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TECHNICAL REPORT EL-80-7

SUITABILITY OF DREDGED MATERIAL FOR RECLAMATION OF SURFACE-MINED LAND

OTTAWA, ILLINOIS, DEMONSTRATION PROJECT

by

Wyman Harrison, Abraham Van Luik

Applied Geoscience and Engineering Group
Energy and Environmental Systems Division
Argonne National Laboratory, Argonne, Ill. 60439

SUITABILITY OF DREDGED MATERIAL FOR RECLAMATION OF SURFACE-MINED LAND

July 1980
Final Report

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Appendix D of this report was written by L. S. Loon, Argonne National Laboratory; Appendix E was written by Conrad Tome, Argonne National Laboratory; and Appendix J was written by T. A. Bannister and T. R. West, Department of Geosciences, Purdue University.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was conducted to monitor the impact upon water quality when using dredged material to reclaim coal-mine spoil. An area of severely degraded mine spoil near Ottawa, Illinois, was divided into four plots by dikes of spoil material covered with heavy plastic. The plots were arranged into a control plot of untreated mine spoil and three treatment plots that received a 0.9-m-thick cover of dredged material and two of these plots received applications of agricultural lime prior to placement of dredged material. The plots

(Continued)

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20. ABSTRACT (Continued).

were instrumented with a Parshall flume to measure runoff, pressure-vacuum soil water samplers to collect water samples within the dredged material/mine spoil profile, and two wells in the vicinity of the plots to collect groundwater samples.

Results included the following:

a. All plots of dredged material became thickly vegetated, whereas the control plot remained unvegetated.

b. Runoff and subsequent erosion were significantly reduced on the dredged material plots.

c. Runoff from the treatment plots was higher in pH and lower in dissolved constituents than runoff from the control plot.

d. No effect of lime could be demonstrated in the limed treatments.

e. Trace constituents and heavy metals were found but at sufficiently low levels in soil water to show that no trace or heavy metal toxic hazard existed in the dredged material.

f. Samples from the wells for monitoring groundwater were low in trace metals.

These results show that the dredged material used in this study is a suitable material for reclaiming severely degraded mine spoil.

PREFACE

This report describes the implementation of a field monitoring study designed to assess changes in groundwater and surface water quality at a Dredged Material Research Program (DMRP) Productive Uses Project (PUP) site. The PUP project site, at Ottawa, Illinois, involves the use of dredged material to reclaim coal-mine spoil. Of concern was the potential for migration of specific compounds and metal ions found in the dredged material. Also of interest was documentation of the degree of mitigation of acid drainage from the mine spoil due to application of the dredged material.

This investigation was conducted under Interagency Agreement WESRF-77-197, entitled "Environmental Analysis of the Use of Dredged Material for Reclamation of Coal-Mine Spoil Near Ottawa, Illinois," dated 26 August 1977, between the U. S. Army Engineer Waterways Experiment Station (WES) and the Energy and Environmental Systems Division, Argonne National Laboratory (ANL).

The principal investigator for the study was Wyman Harrison, ANL. The coauthor, Abraham Van Luik, ANL, participated in interpretation of the results of the field and laboratory work.

Respective authors of Appendixes D, E, and J were L. S. Loon, ANL; Conrad Tome, ANL; and T. A. Bannister and T. R. West, Department of Geosciences, Purdue University.

The project was conducted under the direct supervision of Mr. Thomas R. Patin, Manager, PUP, and the general supervision of Dr. John Harrison, Chief, Environmental Laboratory, WES.

The authors express their appreciation to Argonne's John F. Freeman and coworkers, especially Marilyn Master, for determining the laboratory chemical parameters. Other Argonne personnel that the authors wish to thank for assisting in this study are Richard Olsen, for guidance relative to chemical analytical techniques, and Jeffery Schubert, for advice and assistance related to the procurement and installation of flumes and soil water samplers. Personnel of DeKalb County Exports, Inc., were also most helpful by providing assistance when our vehicles became mired in mud or when fresh water or odd pieces of equipment were needed.

Installation of the water sampling equipment was aided significantly by the following personnel from WES: Dick Lee, Jose Llopis, and Robert Peters. Appreciation is expressed for the technical guidance provided by WES manager Thomas Patin. Thanks also go to J. J. Jurinak, Head of the Department of Soil Science and Biometerology at Utah State University, for his careful review of the manuscript. Eugene Perrier, Dick Lee, and Thomas Patin, all of WES, also reviewed the manuscript.

The Directors of WES during conduct of this study and preparation of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
cups	0.0002366	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres

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* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

SUITABILITY OF DREDGED MATERIAL FOR RECLAMATION OF SURFACE-MINED LAND

Ottawa, Illinois, Demonstration Project

PART I: INTRODUCTION

Project Description

Overview

1. The primary objective of the Dredged Material Research Program's strip mine reclamation project at Ottawa, Illinois, is to demonstrate the feasibility of using a cover of dredged material to reduce acid surface runoff and drainage from coal-mine spoil. A secondary but significant objective of the demonstration project is to promote the use of dredged material in enhancing land that has been degraded by strip mining activities.

Choice of project location

2. The project location is on the Illinois River in LaSalle County near Ottawa, Illinois (Figure 1). The site is being leased by the Corps of Engineers from Ottawa Silica Company, which purchased the property sometime after coal mining ceased in the 1930's.

3. Several factors were involved in selection of the site:

a. The Illinois River waterway bisects a number of Illinois counties with prelaw abandoned lands and connects these counties to sources of dredged material near Chicago.

b. The cost of confined disposal of dredged material in the Great Lakes region has risen notably to the point where distant land disposal could be economically competitive despite transportation costs.

c. The potential for using dredged material in Illinois is good (where over 40,500 ha of land were surface mined prior to legislation requiring mined land reclamation).

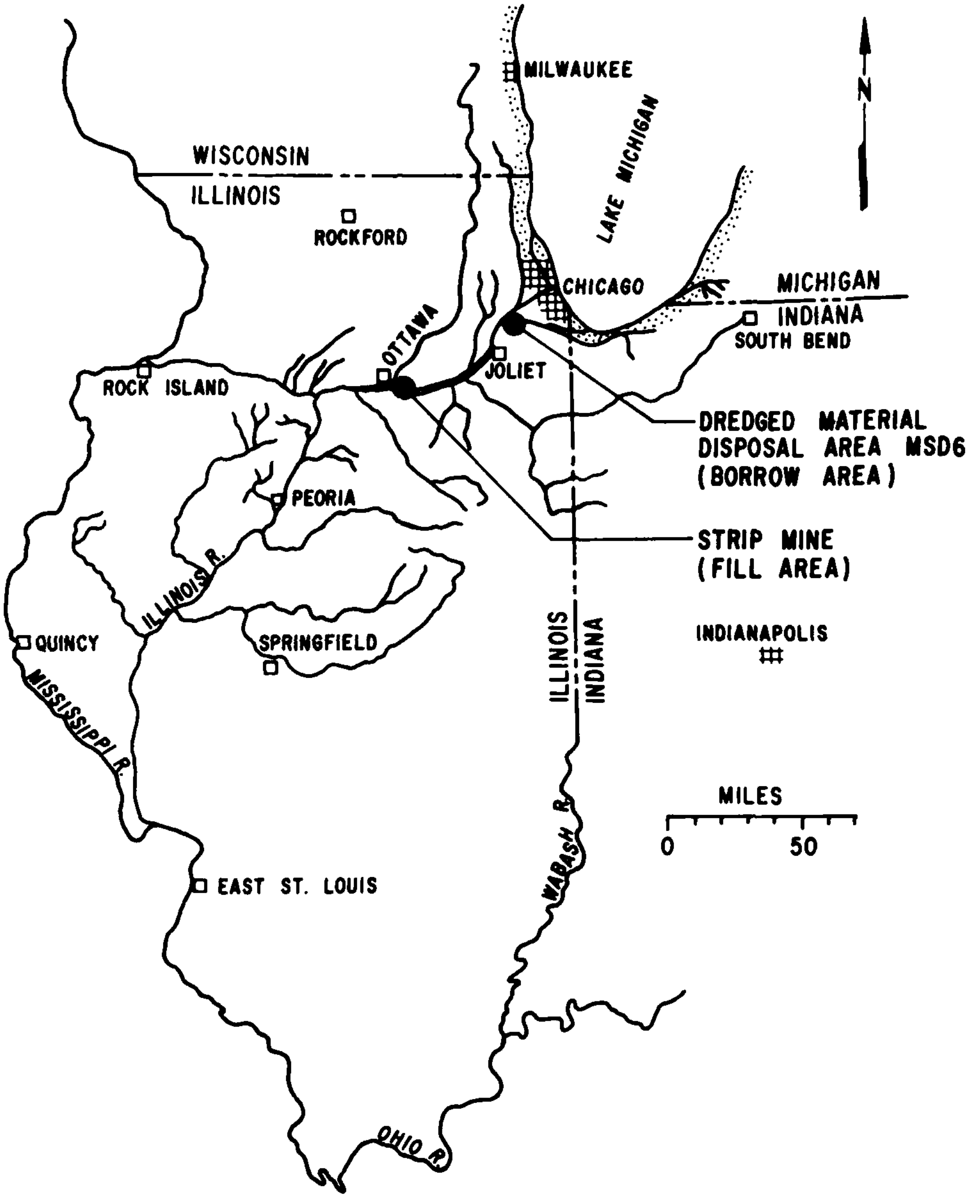

Figure 1. Location map

d. The Ottawa Silica Company was interested in reclaiming the property.

e. The site is only 300 m from the Illinois River, which makes it accessible to barges carrying dredged material, and it is a reasonable distance (115 river km) from a source of dredged material (Figure 1) near Chicago.

f. The site is extremely degraded and would remain so indefinitely unless subjected to some form of reclamation activity.

Site description

4. Overburden removed to expose the seam of Number 2 coal at the demonstration site consisted of a silt loam topsoil overlying a silty clay loam subsoil. This soil was weathered from medium-textured loess or outwash, overlying shale bedrock of Pennsylvanian age. The substratum of gray shale that directly overlaid the coal contained pyrite nodules which, when exposed in the spoil piles, weathered to release sulfuric acid. It is this acid that prevents revegetation of the site and solubilizes the potentially toxic trace elements that are of major concern in the present study. The three soil components--surface, subsurface, and substratum--are visually distinguishable in the spoil piles. They are described and characterized more completely in the appendixes to this report.

Treatment rationale

5. Expected benefits from application of dredged material over graded mine spoil at the Ottawa site were:

a. Establishment of vegetation.

b. Prevention of erosion.

c. Improvement of surface water quality.

d. Improvement of groundwater quality.

Perusal of the literature[1-3] shows that selective replacement of mine spoils during the regrading operation can serve as an alternative to using an imported material as a spoil cover. Selective replacement requires liming and fertilization to establish vegetation on spoil after regrading and such replacement can have significant economic penalties because of the rehandling involved.

6. Selective replacement, even if economically feasible, offers only a short-term alternative to imported cover material. The thin calcareous topsoil layer was diluted during the mining and regrading processes. In addition, weathering and leaching of the calcareous layer by acid soil solutions of adjacent and overlying acid mine spoil materials have substantially reduced the capacity of the topsoil to neutralize the acidity that will continue to be produced in these strip-mined spoil materials. This does not mean, however, that a rough measure of selectivity in the cut-and-fill operation should not be investigated when planning large-scale reclamation of the strip-mined lands in and around Ottawa. Treatment of the regraded spoils by applying a cover of environmentally acceptable dredged material promises a long-term, relatively low-cost solution to the reclamation of these lands. An evaluation of the environmental acceptability and reclamation performance of the dredged material used at the demonstration site was the purpose of this study.

Source of dredged material

7. Dredged material for the project was obtained from disposal area MSD6, owned by the Metropolitan Sanitary District of Greater Chicago. The dredged material containment area is located on the north side of the Calumet-Saginaw Channel and was last used for disposal in 1973. A survey in 1976 by G. Wilhelm* of the plants growing on the surface on the material revealed 42 species. Approximately 3800 m^3 of the dried crust layer of a soil consistency was removed and transported by truck to the Ottawa demonstration site.

Site preparation

8. Construction of the demonstration site was under the direction of the Chicago District, Corps of Engineers. The site consisted of a series of

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* Gerould Wilhelm, 1976, interoffice memorandum, "Vegetation of the Alsip Dredged Material Disposal Site," Morton Arboretum, Lisle, Illinois.

northwest-southeast trending parallel ridges (Figure 2) of mine spoil 12 to 15 m in width and 6 to 9 m high. The spoil consisted of fat clay and clay shale with intermixed lignite and pyritic fragments. A gently sloping plain extended about 230 m south of the site to the Illinois River.

9. The demonstration site was constructed by leveling a section of the center two ridges of a series of four parallel ridges and forming a raised plateau. The elevation of the plots (148.7 to 149.4 m) was considered sufficient to keep to a minimum any contaminants that might leach through the dredged material and mine spoil to the water table (approximate elevation 142 m).

10. The demonstration site consisted of four diked test plots 24.4 by 54.9 m (Figure 2). The 1.5-m-high dikes were constructed from mine spoil and covered with heavy-duty plastic. Their purpose was to separate plots and keep surface runoff segregated.

11. The four test plots are indicated by Roman numerals on Figures 2 and 3 and consist of:

Plot I:	A control plot of untreated mine spoil
Plot II:	A 0.9-m-thick covering of dredged material
Plot III:	A 0.9-m-thick covering of dredged material over a zone with 11 metric tons/ha of ground agricultural lime mixed into the upper 0.15 m of the mine spoil
Plot IV:	A 0.9-m-thick covering of dredged material overlying a zone with 17 metric tons/ha of ground agricultural lime mixed into the upper 0.15 m of the mine spoil

12. After construction of the plots, all plots were seeded with the six types of grass listed in Table 1. Rates of application of seed varied between 17 and 22 kg/ha, with a total seed application of 112 kg/ha/plot.

13. After seeding, wheat straw mulch was placed on each plot at a rate of 4.5 metric tons per hectare. The mulch was sprayed with an asphalt

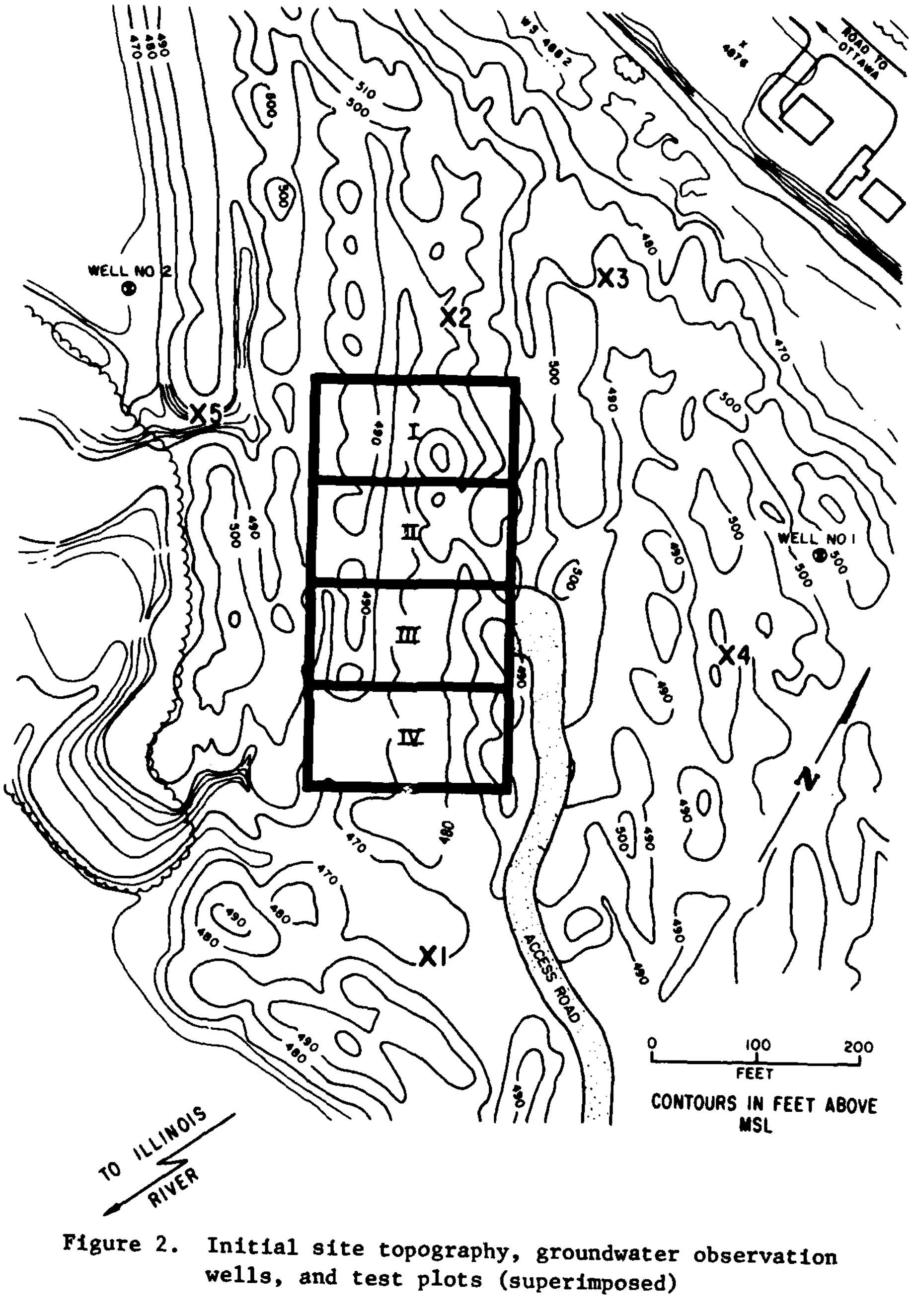

Figure 2. Initial site topography, groundwater observation wells, and test plots (superimposed)

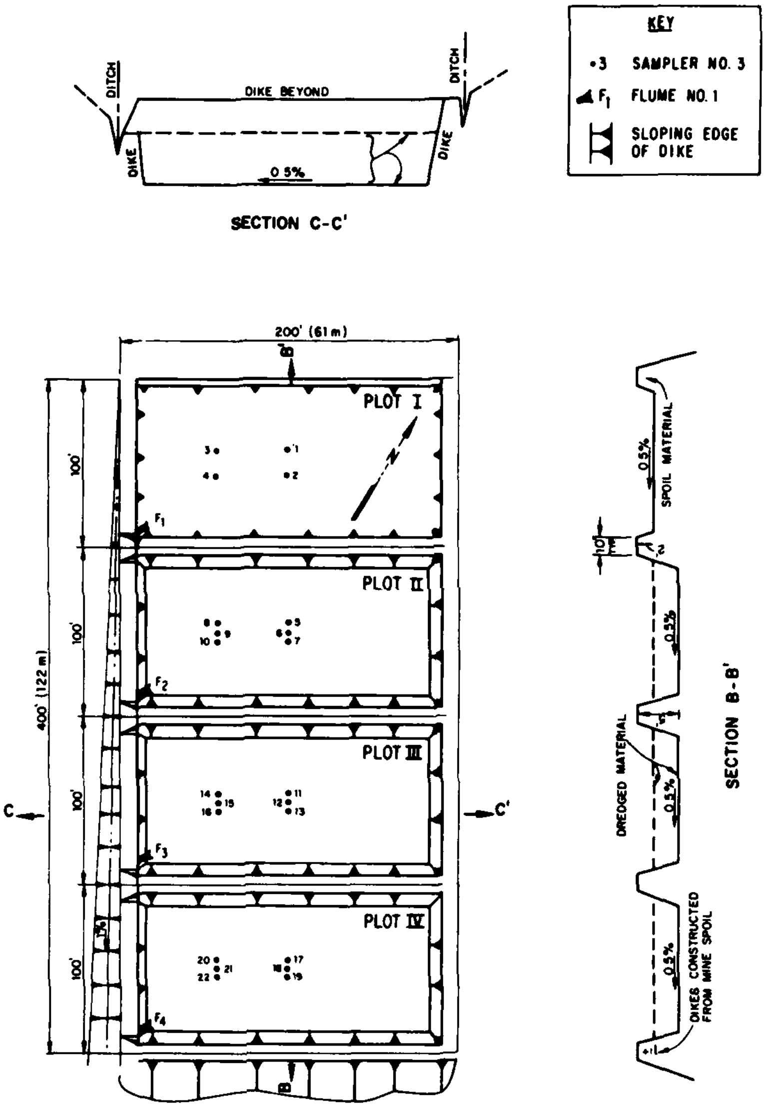

Figure 3. Plan and profile views of test plots and locations of soil water samplers

Table 1

Grass Seeds and Application Rates

Seed Mixture	Application Rate kg/ha
Kentucky bluegrass (*Poa pratensis*)	17
Kentucky 31 tall fescue (*Festuca arundinacea*)	22
Lincoln smooth brome (*Bromus interimis*)	17
Blackwell switchgrass (*Panicum virgatum*)	22
Birdsfoot trefoil (Empire) (*Lotus corniculatus*)	17
Perennial ryegrass (*Lolium perenne*)	17
	112

emulsion to form a binder. When the stand was established, Corps of Engineers personnel took samples of fescue for chemical analysis to measure plant uptake of heavy metal contaminants.

Water Quality Study

14. The primary objective of the water quality study was to monitor selected chemical compounds and metals present in the dredged material. The objective was to be accomplished by analyzing samples of soil water, local groundwater, and surface runoff taken either routinely or at the time of rainfall, as appropriate. The chemical parameters to be analyzed in the runoff, leachate, and groundwater were pH, acidity, alkalinity, total phosphorus, orthophosphate, total Kjeldahl nitrogen (TKN), ammonia nitrogen, nitrate nitrogen, chloride, cyanide, sulfate, sulfide, silica, calcium, magnesium, sodium, potassium, strontium, aluminum, cadmium, chromium, copper, iron, mercury, manganese, nickel, lead, and zinc.

15. Appendix A contains the water quality data for 9 November 1977-13 November 1978.

PART II: MONITORING STUDY

Runoff Gaging and Sampling

Basic plan

16. As seen in Figure 3, each of the experimental plots was graded to a 0.5 percent slope to direct runoff toward the southern corner of the plot. The amount of runoff from each plot was gaged with a flume and a water level recorder.

Equipment used and installation

17. The flumes used for gaging runoff were Parshall flumes made of fiberglass-reinforced polyester.* The throat width was 229 mm.** Each had an integral float well into which a Stevens Type F (Model 68) recorder† was installed. Each prefabricated flume was carefully leveled when emplaced in the corner of a plot; inlet wing walls were used to direct the runoff into the flume.

Soil Water Sampling

Basic plan

18. Pressure-vacuum soil water samplers (called samplers elsewhere) were chosen over groundwater-removal pits and pan collectors because of the ease of sampler installation, operation, and their inherent safety over pits. Their relatively small size, and the general dryness of the soil, usually precluded collection of 0.5 ℓ or more of water, a condition that limited the number of parameters that could be determined at each sampling depth. Samplers were installed at each of the 22 points shown in Figure 3. The depth of each

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* Plasti-Fab, Inc., Tualatin, Oregon.

** A table of factors for converting U. S. customary units of measurement to metric (SI) can be found on page 11.

† Leupold and Stevens, Inc., Beaverton, Oregon.

sampler's porous ceramic cup and the material in which the cup rested are given in Table 2.

19. The monitoring plan called for sampling soil water a few days after a significant rain or once every 4 weeks, whichever seemed most appropriate. The porous cups of the samplers were positioned at depths (Table 2) of approximately 0.6, 0.9, and 1.52 m. Thus, soil water could be drawn from essentially the same levels in each plot: an upper level in mine spoil or dredged material, the level at which the dredged material interfaced with the mine spoil, and a lower level in mine spoil.

Equipment used and installation

20. Pressure-vacuum soil water samplers* were made up at the factory with plastic pipe reservoirs 53 cm long. Plastic access tubes were added prior to installation and these tubes were terminated above ground with short lengths of neoprene tubing (3/16 in. in diameter by 1/8 in. wall) and pinch clamps. Short pieces of tapered wooden dowel were inserted in the free ends of the neoprene tubes to prevent fouling by soil.

21. Five-centimetre-diameter holes were augered to accept each soil water sampler. These holes provided a tight fit. Just prior to insertion of samplers 1-7, 1 cup of minus-200-mesh "Tip-top" silica sand (99.89 percent silica) was put into the hole and moistened with about 225 ml water. (for samplers 8-23, only 1/2 cup of sand was used). The sand provided hydraulic continuity between the porous cup and surrounding material when the soil matrix was saturated. After insertion of each sampler, 200 ml of bentonite was packed around the top; the rest of the hole was filled with dredged material or spoil, as appropriate.

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* Model 1920, Soil Moisture Equipment Corp., Santa Barbara, California.

Table 2

Details of Emplacement of Pressure-Vacuum Soil Water Samplers

Sampler No.	Plot No.	Depth of Tip of Ceramic Cup Below Plot Surface (m)	Installation Notes
1	I	0.61	Standing water to top hole
2	I	1.5	Hole dry, only 0.61 m from No. 1
3	I	0.61	
4	I	1.5	
5	II	0.61	May have some bentonite around cup
6	II	0.99	Interface at 0.99 m
7	II	1.4	
8	II	0.66	
9	II	0.91	Interface at 0.99 m
10	II	1.5	
11	III	0.61	Interface from 0.87-1.03 m
12	III	0.91	Cup in limed layer
13	III	1.5	
14	III	0.61	
15	III	0.91	Cup in limed layer
16	III	1.5	
17	IV	0.61	
18	IV	1.1	Interface from 0.99-1.05 m
19	IV	1.6	0.3-m limed layer
20	IV	0.61	
21	IV	1.2	
22	IV	1.6	Interface from 1.08-1.30 m
23	IV		Replacement for No. 19

22. Installation of the soil water samplers was completed on 3 November 1977, and at 1300 hr each sampler was filled with distilled water to moisten the cup. At 0800 hr on 4 November, the distilled water was pumped out (with a Model 1920K1 pressure-vacuum hand pump) and a 60-centibar vacuum was placed on the sampler. The first soil water samples for analysis were drawn on 9 November at 1400 hr. Samplers were completely evacuated at each sampling. About 2.5 hr was required to sample and reinstitute vacuums on each sampler.

23. Appendix B includes the model used for interpretation of soil water samples.

Groundwater Sampling

24. Groundwater was sampled once monthly at the two observation wells of Figure 2 to assess possible contamination of the local groundwater by leachate from the dredged material. The wells were installed by a Corps contractor and consisted of 51-mm-diam galvanized pipe. Well No. 1 (Figure 2) had a total depth of 11.4 m and terminated in a 51- by 914-mm screen set in clay. Well No. 2 had a depth of 6.86 m with the lower 3.05 m in bedrock.

25. When sampled for the first time (20 November 1977), the water in Well No. 1 was 10.5 m from the top of the well pipe (pipe-top elevation = 151 m); the water level in Well No. 2 was 1.37 m from the top of the well pipe (pipe top elevation = 142.9 m). Water in both wells was blown out with compressed air conducted to the well bottom by a plastic pipe. The wells were allowed to fill up over a 2-1/2- to 3-hr period and then sampled with a plastic thief sampler. Only a 600-ml sample could be obtained from Well No. 1 and the water was very muddy. A full litre was obtained from Well No. 2.

Ancillary Samples and Observations

26. A 279-mm rain gage* was installed on 8 November 1977. A second gage, a tipping-bucket rain gage** that records rainfall and temperature automatically, was installed on 9 August 1978. The rainfall data are summarized and analyzed in Appendix C. Details of gage installation and rainfall records are described in Appendixes D and E.

27. Four analyses of samples of mine spoil are presented in Appendix F. Appendices G, H, and I present the results of ancillary studies on surface water quality before and after treatment, mine spoil variability in terms of soil moisture and acidity, and quantity of spoil and dredged material contact waters, respectively. Appendix J presents information on site geohydrology that was developed by Purdue University as a result of soil borings and a review of the literature. Results of the ancillary observations and studies reported in the appendixes are used in the interpretation of water quality results obtained in the main part of the study. Figure 4 shows part of the test site as it appeared on 25 October 1978.

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* Taylor, Clear Vu.

