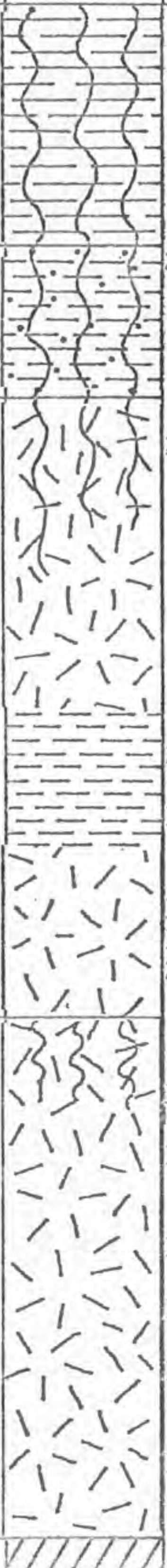
S-5	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	130.	<.12	19.	20.	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	63.	.26	19.	15.		
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	20.	<.12	14.	13.	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	17.	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	28.	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	48.	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	40.	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	11.	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	51.	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–
42	–	–	–	–	–	–	–	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	–	–	–	–	–	–	–	–	–	–	–	–
46	–	–	–	–	–	–	–	–	–	–	–	–
47	–	–	–	–	–	–	–	–	–	–	–	–
48	–	–	–	–	–	–	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–
50	–	–	–	–	–	–	–	–	–	–	–	–
51	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A S-5 L.S. = 507.07			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
52	31.5-32.0	GLASFORD| FORMATION| TILL|		–	–	–	–	4	25	46	29
53	32.5-33.0			–	–	–	–	4	30	43	27
54	33.0-33.5			–	–	–	–	3	29	42	29
55	33.5-34.0			–	–	–	–	3	25	47	28
56	34.5-35.0			21.3	–	–	–	3	19	51	30
57	35.0-35.5	LIERLE| CLAY| (12-52-36)|		–	–	–	–	0	17	53	30
58	35.5-36.0			–	–	–	–	1	13	58	29
59	36.0-36.5			–	–	–	–	0	9	58	33
60	36.5-37.0			–	–	–	–	0	10	56	34
61	37.0-37.5			–	–	–	–	0	9	60	31
62	37.5-38.0			–	–	–	–	0	9	58	33
63	38.0-38.5			–	–	–	–	0	10	56	32
64	38.5-39.0			–	–	–	–	0	6	63	31
65	39.0-39.5			–	–	–	–	0	6	64	30
66	39.5-40.0			18.7	–	–	–	1	13	53	34
67	40.0-40.5			–	–	–	–	0	8	61	31
68	40.5-41.0			–	–	–	–	0	13	53	34
69	41.0-41.5			–	–	–	–	0	19	48	33
70	41.5-42.0			–	–	–	–	1	2	61	37
71	42.0-42.5			–	–	–	–	2	20	36	44
72	42.5-43.0			–	–	–	–	1	19	35	46
73	43.0-43.5			–	–	–	–	1	19	35	46
74	43.5-44.0			–	–	–	–	1	24	37	39
75	44.0-44.5	BANNER| FORMATION| TILL| (25-45-30)|		–	–	–	–	3	28	42	30
76	44.5-45.0			–	–	–	–	4	27	41	32
77	45.0-45.5			–	–	–	–	15	26	43	31
78	45.5-46.0			–	–	–	–	4	27	41	32
79	46.0-46.5			–	–	–	–	3	27	41	32
80	47.0-47.5			–	–	–	–	3	29	40	31
81	47.5-48.0			–	–	–	–	6	28	41	31
82	48.0-48.5			–	–	–	–	4	27	42	31
83	48.5-49.0			–	–	–	–	3	28	42	30
84	49.0-49.5			–	–	–	–	3	26	42	32
85	50.0-50.5			12.0	–	–	–	2	30	41	29
86	50.5-51.0			–	–	–	–	3	29	42	29
87	51.0-51.5			–	–	–	–	3	30	42	28
88	51.5-52.0			–	–	–	–	3	30	44	26
89	52.0-52.5			–	–	–	–	5	29	43	28
90	52.5-53.0			–	–	–	–	2	29	45	26
91	53.0-53.5			–	–	–	–	3	15	65	20
92	54.0-54.5			–	–	–	–	1	19	46	35
93	54.5-55.0			13.0	–	–	–	4	19	53	28
94	56.0-56.2			–	–	–	–	2	21	45	34
95	56.5-57.0			–	–	–	–	3	21	46	33
96	57.0-57.5			–	–	–	–	4	20	46	34
97	57.5-58.0			–	–	–	–	6	17	50	33
98	58.0-58.2			–	–	–	–	3	20	46	34
99	59.7-60.2			12.8	–	–	–	–	–	–	–
		BEDROCK									

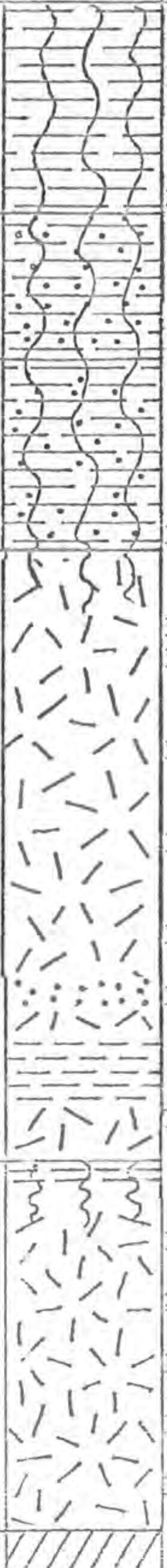
S-5	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
52	–	–	–	–	–	–	–	–	–	–	–	–
53	–	–	–	–	–	–	–	–	–	–	–	–
54	–	–	–	–	–	–	–	–	–	–	–	–
55	–	–	–	–	–	–	–	–	–	–	–	–
56	–	–	–	–	–	–	–	–	–	–	–	–
57	–	–	–	–	–	–	–	–	–	–	–	–
58	–	–	–	–	–	–	–	–	–	–	–	–
59	–	–	–	–	–	–	–	–	–	–	–	–
60	–	–	–	–	–	–	–	–	–	–	–	–
61	–	–	–	–	–	–	–	–	–	–	–	–
62	–	–	–	–	–	–	–	–	–	–	–	–
63	–	–	–	–	–	–	–	–	–	–	–	–
64	–	–	–	–	–	–	–	–	–	–	–	–
65	–	–	–	–	–	–	–	–	–	–	–	–
66	–	–	–	–	–	–	–	–	–	–	–	–
67	–	–	–	–	–	–	–	–	–	–	–	–
68	–	–	–	–	–	–	–	–	–	–	–	–
69	–	–	–	–	–	–	–	–	–	–	–	–
70	–	–	–	–	–	–	–	–	–	–	–	–
71	–	–	–	–	–	–	–	–	–	–	–	–
72	–	–	–	–	–	–	–	–	–	–	–	–
73	–	–	–	–	–	–	–	–	–	–	–	–
74	–	–	–	–	–	–	–	–	–	–	–	–
75	–	–	–	–	–	–	–	–	–	–	–	–
76	–	–	–	–	–	–	–	–	–	–	–	–
77	–	–	–	–	–	–	–	–	–	–	–	–
78	–	–	–	–	–	–	–	–	–	–	–	–
79	–	–	–	–	–	–	–	–	–	–	–	–
80	–	–	–	–	–	–	–	–	–	–	–	–
81	–	–	–	–	–	–	–	–	–	–	–	–
82	–	–	–	–	–	–	–	–	–	–	–	–
83	–	–	–	–	–	–	–	–	–	–	–	–
84	–	–	–	–	–	–	–	–	–	–	–	–
85	–	–	–	–	–	–	–	–	–	–	–	–
86	–	–	–	–	–	–	–	–	–	–	–	–
87	–	–	–	–	–	–	–	–	–	–	–	–
88	–	–	–	–	–	–	–	–	–	–	–	–
89	–	–	–	–	–	–	–	–	–	–	–	–
90	–	–	–	–	–	–	–	–	–	–	–	–
91	–	–	–	–	–	–	–	–	–	–	–	–
92	–	–	–	–	–	–	–	–	–	–	–	–
93	–	–	–	–	–	–	–	–	–	–	–	–
94	–	–	–	–	–	–	–	–	–	–	–	–
95	–	–	–	–	–	–	–	–	–	–	–	–
96	–	–	–	–	–	–	–	–	–	–	–	–
97	–	–	–	–	–	–	–	–	–	–	–	–
98	–	–	–	–	–	–	–	–	–	–	–	–
99	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A S-6 L.S. = 510.51			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (5-59-36)		–	–	–	–	3	7	72	21
2	1.0-1.5			–	–	–	–	1	3	61	36
3	1.5-2.0			–	–	–	–	0	0	47	53
4	2.0-2.5			–	–	–	–	0	9	57	34
5	3.5-4.0	ROXANA SILT (17-56-27)		–	–	–	–	1	17	56	27
6	4.0-4.5			–	–	–	–	2	19	56	25
7	4.5-5.0			–	–	–	–	–	–	–	–
8	5.5-6.0			24.4	–	–	–	1	17	56	27
9	6.0-6.5			–	–	–	–	1	15	57	28
10	6.5-7.0	BERRY CLAY (33-40-27)		–	–	–	–	3	33	45	22
11	7.0-7.5			–	–	–	–	–	–	–	–
12	8.5-9.0			–	–	–	–	0	25	48	27
13	9.0-9.5			–	–	–	–	–	–	–	–
14	10.0-10.5			20.9	–	–	–	–	–	–	–
15	10.5-11.0			–	–	–	–	3	42	27	31
16	11.0-11.5	HAGARSTOWN		–	–	–	–	6	38	31	31
17	11.5-12.0			–	–	–	–	0	4	35	61
18	12.0-12.5	GLASFORD FORMATION TILL (31-41-28)		–	–	–	–	3	35	37	28
19	13.0-13.5			–	–	–	–	–	–	–	–
20	14.5-15.0			–	–	–	–	6	31	38	31
21	15.0-15.6			16.1	–	–	–	–	–	–	–
22	16.5-17.0			–	–	–	–	4	36	39	35
23	18.5-19.0			11.8	–	–	–	–	–	–	–
24	21.0-21.5			–	–	–	–	3	36	40	24
25	25.0-25.5			11.2	–	–	–	–	–	–	–
26	28.5-29.0			–	–	–	–	16	31	41	28
27	30.5-31.0			11.4	–	–	–	–	–	–	–
28	33.0-33.5			–	–	–	–	5	31	44	25
29	36.5-37.0			–	–	–	–	3	28	45	27
30	38.0-38.5			14.1	–	–	–	–	–	–	–
31	40.5-41.0			14.7	–	–	–	–	–	–	–
32	41.0-41.5			–	–	–	–	3	29	45	26
33	44.5-45.0			–	–	–	–	3	24	44	32
34	45.0-45.5	BANNER FORMATION TILL (23-43-34)		–	–	–	–	3	32	38	30
35	49.0-49.5			14.1	–	–	–	–	–	–	–
36	54.2-54.5			15.0	–	–	–	–	–	–	–
37	56.0-56.5			–	–	–	–	3	23	44	33
38	56.5-57.0			–	–	–	–	4	20	42	36
39	60.0-60.5			16.5	–	–	–	–	–	–	–
40	61.0-61.5			–	–	–	–	7	22	44	34
41	64.5-65.0			12.2	–	–	–	–	–	–	–
42	65.0-65.5			–	–	–	–	4	22	43	35
43	65.5-66.0			–	–	–	–	3	21	43	36
		BEDROCK									

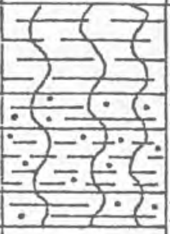
S-6	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	740	.54	13.	23.		
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	30.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	74.	.28	18.	19.	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	38.	.18	9.6	12.	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	28.	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	58.	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	50.	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	51.	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	––	–	–	–	–	–	–	–	–
42	–	–	–	–	–	–	–	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–

	SITE A S-7 L.S. = 506.78			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (9-59-32)		–	–	–	–	2	8	67	25
2	1.0-1.5			–	–	–	–	3	8	66	26
3	1.5-2.0			–	–	–	–	–	–	–	–
4	2.0-2.5			–	–	–	–	1	6	56	38
5	2.5-3.0			–	–	–	–	–	–	–	–
6	4.0-4.5			–	–	–	–	1	10	53	37
7	4.5-5.0			–	–	–	–	2	15	50	35
8	5.0-5.5	BERRY CLAY		23.5	–	–	–	–	–	–	–
9	5.5-6.0			–	–	–	–	–	–	–	–
10	6.0-6.5			–	–	–	–	1	13	48	39
11	8.0-8.5			–	–	–	–	–	–	–	–
12	8.5-9.0			–	–	–	–	1	26	36	38
13	10.0-10.5	GLASFORD FORMATION TILL (30-38-32)		–	–	–	–	1	25	36	39
14	10.5-11.0			20.1	–	–	–	–	–	–	–
15	11.0-11.5			–	–	–	–	2	37	36	27
16	11.5-12.0			–	–	–	–	–	–	–	–
17	12.0-12.5			–	–	–	–	–	–	–	–
18	13.5-14.0			–	–	–	–	3	33	37	30
19	15.5-16.0			–	–	–	–	–	–	–	–
20	16.5-17.0			–	–	–	–	5	29	42	29
21	18.5-19.0			–	–	–	–	4	29	45	26
22	21.0-21.5			–	–	–	–	4	23	47	30
23	21.5-22.0			–	–	–	–	1	5	52	43
24	22.5-23.0			24.7	–	–	–	–	–	–	–
25	23.0-23.5			–	–	–	–	1	19	37	34
26	24.0-24.5			15.7	–	–	–	–	–	–	–
27	25.5-26.0			–	–	–	–	17	39	15	46
28	28.0-28.5			–	–	–	–	3	31	39	30
29	31.5-32.0			13.1	–	–	–	–	–	–	–
30	35.0-35.5			13.0	–	–	–	–	–	–	–
31	37-5-38.0			20.9	–	–	–	–	–	–	–
32	38.0-38.5			–	–	–	–	2	31	40	29
33	40.5-41.0	BANNER FORMATION TILL (23-45-32)		–	–	–	–	2	26	43	31
34	43.0-43.5			–	–	–	–	1	21	37	42
35	46.0-46.5			15.5	–	–	–	–	–	–	–
36	46.5-47.0			–	–	–	–	2	28	39	33
37	48.5-49.0			13.4	–	–	–	–	–	–	–
38	49.0-49.5			–	–	–	–	5	28	40	32
39	52.5-53.0			–	–	–	–	4	28	44	28
40	54.5-55.0			14.8	–	–	–	–	–	–	–
41	56.5-57.0			–	–	–	–	1	21	34	45
42	58.5-59.0			13.1	–	–	–	–	–	–	–
43	61.5-62.0			–	–	–	–	3	22	34	44
44	65.5-66.0			14.4	–	–	–	–	–	–	–
45	66.0-66.5			–	–	–	–	7	20	45	35
46	68.0-68.5			–	–	–	–	1	21	45	34
47	69.2-69.5			13.0	–	–	–	–	–	–	–
48	69.5-70.0			–	–	–	–	4	21	45	34
49	70.0-70.5			–	–	–	–	3	20	43	37
		BEDROCK									

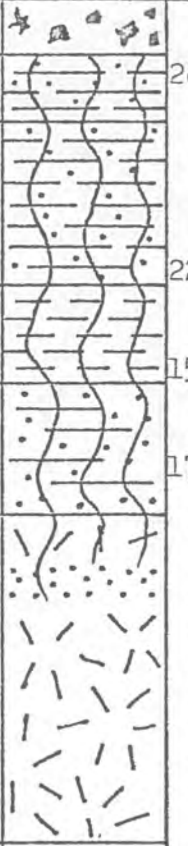
S-7	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	150.	<.12	13.	20.	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	38.	<.12	16.	20.	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	19.	<.12	14.	13.	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	15.	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	35.	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	60.	–	–	–	–	–
16	–	–	–	–	–	–	89.	–	–	–	–	–
17	–	–	–	–	–	–	57.	–	–	–	–	–
18	–	–	–	–	–	–	54.	–	–	–	–	–
19	–	–	–	–	–	–	45.	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–
42	–	–	–	–	–	–	–	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	–	–	–	–	–	–	–	–	–	–	–	–
46	–	–	–	–	–	–	–	–	–	–	–	–
47	–	–	–	–	–	–	–	–	–	–	–	–
48	–	–	–	–	–	–	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–

	SITE A S-8 L.S. = 506.13			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS (9-52-39)		–	–	–	–	3	8	45	47
2	1.5-2.0			31.0	–	–	–	–	–	–	–
3	2.0-2.5			–	–	–	–	1	11	53	36
4	3.0-3.5			–	–	–	–	–	–	–	–
5	3.5-4.0			–	–	–	–	1	9	54	37
6	4.0-4.5			25.8	–	–	–	0	9	54	37
7	4.5-5.0	BERRY CLAY (21-45-34)		–	–	–	–	1	19	48	33
8	5.0-5.5			–	–	–	–	–	–	–	–
9	6.0-6.5			–	–	–	–	1	25	43	32
10	7.0-7.5			–	–	–	–	1	29	39	32
11	7.5-8.0			–	–	–	–	0	11	51	38
12	8.0-8.5	HAGARSTOWN MEMBER (36-31-33)		–	–	–	–	41	26	28	46
13	8.5-9.0			–	–	–	–	2	33	31	36
14	9.0-9.5			–	–	–	–	3	34	32	34
15	9.5-10.0			–	–	–	–	–	–	–	–
16	10.0-10.5			–	–	–	–	1	43	29	28
17	11.0-11.5			19.7	–	–	–	6	43	34	23
18	11.5-12.0	GLASFORD FORMATION TILL (30-41-29)		–	–	–	–	–	–	–	–
19	13.0-13.5			–	–	–	–	5	33	40	27
20	14.0-14.5			12.7	–	–	–	4	32	40	28
21	14.5-15.0			12.1	–	–	–	–	–	–	–
22	15.0-15.5			–	–	–	–	–	–	–	–
23	15.5-16.0			–	–	–	–	12	33	39	28
24	16.5-17.0			11.8	–	–	–	–	–	–	–
25	22.0-22.5			–	–	–	–	16	29	40	31
26	24.5-25.0			–	–	–	–	5	31	41	28
27	25.0-25.5			14.5	–	–	–	3	34	34	32
28	29.0-29.5			–	–	–	–	2	27	43	30
29	33.0-33.5			–	–	–	–	5	32	38	30
30	34.0-34.5			13.4	–	–	–	–	–	–	–
31	38.0-38.5			–	–	–	–	3	26	35	39
32	40.0-40.5			13.0	–	–	–	–	–	–	–
33	42.0-42.5			–	–	–	–	4	14	57	29
34	43.5-44.0			–	–	–	–	5	31	53	16
35	44.5-45.0			–	–	–	–	1	24	63	13
36	46.0-46.5			12.1	–	–	–	–	–	–	–
37	49.0-49.5			–	–	–	–	4	31	39	30
38	49.5-50.0	BANNER FORMATION TILL (25-43-32)		–	–	–	–	2	22	64	14
39	50.0-50.5			–	–	–	–	2	26	39	35
40	51.0-51.5			14.9	–	–	–	–	–	–	–
41	52.0-52.5			–	–	–	–	4	33	36	31
42	54.0-54.5			21.3	–	–	–	–	–	–	–
43	55.0-55.5			–	–	–	–	3	31	38	31
44	56.0-56.5			10.4	–	–	–	–	–	–	–
45	59.0-59.5			–	–	–	–	14	22	49	29
46	60.0-60.5			13.0	–	–	–	–	–	–	–
47	62.0-62.5			–	–	–	–	6	23	43	34
48	64.0-64.5			12.3	–	–	–	–	–	–	–
49	64.5-65.0			–	–	–	–	5	22	47	31
		BEDROCK									

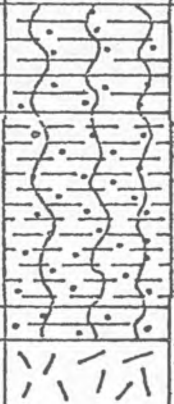
S-8	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	77.	1.1	11.	18.	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	71.	.42	21.	20.	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	28.	.30	12.	12.	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	420.	.72	12.	19.	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	55.	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	41.	–	–	–	–	–
19	–	–	–	–	–	–	50.	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	54.	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–
42	–	–	–	–	–	–	–	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	–	–	–	–	–	–	–	–	–	–	–	–
46	–	–	–	–	–	–	–	–	–	–	–	–
47	–	–	–	–	–	–	–	–	–	–	–	–
48	–	–	–	–	–	–	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A S-11 L.S. = 507.82			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	2.0-2.5	PEORIA LOESS		–	–	–	–	–	–	–	–
2	4.0-4.5			22.6	–	–	–	–	–	–	–
3	6.0-6.5	ROXANA SILT		19.5	–	–	–	–	–	–	–
4	8.0-8.5	BERRY CLAY		–	–	–	–	–	–	–	–
5	9.5-10.0			–	–	–	–	–	–	–	–
6	12.0-12.5	HAGARSTOWN		18.9	–	–	–	–	–	–	–

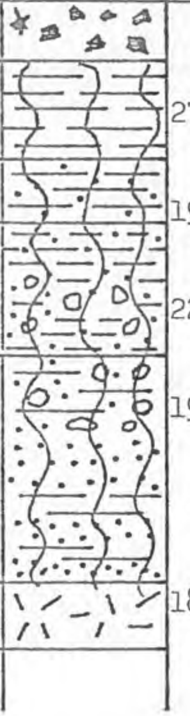
S-11	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	130.	.12	16.	16.	–	–
2	–	–	–	–	–	–	44.	.28	15.	14.	–	–
3	–	–	–	–	–	–	15.	<.12	8.4	9.5	–	–
4	–	–	–	–	–	–	18.	–	–	–	–	–
5	–	–	–	–	–	–	28.	–	–	–	–	–
6	–	–	–	–	–	–	56.	–	–	–	–	–

No.	SITE A S-12 L.S. = 508.57			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5–2.0	FILL		–	–	–	–	–	–	–	–
2	3.5–4.0	PEORIA LOESS		28.5	–	–	–	0	47	10	43
3	5.0–5.5			–	–	–	–	0	3	72	25
4	6.0–6.5	ROXANA SILT (37-31-32)		–	–	–	–	5	42	29	29
5	7.5–8.0			–	–	–	–	–	–	–	–
6	8.0–8.5			–	–	–	–	1	37	30	33
7	9.5–10.0			–	–	–	–	–	–	–	–
8	10.6–11.3			22.0	–	–	–	2	30	35	35
9	11.5–12.0	BERRY CLAY (34-31-35)		–	–	–	–	1	29	34	37
10	12.0–12.5			–	–	–	–	1	30	44	26
11	13.5–14.0			15.3	–	–	–	3	43	15	42
12	14.0–14.5	HAGARSTOWN MEMBER (36-34-30)		–	–	–	–	3	31	34	35
13	14.5–15.0			–	–	–	–	1	41	33	26
14	15.0–15.5			17.4	–	–	–	–	–	–	–
15	15.5–16.0			–	–	–	–	–	–	–	–
16	16.0–16.5	GLASFORD FORMATION TILL (30-38-32)		–	–	–	–	4	34	36	30
17	16.5–17.0			–	–	–	–	3	48	32	30
18	17.0–17.5			–	–	–	–	5	28	32	40
19	18.0–18.5			–	–	–	–	–	–	–	–
20	19.2–19.8			–	–	–	–	6	32	39	29
21	20.5–21.0			–	–	–	–	–	–	–	–
22	21.5–22.0			–	–	–	–	9	28	44	28
23	23.0–23.5			–	–	–	–	–	–	–	–
24	23.5–24.0			–	–	–	–	1	12	52	36
25	26.0–26.5			–	–	–	–	–	–	–	–

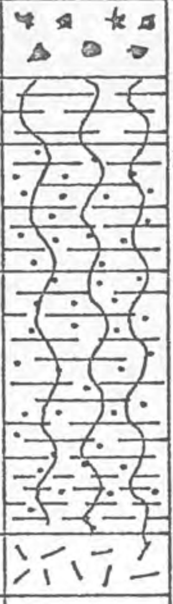
S-12	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	57,000	24.	17.	14.	–	–
2	–	–	–	–	–	–	9,500	36.	18.	42.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	4,700	–	–	–	–	–
5	–	–	–	–	–	–	4,600	15.	43.	55.	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	7,800	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	8,900	32.	11.	14.	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	6,200	–	–	–	4.8	2.9
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	7,400	31.	15.	19.	4.9	3.7
15	–	–	–	–	–	–	3,700	29.	14.	7.9	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	1,200.	12.	17.	12.	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	190.	1.6	17.	9.6	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	290.	1.8	15.	7.6	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	150.	1.3	14.	10.	–	–

	SITE A S-13 L.S. = 507.00			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	5.5–6.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	7.5–8.0	ROXANA SILT		26.8	–	–	–	–	–	–	–
3	9.0–9.5	BERRY CLAY		–	–	–	–	–	–	–	–
4	10.5–11.0			–	–	–	–	–	–	–	–
5	11.0–11.5			–	–	–	–	–	–	–	–
6	11.5–12.0			–	–	–	–	–	–	–	–
7	12.5–13.0			20.0	–	–	–	–	–	–	–
8	13.0–13.5			–	–	–	–	–	–	–	–
9	14.5–15.0	HAGARSTOWN		–	–	–	–	–	–	–	–
10	16.5–17.0	GLASFORD FORMATION TILL		15.5	–	–	–	–	–	–	–

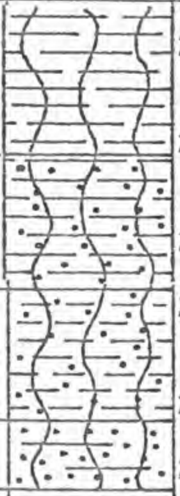
S-13	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	2700.	4.1	16.	22.	–	–
2	–	–	–	–	–	–	200.	1.22	14.	18.	–	–
3	–	–	–	–	–	–	770.	–	–	–	–	–
4	–	–	–	–	–	–	1100.	–	–	–	–	–
5	–	–	–	–	–	–	1600.	3.26	11.	14.	–	–
6	–	–	–	–	–	–	1300.	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	44.	.40	13.	16.	–	–
9	–	–	–	–	–	–	43.	–	–	–	–	–
10	–	–	–	–	–	–	77.	–	–	–	–	–

	SITE A S-14 L.S. = 504.45			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	2.0-2.5	FILL		–	–	–	–	20	33	51	16
2	3.5-4.0	PEORIA LOESS		–	–	–	–	1	7	49	44
3	4.0-4.5			27.1	–	–	–	–	–	–	–
4	4.5-5.0			–	–	–	–	1	14	51	35
5	5.0-5.5	ROXANA SILT		–	–	–	–	1	37	30	33
6	5.5-6.0			19.7	–	–	–	–	–	–	–
7	6.0-6.5	BERRY CLAY		–	–	–	–	–	–	–	–
8	8.0-8.5			–	–	–	–	–	–	–	–
9	10.0-10.5			22.0	–	–	–	–	–	–	–
10	10.5-11.0			–	–	–	–	–	–	–	–
11	13.0-13.5	HAGARSTOWN MEMBER		–	–	–	–	–	–	–	–
12	13.5-14.0			19.7	–	–	–	–	–	–	–
13	14.0-14.5			–	–	–	–	–	–	–	–
14	14.5-15.0			–	–	–	–	–	–	–	–
15	15.0-15.5			–	–	–	–	–	–	–	–
16	16.0-16.5			–	–	–	–	–	–	–	–
17	17.0-17.5			–	–	–	–	–	–	–	–
18	18.0-18.5	GLASFORD FORMATION TILL		18.5	–	–	–	–	–	–	–
19	18.5-19.0			–	–	–	–	–	–	–	–

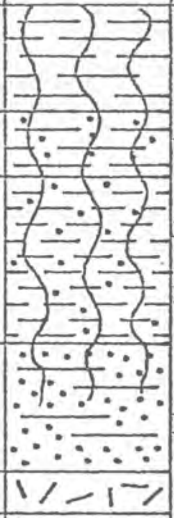
S-14	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	140,000.	7.8	5600.	6500.	–	–
2	–	–	–	–	–	–	15,000.	1.3	31.	24.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	400.	.36	32.	27.	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	18.	<.06	7.8	8.1	–	–
8	–	–	–	–	–	–	49.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	62.	.12	12.	18.	–	–
11	–	–	–	–	–	–	73.	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	130.	.10	8.8	11.	–	–
14	–	–	–	–	–	–	–	–	–	–	7.2	1.6
15	–	–	–	–	–	–	59.	–	–	–	–	–
16	–	–	–	–	–	–	49.	–	–	–	–	–
17	–	–	–	–	–	–	81.	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	60.	–	–	–	–	–

	SITE A S-15 L.S. = 508.92			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5-2.0	FILL		–	–	–	–	–	–	–	–
2	3.0-3.5	PEORIA LOESS		–	–	–	–	–	–	–	–
3	5.5-6.0			–	–	–	–	–	–	–	–
4	6.5-7.0	ROXANA SILT		26.3	–	–	–	–	–	–	–
5	7.5-8.0			–	–	–	–	–	–	–	–
6	8.5-9.0			30.2	–	–	–	–	–	–	–
7	9.5-10.0			–	–	–	–	–	–	–	–
8	11.0-11.5	BERRY CLAY AND HAGARSTOWN MEMBER		20.7	–	–	–	–	–	–	–
9	11.5-12.0			–	–	–	–	–	–	–	–
10	12.0-12.5			–	–	–	–	–	–	–	–
11	12.5-13.0			–	–	–	–	–	–	–	–
12	13.0-13.5			–	–	–	–	–	–	–	–
13	13.5-14.0			22.5	–	–	–	–	–	–	–
14	15.5-16.0			–	–	–	–	–	–	–	–
15	16.0-16.5			21.1	–	–	–	–	–	–	–
16	17.5-18.0	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
17	18.5-19.0			21.1	–	–	–	–	–	–	–

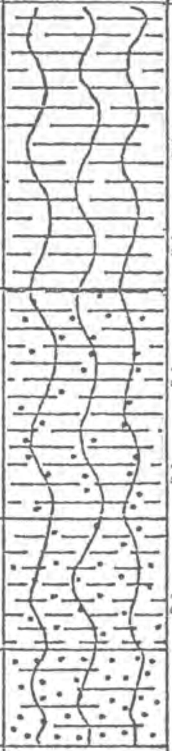
S-15	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	1700.	12.	400.	310.		
2	–	–	–	–	–	–	600.	1.6	13.	98.	–	–
3	–	–	–	–	–	–	1100.	6.0	11.	13.	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	590.	.76	11.	12.	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	36.	.10	9.8	13.	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	79.	–	–	–	–	–
10	–	–	–	–	–	–	100.	–	–	–	–	–
11	–	–	–	–	–	–	2500.	–	–	–	–	–
12	–	–	–	–	–	–	2700.	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	2700.	4.2	16.	10.	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	150.	2.5	19.	12.	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A S-16 L.S. = 505.81 Depth of Sample (ft)	Unit Description	Graphic Log	Engineering Data W %	Gs	Void Ratio	Dry Den #/ft³	Grain Size Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS		29.0	–	–	–	–	–	–	–
2	1.5-2.0			–	–	–	–	–	–	–	–
3	3.0-3.5			–	–	–	–	–	–	–	–
4	3.5-4.0			27.2	–	–	–	–	–	–	–
5	4.5-5.0	ROXANA SILT		–	–	–	–	–	–	–	–
6	7.5-8.0			–	–	–	–	–	–	–	–
7	8.5-9.0			24.0	–	–	–	–	–	–	–
8	9.5-10.0			–	–	–	–	–	–	–	–
9	11.0-11.5	BERRY CLAY		23.8	–	–	–	–	–	–	–
10	11.5-12.0			–	–	–	–	–	–	–	–
11	13.0-13.5			–	–	–	–	–	–	–	–
12	13.5-14.0			25.7	–	–	–	–	–	–	–
13	15.0-15.5	HAGARSTOWN		–	–	–	–	–	–	–	–
14	16.0-16.5			20.3	–	–	–	–	–	–	–

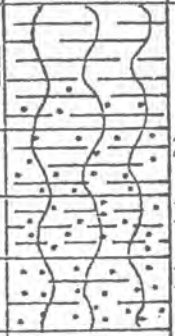
S-16 No.	X-Ray Data DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Chemical Data Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	250.	.14	13.	14.	–	–
3	–	–	–	–	–	–	28.	<.12	12.	11.	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	2700.	.82	26.	63.	–	–
6	–	–	–	–	–	–	27.	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	280.	.44	20.	20.	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	17.	–	–	–	–	–
11	–	–	–	–	–	–	29.	.20	11.	10.	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	53.	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–