** Model 302, Meteorology Research, Inc.

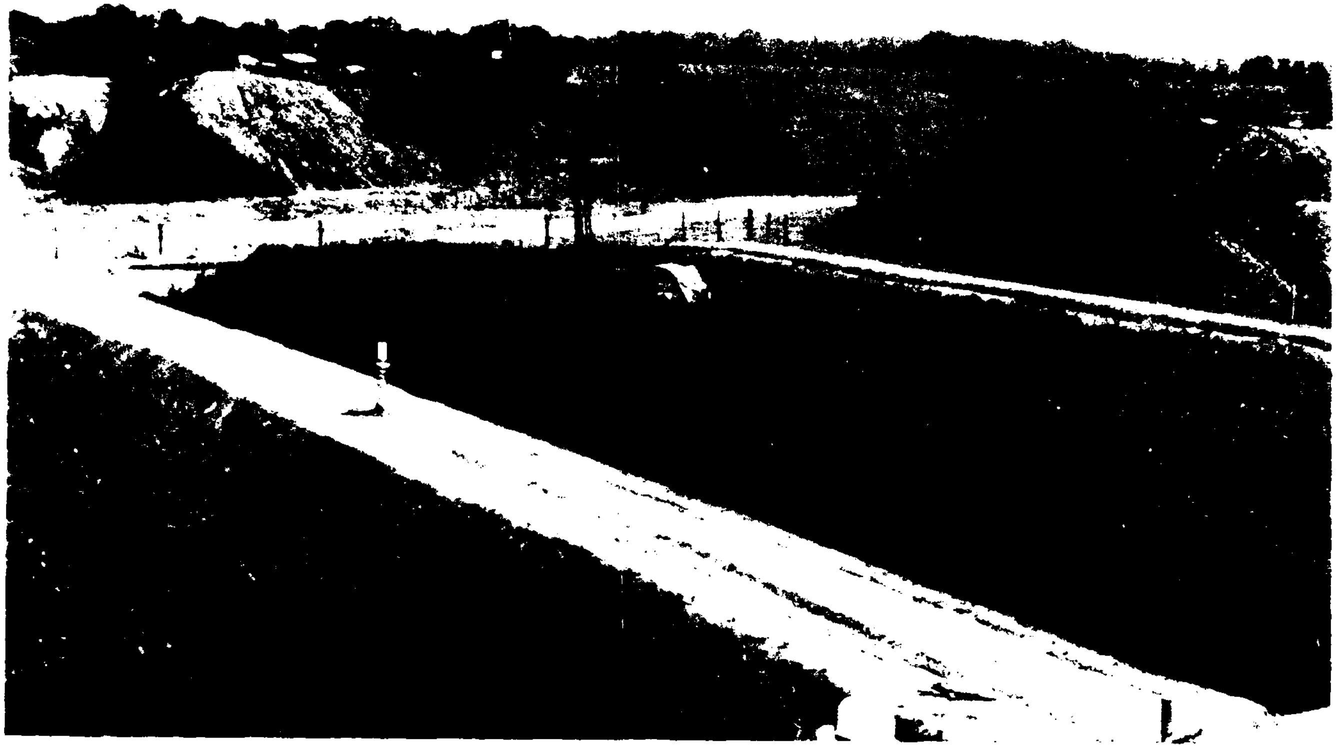

Figure 4. Treatment Plots III and IV and surrounding spoil banks. View is due east (cf. Figure 2) and shows luxuriant growth of weeds, rain gage on center of spoil berm separating plots, flume and recorder housing in extreme foreground, and soil-boring rig in center of picture

PART III: FIELD AND LABORATORY CHEMICAL METHODOLOGY

28. The procedures discussed in the following paragraphs were adopted for preserving and transporting samples and for determining pH at the site.

29. Each sample was drawn into a 1-ℓ widemouth container. Prior to use, the containers were acid-washed with 10 percent HNO_3 and then rinsed once with once-distilled water and five times with double-distilled water. Before dividing and adding preservatives, the samples were placed in an insulated cooler and held at $<4°C$. All samples, both with and without preservatives added, were transported to the laboratory in refrigerator coolers.

30. Water sample pH was determined at the site no more than 2 hr after bulk sample withdrawal. Following the pH determination, a sample was divided and preservatives added according to the schedule of Table 3. (Note that 100 ml of untreated sample water was held at $\sim 4°C$ for determination of acidity, alkalinity, chloride, and sulfate.)

31. The procedures presented in Table 4 were adopted for laboratory analysis of the water samples.

Table 3

Scheme Followed for Preserving Water Samples

Parameter(s)	Volume Sample Preserved, ml	Preservative
Nitrate + Nitrite-N	50	0.25 ml, 50% H_2SO_4*
Zn, Cu, Cd, Pb, Cr, Ni, Al, Mn, K, Fe,	50	0.5 ml, 50% HNO_3*
Ca, Na, Mg, Sr	50	filtered in laboratory and then acidified with ultrapure HNO_3 at rate of 5 ml/ℓ
Hg	100	1.0 ml 50% HNO_3*
Total P		
TKN; Total P	200	0.8 ml 0.5% $HgCl_2$ solution
Orthophosphate (PO_4)	50	0.125 ml 0.5% $HgCl_2$
Ammonia-N	50	0.25 ml 50% H_2SO_4*
Sulfide	25	25 ml sulfide anti-oxidant buffer No. 2
Cyanide	50	0.5 m 6 N NaOH

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* A 50 percent solution of the concentrated acid. This is used for safety of handling in the field.

Table 4

Procedures for the Laboratory Analyses of Water Samples

Parameter	Technique	Detection Limit	Precision	Reference
Field				
pH				Standard Methods[4]
				↓
Laboratory				↓
Acidity			±1.8 mg/ℓ	↓
Alkalinity			±5.0 mg/ℓ	↓
Chloride		1.0 mg/ℓ	±4.2 percent	↓
Electrical Conductivity (EC)		0.1 mmhos/cm	±3.0 percent	↓
Cyanide	Model 94-16*	0.0004 mg/ℓ	±6.0 percent	↓
				Orion Research[5]
Ammonia	Model 95-10*	0.08 mg/ℓ	±2.0 percent	Orion Research[6]
Nitrate + Nitrite	Chromotropic acid			Standard Methods[4]
TKN				Standard Methods[4]
Dissolved PO_4		0.05 mg/ℓ	±2.0 percent	EPA[7]**
Total phosphorus		0.05 mg/ℓ		EPA[7]
Redox potential	Model 96-78*			Orion Research[8]
Silica		0.5 mg/ℓ	±7.0 percent	Standard Methods[4]
Sulfate		2 mg/ℓ	±9.0 percent	Standard Methods[4]
Sulfide	Model 94-16*	0.0006 mg/ℓ	±2.0 percent	Orion Research[5]
Alkali & Alkaline Earths	Atomic absorption			Perkin-Elmer[9]
Calcium	spectrophotometer	0.2 mg/ℓ	±10.0 percent	Zasoski and Burau[10]
Magnesium	↓	0.2 mg/ℓ	±10.0 percent	↓
Sodium	↓	0.2 mg/ℓ	±10.0 percent	↓
Potassium	↓	0.2 mg/ℓ	±10.0 percent	↓
Strontium	↓	0.5 mg/ℓ	±10.0 percent	↓

(Continued)

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* Specific ion electrode.

** EPA = U. S. Environmental Protection Agency.

Table 4 (Concluded)

Parameter	Technique	Detection Limit	Precision	Reference
Trace metals	Atomic absorption spectrophotometer			
Aluminum		0.10 mg/ℓ	±10.0 percent	Perkin-Elmer[9]
Cadmium		0.02 mg/ℓ	±10.0 percent	Martin, Kopp, and Ediger
Chromium		0.05 mg/ℓ	±10.0 percent	EPA[7]
Copper		0.05 mg/ℓ	±10.0 percent	
Iron		0.10 mg/ℓ	±10.0 percent	
Manganese		0.02 mg/ℓ	±10.0 percent	
Nickel		0.05 mg/ℓ	±10.0 percent	
Lead		0.05 mg/ℓ	±10.0 percent	
Zinc		0.05 mg/ℓ	±10.0 percent	
Mercury	↓	0.00010 mg/ℓ	±10.0 percent	↓

PART IV: RESULTS AND DISCUSSION

Presentation of Analytical and Supporting Data

32. The results of the chemical analyses for all runoff, soil moisture, and well samples are presented in Appendix A. The model used for the interpretation of the soil water samples is presented in Appendix B. The more meaningful of these results were abstracted and tabulated for interpretation in this section of the report. Chemical interferences were encountered when the turbidimetric barium precipitation method for sulfate was used with some samples. Sulfate concentration values were determined by balancing the cations with anion concentrations, assuming chloride and sulfate constituted the majority of the total anions in solution. The problem was corrected by the adoption of an automated sulfate procedure toward midyear 1978. Standard nitrate procedures were also found unsatisfactory in these samples. (A discussion of the nitrate and sulfate analytical problems appears under "Data Reliability" in Appendix A.)

Quality of Runoff Water

33. The quality of runoff water was expected to differ markedly between the treated and untreated study plots. Changes in surface water quality that may take place over an extended period are more pertinent for the evaluation of dredged material as a permanent cover treatment for degraded lands and are discussed in the section that follows.

Plot I: Freshly graded spoil

34. Runoff samples were obtained on five dates during the course of this study. Selected water quality parameters for five dates are presented in Table 5. On only one of these five occasions did the storm and runoff conditions allow for

Table 5

Selected Water Quality Data for Treatment Plot I Runoff Samplings Listed by Collection Date and Time of Samplings with Respect to Onset of Runoff (I), Peak Flow of Runoff (M), and Final Runoff (F)

Sampling Date Rainfall Amount Runoff Sampling Time	12/17/77 Unknown I	4/10/78 I	4/10/78 0.89 in. M	4/10/78 F	6/26/78 2.28 in. F	7/26/78 0.81 in. F	11/13/78 0.35 in. F
Acidity, mg/ℓ	946.	1340.	236.	169.	1824.	842.	2700.
Alkalinity, mg/ℓ	--	--	--	--	--	--	--
pH	3.90	3.34	3.72	3.50	2.98	3.30	2.40
EC, mmhos	1.98(est)*	2.45	1.05	0.82	2.90	2.41(est)*	4.13(est)*
$PO_4^{\equiv}$, mg/ℓ	0.13	0.03	0.01	0.05	0.05	0.08	2.60
$SO_4^{=}$, mg/ℓ **	1500.	2000.	650.	400.	2300.	1900.	3500.
$C\ell^{-}$, mg/ℓ	10.	<1.	<1.	<1.	3.	1.	2.
Ca^{++}, mg/ℓ	169.	203.	86.8	57.6	120.	91.6	138.
Mg^{++}, mg/ℓ	197.	242.	72.3	41.8	261.	235.	390.
Sr^{++}, mg/ℓ	0.6	<0.5	<0.5	<0.5	0.9	<0.5	<0.5
Na^{+}, mg/ℓ	2.68	1.73	0.98	0.72	1.52	1.52	5.00
K^{+}, mg/ℓ	0.87	1.15	0.58	<0.50	0.70	1.10	0.93
Zn^{++}, mg/ℓ	0.92	1.64	0.39	0.26	1.06	0.78	1.85
Cu^{++}, mg/ℓ	0.08	0.27	0.03	0.02	0.35	0.18	<0.05
Ni^{++}, mg/ℓ	0.86	1.34	0.32	0.17	0.16	0.13	2.37
Mn^{++}, mg/ℓ	11.4	17.0	4.60	2.29	17.6	15.6	27.6
Fe^{++}, mg/ℓ	1.50	3.66	<0.10	<0.10	57.6	26.6	78.5
Al^{+++}, mg/ℓ	56.5	102.	24.7	16.2	151.	125.	256.

* Estimated by regression with total cation concentration milliequivalents per litre.

** Estimated from charge balance calculation.

collection of initial, maximum, and final runoff samples. The 12/17/77 sampling consisted of snowmelt runoff. The 4/10/78 storm dropped 0.89 in. of rain over a period of approximately 3 hr, allowing the collection of three well-separated samples. The collections of 6/26/78 and 7/26/78 represented the last portions of 2.28- and 0.81-in. rainstorms, respectively.

35. An examination of the initial, maximum, and final runoff samplings of 4/10/78 reveals the initial peaking and subsequent tapering of the dissolved solids loading. A multitude of variables, such as collection time with respect to the total runoff time, magnitude of the rainfall and runoff, weather between events, and others, may affect the water quality found in each of the collected samples.

36. It is speculated that erosion will continue to expose fresh pyritic material that will be oxidized. A reduction in acidification is, therefore, not expected for the untreated spoil plot runoff, except as an annual wintertime decrease in response to lowered temperatures.[12] Runoff water quality can be expected to be acidic (pH 3.9 or less) and contain elevated concentrations of: sulfate (>400 mg/ℓ), zinc (>0.26 mg/ℓ), nickel (>0.13 mg/ℓ), manganese (>2.3 mg/ℓ), iron (∿78 mg/ℓ), and aluminum (∿256 mg/ℓ).

37. The literature concerning rates and mechanisms of pyrite oxidation describes a very slow initial oxidation rate involving the diffusion of oxygen onto a fresh pyritic surface.[13] The result of this initial oxidation step is the direct oxidation of iron pyrite to iron sulfate.[14] After this initial step there is Fe (II) in solution that may be chemically or biologically oxidized to Fe (III), which in turn oxidizes sulfide on contact. The rate-determining step for the continuing oxidation process is, therefore, the chemical or biological oxidation of iron.[15]

Plots II, III, and IV: Dredged material treatments

38. Table 6 presents a portion of the water quality analyses for the runoff waters collected from the dredged material treatment plots. Vegetative growth on these plots was prolific and, with the subsequent high demand for water, runoff from these plots was limited after the April sampling. For example, no runoff was detected from Plot II for the tail end of the 2.28-in. storm of 6/26/78. The small volumes of runoff collected from the 0.81-in. storm of 7/26/78 for Plots III and IV allowed the determination of only the pH and cation concentrations. The runoff water quality from these plots can be expected to be near neutral (pH $\sim$ 7.29) and, unlike Plot I, they contain low levels of sulfate ($\sim$250 mg/ℓ), iron ($\sim$0.68 mg/ℓ), and aluminum ($\sim$0.64 mg/ℓ).

39. Table 7 presents high and mean values for the 4/10/78 runoff water quality parameters for the untreated and for the combined treated plots. These data show that the concentration of the parameters for the dredged material plots was always less than tolerances suggested for irrigation water for the 4/10/78 storm. However, several parameters for the runoff from Plot I exceeded suggested irrigation water tolerance levels.

40. Comparison of the mean values of Table 6 with water quality criteria for irrigation waters indicates that the dredged material runoff waters did not exceed any of the recommended concentration limits for any of the measured parameters.[16-18] In some of the runoff samples from Plot I, aluminum, copper, manganese, and nickel concentrations exceeded criteria for irrigation waters as suggested. The pH of the runoff samples from the untreated plot fails to meet the lowest suggested pH criterion (pH = 5.0) for irrigation waters.[16]

Table 6

Selected Water Quality Data for Runoff Samples from Treatment Plots II, III, and IV, Listed by Collection Date and Time of Sampling with Respect to Onset of Runoff (I), Peak Flow of Runoff (M), and Final Runoff (F)

Treatment Plot Sampling Date Runoff Sampling Time	II 4/10/78 I	II 4/10/78 M	II 4/10/78 F	III 12/17/77 F	III 4/10/78 I	III 4/10/78 M	III 4/10/78 F	III 6/26/78 F	III 7/26/78 F	IV 4/10/78 I	IV 4/10/78 M	IV 4/10/78 F	IV 6/26/78 F	IV 7/26/78 F
Acidity, mg/ℓ	19.7	19.7	15.8	49.2	15.8	15.8	7.9	4.6	--	11.8	17.7	19.7	0.0	--
Alkalinity, mg/ℓ	47.2	23.0	23.0	32.8	37.7	21.3	23.0	16.4	--	37.7	19.7	12.0	19.7	--
pH	7.28	7.20	7.15	6.90	7.41	7.30	7.27	7.31	6.10	7.42	7.15	7.32	9.59	6.69
EC, mmhos/cm	1.05	0.48	0.40	--	0.87	0.37	0.39	0.33	--	0.64	0.32	0.32	0.24	--
$PO_4^{\equiv}$, mg/ℓ	0.02	0.04	0.05	0.32	0.03	0.06	0.05	0.62	--	0.05	0.05	0.07	1.08	--
$SO_4^{=}$, mg/ℓ*	550	300	200	700	500	200	200	100	50	350	150	150	50	--
Cl^-, mg/ℓ	6.0	5.0	<0.5	15	<0.5	<0.5	<0.5	2.7	--	<0.5	<0.5	<0.5	6.4	--
HCO_3^-, mg/ℓ	58	--	28	0	46	26	28	--	--	46	24	28	--	--
Ca^{++}, mg/ℓ	174	87.4	62.7	252	146	65.0	64.0	37.1	10.7	115	47.7	49.0	12.1	6.51
Mg^{++}, mg/ℓ	43.9	17.3	12.2	35.0	31.7	9.63	9.63	6.33	2.62	17.7	8.10	7.45	2.62	2.07
Na^+, mg/ℓ	4.60	1.64	1.23	5.04	3.89	1.44	1.34	6.47	1.52	2.20	0.98	0.98	10.2	2.76
K^+, mg/ℓ	4.45	1.64	1.28	1.14	2.64	0.99	1.12	14.3	5.48	2.74	0.60	1.07	25.7	8.76
Fe^{++}, mg/ℓ	<0.02	0.60	0.50	0.51	1.05	0.64	1.34	2.04	1.10	0.40	<0.02	<0.02	0.97	0.34
Al^{+++}, mg/ℓ	0.3	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	0.6	0.6	<0.1	<0.1	<0.1	7.14	<0.1

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* Estimated by difference.

Table 7

Comparison of Runoff Water Quality for the 4/10/78 Storm on Untreated and Treated Plots[3]

Parameter	Untreated (Plot I)		Irrigation Water Tolerances		Treated (Plots II, III, and IV)	
	High Value	Mean Value	For Continuous Use	For Short-Term Use	High Value	Mean Value
Acidity, mg/ℓ	1340	582			19.7	16.0
Alkalinity, mg/ℓ	--	--			47.2	28.3
pH, low value	3.34	3.52			7.15	7.28
EC, mmhos/cm	2446	1436			1045	536
PO_4, mg/ℓ	<0.05	<0.05			0.06	<0.05
Total P, mg/ℓ	0.15	<0.05			0.15	0.10
TKN, mg/ℓ	0.85	0.65			1.80	0.95
NH_3, mg/ℓ	0.42	0.33			0.25	0.22
NO_3, mg/ℓ	3.0	2.2			0.32	0.32
SO_4, mg/ℓ	1500	633			300	131
Cl, mg/ℓ	<1	<1			6	1.2
Ca, mg/ℓ	203	116			174	90.1
Mg, mg/ℓ	242	119			43.9	17.5
Na, mg/ℓ	1.73	1.14			4.60	2.03
K, mg/ℓ	1.15	.58			4.45	1.84
Fe, mg/ℓ	3.66	1.22			1.34	0.50
Al, mg/ℓ	102	47.6	1.0	20	0.3	<0.1
Sr, mg/ℓ	<0.5	<0.5			<0.5	<0.5
Mn, mg/ℓ	17.0	7.96	2.0	20	<0.02	<0.02
Cd, mg/ℓ	<0.02	<0.02	0.005	0.05	<0.02	<0.02
Cu, mg/ℓ	0.27	0.09	0.2	5.0	<0.05	<0.05

(Continued)

Table 7 (Concluded)

Parameter	Untreated (Plot I)		Irrigation Water Tolerances		Treated (Plots II, III, and IV)	
	High Value	Mean Value	For Continuous Use	For Short Term Use	High Value	Mean Value
Cr, mg/ℓ	<0.27	<0.05	5.0	20	<0.05	<0.05
Ni, mg/ℓ	1.34	0.61	0.5	2.0	<0.05	<0.05
Pb, mg/ℓ	0.12	0.04	5.0	20	<0.05	<0.05
Zn, mg/ℓ	1.64	0.76	5.0	10	0.06	0.05
CN, mg/ℓ	0.022	0.019			0.020	0.019
Sulfide, mg/ℓ	0.016	0.006			1.68	0.19

Quality of Soil Water

41. The objective for sampling and analyses of soil water was to determine the effect of dredged material treatments on soil solutions with respect to migration of chemical constituents from dredged material into spoil. (The word soil refers to the matrix composed of both dredged material and spoil in the treatment plots.)

42. The experimental design used to assess the effects of differing dredged material treatments involved four treatments, with soil water sampled at three depths, with two replications. Because it became necessary to combine replicated samplings to meet sample volume requirements, the use of analysis of variance for treatment effects could not be applied rigorously. For example, an evaluation of the treatment effect on pH at a given depth has the addition of lime as a variable. However, if only treatments for Plots II, III, and IV are considered, then one has a randomized block with the amount of lime as the treatment, and analysis of variance may be applied rigorously to assess treatment, depth, and sampling time effects on pH, as illustrated in Table 8.

43. Table 8 shows that the means for pH at the three different depths and for the three different treatments all differed significantly because the three depths sampled represent (a) the dredged material, (b) the dredged material and spoil material interface, and (c) the mine spoil. The three lime treatments were designed to be: (Plot II) 0 metric tons/ha added lime, (Plot III) 11 metric tons/ha added lime, and (Plot IV) 17 metric tons/ha added lime, respectively. The significant differences (Table 8) in mean pH for the treatment plots suggest that the neutralizing effect of the agricultural limestone applications were not discernable by the soil water samples.

Table 8

Analysis of Variance to Evaluate Significance of Lime Treatment and Sampling Depth Effects on the pH of Soil Water

Experimental Plots	Depth	Time of Sampling 1 20 Nov 1977	2 16 May 1978	3 13 Jun 1978	4 20 Jul 1978	5 9 Aug 1978	6 11 Oct 1978	7 8 Nov 1978	Experimental Plots
II	1	8.00	6.80	6.70	6.80	7.02	7.45	7.70	II
	2	7.95	6.70	6.60	6.79	7.08	7.30	8.00	
	3	5.40	4.85	5.80	5.89	5.77	5.85	4.80	
III	1	8.00	6.80	6.85	6.70	7.40	7.60	7.50	III
	2	7.85	6.68	6.65	6.65	6.90	7.10	6.80	
	3	2.50	3.18	2.90	2.46	2.40	3.35	2.60	
IV	1	8.05	6.75	6.80	6.79	7.60	7.65	7.70	IV
	2	5.70	6.65	6.60	6.20	6.69	7.15	7.10	
	3	4.65	3.90	3.90	3.65	3.78	4.45	4.00	

Means (Depth) 1 = 7.26 m 2 = 6.92 m 3 = 4.10 m

Means (Treatment) II = 6.63 III = 5.66 IV = 6.00

Analysis of Variance =	Sums of Squares		df	Mean Squares	F-Level	99% Confidence Level Critical F-Values (for 40 df denominator)	Consequence
	Total	166.59	62				
	Treatments	10.19	2	5.09	10.68	5.18	Treatments significant
	Depths	126.96	2	63.48	124.47	5.18	Depths significant
	Error	29.44	58	0.51			

Note: Treatment, depth, and sampling times are fixed variables. This table uses data for the seven monthly samplings for which pH values were obtained for every sample, i.e., the sample number varied.

Results from control plot

44. Major ion concentrations and data for soil water samples for the control plot (Plot I) are tabulated in Table 9. The most striking feature of these data is the pH difference between the 0.6- and 1.5-m sampling depths. The initial low pH value for the 20 Nov 1977 1.5-m sampling (Table 9) is most likely attributable to contamination of the bore hole by surface material when the sampler was installed.

45. Table 10 shows a significant, but weak, negative linear relationship between calcium in the soil solution at 0.6 m and total precipitation between collection dates. None of the other parameters were correlatable with precipitation. Application of the thermodynamic solubility model (described in Appendix B) showed that calcium sulfate, gypsum, was saturated in a number of these 0.6-m soil solutions.

46. Part II of Table 10 shows that all four parameters were weakly correlated with temperature; however, sodium and manganese tended to decrease as the weather got warmer. The remaining parameters were not correlatable with mean temperature. The manganese results suggest removal by leaching, similar to sodium. From Table 9, however, it may be seen that manganese does not appear in large quantities in the 1.5-m soil solutions. This, it may be speculated, stems from the strongly pH-dependent nature of manganese solubility.[15]

47. Table 11 lists trace metal concentrations for Plot I at the 0.6- and 1.5-m depths. Over the study period, definite increases in the 0.6-m nickel and zinc concentrations are apparent, with some nickel present in the near neutral 1.5-m depth. Results of a laboratory pyritic material oxidation study (see Appendix H) indicated that chromium, cadmium, and lead were solubilized during pyrite oxidation at measurable concentrations. There was no indication of downward movement of either chromium or cadmium in the data

Table 9

Data for Selected Water Quality Parameters for Soil and Runoff Waters for Plot I

		Soil Water*										Between Collection Dates	
Depth, m	Date	Ca	Mg	Na	K	Sr	Al	Fe	Mn	SO_4**	pH	Mean Temperature °F	Cumulative Rainfall in.
0.6	20 Nov	415	3660	77.4	15.8	--	68.0	31.5	202	16400	5.4	51	1.91
	27 Nov	472	3650	78.2	13.0	1.0	148	14.4	216	18500	5.4	28	0.58
	4 Dec	373	3390	91.7	9.5	0.7	124	4.79	182	15500	5.2	26	0.75
	17 Dec	349	1070	418	7.8	1.6	173	0.56	203	7250	4.6	24	1.01
	17 Apr	231	1110	201	4.9	1.2	--	--	--	5380	4.3	28	4.69
	16 May	146	605	88.5	8.0	0.5	217	1.24	48.6	4180	4.1	54	5.73
	13 Jun	446	1090	70.4	6.9	0.7	453	1.20	76.8	8020	3.8	71	0.41
	20 Jul	150	998	42.3	5.8	0.6	319	2.12	39.5	6190	3.4	76	5.50
	9 Aug	213	968	38.6	5.2	0.6	484	2.50	87.6	7150	3.5	73	2.22
	6 Sep	168	1380	55.3	9.1	<0.5	474	5.79	106	8740	4.2	76	1.62
	11 Oct	143	1700	50.1	7.4	<0.5	683	23.3	86.6	11000	3.8	68	5.72
	8 Nov	146	1820	55.4	6.7	<0.5	455	6.89	115	10300	3.5	53	1.68
1.5	20 Nov	330	726	83.0	18.6	--	0.20	<0.10	0.86	3840	4.8		
	27 Nov	523	1280	194	21.9	3.4	0.17	0.10	1.03	6770	7.4		
	4 Dec	512	1300	195	24.7	3.3	0.10	0.10	0.85	6820	6.5		
	17 Dec	662	1060	90.6	18.5	2.8	<0.10	0.11	0.47	6000	7.8		
	17 Apr	628	739	156	20.1	3.4	2.19	--	5.95	4560	6.8		
	16 May	441	928	238	22.3	2.7	<0.10	0.50	1.87	5230	6.8		
	13 Jun	594	959	243	21.8	1.1	7.13	2.50	3.61	5760	6.5		
	20 Jul	372	922	204	19.0	3.6	1.96	0.16	1.48	4370	6.7		
	9 Aug	409	837	158	18.5	2.9	<0.10	<0.10	0.52	4660	6.7		
	6 Sep	313	965	179	27.4	2.4	1.00	0.19	1.83	4990	7.2		
	11 Oct	217	1020	174	22.3	0.6	<0.10	0.16	0.43	4370	7.3		
	8 Nov	541	915	143	23.9	1.9	0.50	<0.10	0.88	4750	7.6		

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* In milligrams per litre except for pH.

** Sulfates estimated from charge balance calculations, Appendix B.

Table 10

Linear Statistical Relationships Between Data for Soil Water Parameters Measured at the 0.6-m Depth and Meteorological Data (for Plot I)

I. Significant relationships between chemical parameters and total precipitation between collection dates.

Parameter	Correlation Coefficient (r)	Degrees of Freedom	Significance Level*(α)	Coefficient of Determination (r^2)
Ca	-0.721	11	0.01	0.520

II. Significant relationships between chemical parameters and mean temperatures between collection dates.

Parameter	Correlation Coefficient (r)	Degrees of Freedom	Significance Level*(α)	Coefficient of Determination (r^2)
Na	-0.638	11	0.05	0.407
Al	0.720	10	0.01	0.518
Mn	-0.818	10	0.01	0.669
pH	-0.700	11	0.01	0.491

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* Critical r values:
df = 10, α = 0.05, r = 0.576;
df = 10, α = 0.01, r = 0.708;
df = 11, α = 0.05, r = 0.553;
df = 11, α = 0.01, r = 0.684.

Table 11

Trace Metal Concentrations in Plot I Soil Solutions in the 0.6- (Acidic) and 1.5-m (Near-Neutral) Zones

		Trace Metal, ppm					
Depth, m	**Date**	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
0.6	20 Nov	<0.02	0.05	0.35	7.00	<0.05	1.95
	27 Nov	0.04	0.27	0.31	6.15	0.38	2.60
	4 Dec	0.02	0.23	0.18	5.24	0.36	2.26
	17 Dec	0.05	0.23	0.19	6.06	0.35	3.74
	17 Apr	0.06	<0.05	-	3.94	-	-
	16 May	<0.02	0.06	0.26	3.59	0.19	2.56
	13 Jun	0.38	0.10	0.33	4.98	0.10	4.42
	20 Jul	<0.02	0.20	0.58	6.49	0.10	3.48
	9 Aug	0.10	0.10	4.33	5.40	0.10	4.97
	6 Sep	0.04	0.06	0.31	9.75	0.42	5.67
	11 Oct	0.04	0.08	0.43	10.8	0.41	7.39
	8 Nov	0.05	0.05	0.27	10.4	0.53	5.89
1.5	20 Nov	<0.02	<0.05	<0.05	0.05	<0.05	<0.05
	27 Nov	<0.02	0.16	0.07	<0.05	0.23	0.08
	4 Dec	<0.02	0.13	0.09	<0.05	0.20	0.07
	17 Dec	<0.02	<0.05	<0.05	<0.05	0.18	0.07
	17 Apr	0.04	<0.05	<0.05	0.32	0.15	0.09
	16 May	<0.02	<0.05	<0.05	0.50	<0.05	0.12
	13 Jun	0.19	0.10	0.05	0.55	0.05	0.21
	20 Jul	<0.02	<0.05	<0.05	0.20	0.05	0.09
	9 Aug	<0.02	<0.05	0.05	0.20	<0.05	<0.05
	6 Sep	<0.02	<0.05	<0.05	0.37	0.28	0.09
	11 Oct	<0.02	<0.05	<0.05	0.26	0.10	<0.05
	8 Nov	0.02	<0.05	<0.05	0.37	0.28	0.07

of Table 11, probably because their concentrations were diluted below detectability in the soil water. Since lead does not move appreciably in soils of pH 5 to 9, and since lead concentrations were comparable to the cadmium levels released in the laboratory pyrite oxidation study, the comparatively high lead concentrations in Table 11 probably represent a high lead background concentration for the spoil material.

Results from the treatment plots

48. The objectives of this study require that the dredged material be examined as to its ability to maintain favorable pH characteristics under field conditions.

49. Table 8 showed that pH variation with time, taken over the whole profile of the treated plots as described by the 0.6-, 0.9-, and 1.5-m samplings, was nonsignificant. The pH changes documented in this study follow the described trends closely enough to allow the statement that, over the course of this study (1 year), no changes in pH have occurred that denote a radical change in the makeup of the dredged material as a soil.

50. The application of the dredged material may stop acid production in the underlying spoil material, and certain concrete and beneficial results in relation to the groundwater quality may be expected:

a. Reduction of mean temperature; oxidation of iron pyrite has a temperature dependence that is eightfold for every 10° increase between 5° and 25°C.[19]

b. Reduction of oxygen access to the pyritic material by providing a physical barrier and by microbial oxygen extraction from percolating waters.

c. Reduction of water access to the pyritic material through consumptive use by the vegetative cover, through the elimination of standing water by grading, and by a reduction in water flow because of water storage in overlying material.

d. Reduction of the removal of oxidation products by percolating water, resulting in a lower total output of acid to the groundwater flow from the oxidation zone.

e. Prevention of continual exposure of fresh pyritic material to the atmosphere by erosive (wind and water) processes.

51. Table 12 presents data for the soil water of the mine spoil to show that the rate of acidification, as measured by the aluminum, iron, and manganese concentrations, has not accelerated under the dredged material cover as it has in the control plot (Table 11). Linear regression analyses were performed using the cumulative number of days between samplings as the dependent variable and the concentrations as the independent variable. The results for the 1.5-m depth show that in Plots II and IV the concentrations of these metals are decreasing, while in Plot III no trend is evidenced. The lack of significance of the correlations in Plot III can be explained by the pH at the 1.5-m depth, which was lower than Plots II and IV (Table 8). For example, the mean pH for Plot III was 2.77; whereas, the mean pH for Plots II and IV was 5.48 and 4.05, respectively.

52. Linear regression analyses were also performed for those parameters which, judging from the Plot I data, could be used as an indicator of acidity. These parameters were specific conductivity, acidity, aluminum, iron, manganese, nickel, zinc, calcium, and magnesium. The results, in Table 12, revealed the following (at 95 percent significance level):

a. In the dredged material, at 0.6 m depth, over the 1-year period of the study:

   (1) The total dissolved salt concentration decreased, as expected for a newly exposed surface.

   (2) In Plot III acidity decreased.

b. In the dredged material/spoil interface (0.9 m), total dissolved salts, aluminum, iron, manganese, nickel, and zinc decreased for one or more of the three treated plots.

c. In the underlying spoil (1.5 m), all the parameters shown decreased in Plots II and IV except calcium; acidity increased in Plot III.

These results, including the relative stability of calcium and magnesium levels in dredged material soil waters, compare well with the observed pH trends already noted earlier in this report.

Table 12

Concentration Changes Over Time for Selected Water Quality Parameters for the Three Treated Plots at Three Sampling Depths

		Correlation Coefficient, Sign, and Degrees of Freedom		
Parameter	Plot	Dredged Material 0.6 m	Interface 0.9 m	Spoil 1.5 m
EC	II	-0.843 4*	-0.849 3	-0.868 4*
	III	-0.904 3*	-0.722 4	-0.408 5
	IV	-0.892 3*	-0.892 5*	-0.983 4*
Acidity	II	-0.702 5	-0.667 4	-0.295 6
	III	-0.941 3*	0.670 4	0.693 7*
	IV	-0.856 3	-0.396 5	-0.690 5
Al	II	-1.000 1	0.000 0	-0.646 9*
	III	0.949 3	-0.658 4	0.320 7
	IV	0.563 4	-0.802 5	-0.797 7*
Fe	II	-0.526 6	0.238 4	-0.866 5*
	III	0.215 6	-0.132 5	0.243 7
	IV	0.287 6	-0.877 7	-0.509 5
Mn	II	-0.426 7	-0.002 8	-0.714 9*
	III	-0.297 7	-0.662 9*	0.414 7
	IV	-0.437 6	-0.906 9*	-0.853 7*
Ni	II	0.024 5	0.190 8	-0.633 9*
	III	-0.167 6	-0.612 9*	0.311 7
	IV	0.318 6	-0.906 9*	-0.801 7*
Zn	II	0.023 8	-0.413 8	-0.506 9
	III	0.099 7	-0.241 9	0.310 7
	IV	-0.386 7	-0.847 9*	-0.898 7*
Ca	II	0.083 7	-0.180 7	-0.237 9
	III	0.399 7	0.348 7	0.294 8
	IV	0.417 7	0.233 8	-0.165 8
Mg	II	-0.182 8	-0.161 8	-0.652 9*
	III	-0.103 8	0.046 9	-0.381 8
	IV	-0.105 8	-0.544 9	-0.723 8

* Significant at 95 percent significance level.

Quality of Groundwater

53. The mean and coefficient of variation of each parameter for Well No. 1 and Well No. 2, as summarized in Table 13, show two relatively stable and uniform groundwaters (see Appendix A). These data suggest that Well No. 1 was in the underclay and Well No. 2 in the St. Peter sandstone (see Appendix J). It may be inferred from the well water data that leachates from the overlying spoil have not contaminated groundwater at these depths and locations.

54. The trace metal content and sulfide content for both wells were initially very high, but tapered off rapidly for most constituents to near detection limits for the remainder of the sampling period (see Appendix A). This trend reflects possible initial contamination related to well drilling. The high concentrations of zinc (Table 13) in the wells was attributed to possible contamination from the well casings.

Table 13

Water Quality Comparison for Well No. 1 and Well No. 2

Parameter mg/ℓ	Well No. 1		Well No. 2	
	$\bar{x}$	CV, %	$\bar{x}$	CV, %
pH	7.31	3.67	6.46	4.06
EC, mmho	2.91	30.3	2.46	36.5
Alkalinity	665	36.1	54.3	92.0
Acidity	130	42.9	697	23.4
Ca	455	29.6	490	17.0
Mg	518	15.9	370	11.9
Sr	5.93	20.9	8.66	37.9
Na	249	22.5	39.9	19.3
K	21.3	24.5	31.3	11.4
Cl	25	1	5	87
SO_4	3300	27.2	3500	15.9
Al	25*	245	2.6*	143
Fe	99*	278	217*	36.9
Mn	3.96*	142	8.20	35.0
Cu	0.12*	143	0.05	--
Cr	0.14	135	0.05	--
Cd	0.07*	204	0.02	--
Ni	0.22*	153	0.64	30.2
Pb	0.34*	126	0.13	63.4
Zn	193*	258	105	51.7
CN	0.023	69.1	0.017	160
Hg	0.0002	247	0.0014	200
TKN	3.23	63.2	2.58	32.8
NH_3-N	2.64	65.3	2.44	87.0
NO_3+NO_2-N	0.19	77.2	0.19	123
Total P	0.08	84.4	0.05	--
PO_4-P	0.05	--	0.05	--
$S^=$	7.65*	297	5.57*	251

---

* Values initially very high, then rapidly decreasing, usually to the detection limit.

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APPENDIX A: WATER QUALITY DATA FOR 9 NOVEMBER 1977-13 NOVEMBER 1978

Data Tables

1. Data for the following 29 parameters are given in Tables A1-A29, listed below; the tables follow the remarks on data reliability.

Data Reliability

2. Sulfate and nitrate analyses were subject to interferences in the solutions obtained in this study.

3. The nitrate method required an initial pH adjustment that caused copious precipitation. Filtration did not always remove all of the precipitate, or additional precipitation would take place after filtration. Repetition of samples gave erratic results. In November 1978, a dual-channel Technicon II autoanalyzer with capability for nitrate analysis was brought on line. This instrument seems to be capable of handling any interferences presented by these solutions. Analyses with this new system were highly reproducible, even when repeated a month apart.

4. That an analytical problem with sulfate existed was not at first recognized, except that the first month's samples had to be diluted and subsequently refiltered. Also, some minor problems with discoloration were noted. The magnitude of the necessary dilutions (16,000 ppm needed to be diluted 1/400 at least), the lack of experience with the samples, and the presence of interfering colors and possible organic interferences may explain the order-of-magnitude discrepancies for a few of the samples in the first sets run. Ignoring those eight samples with very high discrepancies, the following trends in the sulfate data were observed:

a. Near-neutral spoil samples (1.5 m, Plot I) tended to be measured an average of 14 percent too high, the variance in measured value being 2.54 times the corresponding calculated variance.

b. Near-neutral well samples (W1 and W2) tended to be an average of 10 percent too high for the measured value; variance for the 15 well sample values was 1.76 times the variance for the corresponding calculated variance value.

c. Acid spoil samples, 26 in all, were an average of 10 percent low on the measured values; 72 percent of the variation in the calculated samples was matched by variation in the corresponding measured values. A regression equation describing the relationship between calculated and measured values is:

$$\text{calc. } SO_4 = 958 + 0.78 \text{ (meas. } SO_4) \qquad (A1)$$

$$[df = 25,\ r = 0.85 \text{ (significant at } \alpha = 0.01)]$$

d. Seventy-four percent of the variance in the calculated sulfate values is matched by variance in the measured values for the dredged material samples. The regression equation is:

$$\text{calc. } SO_4 = 1626 + 0.43 \text{ (meas. } SO_4) \qquad (A2)$$

$$[df = 40,\ r = 0.86 \text{ (significant at } \alpha = 0.01)]$$

5. It is concluded from these calculations that in the near-neutral samples the error encountered is not, on the average, unreasonable considering the 100 to 1 dilutions necessary and the inherent 10 percent uncertainty of the method. (Standard Methods[11*] described a 9.7 percent relative standard deviation for 19 laboratory determinations of sulfate, for a sample that required a 1/10 dilution).

6. The systematic nature of the sulfate analytical results for acid spoil and dredged material samples seems due to negative interferences. Standard Methods[11] described color and dissolved organics as significant interferences. It is clear that an improved method for analysis of sulfates must be found for continued work on sulfate analysis for the Ottawa site samples. It is also possible that the present practice of controlling iron discoloration by the addition of ethylenediaminetetraacetic acid (EDTA) is a large contributor to this systematic error, but this has not as yet been explored. High concentrations of alkali metals and manganese are also possible interferences. In the first 2-month's sample results there was a statistically significant ($\alpha = 0.01$) relationship between manganese concentration and the extent of sulfate deviation. After changes were made in the procedure (EDTA addition to control the metal interferences) the errors became more systematic, as described by the regression equations given above.

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* Raised numerals refer to similarly numbered items in the References at the end of the main text.

7. Occasional spot checks, usually by repeating a set of analyses, showed that other routine methods used in this study were acceptably accurate, with a mean of 10 percent or less for most of the calculated coefficients of variation.

Examples of Symbols Used in This Appendix

L1 = soil water sampler number 1

W1 = observation well number 1

$F1_I$ = initial runoff sample at flume number 1

$F1_M$ = midpoint or peak runoff sample at flume number 1

$F1_F$ = final runoff sample at flume number 1

R = rainfall sample (an integrated sample over period runoff samples were being taken)

NOTE: See Figure 3 of the main text for location of soil water samplers, etc.

Table A1

Acidity (as ppm $CaCO_3$) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1																		
L1 + L3				66.9				42.4	Misg. sample	3620.		194.		3670.	2,780.	10,000.	3,610.	
L2 + L4								156.		175.		121.		47.5	185.	150.	73.4	
L3																		
L4																		
L5 + L8								114.		209.		47.5		8.6		17.5	14.4	
L6 + L9										213.		47.5		8.6		37.5	28.0	
L7																		
L7 + L10				862.				80.5		2840.		51.8		13.0		47.5	118.	
L8																		
L9																		
L10																		
L11 + L14								110.		--		60.5				22.5	40.0	
L12																		
L12 + L15								8.4		--		47.5		13.0		27.5	65.6	
L13				918.														
L13 + L16								139.		2750.		5400.		6804.	7,280.	4,000.	4,400.	
L14	31.5																	
L15																		
L16																		
L17 + L20								114.		--		21.6				27.5	19.2	
L18 + L21								86.9		--		220.		17.3	45.4	21.5	48.0	
L19																		
L19 + L22										3100.		181.		1730.	1,590.	163.	320.	
L20																		
L21																		
L22				181.														
L23																		
W1				224.		118.				118.		108.		30.2	166.	160.	118.	
W2				650.	822.	823.				759.		851.		389.	601.	842.	536.	
$F1_I$					945.		1340.											
$F1_M$							236.											
$F1_F$							169.				1820.		842.				3,700.	2,200.
$F2_I$							19.7											
$F2_M$							19.7											
$F2_F$							15.8											
$F3_I$					49.2		15.8											
$F3_M$							15.8											
$F3_F$							7.9				4.5		36.1					
$F4_I$							11.8											
$F4_M$							17.7											
$F4_F$							19.7						8.64					
R							78.8											

Table A2

Alkalinity (as ppm $CaCO_3$) For Water Samples Collected During the Period 9 November 1977 -- 8 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1																		
L1 + L3				16.4				--	Misg.	--		630.		259.	--	--	--	
L2 + L4								213.2	sample	812.					631.	592.	492.	
L3																		
L4																		
L5 + L8								167.		1827.		253.		75.4		131.	164.	
L6 + L9					203.					1630.		302.		55.8		188.	164.	
L7																		
L7 + L10				--				--		--		91.8		16.4		14.4	--	
L8																		
L9																		
L10																		
L11 + L14								188.		2296.		243.				164.	213.	
L12																		
L12 + L15								19.6		6970.		282.		68.9		108.	102.	
L13				--														
L13 + L16								--		557.		--		--	--	--	--	
L14	167.																	
L15																		
L16																		
L17 + L20								162.		682.		253.				182.	164.	
L18 + L21					--			70.5		449.		279.		108.	156.	90.2	180.	
L19																		
L19 + L22										--		--		--	--	--	--	
L20																		
L21																		
L22				--														
L23																		
W1				557.		1056.16				956.		629.		289.	594.	584.	656.	
W2				55.	--					162.		23.0		9.84	49.2	45.1	36.1	
$F1_I$					--		--											
$F1_M$							--										--	
$F1_F$							--				--		--					--
$F2_I$							47.2											
$F2_M$							22.9											
$F2_F$							22.9											
$F3_I$					32.8		37.7											
$F3_M$							21.3											
$F3_F$							22.9				16.4		47.5					
$F4_I$							37.7											
$F4_M$							17.6											
$F4_F$							22.9				19.7		13.8					
R							--											

Table A3

pH For Water Samples Collected During the Period

9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			5.3	5.2														
L1 + L3		5.45			4.60			4.32	4.10	3.80		3.41		3.51	4.2	3.8	3.5	
L2 + L4		4.75			7.80	6.93		6.81	6.78	6.50		6.70		6.71	7.2	7.3	7.6	
L3			5.6	5.3														
L4			7.4	6.5														
L5 + L8		8.00			8.10			6.89	6.80	6.70		6.80		7.02		7.45	7.7	
L6 + L9		7.95			7.00				6.70	6.60		6.79		7.08		7.3	8.0	
L7				4.5														
L7 + L10		5.40						4.15	4.85	5.80		5.89		5.77		5.85	4.8	
L8																		
L9			5.1															
L10				4.7														
L11 + L14		8.00			7.85			7.02	6.80	6.85		6.70		7.40		7.6	7.5	
L12			5.4															
L12 + L15		7.85			7.10			6.88	6.68	6.65		6.65		6.90		7.1	6.8	
L13			4.55	2.3		4.15												
L13 + L16		2.50						2.00	3.18	2.90		2.46		2.40	3.1	3.35	2.6	
L14	7.2					2.98												
L15																		
L16			4.9															
L17 + L20		8.05			7.80			6.86	6.75	6.80		6.79		7.60		7.65	7.7	
L18 + L21		5.70			4.90	4.35		6.32	6.65	6.60		6.20		6.69	7.2	7.25	7.2	
L19																		
L19 + L22						3.15			3.90	3.90		3.65		3.78	4.1	4.45	4.0	
L20																		
L21																		
L22		4.65	4.3	4.4														
L23																		
W1		6.70				7.75			7.40	7.10		7.29		7.30	7.4	7.4	7.4	
W2		6.65			6.40	6.41			6.45	6.50		6.30		6.40	7.1	6.2	6.2	
$F1_I$					3.90		3.34											
$F1_M$							3.72										3.0	
$F1_F$							3.50				2.98		3.30					2.4
$F2_I$							7.28											
$F2_M$							7.20											
$F2_F$							7.15											
$F3_I$					6.90		7.41											
$F3_M$							7.30											
$F3_F$							7.27				7.31		6.10					
$F4_I$							7.42											
$F4_M$							7.15											
$F4_F$							7.32				9.59		6.69					
R							2.85											

Table A4

Chloride (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			28															
L1 + L3		20		1				6	Misg.	INTERFS		2		2	3	8	8	
L2 + L4		5						16	sample	8		3		3	3	5	5	
L3			13															
L4																		
L5 + L8		20						32		13		23		25		16	29	
L6 + L9		12			15					24		32		29		26	28	
L7																		
L7 + L10		1		15				34		<1		31		29		24	27	
L8																		
L9																		
L10																		
L11 + L14								87		7		25				21	40	
L12			2															
L12 + L15								6		8		30		29		31	31	
L13																		
L13 + L16		200		100				INTERFS.		9		29		15		26	32	
L14	15																	
L15																		
L16																		
L17 + L20		30						7		10		19				35	52	
L18 + L21		22			10			5		9		32		35		31	32	
L19																		
L19 + L22										10		7		13		22	34	
L20																		
L21																		
L22		20		30						18								
L23										2								
W1		5		35		23				18		29		25		22	25	
W2		35		15	<1	5				2		3		2		4	4	
$F1_I$					10		<1											
$F1_M$							<1										5	
$F1_F$							<1				3		1					2
$F2_I$							6											
$F2_M$							5											
$F2_F$							<1											
$F3_I$					15		<1											
$F3_M$							<1											
$F3_F$							<1				3		1					
$F4_I$							<1											
$F4_M$							<1											
$F4_F$							<1				6		2					
R							<1											

Table A5

Specific Conductance (μmhos/cm at 25°C) For Water Samples Collected On 9 November 1977 and During the Period 30 March -- 8 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1																		
L1 + L3								6,034	Misg.	5,612		misg.		4490	4240	3640	4540	
L2 + L4								4,782	sample	4,988				2960	2900	2600	2730	
L3																		
L4																		
L5 + L8								2,880		3,118				1265		980	1450	
L6 + L9										2,619				1510		1410	1450	
L7																		
L7 + L10								5,170		2,619				1448		1240	1520	
L8																		
L9																		
L10																		
L11 + L14								2,766		3,118						1330	1500	
L12																		
L12 + L15								3,012		2,908				1683		1630	2290	
L13																		
L13 + L16								6,467		4,652				6630	6520	3700	5000	
L14	14,175																	
L15																		
L16																		
L17 + L20								2,937		2,908						1163	1790	
L18 + L21								4,422		2,908				1836	1380	1480	1790	
L19																		
L19 + L22										8,141				5100	4360	2550	2390	
L20																		
L21																		
L22																		
L23																		
W1						4,260				3,722				2550	2650	2215	2060	
W2						3,885				3,256				2040	2150	1660	1780	
$F1_I$							2,446											
$F1_M$							1,045											
$F1_F$							816				2,900		1242					
$F2_I$							1,045											
$F2_M$							477											
$F2_F$							397											
$F3_I$							872											
$F3_M$							368											
$F3_F$							389				329		120					
$F4_I$							644											
$F4_M$							315											
$F4_F$							318				236		116					
R							516											

Table A6

Cyanide (ppm) For Water Samples Collected During The Period 9 November 1977 -- 8 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	10 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978
L1																	
L1 + L3								0.0101	0.0065	<0.0005		<0.0005		<0.0005	<0.0005	<0.0005	
L2 + L4								0.0152	0.0103	0.0039		0.0038		0.0030	0.0020	0.0030	
L3																	
L4																	
L5 + L8								0.0216	0.0299	0.0275		0.0124		0.0100			
L6 + L9					<0.0005				0.0205	0.0192						0.0130	0.0110
L7																	
L7 + L10								0.0069	0.0299	0.0169		0.0161		0.0130	0.0060	0.0080	0.0340
L8																	
L9																	
L10																	
L11 + L14								0.0203	0.0361	0.0299		0.0192					0.0270
L12																	
L12 + L15								0.0231	0.0361	0.0152		0.0219		0.0180		0.0110	
L13																	
L13 + L16								0.0083	<0.0005	<0.0005		<0.0005		<0.0005	<0.0005	<0.0005	
L14																	
L15																	
L16																	
L17 + L20	0.0027							0.0191	0.0124	0.0038							
L18 + L21								0.0169	0.0219	0.0103		0.0088		0.0140	0.0110	0.0110	
L19																	
L19 + L22									<0.0005	<0.0005		<0.0005		<0.0005	<0.0005	0.0110	
L20																	
L21	<0.0005																
L22																	
L23																	
W1				0.0447		0.0032			0.0254	0.0075		0.0114		0.0400	0.0340	0.0150	
W2		<0.0005		0.0848	0.0007	0.0231			<0.0005	0.0011				0.0030	0.0060	0.0130	
$F1_I$					0.0246		0.0169										
$F1_M$							0.0216										
$F1_F$							0.0179				0.0054		0.0110				
$F2_I$							0.0191										
$F2_M$							0.0191										
$F2_F$							0.0191										
$F3_I$					0.0009		0.0191										
$F3_M$							0.0191										
$F3_F$							0.0191				0.0103		0.0120				
$F4_I$							0.0203										
$F4_M$							0.0191										
$F4_F$							0.0191				0.0137		0.0180				
R							0.0032										

Table A7

Ammonia Nitrogen (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1976
L1			1.06															
L1 + L3		0.76		0.45	0.23				0.48	INTERF.		1.15		0.12	1.20	0.84	0.72	
L2 + L4		0.36			0.11			<0.08	<0.08	<0.08		0.46		INTERF.	<0.08	<0.08	0.16	
L3			1.15															
L4			0.33	0.25														
L5 + L8		1.94			0.48			1.48	10.0	2.94		5.78		0.14		<0.08	0.12	
L6 + L9		1.76			0.11				3.2	2.14		0.94		0.23	0.37	0.28	<0.08	
L7																		
L7 + L10		2.59		12.2				INTERFS.	2.96	2.36		1.44		1.60	1.20	0.96		
L8																		
L9																		
L10																		
L11 + L14		4.27			0.08			1.22	12.0	2.94		1.01		0.18		0.16	<0.08	
L12			2.37															
L12 + L15		10.0			0.73			1.22	7.6	4.39		0.77		1.12		0.24	0.16	
L13																		
L13 + L16		2.57						INTERFS.	3.52	INTERF.		2.56		2.56		1.28	1.04	
L14																		
L15																		
L16																		
L17 + L20		0.70			0.55			0.41	3.92	2.63		7.10				0.08	<0.08	
L18 + L21	0.79	1.04			1.31			2.54	6.80	4.39		1.15		2.64	1.84	1.12	0.64	
L19																		
L19 + L22									0.80	INTERF.		0.75		1.44	2.08	1.04	1.20	
L20																		
L21																		
L22		0.63		0.83														
L23																		
W1		2.06		6.26		0.63			1.60	5.19		2.24		2.48	2.24	1.92	1.76	
W2		3.36			0.08	0.28			1.92	7.82		2.06		2.16	2.32	2.32	2.08	
$F1_I$					0.30		0.42											
$F1_N$							0.29										0.24	
$F1_F$							0.29				2.34		INTERF.					0.24
$F2_I$							0.26											
$F2_N$							0.23											
$F2_F$							0.19											
$F3_I$					0.09		0.24											
$F3_N$							0.24											
$F3_F$							0.25				0.44		1.25					
$F4_I$							0.17											
$F4_N$							0.18											
$F4_F$							0.25				0.48		0.60					
R							0.30											

Table A8

Nitrate + Nitrite Nitrogen (ppm) For Water Samples Collected

During the Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			INTERF.															
L1 + L3		9.75		6.25	8.00			3.25	INTERFS.	.90		0.42		0.37	0.62	<0.10	<0.10	
L2 + L4		9.25		8.25	5.50			0.80	4.98	2.25		5.25		2.25	2.80	2.24	2.56	
L3			0.34															
L4			INTERF.	INTERF.														
L5 + L8		<0.10			0.90			0.72	1.57	<0.10		7.25		4.75		15.5	52.8	
L6 + L9		0.20			1.13				<0.10	INTERFS.		6.00		0.40	<0.10	18.0	<0.10	
L7																		
L7 + L10		INTERFS.		--				0.85	INTERFS.	0.25		7.75		2.50	8.70	11.3	12.3	
L8																		
L9			0.15															
L10																		
L11 + L14		<0.10			1.25			<0.10	<0.10	INTERFS.		INTERF.		INTERF.		16.8	52.8	
L12			0.44															
L12 + L15		<0.10			0.62			<0.10		INTERFS.		7.00		2.00		5.30	<0.10	
L13																		
L13 + L16		INTERFS.		--				16.5		2.45		INTERF.		7.00	0.70	9.80	15.3	
L14																		
L15																		
L16																		
L17 + L20		2.42			4.50			9.5		1.02		INTERF.		MISG.		22.5	56.8	
L18 + L21	<0.1	INTERFS.						<0.10	<0.10	<0.10		INTERF.		2.00	5.50	22.5	<0.10	
L19																		
L19 + L22									8.40	10.25		9.25		7.00	0.30	8.30	16.0	
L20																		
L21																		
L22		INTERFS.	1.25	3.10														
L23																		
W1		0.21		0.21		misg.			0.17	<0.10		0.18		<0.10	0.57	<0.10	<0.10	
W2		INTERFS.		<0.10	<0.10	sample			<0.10	0.80		0.19		<0.10	<0.10	<0.10	<0.10	
$F1_I$					0.33		3.0											
$F1_M$							2.7										<0.10	
$F1_F$							1.0				0.86		6.25					<0.10
$F2_I$							0.32											
$F2_M$							0.32											
$F2_F$																		
$F3_I$					0.67		0.32											
$F3_M$																		
$F3_F$											0.48		3.0					
$F4_I$																		
$F4_M$																		
$F4_F$											0.36		6.0					
R																		