	SITE A S-17 L.S. = 505.89			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5–2.0	PEORIA LOESS		31.7	–	–	–	–	–	–	–
2	2.0–2.5			–	–	–	–	–	–	–	–
3	3.5–4.0	ROXANA SILT		24.7	–	–	–	–	–	–	–
4	4.0–4.5			–	–	–	–	–	–	–	–
5	5.5–6.0	BERRY CLAY		–	–	–	–	–	–	–	–
6	6.0–6.5			20.1	–	–	–	–	–	–	–
7	8.0–8.5			–	–	–	–	–	–	–	–
8	8.5–9.0			20.2	–	–	–	–	–	–	–
9	10.0–10.5			–	–	–	–	–	–	–	–
10	11.5–12.0	HAGARSTOWN MEMBER		–	–	–	–	–	–	–	–
11	12.0–12.5			–	–	–	–	–	–	–	–
12	13.5–14.0			15.3	–	–	–	–	–	–	–
13	14.0–14.5			–	–	–	–	–	–	–	–
14	16.0–16.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–

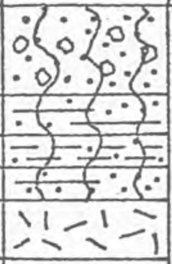
S-17	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	1200.	1.0	35	60.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	330.	.32	26.	36.	–	–
5	–	–	–	–	–	–	10.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	20.	.18	8.1	16.	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	36.	–	–	–	–	–
10	–	–	–	–	–	–	46.	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	41.	–	–	–	–	–
14	–	–	–	–	–	–	46.	–	–	–	–	–

	SITE A S-18 L.S. = 510.14			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	4.0–4.5	PEORIA LOESS		–	–	–	–	–	–	–	–
2	4.5–5.0			–	–	–	–	1	8	62	30
3	5.0–5.5			28.5	–	–	–	–	–	–	–
4	5.5–6.0			–	–	–	–	–	–	–	–
5	7.0–7.5			–	–	–	–	–	–	–	–
6	7.5–8.0			22.6	–	–	–	–	–	–	–
7	8.0–8.5			–	–	–	–	1	6	56	38
8	9.0–9.5	ROXANA SILT		–	–	–	–	1	26	35	39
9	9.5–10.0			–	–	–	–	–	–	–	–
10	10.0–10.5			22.5	–	–	–	–	–	–	–
11	11.0–11.5			–	–	–	–	4	8	56	36
12	11.5–12.0			–	–	–	–	3	24	31	45
13	12.5–13.0			23.4	–	–	–	–	–	–	–
14	13.5–14.0			–	–	–	–	1	20	38	42
15	14.0–14.5	BERRY CLAY		–	–	–	–	2	52	29	19
16	14.5–15.0			–	–	–	–	1	27	27	46
17	15.0–15.5			22.9	–	–	–	–	–	–	–
18	15.5–16.0			–	–	–	–	–	–	–	–
19	16.0–16.5	HAGARSTOWN MEMBER		–	–	–	–	4	55	30	15
20	16.5–17.0			–	–	–	–	13	51	27	22
21	17.5–18.0			–	–	–	–	–	–	–	–

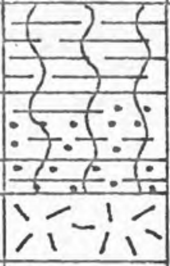
S-18	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	7900.	29.	32.	270.	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	7300.	–	–	–	–	–
5	–	–	–	–	–	–	5800.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	3400.	6.0	9.6	9.8	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	4100.	7.1	11.	14.	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	3800.	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	4100.	–	–	–	5.2	5.9
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	100.	1.9	12.	10.	7.6	3.4

No.	SITE A S-22 L.S. = 503.50			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS		–	–	–	–	–	–	–	–
2	2.0-2.5			–	–	–	–	–	–	–	–
3	3.5-4.0			–	–	–	–	–	–	–	–
4	4.5-5.0	ROXANA SILT		22.8	–	–	–	–	–	–	–
5	5.5-6.0			–	–	–	–	–	–	–	–
6	6.5-7.0	BERRY CLAY		17.5	–	–	–	–	–	–	–
7	7.5-8.0			–	–	–	–	–	–	–	–
8	8.5-9.0	HAGARSTOWN		18.6	–	–	–	–	–	–	–
9	9.5-10.0			–	–	–	–	–	–	–	–

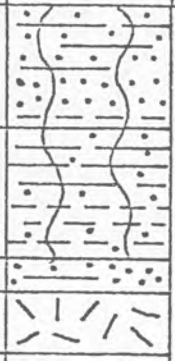
S-22 No.	X-Ray Data						Chemical Data					
	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	11,000.	–	–	–	–	–
2	–	–	–	–	–	–	330.	–	–	–	–	–
3	–	–	–	–	–	–	9,600.	–	–	–	–	–
4	–	–	–	–	–	–	61.	–	–	–	–	–
5	–	–	–	–	–	–	3,800.	–	–	–	–	–
6	–	–	–	–	–	–	36.	–	–	–	–	–
7	–	–	–	–	–	–	150.	–	–	–	–	–
8	–	–	–	–	–	–	50.	–	–	–	–	–
9	–	–	–	–	–	–	57.	–	–	–	–	–

	SITE A S-23 L.S. = 502.64			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5-2.0	ALLUVIUM		–	–	–	–	–	–	–	–
2	3.5-4.0			–	–	–	–	–	–	–	–
3	4.5-5.0	ROXANA SILT		24.1	–	–	–	–	–	–	–
4	6.0-6.5	BERRY CLAY		17.1	–	–	–	–	–	–	–
5	7.5-8.0	HAGARSTOWN		–	–	–	–	–	–	–	–
6	9.0-9.5	GLASFORD FORMATION TILL		21.7	–	–	–	–	–	–	–
7	9.5-10.0			–	–	–	–	–	–	–	–

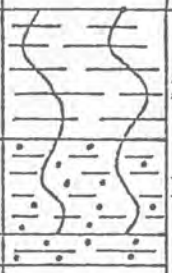
S-23	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	12,000.	–	–	–	–	–
2	–	–	–	–	–	–	8,900.	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	59.	–	–	–	–	–
5	–	–	–	–	–	–	62.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	49.	–	–	–	–	–

	SITE A S-24 L.S. = 500.79			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5-2.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.5-4.0			–	–	–	–	–	–	–	–
3	4.0-4.5	ROXANA SILT		13.8	–	–	–	–	–	–	–
4	5.5-6.0	BERRY CLAY		–	–	–	–	–	–	–	–
5	7.0-7.5	HAGARSTOWN		–	–	–	–	–	–	–	–
6	9.0-9.5	GLASFORD FORMATION TILL		12.3	–	–	–	–	–	–	–
7	9.5-10.0			–	–	–	–	–	–	–	–
				-							

S-24	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	6500.	–	–	–	–	–
2	–	–	–	–	–	–	300.	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	190.	–	–	–	–	–
5	–	–	–	–	–	–	94.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	55.	–	–	–	–	–

No.	SITE A S-25 L.S. = 500.37			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5-2.0	ALLUVIUM		27.5	–	–	–	–	–	–	–
2	2.5-3.0			–	–	–	–	–	–	–	–
3	4.5-5.0			–	–	–	–	–	–	–	–
4	6.5-7.0	ROXANA SILT & BERRY CLAY		–	–	–	–	–	–	–	–
5	8.0-8.5			–	–	–	–	–	–	–	–
6	8.5-9.0			23.8	–	–	–	–	–	–	–
7	9.0-9.5			–	–	–	–	–	–	–	–
8	9.5-10.0	HAGARSTOWN		–	–	–	–	–	–	–	–
9	10.5-11.0	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–

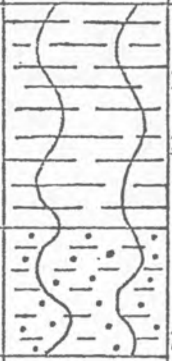
S-25	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	5600.	–	–	–	–	–
3	–	–	–	–	–	–	5100.	–	–	–	–	–
4	–	–	–	–	–	–	46.	–	–	–	–	–
5	–	–	–	–	–	–	1100.	–	–	–	–	–
6	–	–	–	–	–	–	220.	–	–	–	–	–
7	–	–	–	–	–	–	34.	–	–	–	–	–
8	–	–	–	–	–	–	43.	–	–	–	–	–
9	–	–	–	–	–	–	44.	–	–	–	–	–

No.	SITE A S-26 L.S. = 499.30			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5–2.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.5–4.0			23.3	–	–	–	–	–	–	–
3	4.0–4.5			–	–	–	–	–	–	–	–
4	6.5–7.0	BERRY CLAY		–	–	–	–	–	–	–	–
5	8.5–9.0			18.4	–	–	–	–	–	–	–
6	9.0–9.5			–	–	–	–	–	–	–	–
7	10.5–11.0	HAGARSTOWN		–	–	–	–	–	–	–	–

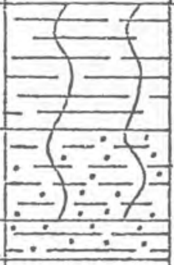
S-26

S-26	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	1700.	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	4400.	–	–	–	–	–
4	–	–	–	–	–	–	130.	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	46.	–	–	–	–	–
7	–	–	–	–	–	–	43.	–	–	–	–	–

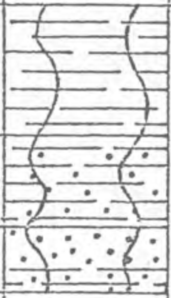
S-27

No.	SITE A S-27 L.S. = 505.29			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	4.5-5.0	PEORIA LOESS AND ROXANA SILT		–	–	–	–	–	–	–	–
2	5.5-6.0			23.2	–	–	–	–	–	–	–
3	6.5-7.0			–	–	–	–	–	–	–	–
4	8.5-9.0			20.5	–	–	–	–	–	–	–
5	9.0-9.5			–	–	–	–	–	–	–	–
6	9.5-10.0			–	–	–	–	–	–	–	–
7	10.0-10.5	BERRY CLAY		–	–	–	–	–	–	–	–
8	10.5-11.0			–	–	–	–	–	–	–	–
9	12.5-13.0			–	–	–	–	–	–	–	–
10	14.0-14.2			21.5	–	–	–	–	–	–	–

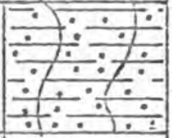
S-27	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	26	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	19	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	100.	–	–	–	–	–
6	–	–	–	–	–	–	85.	–	–	–	–	–
7	–	–	–	–	–	–	12.	–	–	–	–	–
8	–	–	–	–	–	–	85.	–	–	–	–	–
9	–	–	–	–	–	–	86.	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–

	SITE A S-28 L.S. = 503.82			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5-2.0	PEORIA LOESS AND ROXANA SILT		–	–	–	–	–	–	–	–
2	3.5-3.8			24.4	–	–	–	–	–	–	–
3	4.0-4.5			–	–	–	–	–	–	–	–
4	5.5-6.0	BERRY CLAY		–	–	–	–	–	–	–	–
5	7.5-8.0			–	–	–	–	–	–	–	–
6	9.0-9.5			21.2	–	–	–	–	–	–	–
7	9.5-10.0	HAGARSTOWN		–	–	–	–	–	–	–	–

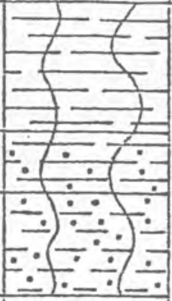
S-28	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	160.	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	300.	–	–	–	–	–
4	–	–	–	–	–	–	58.	–	–	–	–	–
5	–	–	–	–	–	–	84.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	54.	–	–	–	–	–

	SITE A S-29 L.S. = 505.59			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	6.5-7.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	8.5-9.0			19.2	–	–	–	–	–	–	–
3	9.0-9.5			–	–	–	–	–	–	–	–
4	11.0-11.5	BERRY CLAY		–	–	–	–	–	–	–	–
5	12.5-13.0			–	–	–	–	–	–	–	–
6	13.5-14.0			18.2	–	–	–	–	–	–	–
7	14.5-15.0	HAGARSTOWN MEMBER		–	–	–	–	–	–	–	–
8	16.5-17.0			14.1	–	–	–	–	–	–	–

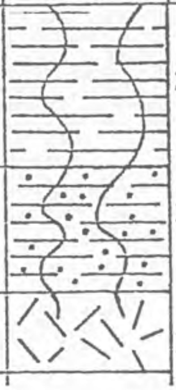
S-29	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	67.	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	120.	–	–	–	–	–
4	–	–	–	–	–	–	63.	–	–	–	–	–
5	–	–	–	–	–	–	47.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	59.	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A S-30 L.S. = 500.65			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	5.0–5.5	FILL		–	–	–	–	–	–	–	–
2	6.0–6.5	PEORIA LOESS		–	–	–	–	–	–	–	–
3	6.5–7.0			27.2	–	–	–	–	–	–	–
4	8.0–8.5			–	–	–	–	–	–	–	–
5	9.5–10.0	ROXANA SILT AND BERRY CLAY		19.9	–	–	–	–	–	–	–
6	10.0–10.5			–	–	–	–	–	–	–	–
7	11.5–12.0			18.5	–	–	–	–	–	–	–
8	12.0–12.5			–	–	–	–	–	–	–	–

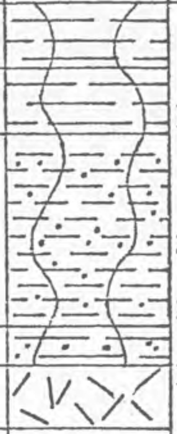
S-30	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	17,000.	–	–	–	–	–
2	–	–	–	–	–	–	1,300.	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	2,100.	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	120.	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	52.	–	–	–	–	–

	SITE A S-31 L.S. = 499.54			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5-2.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.5-4.0			–	–	–	–	–	–	–	–
3	4.0-4.5			25.1	–	–	–	–	–	–	–
4	4.5-5.0	ROXANA SILT		–	–	–	–	–	–	–	–
5	6.5-7.0			–	–	–	–	–	–	–	–
6	8.5-9.0	BERRY CLAY		21.4	–	–	–	–	–	–	–
7	9.5-10.0			–	–	–	–	–	–	–	–
8	11.5-12.0			–	–	–	–	–	–	–	–

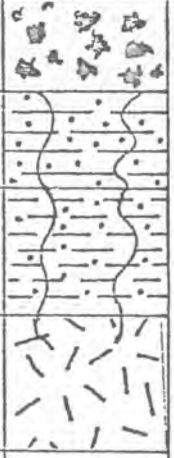
S-31	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	2,000.	–	–	–	–	–
2	–	–	–	–	–	–	4,000.	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	850.	–	–	–	–	–
5	–	–	–	–	–	–	120.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	73.	–	–	–	–	–
8	–	–	–	–	–	–	77.	–	–	–	–	–

	SITE A S-32 L.S. = 498.44			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5–2.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.5–4.0			26.8	–	–	–	–	–	–	–
3	4.0–4.5			–	–	–	–	–	–	–	–
4	4.5–5.0			–	–	–	–	–	–	–	–
5	6.5–7.0	ROXANA SILT AND BERRY CLAY		–	–	–	–	–	–	–	–
6	8.5–9.0			23.8	–	–	–	–	–	–	–
7	9.0–9.5			–	–	–	–	–	–	–	–
8	11.5–12.0			–	–	–	–	–	–	–	–
9	13.5–14.0	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
10	14.5–15.0			12.8	–	–	–	–	–	–	–

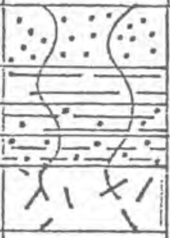
S-32	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	2100.	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	540.	–	–	–	–	–
4	–	–	–	–	–	–	460.	–	–	–	–	–
5	–	–	–	–	–	–	250.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	520.	–	–	–	–	–
8	–	–	–	–	–	–	61.	–	–	–	–	–
9	–	–	–	–	–	–	64.	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A S-33 L.S. = 497.92			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5-2.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.5-4.0	ROXANA SILT		–	–	–	–	–	–	–	–
3	4.0-4.5			30.3	–	–	–	–	–	–	–
4	4.5-5.0	BERRY CLAY		–	–	–	–	–	–	–	–
5	6.0-6.5			–	–	–	–	–	–	–	–
6	7.0-7.5			–	–	–	–	–	–	–	–
7	8.5-9.0			22.2	–	–	–	–	–	–	–
8	9.5-10.0			–	–	–	–	–	–	–	–
9	11.0-11.5			20.1	–	–	–	–	–	–	–
10	12.0-12.5	HAGARSTOWN		–	–	–	–	–	–	–	–
11	12.5-13.0	GLASFORD FORMATION TILL		17.7	–	–	–	–	–	–	–
12	14.0-14.5			–	–	–	–	–	–	–	–

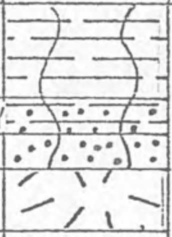
S-33	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/100g
1	–	–	–	–	–	–	11,000.	–	–	–	–	–
2	–	–	–	–	–	–	4,500.	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	120.	–	–	–	–	–
5	–	–	–	–	–	–	77.	–	–	–	–	–
6	–	–	–	–	–	–	33.	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	56.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	62.	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	46.	–	–	–	–	–

No.	SITE A S-34 L.S. = 503.69			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	FILL		–	–	–	–	–	–	–	–
2	2.5-3.0			–	–	–	–	–	–	–	–
3	4.5-5.0	PEORIA LOESS AND ROXANA SILT		–	–	–	–	2	13	61	26
4	5.0-5.5			–	–	–	–	0	3	76	21
5	7.0-7.5			–	–	–	–	2	19	45	36
6	7.5-8.0	BERRY CLAY (34-34-32)		–	–	–	–	1	27	40	33
7	9.0-9.5			–	–	–	–	2	39	33	28
8	10.5-11.0			–	–	–	–	–	–	–	–
9	11.0-11.5			–	–	–	–	4	35	32	33
10	11.5-12.0	GLASFORD FORMATION TILL (35-37-28)		–	–	–	–	3	37	36	27
11	14.0-14.5			–	–	–	–	6	35	34	31
12	17.0-17.5			–	–	–	–	7	32	42	26
13	19.0-19.5			–	–	–	–	–	–	–	–

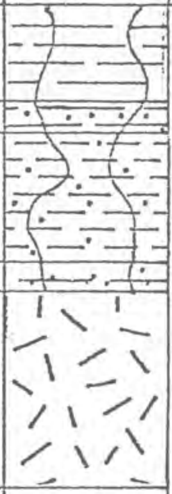
S-34 No.	X-Ray Data						Chemical Data					
	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	20,000.	34.	28000.	25000.	–	–
2	–	–	–	–	–	–	24,000.	85.	16000.	11000.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	110.	.13	46.	15.	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	32.	.12	38.	4.0	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	27.	.27	41.	2.2		
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	30.	<D.L.	36.	7.2	–	–

No.	SITE A S-35 L.S. = 506.36			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	ALLUVIUM		–	–	–	–	–	–	–	–
2	3.0-3.5	PEORIA LOESS		–	–	–	–	–	–	–	–
3	6.0-6.5	ROXANA SILT		–	–	–	–	–	–	–	–
4	9.0-9.5	BERRY CLAY		–	–	–	–	–	–	–	–
5	12.0-12.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
6	15.0-15.5			–	–	–	–	–	–	–	–

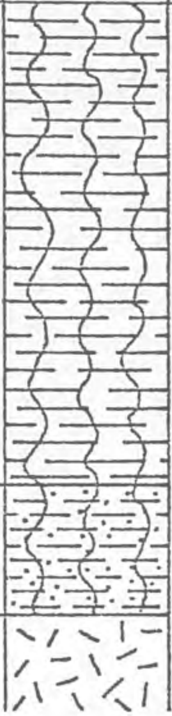
S-35	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/100g
1	–	–	–	–	–	–	1300.	2.1	650.	490.	–	–
2	–	–	–	–	–	–	8.8	.14	36.	8.3	–	–
3	–	–	–	–	–	–	14.	<D.L	31.	6.7	–	–
4	–	–	–	–	–	–	25.	"	35.	6.0	–	–
5	–	–	–	–	–	–	72.	.24	42.	22.	–	–
6	–	–	–	–	–	–	28.	.41	30.	4.6	–	–

	SITE A S-36 L.S. = 503.47			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0–0.3	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.0–3.5			–	–	–	–	–	–	–	–
3	6.0–6.5	ROXANA & BERRY		–	–	–	–	–	–	–	–
4	10.5–11.0	HAGARSTOWN		–	–	–	–	–	–	–	–
5	14.0–14.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
6	18.5–19.0			–	–	–	–	–	–	–	–

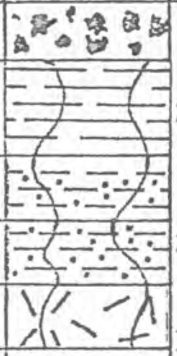
S-36	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	92.	.33	47.	26.	–	–
2	–	–	–	–	–	–	14.	.05	27.	9.9	–	–
3	–	–	–	–	–	–	50.	<D.L.	21.	7.1	–	–
4	–	–	–	–	–	–	13.	"	31.	<D.L.	–	–
5	–	–	–	–	–	–	110.	.42	33.	7.5	–	–
6	–	–	–	–	–	–	36.	<D.L.	45.	6.6	–	–

No.	SITE A S-37 L.S. = 503.56			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (17-50-33)		–	–	–	–	0	16	52	32
2	1.5-2.0			–	–	–	–	1	19	48	33
3	3.5-4.0	ROXANA SILT		–	–	–	–	2	24	39	37
4	5.5-6.0	BERRY CLAY (23-41-36)		–	–	–	–	0	21	42	37
5	6.0-6.5			–	–	–	–	–	–	–	–
6	6.5-7.0			–	–	–	–	2	25	40	35
7	7.0-7.5			–	–	–	–	1	24	41	35
8	9.0-9.5	HAGARSTOWN		–	–	–	–	6	51	31	18
9	13.0-13.5	GLASFORD FORMATION TILL (32-39-29)		–	–	–	–	8	33	38	29
10	15.5-16.0			–	–	–	–	4	33	40	27
11	16.0-16.5			–	–	–	–	–	–	–	–
12	18.5-19.0			–	–	–	–	4	33	41	26
13	19.0-19.5			–	–	–	–	–	–	–	–
14	23.5-24.0			–	–	–	–	5	29	38	33

S-37	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	180.	.64	140.	64.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	24.	<D.L.	39.	6.9	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	22.	<D.L.	47.	3.9	–	–
9	–	–	–	–	–	–	42.	.20	40.	11.	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	39.	<D.L.	59.	5.9	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	30.	.18	45.	6.0		
14	–	–	–	–	–	–	–	–	–	–	–	–

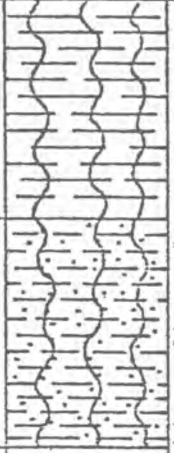
	SITE A C-2 L.S. = 509.06			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	PEORIA LOESS AND ROXANA SILT		–	–	–	–	–	–	–	–
2	1.0-1.5			–	–	–	–	1	8	65	27
3	2.0-2.5			–	–	–	–	–	–	–	–
4	3.0-3.5			–	–	–	–	1	4	49	47
5	4.0-4.5			22.9	–	–	–	–	–	–	–
6	4.5-5.0			–	–	–	–	–	–	–	–
7	5.5-6.0			–	–	–	–	0	5	59	36
8	6.5-7.0			–	–	–	–	–	–	–	–
9	8.0-8.5			–	–	–	–	–	–	–	–
10	8.5-9.0			–	–	–	–	2	19	48	33
11	9.0-9.5			–	–	–	–	–	–	–	–
12	10.5-11.0			–	–	–	–	–	–	–	–
13	11.0-11.5			21.1	–	–	–	1	18	41	41
14	11.5-12.0			–	–	–	–	–	–	–	–
15	12.3-12.8	BERRY CLAY		–	–	–	–	–	–	–	–
16	12.8-13.3			21.9	–	–	–	0	19	49	32
17	13.3-13.8			–	–	–	–	–	–	–	–
18	14.3-14.8			–	–	–	–	–	–	–	–
19	14.8-15.3	GLASFORD FORMATION TILL		–	–	–	–	2	40	34	26
20	15.3-15.8			–	–	–	–	3	42	29	29
21	15.8-16.3			–	–	–	–	5	35	43	22

C-2	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	7800.	3.7	1100.	2500.	–	–
2	–	–	–	–	–	–	630.	1.2	6.5	25.	–	–
3	–	–	–	–	–	–	1400.	–	–	–	–	–
4	–	–	–	–	–	–	1400.	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	1600.	.74	16.	13.	–	–
7	–	–	–	–	–	–	1600.	–	–	–	–	–
8	–	–	–	–	–	–	1800.	–	–	–	–	–
9	–	–	–	–	–	–	1400.	.68	13.	15.	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	940.	–	–	–	5.6	6.5
12	–	–	–	–	–	–	930.	.46	11.	12.	6.1	5.4
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	540.	–	–	–	–	–
15	–	–	–	–	–	–	240.	–	–	–	6.0	5.4
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	220.	<.08	11.	11.	–	–
18	–	–	–	–	–	–	970.	<.08	12.	11.	6.3	5.9
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	43.	<.12	16.	14.	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–

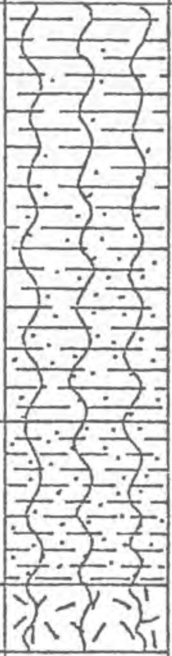
No.	SITE A C-3 L.S. = 508.14			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	FILL		–	–	–	–	–	–	–	–
2	3.0-3.5	PEORIA LOESS		–	–	–	–	–	–	–	–
3	4.0-4.5			29.7	–	–	–	–	–	–	–
4	4.5-5.0			–	–	–	–	–	–	–	–
5	6.0-6.5	ROXANA SILT		–	–	–	–	–	–	–	–
6	8.0-8.5			–	–	–	–	–	–	–	–
7	9.0-9.5	BERRY CLAY		22.0	–	–	–	–	–	–	–
8	10.5-11.0			–	–	–	–	–	–	–	–
9	13.0-13.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
10	13.5-14.0			18.9	–	–	–	–	–	–	–

C-3

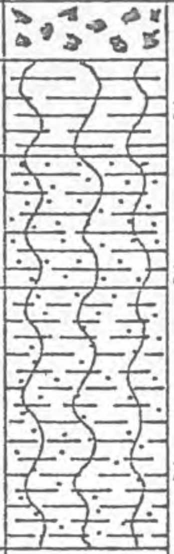
C-3	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	1600.	–	–	–	–	–
2	–	–	–	–	–	–	1400.	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	340.	–	–	–	–	–
5	–	–	–	–	–	–	420.	–	–	–	–	–
6	–	–	–	–	–	–	870.	–	–	–	–	–
7	–	–	–	–	–	–	710.	–	–	–	–	–
8	–	–	–	–	–	–	61.	–	–	–	–	–
9	–	–	–	–	–	–	48.	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–

	SITE A C-4 L.S. = 507.60			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS		–	–	–	–	15	23	46	31
2	1.5-2.0			–	–	–	–	–	–	–	–
3	2.0-2.5			–	–	–	–	0	6	75	19
4	3.0-3.5			–	–	–	–	–	–	–	–
5	4.5-5.0			–	–	–	–	0	5	46	49
6	5.0-5.5			–	–	–	–	0	9	66	25
7	5.5-6.0	ROXANA SILT AND BERRY CLAY		20.2	–	–	–	0	12	55	33
8	6.5-7.0			–	–	–	–	–	–	–	–
9	8.5-9.0			–	–	–	–	–	–	–	–
10	9.0-9.5			21.8	–	–	–	–	–	–	–
11	10.5-11.0			–	–	–	–	–	–	–	–
12	12.5-13.0			–	–	–	–	–	–	–	–
13	14.0-14.5			15.0	–	–	–	–	–	–	–

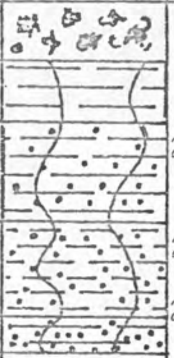
C-4	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	3900.	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	860.	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	69.	–	–	–	–	–
9	–	–	–	–	–	–	85.	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	40.	–	–	–	–	–
12	–	–	–	–	–	–	50.	–	–	–	–	–
13	–	–	–	–	–	–	48.	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–

	SITE A C-5 L.S. = 507.80			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS AND ROXANA SILT		–	–	–	–	–	–	–	–
2	2.0-2.5			–	–	–	–	0	4	69	27
3	2.5-3.0			–	–	–	–	–	–	–	–
4	3.5-4.0			–	–	–	–	0	1	48	51
5	4.0-4.5			28.0	–	–	–	–	–	–	–
6	6.0-6.5			–	–	–	–	0	4	58	38
7	6.5-7.0			–	–	–	–	0	11	59	30
8	8.0-8.5			–	–	–	–	–	–	–	–
9	8.5-9.0			–	–	–	–	–	–	–	–
10	9.0-9.5			–	–	–	–	–	–	–	–
11	9.5-10.0			–	–	–	–	0	5	55	40
12	10.5-11.0			–	–	–	–	–	–	–	–
13	11.0-11.5	BERRY CLAY		–	–	–	–	1	30	33	37
14	11.5-12.0			26.2	–	–	–	–	–	–	–
15	12.0-12.5			–	–	–	–	–	–	–	–
16	13.0-13.5			–	–	–	–	–	–	–	–
17	13.5-14.0			–	–	–	–	3	29	33	38
18	14.0-14.5	GLASFORD FORMATION TILL		–	–	–	–	3	27	45	28
19	14.5-15.0			18.8	–	–	–	13	37	33	30

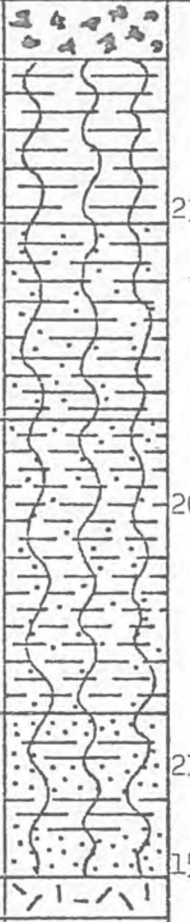
C-5	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	64,000.	45.	4,100.	4,100.	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	2,800.	–	–	–	–	–
4	–	–	–	–	–	–	830.	.50	28.	17.	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	27.	1.0	12.	12.	–	–
7	–	–	–	–	–	–	–	–	–	–	6.9	5.9
8	–	–	–	–	–	–	390.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	6.5	5.4
10	–	–	–	–	–	–	270.	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	6.1	6.8
12	–	–	–	–	–	–	500.	12.	11.	16.	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	2,000.	22.	10.	13.	–	–
15	–	–	–	–	–	–	–	–	–	–	5.5	5.1
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	4,300.	–	–	–	–	–
18	–	–	–	–	–	–	4,300.	26.	14.	14.	5.6	3.4
19	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A C-6 L.S. = 508.06			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	0.5–1.0	FILL		–	–	–	–	–	–	–	–
2	3.0–3.5	PEORIA LOESS		–	–	–	–	1	20	55	25
3	3.5–4.0			23.9	–	–	–	1	4	77	19
4	5.5–6.0			–	–	–	–	–	–	–	–
5	6.0–6.5	ROXANA SILT		–	–	–	–	0	32	44	24
6	7.5–8.0			–	–	–	–	–	–	–	–
7	8.5–9.0			–	–	–	–	–	–	–	–
8	9.0–9.5			21.4	–	–	–	3	22	43	35
9	10.5–11.0	BERRY CLAY		–	–	–	–	1	29	31	40
10	11.0–11.5			–	–	–	–	–	–	–	–
11	12.0–12.5			–	–	–	–	2	32	33	35
12	13.0–13.5			–	–	–	–	–	–	–	–
13	13.5–14.0			–	–	–	–	2	28	39	33
14	14.0–14.5			23.3	–	–	–	–	–	–	–
15	15.5–16.0			–	–	–	–	–	–	–	–
16	17.5–18.0			–	–	–	–	–	–	–	–