Table A9

Total Kjeldahl Nitrogen (ppm) For Water Samples Collected

During the Period 9 November 1977 -- 8 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1																		
L1 + L3								0.65	1.15	0.65		1.70		1.00	1.00	1.15	1.15	
L2 + L4					0.35			0.55	0.55	0.35		0.65		0.25	0.20	0.30	0.25	
L3																		
L4																		
L5 + L8								9.30	12.65	11.20		4.75		2.75		2.65	no sample	
L6 + L9					6.35				7.20	6.70				2.25		3.65	3.20	
L7																		
L7 + L10								2.40	2.30	7.20		7.10		3.50		2.90	2.60	
L8																		
L9																		
L10																		
L11 + L14	5.50							5.35	13.90	11.45		6.75				3.65	no sample	
L12																		
L12 + L15					8.75			6.35	13.80	10.45				2.00		3.70	3.25	
L13																		
L13 + L16								4.55	8.46	3.55				7.50	5.45	4.05	2.85	
L14																		
L15																		
L16																		
L17 + L20								6.25	12.00	8.00						4.30	no sample	
L18 + L21								5.45		8.40		9.90		5.25	4.55	4.25	3.00	
L19																		
L19 + L22														2.75	3.25	3.00	3.85	
L20																		
L21																		
L22																		
L23																		
W1		3.20		1.55		4.4			2.15	4.25		8.25		2.75	1.50	2.20	2.00	
W2		2.25		3.05	3.15	4.75			2.55	1.70		2.65		2.00	2.00	2.10	2.20	
$F1_I$					0.90		0.85											
$F1_M$							0.60											
$F1_F$							0.50				1.75		0.95					
$F2_I$							1.80											
$F2_M$							0.85											
$F2_F$							0.65											
$F3_I$					2.10		1.50											
$F3_M$							0.70											
$F3_F$							0.65				0.60		1.25					
$F4_I$							1.25											
$F4_M$							0.60											
$F4_F$							0.55				0.70		1.05					
R							0.50											

Table A10

Orthophosphate (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1																	-	
L1 + L3								<0.05	0.15	0.62		1.50		1.20	1.20	0.80	0.60	
L2 + L4								<0.05	<0.05	<0.05		<0.05		<0.05	<0.05	<0.05	<0.05	
L3																		
L4																		
L5 + L8								<0.05	0.29	0.07		<0.05		<0.05		<0.05	no sample	
L6 + L9					0.18				<0.05	<0.05				<0.05		<0.05	<0.05	
L7																		
L7 + L10								<0.05	<0.05	<0.05		<0.05		<0.05		<0.05	<0.05	
L8																		
L9																		
L10																		
L11 + L14	0.06							<0.05	<0.05	<0.05		<0.05				<0.05	no sample	
L12																		
L12 + L15					0.10			<0.05	0.42	<0.05				<0.05		<0.05	<0.05	
L13																		
L13 + L16								0.57	10.5	1.00				10.5	9.50	1.00	4.50	
L14	0.057																	
L15																		
L16																		
L17 + L20								<0.05	0.11	0.05						0.25	no sample	
L18 + L21								<0.05	0.48	0.07		<0.05		<0.05	<0.05	0.05	<0.05	
L19																		
L19 + L22									<0.05					0.13	0.15	0.12	<0.05	
L20																		
L21																		
L22																		
L23																		
W1		<0.05		<0.05		<0.05			<0.05	0.11		<0.05		<0.05	<0.05	<0.05	<0.05	
W2		<0.05		0.17	0.20	<0.05			<0.05	<0.05		<0.05		0.06	<0.05	<0.05	<0.05	
$F1_I$					0.13		<0.05											
$F1_M$							<0.05										6.60	
$F1_F$							<0.05				0.05		0.08					2.60
$F2_I$							<0.05											
$F2_M$							<0.05											
$F2_F$							<0.05											
$F3_I$					0.32		<0.05											
$F3_M$							<0.05											
$F3_F$							<0.05				0.62							
$F4_I$							<0.05						0.09					
$F4_M$							<0.05											
$F4_F$							0.06				1.08		0.38					
R							<0.05											

Table A11

Total Phosphorus (ppm) For Water Samples Collected During The Period 9 November 1977 -- 8 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	10 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1																		
L1 + L3								<0.05	0.10	0.10		<0.05		0.65	0.70	1.20	0.90	
L2 + L4					<0.05			<0.05	0.05	<0.05		0.05		<0.05	0.05	0.10	<0.05	
L3																		
L4																		
L5 + L8								<0.05	0.10	0.05		0.50		0.10		0.55	no sample	
L6 + L9					0.05				0.10	0.05				0.05		0.10	<0.05	
L7																		
L7 + L10								<0.05	0.10	0.05		<0.05		<0.05		0.15	<0.05	
L8																		
L9																		
L10																		
L11 + L14	0.05							0.05	0.10	0.05		0.05				0.15	no sample	
L12																		
L12 + L15					0.05			0.05	0.15	0.05				0.05		0.15	<0.05	
L13																		
L13 + L16								1.70	1.80	0.30				4.85	4.40	2.55	1.55	
L14																		
L15																		
L16																		
L17 + L20								0.05	0.15	0.05						0.70	no sample	
L18 + L21								<0.05		0.05		0.05		0.15	0.20	0.20	<0.05	
L19																		
L19 + L22														0.10	0.20	0.15	<0.	
L20																		
L21																		
L22																		
L23																		
W1		0.05		<0.05		0.05			0.05	0.25		0.05		<0.05	0.05	0.15	<0.05	
W2		<0.05		<0.05	<0.05	<0.05			0.05	<0.05		0.05		<0.05	0.05	0.10	<0.05	
$F1_I$					0.05		0.15											
$F1_M$							<0.05											
$F1_P$							<0.05				3.50		0.40					
$F2_I$							0.05											
$F2_M$							0.10											
$F2_P$							0.05											
$F3_I$					0.10		0.15											
$F3_M$							0.10											
$F3_P$							0.10				0.40		0.20					
$F4_I$							0.15											
$F4_M$							0.10											
$F4_P$							0.10				0.35		0.35					
R							<0.05											

Table A12

Concentration of Silica (ppm) For Water Samples Collected During The Period 9 November -- 17 December 1977

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978		
L1			26.0													
L1 + L3		36.0														
L2 + L4		8														
L3			22.8													
L4																
L5 + L8		28.0														
L6 + L9		24.8			20.4											
L7																
L7 + L10		40.0		39												
L8																
L9																
L10																
L11 + L14		12.0														
L12			44.0													
L12 + L15		16.0														
L13																
L13 + L16		2,200														
L1·	11.3															
L15																
L16																
L17 + L20		18.0														
L18 + L21		42.0			52											
L19																
L19 + L22																
L20																
L21																
L22		125		110.0												
L23																
W1		6.0		14												
W2		65.0		47.0	31											
$F1_I$					9											
$F1_M$																
$F1_F$																
$F2_I$																
$F2_M$																
$F2_F$																
$F3_I$																
$F3_M$																
$F3_F$																
$F4_I$																
$F4_M$																
$F4_F$																
R																

Table A13

Sulfate (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			3,350															
L1 + L3		2,500		1,750				8,400	Misg.	7,750		8,980		8,700	9,200	10,000	9,700	
L2 + L4		4,625						3,700	sample	4,250		4,600		4,800	5,160	4,300	4,800	
L3			2,175															
L4																		
L5 + L8		625						900		1,625		500		970		970	1,320	
L6 + L9		1,275			1,638					1,875		550		1,120		1,320	1,320	
L7																		
L7 + L10		3,875		4,875				5,800		2,500		2,050		1,340		1,370	1,720	
L8																		
L9																		
L10																		
L11 + L14		1,000						800		1,700		600				1,350	1,760	
L12			1,875															
L12 + L15		4,562						1,400		2,450		1,700		1,600		2,270	9,600	
L13				1,175														
L13 + L16		2,200						4,600		6,500		6,150		10,700	8,400	5,200	8,400	
L14	335																	
L15																		
L16																		
L17 + L20								1,300		1,750		1,080				1,200	1,600	
L18 + L21		7,375			5,875			4,400		1,800		2,000		1,460	1,720	1,520	2,130	
L19																		
L19 + L22										3,050				8,300	6,100	5,300	6,000	
L20																		
L21																		
L22		2,225		2,300														
L23																		
W1		2,375		3,750		2,600				2,750		2,700		2,380	2,300	4,200	4,200	
W2		3,125		3,875	3,125	3,800				3,875		2,950		2,900	2,220	2,820	3,800	
$F1_I$					1,625		1,500											
$F1_M$							200										9,400	
$F1_F$							200				2,580		1,920					8,800
$F2_I$							200											
$F2_M$							100											
$F2_F$							100											
$F3_I$					550		300											
$F3_M$							100											
$F3_F$							50				50		55					
$F4_I$							200											
$F4_M$							100											
$F4_F$							30				55		65					
R							10											

Table A14

Sulfide (ppm) For Water Samples Collected During

The Period 9 November 1977 -- 8 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	22 NOV 1977	4 DEC 1977	17 DEC 1977	10 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978
L1																	
L1 + L3								<0.001	<0.001			<0.001		0.003	no sample.	0.010	<0.001
L2 + L4								<0.001	<0.001	<0.001		0.003		<0.001		<0.001	<0.001
L3																	
L4																	
L5 + L8				0.002			<0.001	0.004	<0.001	<0.001		0.004		<0.001		<0.001	<0.001
L6 + L9				0.002				0.002	0.004	0.011		0.004		0.005		<0.001	<0.001
L7																	
L7 + L10							0.008	<0.001	<0.001	0.005		0.005		<0.001		<0.001	<0.001
L8																	
L9	<0.001																
L10																	
L11 + L14							0.003	0.001	0.002	<0.001		0.003				<0.001	<0.001
L12																	
L12 + L15							0.003	0.001	0.002	0.009		0.007		0.004			<0.001
L13																	
L13 + L16							0.004	<0.001	<0.001	0.006		0.004		0.022		0.030	0.110
L14																	
L15																	
L16																	
L17 + L20							0.003	<0.001	<0.001	0.001		<0.001				<0.001	0.020
L18 + L21							0.001	<0.001	<0.001	<0.001		0.015		<0.001		<0.001	0.030
L19																	
L19 + L22								<0.001	<0.001	<0.001		<0.001		0.004		<0.001	no sample
L20																	
L21																	
L22	<0.001																
L23																	
W1			68.16		0.159			<0.001	<0.001	0.283		0.041		0.170		0.017	0.022
W2		45.12	16.11	<0.0001	0.004			<0.001	<0.001	<0.001				0.005		<0.001	0.060
$F1_I$				<0.0001		0.016											
$F1_M$						0.001											
$F1_F$						0.001					0.256		<0.001				
$F2_I$						0.011											
$F2_M$						0.001											
$F2_F$						0.010											
$F3_I$						0.001											
$F3_M$						0.005											
$F3_F$						0.001					<0.001		<0.001				
$F4_I$						1.68											
$F4_M$						0.001											
$F4_F$						0.001					<0.001		<0.001				
R						0.001											

Table A15

Concentration of Calcium (ppm) For Water Samples Collected During

The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			525															
L1 + L3		415		373	349			231	146	446		150		213	168	143	146	
L2 + L4		330			662			628	441	594		372		409	313	217	541	
L3			420															
L4			523	512														
L5 + L8		443						596	484	735		474		420	no sample	354	681	
L6 + L9		554							536	748		523		482	242	587	574	
L7																		
L7 + L10		446		551				477	434	683		521		432	249	366	548	
L8					645													
L9					553													
L10																		
L11 + L14		536						553	674	774		552		521	no sample	640	733	
L12			564															
L12 + L15		501						520	553	750		535		498	no sample	616	608	
L13																		
L13 + L16		33.6						481	601	496		276		126	126	315	642	
L14																		
L15																		
L16																		
L17 + L20		489						526	498	754		518		429	no sample	644	679	
L18 + L21		395						520	503	532		521		404	282	556	580	
L19																		
L19 + L22										228		113		202	147	292	496	
L20	317																	
L21	408																	
L22		403		362					82.7									
L23																		
W1		308		368		338			397	548		405		412	296	537	379	
W2		498		604	440	506			440	600		433		438	331	563	539	
$F1_I$					169		203											
$F1_M$							86.8										141	
$F1_F$							57.6				120		91.6					138
$F2_I$							174											
$F2_M$							87.4											
$F2_F$							62.7											
$F3_I$					252		146											
$F3_M$							65.0											
$F3_F$							64.0				37.1		10.7					
$F4_I$							115											
$F4_M$							47.7											
$F4_F$							49.0				12.1		6.51					
R							11.4											

Table A16

Concentration of Magnesium (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	28 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			4,200															
L1 + L3		3,660		3,390	1,070			1110	605	10		998		968	1,380	1,700	1,820	
L2 + L4		726			1,060			739	928	959		922		837	965	1,020	915	
L3			3,100															
L4			1,280	1,300														
L5 + L8		143			120			192	232	245		110		89	no sample	87.0	149	
L6 + L9		199			183				265	239		136		121	118	187	234	
L7																		
L7 + L10		472		371				699	374	240		199		162	118	157	235	
L8																		
L9																		
L10																		
L11 + L14		165			146			194	273	240		106		111	no sample	111	207	
L12			289															
L12 + L15		650			446			193	413	349		261		241	no sample	346	790	
L13																		
L13 + L16		3,350						362	1,175	683		597		1,066	1,400	684	2,330	
L14																		
L15																		
L16																		
L17 + L20		150			154			181	273	195		111		95	no sample	129	191	
L18 + L21		878			177			750	413	241		281		261	219	243	303	
L19																		
L19 + L22										457		1,224		1,110	2,340	813	575	
L20	55.5																	
L21	239																	
L22		2,720		2,510					1,625									
L23																		
W1		372		396		491			634	568		517		512	554	598	543	
W2		381		442	344	405			442	381		339		312	342	350	334	
$P1_I$					197		242.											
$P1_M$							72.3										1,130	
$P1_F$							41.8				261		235					[illegible]
$P2_I$							43.9											
$P2_M$							17.3											
$P2_F$							12.2											
$P3_I$					35		31.7											
$P3_M$							9.63											
$P3_F$							9.63				6.33		2.62					
$P4_I$							17.7											
$P4_M$							8.10											
$P4_F$							7.45				2.62		2.07					
R							24.1											

Table A17

Concentration of Sodium (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	6 NOV 1978	13 NOV 1978
L1			97.5															
L1 + L3		77.4		91.7	418.			201.	88.5	70.4		42.3		38.6	55.3	50.1	55.4	
L2 + L4		83.0			90.6			156.	238.	243.		204.		158.	179.	174.	143.	
L3			58.8															
L4			194.	195.														
L5 + L8		96.2			225.			146.	117.	106		44.8		36.2	no sample	32.7	46.4	
L6 + L9		22.7			206.				96.0	87.4		67.1		63.4	57.7	45.1	40.7	
L7																		
L7 + L10		25.1		15.8				167.	108.	67.2		47.3		38.6	43.6	31.3	41.5	
L8																		
L9																		
L10																		
L11 + L14		28.3			27.7			92.4	57.0	57.9		34.9		37.4	no sample	31.8	50.0	
L12			8.7															
L12 + L15		35.7			265.			223.	89.0	39.0		39.9		34.9	no sample	36.6	35.7	
L13																		
L13 + L16		10.4						74.3	10	71.5		39.9		37.4	34.6	37.0	34.8	
L14																		
L15																		
L16																		
L17 + L20		25.2			73.3			263.	181.	168.		31.2		31.2	no sample	64.0	63.3	
L18 + L21		72.8			74.3			122.	155.	173.		90.6		62.1	45.9	38.4	41.3	
L19																		
L19 + L22										38.7		103.		102.	75.2	60.6	65.6	
L20	18.9																	
L21	108																	
L22		52.4		395.					50.5									
L23																		
W1		201.		188.		245.			391.	249.		219.		232.	271.	236.	256.	
W2		36.7		32.2	34.7	36.9			58.0	39.8		32.4		34.9	48.0	42.6	42.6	
$F1_I$					2.68		1.73											
$F1_M$							0.98										6.7	
$F1_F$							0.72				1.52		1.52					5.0
$F2_I$							4.60											
$F2_M$							1.64											
$F2_F$							1.23											
$F3_I$					5.04		3.89											
$F3_M$							1.44											
$F3_F$							1.34				6.47		1.52					
$F4_I$							2.20											
$F4_M$							0.98											
$F4_F$							0.98				10.2		2.76					
R							0.94											

Table A18

Concentration of Potassium (ppm) For Water Samples Collected During The Period 9 November -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			17															
L1 + L3		15.8		9.5	7.8			4.90	8.00	6.9		5.83		5.24	9.07	7.35	6.73	
L2 + L4		18.6			18.5			20.1	22.3	21.8		19.0		18.5	27.4	22.3	23.9	
L3			9.0															
L4			21.9	24.7														
L5 + L8		6.9			7.5			8.62	11.4	11.6		4.18		3.72	no sample	8.90	6.43	
L6 + L9		4.8			6.3				7.20	7.1		4.42		3.61	6.09	8.81	6.79	
L7																		
L7 + L10		9.8		8.2				3.67	6.00	5.7		4.53		3.78	6.10	7.51	5.50	
L8																		
L9																		
L10																		
L11 + L14		6.7			6.2			6.02	10.3	10.5		4.42		5.36	no sample	7.06	4.11	
L12			8.8															
L12 + L15		7.0			7.3			6.38	8.10	6.4		6.68		3.16	no sample	8.72	4.84	
L13																		
L13 + L16		6.0						< .1	1.70	1.4		1.22		0.61	1.28	3.60	1.29	
L14																		
L15																		
L16																		
L17 + L20		4.8			5.3			7.88	9.70	9.7		3.84		9.76	no sample	10.6	6.25	
L18 + L21		4.1			4.1			6.29	8.30	7.6		6.07		8.02	15.2	16.7	6.78	
L19																		
L19 + L22										3.5		2.27		1.84	2.65	5.26	3.34	
L20	4.0																	
L21	3.9																	
L22		7.2		3.58					5.60									
L23																		
W1		17.5		16.2		21.7			21.7	35.1		20.8		18.3	22.0	20.5	19.4	
W2		37.2		30.5	31.6	31.5			35.7	27.4		27.1		26.4	35.0	30.1	32.2	
$F1_I$					0.87		1.15											
$F1_M$							0.58										0.54	
$F1_F$							<0.10				0.70		1.10					0.93
$F2_I$							4.45											
$F2_M$							1.64											
$F2_F$							1.28											
$F3_I$					1.14		2.68											
$F3_M$							0.99											
$F3_F$							1.12				14.3		5.48					
$F4_I$							2.74											
$F4_M$							0.60											
$F4_F$							1.07				25.7		8.76					
R							< .10											

Table A19

Concentration of Strontium (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	22 NOV 1977	4 DEC 1977	[illegible] DEC 1977	[illegible] MAR 1978	[illegible] APR 1978	[illegible] APR 1978	16 MAY 1978	[illegible] JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	[illegible] SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			1.1															
L1 + L3				0.7	1.6			1.2	0.5	0.7		0.6		0.6	<0.5	<0.5	<0.5	
L2 + L4					2.8			3.4	2.7	1.1		3.6		2.9	[illegible]	0.6	1.9	
L3			0.8															
L4			3.4	3.3														
L5 + L8					1.1			1.2	1.2	0.9		0.9		0.9	no sample	<0.5	1.4	
L6 + L9					0.9				1.1	0.6		0.6		0.6	<0.5	<0.5	<0.5	
L7																		
L7 + L10			0.5					1.2	2.0	0.5		0.9		0.6	<0.5	<0.5	<0.5	
L8																		
L9																		
L10																		
L11 + L14					0.9			0.5	1.0	0.5		0.6		0.9	no sample	0.5	0.6	
L12			0.6															
L12 + L15					1.0			<0.5	0.8	0.5		0.6		0.6	no sample	<0.5	<0.5	
L13																		
L13 + L16								0.8	<0.5	<0.5		0.6		0.6	<0.5	0.6	<0.5	
L14																		
L15																		
L16																		
L17 + L20					1.0			0.8	1.2	0.9		0.6		0.6	no sample	0.7	0.7	
L18 + L21					0.5			<0.5	1.1	0.7		0.6		0.6	<0.5	<0.5	<0.5	
L19																		
L19 + L22										<0.5		0.6		0.9	<0.5	<0.5	0.6	
L20	0.6																	
L21	0.8																	
L22				1.2					<0.5									
L23																		
W1				4.1		6.4			6.9	7.8		6.7		6.7	5.0	5.1	4.2	
W2				9.4	10.0	12.9			10.6	<0.5		10.1		9.8	7.1	8.1	8.1	
$F1_I$					0.6		<0.5											
$F1_M$							<0.5											
$F1_F$							<0.5				0.9		<0.5				<0.5	<0.5
$F2_I$							<0.5											
$F2_M$							<0.5											
$F2_F$							<0.5											
$F3_I$					0.5		<0.5											
$F3_M$							<0.5											
$F3_F$							<0.5				<0.5		<0.5					
$F4_I$							<0.5											
$F4_M$							<0.5											
$F4_F$							<0.5				<0.5		<0.5					
R							<0.5											

Table A20

Concentration of Aluminum (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			203															
L1 + L3		68.0		125.	173.				217.	453.		319.		484.	474.	683.	455.	
L2 + L4		0.20			<0.10			2.19	<0.10	7.13		1.96		<0.10	1.00	<0.10	0.50	
L3			92.7															
L4			0.17	0.10														
L5 + L8		0.19			0.15			<0.10	<0.10	<0.10		<0.10		<0.10	<0.10	<0.10	<0.10	
L6 + L9		0.14			<0.10				<0.10	<0.10		<0.10		<0.10		<0.10	<0.10	
L7																		
L7 + L10		113.		91.5				204.	14.8	14.1		1.96		0.57	1.20	0.20	17.9	
L8																		
L9																		
L10																		
L11 + L14		0.14			0.21			0.29	<0.10	<0.10		<0.10				<0.10	<0.10	
L12			51.6															
L12 + L15		14.6			4.08			0.29	<0.10	<0.10		<0.10		0.20		<0.10	2.30	
L13																		
L13 + L16								136.	412.	449.		60.9		769.	790.	336.	403.	
L14																		
L15																		
L16																		
L17 + L20		0.16			0.25			0.29	<0.10	<0.10		<0.10				0.20	0.40	
L18 + L21		21.0			45.8			0.59	<0.10	<0.10		0.30		0.96	1.70	<0.10	0.10	
L19																		
L19 + L22									169.	480.		311.		196.	294.	119.	47.5	
L20	0.19			557.														
L21	2.85																	
L22																		
L23																		
W1		191.		56.0		<0.10			<0.10	0.20		<0.10		0.57	0.60	<0.10	<0.10	
W2		10.7		8.25	1.11	4.83			<0.10	2.89		<0.10		<0.10	0.50	<0.10	<0.10	
$F1_I$					56.5		102.											
$F1_M$							24.7										397.	
$F1_F$							16.2				151.		125.					256.
$F2_I$							0.29											
$F2_M$							<0.10											
$F2_F$							<0.10											
$F3_I$					0.29		<0.10											
$F3_M$							<0.10											
$F3_F$							<0.10				0.63		0.63					
$F4_I$							<0.10											
$F4_M$							<0.10											
$F4_F$							<0.10				7.14		<0.10					
R							<0.10											

Table A21

Concentration of Cadmium (ppm) For Water Samples Collected During

The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			0.05															
L1 + L3		<0.02		0.02	0.05			0.06	<0.02	0.18		<0.02		0.10	0.04	0.04	0.05	
L2 + L4		<0.02			<0.02			0.04	<0.02	0.19		<0.02		<0.02	<0.02	<0.02	<0.02	
L3			0.03															
L4			<0.02	<0.02														
L5 + L8		<0.02			<0.02			0.02	<0.02	<0.02		<0.02		<0.02		<0.02	0.03	
L6 + L9		<0.02			<0.02				<0.02	<0.02		<0.02		<0.02	<0.02	0.04	0.03	
L7																		
L7 + L10		<0.02		<0.02				0.10	0.03	<0.02		<0.02		<0.02	0.03	<0.02	0.03	
L8																		
L9																		
L10																		
L11 + L14		<0.02			<0.02			0.02	0.02	<0.02		<0.02				<0.02	0.03	
L12			<0.02															
L12 + L15		<0.02			<0.02			0.02	0.05	<0.02		<0.02		<0.02		<0.02	0.03	
L13																		
L13 + L16								0.09	0.06	<0.02		<0.02		0.15	0.05	0.02	0.04	
L14																		
L15																		
L16																		
L17 + L20		<0.02			<0.02			0.04	0.05	<0.02		<0.02				<0.02	0.02	
L18 + L21		<0.02			0.02			0.06	0.05	<0.02		<0.02		<0.02	0.02	<0.02	0.02	
L19																		
L19 + L22									0.06	0.18		0.05		0.15	0.03	<0.02	0.03	
L20	<0.02																	
L21	1.07																	
L22				0.04														
L23																		
W1		0.26		0.08		<0.02			0.05	<0.02		<0.02		<0.02	0.18	0.03	0.05	
W2		<0.02		<0.02	<0.02	<0.02			<0.02	<0.02		<0.02		<0.02	<0.02	<0.02	0.04	
$F1_I$					<0.02		<0.02											
$F1_M$							<0.02										0.03	
$F1_F$							<0.02				0.02		0.02					<0.02
$F2_I$							<0.02											
$F2_M$							<0.02											
$F2_F$							<0.02											
$F3_I$					<0.02		<0.02											
$F3_M$							<0.02											
$F3_F$							<0.02				0.02		0.02					
$F4_I$							<0.02											
$F4_M$							<0.02											
$F4_F$							<0.02				0.02		0.02					
R							<0.02											

Table A22

Concentration of Chromium (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			0.29															
L1 + L3		0.05		0.23	0.23			<0.05	0.06	0.10		0.20		0.10	0.06	0.08	0.05	
L2 + L4		<0.05			<0.05			<0.05	<0.05	0.10		<0.05		<0.05	<0.05	<0.05	<0.05	
L3			0.24															
L4			0.16	0.13														
L5 + L8		<0.05			0.05			<0.05	<0.05	<0.05		<0.05		<0.05		<0.05	<0.05	
L6 + L9		<0.05			0.06				<0.05	<0.05		<0.05		<0.05	<0.05	<0.05	<0.05	
L7																		
L7 + L10		<0.05		0.10				<0.05	<0.05	<0.05		<0.05		<0.05	<0.05	<0.05	<0.05	
L8																		
L9																		
L10																		
L11 + L14		<0.05			0.06			<0.05	<0.05	<0.05		<0.05				<0.05	<0.05	
L12			0.10															
L12 + L15		<0.05			0.10			<0.05	<0.05	<0.05		<0.05		<0.05		<0.05	<0.05	
L13																		
L13 + L16								<0.05	0.44	0.23		0.30		0.43	0.35	0.15	0.17	
L14																		
L15																		
L16																		
L17 + L20		<0.05			0.06			<0.05	<0.05	<0.05		<0.05				<0.05	<0.05	
L18 + L21		<0.05			0.10			<0.05	<0.05	<0.05		<0.05		<0.05	<0.05	<0.05	<0.05	
L19																		
L19 + L22									0.10	0.23		0.30		0.10	0.05	<0.05	<0.05	
L20	<0.05																	
L21	<0.05																	
L22				0.34														
L23																		
W1		0.59		0.33		<0.05			<0.05	<0.05		<0.05		<0.05	0.06	<0.05	<0.05	
W2		<0.05		0.12	0.07	<0.05			<0.05	<0.05		<0.05		<0.05	<0.05	<0.05	<0.05	
$F1_I$					0.06		<0.05											
$F1_M$							<0.05										0.14	
$F1_F$							<0.05				0.20		<0.05					0.09
$F2_I$							<0.05											
$F2_M$							<0.05											
$F2_F$							<0.05											
$F3_I$					<0.05		<0.05											
$F3_M$							<0.05											
$F3_F$							<0.05				<0.05		<0.05					
$F4_I$							<0.05											
$F4_M$							<0.05											
$F4_F$							<0.05				<0.05		<0.05					
R							<0.05											

Table A23

Concentration of Copper (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			0.29															
L1 + L3		0.35		0.18	0.19				0.26	0.33		0.58		4.33	0.31	0.43	0.27	
L2 + L4		<0.05			<0.05			<0.05	<0.05	0.05		<0.05		0.05	<0.05	<0.05	<0.05	
L3			0.33															
L4			0.07	0.09														
L5 + L8		<0.05			0.16			<0.05	<0.05	0.05		0.06		0.05		<0.05	0.10	
L6 + L9		0.10			0.25				<0.05	<0.05		0.06		0.05	<0.05	<0.05	0.06	
L7																		
L7 + L10		0.25		0.10				0.53	0.08	0.05		0.06		0.05	<0.05	<0.05	0.07	
L8																		
L9																		
L10																		
L11 + L14		0.21			0.43			0.12	<0.05	<0.05		0.06				<0.05	0.08	
L12			0.21															
L12 + L15		0.45			0.17			0.05	<0.05	0.05		0.06		0.1[illegible]		<0.05	1.15	
L13																		
L13 + L16								1.50	1.63	1.05		0.99		2.23	2.63	0.98	<0.05	
L14																		
L15																		
L16																		
L17 + L20		0.13			0.09			0.54	0.08	0.10		0.18				<0.05	<0.05	
L18 + L21		0.43			0.26			0.15	<0.05	<0.05		<0.05		0.05	<0.05	<0.05	0.05	
L19																		
L19 + L22									0.12	0.33		0.35		0.20	0.18	0.09	0.51	
L20	<0.05																	
L21	1.07																	
L22				0.59														
L23																		
W1		0.59		0.22		<0.05			0.05	0.05		<0.05		<0.05	<0.05	<0.05	<0.05	
W2		<0.05		<0.05	0.07	<0.05			<0.05	<0.05		<0.05		<0.05	<0.05	<0.05	<0.05	
$P1_I$					0.08		0.27											
$P1_M$							<0.05										0.25	
$P1_F$							<0.05				0.35		0.18					<0.05
$P2_I$							<0.05											
$P2_M$							<0.05											
$P2_F$							<0.05											
$P3_I$					<0.05		<0.05											
$P3_M$							<0.05											
$P3_F$							<0.05				<0.05		<0.05					
$P4_I$							<0.05											
$P4_M$							<0.05											
$P4_F$							<0.05				<.0		<0.05					
R							<0.05											