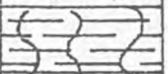
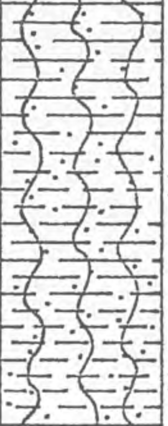
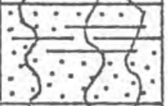
C-6	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	35,000	43.	1000.	2000.	–	–
2	–	–	–	–	–	–	9,000	40.	72.	260.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	3,400.	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	6,300.	18.	22.	110.	–	–
7	–	–	–	–	–	–	7,000.	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	710.	3.7	7.0	13.	5.3	5.6
11	–	–	–	–	–	–	98.	.12	8.5	19.	6.3	7.1
12	–	–	–	–	–	–	160.	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	62.	<.08	6.8	9.5	–	–
16	–	–	–	–	–	–	53.	–	–	–	–	–

	SITE A C-7 L.S. = 506.99			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	FILL		–	–	–	–	–	–	–	–
2	3.0-3.5	PEORIA LOESS		–	–	–	–	–	–	–	–
3	3.5-4.0			–	–	–	–	–	–	–	–
4	5.5-6.0	ROXANA SILT		26.3	–	–	–	–	–	–	–
5	6.0-6.5			–	–	–	–	–	–	–	–
6	7.5-8.0			–	–	–	–	–	–	–	–
7	8.5-9.0	BERRY CLAY		26.0	–	–	–	–	–	–	–
8	9.5-10.0			–	–	–	–	–	–	–	–
9	11.5-12.0			28.5	–	–	–	–	–	–	–
10	12.0-12.5	HAGARSTOWN		–	–	–	–	–	–	–	–

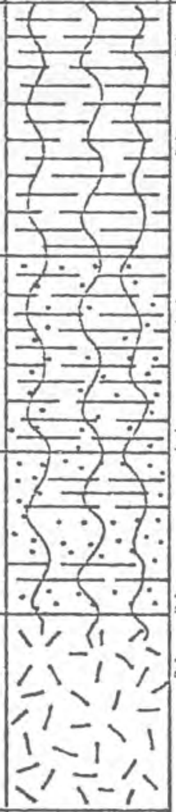
C-7	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	6000.	32.	8.5	130.	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	770.	–	–	–	–	–
6	–	–	–	–	–	–	740.	.38	11.	13.	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	860.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	72.	<.08	14.	14.	–	–

	SITE A C-8 L.S. = 505.85			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5-2.0	FILL		–	–	–	–	–	–	–	–
2	2.0-2.5	PEORIA LOESS		–	–	–	–	0	9	66	25
3	2.5-3.0			–	–	–	–	0	4	52	44
4	3.0-3.5			–	–	–	–	0	7	57	36
5	3.5-4.0			–	–	–	–	1	8	58	34
6	4.0-4.5			23.5	–	–	–	–	–	–	–
7	4.5-5.0	ROXANA SILT		–	–	–	–	4	11	62	27
8	5.0-5.5			–	–	–	–	0	12	61	27
9	5.5-6.0			–	–	–	–	0	14	56	30
10	6.0-6.5			–	–	–	–	0	10	58	32
11	6.5-7.0			–	–	–	–	0	14	59	27
12	7.0-7.5			–	–	–	–	1	17	55	28
13	8.0-8.5	BERRY CLAY		–	–	–	–	0	24	36	40
14	8.5-9.0			–	–	–	–	1	24	36	40
15	9.0-9.5			20.5	–	–	–	–	–	–	–
16	9.5-10.0			–	–	–	–	1	27	35	38
17	11.0-11.5			–	–	–	–	1	25	33	42
18	11.5-12.0			–	–	–	–	1	26	38	36
19	12.0-12.5			–	–	–	–	1	28	32	40
20	12.5-13.0			–	–	–	–	3	29	36	35
21	13.0-13.5			–	–	–	–	2	29	34	37
22	13.5-14.0	HAGARSTOWN MEMBER		–	–	–	–	3	32	36	32
23	14.0-14.5			21.3	–	–	–	–	–	–	–
24	14.5-15.0			–	–	–	–	2	32	35	33
25	15.0-15.5			–	–	–	–	5	31	39	30
26	15.5-16.0			15.9	–	–	–	–	–	–	–
27	16.5-16.6	GLASFORD FORMATION TILL		–	–	–	–	4	32	38	30

C-8	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/100g
1	–	–	–	–	–	–	220,000.	11.	2300.	13,000.	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	14,000.	4.5	18.	80.	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	160.	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–

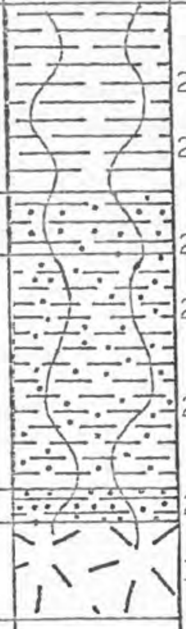
	SITE A C-9 L.S. = 507.87			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	FILL		–	–	–	–	–	–	–	–
2	3.0-3.5			–	–	–	–	28	31	36	33
3	6.5-7.0	PEORIA LOESS		24.6	–	–	–	–	–	–	–
4	7.0-7.5			–	–	–	–	–	–	–	–
5	7.5-8.0	ROXANA SILT AND BERRY CLAY		–	–	–	–	1	40	40	20
6	8.0-8.5			–	–	–	–	1	31	46	23
7	8.5-9.0			–	–	–	–	1	29	47	24
8	9.0-9.5			–	–	–	–	1	29	45	26
9	9.5-10.0			–	–	–	–	1	30	33	37
10	10.5-11.0			18.8	–	–	–	–	–	–	–
11	11.0-11.5			–	–	–	–	1	30	34	36
12	11.5-12.0			–	–	–	–	3	31	32	37
13	12.0-12.5			–	–	–	–	0	27	40	33
14	13.5-14.0			–	–	–	–	1	31	39	30
15	14.0-14.5			–	–	–	–	1	31	39	30
16	14.5-15.0			20.0	–	–	–	–	–	–	–
17	15.5-16.0			–	–	–	–	2	29	34	37
18	16.0-16.5	HAGARSTOWN MEMBER		–	–	–	–	3	33	31	36
19	16.5-17.0			–	–	–	–	1	33	33	34
20	17.0-17.5			–	–	–	–	2	32	33	35
21	17.5-18.0	GLASFORD FORMATION TILL		–	–	–	–	5	30	36	34
22	18.0-18.5			–	–	–	–	2	30	37	33
23	18.5-19.0			–	–	–	–	3	28	44	28
24	19.0-19.5			13.3	–	–	–	–	–	–	–
25	19.5-20.0			–	–	–	–	7	33	39	28

C-9	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	150,000.	34.	5100.	23000.	–	–
2	–	–	–	–	–	–	340,000.	86.	1600.	20000.	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	13,000.	6.0	42.	200.	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	240.	.22	10.	9.1	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	160.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	66.	<.08	11.	14.	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	99.	–	–	–	6.2	5.9
14	–	–	–	–	–	–	500.	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	1100.	.62	22.	66.	6.3	5.4
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	190.	.36	15.	23.	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE A C-10 L.S. = 505.07			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS		23.6	–	–	–	–	–	–	–
2	1.5-2.0			–	–	–	–	1	14	66	20
3	2.0-2.5			–	–	–	–	1	12	64	24
4	3.5-4.0			21.6	–	–	–	–	–	–	–
5	4.0-4.5			–	–	–	–	1	10	46	44
6	4.5-5.0			–	–	–	–	1	5	49	46
7	5.0-5.5			–	–	–	–	1	12	56	32
8	5.5-6.0	ROXANA SILT AND BERRY CLAY		–	–	–	–	1	12	55	33
9	6.0-6.5			33.4	–	–	–	–	–	–	–
10	6.5-7.0			–	–	–	–	0	23	44	33
11	7.0-7.5			–	–	–	–	1	34	31	35
12	8.0-8.5			–	–	–	–	0	23	42	35
13	8.5-9.0			18.2	–	–	–	–	–	–	–
14	9.0-9.5	HAGARSTOWN MEMBER		–	–	–	–	2	37	30	33
15	9.5-10.0			–	–	–	–	2	37	29	34
16	10.5-11.0			–	–	–	–	6	42	32	26
17	11.0-11.5			–	–	–	–	2	37	29	34
18	11.5-12.0			20.6	–	–	–	–	–	–	–
19	12.0-12.5	GLASFORD FORMATION TILL		–	–	–	–	2	30	35	35
20	13.5-14.0			21.5	–	–	–	–	–	–	–
21	14.0-14.5			–	–	–	–	3	33	33	34
22	14.5-15.0			–	–	–	–	6	31	36	33
23	15.0-15.5			–	–	–	–	4	33	38	29
24	15.5-16.0			–	–	–	–	4	33	36	31

C-10	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	2,600.	1.4	4.8	31.	4.12	–
3	–	–	–	–	–	–	1,400.	<.08	18.	42.	4.20	
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	110.	–	–	–	630	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	180.	–	–	–	5.80	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	720.	.62	15.	15.	5.45	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	230.	–	–	–	6.25	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	1100.	.24	14.	20.	5.20	–
15	–	–	–	–	–	–	–	–	–	–	5.6	5.4
16	–	–	–	–	–	–	850.	–	–	–	5.22	2.5
17	–	–	–	–	–	–	1900.	.52	14.	16.	5.10	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	850.	–	–	–	5.05	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	780.	.36	23.	14.	5.60	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–

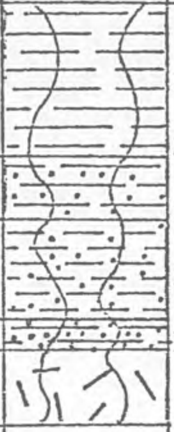
C-12

	SITE A C-12 L.S. = 505.66			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS		–	–	–	–	–	–	–	–
2	1.5-2.0			24.2	–	–	–	–	–	–	–
3	3.0-3.5			–	–	–	–	–	–	–	–
4	4.0-4.5			27.3	–	–	–	–	–	–	–
5	4.5-5.0			–	–	–	–	–	–	–	–
6	5.5-6.0	ROXANA SILT		–	–	–	–	–	–	–	–
7	6.5-7.0	BERRY CLAY		25.0	–	–	–	–	–	–	–
8	8.0-8.5			–	–	–	–	–	–	–	–
9	9.0-9.5			21.9	–	–	–	–	–	–	–
10	9.5-10.0			–	–	–	–	–	–	–	–
11	10.5-11.0			–	–	–	–	–	–	–	–
12	11.5-12.0			20.8	–	–	–	–	–	–	–
13	12.0-12.5			–	–	–	–	–	–	–	–
14	13.0-13.5			–	–	–	–	–	–	–	–
15	14.0-14.5	HAGARSTOWN		22.8	–	–	–	–	–	–	–
16	15.5-16.0	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
17	16.5-17.0			12.2	–	–	–	–	–	–	–
18	17.0-17.5			–	–	–	–	–	–	–	–

C-12

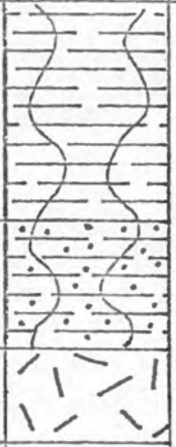
C-12	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	440.	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	40.	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	350.	–	–	–	–	–
6	–	–	–	–	–	–	10.	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	31.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	470.	–	–	–	–	–
11	–	–	–	–	–	–	80.	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	100.	–	–	–	–	–
14	–	–	–	–	–	–	50.	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	60.	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	86.	–	–	–	–	–

C-13

No.	SITE A C-13 L.S. = 506.62			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	0.5–1.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	1.5–2.0			28.0	–	–	–	–	–	–	–
3	3.5–4.0			–	–	–	–	–	–	–	–
4	4.0–4.5			23.9	–	–	–	–	–	–	–
5	6.0–6.5	ROXANA SILT		–	–	–	–	–	–	–	–
6	6.5–7.0			25.0	–	–	–	–	–	–	–
7	8.0–8.5	BERRY CLAY		–	–	–	–	–	–	–	–
8	9.0–9.5			23.4	–	–	–	–	–	–	–
9	10.0–10.5			–	–	–	–	–	–	–	–
10	11.5–12.0	HAGARSTOWN		19.3	–	–	–	–	–	–	–
11	12.0–12.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–

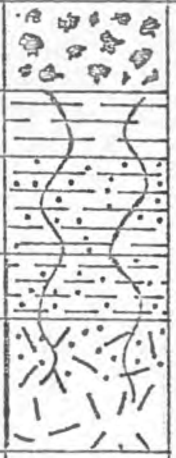
C-13

C-13 No.	X-Ray Data						Chemical Data					
	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	98.	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	28.	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	33.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	34.	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	36.	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	50.	–	–	–	–	–

No.	SITE A C-14 L.S. = 508.68			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS AND ROXANA SILT		–	–	–	–	–	–	–	–
2	1.5-2.0			–	–	–	–	–	–	–	–
3	2.5-3.0			–	–	–	–	–	–	–	–
4	4.0-4.5			–	–	–	–	–	–	–	–
5	5.0-5.5			–	–	–	–	–	–	–	–
6	6.5-7.0			–	–	–	–	–	–	–	–
7	8.0-8.5	BERRY CLAY		–	–	–	–	–	–	–	–
8	9.0-9.5			–	–	–	–	–	–	–	–
9	10.0-10.5			–	–	–	–	–	–	–	–
10	11.5-12.0			–	–	–	–	–	–	–	–
11	13.0-13.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–

C-14

C-14	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	1900.	–	–	–	–	–
2	–	–	–	–	–	–	1800.	–	–	–	–	–
3	–	–	–	–	–	–	21.	–	–	–	–	–
4	–	–	–	–	–	–	50.	–	–	–	–	–
5	–	–	–	–	–	–	16.	–	–	–	–	–
6	–	–	–	–	–	–	19.	–	–	–	–	–
7	–	–	–	–	–	–	26.	–	–	–	–	–
8	–	–	–	–	–	–	17.	–	–	–	–	–
9	–	–	–	–	–	–	48.	–	–	–	–	–
10	–	–	–	–	–	–	62.	–	–	–	–	–
11	–	–	–	–	–	–	48.	–	–	–	–	–

No.	SITE A C-15 L.S. = 508.72 Depth of Sample (ft)	Unit Description	Graphic Log	Engineering Data W %	Gs	Void Ratio	Dry Den #/ft³	Grain Size Gvl %	Sd %	St %	Cl %
1	3.5-4.0	FILL		–	–	–	–	–	–	–	–
2	4.5-5.0			–	–	–	–	–	–	–	–
3	6.0-6.5	PEORIA LOESS		–	–	–	–	–	–	–	–
4	7.0-7.5			–	–	–	–	–	–	–	–
5	8.0-8.5	ROXANA SILT		–	–	–	–	–	–	–	–
6	9.0-9.5			–	–	–	–	–	–	–	–
7	9.5-10.0			–	–	–	–	–	–	–	–
8	10.5-11.0	BERRY CLAY		–	–	–	–	–	–	–	–
9	12.0-12.5			–	–	–	–	–	–	–	–
10	14.0-14.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
11	15.5-16.0			–	–	–	–	–	–	–	–
12	17.0-17.5			–	–	–	–	–	–	–	–
13	18.0-18.5			–	–	–	–	–	–	–	–

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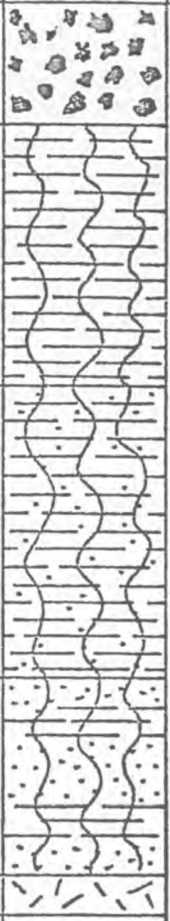
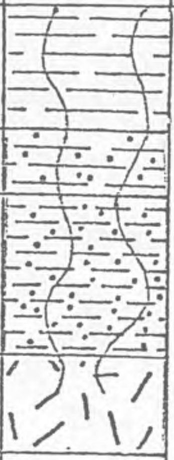
C-15 No.	X-Ray Data DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Chemical Data Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	63,000	83	2200.	9500.	–	–
2	–	–	–	–	–	–	80,000.	–	–	–	–	–
3	–	–	–	–	–	–	2,800.	5.7	17.	27.	–	–
4	–	–	–	–	–	–	5,100.	–	–	–	–	–
5	–	–	–	–	–	–	2,200.	–	–	–	–	–
6	–	–	–	–	–	–	2,100.	–	–	–	–	–
7	–	–	–	–	–	–	6,700.	26.	120.	540.	–	–
8	–	–	–	–	–	–	730.	–	–	–	–	–
9	–	–	–	–	–	–	2,500.	4.6	33.	79.	–	–
10	–	–	–	–	–	–	230.	–	–	–	–	–
11	–	–	–	–	–	–	240.	.26	17.	48.	–	–
12	–	–	–	–	–	–	1,400.	4.2	29.	110.	–	–
13	–	–	–	–	–	–	82.	1.1	21.	19.	–	–

No.	SITE A C-16 L.S. = 507.24			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0–0.5	FILL		–	–	–	–	–	–	–	–
2	1.0–1.5			–	–	–	–	–	–	–	–
3	2.0–2.5			–	–	–	–	35	58	23	19
4	2.5–3.0	PEORIA LOESS		–	–	–	–	0	6	60	34
5	3.0–3.5			–	–	–	–	0	2	64	34
6	3.5–4.0			27.2	–	–	–	–	–	–	–
7	4.0–4.5			–	–	–	–	1	14	53	33
8	4.5–5.0			–	–	–	–	0	18	54	28
9	6.5–7.0			–	–	–	–	2	18	54	28
10	7.0–7.5			24.0	–	–	–	1	19	53	28
11	7.5–8.0			–	–	–	–	3	30	46	24
12	8.0–8.5	ROXANA SILT AND BERRY CLAY		–	–	–	–	2	38	42	20
13	8.5–9.0			23.8	–	–	–	–	–	–	–
14	9.0–9.5			–	–	–	–	0	4	63	33
15	9.5–10.0			–	–	–	–	1	22	41	37
16	10.0–10.5			–	–	–	–	1	20	52	28
17	10.5–11.0			–	–	–	–	1	29	36	35
18	11.0–11.5			25.7	–	–	–	–	–	–	–
19	11.5–12.0			–	–	–	–	3	27	37	36
20	12.0–12.5			–	–	–	–	2	30	35	35
21	12.5–13.0	HAGARSTOWN MEMBER		–	–	–	–	1	34	35	31
22	13.0–13.5			–	–	–	–	1	36	36	28
23	13.5–14.0			20.3	–	–	–	1	44	35	21
24	14.0–14.5			–	–	–	–	3	46	35	19
25	14.5–15.0			–	–	–	–	4	69	20	11
26	15.0–15.5			–	–	–	–	5	65	21	14
27	16.0–16.5	GLASFORD FORMATION TILL		–	–	–	–	11	39	39	22

C-16	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	420,000.	42.	3700.	8000.	–	–
2	–	–	–	–	–	–	14,000.	–	–	–	–	–
3	–	–	–	–	–	–	20,000.	9.	380.	1200.	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	140.	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	80.	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	27.	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	25.	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	20.	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	140.	–	–	–	7.4	4.9
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	33.	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	42.	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	120.	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	31.	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	--	–	–	–	–	–

No.	SITE A C-19 L.S. = 504.37			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.5-4.0			–	–	–	–	–	–	–	–
3	4.5-5.0			22.5	–	–	–	–	–	–	–
4	6.0-6.5	ROXANA SILT		–	–	–	–	–	–	–	–
5	7.0-7.5			23.7	–	–	–	–	–	–	–
6	8.5-9.0	BERRY CLAY		–	–	–	–	–	–	–	–
7	9.0-9.5			22.3	–	–	–	–	–	–	–
8	10.5-11.0			–	–	–	–	–	–	–	–
9	11.0-11.5			–	–	–	–	–	–	–	–
10	11.5-12.0			–	–	–	–	–	–	–	–
11	13.0-13.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
12	14.0-14.5			15.4	–	–	–	–	–	–	–
13	14.5-15.0			–	–	–	–	–	–	–	–

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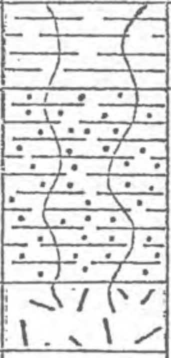
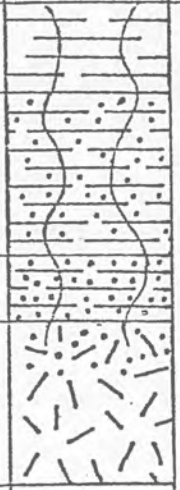
C-19	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	1000.	–	–	–	–	–
2	–	–	–	–	–	–	1200.	–	–	–	–	–
3	–	–	–	–	–	–	20.	–	–	–	–	–
4	–	–	–	–	–	–	69.	–	–	–	–	–
5	–	–	–	–	–	–	27.	–	–	–	–	–
6	–	–	–	–	–	–	42.	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	180.	–	–	–	–	–
9	–	–	–	–	–	–	470.	–	–	–	–	–
10	–	–	–	–	–	–	53.	–	–	–	–	–
11	–	–	–	–	–	–	150.	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	52.	–	–	–	–	–

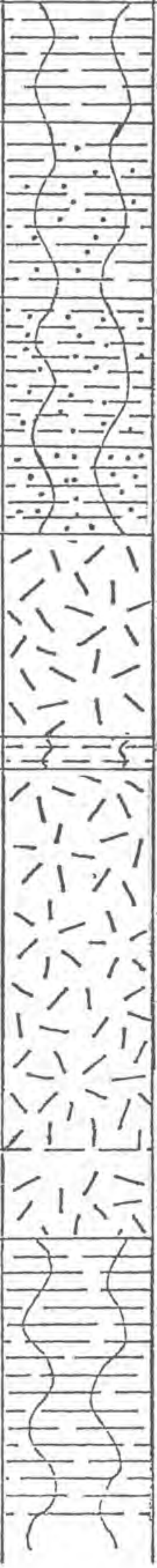
No.	SITE A C-20 L.S. = 505.58			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.5-4.0			–	–	–	–	–	–	–	–
3	5.5-6.0	ROXANNA SILT AND BERRY CLAY		–	–	–	–	–	–	–	–
4	6.5-7.0			20.2	–	–	–	–	–	–	–
5	8.0-8.5			–	–	–	–	–	–	–	–
6	8.5-9.0			22.7	–	–	–	–	–	–	–
7	9.0-9.5			–	–	–	–	–	–	–	–
8	10.5-11.0			–	–	–	–	–	–	–	–
9	12.0-12.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
10	13.5-14.0			–	–	–	–	–	–	–	–

C-20	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	290.	–	–	–	–	–
2	–	–	–	–	–	–	25.	–	–	–	–	–
3	–	–	–	–	–	–	2400.	–	–	–	–	–
4	–	–	–	–	–	–	15.	–	–	–	–	–
5	–	–	–	–	–	–	390.	–	–	–	–	–
6	–	–	–	–	–	–	23.	–	–	–	–	–
7	–	–	–	–	–	–	36.	–	–	–	–	–
8	–	–	–	–	–	–	78.	–	–	–	–	–
9	–	–	–	–	–	–	65.	–	–	–	–	–
10	–	–	–	–	–	–	59.	–	–	–	–	–

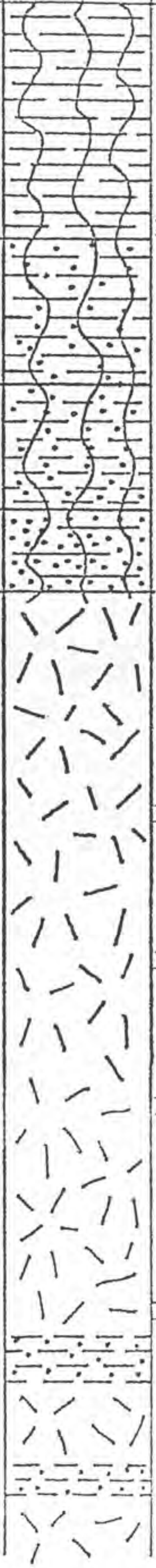
No.	SITE A C-21 L.S. = 506.43			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.0-3.5			–	–	–	–	–	–	–	–
3	5.5-6.0	ROXANNA SILT AND BERRY CLAY		–	–	–	–	–	–	–	–
4	6.0-6.5			22.6	–	–	–	–	–	–	–
5	7.0-7.5			–	–	–	–	–	–	–	–
6	9.0-9.5			–	–	–	–	–	–	–	–
7	9.5-10.0			20.7	–	–	–	–	–	–	–
8	11.0-11.5	HAGARSTOWN		–	–	–	–	–	–	–	–
9	11.5-12.0			27.7	–	–	–	–	–	–	–
10	13.0-13.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
11	14.5-15.0			–	–	–	–	–	–	–	–
12	15.0-15.5			16.8	–	–	–	–	–	–	–
13	15.5-16.0			–	–	–	–	–	–	–	–
14	16.5-17.0			–	–	–	–	–	–	–	–

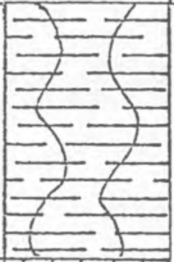
C - 21

C-21	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	2900.	–	–	–	–	–
2	–	–	–	–	–	–	45.	–	–	–	–	–
3	–	–	–	–	–	–	100.	–	–	–	–	–
4	–	–	–	–	–	–	25.	–	–	–	–	–
5	–	–	–	–	–	–	15.	–	–	–	–	–
6	–	–	–	–	–	–	25.	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	26.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	81.	–	–	–	–	–
11	–	–	–	–	–	–	49.	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	48.	–	–	–	–	–
14	–	–	–	–	–	–	47.	–	–	–	–	–

No.	SITE B B-1 L.S. = 457.36			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.5–2.0	PEORIA LOESS (5-63-32)		–	–	–	–	0	5	67	28
2	3.5–4.0			27.8	2.70	.78	94	–	–	–	–
3	4.0–4.5			–	–	–	–	1	4	59	37
4	5.9–6.4	ROXANNA SILT (16-58-28)		–	–	–	–	0	14	57	29
5	6.4–6.9			–	–	–	–	–	–	–	–
6	6.9–7.4			–	–	–	–	1	19	52	29
7	7.4–7.9			–	–	–	–	–	–	–	–
8	8.0–8.4			–	–	–	–	0	16	57	27
9	8.4–8.9			25.0	2.67	.64	102	–	–	–	–
10	9.1–9.6	BERRY CLAY (30-38-32)		–	–	–	–	1	26	43	31
11	10.1–10-6			–	–	–	–	1	31	36	33
12	10.6–11.1			–	–	–	–	–	–	–	–
13	11.1–11.6			–	–	–	–	1	37	30	33
14	12.0–12.5			–	–	–	–	0	27	44	29
15	13.0–13.5	HAGARSTOWN (37-27-36)		–	–	–	–	13	38	24	38
16	13.5–14.0			19.4	2.67	.49	112	–	–	–	–
17	15.0–15.5			–	–	–	–	4	35	31	34
18	15.7–16.2	GLASFORD FORMATION TILL (34-38-28)		–	–	–	–	3	32	40	28
19	17.0–17.5			–	–	–	–	2	30	42	28
20	18.1–18.6			10.7	2.70	.28	131	–	–	–	–
21	18.6–19.1			–	–	–	–	5	34	37	29
22	20.0–20.5			–	–	–	–	3	33	40	27
23	21.1–21.6			–	–	–	–	4	33	39	28
24	22.1–22.6			–	–	–	–	4	41	34	25
25	23.1–23.2	LIERLE CLAY		–	–	–	–	7	27	40	33
26	23.2–23.7	BANNER FORMATION TILL (34-41-25)		–	–	–	–	1	19	39	42
27	24.0–24.5			–	–	–	–	5	28	39	33
28	25.0–25.5			–	–	–	–	6	27	42	31
29	26.0–26.5			–	–	–	–	2	28	41	31
30	28.4–28.9			10.2	2.67	.30	128	3	28	41	31
31	29.0–29.5			–	–	–	–	4	36	40	24
32	30.0–30.5			–	–	–	–	5	31	40	29
33	31.0–31.5			10.4	2.67	.28	130	6	34	43	23
34	32.0–32.5			–	–	–	–	6	33	42	25
35	33.1–33.6			–	–	–	–	7	36	42	22
36	34.0–34.5			–	–	–	–	3	39	42	19
37	35.1–35.6	(oxidized)		–	–	–	–	5	50	35	15
38	38.0–38.5			–	–	–	–	7	38	42	20
39	39.0–39.5	(unoxidized) (25-44-31)		–	–	–	–	3	23	44	33
40	39.9–40.4			16.2	2.67	.43	117	–	–	–	–
41	41.0–41.5			–	–	–	–	3	28	43	29
42	42.0–42.5	ENION FORMATION (7-59-34)		–	–	–	–	0	7	59	34
43	43.0–43.5			–	–	–	–	0	9	63	28
44	43.6–44.0			18.8	2.66	.45	115	–	–	–	–
45	44.1–44.6			–	–	–	–	0	10	60	30
46	45.1–45.6			–	–	–	–	0	6	48	46
47	46.0–46.5			–	–	–	–	0	6	48	46
48	46.6–46.8			–	–	–	–	–	–	–	–
49	46.8–47.3			20.7	2.66	.54	108	–	–	–	–
50	48.0–48.5			–	–	–	–	0	8	59	33

B-1	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	1.65	48	37	15	N.D.	N.D.	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	1.7	8.3	12	5	N.D.	N.D.	680.	–	–	–	–	–
4	1.06	81	11.5	7.5	N.D.	N.D.	370	–	–	–	–	–
5	–	–	–	–	–	–	50	–	–	–	–	–
6	0.75	81	10	9	N.D.	N.D.	–	–	–	–	–	–
7	–	–	–	–	–	–	370	–	–	–	–	–
8	1.12	79.5	13	7.5	N.D.	N.D.	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	.85	81	10.5	8.5	N.D.	N.D.	250	–	–	–	–	–
11	.81	79	11.5	9.5	N.D.	N.D.	20	.08	–	7.6	–	–
12	–	–	–	–	–	–	30	–	–	–	–	–
13	1.14	75.5	15.5	9	N.D.	N.D.	–	–	–	–	–	–
14	.88	80	11.5	8.5	N.D.	N.D.	52	–	–	–	–	–
15	1.55	75	17.5	7.5	18	–	21	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	1.55	70	21	9	N.D.	N.D.	–	–	–	–	–	–
18	1.67	47.5	37.5	15	7	21	–	–	–	–	–	–
19	1.08	38.5	38	23.5	24	27	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	.95	26	43.5	30.5	18	14	–	–	–	–	–	–
22	1.40	33	45.5	21.5	14	17	–	–	–	–	–	–
23	1.04	27.5	44	28.5	22	21	–	–	–	–	–	–
24	.94	19.5	47	33.5	11	15	–	–	–	–	–	–
25	1.45	19	55.5	25.5	35	14	–	–	–	–	–	–
26	.89	64	20.5	15.5	N.D.	N.D.	–	–	–	–	–	–
27	1.7	17.5	59.5	23	49	23	–	–	–	–	–	–
28	1.8	10.5	65	22.5	20	9	–	–	–	–	–	–
29	2.4	26.5	57.5	16	41	15	–	–	–	–	–	–
30	2.2	19	62.5	18.5	34	16	–	–	–	–	–	–
31	3.3	21	66.5	13.5	36	20	–	–	–	–	–	–
32	2.9	19	65.5	15.5	46	21	56.	.20	–	11.	–	–
33	2.6	16	67	17	39	19	–	–	–	–	–	–
34	2.8	16	67.5	16.5	35	16	–	–	–	–	–	–
35	2.4	17.5	64.5	18	51	21	–	–	–	–	–	–
36	3.1	10.5	74.5	16	38	20	–	–	–	–	–	–
37	2.2	14.5	65.5	20	38	35	–	–	–	–	–	–
38	2.4	10.5	70.5	19	45	27	–	–	–	–	–	–
39	1.55	20	56	24	25	10	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	.97	31.5	40.5	28	N.D.	N.D.	–	–	–	–	–	–
42	.62	64	17.5	18.5	N.D.	N.D.	–	–	–	–	–	–
43	.63	68.5	15.5	16	N.D.	N.D.	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	.49	65.5	14.5	20	N.D.	N.D.	–	–	–	–	–	–
46	.46	67	13.5	19.5	N.D.	N.D.	–	–	–	–	–	–
47	.60	66	16	18	N.D.	N.D.	–	–	–	–	–	–
48	–	–	–	–	–	–	24.	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–
50	.59	72.5	13	14.5	N.D.	N.D.	–	–	–	–	–	–