Table A24

Concentration of Iron (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			28.3															
L1 + L3		31.5		4.79	0.56				1.24	1.20		2.12		2.50	5.79	23.3	6.89	
L2 + L4		<0.10			0.11				0.50	2.50		0.16		<0.10	0.19	0.16	<0.10	
L3			0.53															
L4			0.10	0.10														
L5 + L8		16.8			5.26			<0.10	0.50	2.50		0.20		<0.10		2.19	7.43	
L6 + L9		0.25			0.27				<0.10	35.2		0.30		<0.10	1.22	<0.10	<0.10	
L7																		
L7 + L10		14.6		7.36				1.00	<0.10	3.40		0.30		<0.10	0.32	<0.10	<0.10	
L8																		
L9																		
L10																		
L11 + L14		6.3			0.31			1.50	<0.10	40.9		0.85				2.26	16.6	
L12			2.61															
L12 + L15		49.3			8.31			1.90	12.8	70.7		0.92		<0.10		<0.10	<0.10	
L13																		
L13 + L16								396.	87.8	237.		146.		489.	786.	245.	296.	
L14																		
L15																		
L16																		
L17 + L20		0.10			0.12			0.20	0.50	9.40		6.43				1.85	1.35	
L18 + L21		265.			305.			1.50	7.09	63.8		41.6		1.78	12.3	<0.10	<0.10	
L19																		
L19 + L22									5.94	14.6		14.8		6.40	7.42	1.70	<0.10	
L20	0.10																	
L21	6.17																	
L22				485.														
L23																		
W1		876		100.		0.85			1.24	7.70		0.45		<0.10	2.24	0.46	0.13	
W2		347.		287.	263.	211.			87.8	283.		118.		249.	228.	160.	149.	
$F1_I$					1.50		3.66											
$F1_M$							<0.10										112.	
$F1_F$							<0.10				56.6		26.6					78.5
$F2_I$							<0.10											
$F2_M$							0.60											
$F2_F$							0.50											
$F3_I$					0.51		1.05											
$F3_M$							0.64											
$F3_F$							1.34				2.04		1.10					
$F4_I$							0.40											
$F4_M$							<0.10											
$F4_F$							<0.10				0.97		0.34					
R							<0.10											

Table A25

Concentration of Manganese (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			202.															
L1 + L3		202.		182.0	203.				48.6	76.8		39.5		87.6	106.	86.6	115.	
L2 + L4		0.86			0.47			5.95	1.87	3.61		1.48		0.52	9.83	0.43	0.88	
L3			229.															
L4			1.03	0.85														
L5 + L8		3.17			4.11			7.60	9.57	6.34		3.57		2.67		<0.02	0.22	
L6 + L9		4.1			4.28				13.6	8.35		4.81		4.33	3.20	5.02	6.63	
L7																		
L7 + L10		32.5		29.8				46.1	16.9	10.0		8.89		7.95	8.24	7.93	13.8	
L8																		
L9																		
L10																		
L11 + L14		2.8			4.52			9.24	11.3	7.06		3.37				0.87	1.12	
L12			22.3															
L12 + L15		20.0			17.3			7.11	18.2	10.02		7.75		7.24		8.14	15.3	
L13																		
L13 + L16								20.5	62.3	58.5		27.1		90.3	99.7	38.6	74.1	
L14																		
L15																		
L16																		
L17 + L20		1.94			2.49			3.15	3.65	3.65		3.57				<0.02	0.18	
L18 + L21		62.0			76.2			44.0	19.0	10.8		14.8		19.1	11.5	11.9	14.94	
L19																		
L19 + L22									74.6	148.		58.4		69.7	97.0	44.9	36.5	
L20	0.85																	
L21	17.9																	
L22				192.														
L23																		
W1		19.0		7.21		.40			1.87	2.04		2.13		1.68	2.95	<0.02	2.26	
W2		3.0		6.2	6.53	9.24			13.6	9.03		10.4		8.09	10.89	6.27	6.88	
$P1_I$					[illegible]		17.0											
$P1_M$							4.60										47.8	
$P1_P$							2.29				17.6		15.6					27.6
$P2_I$							≤0.02											
$P2_M$							<0.02											
$P2_P$							<0.02											
$P3_I$					0.09		<0.02											
$P3_M$							<0.02											
$P3_P$							≤0.02				0.04		0.04					
$P4_I$							<0.02											
$P4_M$							<0.02											
$P4_P$							<0.02				<0.02		<0.02					
R							<0.02											

Table A26

Concentration of Nickel (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			5.62															
L1 + L3		7.00		5.24	6.06			3.94	3.59	4.98		6.49		5.40	9.75	10.8	[illegible]	
L2 + L4		0.05			<0.05			0.32	0.50	0.55		0.20		0.20	0.37	0.26	0.37	
L3			6.68															
L4			<0.05	<0.05														
L5 + L8		0.14			<0.05			<0.05	0.50	0.20		0.10		0.40		<0.05	0.14	
L6 + L9		0.18			<0.05				0.39	0.40		0.20		0.35	0.15	0.14	0.21	
L7				1.87														
L7 + L10		2.89						4.63	1.27	0.40		0.30		0.50	0.38	0.41	0.64	
L8																		
L9																		
L10																		
L11 + L14		0.11			<0.05			0.32	0.50	0.30		0.10				0.06	0.18	
L12			1.53		0.45													
L12 + L15		0.96						0.23	0.61	0.35		0.30		0.20		0.34	0.59	
L13																		
L13 + L16								1.89	5.24	3.97		3.00		5.45	9.31	3.41	4.31	
L14																		
L15																		
L16																		
L17 + L20		0.11			<0.05			0.13	0.39	0.40		0.10				0.16	0.36	
L18 + L21		3.03			2.74			1.59	0.72	0.30		0.40		0.55	0.72	0.39	0.41	
L19																		
L19 + L22									4.03	5.50		7.19		3.75	5.37	2.41	1.39	
L20	<0.05																	
L21	0.81																	
L22				8.71														
L23																		
W1		1.19		0.25		<0.05			<0.05	<0.05		0.05		<0.05	0.41	0.10	0.21	
W2		1.03		0.61	0.43	.64			0.94	0.50		0.70		0.50	0.71	0.47	0.53	
$F1_I$					0.86		1.34											
$F1_M$							0.32										4.09	
$F1_F$							0.17				0.16		0.13					2.37
$F2_I$							<0.05											
$F2_M$							<0.05											
$F2_F$							<0.05											
$F3_I$					<0.05		<0.05											
$F3_M$							<0.05											
$F3_F$							<0.05				< .05		< .05					
$F4_I$							<0.05											
$F4_M$							<0.05											
$F4_F$							<0.05				< .05		< .05					
R							<0.05											

Table A27

Concentration of Lead (ppm) For Water Samples Collected During

The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			0.45															
L1 + L3		<0.05		0.36	0.35				0.19	0.10		0.10		0.10	0.42	0.41	0.53	
L2 + L4		<0.05			0.18			0.15	<0.05	0.05		0.05		<0.05	0.28	[illegible]	0.28	
L3			0.32															
L4			0.23	0.20														
L5 + L8		<0.05			0.14			<0.05	<0.05	<0.05		<0.05		<0.05		<0.05	0.15	
L6 + L9		<0.05			0.11				<0.05	<0.05		<0.05		<0.05	0.11	<0.05	.15	
L7																		
L7 + L10		<0.05		0.11				0.15	0.19	0.05		0.05		<0.05	0.26	0.05	0.14	
L8																		
L9																		
L10																		
L11 + L14		<0.05			0.10			<0.05	<0.05	<0.05		0.05				0.09	0.18	
L12			0.12															
L12 + L15		<0.05			0.09			0.09	<0.05	<0.05		<0.05		<0.05		0.14	0.19	
L13																		
L13 + L16								0.17	0.19	0.05		0.05		0.10	0.47	0.26	0.37	
L14																		
L15																		
L16																		
L17 + L20		<0.05			0.12			0.07	<0.05	<0.05		<0.05				0.18	0.24	
L18 + L21		<0.05			0.18			0.19	<0.05	<0.05		<0.05		<0.05	0.10	0.09	0.17	
L19																		
L19 + L22									0.23	0.41		0.15		0.10	0.39	0.21	0.23	
L20	<0.05																	
L21	<0.05																	
L22				0.30														
L23																		
W1		1.4		0.71		0.24			<0.05	0.05		0.05		0.05	0.40	0.17	0.27	
W2		<0.05		0.18	0.19	0.23			<0.05	<0.05		0.05		<0.05	0.16	0.14	0.24	
$F1_I$					0.05		0.12											
$F1_M$							<0.05										0.26	
$F1_F$							<0.05				0.05		0.05					[illegible]
$F2_I$							<0.05											
$F2_M$							<0.05											
$F2_F$							<0.05											
$F3_I$					<0.05		<0.05											
$F3_M$							<0.05											
$F3_F$							<0.05				<0.05		<0.05					
$F4_I$							<0.05											
$F4_M$							<0.05											
$F4_F$							<0.05				<0.05		<0.05					
R							<0.05											

Table A28

Concentration of Zinc (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1			3.36															
L1 + L3		1.95		2.26	3.74				2.56	4.42		3.48		4.97	5.67	7.39	5.89	
L2 + L4		<0.05			0.07			0.09	0.12	0.21		0.09		0.05	0.09	0.05	0.07	
L3			1.85															
L4			0.08	0.07														
L5 + L8		2.60			2.93			1.46	7.22	5.03		3.34		1.99		2.14	3.60	
L6 + L9		3.30			3.00				5.59	3.41		3.61		2.21	1.95	1.93	2.35	
L7																		
L7 + L10		3.30		1.60				4.68	2.08	1.28		0.90		1.00	1.16	1.07	1.73	
L8																		
L9																		
L10																		
L11 + L14		2.10			3.08			1.88	4.48	2.03		2.58				2.05	3.44	
L12																		
L12 + L15		6.00	1.06		4.14			2.16	4.91	2.35		3.37		3.62		1.77	3.27	
L13																		
L13 + L16								5.60	5.84	5.29		4.47		6.51	12.4	5.49	6.61	
L14																		
L15																		
L16																		
L17 + L20		2.40			3.36			1.99	3.83	2.52		2.70				0.52	2.73	
L18 + L21		5.80			4.54			2.19	2.19	1.31		1.87		1.96	1.95	1.22	2.11	
L19																		
L19 + L22									2.60	3.41		2.54		1.93	2.68	1.70	1.55	
L20	1.09																	
L21	3.90																	
L22				11.8														
L23																		
W1		1,600.		212.		7.20			1.24	37.3		18.1		14.4	16.3	<0.05	26.3	
W2		36.0		133.	147.	141.			17.9	87.0		22.6		131.0	161.	128.	145.	
$F1_I$					0.92		1.64											
$F1_M$							0.39										3.58	
$F1_P$							0.26				1.06		0.78					1.85
$F2_I$							0.06											
$F2_M$							0.04											
$F2_P$							<0.05											
$F3_I$					0.21		<0.05											
$F3_M$							<0.05											
$F3_P$							<0.05				0.08		0.06					
$F4_I$							<0.05											
$F4_M$							<0.05											
$F4_P$							<0.05				<0.05		0.06					
R							<0.05											

Table A29

Concentration of Mercury (ppm) For Water Samples Collected During The Period 9 November 1977 -- 13 November 1978

WATER SAMPLE DESIGNATION	9 NOV 1977	20 NOV 1977	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1978	10 APR 1978	17 APR 1978	16 MAY 1978	13 JUN 1978	26 JUN 1978	20 JUL 1978	26 JUL 1978	9 AUG 1978	6 SEP 1978	11 OCT 1978	8 NOV 1978	13 NOV 1978
L1																		
L1 + L3		0.00020						<0.00010	0.00395	0.00149		<0.00010		<0.00010	<0.00010	0.00160	0.00125	
L2 + L4		<0.00010			0.00020			<0.00010	<0.00010	0.00046		<0.00010		<0.00010	<0.00010	0.00026	<0.00010	
L3																		
L4																		
L5 + L8								0.00012	0.03293	0.00185		<0.00010				0.00036	0.00016	
L6 + L9					0.00020				0.02907	0.00485						0.00046	0.00014	
L7																		
L7 + L10		0.00020						0.00010	0.04854	0.00516		<0.00010		0.00027		0.00080	0.00028	
L8																		
L9																		
L10																		
L11 + L14								0.00021	0.00670	0.00060		<0.00010				<0.00010	0.00014	
L12																		
L12 + L15					0.00020			0.00044	0.04214	0.00049		0.00012				0.00051	0.00062	
L13																		
L13 + L16								<0.00010	0.00190	0.00627				0.00010	0.00019	0.00083	0.00048	
L14																		
L15																		
L16																		
L17 + L20					0.00030			0.00100	0.05220	0.00125						0.00027	0.00019	
L18 + L21		0.00030			0.00030			0.00018	0.05231	0.00125		<0.00010		0.00042	<0.00010	0.00053	<0.00010	
L19																		
L19 + L22									0.03118	0.00171				<0.00010		0.00100	0.00620	
L20	0.00020																	
L21	0.00060																	
L22																		
L23																		
W1		0.00060							0.01338	0.00049		<0.00010		0.00020	<0.00010	<0.00010	<0.00010	
W2		0.00050			0.00030				0.00870	0.00129		<0.00010		0.00086	<0.00010	0.00058	0.00012	
$F1_I$					0.00020													
$F1_M$																	0.00063	
$F1_F$											0.00011		0.00037					<0.00010
$F2_I$																		
$F2_M$																		
$F2_F$																		
$F3_I$					0.00030													
$F3_M$																		
$F3_F$											0.00070		<0.00010					
$F4_I$																		
$F4_M$																		
$F4_F$											0.00024		<0.00010					
R																		

APPENDIX B: MODEL USED FOR INTERPRETATION OF SOIL WATER SAMPLES

1. A thermodynamic solubility model was used to attempt delineation of the principal factors controlling the chemical composition of the soil solutions collected in this study. The model compared the concentrations of soil solution constituents against known limits for the presence of constituents in a saturated condition. Saturation would suggest the presence of a solid mineral phase controlling solubility for the chemical constituents involved, or the possibility of chemical precipitation of such a mineral from the soil solution. Undersaturation would suggest either that an insufficient time had elapsed to allow equilibrium to be attained between the solution and solid phase of a mineral, or that solubility was being controlled by an adsorption process or inorganic or organic adsorbents. The soil chemistry of Ca, Mg, Na, K, Cd, Cr, Hg, Pb, and Zn were simulated using the model described below.

2. Chemical equilibrium was assumed in the model and the ionic forms of the heavy metals chosen were the thermodynamically stable forms that exist under natural aerobic conditions. The forms of the heavy metals were taken as Zn^{2+}, Pb^{2+}, Cd^{2+}, Hg^{2+}, and CrO_4^{-2}. The partitioning of Hg and Cr between their various valence states was considered a second-order correction.

3. Input consisted of the enumerated cations, pH, and the anions Cl^- and SO_4^{2-}. Carbonate and bicarbonate activities were calculated from pH assuming atmospheric CO_2 partial pressure.[15*] Initially, the ionic strength μ was calculated from the molar concentration M_i and valence Z_i for all the ionic species in solution:

$$\mu = 1/2 \sum_{i-1}^{i=n} M_i Z_i^2 \qquad \text{(B1)}$$

Then the activity coefficient γ_i for each ionic specie i was calculated from Stumm and Morgan[15] as:

$$\log \gamma_i = -A\, Z_i^2 \left(\mu\ 1/2(1+\mu\ 1/2)-b\mu\right) \qquad \text{(B2)}$$

---

* Raised numerals refer to similarly numbered items in the References at the end of the main text.

where

A = 0.509 for an aqueous solution at 25°C

b = 0.2

When the activity coefficients were estimated, the ion activities M were calculated using a mass balance approach that incorporated ion pair formation in the soil solution. For example, the total analytical concentration of a heavy metal cation in solution M_T in terms of the ion pairs considered in this model was given by:

$$M_T = \left[M^{2+}\right] + \left[MSO_4{}^o\right] + \left[MCl^+\right] + \left[MCO_3{}^o\right] + \left[MHPO_4{}^o\right] \tag{B3}$$

where $\left[\ \right]$ represents concentration in moles per litre and $(M_i) = \gamma_i[M_i]$, in terms of activities. Where ( ) represents activity, Equation B3 is written:

$$M_T = \frac{(M^{2+})}{\gamma_m} + \frac{\left(MSO_4{}^o\right)}{\gamma_{mso_4}} + \frac{(MCl^+)}{\gamma_{mcl}} + \frac{\left(MCO_3{}^o\right)}{\gamma_{mco_3}} + \frac{\left(MHPO_4{}^o\right)}{\gamma_{mhpo_4}} \tag{B4}$$

In general, for any ion pair of the form MX , one can write:

$$MX^{i-j} = M^{i+} + X^{j-}$$

and

$$K_{MX}{}^{i-j} = \frac{(M^{i+})(X^{j-})}{(MX^{i-j})} \tag{B5}$$

or

$$(MX^{i-j}) = \frac{(M^{i+})(X^{j-})}{K_{MX}{}^{i-j}}$$

where

$K_{MX}{}^{i-j}$ = the dissociation constant for the ion pair MX^{i-j}

i+ = the charge on cation M

j- = the charge on anion X

Making the substitution given in Equation B5 for all complexes and rearranging Equation B4 gives:

$$(M^{2+}) = M_T\left(\frac{1}{\gamma_m} + \frac{(SO_4)}{\gamma K_{mso_4}} + \frac{(Cl)}{\gamma K_{mcl}} + \frac{(CO_3)}{\gamma K_{mco_3}} + \frac{(HPO_4)}{\gamma K_{mhpo_4}}\right)^{-1} \qquad \text{(B6)}$$

All anions and cations whose calculations appear in this model were treated in this manner.

4. Each charged ion pair contributed to the ionic strength thus: the activities of all ion pairs MX^{i-j} were calculated from Equation B5 after M^{i+} and X^{j-} were calculated using expressions of the form given by Equation B6. Because ionic strength is based on concentrations, each calculated ion pair activity was divided by its respective activity coefficient and fed into a new ionic strength expression that incorporated ion pairs in its computation. This process was repeated in an interative dissolved oxygen (DO) loop until successive ionic strength values differed by less than 1 × 10^{-6}M/ℓ. The computed activities for the cations, anions, CO_3, HCO_3, and the pH and pOH were then routed to a routine that calculated ion activity products for the most sparingly soluble salts known for each cation. The ratio of these calculated ion activity products to known solubility product constants for each salt provided an estimate of the saturation status of each ion with respect to these salts.

5. The minerals considered in this model as possible solubility-controlling solid phases were

Anglesite	$PbSO_4$
Antarcticite	$CaCl_2 \cdot 6H_2O$
Aragonite	$CaCO_3$
Arcanite	K_2SO_4
Bischofite	$MgCl_2 \cdot 6H_2O$
Brucite	$Mg(OH)_2$
Cerussite	$PbCO_3$
Epsomite	$MgSO_4 \cdot 7H_2O$
Gibbsite	$Al(OH)_3$
Gibbsite (amorphous)	$Al_2O_3 \cdot 3H_2O$
Gysum	$CaSO_4 \cdot 2H_2O$
Halite	$NaCl$
Hexahydrite	$MgSO_4 \cdot 6H_2O$
Hydromagnesite	$Mg_4(CO_3)_3(OH)_2 \cdot 3H_2O$

Kieserite	$MgSO_4 \cdot H_2O$
Lead hydroxide	$Pb(OH)_2$
Magnesite	$MgCO_3$
Mercuric chloride	$HgCl_2$
Mirabilite	$Na_2SO_4 \cdot 10H_2O$
Nesquihonite	$MgCO_3 \cdot 6H_2O$
Otavite	$CdCO_3$
Smithsonite	$ZnCO_3$
Sylvite	KCl
Thenardite	Na_2SO_4
Zinkosite	$ZnSO_4$

No sparingly soluble chromate salts are known to exist naturally, hence these computations were not done for Cr.

6. In addition, the solubility status of the following minerals was estimated using the activity coefficient of the Zn^{2+} cation as the activity coefficient for the divalent cations. Fe^{3+} activities were calculated from Fe^{3+} to Fe^{2+} ratios which were determined by a formula using a status of the S^{2-}/SO_4^{2-} redox couple.[38] These estimated cation activities and the calculated anion activities were used to estimate ion activity products for the following minerals:

Amorph. iron oxide	$Fe(OH)_3$
Celestite	$SrSO_4$
Melanterite	$FeSO_4 \cdot 7H_2O$
Pyrochroite	$Mn(OH)_2$
Rhodochrosite	$MnCO_3$
Siderite	$FeCO_3$
Strontianite	$SrCO_3$

APPENDIX C: METEOROLOGICAL DATA

1. Rainfall data for the study were collected and reported by P. Johnston, an amateur meteorologist living in Ottawa. The rain gage used was located a distance of approximately one third mile from the demonstration plots.

2. With respect to the needs of this study, with only one individual responsible for collecting daily 8 a.m. readings, there is a likelihood for errors of omission, of failure to read at the exact time, or failure to read accurately during adverse weather. An evaluation was made, therefore, of the accuracy and reliability of the observed data, using data abstracted from appropriate volumes of the U.S. Environmental Data Service's publication Climatological Data, and the data of Appendix C, following.

3. It is a well-established practice in hydrology and meteorology to compare weather data for stations within a given climatological region by using linear correlation for monthly rainfall averages over a period of many years. Such details as the approximate time a rain gage was moved from a central city to an airport location may be discovered by detecting a change in the slope of the linear regression lines comparing data for the years before and after the move.

4. Weather service gage readings are reported for a midnight-to-midnight day, or for an 8 a.m.-to-8 a.m. day, depending on the type of gage and the type of facility. Similarly, the recently installed recording rainfall gage at the demonstration site is reported on a midnight-to-midnight basis, while the gage tended by Mr. Johnston was reported daily at 8 a.m.

5. Day-to-day readings between the two onsite gages may, therefore, vary significantly for day-to-day readings. A one-half-in. (13-mm) storm that began at 6 a.m. and ended at 10 a.m. would be recorded over 2 days by the manual gage and over 1 day by the recording gage. Similarly, a 10 p.m.-to-2 a.m. storm would be reported as rainfall over 2 days by the recording gage and as rainfall on a single day by the manual gage.

6. From these considerations it may be seen, however, that rainfall values reported for a total event would overcome this 8-hr discrepancy. Collecting daily data into single rainfall (or snowfall) event totals also alleviates the dissimilarities that may be imposed by the time of arrival and departure of a storm for two stations at some distance from each other. Large storm systems that may affect an area for longer periods of time are likely to display highly localized variations in precipitation intensity. Comparing rainfall data per event for stations affected by the same large system, rather than comparing per time increment, will serve to smooth out time-dependent variability and leave only the storm spatial variability as the significant variable affecting the amounts of precipitation reported. This is the same result as is obtained by taking cumulative precipitation data over a longer period of time, such as monthly cumulative average comparisons over decades.

7. In addition to compiling meteorological data in terms of total single-event values, three stations were considered in an analysis of the rainfall data obtained so as to provide a check on the comparison method before its application.

8. Table C1 gives the daily reported precipitation amounts for rain gages at Marseilles Lock, Ottawa, Ill., and Utica-Starved Rock Dam, Illinois. Marseilles Lock is approximately 8 miles east-southeast of Ottawa, while Utica-Starved Rock Dam is approximately 11 miles west-southwest of Ottawa. All three stations are located within the Northeast climatological Division of Illinois.

9. Table C2 presents snow depths and water equivalents reported for the Ottawa weather station during the winter of 1978. Discounting snows that fell on days during which temperature rose above freezing, the snow/water depth ratio is shown to be 12.8. This ratio was used to convert snow depths to their water equivalents for snow data reported for the gage tended by Mr. Johnston. Daily rainfall for this gage over this study is given in Table C3, together with data from the recording gage at the demonstration site that came on line in August 1978.

Table C1

Total Precipitation, Daily, Marseilles Lock/ Ottawa/Utica-Starved Rock, Illinois

Day	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Day
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			1
2		[illegible]	T T	[illegible]	[illegible]		[illegible]	2
3		.02 T			[illegible]	[illegible]	[illegible]	3
4					[illegible]		[illegible]	4
5	[illegible] .02 [illegible]		.12 T		[illegible]		[illegible]	5
6			[illegible] .26 [illegible]	T			[illegible]	6
7	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	7
8	.98 [illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	8
9		[illegible]	[illegible]	T T T			[illegible]	9
10	T .18	.05 .02	T				[illegible]	10
11	[illegible] .16	.01 T					[illegible]	11
12				.12				12
13			T	[illegible]	[illegible]			13
14		.02 .02	T	[illegible]	[illegible]	[illegible]		14
15	T .06					[illegible]		15
16	.06 T T			T	T T	[illegible]		16
17		.19 .01	[illegible]	[illegible]				17
18			[illegible]				[illegible]	18
19				[illegible]			[illegible]	19
20		[illegible] .26 .02	[illegible]	[illegible]			[illegible]	20
21		T .01	[illegible]	[illegible]	T	[illegible]	[illegible]	21
22	[illegible]		.33 T					22
23	[illegible] .24 .22	.03 .05			[illegible]		[illegible]	23
24	.17 .04 .18	.06 .01		[illegible]	[illegible]		[illegible]	24
25	.73 .60 .81	.21 .42 [illegible]		[illegible]		[illegible]	[illegible]	25
26		.31 T		[illegible]		[illegible]		26
27		[illegible] .25 [illegible]		[illegible]		[illegible]		27
28		[illegible] .08	T T T	[illegible]				28
29								29
30								30
31	↓ [illegible] .32			↓ [illegible]				31
Totals	3.60 3.91 3.30	2.2[illegible] 1.59 1.5[illegible]	2.23 1.86 [illegible]	[illegible] .98 .92	[illegible]	[illegible]	[illegible]	Totals

Day	May	Jun	Jul	Aug	Sep	Oct	Nov	Day
1			[illegible]	.01				1
2			.04 [illegible] .22	[illegible]				2
3			[illegible] .02	T		[illegible]		3
4	[illegible]	T	T					4
5	[illegible]					[illegible]		5
6	[illegible]					[illegible]	[illegible]	6
7	[illegible]	[illegible]	[illegible]				[illegible]	7
8	[illegible]	[illegible]	.08 .08					8
9	[illegible]	T	[illegible] .11	T .20 .02				9
10	[illegible]					[illegible]		10
11	[illegible]		[illegible] .05	[illegible]	T	[illegible]		11
12	[illegible]						[illegible]	12
13	[illegible]		[illegible] .98 1.48		[illegible]	[illegible]	[illegible]	13
14	[illegible]		[illegible]		[illegible] .16	[illegible]	[illegible] .06	14
15	[illegible]				[illegible]	[illegible]		15
16		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	16
17		[illegible]	[illegible]		[illegible]		[illegible]	17
18		[illegible]		[illegible]	[illegible]		[illegible]	18
19			[illegible] .01	[illegible]	[illegible]	[illegible]		19
20		[illegible]	[illegible]				[illegible]	20
21		[illegible]	[illegible]		[illegible] .10 [illegible]		[illegible]	21
22			[illegible]		[illegible]		[illegible]	22
23	[illegible]		[illegible]			[illegible]	[illegible]	23
24	[illegible]			[illegible] .48 .28				24
25		/2.33		[illegible]		[illegible]		25
26		1.11 .48 [illegible]	.89			[illegible]	[illegible]	26
27		[illegible]	1.19 [illegible]	T [illegible] T			[illegible]	27
28		.01 .01		[illegible] T			[illegible]	28
29			[illegible]				[illegible]	29
30	[illegible]	[illegible] .15 [illegible]	[illegible]		[illegible] .36		.01	30
31								31
Totals	[illegible]	↓ [illegible]	↓ [illegible]	[illegible]	[illegible]	1.94 1.99 1.96	[illegible]	Totals

↓↑ Continued to or from next or preceding month in the determination of storm event precipitation totals.