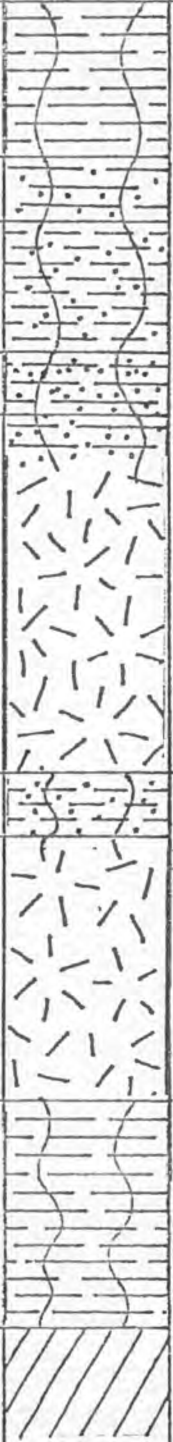
No.	SITE A S-2 L.S. = 507.83 Depth of Sample (ft)	Unit Description	Graphic Log	Engineering Data W %	Gs	Void Ratio	Dry Den #/ft³	Grain Size Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (6-60-34)		–	–	–	–	1	7	71	20
2	1.0-1.5			–	–	–	–	–	–	–	–
3	1.7-2.2			–	–	–	–	0	4	57	39
4	2.7-3.2			–	–	–	–	1	6	56	38
5	3.2-3.7			–	–	–	–	–	–	–	–
6	3.7-4.2			–	–	–	–	1	5	57	38
7	4.2-4.7			24.2	2.76	–	–	–	–	–	–
8	4.7-5.2	ROXANA SILT (24-40-36)		–	–	–	–	1	17	52	31
9	5.8-6.3			–	–	–	–	1	19	44	37
10	7.3-7.6			–	–	–	–	–	–	–	–
11	7.7-8.2			–	–	–	–	2	30	33	37
12	9.1-9.6			–	–	–	–	2	31	30	39
13	9.7-10.2	BERRY CLAY (37-31-32)		–	–	–	–	1	28	36	36
14	10.7-11.2			–	–	–	–	2	33	31	36
15	11.3-11.8			–	–	–	–	10	39	29	32
16	12.4-12.7			–	–	–	–	–	–	–	–
17	12.7-13.2	HAGARSTOWN		–	–	–	–	3	51	27	22
18	13.2-13.7			–	–	–	–	–	–	–	–
19	13.7-14.2			–	–	–	–	4	44	38	18
20	14.7-15.2	GLASFORD FORMATION TILL (29-40-31)		–	–	–	–	7	37	37	26
21	15.7-16.2			–	–	–	–	5	41	33	26
22	16.2-16.7			–	–	–	–	–	–	–	–
23	17.7-18.2			–	–	–	–	4	35	36	29
24	18.2-18.7			–	–	–	–	–	–	–	–
25	18.7-19.2			–	–	–	–	5	30	45	25
26	19.5-20.0			–	–	–	–	3	32	40	28
27	20.1-20.6			13.5	2.70	.39	122	–	–	–	–
28	20.6-21.1			–	–	–	–	3	28	43	29
29	21.7-22.2			–	–	–	–	4	28	39	33
30	22.7-23.2			–	–	–	–	3	35	37	28
31	23.7-24.2			–	–	–	–	3	30	39	31
32	24.2-24.7			15.8	2.70*	.45	117	–	–	–	–
33	24.7-25.2			–	–	–	–	4	30	41	29
34	25.2-25.7			–	–	–	–	–	–	–	–
35	25.7-26.2			–	–	–	–	5	30	40	30
36	26.7-27.2			–	–	–	–	8	27	42	31
37	27.7-28.2			15.7	2.70*	.41	119	–	–	–	–
39	29.5-30.0			–	–	–	–	3	30	38	32
39	31.5-32.0			–	–	–	–	3	26	38	36
40	32.7-33.2			–	–	–	–	5	29	40	31
41	33.7-34.2			–	–	–	–	5	29	41	30
42	34.2-34.7			–	–	–	–	–	–	–	–
43	34.7-35.2			–	–	–	–	3	30	38	32
44	35.2-35.7			16.8	2.70*	.43	118	–	–	–	–
45	36.2-36.7			–	–	–	–	3	27	42	31
46	36.9-37.4			–	–	–	–	1	22	41	37
47	37.7-38.2			–	–	–	–	1	20	40	40
48	38.7-39.2			–	–	–	–	14	33	37	30
49	39.3-39.7			–	–	–	–	–	–	–	–
50	39.7-40.2			–	–	–	–	1	18	49	33
51	42.0-42.5			–	–	–	–	4	29	41	30

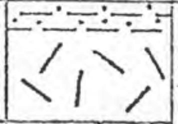
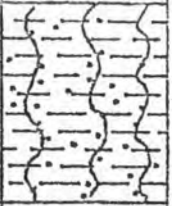
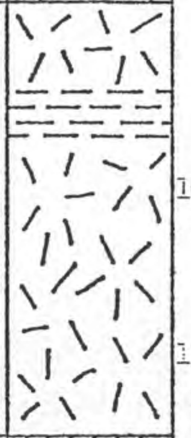
B-1	SITE B B-1 L.S. = 457.36			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
51	49.0-49.5	ENION FORMATION		–	–	–	–	0	16	53	31
52	50.0-50.5			–	–	–	–	0	2	72	26
53	51.0-51.5			–	–	–	–	0	3	74	23
54	56.0-56.5			–	–	–	–	2	5	61	34
55	57.0-57.5			–	–	–	–	3	5	61	34
56	59.0-59.5			–	–	–	–	2	7	63	30
57	59.8-60.4			–	–	–	–	1	8	61	31
58	60.4-60.9	BEDROCK		–	–	–	–	–	–	–	–

S-21	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	–	–	–	46.	–	–
2	–	–	–	–	–	–	16,000	–	19.	20.	–	–
3	1.4	82	12	6	N.D.	N.D.	–	–	–	–	–	–
4	1.6	84	11	5	N.D.	21	–	–	–	–	6.3	9.2
5	–	–	–	–	–	–	71	.24	35.	34.	–	–
6	1.5	81	13	6	N.D.	15	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	1.2	82	11	7	N.D.	N.D.	–	–	–	–	–	–
9	1.1	81	12	7	N.D.	N.D.	670.	.46	26.	35.	–	–
10	–	–	–	–	–	–	430.	N.S.	23.	24.	–	–
11	1.2	87	8	5	N.D.	N.D.	–	–	–	–	–	–
12	1.4	83	11	6	N.D.	N.D.	500.	20.	22.	31.	–	–
13	1.1	75	15	10	N.D.	N.D.	–	–	–	–	–	–
14	0.9	77	13	10	N.D.	18	–	–	–	–	–	–
15	2.1	65	26	9	N.D.	16	320.	7.8	8.0	8.0	–	–
16	–	–	–	–	–	–	350.	–	–	–	–	–
17	1.8	57	31	12	N.D.	10	–	–	–	–	–	–
18	–	–	–	–	–	–	270.	5.0	27.	21.	–	–
19	2.1	25	56	19	N.D.	N.D.	–	–	–	–	–	–
20	2.4	27	57	16	N.D.	25	–	–	–	–	–	–
21	2.1	29	54	17	26	15	1100.	1.6	330.	200.	7.4	7.4
22	–	–	–	–	–	–	–	–	–	–	7.5	5.4
23	1.4	22	53	25	25	18	–	–	–	–	–	–
24	–	–	–	–	–	–	45.	.18	24.	20.	7.4	6.5
25	1.3	43	38	19	19	14	–	–	–	–	–	–
26	1.3	45	36	19	16	14	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	1.1	50	31	19	27	15	–	–	–	–	–	–
29	1.3	53	31	16	15	20	37.	.14	27.	26.	–	–
30	1.3	51	32	17	19	17	–	–	–	–	–	–
31	1.0	51	29	20	13	17	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	1.4	43	38	19	22	18	–	–	–	–	–	–
34	–	–	–	–	–	–	120.	.12	37.	35.	7.5	5.9
35	1.2	47	34	19	15	15	–	–	–	–	–	–
36	1.2	52	30	18	30	N.D.	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	1.1	50	31	19	17	16	35.	~0.4	12.	9.8	–	–
39	1.0	55	26	19	15	16	–	–	–	–	–	–
40	1.2	46	34	20	18	N.D.	–	–	–	–	–	–
41	1.1	45	35	20	17	11	–	–	–	–	–	–
42	–	–	–	–	–	–	33.	~.04	26.	39.	–	–
43	1.3	49	33	18	21	18	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	1.1	51	31	18	22	15	–	–	–	–	–	–
46	0.9	76	14	10	12	N.D.	39.	.16	21.	25.	–	–
47	1.1	80	12	8	15	16	–	–	–	–	–	–
48	1.2	31	44	25	30	19	–	–	–	–	–	–
49	–	–	–	–	–	–	47.	.22	27.	23.	–	–
50	1.0	57	26	17	15	20	–	–	–	–	–	–
51	1.1	37	39	24	13	23	–	–	–	–	–	–

B-1

B-1	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
51	.52	68	14	18.5	N.D.	N.D.	–	–	–	–	–	–
52	.65	66.5	16.5	17	N.D.	N.D.	–	–	–	–	–	–
53	.66	66	19.5	19.5	N.D.	N.D.	–	–	–	–	–	–
54	.53	64.5	15.5	20	N.D.	N.D.	–	–	–	–	–	–
55	.55	68.5	14	17.5	N.D.	N.D.	–	–	–	–	–	–
56	.61	68.5	15	16.5	N.D.	N.D.	–	–	–	–	–	–
57	.57	63	17	20	N.D.	N.D.	98.	.16	–	18.	–	–
58	1.6	11	62.5	26.5	N.D.	N.D.	–	–	–	–	–	–

No.	SITE B B-2 L.S. = 459.38			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (4-62-34)		–	–	–	–	1	7	71	22
2	1.5-2.0			–	–	–	–	0	2	53	45
3	3.0-3.5			–	–	–	–	0	2	62	36
4	3.5-4.0			22.5	2.70	.62	104	–	–	–	–
5	4.6-5.1	ROXANNA SILT (20-54-26)		–	–	–	–	2	19	56	25
6	5.1-5.6			–	–	–	–	–	–	–	–
7	6.1-6.6	BERRY CLAY (32-36-32)		–	–	–	–	1	21	53	26
8	7.2-7.7			20.7	2.70	.59	107	–	–	–	–
9	8.0-8.5			–	–	–	–	2	26	41	33
10	10.0-10.5			–	–	–	–	4	38	32	30
11	11.2-11.7	HAGARSTOWN (46-19-35)		20.4	2.66	.56	106	3	46	22	32
12	12.0-12.5			–	–	–	–	17	46	15	39
13	13.2-13.7	GLASFORD FORMATION TILL (35-39-26)		–	–	–	–	24	60	16	24
14	14.0-14.5			–	–	–	–	1	18	57	25
15	14.8-15.3			–	–	–	–	7	28	40	32
16	16.5-17.0			–	–	–	–	4	34	38	28
17	17.5-18.0			–	–	–	–	3	30	53	17
18	18.0-18.5			–	–	–	–	8	39	38	23
19	19.0-19.5			–	–	–	–	7	42	36	22
20	20.0-20.5			–	–	–	–	6	35	41	24
21	21.0-21.4			–	–	–	–	5	37	38	25
22	21.4-21.9			9.1	2.70	.30	130	–	–	–	–
23	22.0-22.5			–	–	–	–	5	34	40	26
24	23.0-23.5	LIERLE CLAY (22-35-43)		–	–	–	–	2	21	34	45
25	25.0-25.5			–	–	–	–	5	22	37	41
26	25.8-26.3	BANNER FORMATION (26-42-32) (oxidized)		15.1	2.70	.41	120	–	–	–	–
27	27.0-27.5			–	–	–	–	4	31	38	31
28	29.0-29.5			–	–	–	–	5	27	46	27
29	32.0-32.5			–	–	–	–	5	26	40	34
30	33.0-33.5			–	–	–	–	8	24	42	34
31	34.2-34.7			–	–	–	–	3	22	45	33
32	35.1-35.6			–	–	–	–	3	26	42	32
33	37.0-37.5			–	–	–	–	8	23	43	34
34	42.0-42.5	ENION FORMATION (8-54-38)		–	–	–	–	0	3	61	36
35	43.0-43.5			–	–	–	–	0	6	55	39
36	45.0-45.5			–	–	–	–	0	7	54	39
37	45.6-46.1			–	–	–	–	–	–	–	–
38	46.1-46.6			–	–	–	–	2	9	54	37
39	47.0-47.5			–	–	–	–	1	10	50	40
40	49.0-49.5			–	–	–	–	1	12	50	38
41	50.0-50.5	BEDROCK		–	–	–	–	0	1	50	49
42	51.0-51.4			–	–	–	–	0	1	49	50
43	52.0-52.5			–	–	–	–	0	2	37	61

	SITE A S-2 L.S. = 507.83			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
52	42.7-43.2	GLASFORD FORMATION TILL		–	–	–	–	3	27	40	33
53	43.2-43.7			14.4	2.70#	.39	121	–	–	–	–
54	43.7-44.1			–	–	–	–	5	31	43	26
55	44.7-45.2	LIERLE CLAY (25-40-35)		–	–	–	–	2	24	39	37
56	45.8-46.3			–	–	–	–	2	25	38	37
57	46.3-46.8			17.7	2.70	.49	113	–	–	–	–
58	46.8-47.2			–	–	–	–	2	26	41	33
59	47.2-47.7			–	–	–	–	–	–	–	–
60	47.7-48.2			–	–	–	–	4	25	44	31
61	48.7-49.2	BANNER FORMATION TILL (25-45-30)		–	–	–	–	4	30	41	29
62	50.1-50.4			–	–	–	–	8	32	41	27
63	50.4-51.1			–	–	–	–	0	36	45	19
64	51.7-52.2			–	–	–	–	1	21	52	27
65	52.7-53.2			–	–	–	–	3	21	44	35
66	53.3-53.8			10.8	2.70	.30	130	–	–	–	–
67	54.3-54.6			–	–	–	–	–	–	–	–
68	54.7-55.2			–	–	–	–	2	18	47	34
69	56.2-56.7			–	–	–	–	4	22	44	34
70	57.2-57.7			–	–	–	–	4	22	45	33
71	58.0-58.5			13.6	2.70#	.37	123	–	–	–	–
72	58.5-59.0			–	–	–	–	–	–	–	–
73	59.0-59.5			–	–	–	–	4	22	44	34
		BEDROCK									

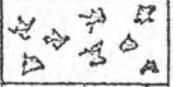
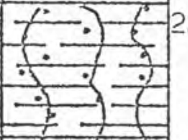
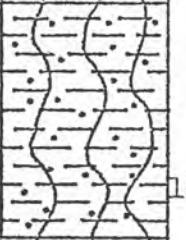
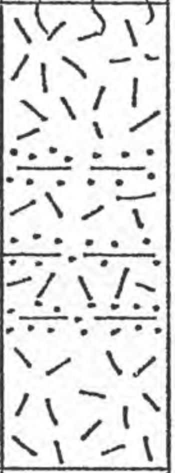
#Estimate

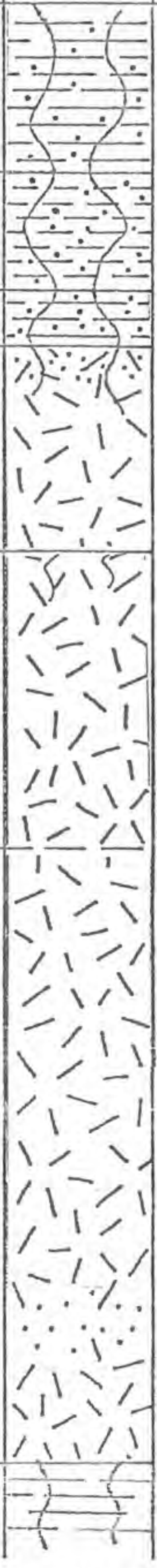
B-2	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	1.65	48	37	15	N.D.	N.D.	–	–	–	–	–	–
2	1.65	75	18	7	N.D.	N.D.	48.	–	–	–	–	–
3	1.6	78.5	15	6.5	N.D.	N.D.	40.	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	1.2	82	11.5	6.5	N.D.	N.D.	25.	–	–	–	–	–
6	–	–	–	–	–	–	23.	–	–	–	–	–
7	1.0	81.5	11	7.5	N.D.	N.D.	18.	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	.68	87	6.5	6.5	N.D.	N.D.	–	–	–	–	–	–
10	1.0	85	9	6	N.D.	N.D.	12	–	–	–	–	–
11	1.07	61	23.5	15.5	N.D.	N.D.	–	–	–	–	–	–
12	1.3	55	29	16	N.D.	N.D.	–	–	–	–	–	–
13	1.9	33	47	20	N.D.	N.D.	70.	–	–	–	–	–
14	3.9	24.5	64.5	11	N.D.	N.D.	–	–	–	–	–	–
15	1.4	22	52.5	25.5	10	68	–	–	–	–	7.4	5.4
16	1.7	31	49.5	19.5	11	29	–	–	–	–	–	–
17	1.1	9.5	57	33.5	19	38	–	–	–	–	–	–
18	1.4	22	52.5	25.5	17	26	36.	–	–	–	–	–
19	1.5	23	53.5	23.5	21	21	–	–	–	–	–	–
20	1.8	27	53	20	23	26	–	–	–	–	–	–
21	2.25	36.5	49	14.5	19	18	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	1.3	36	42.5	21.5	20	24	–	–	–	–	–	–
24	0.7	60	21	19	N.D.	N.D.	–	–	–	–	–	–
25	1.06	50	30.5	19.5	N.D.	12	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	2.9	11	72.5	16.5	41	16	–	–	–	–	–	–
28	5.0	13.5	76	10.5	40	22	–	–	–	–	–	–
29	2.4	17	65	18	37	14	–	–	–	–	–	–
30	2.2	24	58.5	17.5	29	15	–	–	–	–	–	–
31	1.4	22.5	52	25.5	30	6	–	–	–	–	–	–
32	1.85	17	61	22	33	17	62.	–	–	–	–	–
33	1.5	26.5	50.5	33	22	13	–	–	–	–	–	–
34	.54	49.5	22.5	28	11	N.D.	–	–	–	–	–	–
35	.53	38	27	35	N.D.	N.D.	–	–	–	–	–	–
36	.55	51	22	27	N.D.	N.D.	–	–	–	–	–	–
37	.42	52.5	18.5	29	N.D.	N.D.	–	–	–	–	–	–
38	.52	54	20	26	N.D.	N.D.	26	–	–	–	–	–
39	.64	46	26	27	9	N.D.	–	–	–	–	–	–
40	.52	34.5	29	36.5	N.D.	10	–	–	–	–	–	–
41	1.35	18	55	27	N.D.	N.D.	–	–	–	–	–	–
42	2.0	7.5	70	23	N.D.	N.D.	120	–	–	–	–	–
43	4.1	6	81	13	11	10	–	–	–	–	–	–

S-2	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
52	0.8	82	9	9	N.D.	12	420.	–	–	–	–	–
53	–	–	–	–	–	–	–	–	–	–	–	–
54	1.6	49	36	15	34	28	–	–	–	–	7.6	4.9
55	1.4	43	39	18	16	30	–	–	–	–	–	–
56	1.6	60	28	12	N.D.	15	260.	.24	83.	130.	7.5	5.4
57	–	–	–	–	–	–	–	–	–	–	–	–
58	1.7	28	51	21	N.D.	18	–	–	–	–	–	–
59	–	–	–	–	–	–	58.	.08	43.	32.	–	–
60	1.4	31	47	22	30	28	–	–	–	–	–	–
61	1.4	21	54	25	34	24	–	–	–	–	–	–
62	1.8	25	54	21	61	25	41.	.28	29.	19.	–	–
63	1.6	24	53	23	33	18	57.	.06	10.	8.0	–	–
64	–	–	–	–	–	–	–	–	–	–	–	–
65	1.2	21	51	28	33	11	–	–	–	–	–	–
66	–	–	–	–	–	–	–	–	–	–	–	–
67	–	–	–	–	–	–	76.	<.04	18.	11.	–	–
68	1.3	20	52	28	37	20	–	–	–	–	–	–
69	1.1	18	51	31	46	22	–	–	–	–	–	–
70	1.3	19	53	28	50	22	–	–	–	–	–	–
71	–	–	–	–	–	–	–	–	–	–	–	–
72	–	–	–	–	–	–	79.	.42	36.	32.	–	–
73	1.2	17	52	31	29	20	–	–	–	–	–	–

No.	SITE A S-9 L.S. = 504.39'			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0–0.5	PEORIA LOESS (11-58-31)		–	–	–	–	–	–	–	–
2	1.0–1.5			–	–	–	–	1	12	59	29
3	1.5–2.0			24.9	–	–	–	–	–	–	–
4	2.0–2.5			–	–	–	–	1	11	56	33
5	2.5–3.0	ROXANA SILT & BERRY CLAY		–	–	–	–	–	–	–	–
6	3.5–4.0			–	–	–	–	1	18	38	44
7	4.0–4.5			24.5	–	–	–	–	–	–	–
8	4.5–5.0			–	–	–	–	0	19	55	26
9	6.0–6.5			–	–	–	–	1	28	37	35
10	6.5–7.0	GLASFORD FORMATION TILL (35-34-31)		15.8	–	–	–	1	34	29	37
11	8.0–8.5			–	–	–	–	1	31	31	38
12	8.5–9.0			–	–	–	–	–	–	–	–
13	9.5–10.0			–	–	–	–	2	38	27	35
14	10.5–11.0			–	–	–	–	1	51	23	26
15	11.0–11.5			28.2	–	–	–	–	–	–	
16	12.0–12.5			–	–	–	–	3	40	35	25
17	12.5–13.0			–	–	–	–	3	40	40	20
18	13.5–13.8			–	–	–	–	–	–	–	–
19	14.5–15.0			11.0	–	–	–	–	–	–	–
20	16.0–16.5			11.0	–	–	–	–	–	–	–
21	18.5–19.0			–	–	–	–	3	34	39	27
22	22.5–23.0			–	–	–	–	6	34	39	27
23	24.5–25.0			14.8	–	–	–	–	–	–	–
24	26.5–27.0			–	–	–	–	5	33	39	28
25	32.0–32.5			8.8	–	–	–	7	38	33	29
26	34.0–34.5			13.2	–	–	–	–	–	–	–
27	35.5–36.0			–	–	–	–	4	36	37	27
28	37.5–38.0			12.9	–	–	–	–	–	–	–
29	39.5–40.0			–	–	–	–	3	33	37	30
30	41.0–41.5			–	–	–	–	6	33	38	29
31	41.5–42.0	BANNER FORMATION TILL (31-45-24)		–	–	–	–	3	25	39	36
32	42.0–42.5			15.7	–	–	–	–	–	–	–
33	42.5–43.0			–	–	–	–	11	30	42	28
34	49.3–49.5			13.5	–	–	–	–	–	–	–
35	50.5–51.0			–	–	–	–	4	30	45	21
36	51.5–52.0			–	–	–	–	3	38	44	18
37	54.0–54.5			16.0	–	–	–	–	–	–	–
38	54.5–55.0			–	–	–	–	0	33	50	17
		BEDROCK									

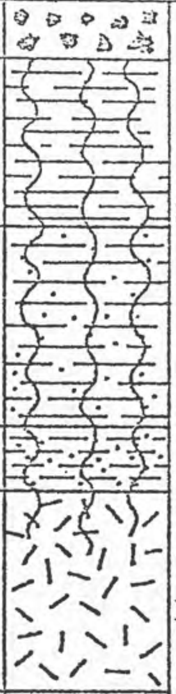
S-91	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/100g
1	–	–	–	–	–	–	1100.	2.0	19.	34.	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	6.0	5.9
5	–	–	–	–	–	–	1600.	2.4	21.	31.	–	–
6	–	–	–	–	–	–	23.	<.12	12.	12.	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	38.	<.12	11.	16.	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	46.	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	60.	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	39.	–	–	–	–	–
18	–	–	–	–	–	–	50.	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	–	–

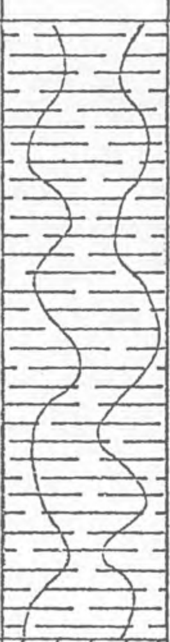
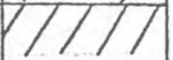
	SITE A S-10 L.S. = 504.16			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	FILL		–	–	–	–	–	–	–	–
2	1.5-2.0			–	–	–	–	–	–	–	–
3	2.0-2.5	ROXANA SILT		22.0	–	–	–	0	15	51	34
4	3.0-3.5			–	–	–	–	–	–	–	–
5	4.5-5.0			–	–	–	–	–	–	–	–
6	5.0-5.7			–	–	–	–	1	16	61	23
7	6.0-6.5	BERRY CLAY (24-36-40)		–	–	–	–	0	21	36	43
8	7.0-7.5			–	–	–	–	0	23	37	40
9	9.0-9.5			–	–	–	–	–	–	–	–
10	9.5-10.0			–	–	–	–	–	–	–	–
11	10.0-10.5			–	–	–	–	–	–	–	–
12	10.7-11.5			16.3	–	–	–	1	29	35	36
13	11.5-12.0			–	–	–	–	–	–	–	–
14	12.5-13.0	GLASFORD FORMATION TILL (34-43-23)		–	–	–	–	5	33	39	28
15	13.5-14.0			–	–	–	–	6	33	41	26
16	15.5-16.0			–	–	–	–	–	–	–	–
17	16.0-16.5			–	–	–	–	3	28	43	29
18	17.5-18.0			–	–	–	–	1	59	25	16
19	18.0-18.5			–	–	–	–	–	–	–	–
20	19.5-20.0			–	–	–	–	0	47	44	9
21	20.0-20.5			–	–	–	–	0	16	72	12
22	20.5-21.0			–	–	–	–	–	–	–	–
23	24.5-25.0			–	–	–	–	5	43	34	23
24	25.0-25.5			–	–	–	–	3	15	47	38
25	25.5-26.0			–	–	–	–	–	–	–	–
26	30.5-31.0			–	–	–	–	–	–	–	–
27	33.5-34.0			–	–	–	–	–	–	–	–

No.	SITE B B-4 L.S. = 446.59 Depth of Sample (ft)	Unit Description	Graphic Log	Engineering Data W %	Gs	Void Ratio	Dry Den #/ft³	Grain Size Gvl %	Sd %	St %	Cl %
1	0.5–0.7	ROXANNA SILT (11-59-30)		–	–	–	–	–	–	–	–
2	0.7–1.2			–	–	–	–	0	13	65	22
3	1.2–1.7			–	–	–	–	–	–	–	–
4	1.7–2.2			–	–	–	–	0	8	56	36
5	2.5–3.0			–	–	–	–	0	12	57	31
6	3.1–3.6	BERRY CLAY (24-40-36)		–	–	–	–	1	16	50	34
7	3.6–4.1			–	–	–	–	1	22	39	39
8	5.5–6.1			–	–	–	–	2	26	39	35
9	6.6–7.1			–	–	–	–	5	32	33	35
10	7.7–8.0	HAGARSTOWN		–	–	–	–	–	–	–	–
11	8.0–8.5			–	–	–	–	1	36	29	35
12	9.1–9.6	GLASFORD FORMATION TILL (49-32-19)		–	–	–	–	6	50	33	17
13	9.6–9.7			–	–	–	–	–	–	–	–
14	10.0–10.5			–	–	–	–	4	54	27	19
15	10.7–11.1			–	–	–	–	3	47	32	21
16				–	–	–	–	–	–	–	–
17	11.5–12.0			–	–	–	–	4	47	34	19
18	12.0–12.5			–	–	–	–	7	38	38	24
19	13.0–13.5	BANNER FORMATION TILL (29-39-32) (oxidized)		–	–	–	–	1	24	40	36
20	14.3–14.9			–	–	–	–	1	28	37	35
21	15.0–15.5			–	–	–	–	3	29	38	33
22	16.0–16.5			–	–	–	–	4	26	40	34
23	17.0–17.6			–	–	–	–	5	27	39	34
24	18.0–18.5			–	–	–	–	3	31	41	28
25	19.1–19.6			–	–	–	–	10	29	41	30
26	20.0–20.5			–	–	–	–	5	29	42	29
27	21.0–21.5			–	–	–	–	4	31	41	28
28	21.9–22.3			–	–	–	–	6	36	35	29
29	23.0–23.5	(unoxidized) (29-43-28)		–	–	–	–	5	33	44	23
30	24.3–24.8			–	–	–	–	7	31	42	27
31	25.0–25.5			–	–	–	–	11	30	45	25
32	26.0–26.5			–	–	–	–	4	28	47	25
33	27.0–27.5			–	–	–	–	5	37	42	21
34	28.0–28.5			–	–	–	–	4	38	41	21
35	28.6–29.1			–	–	–	–	–	–	–	–
36	29.1–29.6			–	–	–	–	6	39	40	21
37	31.0–31.5			–	–	–	–	5	37	42	21
38	32.0–32.5			–	–	–	–	4	22	46	32
39	32.6–33.1			–	–	–	–	–	–	–	–
40	33.1–33.6			–	–	–	–	2	20	46	34
41	36.0–36.5			–	–	–	–	3	33	35	32
42	36.8–37.3			–	–	–	–	2	19	46	35
43	38.0–38.5			–	–	–	–	3	33	42	25
44	39.0–39.4			–	–	–	–	0	62	19	19
45	39.4–39.9			–	–	–	–	–	–	–	–
46	40.0–40.5			–	–	–	–	3	14	47	39
47	41.0–41.5			–	–	–	–	3	18	53	29
48	42.0–42.5			–	–	–	–	1	14	47	39
49	42.8–43.3			–	–	–	–	2	19	46	35
50	44.0–44.5	ENION FORMATION		–	–	–	–	13	12	50	38
51	45.0–45.5			–	–	–	–	10	17	43	40

S-10	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	80,000	39.	6,800	9,200	5.65	–
2	–	–	–	–	–	–	840.	4.1	14.	18.	6.75	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	400.	1.2	17.	16.	6.89	–
5	–	–	–	–	–	–	680.	4.5	14.	13.	6.15	–
6	–	–	–	–	–	–	400.	2.9	10.	12.	6.10	–
7	–	–	–	–	–	–	680.	5.8	9.4	14.	5.95	–
8	–	–	–	–	–	–	800.	2.4	5.6	10.	5.52	–
9	–	–	–	–	–	–	1200.	3.0	8.2	19.	5.55	5.9
10	–	–	–	–	–	–	1800.	–	–	–	5.30	–
11	–	–	–	–	–	–	2000.	3.8	44.	60.	5.80	5.9
12	–	–	–	–	–	–	1500	–	–	–	5.38	–
13	–	–	–	–	–	–	1600	2.4	18.	10.	5.48	2.8
14	–	–	–	–	–	–	200.	1.0	16.	12.	7.55	3.1
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	41.	.28	13.	5.9	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	91.	1.8	14.	8.0	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	21.	.21	11.	6.6	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	21.	.12	7.4	2.8	–	–
26	–	–	–	–	–	–	41.	.15	11.	10.0	–	–
27	–	–	–	–	–	–	43.	.08	14.	12.0	–	–