Note: T = trace.

Table C2

Water Equivalents for Snowfalls at the Ottawa Weather Service Gage

Day	Nov 1977 Snow	Nov 1977 H_2O	Dec 1977 Snow	Dec 1977 H_2O	Jan 1978 Snow	Jan 1978 H_2O	Feb 1978 Snow	Feb 1978 H_2O	Mar 1978 Snow	Mar 1978 H_2O
1					4.0	0.28*	0.3	T		
2			2.0	0.50*			0.4	T	0.6	0.05
3							0.5	0.02	1.0	0.07
4							1.0	0.06		
5			1.0	0.12*			0.2	0.02		
6			2.0	0.16						
7										
8			4.5	0.36						
9										
10										
11										
12					1.5	0.12				
13					1.5	0.08	4.0	0.36		
14					0.5	0.05	0.3	0.02*		
15										
16										
17										
18										
19					0.5	0.01				
20			2.5	0.58*	1.0	0.06				
21			1.5	0.13						
22										
23							0.3	0.01		
24					0.5	0.10*				
25	3.5	0.32*							0.9	0.51*
26					3.0	0.23			0.3	0.10
27	2.5	0.25								
28			0.2	T						
29										
30										
31					0.3	T				

* Temps. at or above 32°F during the day, numbers not used.

AD-A088 586 ARGONNE NATIONAL LAB IL F/G 13/2
SUITABILITY OF DREDGED MATERIAL FOR RECLAMATION OF SURFACE-MINE--ETC(U)
JUL 80 W HARRISON, A VAN LUIK, L S LOON WESRF-77-197
UNCLASSIFIED WES/TR/EL-80-7 NL

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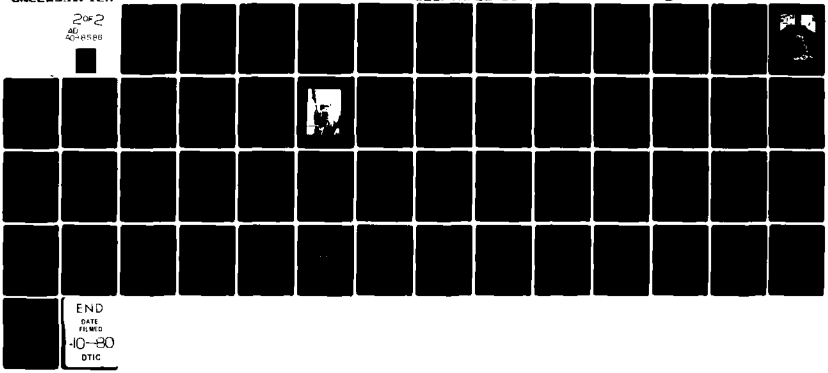

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Table C3

Total Daily Precipitation, Mr. Johnston's/Demonstration Site Gages

	Nov 77	Dec 77	Jan 78	Feb 78	Mar 78	Apr 78	May 78	Jun 78	Jul 78	Aug 78	Sep 78	Oct 78	Nov 78	
1				.12*					0.48	0.07			/MISDA	1
2												0.43/0.46	/MISDA	2
3					0.01*	T						/0.05	0.24/MISDA	3
4					T							0.17/0.01	T/MISDA	4
5						0.02	0.68					/0.12	0.32/MISDA	5
6		0.31*					0.06						T/MISDA	6
7			0.17			0.05		0.31	0.04				/MISDA	7
8		0.47*				0.02	0.58			0.02			/MISDA	8
9									0.06			0.07		9
10						0.89				/0.29		/0.06		10
11						0.51	0.14			/0.24		/0.35	T	11
12			0.20*				1.43		1.05		0.19/0.19	/0.01	0.29/0.03	12
13		0.03	0.12*	0.35*			1.21				0.15/		/0.32	13
14				0.03*	0.25						/0.25			14
15				T						0.45/0.54			0.16/0.06	15
16		0.16*					0.04	0.91	0.24		1.43/0.03	T	0.58/0.45	16
17								0.06		0.51/0.19	2.47/2.16		end of	17
18						0.97		0.02	T	/0.34	0.32/0.69	/0.17	record	18
19	0.11					T			T	/0.03				19
20		0.23*	0.09*					0.29	0.03		0.11/0.07			20
21					0.17	0.11			0.42		/0.02			21
22							0.05		0.39			0.48/0.17	/0.35	22
23												/0.29	/0.16	23
24						0.05	0.05			0.35/0.34		0.08		24
25	0.16*				0.22	0.46		2.21				0.39/0.45		25
26			0.20*					0.07	0.81				/0.07	26
27	0.31*				0.02								/0.14	27
28		0.04*						T		0.02/0.04			/0.01	28
29								0.07	0.08		0.38	/MISDA	/0.01	29
30											/0.48	/MISDA	end of	30
31		0.12*										/MISDA	record	31

*Water equivalent = $\frac{\text{"snow"}}{12.8}$

MISDA = Missing data

10. Per event rainfall totals for all five stations are given in Table C4.

11. From Tables C1 and C4, one may infer that there were some omissions in Mr. Johnston's reports. In particular, the 1 December 1977 and 1 January 1978 storms appear to have been missed, as well as the 16 August and 18 October storms of 1978.

12. These four missing values were estimated to be the mean of two estimated values obtained using three-way linear correlations between Mr. Johnston's gage and the gages at Marseilles Lock and Ottawa and the recording gages installed later at the study site. Three-way linear correlation analysis was performed to check the method of reporting station comparison. The results appear in Table C5.

13. From Table C5 it may be seen that 97 percent of the variability in the Ottawa data correspond to variability in the data from Marseilles and Utica. The regression line equation shows the intercept to be close to zero, suggesting that there is very little, if any, systematic difference between the rainfall amounts of these three stations, as is supported by the similarity in the totals shown for the 70 events. The higher coefficient for the (A) Marseilles data as compared with the coefficient for the (C) Utica data suggests that Ottawa rainfall variations correspond more closely to Marseilles than to Utica rainfall variations. This is confirmed by the higher covariance for the Ottawa-Marseilles (AB) data as compared to Ottawa-Utica (BC) covariance. (Note that covariances are not commutative.)

14. Data of Table C5 imply that valid event comparisons may be made for precipitation totals over relatively short periods of time using linear statistical relationships.

15. There were 54 events in which rainfall was reported for the Marseilles Lock, Ottawa, and Mr. Johnston's gages. Linear multiple correlation comparing these three stations gave the results reported in Table C6.

Table C4

Total Precipitation Per Storm Event: Comparisons for the Five Rain Gage Stations

Event No.		Oct 1977	Nov 1977	Dec 1977	Jan 1978	Feb 1978	Mar 1978	Apr 1978	May 1978	Jun 1978	Jul 1978	Aug 1978	Sep 1978	Oct 1978	Nov 1978
1	A. Marseilles	1.43	1.13	0.60	0.32	0.10	0.12	2.71	2.03	0.21	0.80	0.07	0.15	0.52	0.52
	B. Ottawa	1.46	0.89	0.50	0.28	0.10	0.12	2.68	1.82	0.39	0.46	0.09	0.47	0.46	0.74
	C. Utica	1.02	0.96	0.35	0.52	0.08	0.13	2.81	2.02	0.33	0.32	0.15	0.45	0.38	0.60
	D. DeKalb Export	-	-	*(0.48)	*(0.26)	0.12	0.01	1.49 (2.48)	1.32	0.31	0.48	0.15	0.34	0.43	0.56
	E. Demonstration Site	-	-	-	-	-	-	-	-	-	-	-	.44	.51	*
2	A.	0.05	0.21	0.24	0.09	0.51	0.10	0.94	2.10	1.21	0.08	T	4.30	0.11	0.37
	B.	0.02	0.18	0.28	0.07	0.38	0.33	0.86	2.26	1.19	0.08	0.20	4.37	0.14	0.45
	C.	0.02	0.21	0.35	0.02	0.37	0.26	1.01	3.26	0.88	0.11	0.02	6.83	0.16	0.49
	D.	-	-	0.31	0.17	0.38	0.25	1.08	2.82	0.99	0.10	0.02	4.22	0.17	0.29
	E.	-	-	-	-	-	-	-	-	-	-	-	2.68	0.11	0.35
3	A.	0.98	0.02	0.40	0.21	0.02	0.25	0.63	0.12	0.71	*	0.24	0.15	0.07	0.55
	B.	1.04	*	0.36	0.25	0.01	0.22	0.58	0.04	0.52	0.05	0.33	0.10	0.08	0.57
	C.	1.04	0.01	0.35	0.21	0.02	0.15	0.57	0.10	0.30	*	0.34	0.53	0.04	0.53
	D.	-	-	0.47	0.32	*	0.17	0.51	0.10	0.29	*	*(0.27)	0.11	0.07	0.74
	E.	-	-	-	-	-	-	-	-	-	-	0.53	0.09	0.42	0.51
4	A.	0.15	0.19	0.02	0.04		0.51		T	3.18	1.01	0.05	0.44	0.06	0.51
	B.	0.18	*	0.01	0.07		0.61		0.09	2.83	0.95	0.67	0.40	0.10	0.56
	C.	0.16	0.01	0.01	0.04		0.51		*	2.02	1.88	0.34	0.36	0.04	0.51
	D.	-	-	*	0.09		0.24		*	2.35	1.05	0.45	0.38	T	*(end of record)
	E.	-	-	-	-		-		-	-	-	0.54	0.48	*	0.51
5	A.	0.06	0.10	0.97	0.37						0.17	0.53		0.19	0.37
	B.	0.06	0.26	0.71	0.33						1.00	0.52		0.20	0.35
	C.	T	0.03	0.34	0.11						0.99	0.32		0.16	0.43
	D.	-	0.11	0.23	0.20						0.24	0.51		*(0.17)	*
	E.	-	-	-	-						-	0.56		0.17	0.23 (end of record)
6	A.	0.93	0.59								0.49	0.21		0.52	
	B.	0.84	0.57								0.95	0.38		0.50	
	C.	1.10	0.33								1.26	0.35		0.60	
	D.	-	0.47								0.84	0.35		0.48	
	E.	-	-								-	0.34		0.46	
7	A.										1.19	T		0.47	
	B.										0.89	0.02		0.51	
	C.										0.44	T		0.61	
	D.										0.81	0.02		0.47	
	E.										-	0.04		0.45	

Note: T=trace reported; ()= (Continued) estimated amounts.

*End of report: Missing data or no rainfall.

Table C5

Three-way Linear Correlation for Stations A*, B*, and C* of Table C4

Total Events Compared: 70

Degrees of Freedom: 69

Coefficient of Determination, $R^2 = 0.97$**

Equation of Regression Line:

$$B = 0.07 + 0.63A + 0.26C$$

Covariances:

$S^{\dagger}_{AB} = 1.30$, $S_{BC} = 1.01$, $S_{AC} = 1.01$

Sums of the 70 Events (inches):

$A = 38.71$, $B = 39.98$, $C = 41.27$

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*A: Marseilles Lock, Ill.
B: Ottawa, Ill.
C: Utica-Starved Rock Dam, Ill.

**Significant at the 99 percent confidence level.

†$S_{xy} = \frac{1}{n-1}\left(\sum_i x_i y_i - \frac{1}{n}\sum x_i y_i\right)$, symmetrical in x and y.

Table C6

Three-way Linear Correlation for Stations A*, B*, and D* of Table C4

Total Events Compared: 54

Degrees of Freedom: 53

Coefficient of Determination, $R^2 = 0.91^{**}$

Equation of Regression Line:

$$D = -0.01 + 0.18A + 0.70B$$

Covariances:

$S_{AD} = 0.88$ $S_{BD} = 0.88$ $S_{AB} = 1.00$

Sums of the 54 Events (inches):

A = 31.33 B = 33.09 D = 28.09

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*A: Marseilles Lock, Ill.
B: Ottawa, Ill.
C: Mr. Johnston's gage, 1/3 mile east of study site.

**Significant at the 99 percent confidence level; 9 percent of Mr. Johnston's gage data variance did not correspond with variance in the data from the Marseilles and Ottawa stations.

16. Table C6 shows that, although the regression was highly significant, the regression equation is not as good a predictor as it was in the case of the three official stations reported in Table C5.

17. The regression equation does have an intercept very close to zero, however, and the coefficients suggest a much greater affinity between Mr. Johnston's data and the Ottawa data as opposed to the Marseilles data. The affinity is expected from the relative distances between the three rain gage locations. Yet, covariances do not bear out this conclusion, suggesting that variances did not correspond to the same extent between Mr. Johnston's gage and the other two gages. The statistical implication of the information is that there are some unique single-event totals in Mr. Johnston's data that do not have parallels in the Ottawa or Marseilles data. The first event in April and the first and second events in May are illustrative cases.

18. A comparison of data in Tables C1 and C3 for these three events shows that there are good reasons to suspect missing data for April 2 and 6, 1978, during the first of the three suspect events, and an estimated value is given for this first event. On the other hand, there is no equally good reason to suspect the data for the first two storms of May 1978, and no estimated values will be computed. Note in Table C4 that the official recording station at Utica-Starved Rock reports a value even higher than the one in question, suggesting a highly variable storm system rather than a reading error.

19. A comparison was made between the data from the recording rain gage at the demonstration site and the data from Mr. Johnston's gage for the period of events in which either or both recorded rainfall. Results appear in Table C7.

20. Comparison 1 in Table C7 implies that the values reported for the two gages nearest the site are very similar and, separately, they are also very similar to the Ottawa site gage. Comparison 3 of Table C7 shows that for the 20 events during which Mr. Johnston recorded rainfall, his data correlated almost perfectly with the combined Marseilles and

Table C7

Comparisons Between Mr. Johnston's Rain Gage (D) and the Demonstration Site Gage (E)

Comparison 1. Per Event Total Rainfall Correlation between the D and E Gages:

Number of Events = 15, 14 degrees of freedom

Regression Coefficient = 0.985 (significant at 99% confidence level)

Coefficient of Determination = 0.97 (97% of variance in common)

Regression Equation: E = 0.17 + 0.60D

E = 0.173 + 0.597D

Comparison 2. Correlation with Ottawa (B) Weather Service Gage, Separately, 15 Events:

a. Mr. Johnston's gage vs. Ottawa gage

r = 0.996

D = -0.02 + 0.97B

b. Demonstration site gage vs. Ottawa gage

r = 0.988

D = 0.16 + 0.58B

c. Weather Service gage comparisons for the same 15 events (to aid interpretation)

1. Marseilles Lock (A) vs. Ottawa (B)

r = 0.983

A = 0.10 + 0.98B

2. Ottawa (B) vs. Utica Starved Rock Dam (C)

r = 0.989

B = 0.22 + 1.58C

Comparison 3. Multiple Linear Correlation of Ottawa and Marseilles Gages vs. Mr. Johnston's Gage and the Demonstration Site Gage:

a. DeKalb Exp. Co. gage, 20 events

R^2 = 1.00

D = -0.01 + 0.35A + 0.62B

b. Demonstration site gage, 17 events

R^2 = 0.96

E = 0.14 - 0.01A + 0.59B

Ottawa gages. Data from the demonstration site gate did not compare as well over the same period, however. Inspection of the data in Table C4 shows a large discrepancy for the demonstration site gage total for the second storm event in September. This discrepancy is responsible for the reduction in the correlation. It is likely that the demonstration site total is in error for this particular total.

21. The regression equations for the precipitation values from Marseilles Lock and Ottawa gages vs. Mr. Johnston's gage (Table C6 and Comparison 3 of Table C7) were used to estimate the five values for Mr. Johnston's gage that appear to be in error. The mean of the two estimated values was taken as the best estimator and was entered in parentheses in Table C4 for each questioned event.

22. Table C4 values for Mr. Johnston's gage, including the five estimated values, were used as the "site" rainfall data in this report. Other meteorological data used in the report include daily mean temperatures, daily high temperatures at or below freezing, and daily high temperatures near freezing. These values were abstracted from the published daily high and low temperatures for Ottawa. Mean values were as $\frac{\text{max} + \text{min}}{2}$ for the purposes of this study. For missing values in the Ottawa record, values for Peru, Ill., approximately 15 miles west of Ottawa, were substituted. Each tabled value was placed in parentheses to denote an estimated value. Temperature data, as used for the site, are given in Table C8.

23. Use was made also of the daily evaporation rate at the Hennepin Power Plant, about 32 miles southwest of Ottawa. Using Hennepin Power Plant pan evaporation rates (a function of temperature, relative humidity, and wind) as approximate evaporation rates for the demonstration site assumes an approximate equality for the averages of these three variables and their interactions between these two sites over the period of interest. Values appear in Table C9.

Table C8

Mean Daily and Monthly Temperatures for Ottawa, Ill.

	Nov 1977	Dec 1977	Jan 1978	Feb 1978	Mar 1978	Apr 1978	May 1978	Jun 1978	Jul 1978	Aug 1978	Sep 1978	Oct 1978	Nov 1978	
1	61	37	24*	14**	24*	59	46	77	80	73	74	59	48	1
2	65	35	9**	14**	23**	42	48	70	80	76	75	61	55	2
3	64	25*	14**	14**	23**	59	50	67	74	71	79	63	59	3
4	58	24**	27*	13**	12**	64	53	68	74	69	70	59	(65)	4
5	55	33*	35	15**	14**	47	44	70	76	70	74	59	64	5
6	58	18**	33	8**	30*	57	49	75	80	71	77	51	55	6
7	59	7**	36	13**	30*	58	52	78	80	74	80	50	43	7
8	60	17**	21*	18**	32*	56	61	68	76	71	81	49	46	8
9	55	9**	0**	21**	28*	58	60	(67)	76	79	81	59	(53)	9
10	39	-1**	3**	20**	35	56	59	67	67	73	(78)	63	53	10
11	35	6**	(9)**	20**	(36)	52	67	78	68	75	82	57	49	11
12	32*	27*	14**	26*	39	59	70	80	(70)	77	80	59	45	12
13	(31)*	38	19**	26**	35	48	61	63	78	78	83	52	54	13
14	(44)	33	22**	27*	37	46	46	66	72	79	80	48	46	14
15	53	35	12**	23**	37	49	55	73	78	83	72	48	36	15
16	47	40	13**	14**	33	47	58	75	74	78	78	50	38	16
17	42	50	17**	11**	30*	44	60	80	76	74	74	47	47	17
18	43	44	18**	12**	32*	52	66	79	78	82	75	52	45	18
19	42	38	25**	12**	42	51	68	71	81	78	82	50	38	19
20	51	29*	23**	17**	43	41	73	76	(83)	69	82	58	32*	20
21	38	24**	14**	16**	44	46	(64)	67	82	69	67	66	29**	21
22	(32)*	23**	12**	14**	51	44	60	70	81	77	59	(59)	32*	22
23	(37)	33	23*	26**	48	59	67	74	76	(74)	61	(59)	38	23
24	35	31*	28*	33	40	56	67	77	70	78	65	47	35	24
25	24*	15**	26**	32*	31**	55	74	80	73	75	63	55	31*	25
26	11**	11**	17**	21**	33	53	80	80	77	(77)	62	50	35	26
27	22**	7**	6**	23**	39	54	80	83	74	78	62	52	35	27
28	18**	19**	9**	29*	50	58	77	78	71	79	58	49	29*	28
29	21**	31*	7**		46	60	79	79	76	72	62	(53)	31*	29
30	25*	25*	9**		46	50	76	81	67	73	67	(56)	26*	30
31		30*	12**		61		75		68	71		51		31
Monthly	42.0	25.2	17.3	18.9	35.4	53.0	62.5	73.7	75.3	74.7	72.5	54.2	42.2	

*denotes a "near-freezing day," a mean at or below 32°F but a high above 32°F.

**denotes a freezing day, with a high at or below 32°F.

NOTE: () = estimated value, using Peru, Ill., data.

Table C9

Evaporation Rates in Inches Per Day for the Hennepin Power Plant, Illinois

Day	Nov 1977	Apr 1978	May 1978	Jun 1978	Jul 1978	Aug 1978	Sept 1978	Oct 1978	Day
1			0.18	0.54			0.19		1
2			0.25	0.33	0.15		0.20	0.36	2
3	0.07			0.26	0.16	0.04	0.28		3
4	0.12		0.44	0.24		0.15	0.30	0.15	4
5	0.14			0.25	0.21		0.21	0.17	5
6	0.05			0.27	0.34	0.47		0.24	6
7			0.08	0.38	0.15		0.46	0.12	7
8				0.11	0.41	0.46	0.27	0.13	8
9			0.29	0.16	0.15		0.24	0.07	9
10				0.19	0.26	0.52	0.25	0.08	10
11			0.38	0.38	0.26	0.13		0.12	11
12			0.03	0.52		0.22			12
13			0.21	0.44		0.16	0.05		13
14			0.15		0.26	0.30	0.39	0.30	14
15			0.00	0.34	0.13		0.39		15
16			0.03	0.23	0.15	0.05			16
17				0.16	0.10			0.30	17
18			0.15	0.24	0.18	0.22			18
19			0.30	0.18		0.29			19
20			0.18	0.27	0.26			0.13	20
21			0.30		0.28	0.65	0.23	0.09	21
22		0.12	0.18	0.27	0.08	0.15		0.05	22
23		0.07	0.17	0.30	0.20		0.15	0.07	23
24		0.37		0.18	0.17	0.27	0.39		24
25		0.00	0.04	0.22	0.35	0.12		0.10	25
26		0.31	0.15	0.34	0.10	0.17	0.33	0.10	26
27		0.13	0.20		0.17	0.05		0.07	27
28		0.18	0.33		0.30	0.27	0.15	0.10	28
29		0.20	0.25	0.59	0.20	0.31		0.10	29
30		0.23	0.41	0.16		0.20	0.30	0.08	30
31					0.11	0.15			31

APPENDIX D: LIQUID PRECIPITATION AND AIR TEMPERATURE AT THE OTTAWA SITE AS MEASURED BY THE ARGONNE INSTRUMENT PACKAGE, AUGUST 1978-NOVEMBER 1978

by

L. S. Van Loon*

Argonne's Instrument Package

1. A rain gage, thermistor, and electronic recording package were installed at the site on 9 August 1978; the package has recorded rainfall and temperature automatically since that time. A brief description of the system follows.

2. A Meteorology Research, Inc. (MRI), Model 302, tipping-bucket rain gage is used to sample precipitation. This rain gage collects precipitation in a 7.86-in.- (200-mm) diam collector tube and funnels the precipitation to a tipping-bucket mechanism. The tipping bucket overbalances and tips once for every 0.01 in. (0.25 mm) of precipitation. Tipping of the bucket is sensed by the reed switch mounted near a magnet on the tipping-bucket mechanism, which produces one switch closure for every tip of the bucket (0.01 in. of rain). The switch closure produced is ideally suited for recording rainfall events on a data recorder available at Argonne National Laboratory (ANL).[20]** The recording package is described later.

3. The rain gage (Figure D1) is installed at the experimental site atop a vertical, 8-in.-diam pipe of 8 ft length. This pipe provides a rigid mount for the rain gage and a convenient, tamper-proof housing for the electronic recording package used with the rain gage. The pipe is

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* EES Division, Argonne National Laboratory.

** Raised numerals refer to similarly numbered items at the end of the main text.

Figure D1. Rain Gage Atop Mounting Pipe, Thermistor Fixture to Right-hand Side buried approximately 4 ft deep in the middle of one of the dikes that separate the four experimental plots. Pipe extending above the ground is wrapped with aluminum foil (Figure D1) to keep a moderate temperature within the pipe containing the recording package.

4. The recording package was designed for use with water-current meters. It records on magnetic-tape cassettes and uses a commercially available digital-stepping cassette recorder (Memodyne Model 201) with conditioning electronics designed at Argonne. The recording package has one digital and two analog inputs available for use. The digital channel is designed to count sequential switch closures and is used to count events from the MRI tipping-bucket rain gage. One analog channel is used with a Yellow Springs Instrument type 44012 bead thermistor to record temperature. The electronics uses low-drain integrated circuitry which is powered by nine alkaline "D-cells" in series that provide a 12-V power supply. The recording package counts switch closures from the tipping-bucket rain gage for an 8-min period and records the total for the period on the cassette tape. Temperature is instantaneously sampled and recorded every 2 min during the 8-min sampling interval. Cassette tape capacity and battery life allow 3 months unattended operation at the 8-min sampling interval. The cassette tape is usually replaced monthly to ensure that the system is operating properly.

5. A cylindrical, polyvinyl chloride (PVC) waterproof vessel of 6-in. (152-mm) diameter and 20-in. length houses the recording package and battery. The vessel is provided with a waterproof, bulkhead-feedthrough connector that accepts the rain gage signal and temperature signal cables. This vessel is inserted in the rain gage mounting pipe described earlier and the rain gage is mounted atop the pipe. The thermistor is contained in a small, protective stainless steel tube molded to the end of a two-wire cable. The resulting temperature sensor is mounted on the side of the support pipe in a convection-aspirated mounting fixture (Figure D1).

Data Reduction and Display

6. Raw data recorded on the magnetic-tape cassette are transcribed at the laboratory onto seven-track magnetic tapes for reduction by Argonne's IBM model 370/195 computer. A computer program that contains the necessary calibration information allows the computer to reduce the raw data to a listed output and provides graphical plots of daily temperature variations and a plot for each 24-hr period (midnight-to-midnight) in which a rainfall event is recorded.

7. Temperature and rainfall data for the period 9 Aug 1978-20 Nov 1978 are available from the authors of this report. The temperature data are displayed as a continuous record (cf. Figure D2); rainfall data are presented only for those days that rainfall occurred (cf. Figure D3). (All of the rainfall data are plotted in Appendix E.)