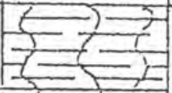
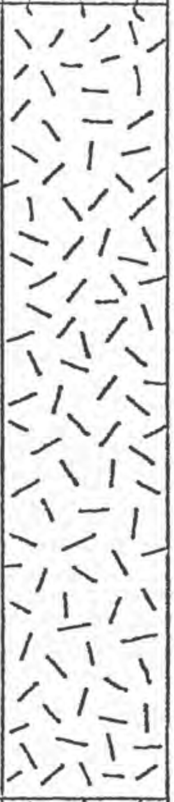
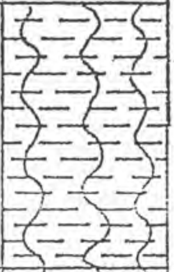
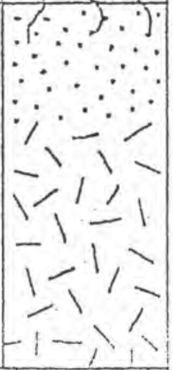
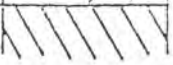
B-4	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	11,000	–	–	–	–	–
2	–	–	–	–	–	–	2,800	–	–	–	–	–
3	–	–	–	–	–	–	1,400	–	–	–	–	–
4	1.03	86	8.5	5.5	N.D.	N.D.	–	–	–	–	–	–
5	1.12	91.5	5.5	3	N.D.	N.D.	–	–	–	–	–	–
6	1.17	.93	4.5	2.5	N.D.	N.D.	32	–	–	–	–	–
7	1.20	93.5	4	2.5	N.D.	N.D.	–	–	–	–	–	–
8	1.19	92.5	5	2.5	N.D.	N.D.	38	–	–	–	–	–
9	1.15	93	4.5	2.5	N.D.	N.D.	–	–	–	–	–	–
10	–	–	–	–	–	–	64	–	–	–	–	–
11	1.85	85.5	10.5	4	N.D.	N.D.	–	–	–	–	–	–
12	3.0	50	41	9	N.D.	N.D.	30	–	–	–	–	–
13	–	–	–	–	–	–	33	–	–	–	–	–
14	2.5	39	48	13	N.D.	N.D.	–	–	–	–	–	–
15	1.8	33	48.5	18.5	N.D.	24	30	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	7.7	4.5
17	2.4	43.5	44	12.5	N.D.	19	39	–	–	–	7.6	11.0
18	1.9	41.5	43.5	15	13	37	40	–	–	–	–	–
19	1.1	23	48	29	N.D.	16	–	–	–	–	–	–
20	1.2	29.5	45.5	25	N.D.	N.D.	60	–	–	–	–	–
21	1.9	20.5	59	20.5	27	15	–	–	–	–	–	–
22	2.0	21	59	20	40	14	–	–	–	–	–	–
23	2.0	25	56	19	36	13	54	–	–	–	–	–
24	2.6	28.5	57	14.5	29	21	–	–	–	–	–	–
25	2.2	24.5	58	17.5	45	15	70	–	–	–	–	–
26	2.05	22	59	19	35	17	–	–	–	–	–	–
27	1.95	25.5	55.5	19	39	12	–	–	–	–	–	–
28	1.7	23	55	22	38	13	42	–	–	–	–	–
29	1.7	15.5	61	23.5	37	17	–	–	–	–	–	–
30	1.7	14	61.5	24.5	41	16	54	–	–	–	–	–
31	1.6	14	60.5	25.5	37	13	–	–	–	–	–	–
32	1.5	12.5	61	26.5	35	11	–	–	–	–	–	–
33	1.7	7.5	66.5	26	43	12	–	–	–	–	–	–
34	1.5	9	63	28	45	13	–	–	–	–	–	–
35	–	–	–	–	–	–	30	–	–	–	–	–
36	1.65	7.5	66	26.5	37	12	–	–	–	–	–	–
37	1.5	8	64	28	42	11	–	–	–	–	–	–
38	.93	17	48	35	19	11	–	–	–	–	–	–
39	–	–	–	–	–	–	60	–	–	–	–	–
40	.90	14	49	37	25	23	–	–	–	–	–	–
41	.93	7	54	39	15	N.D.	–	–	–	–	–	–
42	.71	8	47	45	16	N.D.	58	–	–	–	–	–
43	.67	10	45	45	9	N.D.	–	–	–	–	–	–
44	.74	12	46	42	N.D.	N.D.	–	–	–	–	–	–
45	–	–	–	–	–	–	54	–	–	–	–	–
46	.69	13	44	43	N.D.	N.D.	–	–	–	–	–	–
47	.70	12	45	43	N.D.	N.D.	–	–	–	–	–	–
48	.75	20	42	38	N.D.	N.D.	–	–	–	–	–	–
49	.68	23	39	38	N.D.	N.D.	68	–	–	–	–	–
50	.71	22	40	38	N.D.	N.D.	–	–	–	–	–	–
51	.70	22	40	38	N.D.	N.D.	–	–	–	–	–	–

	SITE A C-1 L.S. = 506.63			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	FILL		–	–	–	–	–	–	–	–
2	1.0-1.5	PEORIA LOESS		–	–	–	–	1	12	63	25
3	1.5-2.0			–	–	–	–	0	4	60	36
4	2.0-2.3			–	–	–	–	–	–	–	–
5	3.5-4.0			–	–	–	–	–	–	–	–
6	4.0-4.5			20.7	–	–	–	–	–	–	–
7	4.5-5.0	ROXANA SILT		–	–	–	–	1	18	49	33
8	5.5-6.0			–	–	–	–	–	–	–	–
9	6.0-6.5			–	–	–	–	2	22	45	33
10	6.5-7.0			–	–	–	–	–	–	–	–
11	8.0-8.5			–	–	–	–	–	–	–	–
12	8.5-9.0			–	–	–	–	1	33	39	28
13	9.0-9.5	BERRY CLAY		–	–	–	–	2	36	30	34
14	11.5-12.0			–	–	–	–	1	32	32	36
15	13.0-13.5	GLASFORD FORMATION TILL		–	–	–	–	12	36	38	26
16	14.0-14.5			–	–	–	–	–	–	–	–
17	15.0-15.5			–	–	–	–	12	37	32	31
18	15.5-16.0			11.7	–	–	–	–	–	–	–
19	16.0-16.5			–	–	–	–	2	34	39	37
20	17.0-17.5			–	–	–	–	–	–	–	–

	SITE B B-4 L.S. = 446.59			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
52	45.6-46.1	ENION FORMATION (7-53-40)		–	–	–	–	–	–	–	–
53	46.1-46.6			–	–	–	–	1	5	47	48
54	47.2-47.7			–	–	–	–	1	8	47	45
55	48.0-48.5			–	–	–	–	0	2	47	51
56	49.1-49.4			–	–	–	–	2	14	42	39
57	50.0-50.5			–	–	–	–	1	7	51	42
58	51.0-51.5			–	–	–	–	2	6	45	49
59	52.0-52.5			–	–	–	–	0	1	70	29
60	53.0-53.5			–	–	–	–	0	2	69	29
61	54.0-54.5			–	–	–	–	0	5	64	31
62	54.5-55.0			–	–	–	–	0	8	58	34
63	55.0-55.5			–	–	–	–	0	8	58	34
64	56.0-56.5			–	–	–	–	1	11	53	36
65	56.6-57.1			–	–	–	–	–	–	–	–
66	57.1-57.6			–	–	–	–	0	7	57	36
67	58.0-58.5			–	–	–	–	0	8	64	28
68	58.6-59.1			–	–	–	–	–	–	–	–
69	59.0-59.5			–	–	–	–	0	2	29	69
70	59.6-60.1	BEDROCK		–	–	–	–	–	–	–	–

B-4	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
52	–	–	–	–	–	–	40	–	–	–	–	–
53	.65	27	35	38	N.D.	N.D.	–	–	–	–	–	–
54	.77	40	32	28	N.D.	N.D.	–	–	–	–	–	–
55	1.23	9	59	32	N.D.	N.D.	–	–	–	–	–	–
56	.68	40	30	30	N.D.	N.D.	–	–	–	–	–	–
57	.63	37.5	30.5	32	N.D.	N.D.	–	–	–	–	–	–
58	.59	33.5	31	35.5	N.D.	N.D.	–	–	–	–	–	–
59	.78	36	34	30	N.D.	N.D.	36	–	–	–	–	–
60	.77	36	34	30	N.D.	N.D.	–	–	–	–	–	–
61	.58	35	30	35	N.D.	N.D.	–	–	–	–	–	–
62	–	–	–	–	–	–	42	–	–	–	–	–
63	.64	28	35.5	36.5	N.D.	N.D.	42	–	–	–	–	–
64	.80	–	–	–	–	–	–	–	–	–	–	–
65	–	–	–	–	–	–	60	–	–	–	–	–
66	–	33.5	35.5	31	N.D.	N.D.	–	–	–	–	–	–
67	–	34.5	33	22.5	N.D.	N.D.	–	–	–	–	–	–
68	–	–	–	–	–	–	130	–	–	–	–	–
69	1.60	29	50	21	N.D.	N.D.	–	–	–	–	–	–
70	–	–	–	–	–	–	38	–	–	–	–	–

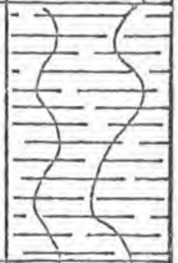
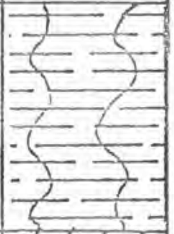
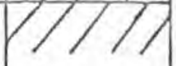
C-1	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	65000.	8.0	7900.	4700.	–	–
2	–	–	–	–	–	–	4500.	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	4,600.	–	–	–	–	–
5	–	–	–	–	–	–	8,600.	1.1	18.	44.	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	1,400.	–	–	–	–	–
8	–	–	–	–	–	–	2,000.	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	1,800.	–	–	–	–	–
11	–	–	–	–	–	–	1,800.	1.6	67.	55.	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	1,300.	–	–	–	–	–
14	–	–	–	–	–	–	1,800.	–	–	–	–	–
15	–	–	–	–	–	–	1,700.	3.6	15.	12.	–	–
16	–	–	–	–	–	–	1,800.	–	–	–	6.7	4.5
17	–	–	–	–	–	–	240.	.24	26.	21.	7.5	4.5
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	84.	–	–	–	–	–
20	–	–	–	–	–	–	40.	<.08	10.	9.6	7.6	3.2

	SITE A SCH-1 L.S. = 487			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	2.0-2.5	PEORIA LOESS		–	–	–	–	0	4	51	45
2	3.5-4.0			–	–	–	–	0	4	59	37
3	4.5-5.0	ROXANA SILT		–	–	–	–	0	14	52	34
4	6.0-6.5			–	–	–	–	–	–	–	–
5	7.5-7.7			–	–	–	–	0	16	57	27
6	8.0-8.5	BERRY CLAY		–	–	–	–	–	–	–	–
7	9.0-9.5			–	–	–	–	2	3	61	36
8	10.7-11.0			–	–	–	–	2	28	40	32
9	11.0-11.5	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
10	13.0-13.2			–	–	–	–	2	35	36	29
11	13.5-14.0			–	–	–	–	–	–	–	–
12	14.0-14.2			–	–	–	–	2	36	33	31
13	15.2-15.5			–	–	–	–	3	33	39	28
14	16.8-17.3			–	–	–	–	–	–	–	–
15	17.5-18.0			–	–	–	–	3	33	41	26
16	21.0-21.5			–	–	–	–	22	31	37	32
17	23.0-23.5			–	–	–	–	–	–	–	–
18	23.5-24.0			–	–	–	–	5	33	42	25
19	25.5-26.0			–	–	–	–	–	–	–	–
20	28.2-28.5			–	–	–	–	5	31	42	27
21	30.0-30.5			–	–	–	–	4	30	42	28
22	33.5-33.8			–	–	–	–	6	33	42	25
23	34.8-35.3			–	–	–	–	–	–	–	–
24	37.3-37.8			–	–	–	–	–	–	–	–
25	38.3-38.7			–	–	–	–	4	30	40	30
26	39.3-39.8			–	–	–	–	–	–	–	–
27	40.7-41.0			–	–	–	–	8	36	36	28
28	42.3-42.8			–	–	–	–	–	–	–	–
29	44.7-45.0			–	–	–	–	3	31	41	28
30	47.8-48.3			–	–	–	–	–	–	–	–
31	48.7-49.0			–	–	–	–	6	24	45	31
32	50.8-51.1			–	–	–	–	3	24	46	30
33	52.5-52.8	LIERLE CLAY		–	–	–	–	0	14	54	32
34	53.5-54.0			–	–	–	–	–	–	–	–
35	54.5-54.8			–	–	–	–	1	21	38	41
36	56.0-56.5			–	–	–	–	–	–	–	–
37	56.5-56.8			–	–	–	–	1	20	38	42
38	58.0-58.5			–	–	–	–	–	–	–	–
39	58.5-58.8			–	–	–	–	0	23	39	38
40	60.5-61.0			–	–	–	–	1	25	38	37
41	62.5-63.0	BANNER FORMATION TILL		–	–	–	–	1	74	8	18
42	63.0-63.5			–	–	–	–	–	–	–	–
43	66.5-67.0			–	–	–	–	1	82	11	7
44	69.0-69.5			–	–	–	–	–	–	–	–
45	71.9-72.2			–	–	–	–	4	23	44	33
46	72.5-73.0			–	–	–	–	–	–	–	–
47	73.9-74.2			–	–	–	–	4	23	45	32
48	74.5-75.0			–	–	–	–	–	–	–	–
49	77.0-77.3			–	–	–	–	4	23	46	31
50	78.0-78.5			–	–	–	–	–	–	–	–
51	80.7-81.0			–	–	–	–	3	23	45	32
		BEDROCK									

SCH-1	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	18.	–	18.	–	–	–
2	–	–	–	–	–	–	25.	–	26.	38.	7.6	4.5
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	17.	.04	14.	18.	7.5	5.6
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	17.	–	27.	27.	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	20.	–	24.	22.	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	34.	.62	20.	21.	6.9	2.5
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	40.	–	27.	22.	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	43.	1.5	23.	18.	–	–
17	–	–	–	–	–	–	32.	.20	21.	17.	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	27.	–	22.	18.	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	35.	.32	32.	46.	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	26.	–	–	–	–	–
24	–	–	–	–	–	–	17.	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	30.	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	35.	~.04	12	9.8	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	36.	<.04	12.	12.	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	13.	<.04	7.6	8.8	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	12.	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	16.	–	14.	17.	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	24.	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–
42	–	–	–	–	–	–	37.	.24	14.	10.	–	–
43	–	–	–	–	–	–	17.	.06	11.	3.	–	–
44	–	–	–	–	–	–	23.	~.04	5.1	3.2	–	–
45	–	–	–	–	–	–	–	–	–	–	–	–
46	–	–	–	–	–	–	48.	–	–	–	–	–
47	–	–	–	–	–	–	–	–	–	–	–	–
48	–	–	–	–	–	–	47.	.40	21.	22.	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–
50	–	–	–	–	–	–	48.	<.04	12.	10.	–	–
51	–	–	–	–	–	–	–	–	–	–	–	–

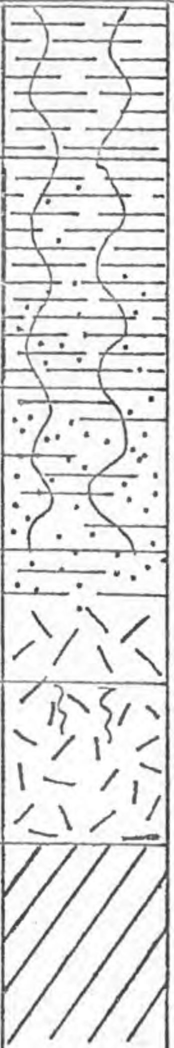
No.	SITE B B-6 L.S. = 455.83			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS (4-64-32)		–	–	–	–	0	6	71	23
2	2.0-2.5			–	–	–	–	1	3	66	31
3	3.0-3.5			–	–	–	–	1	4	62	34
4	4.0-4.5			26.3	–	–	–	1	3	58	39
5	4.5-5.0			–	–	–	–	–	–	–	–
6	6.0-6.5	ROXANNA SILT AND BERRY CLAY (24-47-29)		–	–	–	–	2	17	54	29
7	7.0-7.5			–	–	–	–	–	–	–	–
8	7.5-8.0			–	–	–	–	1	18	53	29
9	8.0-8.4			–	–	–	–	1	21	56	23
10	8.4-8.9			–	–	–	–	1	22	47	30
11	8.9-9.4			–	–	–	–	2	26	43	31
12	10.0-10.5			–	–	–	–	1	31	40	29
13	10.5-11.0			23.6	–	–	–	–	–	–	–
14	11.0-11.5			–	–	–	–	1	30	39	31
15	12.0-12.5	HAGARSTOWN (42-30-28)		–	–	–	–	4	48	25	27
16	13.2-13.7			14.7	–	–	–	–	–	–	–
17	14.0-14.5			–	–	–	–	3	35	35	30
18	14.5-15.0	GLASFORD FORMATION TILL (37-42-21)		–	–	–	–	5	34	47	19
19	15.0-15.5			–	–	–	–	4	34	45	21
20	16.0-16.5			–	–	–	–	6	36	42	22
21	17.0-17.5			–	–	–	–	7	40	43	17
22	18.0-18.5			–	–	–	–	7	48	40	12
23	19.0-19.4			–	–	–	–	7	38	39	23
24	19.4-19.9			9.1	–	–	–	–	–	–	–
25	20.0-20.5			–	–	–	–	6	36	41	23
26	21.0-21.5			–	–	–	–	10	41	37	22
27	22.0-22.5			–	–	–	–	4	33	42	25
28	23.0-23.5			–	–	–	–	7	31	44	25
29	23.8-24.3	BANNER FORMATION TILL (23-44-33) (oxidized)		14.7	–	–	–	–	–	–	–
30	24.3-24.8			–	–	–	–	4	28	41	31
31	26.1-26.6			–	–	–	–	8	23	41	36
32	27.0-27.5			–	–	–	–	3	23	43	34
33	28.0-28.5			–	–	–	–	3	25	42	33
34	28.5-29.0			–	–	–	–	12	21	42	37
35	29.0-29.5			–	–	–	–	5	22	46	32
36	30.0-30.5			–	–	–	–	5	23	43	34
37	30.9-31.4			13.2	–	–	–	5	23	43	34
38	32.0-32.5			–	–	–	–	5	25	43	33
39	33.0-33.5			–	–	–	–	8	26	43	31
40	34.1-34.6			16.7	–	–	–	5	24	43	33
41	35.0-35.5			–	–	–	–	19	22	38	40
42	35.6-36.0			–	–	–	–	–	–	–	–
43	36.0-36.5			–	–	–	–	5	23	50	27
44	37.0-37.5			–	–	–	–	3	24	44	32
45	38.0-38.5			–	–	–	–	4	28	41	31
46	39.0-39.5			–	–	–	–	3	21	47	32
47	40.0-40.5			–	–	–	–	5	20	46	34
48	40.6-41.1			16.1	–	–	–	–	–	–	–
49	42.1-42.6	BEDROCK		–	–	–	–	2	2	32	66
50	42.7-43.2			–	–	–	–	7	25	48	27

B-6	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/100g
1	1.2	–	–	–	–	–	46,000	–	–	–	–	–
2	1.4	45.5	37	17.5	N.D.	N.D.	–	–	–	–	–	–
3	1.3	64	24	12	N.D.	20	–	–	–	–	–	–
4	1.4	72	16	8	N.D.	14	–	–	–	–	–	–
5	–	–	–	–	–	–	440	–	–	–	–	–
6	1.3	85.5	9.5	5	N.D.	10	–	–	–	–	–	–
7	–	–	–	–	–	–	24	–	–	–	–	–
8	0.8	82	10	8	N.D.	N.D.	–	–	–	–	–	–
9	0.7	82.5	9	8.5	N.D.	15	–	–	–	–	–	–
10	0.9	83.5	9.5	7	15	9	–	–	–	–	–	–
11	0.8	86	7.5	6.5	N.D.	N.D.	74	–	–	–	–	–
12	0.6	84.5	7.5	8	N.D.	N.D.	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	0.9	83.5	9.5	7	N.D.	N.D.	–	–	–	–	–	–
15	1.0	79.5	12.5	8	N.D.	20	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	1.5	71.5	19.5	9	9	9	–	–	–	–	7.6	–
18	1.6	35	45.5	19.5	N.D.	N.D.	–	–	–	–	–	–
19	1.6	30.5	49	20.5	11	31	–	–	–	–	–	–
20	2.6	43.5	45	11.5	21	35	–	–	–	–	–	–
21	1.8	33.5	48.5	18	29	64	–	–	–	–	–	–
22	2.3	41.5	46	12.5	40	55	–	–	–	–	–	–
23	1.8	34.5	48	17.5	26	30	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	1.5	43.5	39	17.5	29	30	–	–	–	–	–	–
26	1.1	33	41	26	21	37	–	–	–	–	–	–
27	1.1	46.5	33.5	20	27	32	–	–	–	–	–	–
28	1.0	52	29	19	13	18	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	1.3	19.5	53.5	27	41	15	–	–	–	–	–	–
31	1.8	21	57.5	21.5	33	26	–	–	–	–	–	–
32	2.4	24	59.5	16.5	33	12	–	–	–	–	–	–
33	2.5	20	63.5	16.5	15	15	–	–	–	–	–	–
34	2.3	26.5	57	16.5	34	16	–	–	–	–	–	–
35	2.4	23	54.5	22.5	27	21	–	–	–	–	–	–
36	2.3	25.5	58	16.5	29	19	84	–	–	–	–	–
37	2.1	26	56	17.5	25	10	–	–	–	–	–	–
38	1.7	25	54	21	42	15	–	–	–	–	–	–
39	1.8	21	57.5	21.5	36	22	–	–	–	–	–	–
40	1.7	18	58.5	23.5	28	10	–	–	–	–	–	–
41	1.3	28	47.5	24.5	35	10	–	–	–	–	–	–
42	–	–	–	–	–	–	66	–	–	–	–	–
43	1.3	26	49	25	21	12	–	–	–	–	–	–
44	1.4	26	50	24	19	10	–	–	–	–	–	–
45	1.4	24.5	50.5	25	25	N.D.	–	–	–	–	–	–
46	1.4	27.5	49	23.5	21	15	–	–	–	–	–	–
47	0.9	22	45	33	23	15	–	–	–	–	–	–
48	–	–	–	–	–	–	–	–	–	–	–	–
49	1.6	8.5	64.5	27	N.D.	13	56	–	–	–	–	–
50	1.6	7	65	28	10	N.D.	–	–	–	–	–	–

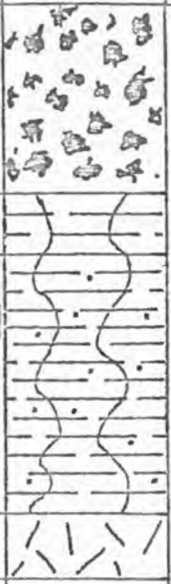
No.	SITE B B-7 L.S. = 455.54			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	FILL		–	–	–	–	–	–	–	–
2	2.5-3.0	ROXANNA SILT AND BERRY CLAY		30.3	–	–	–	–	–	–	–
3	3.0-3.5			–	–	–	–	–	–	–	–
4	3.5-4.0			–	–	–	–	–	–	–	–
5	6.7-7.2			–	–	–	–	–	–	–	–
6	7.2-7.7			–	–	–	–	1	24	46	30
7	7.7-8.2			–	–	–	–	–	–	–	–
8	8.2-8.6			–	–	–	–	–	–	–	–
9	14.6-15.1			22.2	–	–	–	–	–	–	–
10	15.6-16.1	HAGARSTOWN		–	–	–	–	–	–	–	–
11	16.1-16.6			–	–	–	–	3	54	20	26
12	17.0-17.5	GLASFORD FORMATION TILL (36-34-30)		–	–	–	–	5	41	28	31
13	18.1-18.6			–	–	–	–	–	–	–	–
14	19.0-19.5			–	–	–	–	2	30	40	30
15	20.1-20.6			23.6	–	–	–	–	–	–	–
16	21.8-22.3	BANNER FORMATION TILL (29-39-32)		–	–	–	–	1	21	54	25
17	23.9-24.4			15.3	–	–	–	4	26	43	31
18	28.0-28.5			–	–	–	–	9	26	43	29
19	29.6-30.1			–	–	–	–	–	–	–	–
20	30.1-30.6			12.9	–	–	–	0	9	61	30
21	32.0-32.5			–	–	–	–	17	35	42	25
22	34.4-34.9			15.1	–	–	–	–	–	–	–
23	36.0-36.5			–	–	–	–	4	25	42	33
24	38.6-39.1			16.8	–	–	–	–	–	–	–
25	40.0-40.5			–	–	–	–	2	14	46	40
26	40.6-41.1			16.8	–	–	–	–	–	–	–
27	41.6-42.1			–	–	–	–	–	–	–	–
28	44.0-44.5			–	–	–	–	1	14	43	43
29	44.6-45.0			23.7	–	–	–	–	–	–	–
30	45.1-45.6			–	–	–	–	–	–	–	–
31	47.0-47.5			–	–	–	–	0	55	25	20
32	49.0-49.5			–	–	–	–	1	18	45	37
33	49.6-50.1			23.0	–	–	–	–	–	–	–
34	51.5-52.0			–	–	–	–	1	8	50	42
35	54.8-55.3	ENION FORMATION (13-49-38)		22.2	–	–	–	0	18	44	38
36	56.3-56.8			18.5	–	–	–	–	–	–	–
37	56.8-57.3			–	–	–	–	0	6	62	32
38	57.3-57.8			–	–	–	–	–	–	–	–
39	59.0-59.5			–	–	–	–	1	9	49	42
40	63.0-63.5			–	–	–	–	2	15	53	32
41	63.9-64.4			–	–	–	–	3	18	39	43
42	64.4-64.9	BEDROCK		21.2	–	–	–	2	2	55	43
43	64.9-65.4			–	–	–	–	–	–	–	–

B-1

B-7	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	16,000	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	1,200	–	–	–	–	–
4	–	–	–	–	–	–	14	–	–	–	–	–
5	–	–	–	–	–	–	25	–	–	–	–	–
6	–	–	–	–	–	–	29	–	–	–	–	–
7	–	–	–	–	–	–	36	–	–	–	–	–
8	–	–	–	–	–	–	74	–	–	–	–	–
9	–	–	–	–	–	–	85	–	–	–	–	–
10	–	–	–	–	–	–	31	–	–	–	–	–
11	–	–	–	–	–	–	65	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	36	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	68	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	60	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	49	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	63	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	–	–	–	–	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	–	–	–	–	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	27	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–
42	–	–	–	–	–	–	65	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–

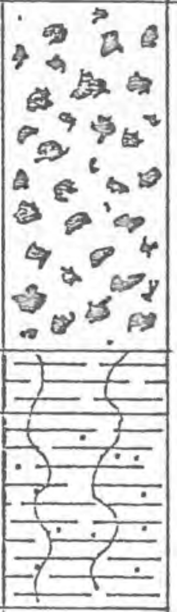
	SITE B B-9 L.S. = 455.67			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS (6-52-42)		–	–	–	–	1	5	67	28
2	2.0-2.5			–	–	–	–	–	–	–	–
3	2.5-3.0			–	–	–	–	1	3	56	41
4	3.8-4.3			–	–	–	–	2	11	32	57
5	4.8-5.0	ROXANA SILT AND BERRY CLAY (25-42-33)		–	–	–	–	–	–	–	–
6	5.0-5.5			–	–	–	–	1	16	52	32
7	6.2-6.5			–	–	–	–	–	–	–	–
8	6.5-7.0			–	–	–	–	1	19	51	30
9	7.2-8.2			–	–	–	–	–	–	–	–
10	8.2-8.7			–	–	–	–	–	–	–	–
11	9.0-9.5			–	–	–	–	1	40	23	37
12	10.0-10.5	HAGARSTOWN (61-16-23)		–	–	–	–	1	54	20	26
13	11.0-11.5			–	–	–	–	–	–	–	–
14	12.2-12.7			–	–	–	–	–	–	–	–
15	13.2-13.7			–	–	–	–	1	90	2	8
16	14.0-14.5			–	–	–	–	3	39	25	36
17	14.5-15.0	GLASFORD FORMATION TILL (37-40-23)		–	–	–	–	7	42	38	20
18	17.0-17.5			–	–	–	–	4	37	39	24
19	19.0-19.5			–	–	–	–	7	36	40	24
20	21.0-21.5			–	–	–	–	3	34	41	25
21	22.0-22.5	BANNER FORMATION TILL (23-42-35)		–	–	–	–	3	24	38	38
22	25.0-25.5			–	–	–	–	8	30	40	30
23	29.0-29.5			–	–	–	–	7	24	42	34
24	33.0-33.5			–	–	–	–	3	22	45	33
25	34.0-34.5			–	–	–	–	3	14	47	39
26	35.0-35.5	BEDROCK (3-49-48)		–	–	–	–	0	7	47	46
27	36.0-36.5			–	–	–	–	2	4	45	51
28	37.0-37.5			–	–	–	–	2	2	49	49
29	38.0-38.5			–	–	–	–	2	3	49	48
30	40.0-40.5			–	–	–	–	1	2	52	46
31	42.0-42.5			–	–	–	–	0	2	51	47

B-9	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	60	–	–	–	–	–
2	–	–	–	–	–	–	36	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	29	–	–	–	–	–
5	–	–	–	–	–	–	27	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	15	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	12	–	–	–	–	–
10	–	–	–	–	–	–	11	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	21	–	–	–	–	–
13	–	–	–	–	–	–	16	–	–	–	–	–
14	–	–	–	–	–	–	18	–	–	–	–	–
15	–	–	–	–	–	–	20	–	–	–	–	–
16	–	–	–	–	–	–	40	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	–	–

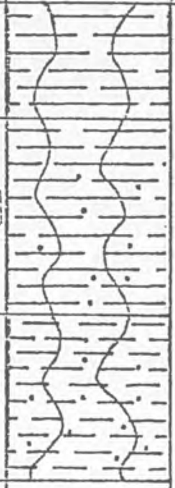
No.	SITE B B-10 L.S. = 440.27 Depth of Sample (ft)	Unit Description	Graphic Log	Engineering Data W %	Gs	Void Ratio	Dry Den #/ft³	Grain Size Gvl %	Sd %	St %	Cl %
1	0.0-0.5	FILL		–	–	–	–	–	–	–	–
2	0.5-1.0			–	–	–	–	–	–	–	–
3	1.0-1.5			–	–	–	–	–	–	–	–
4	1.5-2.0			–	–	–	–	–	–	–	–
5	4.8-5.3			–	–	–	–	–	–	–	–
6	5.3-5.8	PEORIA LOESS		–	–	–	–	–	–	–	–
7	5.8-6.3			–	–	–	–	–	–	–	–
8	6.3-6.8	ROXANNA SILT AND BERRY CLAY		–	–	–	–	–	–	–	–
9	6.8-7.3			–	–	–	–	–	–	–	–
10	7.3-7.8			–	–	–	–	–	–	–	–
11	7.8-8.3			–	–	–	–	–	–	–	–
12	8.3-8.8			–	–	–	–	–	–	–	–
13	8.8-9.3			–	–	–	–	–	–	–	–
14	9.3-9.8			–	–	–	–	–	–	–	–
15	10.6-11.1	GLASFORD FORMATION TILL		–	–	–	–	–	–	–	–
16	11.1-11.6			–	–	–	–	–	–	–	–
17	11.6-12.1			–	–	–	–	–	–	–	–

10

B-10 No.	X-Ray Data DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Chemical Data Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/100g
1	–	–	–	–	–	–	9600	–	–	–	–	–
2	–	–	–	–	–	–	14000	–	–	–	–	–
3	–	–	–	–	–	–	12000	–	–	–	–	–
4	–	–	–	–	–	–	17000	–	–	–	–	–
5	–	–	–	–	–	–	13000	–	–	–	–	–
6	–	–	–	–	–	–	8600	–	–	–	–	–
7	–	–	–	–	–	–	4800	–	–	–	–	–
8	–	–	–	–	–	–	2300	–	–	–	–	–
9	–	–	–	–	–	–	130	–	–	–	–	–
10	–	–	–	–	–	–	41	–	–	–	–	–
11	–	–	–	–	–	–	51	–	–	–	–	–
12	–	–	–	–	–	–	57	–	–	–	–	–
13	–	–	–	–	–	–	58	–	–	–	–	–
14	–	–	–	–	–	–	66	–	–	–	–	–
15	–	–	–	–	–	–	280	–	–	–	–	–
16	–	–	–	–	–	–	60	–	–	–	–	–
17	–	–	–	–	–	–	74	–	–	–	–	–

	SITE B B-11 L.S. = 438.79			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	FILL		–	–	–	–	–	–	–	–
2	0.5-1.0			–	–	–	–	–	–	–	–
3	1.0-1.5			–	–	–	–	–	–	–	–
4	1.5-2.0			–	–	–	–	–	–	–	–
5	2.0-2.5			–	–	–	–	–	–	–	–
6	2.5-3.0			–	–	–	–	–	–	–	–
7	3.0-3.5			–	–	–	–	–	–	–	–
8	3.5-4.0			–	–	–	–	–	–	–	–
9	4.0-4.5			–	–	–	–	–	–	–	–
10	4.5-4.7			–	–	–	–	–	–	–	–
11	5.0-5.5	PEORIA LOESS		–	–	–	–	–	–	–	–
12	5.5-6.0			–	–	–	–	–	–	–	–
13	6.0-6.5	ROXANNA SILT AND BERRY CLAY		–	–	–	–	–	–	–	–
14	6.5-7.0			–	–	–	–	–	–	–	–
15	7.0-7.3			–	–	–	–	–	–	–	–
16	7.5-8.0			–	–	–	–	–	–	–	–
17	8.0-8.5			–	–	–	–	–	–	–	–
18	8.5-9.0			–	–	–	–	–	–	–	–

B-11	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	33,000	–	–	–	–	–
2	–	–	–	–	–	–	28,000	–	–	–	–	–
3	–	–	–	–	–	–	20,000	–	–	–	–	–
4	–	–	–	–	–	–	27,000	–	–	–	–	–
5	–	–	–	–	–	–	35,000	–	–	–	–	–
6	–	–	–	–	–	–	26,000	–	–	–	–	–
7	–	–	–	–	–	–	19,000	–	–	–	–	–
8	–	–	–	–	–	–	18,000	–	–	–	–	–
9	–	–	–	–	–	–	19,000	–	–	–	–	–
10	–	–	–	–	–	–	10,000	–	–	–	–	–
11	–	–	–	–	–	–	3,800	–	–	–	–	–
12	–	–	–	–	–	–	960	–	–	–	–	–
13	–	–	–	–	–	–	760	–	–	–	–	–
14	–	–	–	–	–	–	80	–	–	–	–	–
15	–	–	–	–	–	–	34	–	–	–	–	–
16	–	–	–	–	–	–	61	–	–	–	–	–
17	–	–	–	–	–	–	76	–	–	–	–	–
18	–	–	–	–	–	–	55	–	–	–	–	–

No.	SITE B B-12 L.S. = 447.55			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	2.5-3.0	PEORIA LOESS		–	–	–	–	–	–	–	–
2	3.0-3.5			–	–	–	–	–	–	–	–
3	3.5-4.0			–	–	–	–	–	–	–	–
4	4.0-4.5	ROXANNA SILT		–	–	–	–	–	–	–	–
5	4.5-5.0			–	–	–	–	–	–	–	–
6	5.0-5.5			–	–	–	–	–	–	–	–
7	5.5-6.0			–	–	–	–	–	–	–	–
8	6.0-6.5			–	–	–	–	–	–	–	–
9	6.5-6.8			–	–	–	–	–	–	–	–
10	7.5-8.0	BERRY CLAY		–	–	–	–	–	–	–	–
11	8.0-8.5			–	–	–	–	–	–	–	–
12	8.5-8.7			–	–	–	–	–	–	–	–
13	8.7-9.2			–	–	–	–	–	–	–	–
14	9.2-9.5			–	–	–	–	–	–	–	–

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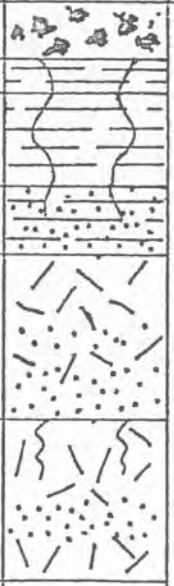
B-12	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	2,100	–	–	–	–	–
2	–	–	–	–	–	–	3.500	–	–	–	–	–
3	–	–	–	–	–	–	1,800	–	–	–	–	–
4	–	–	–	–	–	–	1,400	–	–	–	–	–
5	–	–	–	–	–	–	1,100	–	–	–	–	–
6	–	–	–	–	–	–	960	–	–	–	–	–
7	–	–	–	–	–	–	1,000	–	–	–	–	–
8	–	–	–	–	–	–	2,200	–	–	–	–	–
9	–	–	–	–	–	–	3,700	–	–	–	–	–
10	–	–	–	–	–	–	4,200	–	–	–	–	–
11	–	–	–	–	–	–	2,800	–	–	–	–	–
12	–	–	–	–	–	–	670	–	–	–	–	–
13	–	–	–	–	–	–	220	–	–	–	–	–
14	–	–	–	–	–	–	3,300	–	–	–	–	–

No.	SITE B B-14 L.S. = 452.07			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	FILL		–	–	–	–	–	–	–	–
2	2.0-2.5	PEORIA LOESS		–	–	–	–	1	25	40	35
3	3.0-3.5	BERRY CLAY (34-32-34)		–	–	–	–	1	33	36	31
4	4.5-5.0			–	–	–	–	4	36	26	38
5	5.2-6.0			–	–	–	–	1	32	35	33
6	7.2-7.7	HAGARSTOWN		–	–	–	–	–	–	–	–
7	9.4-9.7			–	–	–	–	3	5	82	13
8	10.0-10.4	GLASFORD FORMATION TILL (32-50-18)		–	–	–	–	–	–	–	–
9	10.4-10.8			–	–	–	–	5	28	57	15
10	10.8-11.2			–	–	–	–	7	36	43	21
11	11.2-11.7			–	–	–	–	–	–	–	–
12	14.2-14.7			–	–	–	–	–	–	–	–
13	16.2-16.7	BANNER FORMATION TILL (28-40-32)		–	–	–	–	1	17	37	46
14	18.2-18.7			–	–	–	–	3	31	42	27
15	18.7-19.2			–	–	–	–	–	–	–	–
16	21.4-21.9			–	–	–	–	–	–	–	–
17	23.9-24.4			–	–	–	–	5	36	42	22

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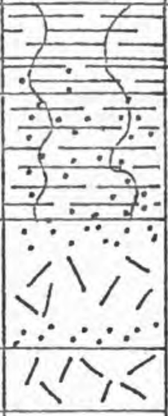
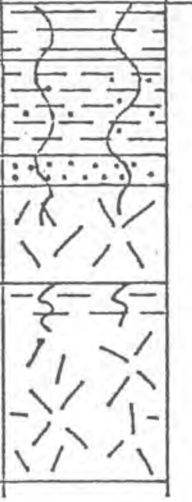
B-14	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	81,000	13	4,600	34,000	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	2,400	2.4	53	29	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	28	0.10	50	10	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	80	0.24	33	58	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	29	0.08	18	18	–	–
12	–	–	–	–	–	–	21	<D.L.	14	8.6	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	36	0.05	22	7.8	–	–
16	–	–	–	–	–	–	36	<D.L.	22	8.1	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–

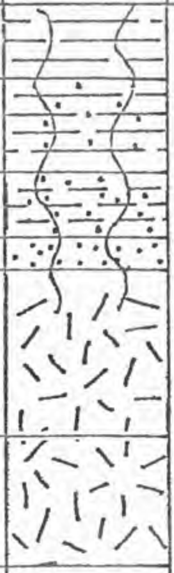
No.	SITE B B-15 L.S. = 448.42			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	3.0-3.5	PEORIA LOESS		–	–	–	–	0	18	54	28
2	6.6-7.1	ROXANNA		–	–	–	–	1	32	27	41
3	7.1-7.6	AND BERRY HAGARSTOWN MEMBER (44-29-27)		–	–	–	–	1	40	28	32
4	7.6-8.1			–	–	–	–	–	–	–	–
5	8.1-8.6			–	–	–	–	5	46	30	24
6	8.6-9.1			–	–	–	–	7	45	29	26
7	11.1-11.6	GLASFORD FORMATION TILL (39-38-23)		–	–	–	–	7	50	33	17
8	12.8-13.5			–	–	–	–	4	35	38	27
9	13.5-14.0			–	–	–	–	5	33	42	25
10	14.5-15.0			–	–	–	–	–	–	–	–
11	17.5-18.0	BANNER TILL (29-39-32)		–	–	–	–	11	25	41	34
12	22.5-23.0			–	–	–	–	5	33	37	30

B-15	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	1,200	2.5	23	29	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	37	0.40	22	9.2	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	22	0.08	14	6.8	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	24	0.19	16	7.6	–	–
11	–	–	–	–	–	–	45	1.9	23	8.4	–	–
12	–	–	–	–	–	–	51	0.21	19	11	–	–

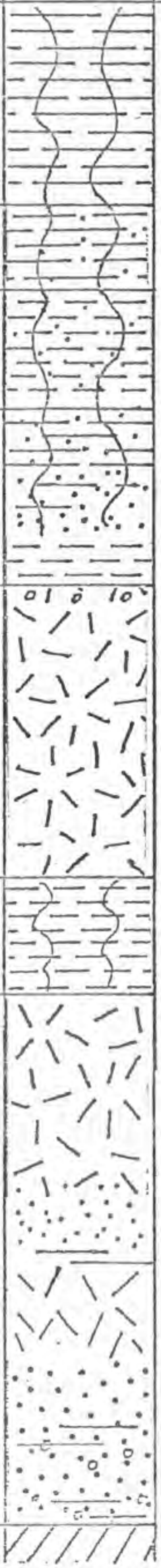
No.	SITE B B-16 L.S. = 446.30			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	PEORIA LOESS		–	–	–	–	1	27	49	24
2	2.0-2.5	BERRY CLAY (37-38-25)		–	–	–	–	1	31	45	24
3	3.0-3.7			–	–	–	–	5	42	31	27
4	3.7-4.3			–	–	–	–	–	–	–	–
5	5.5-6.0	HAGARSTOWN		–	–	–	–	3	61	14	25
6	6.7-7.5	GLASFORD FORMATION TILL (40-36-24)		–	–	–	–	4	38	36	26
7	8.0-8.5			–	–	–	–	5	41	37	22
8	11.5-12.0			–	–	–	–	7	40	35	25
9	12.0-12.5			–	–	–	–	15	22	25	53
10	16.0-16.5	BANNER FORMATION TILL (28-34-38)		–	–	–	–	–	–	–	–
11	18.0-18.5			–	–	–	–	–	–	–	–
12	20.5-21.0			–	–	–	–	6	33	38	29
13	21.5-22.0			–	–	–	–	–	–	–	–
14	24.5-25.0			–	–	–	–	8	30	39	31

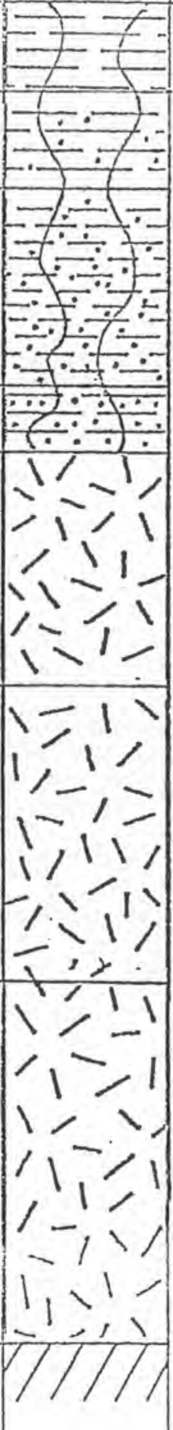
B-16

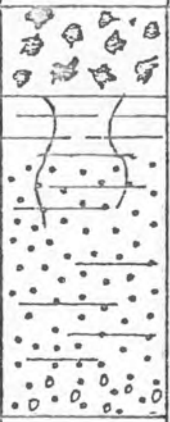
B-16 No.	X-Ray Data						Chemical Data					
	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	66	0.08	20	18	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	29	0.05	15	8.8	–	–
5	–	–	–	–	–	–	32	0.05	13	7.7	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	29	< D.L.	15	8.8	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	58	< D.L	25	13	–	–
10	–	–	–	–	–	–	51	0.21	20	9.4	–	–
11	–	–	–	–	–	–	27	0.08	16	7.2	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	46	0.18	24	9.7	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–

	SITE B B-17 L.S. = 444.77			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS		–	–	–	–	4	20	49	31
2	2.0-2.5			–	–	–	–	–	–	–	–
3	3.0-3.7	ROXANNA SILT		–	–	–	–	5	24	50	26
4	3.7-4.3			–	–	–	–	–	–	–	–
5	5.5-6.0			–	–	–	–	–	–	–	–
6	6.0-6.7	BERRY CLAY		–	–	–	–	2	18	50	32
7	8.1-8.8			–	–	–	–	9	41	35	24
8	10.0-10.5	HAGARSTOWN		–	–	–	–	–	–	–	–
9	10.5-11.0	GLASFORD FORMATION TILL (25-41-34)		–	–	–	–	1	19	37	44
10	13.5-14.0			–	–	–	–	–	–	–	–
11	16.0-16.5			–	–	–	–	3	29	39	32
12	17.5-18.0			–	–	–	–	–	–	–	–
13	19.0-19.5			–	–	–	–	4	28	46	26
14	19.5-20.0	BANNER FORMATION TILL (24-48-28)		–	–	–	–	2	20	55	25
15	20.0-20.5			–	–	–	–	4	27	53	20
16	21.5-22.0			–	–	–	–	4	25	43	32
17	23.5-24.0			–	–	–	–	5	24	42	34

B-17	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	550	0.08	15	13	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	33	0.08	15	12	–	–
5	–	–	–	–	–	–	580	<D.L	46	65	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	21	0.08	9.2	5.0	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	46	0.08	18	8.7	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	48	0.23	19	7.0	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	45	0.05	18	7.9	–	–

	SITE B BCH-1 L.S. = 452			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS (3-65-32)		–	–	–	–	0	4	80	16
2	2.0-2.5			–	–	–	–	0	2	67	31
3	3.0-3.5			–	–	–	–	0	2	68	30
4	4.0-4.5			–	–	–	–	1	1	53	46
5	4.8-5.3			–	–	–	–	1	5	58	37
6	5.5-6.0			–	–	–	–	1	5	63	32
7	6.5-7.0	ROXANNA SILT (15-58-27)		–	–	–	–	0	14	58	28
8	7.5-8.0			–	–	–	–	1	14	58	28
9	8.5-9.0			–	–	–	–	1	16	58	26
10	9.0-9.5	BERRY CLAY (25-42-33)		–	–	–	–	0	11	58	31
11	10.0-10.5			–	–	–	–	2	30	43	27
12	11.2-11.7			–	–	–	–	1	28	37	35
13	12.0-12.5			–	–	–	–	1	31	30	39
14	13.0-13.5	HAGARSTOWN MEMBER		–	–	–	–	2	36	40	24
15	13.5-14.0			–	–	–	–	3	41	31	28
16	14.0-14.5			–	–	–	–	2	18	49	33
17	15.0-15.5			–	–	–	–	2	86	3	11
18	15.5-16.0			–	–	–	–	0	6	37	57
19	16.0-16.5			–	–	–	–	0	8	52	80
20	18.0-18.5	GLASFORD FORMATION TILL (34-39-27)		–	–	–	–	14	34	39	27
21	20.0-20.5			–	–	–	–	4	32	42	26
22	21.3-21.8			–	–	–	–	6	35	39	26
23	22.0-22.5			–	–	–	–	5	37	28	25
24	23.0-23.5			–	–	–	–	4	38	37	25
25	24.0-24.5			–	–	–	–	8	30	40	30
26	24.9-25.4			–	–	–	–	5	33	39	28
27	26.0-26.5			–	–	–	–	4	34	39	27
28	27.0-27.5			–	–	–	–	8	35	35	30
29	28.0-28.5			–	–	–	–	6	30	40	30
30	30.0-30.5	LIERLE CLAY (31-32-37)		–	–	–	–	1	22	36	42
31	31.0-31.5			–	–	–	–	2	30	34	36
32	31.5-32.0			–	–	–	–	4	48	16	36
33	32.5-33.0			–	–	–	–	0	23	43	34
34	33.0-33.5	BANNER FORMATION TILL (38-41-21)		–	–	–	–	7	53	30	17
35	34.0-34.5			–	–	–	–	6	35	41	24
36	35.0-35.5			–	–	–	–	11	35	41	24
37	36.0-36.5			–	–	–	–	5	41	38	21
38	37.0-37.5			–	–	–	–	5	43	40	17
39	38.0-38.5			–	–	–	–	20	31	45	24
40	39.5-40.0			–	–	–	–	18	42	36	22
41	40.5-41.0			–	–	–	–	10	68	15	17
42	41.5-42.0			–	–	–	–	5	42	39	19
43	42.5-43.0			–	–	–	–	5	35	45	20
44	43.0-43.5			–	–	–	–	5	33	41	26
45	44.0-44.5			–	–	–	–	5	41	39	20
46	45.0-45.5			–	–	–	–	1	61	24	15
47	46.0-46.5			–	–	–	–	1	66	8	26
48	47.0-47.5			–	–	–	–	2	75	14	11
49	48.0-48.5			–	–	–	–	44	24	68	8
50	48.5-49.0			–	–	–	–	0	94	1	5
51	50.0-50.5			–	–	–	–	49	39	32	29
		BEDROCK									

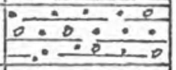
	SITE B B-3 L.S. = 449.93			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	2.4-2.9	PEORIA LOESS (6-69-25)		–	–	–	–	–	–	–	–
2	2.9-3.4			–	–	–	–	1	6	69	25
3	3.9-4.4	ROXANNA SILT (20-52-28)		–	–	–	–	0	20	60	20
4	5.0-5.5			–	–	–	–	4	24	48	28
5	6.0-6.5			–	–	–	–	1	16	48	35
6	7.4-7.9	BERRY CLAY (47-26-27)		–	–	–	–	–	–	–	–
7	7.9-8.4			–	–	–	–	1	45	25	30
8	8.4-8.9			17.8	2.66	.49	112	–	–	–	–
9	9.9-10.4			–	–	–	–	1	48	27	25
10	10.4-10.9			–	–	–	–	–	–	–	–
11	10.9-11.4			–	–	–	–	1	49	27	24
12	11.6-12.1	HAGARSTOWN (47-34-19)		–	–	–	–	–	–	–	–
13	12.1-12.6			–	–	–	–	15	47	34	19
14	13.0-13.5	GLASFORD FORMATION TILL (42-38-20)		–	–	–	–	7	50	33	17
15	14.0-14.5			–	–	–	–	5	40	46	14
16	14.5-15.1			–	–	–	–	–	–	–	–
17	15.1-15.6			–	–	–	–	14	47	37	16
18	17.1-17.6			–	–	–	–	8	36	38	26
19	18.1-18.6			–	–	–	–	7	37	38	25
20	19.1-19.5			–	–	–	–	7	43	35	22
21	20.1-20.6	BANNER FORMATION TILL (31-41-28) (oxidized)		–	–	–	–	5	27	47	26
22	22.0-22.5			–	–	–	–	3	25	41	34
23	22.9-23.0			–	–	–	–	25	38	38	24
24	24.2-24.7			–	–	–	–	3	29	39	32
25	25.0-25.5			–	–	–	–	4	32	40	28
26	26.1-26.6			–	–	–	–	8	35	38	27
27	26.9-27.4			–	–	–	–	5	37	40	23
28	29.2-29.6			–	–	–	–	11	25	48	27
29	31.0-31.5			–	–	–	–	18	34	42	24
30	31.7-32.1	(unoxidized) (21-45-34)		–	–	–	–	–	–	–	–
31	32.1-32.6			–	–	–	–	2	24	43	33
32	33.1-33.6			–	–	–	–	6	21	43	36
33	34.1-34.3			–	–	–	–	–	–	–	–
34	35.0-35.5			–	–	–	–	3	21	47	32
35	36.0-36.5			–	–	–	–	2	23	44	33
36	37.0-37.5			–	–	–	–	2	19	47	34
37	37.7-38.1			–	–	–	–	–	–	–	–
38	38.1-38.6			–	–	–	–	3	23	45	32
39	39.1-39.6			–	–	–	–	5	18	46	35
40	40.0-40.5			–	–	–	–	2	21	45	34
		BEDROCK									

No.	SITE D D-2 L.S. = 478.92			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0–2.0	FILL		–	–	–	–	–	–	–	–
2	2.6–3.3			–	–	–	–	–	–	–	–
3	4.5–5.0	HENRY FORMATION		–	–	–	–	–	–	–	–
4	7.0–8.0			–	–	–	–	–	–	–	–
5	8.5–9.0			–	–	–	–	–	–	–	–
6	10.5–11.0			–	–	–	–	–	–	–	–
7	12.5–13.0			–	–	–	–	–	–	–	–
8	14.0–16.0			–	–	–	–	–	–	–	–
9	17.5–19.5			–	–	–	–	–	–	–	–
10	20.0–22.0			–	–	–	–	–	–	–	–
11	22.0–23.5			–	–	–	–	–	–	–	–
12	24.0–26.0			–	–	–	–	–	–	–	–

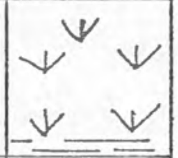
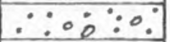
D-2	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	64,000.	113.	3700.	15,000.	–	–
2	–	–	–	–	–	–	20,000.	35.	4200.	16,000.	–	–
3	–	–	–	–	–	–	3,600.	34.	17.	76.	–	–
4	–	–	–	–	–	–	1,200.	8.5	11.	<4	–	–
5	–	–	–	–	–	–	1,800.	7.8	29.	<4	–	–
6	–	–	–	–	–	–	1,700.	4.9	21.	<4	–	–
7	–	–	–	–	–	–	13,000.	14.	19.	<4	–	–
8	–	–	–	–	–	–	1,300.	2.9	25.	67	–	–
9	–	–	–	–	–	–	55.	<.6	20.	<4	–	–
10	–	–	–	–	–	–	590.	<.6	16.	45.	–	–
11	–	–	–	–	–	–	71.	<.6	7.7	<4	–	–
12	–	–	–	–	–	–	93.	<.6	9.4	<4	–	–

	SITE D D-3 L.S. = 469.58			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0–0.8	FILL		–	–	–	–	–	–	–	–
2	2.0–2.8			–	–	–	–	–	–	–	–
3	4.5–5.0	HENRY FORMATION		–	–	–	–	–	–	–	–
4	6.5–7.0			–	–	–	–	–	–	–	–
5	8.5–9.0			–	–	–	–	–	–	–	–
6	10.5–11.0			–	–	–	–	–	–	–	–
7	12.5–13.0			–	–	–	–	–	–	–	–
8	13.5–14.0			–	–	–	–	–	–	–	–
9	15.5–16.0			–	–	–	–	–	–	–	–
10	17.0–18.8			–	–	–	–	–	–	–	–
11	19.0–20.2			–	–	–	–	–	–	–	–
12	21.0–22.6			–	–	–	–	–	–	–	–

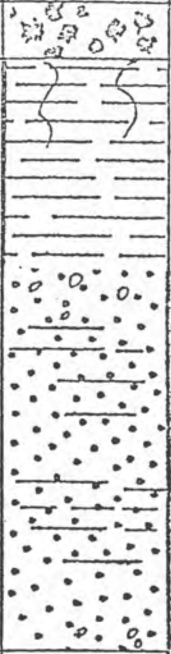
D-3	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	50,000.	54.	5,300.	20,000.	–	–
2	–	–	–	–	–	–	12,000.	23.	2,700.	24,000.	–	–
3	–	–	–	–	–	–	3,100.	16.	14.	24.	–	–
4	–	–	–	–	–	–	3,500.	19.	17.	90.	–	–
5	–	–	–	–	–	–	3,600.	16.	11.	21.	–	–
6	–	–	–	–	–	–	2,300.	3.7	17.	68.	–	–
7	–	–	–	–	–	–	1,600.	.86	22.	27.	–	–
8	–	–	–	–	–	–	2,700.	2.4	23.	21.	–	–
9	–	–	–	–	–	–	1,600.	2.1	22.	38.	–	–
10	–	–	–	–	–	–	640.	.76	9.	42.	–	–
11	–	–	–	–	–	–	700.	<.6	8.4	17.	–	–
12	–	–	–	–	–	–	290.	<.6	6.8	<4.	–	–

No.	SITE D D-5 L.S. = 473.56			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	2.0-2.5	FILL		–	–	–	–	–	–	–	–
2	5.5-6.0	GRAYSLAKE PEAT		–	–	–	–	–	–	–	–
3	7.5-7.9			–	–	–	–	–	–	–	–
4	11.5-11.9	HENRY FORMATION		–	–	–	–	–	–	–	–
5	13.5-14.0			–	–	–	–	–	–	–	–

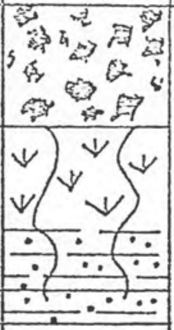
D-5	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	11,000.	43.	660.	1000.	–	–
2	–	–	–	–	–	–	120.	<.6	19.	<4.	–	–
3	–	–	–	–	–	–	82.	<.6	18.	21.	–	–
4	–	–	–	–	–	–	200.	1.1	14.	8.3	–	–
5	–	–	–	–	–	–	180.	.22	24.	34.	–	–

	SITE D D-7 L.S. = 467.29			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	0.5–1.0	FILL		–	–	–	–	–	–	–	–
2	4.5–5.0			–	–	–	–	–	–	–	–
3	6.5–7.0			–	–	–	–	–	–	–	–
4	12.5–13.0			–	–	–	–	–	–	–	–
5	14.5–15.0			–	–	–	–	–	–	–	–
6	18.5–19.0	GRAYSLAKE PEAT		–	–	–	–	–	–	–	–
7	20.5–21.0			–	–	–	–	–	–	–	–
8	22.5–23.0			–	–	–	–	–	–	–	–
9	24.5–25.0			–	–	–	–	–	–	–	–
10	26.5–27.0			–	–	–	–	–	–	–	–
11	28.5–29.0	HENRY FM.		–	–	–	–	–	–	–	–

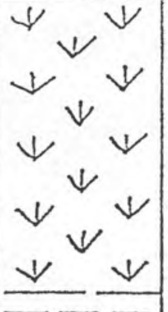
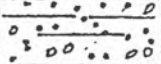
D-7	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	52,000.	<.6	720.	3,300.	–	–
2	–	–	–	–	–	–	24,000.	120.	560.	1,200.	–	–
3	–	–	–	–	–	–	18,000.	71.	700.	2,600.	–	–
4	–	–	–	–	–	–	21,000.	120.	170.	960.	–	–
5	–	–	–	–	–	–	39,000.	300.	220.	1,200.	–	–
6	–	–	–	–	–	–	24.	2.2	.92	9.0	–	–
7	–	–	–	–	–	–	9.1	<.6	.20	<4.	–	–
8	–	–	–	–	–	–	24.	<.6	1.9	<4.	–	–
9	–	–	–	–	–	–	56.	<.6	8.8	16.	–	–
10	–	–	–	–	–	–	2,900.	<.6	19.	74.	–	–
11	–	–	–	–	–	–	–	<.6	18.	<4.	–	–

	SITE D. D-1 L.S. = 490.98			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5–1.0	FILL		–	–	–	–	–	–	–	–
2	2.8–3.5	HENRY FORMATION		–	–	–	–	–	–	–	–
3	4.0–4.5			–	–	–	–	–	–	–	–
4	6.0–6.5			–	–	–	–	–	–	–	–
5	7.5–8.0			–	–	–	–	–	–	–	–
6	9.5–10.0			–	–	–	–	–	–	–	–
7	11.7–12.3			–	–	–	–	–	–	–	–
8	13.5–14.0			–	–	–	–	–	–	–	–
9	15.7–16.3			–	–	–	–	–	–	–	–
10	18.5–19.0			–	–	–	–	–	–	–	–
11	20.5–21.0			–	–	–	–	–	–	–	–
12	22.5–23.0			–	–	–	–	–	–	–	–
13	24.0–24.5			–	–	–	–	–	–	–	–
14	26.5–27.0			–	–	–	–	–	–	–	–
15	28.6–29.3			–	–	–	–	–	–	–	–
16	30.5–31.0			–	–	–	–	–	–	–	–
17	32.0–34.0			–	–	–	–	–	–	–	–
18	34.0–36.0			–	–	–	–	–	–	–	–
19	36.0–38.0			–	–	–	–	–	–	–	–

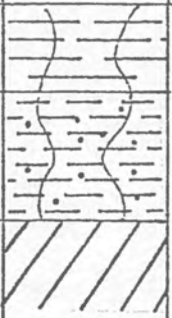
D-1	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	63,000.	84.	3,200	37,000	–	–
2	–	–	–	–	–	–	1,500.	13.	17.	24.	–	–
3	–	–	–	–	–	–	5,000.	51.	11.	26.	–	–
4	–	–	–	–	–	–	2,000.	71.	18.	33.	–	–
5	–	–	–	–	–	–	7,100.	33.	18.	12.	–	–
6	–	–	–	–	–	–	3,700.	10.	11.	14.	–	–
7	–	–	–	–	–	–	25,000.	1.9	11.	3.9	–	–
8	–	–	–	–	–	–	16,000.	<.6	10.	6.3	–	–
9	–	–	–	–	–	–	360.	<.6	16.	52.	–	–
10	–	–	–	–	–	–	43.	<.6	11.	4.9	–	–
11	–	–	–	–	–	–	57.	<.6	16.	7.7	–	–
12	–	–	–	–	–	–	22.	<.6	7.3	<4	–	–
13	–	–	–	–	–	–	13.	<.6	5.2	11	–	–
14	–	–	–	–	–	–	17.	<.6	6.	<4	–	–
15	–	–	–	–	–	–	46.	.72	17.	17.	–	–
16	–	–	–	–	–	–	49.	1.5	20.	9.	–	–
17	–	–	–	–	–	–	37.	1.1	14.	15.	–	–
18	–	–	–	–	–	–	45.	.36	9.4	28	–	–
19	–	–	–	–	–	–	37.	.9	9.3	17.	–	–

	SITE D D-4 L.S. = 464.82			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0–2.0	FILL		–	–	–	–	–	–	–	–
2	2.0–3.0			–	–	–	–	–	–	–	–
3	4.6–5.3			–	–	–	–	–	–	–	–
4	6.5–7.0	GRAYSLAKE PEAT		–	–	–	–	–	–	–	–
5	8.6–9.3			–	–	–	–	–	–	–	–
6	10.6–11.3			–	–	–	–	–	–	–	–
7	12.6–13.3			–	–	–	–	–	–	–	–
8	14.5–15.0			–	–	–	–	–	–	–	–
9	16.5–17.0	HENRY FM.		–	–	–	–	–	–	–	–

D-4.	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal. cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
1	–	–	–	–	–	–	29,000.	82.	3,500.	440.	6.75	–
2	–	–	–	–	–	–	18,000.	85.	2,200.	6800.	6.50	–
3	–	–	–	–	–	–	7,700.	1400.	2,400.	16000.	6.25	–
4	–	–	–	–	–	–	1,600.	22.	50.	150.	5.45	–
5	–	–	–	–	–	–	49.	<.6	1.1	11.	7.52	–
6	–	–	–	–	–	–	34.	<.6	2.8	8.2	7.45	–
7	–	–	–	–	–	–	46.	<.6	11.	9.6	6.75	–
8	–	–	–	–	–	–	33.	<.6	11.	5.5	7.20	–
9	–	–	–	–	–	–	–	<.6	13.	<.4	7.57	–

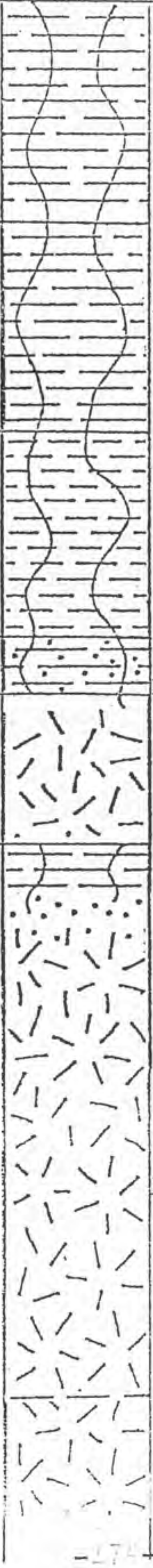
	SITE D D-6 L.S. = 456.29			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	GRAYSLAKE PEAT		–	–	–	–	–	–	–	–
2	2.5-3.0			–	–	–	–	–	–	–	–
3	4.5-5.0			–	–	–	–	–	–	–	–
4	6.5-7.0			–	–	–	–	–	–	–	–
5	8.5-9.0			–	–	–	–	–	–	–	–
6	10.5-11.0			–	–	–	–	–	–	–	–
7	12.5-13.0			–	–	–	–	–	–	–	–
8	14.5-15.0			–	–	–	–	–	–	–	–
9	16.5-17.0			–	–	–	–	–	–	–	–
10	18.5-19.0			–	–	–	–	–	–	–	–
11	20.0-22.0	HENRY FORMATION		–	–	–	–	–	–	–	–
12	22.0-24.0			–	–	–	–	–	–	–	–

D-6	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	2600.	27.	90.	250.	–	–
2	–	–	–	–	–	–	1100.	11.	9.5	56.	–	–
3	–	–	–	–	–	–	1200.	16.	28.	92.	–	–
4	–	–	–	–	–	–	6.	1.0	.56	<4.	–	–
5	–	–	–	–	–	–	110.	1.0	2.2	7.3	–	–
6	–	–	–	–	–	–	62.	<.6	7.6	12.	–	–
7	–	–	–	–	–	–	87.	<.6	19.	16.	–	–
8	–	–	–	–	–	–	14.	<.6	1.2	3.9	–	–
9	–	–	–	–	–	–	18.	<.6	3.5	11.	–	–
10	–	–	–	–	–	–	64.	<.6	18.	6.7	–	–
11	–	–	–	–	–	–	150.	<.6	16.	20.	–	–
12	–	–	–	–	–	–	30.	<.6	8.6	4.	–	–