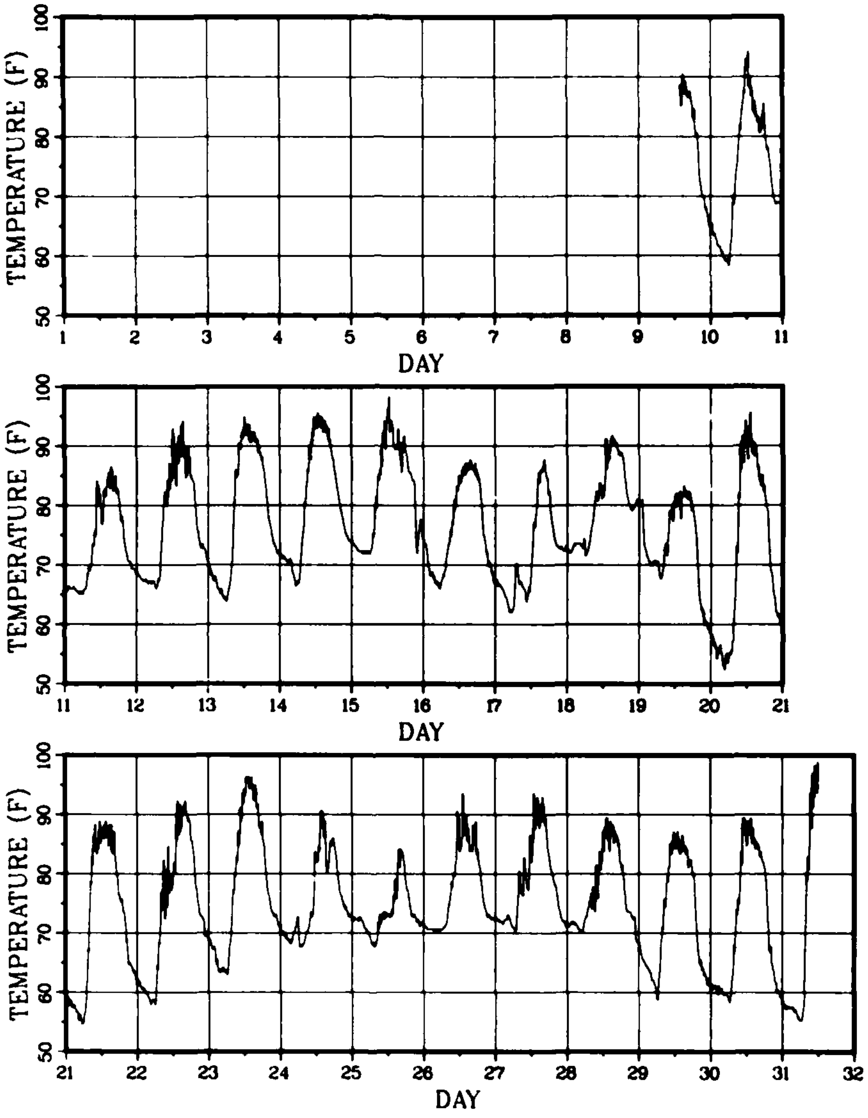

Figure D2. Temperature Record for August 1978

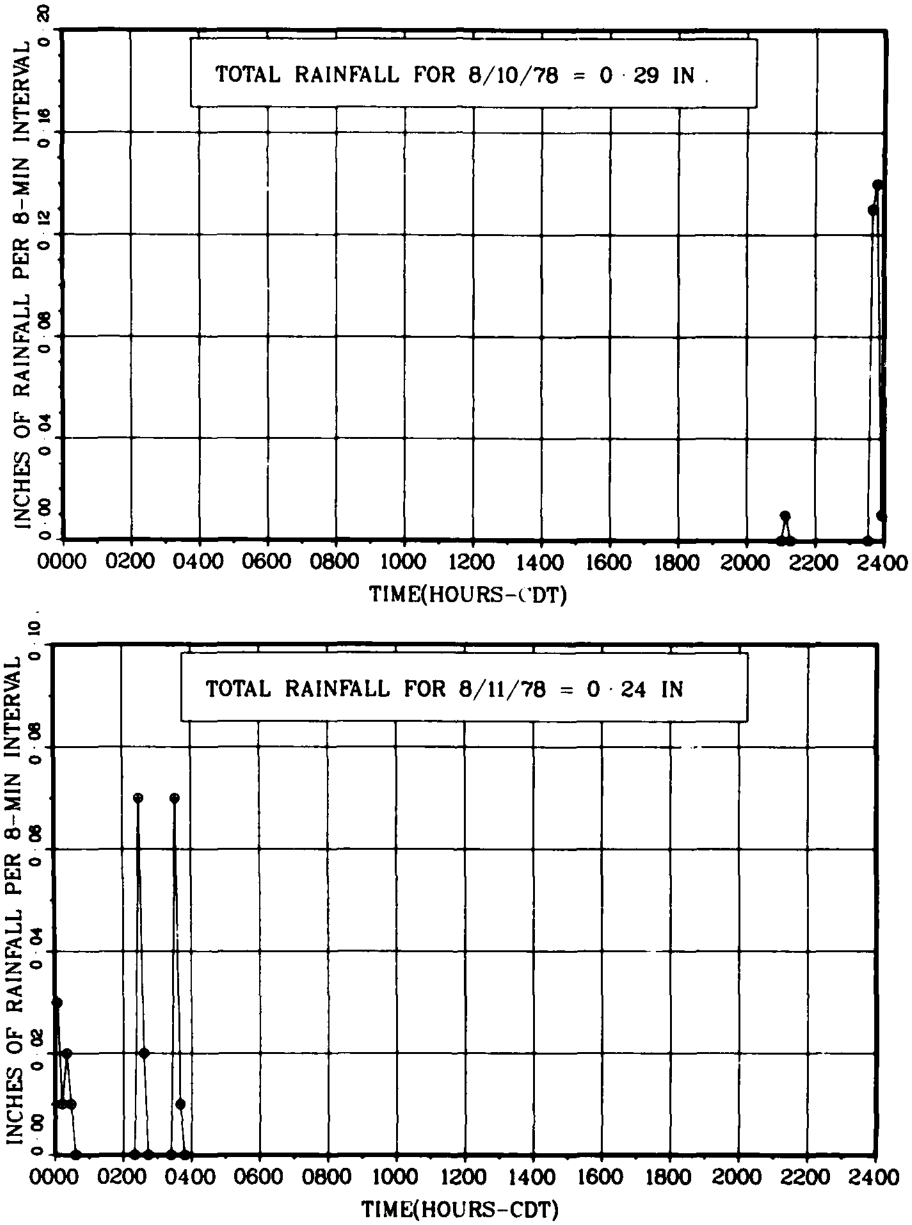

Figure D3. Rainfall Records for August 10 and 11, 1978

APPENDIX E: EQUIPMENT AND METHODS FOR MONITORING RUNOFF AND RAINFALL/RUNOFF DATA FOR THE PERIOD APRIL-NOVEMBER 1978

by

Conrad Tome*

Description of Runoff Monitoring Equipment

1. The Parshall flume[21]** is an empirically rated, channel-shaped device made of fiberglass. It has a converging section (entrance), a throat section (restriction for increasing the velocity), and a diverging section (exit). Along one side and integrated into the wall of the flume is a float well used to calm the water surface during turbulence at the measuring point. One significant advantage of the Parshall flume is that the high velocities created tend to make it a self-cleaning device by eliminating any deposition of solids or sediments that would adversely affect the measuring accuracy.

2. Four Parshall flumes were installed, leveled, and backfilled on two sides to make them an integral part of the dikes surrounding Plots I through IV. Later, a 3-ft concrete apron was laid in front of each flume to prevent runoff from undermining the structure. A short concrete ramp was emplaced also at the rear of each flume, followed by 5 ft of crushed stone (Figure E1) to prevent erosion on the downflow side of each flume.

3. Flow through the flumes is a function of water depth, and depth can be measured on a staff gage placed in the throat section. The depths are then referred to an appropriate rating curve or table to obtain water volume per unit time, here cubic feet per second.

4. To facilitate continuous monitoring, Stevens Type F water level recorders[22] were installed on each flume. They are self-contained,

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* EES Division, Argonne National Laboratory.

** Raised numbers refer to similarly numbered items at the end of the main text.

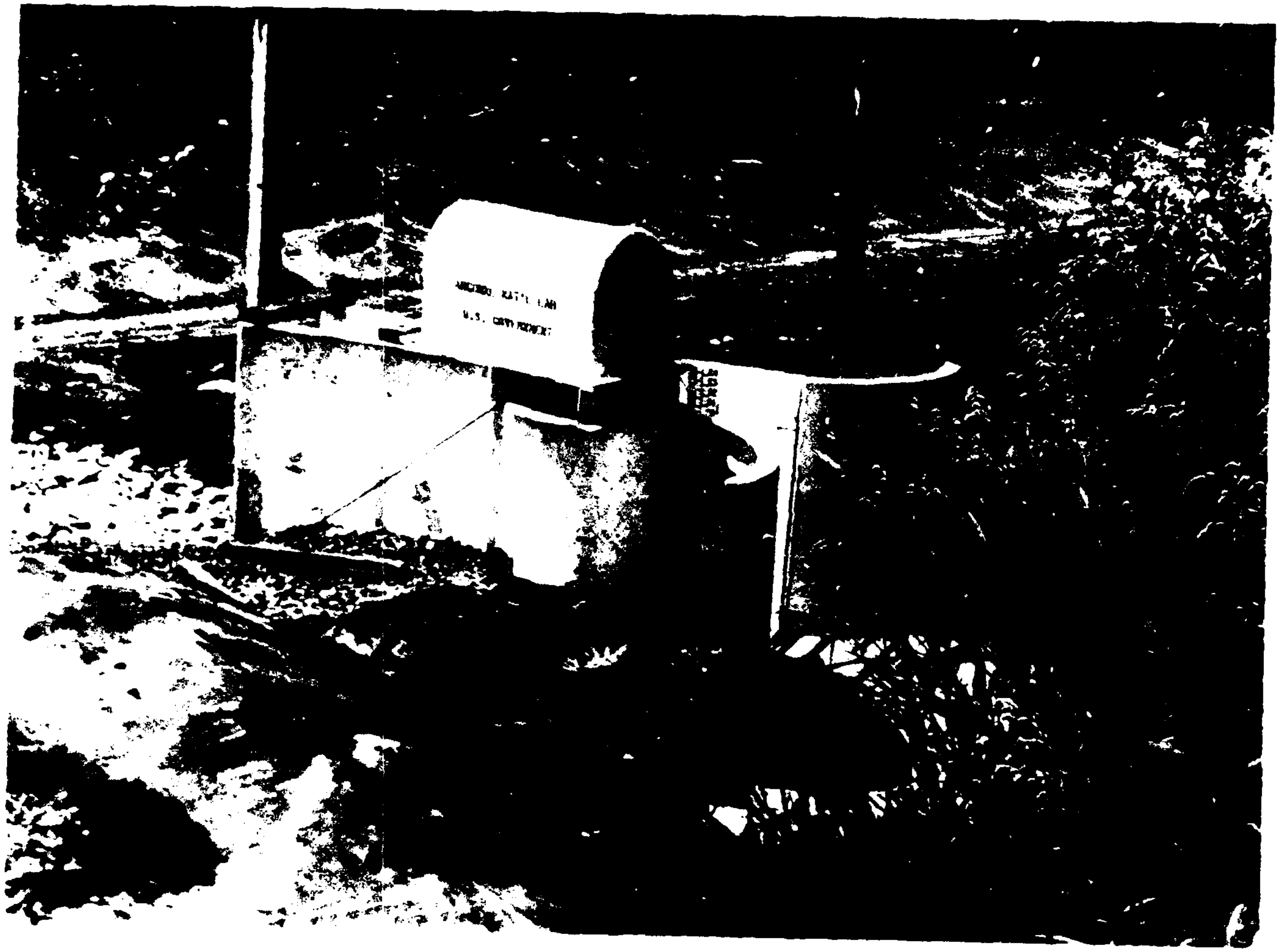

Figure E1. Flume at South Corner of Plot III. Water Flow from Right to Left. Steven Recorder Under Housing compact, portable, and independent of external power. The recorders were used to record the rise and fall of a float on a changing water level in the float well of the Parshall flume. A spring-wound clock drove the chart drum for 8 days while the chart permitted recording changes of as little as 0.01 ft.[23] Each recorder was protected from the weather and from vandals by a locked fiberglass enclosure on top of the float well. All clocks were wound once each week, new charts were installed, and the water levels were brought to the bottom of the measuring port in the float wells before setting the chart pens on zero. (Unfortunately, this last-mentioned procedure was not instituted until July 1978.) Data were recorded as depth of flow through the flume throat as a function of time.

Data Reduction and Presentation

5. Chart data were reduced by measuring the length of the spike in each runoff record and comparing this value to the table[22] to obtain the maximum instantaneous volumetric discharge during the runoff event. Only instantaneous runoff maxima are presented because oftentimes either initial or final chart zero were questionable. This problem was due primarily to the aforementioned failure to fill the float well when zeroing a new chart or to evaporative loss of float well water through time. Also, two recorders were vandalized and one recorder's clock malfunctioned for 2 months. For these reasons it was decided not to reduce the runoff data in terms of total runoff per event and to use only peak runoff flows for comparison with total rainfall data. Rainfall and runoff data are presented simultaneously, by months (April-November 1978), in Figures E1-E8, respectively.

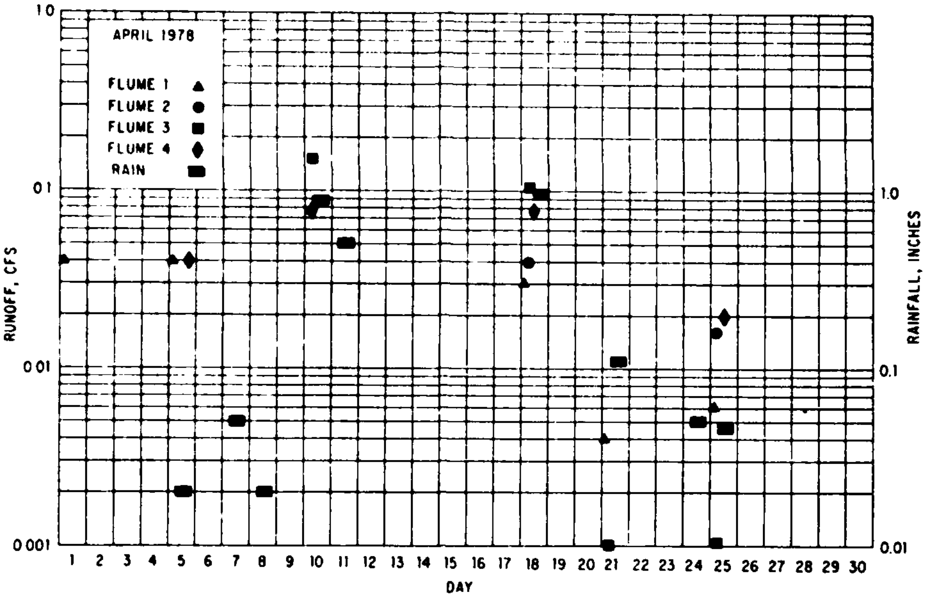

Figure E2. Rainfall and Runoff Data, April 1978

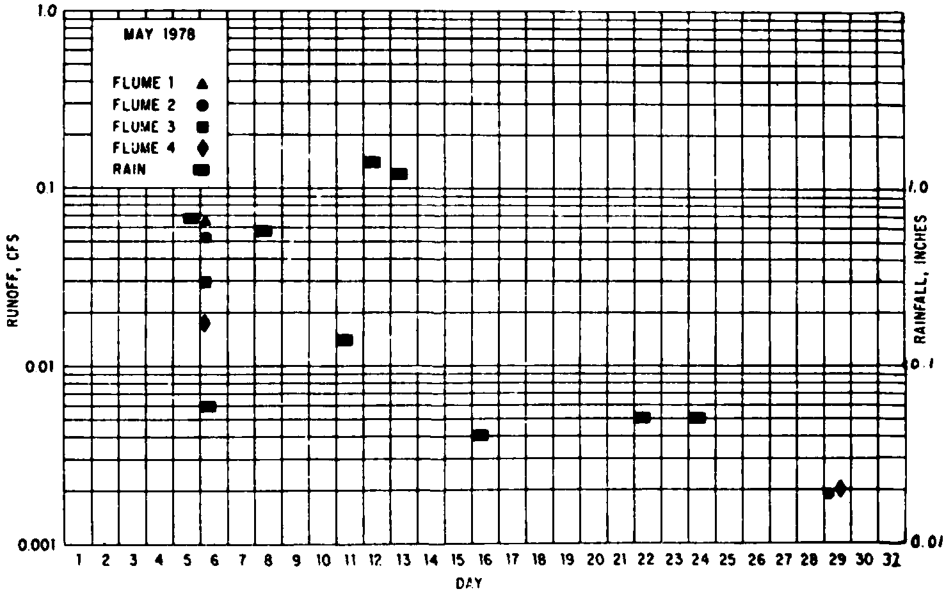

Figure E3. Rainfall and Runoff Data, May 1978

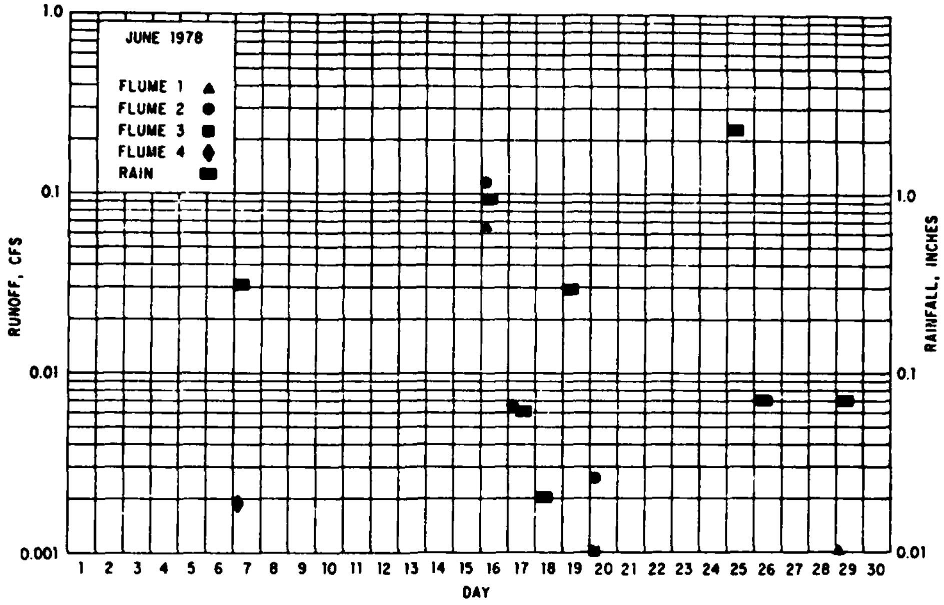

Figure E4. Rainfall and Runoff Data, June 1978

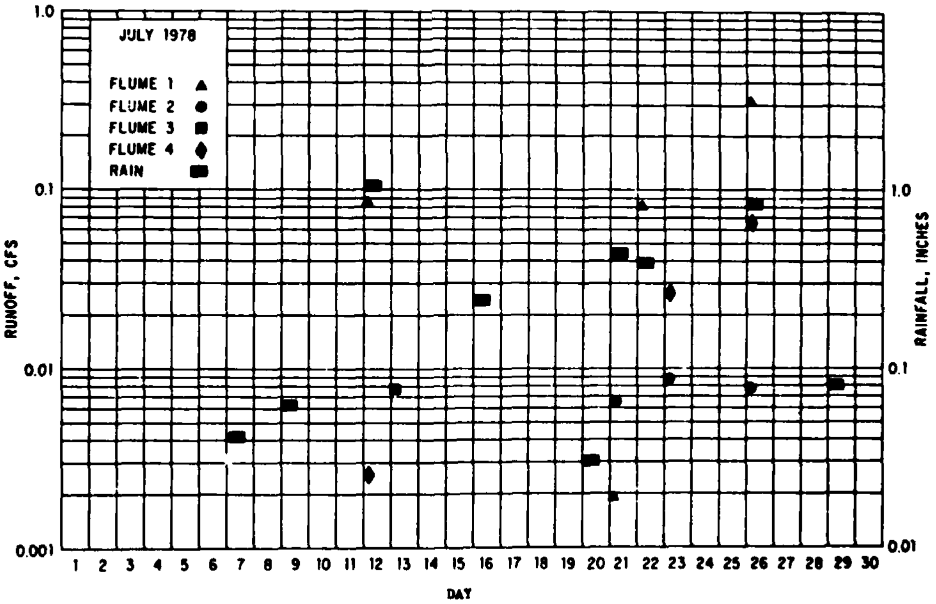

Figure E5. Rainfall and Runoff Data, July 1978

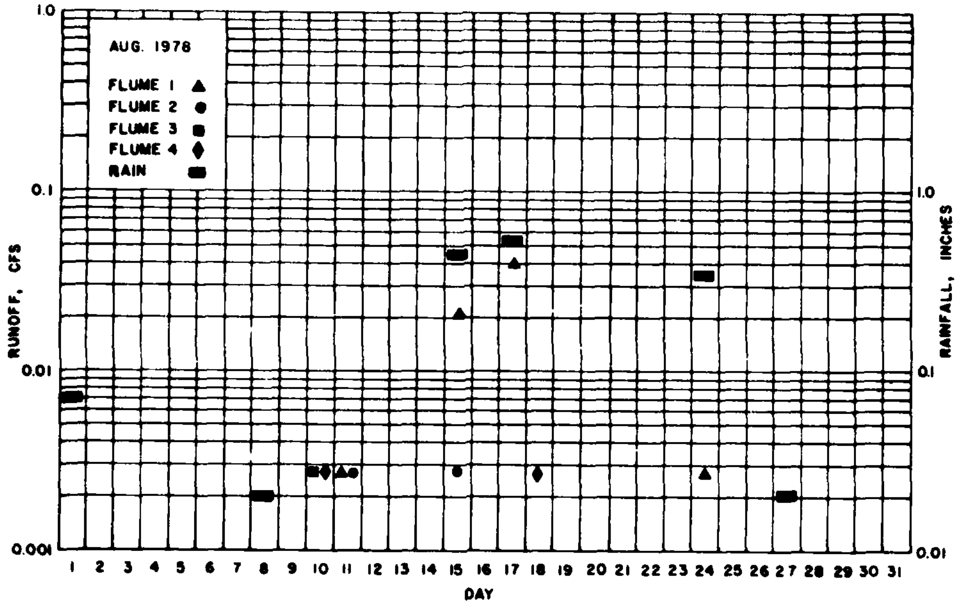

Figure E6. Rainfall and Runoff Data, August 1978

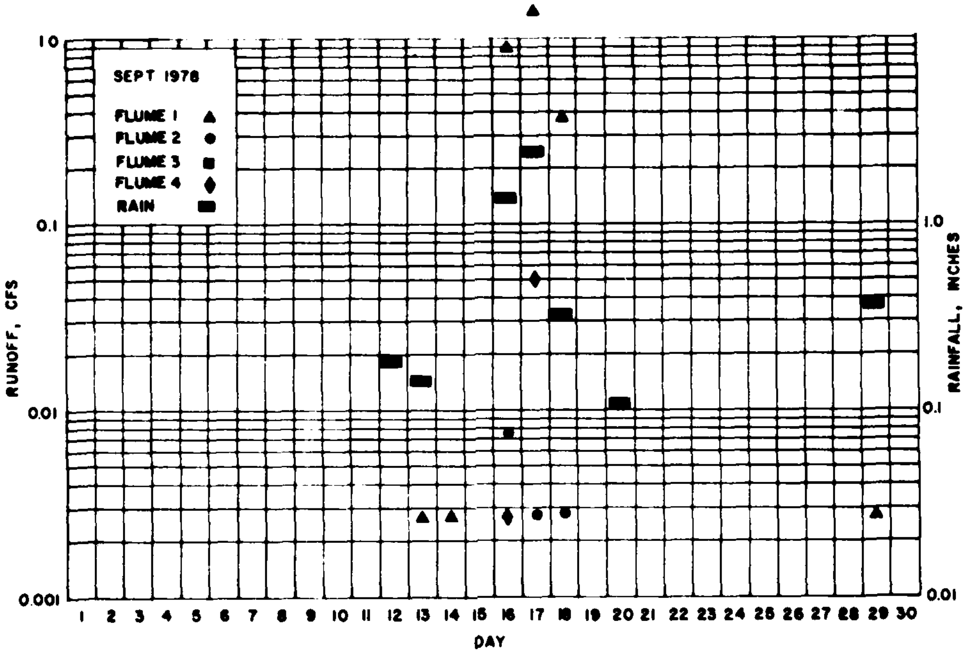

Figure E7. Rainfall and Runoff Data, September 1978

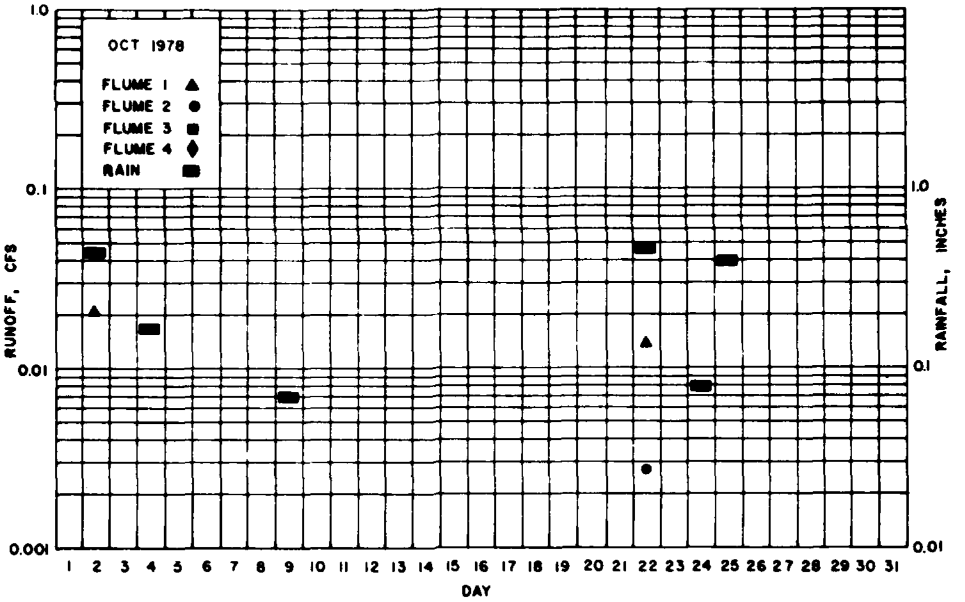

Figure E8. Rainfall and Runoff Data, October 1978

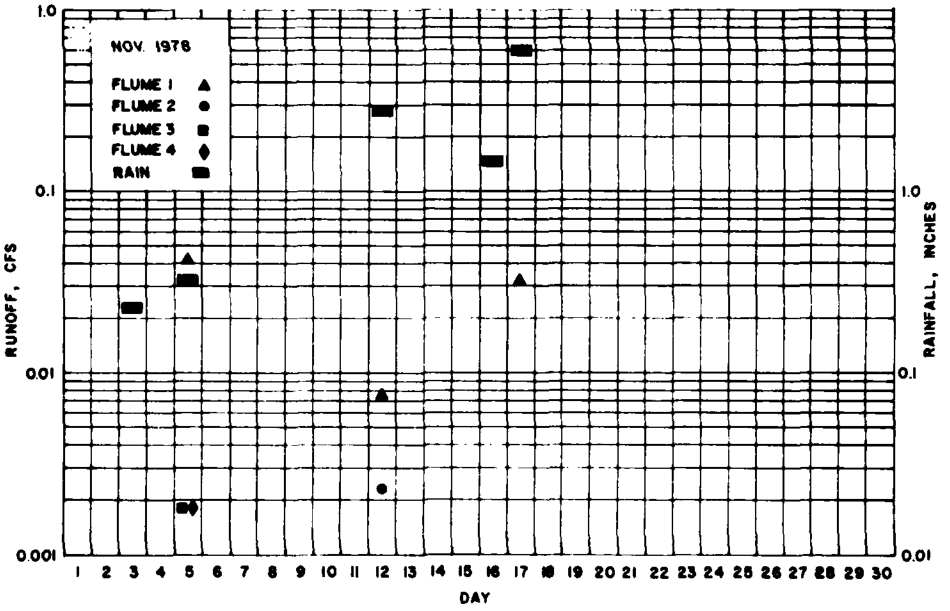

Figure E9. Rainfall and Runoff Data, November 1978

APPENDIX F:

ANALYSIS OF MINE SPOIL SAMPLES, BY THE PURDUE UNIVERSITY SOIL SURVEY LABORATORY

Particle-size distribution (mm), % of <2 mm

	total sand	vcs* 2-1	cs* 1-0.5	ms* 0.5-0.25	fs* 0.25-0.05	vfs* 0.25-0.10	silt 0.05-0.002	clay 0.002	fine silt
671	8.5	0.2	0.6	0.9	3.3	3.5	65.3	26.2	36.4
672	28.4	2.5	6.9	7.7	8.0	8.0	52.9	18.7	40.0
673	1.6	0.2	0.1	0.5	0.5	0.5	56.5	41.9	52.9
674	1.3	2.5	4.0	2.2	1.8	1.8	58.5	30.2	54.1

Extractable cations

	pH				(Meq/100 g)			Ext.	CEC†	Base Sat.	Org. C
	(1:1)**	KCl	$CaCl_2$	Ca	Mg	Na	K	Acid	(Sum)	(%)	(%)
671	2.8	2.5	2.7	0.9	13.5	0.01	0.02	40.6	55.03	26.2	0.74
672	2.5	2.1	2.4	7.9	21.0	0.01	0.01	35.7	64.62	44.8	7.62
673	2.7	2.4	2.7	8.6	16.9	0.03	0.02	23.1	48.65	52.5	0.64
674	3.6	3.1	3.5	9.4	3.1	0.38	0.02	10.9	23.8	54.2	0.65

671 Weathered material from bank of dry stream near Well #2.

672 Fresh Material with some lignitic coal, mostly gray shale, from cut in spoil banks ≃ 15 feet below surface.

673 Fresh material from ≃ 15 feet below surface in another spoil bank.

674 Weathered material from hilltop.

* vcs = very coarse sand; cs = coarse sand; ms = medium sand; fs = fine sand; vfs = very fine sand

** 1 part soil to 1 part distilled water, mixed and measured after equilibration.

† Cation exchange capacity.

APPENDIX G: CHEMISTRY OF MINE SPOIL SURFACE WATER BEFORE AND AFTER TREATMENT WITH DREDGED MATERIAL

Objective

1. The objective of this special study was to characterize chemically water standing at various places around and upon the experimental plots in order to assess the changes in surface water quality that could be expected after "topsoiling" with dredged material.

Investigative Method

2. The site had many small, closed basins that held water from rainfall or snowmelt for extended periods of time. In addition, there were groundwater seeps into the natural drainage pathways that were quite evident after surface runoff had ceased to flow through these channels. Also, water stood on each of the four treatment plots at the site for a few days after a rain.

3. A sampling was made at nine points (five of which are marked on Figure G1) of surface water ponding or seepage in early May 1978. Samples were taken in duplicate and analyzed for 23 parameters. The sampling points were:

1) the catchment below the access road before it reaches the treatment plots,
2) a small, deep basin just north of treatment Plot I,
3) a similar basin further north from the north end of treatment Plot I,
4) the basin between the graded area and the Well No. 1 basin, directly in line with Plot III,
5) a seep into the drainage directly west of Plot I, and
6 through 9) standing waters in treatment Plots I through IV, respectively.