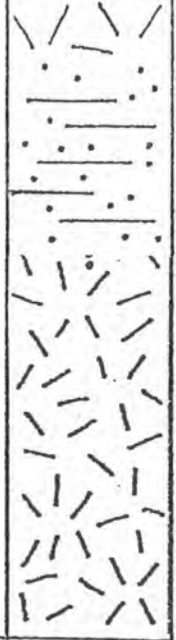
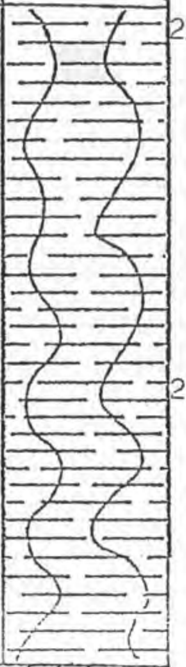
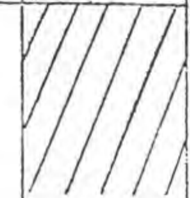
No.	SITE C M-1 L.S. = 627.78			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.8–1.0	PEORIA LOESS (19-59-22)		–	–	–	–	2	14	62	24
2	2.0–2.2			–	–	–	–	5	23	56	21
3	3.0–3.2	BERRY CLAY (25-49-26)		–	–	–	–	5	25	50	25
4	4.0–4.2			–	–	–	–	6	27	48	25
5	5.0–5.2			–	–	–	–	4	25	48	27
6	6.0–6.2			–	–	–	–	6	23	51	26
7	7.0–7.2	BEDROCK (47-31-22)		–	–	–	–	15	60	22	18
8	8.0–8.2			–	–	–	–	3	35	37	28
9	8.3–8.5			–	–	–	–	6	47	34	19

B-31	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/100g
1	–	–	–	–	–	–	860	–	–	–	–	–
2	–	–	–	–	–	–	860	–	–	–	–	–
3	–	–	–	–	–	–	100	–	–	–	–	–
4	1.19	77.5	14.5	8	N.D.	N.D.	52	–	–	–	–	–
5	1.11	85.5	9	5.5	N.D.	15	34	–	–	–	–	–
6	–	–	–	–	–	–	170	–	–	–	–	–
7	1.15	93.5	4	2.5	N.D.	N.D.	22	–	–	–	7.0	8.4
8	–	–	–	–	–	–	–	–	–	–	–	–
9	1.30	93	4.5	2.5	11	14	26	–	–	–	6.9	7.7
10	–	–	–	–	–	–	40	–	–	–	–	–
11	1.22	93	4.5	2.5	10	11	28	–	–	–	–	–
12	–	–	–	–	–	–	29	–	–	–	–	–
13	1.88	70	22	8	N.D.	26	–	–	–	–	–	–
14	1.45	24	52	24	N.D.	38	38.	–	–	–	–	–
15	1.58	24	53.5	22.5	8	33	–	–	–	–	–	–
16	–	–	–	–	–	–	19	–	–	–	–	–
17	1.55	25.5	52	22.5	15	25	–	–	–	–	–	–
18	1.25	37	41	22	23	21	34	–	–	–	–	–
19	1.45	40	41	19	16	21	–	–	–	–	–	–
20	1.57	38	43.5	18.5	18	25	–	–	–	–	–	–
21	1.35	18	55	27	28	10	60	–	–	–	–	–
22	1.75	18.5	59	22.5	30	14	–	–	–	–	–	–
23	.67	10	45	45	14	13	56	–	–	–	–	–
24	3.2	25	62	13	28	15	52	–	–	–	–	–
25	4.1	22	67	11	30	20	–	–	–	–	–	–
26	2.9	22.5	63	14.5	38	13	–	–	–	–	–	–
27	2.5	18	65.5	17.5	37	30	44	–	–	–	–	–
28	1.8	17	60.5	22.5	21	16	44	–	–	–	–	–
29	2.1	7	71	22	40	5	–	–	–	–	–	–
30	–	–	–	–	–	–	56	–	–	–	–	–
31	1.1	16.5	52	31.5	40	12	–	–	–	–	–	–
32	.92	17.5	48	34.5	19	13	–	–	–	–	–	–
33	–	–	–	–	–	–	160	–	–	–	–	–
34	.94	19	47	33.5	24	N.D.	–	–	–	–	–	–
35	1.0	14	52	34	15	N.D.	–	–	–	–	–	–
36	.85	12	49.5	38.5	19	10	–	–	–	–	–	–
37	–	–	–	–	–	–	52	–	–	–	–	–
38	.96	12.5	51.5	36	35	10	–	–	–	–	–	–
39	.84	16	43	37	27	18	–	–	–	–	–	–
40	.85	11.5	50	39	21	16	–	–	–	–	–	–

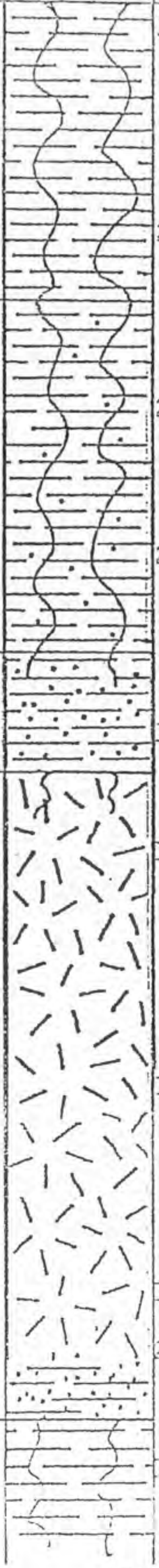
No.	SITE C M-2 L.S. = 615.30			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.3-1.5	PEORIA LOESS (5-55-40)		–	–	–	–	0	5	56	39
2	2.3-2.5			–	–	–	–	0	4	48	48
3	3.5-3.7			–	–	–	–	0	5	61	34
4	4.8-5.0	ROXANNA SILT AND BERRY CLAY (17-43-40)		–	–	–	–	0	19	36	45
5	5.5-5.7			–	–	–	–	0	12	51	37
6	6.3-6.5			–	–	–	–	0	19	44	37
7	7.8-8.0			–	–	–	–	1	19	42	39
8	8.8-9.0	GLASFORD FORMATION TILL (34-33-33)		–	–	–	–	1	29	34	37
9	10.5-10.7			–	–	–	–	1	26	32	42
10	11.3-11.5			–	–	–	–	4	29	35	36
11	12.0-12.2			–	–	–	–	0	36	29	35
12	13.0-13.2			–	–	–	–	4	43	32	25
13	13.8-14.0			–	–	–	–	4	26	46	28
14	14.4-14.6			–	–	–	–	4	47	28	25
15	15.5-15.8	BEDROCK (7-63-30)		–	–	–	–	0	7	61	32
16	16.5-16.8			–	–	–	–	1	7	65	28

No.	SITE B B-5 L.S. = 447.55'			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0-0.5	PEORIA LOESS (3-77-20)		–	–	–	–	–	–	–	–
2	0.5-1.0			–	–	–	–	–	–	–	–
3	1.0-1.5			–	–	–	–	–	–	–	–
4	2.0-2.5			–	–	–	–	–	–	–	–
5	2.5-3.0			–	–	–	–	0	3	79	18
6	3.0-3.5			–	–	–	–	0	5	77	18
7	3.5-4.0			–	–	–	–	0	2	76	22
8	4.0-4.5	ROXANNA SILT (14-61-25)		–	–	–	–	1	12	70	18
9	4.5-5.0			–	–	–	–	1	12	66	22
10	5.0-5.5			27.8	–	–	–	1	10	65	25
11	5.5-5.6			–	–	–	–	1	12	59	29
12	6.0-6.5			–	–	–	–	2	12	64	24
13	6.5-7.0			–	–	–	–	1	15	60	25
14	7.0-7.5			–	–	–	–	2	23	48	29
15	7.5-8.0	BERRY CLAY (35-38-27)		–	–	–	–	1	27	43	30
16	8.0-8.5			–	–	–	–	13	53	26	21
17	8.5-9.0			–	–	–	–	–	–	–	–
18	9.0-9.4			–	–	–	–	2	13	61	26
19	9.5-10.0			–	–	–	–	7	46	28	26
20	10.0-10.5			–	–	–	–	3	40	32	28
21	10.6-11.1			–	–	–	–	11	32	38	30
22	11.1-11.6	HAGARSTOWN		–	–	–	–	13	55	23	22
23	11.6-11.8			24.2	–	–	–	–	–	–	–
24	11.8-12.3	GLASFORD FORMATION TILL (37-39-24)		–	–	–	–	–	–	–	–
25	12.3-12.8			–	–	–	–	–	–	–	–
26	13.5-14.0			–	–	–	–	7	40	38	22
27	14.1-14.6			–	–	–	–	11	35	39	26
28	14.6-15.1			–	–	–	–	–	–	–	–
29	16.1-16.6	GLASFORD FORMATION TILL (31-40-29) (oxidized)		–	–	–	–	2	17	36	47
30	16.6-17.1			–	–	–	–	–	–	–	–
31	17.1-17.6			–	–	–	–	3	24	36	40
32	17.6-18.1			–	–	–	–	–	–	–	–
33	18.1-18.6			–	–	–	–	–	–	–	–
34	18.6-19.1			–	–	–	–	29	48	28	24
35	19.1-19.6			–	–	–	–	5	31	39	30
36	20.3-20.8			–	–	–	–	5	29	41	30
37	20.8-21.3			–	–	–	–	4	32	42	26
38	21.3-21.8			–	–	–	–	–	–	–	–
39	21.8-22.3			–	–	–	–	5	32	42	26
40	22.4-22.9			12.4	–	–	–	–	–	–	–
41	22.9-23.4			–	–	–	–	–	–	–	–
42	23.4-23.9			–	–	–	–	5	38	33	29
43	23.9-24.4			–	–	–	–	4	25	50	25
44	24.5-25.0			–	–	–	–	–	–	–	–
45	25.0-25.5			–	–	–	–	4	24	52	24
46	25.5-26.0			–	–	–	–	–	–	–	–
47	26.0-26.3			–	–	–	–	12	41	37	22
48	26.3-26.8	(unoxidized) (35-33-32)		–	–	–	–	–	–	–	–
49	26.8-27.3			–	–	–	–	7	38	35	27
50	27.3-27.8			–	–	–	–	–	–	–	–
51	27.8-28.0			–	–	–	–	–	–	–	–

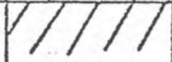
B-5	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/1	Cd mg/1	Cu mg/1	Pb mg/1	pH	CEC meg/100g
1	–	–	–	–	–	–	4200	5.8	2,200	2,000	4.80	–
2	–	–	–	–	–	–	2200	12	270	210	5.20	–
3	–	–	–	–	–	–	1200	19	260	140	4.45	–
4	–	–	–	–	–	–	520	2.2	100	480	4.40	–
5	–	–	–	–	–	–	320	1.3	82	390	4.50	–
6	–	–	–	–	–	–	350	.94	58	240	4.15	–
7	–	–	–	–	–	–	340	.96	48	84	4.00	–
8	–	–	–	–	–	–	440	.04	39	16	3.90	–
9	–	–	–	–	–	–	720	1.7	7.7	6.9	3.65	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	1.3	–	–	–	–	–	680	1.6	9.6	9.3	3.82	–
12	1.5	–	–	–	–	–	1700	3.0	18	19	4.20	–
13	1.4	61.5	36.5	12	N.D.	N.D.	1800	3.6	9.6	11.	4.50	–
14	1.3	67	22	11	N.D.	N.D.	2600	6.4	13	23	5.45	
15	1.35	80	13.5	6.5	N.D.	15	–	–	–	–	–	–
16	1.6	75	17.5	7.5	N.D.	N.D.	1900	7.2	15	27	5.25	–
17	–	–	–	–	–	–	1800	4.0	8.9	12.	5.48	–
18	1.3	63	24	13	N.D.	N.D.	2200	2.6	13.	12.	5.40	–
19	1.16	83	11	6	N.D.	N.D.	–	–	–	–	–	–
20	1.27	86.5	9	4.5	N.D.	N.D.	–	–	–	–	–	–
21	1.5	81	13	6	N.D.	N.D.	1600	5.6	18.	33.	5.80	–
22	1.3	79	14	7	N.D.	N.D.	2200	3.2	13.	14.	5.75	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	840	2.1	8.1	10	7.85	–
25	–	–	–	–	–	–	79	.10	18	16	7.65	–
26	2.1	39	46.5	14.5	25	31	–	–	–	–	–	–
27	2.7	41	37	12	19	29	400	.78	9.6	10	7.47	–
28	–	–	–	–	–	–	76	<.04	24	15	7.30	–
29	1.7	37	45	18	N.D.	N.D.	88	<.04	23	15	7.30	–
30	–	–	–	–	–	–	–	–	–	–	7.30	–
31	1.97	21	59	20	N.D.	N.D.	–	–	–	–	7.80	–
32	–	–	–	–	–	–	–	–	–	–	7.90	–
33	–	–	–	–	–	–	–	–	–	–	7.95	–
34	–	–	–	–	22	12	–	–	–	–	7.92	–
35	2.1	18	62	20	31	17	51	<.02	15	9.5	7.97	–
36	2.8	23	62	15	50	16	–	–	–	–	7.97	–
37	3.5	26	62	12	36	18	–	–	–	–	8.10	–
38	–	–	–	–	–	–	–	–	–	–	7.95	–
39	3.2	28	59.5	12.5	50	16	47	.22	41	31	7.97	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	7.90	–
42	3.6	28	60.5	11.5	40	19	–	–	–	–	7.90	–
43	2.76	34	53	13	36	11	–	–	–	–	7.86	–
44	–	–	–	–	–	–	–	–	–	–	7.85	–
45	2.85	33.5	54	12.5	32	12	–	–	–	–	–	–
46	–	–	–	–	–	–	–	–	–	–	8.00	–
47	3.2	23.5	63.5	13	17	22	–	–	–	–	8.03	–
48	–	–	–	–	–	–	–	–	–	–	8.01	–
49	4.8	13.5	76	10.5	28	12	–	–	–	–	8.08	–
50	–	–	–	–	–	–	–	–	–	–	8.08	–
51	–	–	–	–	–	–	22	.05	11.	11.	7.93	–

	SITE B B-5 L.S. = 447.55			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
52	28.0-28.5	BANNER FORMATION TILL (35-33-32)		–	–	–	–	3	24	43	33
53	28.6-29.1			14.0	–	–	–	–	–	–	–
54	29.1-29.6			–	–	–	–	17	45	29	26
55	29.6-30.1			–	–	–	–	–	–	–	–
56	30.1-30.6			–	–	–	–	20	48	25	27
57	30.6-31.1			–	–	–	–	–	–	–	–
58	31.1-31.6			–	–	–	–	16	47	27	26
59	31.6-32.1			12.5	–	–	–	–	–	–	–
60	32.1-32.4			–	–	–	–	–	–	–	–
61	33.0-33.5			–	–	–	–	5	23	36	41
62	33.5-34.0			–	–	–	–	–	–	–	–
63	34.0-34.5			–	–	–	–	4	21	45	34
64	34.5-35.0			–	–	–	–	–	–	–	–
65	35.0-35.5			–	–	–	–	11	31	38	31
66	35.5-36.0			–	–	–	–	–	–	–	–
67	36.0-36.4			–	–	–	–	5	20	45	35
68	36.5-37.0			–	–	–	–	–	–	–	–
69	37.0-37.5			–	–	–	–	4	20	47	33
70	37.5-38.0			–	–	–	–	–	–	–	–
71	38.0-38.5	ENION FORMATION (7-48-45)		21.1	–	–	–	6	24	38	38
72	38.6-39.1			–	–	–	–	–	–	–	–
73	39.1-39.6			–	–	–	–	2	5	47	47
74	39.6-40.1			–	–	–	–	–	–	–	–
75	40.1-40.6			–	–	–	–	1	10	46	44
76	40.6-41.1			–	–	–	–	–	–	–	–
77	41.1-41.6			–	–	–	–	6	8	49	43
78	41.7-42.2			–	–	–	–	–	–	–	–
79	42.2-42.7			–	–	–	–	6	10	52	38
80	42.7-43.2			–	–	–	–	–	–	–	–
81	43.2-43.7			–	–	–	–	25	18	51	31
82	43.7-44.2			23.5	–	–	–	–	–	–	–
83	44.2-44.7			–	–	–	–	–	–	–	–
84	44.7-45.2			–	–	–	–	0	4	56	40
85	45.2-45.7			–	–	–	–	1	6	46	48
86	46.2-46.4			–	–	–	–	0	6	45	49
87	46.4-46.9			–	–	–	–	0	7	44	49
88	46.9-47.4			–	–	–	–	–	–	–	–
89	47.4-47.9			–	–	–	–	0	4	48	48
90	47.9-48.4			–	–	–	–	0	4	39	57
91	48.4-48.9	BEDROCK (2-49-49)		20.3	–	–	–	–	–	–	–
92	48.9-49.4			–	–	–	–	0	2	53	45
93	49.4-49.8			–	–	–	–	–	–	–	–
94	49.8-50.3			–	–	–	–	0	1	48	51
95	50.3-50.8			–	–	–	–	–	–	–	–
96	50.8-51.3			–	–	–	–	0	3	48	49
97	51.3-51.8			–	–	–	–	–	–	–	–
98	51.8-52.3			–	–	–	–	0	2	49	49

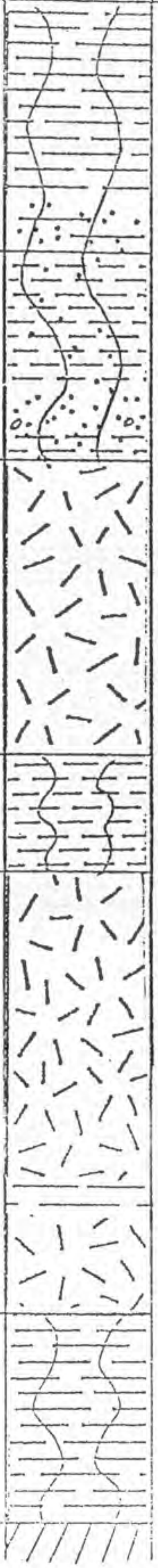
B-5												
	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/ 100g
52	2.1	18.5	62	19.5	28	12	–	–	–	–	–	–
53	–	–	–	–	–	–	–	–	–	–	–	–
54	1.05	17	51	32	15	N.D.	–	–	–	–	8.08	–
55	–	–	–	–	–	–	–	–	–	–	8.08	–
56	1.03	10.5	54.5	35	15	21	61.	.08	270	33	8.06	–
57	–	–	–	–	–	–	–	–	–	–	7.92	–
58	0.9	13	51	36	N.D.	N.D.	–	–	–	–	8.10	–
59	–	–	–	–	–	–	–	–	–	–	–	–
60	–	–	–	–	–	–	–	–	–	–	7.65	–
61	1.07	26	45	28	34	15	–	–	–	–	7.70	–
62	–	–	–	–	–	–	–	–	–	–	7.65	–
63	0.9	20.5	45	34.5	24	N.D.	–	–	–	–	7.50	–
64	–	–	–	–	–	–	60	.12	15	13	7.00	–
65	0.8	15	46	39	20	N.D.	–	–	–	–	7.60	–
66	–	–	–	–	–	–	–	–	–	–	7.69	–
67	0.6	20	39	41	24	12	–	–	–	–	7.75	–
68	–	–	–	–	–	–	–	–	–	–	7.78	–
69	0.7	18.5	41	40.5	N.D.	N.D.	–	–	–	–	7.75	–
70	–	–	–	–	–	–	–	–	–	–	7.80	–
71	0.9	14.5	50	36	N.D.	N.D.	–	–	–	–	–	–
72	–	–	–	–	–	–	86	.40	24	21	7.70	–
73	0.7	23	40	37	N.D.	N.D.	–	–	–	–	7.70	–
74	–	–	–	–	–	–	–	–	–	–	7.25	–
75	0.5	26.5	30	44	N.D.	N.D.	–	–	–	–	7.60	–
76	–	–	–	–	–	–	–	–	–	–	7.70	–
77	0.5	26.5	29.5	44	N.D.	N.D.	–	–	–	–	7.35	–
78	–	–	–	–	–	–	–	–	–	–	7.55	–
79	0.5	30.5	30.5	39	N.D.	N.D.	–	–	–	–	7.60	–
80	–	–	–	–	–	–	61	.68	38	71	7.52	–
81	–	–	–	–	–	–	–	–	–	–	7.55	–
82	–	–	–	–	–	–	–	–	–	–	–	–
83	–	–	–	–	–	–	–	–	–	–	7.80	–
84	0.6	46	25	29	N.D.	N.D.	–	–	–	–	7.20	–
85	0.6	41	26.5	32.5	N.D.	N.D.	–	–	–	–	7.70	–
86	0.5	36	25.5	38	N.D.	N.D.	–	–	–	–	7.90	–
87	0.5	46	24	30	N.D.	N.D.	–	–	–	–	7.63	–
88	–	–	–	–	–	–	36	<.02	15	14	7.50	–
89	0.5	46	23.5	31.5	N.D.	N.D.	–	–	–	–	6.72	–
90	0.5	38.5	25.5	36	N.D.	N.D.	–	–	–	–	7.56	–
91	–	–	–	–	–	–	–	–	–	–	–	–
92	0.7	16	42	42	N.D.	N.D.	–	–	–	–	7.72	–
93	–	–	–	–	–	–	–	–	–	–	7.83	–
94	1.0	16	49	35	N.D.	30	–	–	–	–	–	–
95	–	–	–	–	–	–	120	.12	20	13	8.00	–
96	1.2	11	58	31	N.D.	N.D.	–	–	–	–	8.07	–
97	–	–	–	–	–	–	–	–	–	–	8.10	–
98	1.7	9	65	26	N.D.	N.D.	–	–	–	–	8.00	–

B-8	SITE B B-8 L.S. = 457.88			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (2-61-37)		29.7	–	–	–	–	–	–	–
2	1.0-1.5			–	–	–	–	1	20	53	27
3	1.5-2.0			–	–	–	–	–	–	–	–
4	2.0-2.5			–	–	–	–	1	2	68	30
5	2.5-3.0			–	–	–	–	–	–	–	–
6	3.0-3.5			–	–	–	–	1	2	51	47
7	3.5-3.7			–	–	–	–	–	–	–	–
8	4.0-4.5			25.3	–	–	–	2	1	65	34
9	5.0-5.5			–	–	–	–	–	–	–	–
10	6.0-6.5			–	–	–	–	0	0	72	28
11	6.5-7.0	ROXANNA SILT AND BERRY CLAY (13-52-35)		–	–	–	–	–	–	–	–
12	7.0-7.5			–	–	–	–	1	7	61	32
13	8.6-9.1			–	–	–	–	–	–	–	–
14	9.1-9.6			26.1	–	–	–	–	–	–	–
15	10.2-10.7			–	–	–	–	0	10	55	35
16	10.7-11.2			–	–	–	–	–	–	–	–
17	12.0-12.5			–	–	–	–	1	12	51	37
18	12.5-13.0			–	–	–	–	–	–	–	–
19	13.0-13.4			22.5	–	–	–	–	–	–	–
20	14.2-14.7			–	–	–	–	–	–	–	–
21	14.7-15.2			–	–	–	–	2	26	36	38
22	17.0-17.5			–	–	–	–	1	8	57	35
23	18.2-18.7	HAGARSTOWN (37-39-24)		–	–	–	–	8	38	34	28
24	19.0-19.5			–	–	–	–	5	37	31	24
25	19.5-20.0			15.7	–	–	–	–	–	–	–
26	20.0-20.5			–	–	–	–	5	37	42	21
27	21.0-21.5	BANNER FORMATION TILL (30-42-28)		–	–	–	–	3	33	40	27
28	22.0-22.5			–	–	–	–	–	–	–	–
29	23.5-24.0			11.1	–	–	–	–	–	–	–
30	24.0-24.5			–	–	–	–	5	30	40	30
31	26.2-26.7			–	–	–	–	–	–	–	–
32	26.7-27.2			–	–	–	–	–	–	–	–
33	27.2-27.7			–	–	–	–	3	34	44	22
34	27.7-28.2			–	–	–	–	–	–	–	–
35	28.6-29.1			–	–	–	–	–	–	–	–
36	29.1-29.6			–	–	–	–	–	–	–	–
37	29.6-30.1			12.8	–	–	–	–	–	–	–
38	30.5-31.0			–	–	–	–	–	–	–	–
39	31.0-31.5			–	–	–	–	8	21	45	34
40	31.5-32.0			–	–	–	–	–	–	–	–
41	32.0-32.5			–	–	–	–	–	–	–	–
42	32.5-33.0			–	–	–	–	–	–	–	–
43	33.0-33.5			–	–	–	–	–	–	–	–
44	35.0-35.5			17.4	–	–	–	–	–	–	–
45	36.0-36.5			–	–	–	–	3	23	46	31
46	38.1-38.6			21.1	–	–	–	–	–	–	–
47	39.1-39.6			–	–	–	–	0	39	37	24
48	40.0-40.5			–	–	–	–	1	58	27	15
49	41.0-41.5	ENION FORMATION		–	–	–	–	0	10	46	44
50	42.3-42.8			15.8	–	–	–	–	–	–	–
51	43.0-43.5			–	–	–	–	0	3	53	44

B-81	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	480	–	–	–	4.25	–
3	–	–	–	–	–	–	230	–	–	–	4.10	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	230	–	–	–	3.97	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	69	–	–	–	5.13	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	6.00	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	44	–	–	–	6.20	–
12	–	–	–	–	–	–	15	–	–	–	6.31	–
13	–	–	–	–	–	–	91	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	21	–	–	–	–	–
16	–	–	–	–	–	–	150	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	32	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	43	–	–	–	6.60	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	40	–	–	–	8.02	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	59	–	–	–	8.03	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	–	–	–	–	8.01	–
32	–	–	–	–	–	–	–	–	–	–	8.08	–
33	–	–	–	–	–	–	–	–	–	–	8.10	–
34	–	–	–	–	–	–	–	–	–	–	8.01	–
35	–	–	–	–	–	–	–	–	–	–	7.95	–
36	–	–	–	–	–	–	–	–	–	–	7.93	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	7.95	–
39	–	–	–	–	–	–	–	–	–	–	7.94	–
40	–	–	–	–	–	–	–	–	–	–	8.00	–
41	–	–	–	–	–	–	81	–	–	–	7.94	–
42	–	–	–	–	–	–	–	–	–	–	7.90	–
43	–	–	–	–	–	–	–	–	–	–	7.99	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	–	–	–	–	–	–	–	–	–	–	–	–
46	–	–	–	–	–	–	–	–	–	–	–	–
47	–	–	–	–	–	–	19	–	–	–	8.35	–
48	–	–	–	–	–	–	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–
50	–	–	–	–	–	–	–	–	–	–	–	–
51	–	–	–	–	–	–	–	–	–	–	–	–

B-8	SITE B B-8 L.S. = 457.88			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
52	44.4-44.9	ENION FORMATION (5-53-42)		–	–	–	–	–	–	–	–
53	45.0-45.5			–	–	–	–	0	4	56	40
54	46.0-46.5			24.0	–	–	–	–	–	–	–
55	49.0-49.5			–	–	–	–	1	5	58	37
56	52.0-52.5			–	–	–	–	0	4	52	44
57	53.0-53.5			–	–	–	–	–	–	–	–
58	54.0-54.5			20.7	–	–	–	–	–	–	–
		BEDROCK									

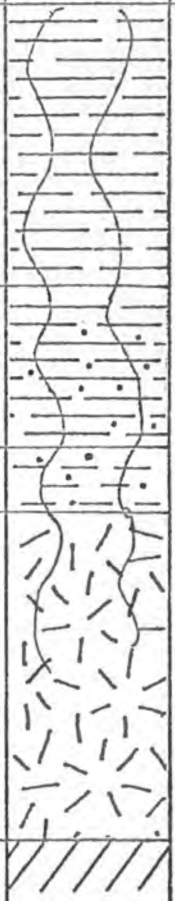
B-8	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
52	–	–	–	–	–	–	14	–	–	–	7.70	–
53	–	–	–	–	–	–	–	–	–	–	–	–
54	–	–	–	–	–	–	–	–	–	–	–	–
55	–	–	–	–	–	–	–	–	–	–	–	–
56	–	–	–	–	–	–	–	–	–	–	–	–
57	–	–	–	–	–	–	76	–	–	–	7.50	–
58	–	–	–	–	–	–	–	–	–	–	–	–

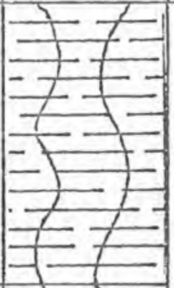
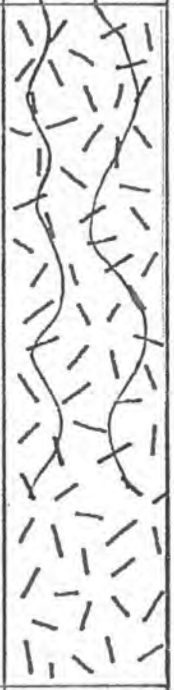
	SITE B BCH-2 L.S. = 445			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	1.0-1.5	PEORIA LOESS AND ROXANA SILT (5-62-33)		–	–	–	–	0	3	73	24
2	1.5-2.0			–	–	–	–	–	–	–	–
3	2.0-2.5			–	–	–	–	0	5	57	38
4	2.9-3.3			–	–	–	–	–	–	–	–
5	3.7-4.0			–	–	–	–	1	8	55	37
6	4.3-4.8			–	–	–	–	–	–	–	–
7	5.1-5.3			–	–	–	–	–	–	–	–
8	6.2-6.5			–	–	–	–	3	45	34	21
9	7.3-7.5	BERRY CLAY (44-25-31)		–	–	–	–	3	39	28	33
10	7.7-8.2			–	–	–	–	–	–	–	–
11	8.2-8.7			–	–	–	–	–	–	–	–
12	8.7-9.0			–	–	–	–	–	–	–	–
13	9.0-9.2			–	–	–	–	3	56	12	32
14	11.2-11.5			–	–	–	–	11	45	26	29
15	12.1-12.3			–	–	–	–	2	38	31	31
16	13.0-13.5	GLASFORD FORMATION TILL (33-44-23)		–	–	–	–	–	–	–	–
17	13.8-14.1			–	–	–	–	8	26	46	28
18	14.8-15.3			–	–	–	–	5	35	39	26
19	16.0-16.3			–	–	–	–	5	35	39	26
20	16.5-17.0			–	–	–	–	–	–	–	–
21	18.5-19.0			–	–	–	–	6	33	42	25
22	20.5-21.0			–	–	–	–	–	–	–	–
23	22.5-23.0			–	–	–	–	3	35	41	24
24	24.3-24.8			–	–	–	–	–	–	–	–
25	25.[illegible]-25.3			–	–	–	–	3	32	43	25
26	2[illegible]-27.3	LIERLE CLAY (22-39-39)		–	–	–	–	1	20	38	42
27	28.0-28.5			–	–	–	–	–	–	–	–
28	29.7-30.0			–	–	–	–	1	20	38	42
29	30.7-31.0			–	–	–	–	1	25	40	35
30	31.5-31.8	BANNER FORMATION TILL (23-47-30)		–	–	–	–	9	26	44	30
31	32.0-32.5			–	–	–	–	–	–	–	–
32	33.5-33.8			–	–	–	–	4	31	43	26
33	34.8-35.8			–	–	–	–	5	31	42	27
34	36.0-36.5			–	–	–	–	5	–	–	–
35	38.7-39.0			–	–	–	–	5	25	43	32
36	40.0-40.5			–	–	–	–	–	–	–	–
37	40.7-41.0			–	–	–	–	3	24	45	31
38	41.5-41.8			–	–	–	–	4	23	44	33
39	43.5-43.8			–	–	–	–	4	24	45	32
40	45.5-45.8			–	–	–	–	4	6	61	33
41	47.5-47.8			–	–	–	–	4	4	67	29
42	50.5-50.7			–	–	–	–	3	16	53	31
43	51.4-51.7			–	–	–	–	3	17	54	29
44	53.4-53.7			–	–	–	–	8	15	54	31
45	55.4-55.7	ENION FORMATION (5-62-33)		–	–	–	–	0	4	57	39
46	57.5-57.8			–	–	–	–	0	7	31	62
47	59.5-59.8			–	–	–	–	0	4	60	36
48	61.5-61.8			–	–	–	–	0	4	62	34
49	63.5-63.6			–	–	–	–	0	4	65	31
50	65.3-65.6			–	–	–	–	0	4	70	26
51	67.5-67.8			–	–	–	–	0	5	67	28
		BEDROCK									

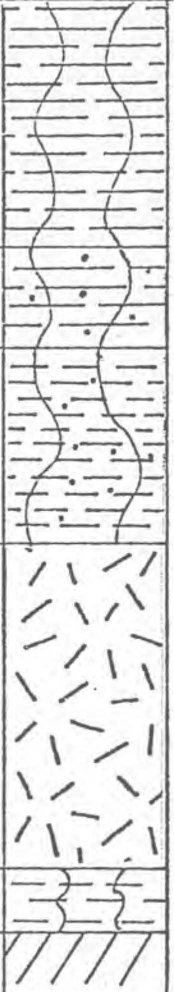
BCH-2	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/ 100g
1	–	–	–	–	–	–	–	–	–	–	5.7	3.9
2	–	–	–	–	–	–	19	<.02	9.7	12	4.6	4.1
3	–	–	–	–	–	–	–	–	–	–	5.2	7.1
4	–	–	–	–	–	–	–	–	–	–	6.1	5.0
5	–	–	–	–	–	–	19	<.02	9.9	12	–	–
6	–	–	–	–	–	–	–	–	–	–	6.2	3.9
7	–	–	–	–	–	–	–	–	–	–	6.3	5.1
8	–	–	–	–	–	–	11	<.02	5.0	6.8	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	6.4	7.1
11	–	–	–	–	–	–	–	–	–	–	6.5	3.9
12	–	–	–	–	–	–	14	<.02	6.6	8.2	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	14	<.02	7.5	7.7	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	38	.14	13	8.9	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	32	.08	11	7.5	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	38	<.02	12	8.3	–	–
21	–	–	–	–	–	–	24	.06	8.7	7.1	–	–
22	–	–	–	–	–	–	32	.06	11	10	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	46	.04	14	11	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	46	.14	19	12	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–
29	–	–	–	–	–	–	–	–	–	–	–	–
30	–	–	–	–	–	–	–	–	–	–	–	–
31	–	–	–	–	–	–	44	.20	11	7.2	–	–
32	–	–	–	–	–	–	–	–	–	–	–	–
33	–	–	–	–	–	–	–	–	–	–	–	–
34	–	–	–	–	–	–	40	.06	15	8.9	–	–
35	–	–	–	–	–	–	–	–	–	–	–	–
36	–	–	–	–	–	–	46	.08	22	11	–	–
37	–	–	–	–	–	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–	–	–	–	–	–
40	–	–	–	–	–	–	–	–	–	–	–	–
41	–	–	–	–	–	–	–	–	–	–	–	–
42	–	–	–	–	–	–	–	–	–	–	–	–
43	–	–	–	–	–	–	–	–	–	–	–	–
44	–	–	–	–	–	–	–	–	–	–	–	–
45	–	–	–	–	–	–	–	–	–	–	–	–
46	–	–	–	–	–	–	–	–	–	–	–	–
47	–	–	–	–	–	–	–	–	–	–	–	–
48	–	–	–	–	–	–	–	–	–	–	–	–
49	–	–	–	–	–	–	–	–	–	–	–	–
50	–	–	–	–	–	–	–	–	–	–	–	–
[illegible]	–	–	–	–	–	–	–	–	–	–	–	–

No.	SITE B BCH-2 L.S. = 445			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
52	69.5-69.8	BEDROCK	▨	–	–	–	–	0	8	45	47
53	71.0-71.3			–	–	–	–	1	4	35	61

BCH-2	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
52	–	–	–	–	–	–	–	–	–	–	–	–
53	–	–	–	–	–	–	–	–	–	–	–	–

	SITE C M-4 L.S. = 614.78			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft^3	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	PEORIA LOESS (14-57-29)		–	–	–	–	25	27	51	22
2	0.5-1.0			–	–	–	–	2	13	58	29
3	1.0-1.5			–	–	–	–	1	16	56	28
4	1.5-2.0			–	–	–	–	2	17	56	27
5	3.0-3.5			–	–	–	–	1	9	58	33
6	3.5-4.0			–	–	–	–	1	7	43	50
7	4.0-4.5			–	–	–	–	1	13	57	30
8	5.0-5.5			–	–	–	–	1	11	59	30
9	5.5-6.0	ROXANNA SILT (17-45-38)		–	–	–	–	1	20	42	38
10	6.0-6.5			–	–	–	–	2	21	40	39
11	6.5-7.0			–	–	–	–	0	27	36	37
12	7.0-7.5			–	–	–	–	1	18	44	38
13	7.5-8.0			–	–	–	–	0	13	49	38
14	8.0-8.5	BERRY CLAY (20-40-40)		–	–	–	–	1	18	40	42
15	8.5-9.0			–	–	–	–	1	22	40	38
16	9.0-9.5	GLASFORD FORMATION TILL (42-30-28)		–	–	–	–	1	4	57	39
17	10.0-10.5			–	–	–	–	5	27	37	36
18	10.5-11.0			–	–	–	–	4	39	28	33
19	12.0-12.5			–	–	–	–	3	45	27	28
20	12.5-13.0			–	–	–	–	4	45	24	31
21	13.0-13.5			–	–	–	–	7	42	33	25
22	13.9-14.3			–	–	–	–	4	45	30	25
23	14.3-14.7			–	–	–	–	6	44	30	26
24	14.7-15.1			–	–	–	–	10	44	30	26
25	15.1-15.5			–	–	–	–	2	43	37	20
		BEDROCK									

No.	SITE C M-5 L.S. = 615.87			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	PEORIA LOESS AND ROXANNA SILT (5-64-31)		–	–	–	–	1	9	61	30
2	0.5-1.0			–	–	–	–	0	7	62	31
3	1.0-1.5			–	–	–	–	1	6	56	38
4	1.5-2.0			–	–	–	–	1	4	73	23
5	2.0-2.5			–	–	–	–	0	4	73	23
6	4.0-4.5			–	–	–	–	0	2	52	46
7	4.5-5.0			–	–	–	–	0	2	70	28
8	5.0-5.5			–	–	–	–	0	1	66	33
9	5.5-6.0	GLASFORD FORMATION TILL (36-34-30)		–	–	–	–	0	20	43	37
10	6.0-6.5			–	–	–	–	1	26	37	37
11	6.5-7.0			–	–	–	–	0	24	37	39
12	7.0-7.5			–	–	–	–	0	23	39	38
13	7.5-8.0			–	–	–	–	0	18	40	42
14	8.0-8.5			–	–	–	–	0	25	37	38
15	8.5-9.0			–	–	–	–	1	23	34	43
16	9.0-9.5			–	–	–	–	2	3	55	42
17	9.5-10.0			–	–	–	–	0	19	42	39
18	10.0-10.5			–	–	–	–	1	18	37	45
19	10.5-11.0			–	–	–	–	1	27	52	21
20	11.0-11.5			–	–	–	–	1	13	49	38
21	11.5-12.0			–	–	–	–	1	30	28	42
22	12.0-12.5			–	–	–	–	1	33	31	36
23	12.5-13.0			–	–	–	–	5	27	33	40
24	13.0-13.5			–	–	–	–	2	44	26	30
25	13.5-14.0			–	–	–	–	2	44	17	39
26	14.0-14.5			–	–	–	–	2	46	26	28
27	14.5-15.0			–	–	–	–	7	46	28	26
28	15.0-15.5			–	–	–	–	6	42	33	25
29	15.5-16.0			–	–	–	–	5	49	24	27

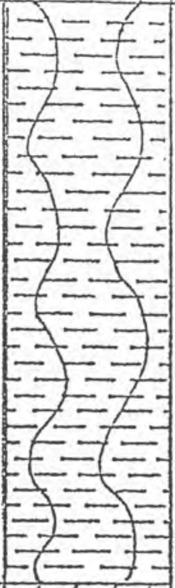
No.	SITE C M-8 L.S. = 614.49			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	PEORIA LOESS (9-61-30)		–	–	–	–	1	12	64	24
2	0.5-1.0			–	–	–	–	1	12	64	24
3	1.0-1.5			–	–	–	–	0	10	61	29
4	1.5-2.0			–	–	–	–	1	8	62	30
5	2.0-2.5			–	–	–	–	0	7	56	37
6	4.0-4.5			–	–	–	–	0	6	57	37
7	4.5-5.0			–	–	–	–	3	9	62	29
8	6.0-6.5	ROXANNA SILT (26-39-35)		–	–	–	–	0	20	46	34
9	6.5-7.0			–	–	–	–	1	27	36	37
10	7.0-7.5			–	–	–	–	2	31	34	35
11	8.5-9.0	BERRY CLAY (34-31-35)		–	–	–	–	1	30	34	36
12	9.0-9.5			–	–	–	–	2	34	35	31
13	9.5-10.0			–	–	–	–	0	30	32	38
14	10.0-10.5			–	–	–	–	1	33	31	36
15	10.5-11.0			–	–	–	–	7	37	26	37
16	11.0-11.5			–	–	–	–	5	38	29	33
17	11.5-12.0	GLASFORD FORMATION TILL (37-34-29)		–	–	–	–	4	48	23	29
18	12.0-12.5			–	–	–	–	4	50	25	25
19	12.5-13.0			–	–	–	–	1	41	35	24
20	13.0-13.5			–	–	–	–	2	43	32	25
21	13.5-13.8			–	–	–	–	4	47	28	25
22	13.8-14.0			–	–	–	–	3	44	31	25
23	17.5-18.0			–	–	–	–	3	25	39	36
24	21.5-22.0			–	–	–	–	1	28	42	30
25	23.5-24.0			–	–	–	–	2	26	40	34
26	27.5-28.0			–	–	–	–	2	20	45	35
27	30.0-30.5	LIERLE CLAY (11-64-25)		–	–	–	–	0	13	62	25
28	33.5-34.0			–	–	–	–	0	9	66	25
		BEDROCK									

No.	SITE C M-3 L.S. = 611.26			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0-0.5	PEORIA LOESS (13-57-30)		–	–	–	–	0	11	63	26
2	0.5-1.0			–	–	–	–	1	11	64	25
3	1.0-1.5			–	–	–	–	1	18	48	34
4	1.5-2.0			–	–	–	–	0	1	69	30
5	2.0-2.5			–	–	–	–	0	22	43	35
6	5.5-6.0	ROXANNA SILT (15-53-32)		–	–	–	–	0	12	64	24
7	6.0-6.5			–	–	–	–	1	19	41	40
8	6.5-7.0	GLASFORD FORMATION TILL (41-29-30)		–	–	–	–	2	27	29	44
9	7.0-7.5			–	–	–	–	0	34	30	36
10	7.5-8.0			–	–	–	–	0	35	26	39
11	8.0-8.5			–	–	–	–	5	6	61	33
12	8.5-8.9			–	–	–	–	4	36	35	29
13	8.9-9.4			–	–	–	–	2	41	33	26
14	9.4-9.9			–	–	–	–	2	46	25	29
15	9.9-10.4			–	–	–	–	5	44	29	27
16	10.4-10.5			–	–	–	–	4	38	38	24
17	10.5-11.0			–	–	–	–	4	42	33	25
18	11.0-11.5			–	–	–	–	7	42	33	25
19	11.5-12.0			–	–	–	–	5	42	31	27
20	12.0-12.5			–	–	–	–	3	43	31	26
21	13.0-13.5	BEDROCK (20-53-27)		–	–	–	–	3	40	28	32
22	13.5-14.0			–	–	–	–	9	31	41	28
23	15.0-15.5			–	–	–	–	5	32	38	30
24	15.5-16.0			–	–	–	–	0	31	44	25
25	16.0-16.5			–	–	–	–	1	7	62	31
26	16.5-17.0			–	–	–	–	0	17	56	27
27	17.0-17.5			–	–	–	–	0	16	56	28
28	19.0-19.5			–	–	–	–	0	0	78	22

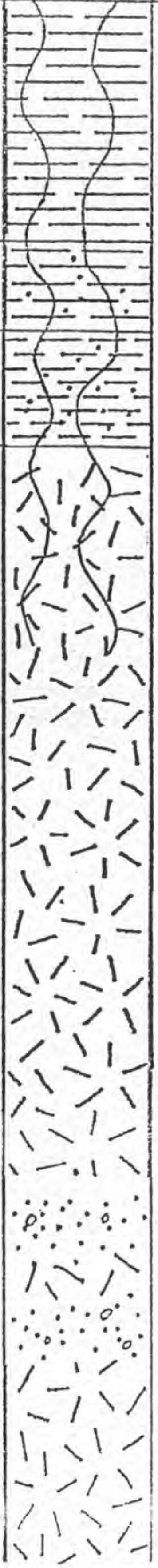
M-3	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/ 100g
1	–	–	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–	–	–	–	–
4	–	–	–	–	–	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	–	–	–	–	–
14	–	–	–	–	–	–	–	–	–	–	–	–
15	–	–	–	–	–	–	–	–	–	–	–	–
16	–	–	–	–	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–	–	–	–	–
18	–	–	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–	–	–	–	–
22	–	–	–	–	–	–	–	–	–	–	–	–
23	–	–	–	–	–	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	–	–	–	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–	–	–	–	–	–

	SITE C M-7 L.S. = 603.76			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (24-49-27)		–	–	–	–	0	21	59	20
2	1.0-1.5			–	–	–	–	1	21	41	32
3	1.5-2.0			–	–	–	–	1	26	50	24
4	2.0-2.5			–	–	–	–	3	24	46	30
5	3.8-4.3			–	–	–	–	1	26	44	30
6	4.3-4.8	ROXANNA SILT		–	–	–	–	1	22	57	21
7	4.8-5.0			–	–	–	–	2	19	41	40
8	5.5-6.0			–	–	–	–	15	35	25	40
9	6.0-6.5			–	–	–	–	5	31	46	23
10	6.5-7.0	GLASFORD FORMATION TILL (29-45-26)		–	–	–	–	8	40	25	35
11	7.0-7.5			–	–	–	–	3	37	33	30
12	7.5-7.8			–	–	–	–	4	43	31	26
13	8.0-8.5			–	–	–	–	3	44	31	25
14	8.5-9.0			–	–	–	–	8	43	30	21
15	9.0-9.5			–	–	–	–	6	7	67	26
16	9.5-10.0			–	–	–	–	4	46	28	26
17	10.0-10.5			–	–	–	–	15	47	33	20
18	10.5-11.0			–	–	–	–	9	33	37	30
19	11.0-11.5			–	–	–	–	1	44	42	14
20	11.5-12.0			–	–	–	–	0	23	63	14
21	12.0-12.5			–	–	–	–	1	13	73	14
22	12.5-13.0			–	–	–	–	1	26	64	10
23	13.0-13.5			–	–	–	–	0	22	68	10
24	13.5-14.0			–	–	–	–	0	15	49	36
25	14.0-14.5			–	–	–	–	2	33	50	17
26	14.5-15.0			–	–	–	–	1	24	52	24
27	15.0-15.5			–	–	–	–	0	12	63	25
28	15.5-16.0			–	–	–	–	–	–	–	–
29	16.0-16.5			–	–	–	–	4	22	54	24
30	16.5-17.0			–	–	–	–	3	29	44	27
31	17.0-17.5			–	–	–	–	3	31	41	28
32	17.5-18.0			–	–	–	–	2	27	45	28
33	18.0-18.5			–	–	–	–	3	2	67	31
34	18.8-19.0			–	–	–	–	1	23	49	28
35	19.0-19.5			–	–	–	–	2	18	46	36
36	19.5-20.0			–	–	–	–	1	22	39	39
37	20.0-20.5			–	–	–	–	2	18	45	37
38	20.5-21.0			–	–	–	–	2	21	43	35
39	21.0-21.5			–	–	–	–	5	18	43	39
40	21.5-22.0			–	–	–	–	3	21	42	37
41	22.0-22.5			–	–	–	–	2	20	41	39
42	22.5-23.0			–	–	–	–	2	21	41	35
43	23.0-23.5			–	–	–	–	2	16	47	37
44	23.5-24.0			–	–	–	–	0	18	42	40
45	24.0-24.5			–	–	–	–	1	16	45	39
46	24.5-25.0			–	–	–	–	2	19	44	37
47	25.0-25.5	LIERLE CLAY (22-50-28)		–	–	–	–	0	10	52	39
48	25.5-26.0			–	–	–	–	0	12	55	33
49	26.0-26.5			–	–	–	–	0	0	62	38
50	26.5-27.0			–	–	–	–	0	9	54	37
51	27.0-27.5			–	–	–	–	0	3	54	43

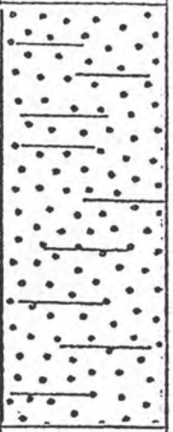
M-7	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meq/100g
1	–	–	–	–	N.D.	N.D.	–	–	–	–	–	–
2	–	–	–	–	N.D.	N.D.	–	–	–	–	–	–
3	–	41½	37	21½	N.D.	N.D.	–	–	–	–	–	–
4	1.03	42	35	23	N.D.	N.D.	–	–	–	–	–	–
5	1.23	53	30½	16½	N.D.	N.D.	–	–	–	–	–	–
6	.88	76	13½	10½	N.D.	N.D.	–	–	–	–	–	–
7	1.18	73	17½	9½	N.D.	N.D.	–	–	–	–	–	–
8	1.21	79	13½	7½	N.D.	N.D.	–	–	–	–	–	–
9	1.67	77½	16	6½	N.D.	N.D.	–	–	–	–	–	–
10	4.1	22	67	11	N.D.	N.D.	–	–	–	–	–	–
11	3.5	17	70	13	N.D.	N.D.	–	–	–	–	–	–
12	3.9	14	73½	12½	12	35	–	–	–	–	–	–
13	4.2	14½	74	11½	17	42	–	–	–	–	–	–
14	4.7	14½	75	10½	11	46	–	–	–	–	–	–
15	4.0	15½	72½	12	30	42	–	–	–	–	–	–
16	3.75	13	74	13	34	38	–	–	–	–	–	–
17	4.0	15½	72½	12	44	30	–	–	–	–	–	–
18	3.7	12½	74	13½	37	22	–	–	–	–	–	–
19	1.4	14	58½	27½	24	21	–	–	–	–	–	–
20	1.87	15½	62	22½	26	17	–	–	–	–	–	–
21	2.8	18	66	16	29	27	–	–	–	–	–	–
22	1.33	11	59	29½	23	10	–	–	–	–	–	–
23	2.16	20	61	19	26	16	–	–	–	–	–	–
24	1.73	12	63½	24½	31	19	–	–	–	–	–	–
25	1.86	25	56	19	36	20	–	–	–	–	–	–
26	2.03	19½	60½	20	43	14	–	–	–	–	–	–
27	1.33	16	56	28	37	24	–	–	–	–	–	–
28	1.45	6½	64	29½	32	14	–	–	–	–	–	–
29	1.24	8	60	32	26	9	–	–	–	–	–	–
30	1.06	8	56½	35½	24	15	–	–	–	–	–	–
31	1.03	9½	55	35½	31	15	–	–	–	–	–	–
32	1.04	7	56½	36½	19	15	–	–	–	–	–	–
33	.96	8½	52	39½	12	9	–	–	–	–	–	–
34	.88	7½	52½	40	19	13	–	–	–	–	–	–
35	.92	9½	52½	38	10	16	–	–	–	–	–	–
36	.83	8	51	41	N.D.	N.D.	–	–	–	–	–	–
37	.94	9	53½	37½	11	15	–	–	–	–	–	–
38	.88	8½	52	39½	21	N.D.	–	–	–	–	–	–
39	.84	10	50	40	N.D.	N.D.	–	–	–	–	–	–
40	.82	11	49	40	N.D.	N.D.	–	–	–	–	–	–
41	.84	11½	49½	39	N.D.	N.D.	–	–	–	–	–	–
42	.80	11	49	40	23	11	–	–	–	–	–	–
43	.86	11	50	39	N.D.	N.D.	–	–	–	–	–	–
44	.85	11	50	39	N.D.	N.D.	–	–	–	–	–	–
45	.79	14	48	38	N.D.	N.D.	–	–	–	–	–	–
46	.88	14	49	37	N.D.	11	–	–	–	–	–	–
47	.40	21½	29	49½	N.D.	N.D.	–	–	–	–	–	–
48	.35	17	28½	54½	16	10	–	–	–	–	–	–
49	.38	24	28	48	N.D.	N.D.	–	–	–	–	–	–
50	.40	24	28½	47½	N.D.	N.D.	–	–	–	–	–	–
51	.33	36	21	43	13	N.D.	–	–	–	–	–	–

M-7	SITE C M-7 L.S. = 608.76			Engineering Data				Grain Size			
No.	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
52	27.5-28.0			–	–	–	–	0	3	62	35
53	28.0-28.5			–	–	–	–	0	20	50	30
54	28.5-29.0			–	–	–	–	0	26	47	27
55	29.0-29.5			–	–	–	–	0	23	48	29
56	29.5-30.0			–	–	–	–	0	19	54	27
57	30.0-30.5			–	–	–	–	0	2	67	31
58	30.5-31.0			–	–	–	–	0	16	50	34
59	31.0-31.5			–	–	–	–	0	10	59	31
60	31.5-32.0	LIERLE CLAY		–	–	–	–	0	1	66	33
61	32.0-32.5			–	–	–	–	0	2	74	24
62	32.5-33.0			–	–	–	–	0	29	52	19
63	33.0-33.5			–	–	–	–	0	28	48	24
64	33.5-34.0			–	–	–	–	0	28	50	22
65	34.0-34.5			–	–	–	–	0	0	76	24
66	34.5-35.0			–	–	–	–	0	31	44	25
67	35.0-35.5			–	–	–	–	0	19	57	24
68	35.5-36.0			–	–	–	–	0	28	45	27
69	36.0-36.5	BEDROCK (24-27-49)		–	–	–	–	3	33	35	32
70	36.5-37.0			–	–	–	–	1	32	25	43
71	37.0-37.5			–	–	–	–	2	16	30	54

M-7	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
52	.33	34½	22	43½	N.D.	N.D.	–	–	–	–	–	–
53	.47	28½	29½	42	N.D.	N.D.	–	–	–	–	–	–
54	.39	26½	27	46½	N.D.	N.D.	–	–	–	–	–	–
55	.36	29	25	46	N.D.	15	–	–	–	–	–	–
56	.29	40½	18	41½	N.D.	N.D.	–	–	–	–	–	–
57	.30	40½	18	41½	N.D.	N.D.	–	–	–	–	–	–
58	.43	34½	25½	40	N.D.	N.D.	–	–	–	–	–	–
59	.36	40½	21	38½	N.D.	N.D.	–	–	–	–	–	–
60	.42	36	24½	39½	N.D.	N.D.	–	–	–	–	–	–
61	.34	26	25	49	N.D.	N.D.	–	–	–	–	–	–
62	.45	12	35½	52½	N.D.	N.D.	–	–	–	–	–	–
63	.495	14½	36	49½	N.D.	N.D.	–	–	–	–	–	–
64	.41	17	32	51	N.D.	N.D.	–	–	–	–	–	–
65	.41	26	28	46	N.D.	N.D.	–	–	–	–	–	–
66	.39	13½	31½	55	N.D.	N.D.	–	–	–	–	–	–
67	.35	12	30½	57½	N.D.	N.D.	–	–	–	–	–	–
68	.49	6	40	54	N.D.	N.D.	–	–	–	–	–	–
69	.44	8½	36½	55	N.D.	N.D.	–	–	–	–	–	–
70	.63	14½	41½	44	N.D.	N.D.	–	–	–	–	–	–
71	.67	5½	47½	47	N.D.	N.D.	–	–	–	–	–	–

No.	SITE C MCH L.S. = 615			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
1	0.0–0.4			–	–	–	–	22	15	55	30
2	0.4–0.9			–	–	–	–	0	13	62	25
3	0.9–1.4	PEORIA LOESS (12-58-30)		–	–	–	–	0	10	62	28
4	1.4–1.9			–	–	–	–	–	–	–	–
5	1.9–2.2			–	–	–	–	–	–	–	–
6	3.2–3.7			–	–	–	–	0	9	54	37
7	3.7–4.2			–	–	–	–	–	–	–	–
8	4.2–4.7			–	–	–	–	–	–	–	–
9	4.7–5.0	ROXANNA SILT (13-53-34)		–	–	–	–	0	13	53	34
10	5.7–6.2			–	–	–	–	–	–	–	–
11	6.2.6.7			–	–	–	–	–	–	–	–
12	6.7–7.2	BERRY CLAY (28-39-33)		–	–	–	–	1	22	47	31
13	8.2–8.7			–	–	–	–	1	30	41	29
14	8.7–9.2			–	–	–	–	1	27	36	37
15	9.7–10.0			–	–	–	–	3	35	30	35
16	10.3–10.8			–	–	–	–	1	29	43	28
17	10.8–11.3			–	–	–	–	–	–	–	–
18	11.3–11.8			–	–	–	–	3	38	30	32
19	11.8–12.3			–	–	–	–	1	39	32	29
20	12.3–12.5			–	–	–	–	–	–	–	–
21	12.6–13.1			–	–	–	–	2	47	27	26
22	13.1–13.6			–	–	–	–	–	–	–	–
23	13.6–14.1			–	–	–	–	–	–	–	–
24	14.1–14.6			–	–	–	–	–	–	–	–
25	14.6–15.0			–	–	–	–	–	–	–	–
26	15.0–15.5			–	–	–	–	8	32	37	31
27	15.5–16.0			–	–	–	–	–	–	–	–
28	16.5–17.0			–	–	–	–	–	–	–	–
29	17.0–17.5			–	–	–	–	–	–	–	–
30	17.5–18.0			–	–	–	–	–	–	–	–
31	18.5–19.0			–	–	–	–	–	–	–	–
32	19.0–19.5	GLASFORD FORMATION TILL (37-35-28)		–	–	–	–	–	–	–	–
33	19.5–20.0			–	–	–	–	–	–	–	–
34	20.0–20.5			–	–	–	–	8	35	36	29
35	21.0–21.5			–	–	–	–	–	–	–	–
36	22.0–22.5			–	–	–	–	–	–	–	–
37	23.0–23.5			–	–	–	–	–	–	–	–
38	24.0–24.5			–	–	–	–	–	–	–	–
39	25.0–25.5			–	–	–	–	8	32	37	31
40	29.0–29.5			–	–	–	–	5	35	37	28
41	29.5–30.0			–	–	–	–	–	–	–	–
42	31.5–32.0			–	–	–	–	6	37	38	25
43	32.0–32.5			–	–	–	–	4	23	49	28
44	33.5–34.0			–	–	–	–	7	46	28	26
45	34.0–34.5			–	–	–	–	4	61	25	14
46	36.0–36.5			–	–	–	–	13	66	17	17
47	37.0–37.5			–	–	–	–	3	35	39	26
48	38.0–38.5			–	–	–	–	–	–	–	–
49	39.0–39.5			–	–	–	–	–	–	–	–
50	39.5–40.0			–	–	–	–	–	–	–	–
51	41.0–41.5			–	–	–	–	–	–	–	–

MCH	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/ sec	Dol cts/ sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/ 100g
1	1.11	20	50	30	N.D.	N.D.	–	–	–	–	–	–
2	1.1	19½	50	30½	N.D.	N.D.	–	–	–	–	–	–
3	1.3	36	42½	21½	N.D.	N.D.	–	–	–	–	–	–
4	1.38	56	29½	14½	N.D.	N.D.	–	–	–	–	–	–
5	–	51	31	18	N.D.	N.D.	–	–	–	–	–	–
6	1.4	72½	18½	9	N.D.	N.D.	–	–	–	–	–	–
7	1.5	70½	20	9½	N.D.	N.D.	–	–	–	–	–	–
8	1.3	75½	16	8½	N.D.	N.D.	–	–	–	–	–	–
9	1.1	65	22	13	N.D.	N.D.	–	–	–	–	–	–
10	1.3	65	23	12	N.D.	N.D.	–	–	–	–	–	–
11	1.07	67½	20	12½	N.D.	N.D.	–	–	–	–	–	–
12	1.17	–	–	–	N.D.	N.D.	–	–	–	–	–	–
13	.82	–	–	–	N.D.	N.D.	–	–	–	–	–	–
14	–	–	–	–	N.D.	N.D.	–	–	–	–	–	–
15	–	–	–	–	N.D.	N.D.	–	–	–	–	–	–
16	2.2	31½	52½	16	N.D.	N.D.	–	–	–	–	–	–
17	.93	41	34½	24½	N.D.	N.D.	–	–	–	–	–	–
18	1.7	44	40½	15½	N.D.	N.D.	–	–	–	–	–	–
19	5.1	31½	60½	8	N.D.	N.D.	–	–	–	–	–	–
20	4.6	22½	67½	10	N.D.	N.D.	–	–	–	–	–	–
21	6.0	17½	72	10½	N.D.	N.D.	–	–	–	–	–	–
22	4.5	15½	73	11½	N.D.	N.D.	–	–	–	–	–	–
23	4.25	16	73½	10½	43	31	–	–	–	–	–	–
24	4.8	15½	72½	12	13	25	–	–	–	–	–	–
25	4.0	15	74½	10½	68	28	–	–	–	–	–	–
26	4.7	15	74½	10½	54	14	–	–	–	–	–	–
27	5.4	14	76½	9½	43	14	–	–	–	–	–	–
28	3.7	10	76	14	52	23	–	–	–	–	–	–
29	2.5	6½	74	19½	75	33	–	–	–	–	–	–
30	2.65	5½	75½	19	58	N.D.	–	–	–	–	–	–
31	1.89	5½	70	24½	64	20	–	–	–	–	–	–
32	2.11	5½	72	22½	60	29	–	–	–	–	–	–
33	1.67	4	68½	27½	48	21	–	–	–	–	–	–
34	1.75	6½	67½	26	53	27	–	–	–	–	–	–
35	1.53	7½	64½	28	41	12	–	–	–	–	–	–
36	1.61	4½	67½	28	48	22	–	–	–	–	–	–
37	1.55	5½	66	28½	33	23	–	–	–	–	–	–
38	1.63	4½	67½	27½	56	20	–	–	–	–	–	–
39	1.49	6	65	29	48	21	–	–	–	–	–	–
40	1.46	6	64½	29½	51	20	–	–	–	–	–	–
41	1.61	5½	67	27½	38	16	–	–	–	–	–	–
42	1.47	8½	63	28½	30	13	–	–	–	–	–	–
43	1.26	9½	59	31½	25	12	–	–	–	–	–	–
44	1.43	10½	61	28½	21	12	–	–	–	–	–	–
45	1.46	10	62	28	28	16	–	–	–	–	–	–
46	1.54	12	62	26	22	13	–	–	–	–	–	–
47	1.67	9	65	26	50	19	–	–	–	–	–	–
48	1.45	8	64	28	60	24	–	–	–	–	–	–
49	1.52	7	64	28	44	22	–	–	–	–	–	–
50	1.18	7	59½	33½	23	12	–	–	–	–	–	–
51	.97	7	55	38	20	11	–	–	–	–	–	–

No.	SITE C MCH L.S. = 615			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft³	Gvl %	Sd %	St %	Cl %
52	41.5–42.0	GLASFORD FORMATION TILL		–	–	–	–	2	36	38	26
53	42.0–42.5			–	–	–	–	–	–	–	–
54	42.5–43.0			–	–	–	–	7	49	31	20
55	44.0–44.5			–	–	–	–	25	60	22	18
56	44.5–45.0	BANNER FORMATION (70-16-14)		–	–	–	–	0	66	15	19
57	45.0–45.5			–	–	–	–	0	70	15	15
58	45.5–46.0			–	–	–	–	0	67	18	15
59	46.2–46.7			–	–	–	–	0	69	18	13
60	46.7–47.2			–	–	–	–	0	0	87	13
61	47.7–48.2			–	–	–	–	0	60	24	16
62	48.2–48.7			–	–	–	–	0	70	14	16
63	48.7–49.2			–	–	–	–	0	67	20	13
64	49.2–49.7			–	–	–	–	0	80	10	10
65	49.7–50.2			–	–	–	–	0	74	15	11
66	50.2–50.7			–	–	–	–	0	73	14	13
67	50.7–51.2			–	–	–	–	–	–	–	–
68	51.7–52.2			–	–	–	–	–	–	–	–

MCH	X-Ray Data						Chemical Data					
No.	DI	M %	I %	C-K %	Cal cts/sec	Dol cts/sec	Zn mg/l	Cd mg/l	Cu mg/l	Pb mg/l	pH	CEC meg/100g
52	.98	10	53½	36½	21	12	–	–	–	–	–	–
53	1.01	7	56	37	21	11	–	–	–	–	–	–
54	1.10	7½	57½	35	17	15	–	–	–	–	–	–
55	1.24	8½	59½	32	34	10	–	–	–	–	–	–
56	.61	5	45½	49½	14	12	–	–	–	–	–	–
57	.22	2	24½	73½	8	11	–	–	–	–	–	–
58	–	–	–	–	–	–	–	–	–	–	–	–
59	–	–	–	–	–	–	–	–	–	–	–	–
60	–	–	–	–	–	–	–	–	–	–	–	–
61	–	–	–	–	–	–	–	–	–	–	–	–
62	.23	2½	25	72½	8	7	–	–	–	–	–	–
63	N.D.	2½	31	66½	N.D.	N.D.	–	–	–	–	–	–
64	–	–	–	–	–	–	–	–	–	–	–	–
65	.21	1½	23½	75	N.D.	N.D.	–	–	–	–	–	–
66	–	–	–	–	–	–	–	–	–	–	–	–
67	.40	6	35	59	N.D.	N.D.	–	–	–	–	–	–
68	.18	2	21	77	N.D.	N.D.	–	–	–	–	–	–