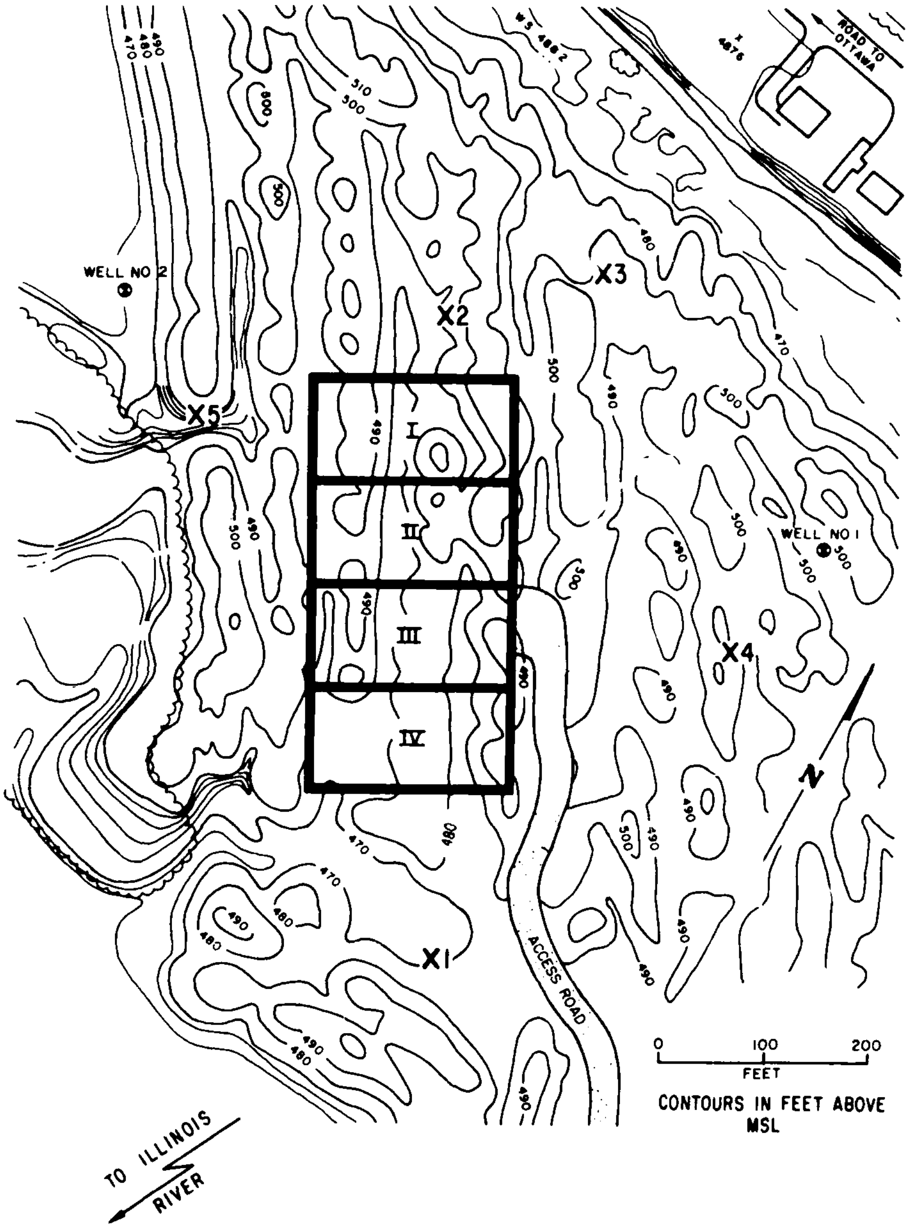

Figure G1. Surface Water Sampling Points

Results

4. The kinds of analyses made and the values obtained are reported in Table G1. Samples were taken in duplicate (a and b in Table G1).

Discussion

5. The data for collection points 1 through 4 are considered to represent water in long-term contact with the spoil materials, reflecting differences attributable only to areal variability. The data (Table G1) for waters at these points show clearly that they are of poor quality in terms of constituents and acidity.

6. The seep water data, collected at points 5a and 5b, describe the effect on soil water quality of slow leaching through a spoil pile. Although both man and animal eschew waters such as these by instinct, accidental ingestion is ever a possibility. The consequences of ingesting small amounts of these waters are not known.

7. It must also be considered that most of these waters do not reach the Illinois River without some dilution by precipitation or groundwater. Only the basin at collection point 1 was overflowing at sampling time. Waters collected at point 1 represent channel drainage from that basin.

8. The results for the treatment plots show a dramatic change between the waters standing on treated and untreated spoil. Waters from the treated plots (samples 7 a and b through 9 a and b) have a definite neutralizing capacity and, with the exception of Cd and Mo, trace metal loadings for the other mine metals analyzed were below flame atomic absorption detection limits. Only two and three values were detected for Cd and Mo, respectively, preventing the drawing of any definite conclusions about the concentrations of these two metals in the dredged material.

Table G1

Chemical Data for Duplicate Samples from Collection Sites 1-9 (Figure G1)

Sample No. / Parameter	1		2		3		4		5		6		7		8		9	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Acidity (ppm)	1427	1407	985	985	623	643	764	905	12,760	15,880	503	543	20.1	36.2	20.1	32.6	24.1	36.2
Alkalinity (ppm)	--	--	--	--	--	--	--	--	--	--	--	--	59.0	59.0	55.8	52.5	62.3	59.0
pH	2.95	2.90	2.50	2.50	2.62	2.62	2.62	2.60	2.15	2.10	2.90	2.90	7.30	7.45	7.62	7.65	7.65	7.70
EC x 10^3 (mmho)	3.37	3.06	2.15	2.04	1.70	1.60	1.93	1.87	8.87	9.28	1.61	1.52	0.83	0.84	0.86	0.88	1.17	1.16
PO_4 (ppm)	0.07		1.65		0.13		17.0		63.6		0.14		0.08		0.13		0.20	
SO_4 (ppm)	5500	3000	1300	1350	1150	1000	1175	1200	12,000	16,000	9500	2000	363	363	400	388	438	537
Cl^- (ppm)	6	<1	6	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ca^{++} (ppm)	172	173	107	108	76.0	74.1	68.3	71.1	36.2	28.0	78.7	80.2	118	121	128	134	179	180
Mg^{++} (ppm)	431	422	104	100	66.9	68.4	89.8	91.1	917	950	104	104	36.2	36.0	32.1	44.5	49.0	48.7
Sr^{++} (ppm)	<0.5	<0.5	<0.5	0.6	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Na^+ (ppm)	5.0	1.0	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	<1.	3.2	4.8	5.6	5.1	5.4	5.4
K^+ (ppm)	0.70	0.80	1.40	1.60	1.10	1.00	<0.5	<0.5	<0.5	<0.5	0.90	0.80	3.15	3.30	2.30	2.60	3.50	3.60
Zn (ppm)	2.07	1.83	0.62	0.56	0.33	0.25	0.38	0.30	8.79	11.6	1.02	0.38	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Co (ppm)	0.87	0.86	0.34	0.34	0.28	0.25	0.28	0.30	3.84	3.53	0.34	0.36	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd (ppm)	0.06	0.04	<0.02	<0.02	0.02	<0.02	0.02	<0.02	0.11	0.09	<0.02	0.04	0.09	<0.02	<0.02	<0.02	<0.02	0.04
Mo (ppm)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.09	<0.05	<0.05	<0.05	<0.05	0.08	<0.05	0.11	0.07
Cu (ppm)	0.17	0.17	0.22	0.17	0.11	0.11	0.11	0.11	2.76	3.12	0.11	0.11	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cr (ppm)	0.09	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.71	0.71	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ni (ppm)	1.88	1.77	0.90	0.90	0.79	0.79	0.79	0.79	7.00	7.65	0.79	1.00	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Pb (ppm)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Mn (ppm)	24.3	24.8	8.50	8.76	5.69	5.44	9.78	7.99	57.0	58.5	12.6	9.78	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Fe (ppm)	1.24	0.50	52.4	51.3	18.4	15.0	11.6	32.8	366.	383.	5.94	8.24	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Al (ppm)	135.	133.	84.0	88.3	53.2	55.1	70.9	73.7	462.	488.	46.9	45.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Conclusions

9. It may be concluded that grading the spoil materials at the Ottawa site would be beneficial because this action would eliminate the many basins and catchments that presently expose some very poor quality waters to the environment. It may also be concluded that waters standing on the dredged material are of acceptable quality relative to their environmental impact.

10. These two conclusions may be combined by stating that, from a surface water quality point of view, grading the mine spoil and covering it with dredged material of the type used in this instance would represent a desirable reclamation procedure for the Ottawa site. It is recognized, however, that the details of the engineering aspects of such a reclamation effort, and their possible impacts, remain to be worked out.

APPENDIX H: SOIL MOISTURE, ACIDITY, AND VARIATIONS IN PLANT GROWTH ON THE MINE SPOIL

Objective

1. The objective of this special study was to determine the small-scale areal variability of selected physical and chemical characteristics of the mine spoil.

Investigative Method

2. Investigation of differences in the spoil material was restricted to soil moisture determination, pH measurement, and a brief study of the oxidizable pyrites in the mine spoil. A 2-in. (51-mm) diam auger was used to core spoil and dredged material to a depth of 180 cm wherever possible. Soil moisture was determined gravimetrically and pH was measured on 1:5 soil:water extracts that had been shaken 36 hr.

Results

Visual reconnaisance

3. Three types of surficial mine spoil could be described visually:

a. Light-colored, silty, weakly structured material supporting plant growth.

b. Slightly darker, more clayey, and moderately structured material, usually with iron oxides evident on surface, and a few well-formed cubic pyrite crystals to be found with some effort, together with an occasional plant.

c. Dark-grey shaley material supporting no vegetation, not even around the erosion pathways. (This is the most eroded of the three types with much pyrite, in striated, conical form throughout.).

Moisture sampling

4. Soil moisture sampling was done in two areas:

a. A hill west of the demonstration site, where adjacent vegetated and nonvegetated areas were cored. Results, presented in Figure H1, show an essentially similar moisture content for the two profiles, with the obvious exception of a decrease in soil moisture attributable to uptake by vegetation. pH values were added to suggest a possible explanation for lack of vegetation on the bare soil. A few plants were successfully invading the bare soil in a few places.

b. Experimental Plots I and II cored to 180 cm in two places each. Results, with standard deviation for the two cores, are presented in Figure H2. The dredged material has significantly more water than the mine spoil and it supports profuse plant growth. The surface depletions may be attributed to evapotranspiration, with an obvious plant effect in the treated plot. The increase in moisture content below the dredged material/spoil interface may be a function of a large increase in matrix potential from the dredged material into the spoil, which could account for the small standard deviation for the moisture content values just above the interface (Figure H2) where moisture content would be controlled by the increased suction below the interface.

Chemical characterization

5. Soil water extractions of 1:5 were performed on the abovementioned cores as well as on cores taken from the hill just north of Well No. 1 (Figure 2, of main text) where the three spoil types occur side by side, as described previously. Since the species that could prove toxic to plant life are largely dependent on pH for their solubility and availability, pH is the most important chemical variable to be determined.

6. Figure H3 illustrates the pH variations observed for the cores taken from treatment Plots I and II. These values were obtained from 1:5 soil/water extracts shaken for 36 hr at room temperature.

7. Spoil acidity is an obvious problem. Dredged material uniformity is suggested by the near-constant pH values through its profile. Note the large pH variabilities in the untreated mine spoil profile. This variability, as described above, reflects the heterogeneity of the spoil material, with types 1, 2, and 3 (as previously described) overlying each other and being somewhat mixed in the profile.

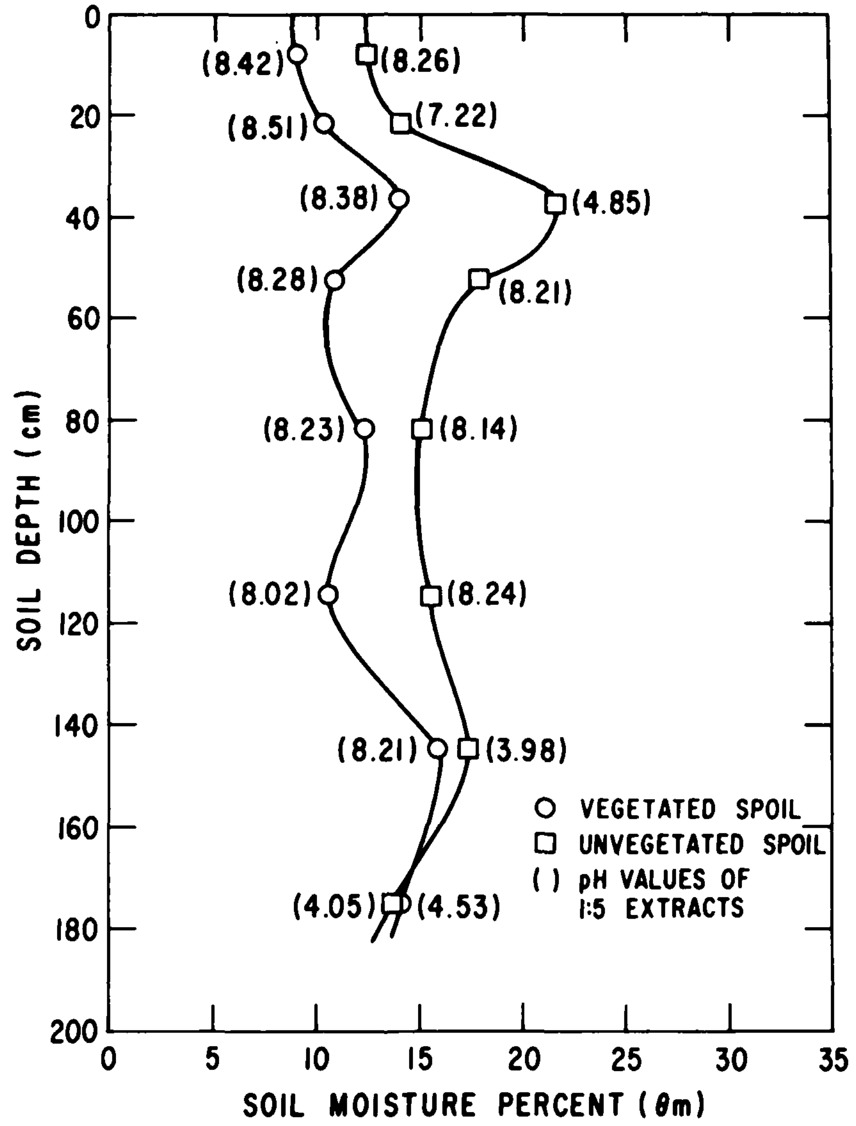

Figure H1. Soil Moisture Curves From Two Cores Taken Side By Side on a Spoil Hill Having Profuse Vegetative Cover Over One Portion and Being Bare Over the Other

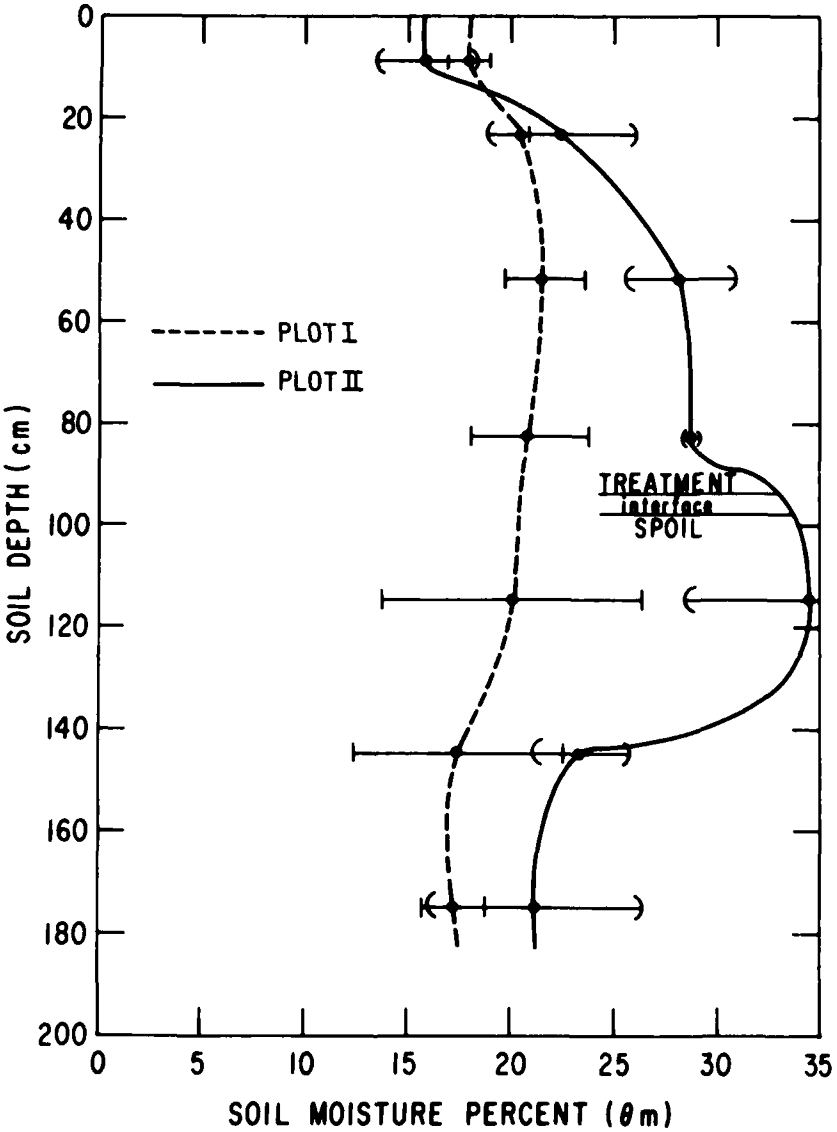

Figure H2. Soil moisture curves for Plots I and II. Average of two cores, ± standard deviation

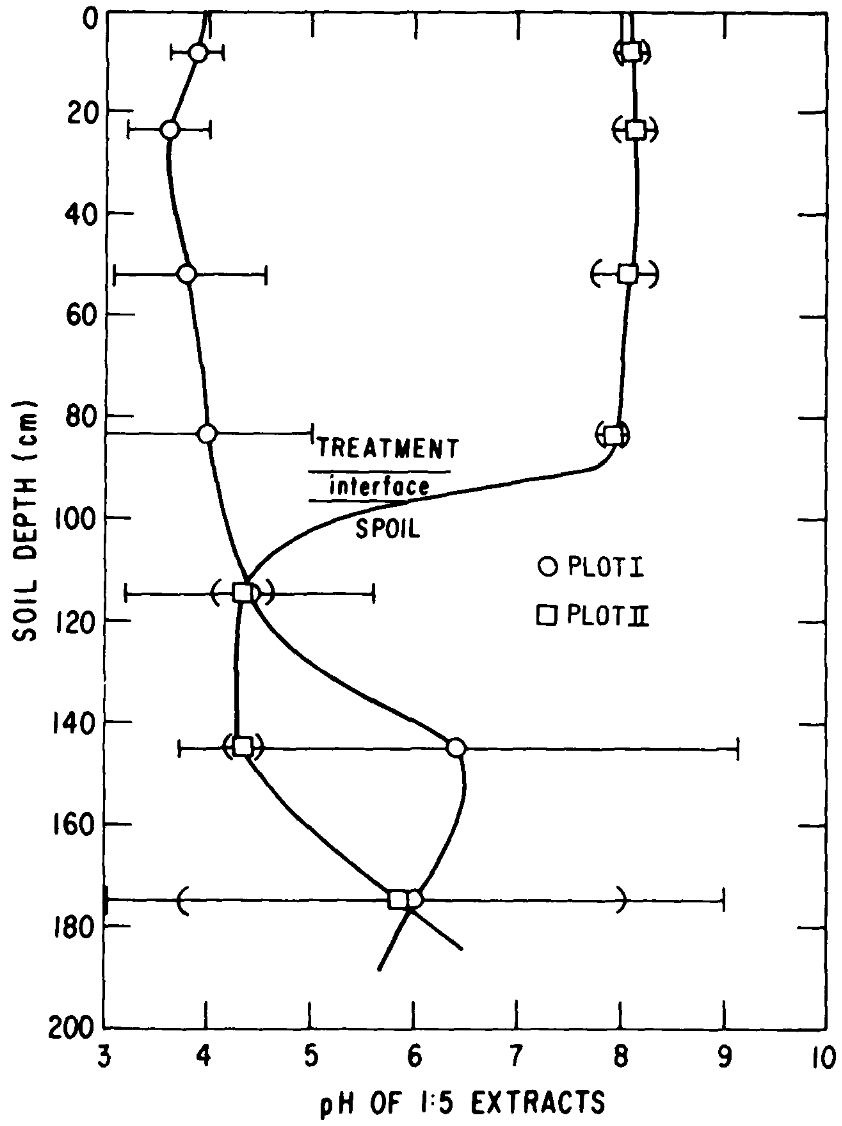

Figure H3. pH variation with depth for 1:5 soil/water extracts. Treatment Plots I and II

8. Figure H4 illustrates the 1:5 extract pH values for each core taken from the three types of mine spoil. The well-vegetated material overlies intermediate pH material, which in turn seems to overlie material of the same composition as the high pH spoil. The extremely low pH material seems to be rather uniform in this sampling. Such profiles are a strong function of sampling location.

9. Table H1 gives a comparison of the compositions of the two pyrite forms found, the cubic crystalline form and the striated conical form. Analyses were performed on 50 percent HNO_3 digests of each material as obtained from the field. Concentrations were normalized with respect to the iron content and expressed as mole ratios to allow qualitative comparisons of composition. This approach is an accepted method in the earth sciences and is used to discriminate between different geological formations or depositional environments.

Table H1

Normalized Molar Compositions of Two Forms of Pyrite Found at the Ottawa Strip Mine Reclamation Project Demonstration Site: A Well-Formed Cubic and a Striated Conical Form

	Concentration rank*		Normalized mole ratio	
Metal	Cubic	Conical	Cubic	Conical
Fe	1	1	1.000	1.000
Al	2	2	0.0167	0.0235
Mn	3	3	0.000743	0.00116
Ni	4	5	0.000172	0.000162
Cr	5	4	0.000124	0.000120
Zn	6	6	0.0000805	0.0000369
Cd	7	8	0.0000401	0.0000332
Cu	8	9	0.0000328	0.0000199
Pb	9	7	0.0000159	0.0000349

*Rank of mole ratios normalized with respect to the iron concentration.

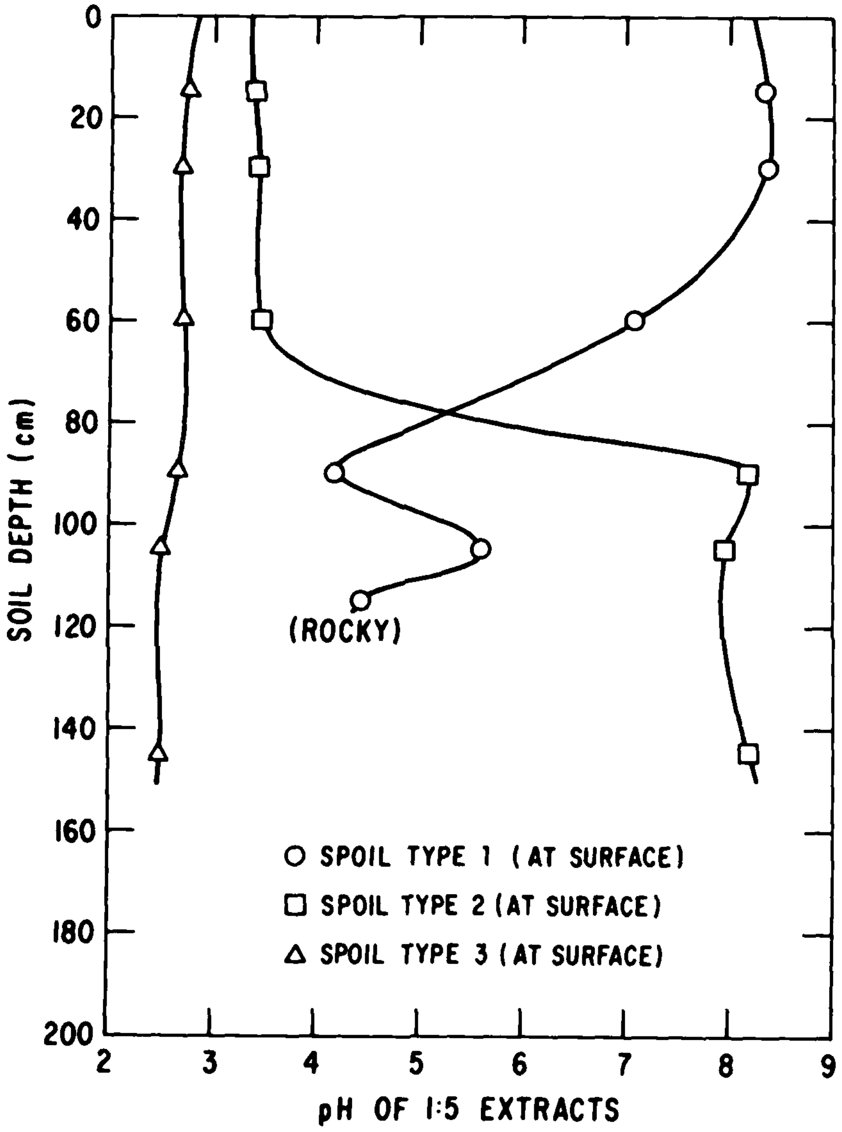

Figure H4. 1:5 Extract pH vs. Depth for Three Adjacent Spoil Types

10. It may be seen that the conical form has nearly twice as much Mn and that its Cu content is not quite one half that of the cubic form. All the metals listed may form sulfides, but it is unlikely that such an unstable sulfide form as Al_2S_3 would be found since it readily decomposes in contact with the atmosphere. These and others of the listed metals are, more likely, weathering products of the shales and clay minerals of the minesoils. Alkaline earths and alkali metals in these extracts were higher for the conical pyrite extracts: measurable amounts of Sr were found, and the Mg, K, Na, and Ca were 12, 4, 3 and 2 times more abundant in association with the conical vs. the cubic form of pyrite.

Conclusions

11. The presence of oxidizable pyrites in the mine spoil presents the real reclamation problem at this site. Regrading the mine spoil and covering it with dredged material, as was done for the study site treatment plots, does not affect the potential acidity of the spoil; however, this procedure does produce a change in the chemical composition, amount, and direction of flow of surface runoff and changes the subsurface water flow characteristics. These physical effects were partly illustrated in Figures H1 and H2. A cursory examination of these figures shows:

a. A general increase in profile moisture content for the spoil of treatment plot I as compared with the nontreatment plot spoils.

b. An apparent "perching" effect below the treatment application zone.

12. The visual reconnaisance and 1:5 extract pH results suggest that some segregation of materials may be possible during the cut-and-fill operation. Such segregation would allow some control over the texture and pH sequence in the replaced and regraded spoil profiles and hence over the groundwater flow and quality. Such measures may further assist in the long-term success of the dredged material cover treatment.

APPENDIX I: CHEMICAL CHARACTERISTICS OF CONTACT WATERS ON SPOIL AND DREDGED MATERIAL

Objective

1. The objective of this special study was to compare the chemistry of the three types of mine spoils (Appendix H) and the dredged material, as it affects the chemistry of 1:5 soil/water extracts with a 36-hr contact time.

Investigative Method

2. The extracts described in Appendix H of this subproject were separated from the soil solid phase by centrifugation and analyzed for pH, electrical conductivity (EC), chloride, sulfate, and the metals Ca, Mg, Na, Sr, K, Al, Fe, Mn, Zn, Cu, Ni, Cd, Pb, Cr, and Mo.

Results

3. Results are given in Tables I1, I2, and I3.

Discussion

Vegetated and unvegetated status of adjacent minesoils of similar appearance

4. The results of Table I1 do not provide an easy answer to the question of why vegetation is abundant on one core site and almost nonexistent on the other. Physical factors also may inhibit plant invasion at this site. The lower pH at the 37-cm sampling depth, with its attendant increase in soluble heavy metals, suggests a shallow lens of more acidic spoil at this depth. That an acidic spoil underlies the minesoil at both core sites is evident from the lower samplings.

Table I1

Chemical Data for 1:5 Soil/Water Extracts:

Comparison between Adjacent Cores Representing Vegetated and Unvegetated Minesoil

Sample Average Depth	pH 25°C	EC µmho/cm	Cl⁻ ppm	SO_4 ppm	Ca ppm	Mg ppm	Na ppm	Sr ppm	K ppm	Al ppm	Fe ppm	Mn ppm	Zn ppm	Cu ppm	Ni ppm	Cd ppm	Pb ppm	Cr ppm	Mo ppm
8 cm																			
VEGETATED	8.42	365.2	<2	27.0	59.2	12.3	3.3	0.6	13.6	<0.2	0.83	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
UNVEGETATED	8.26	1428.0	4	1140.0	358.0	65.1	7.3	0.5	9.8	<0.2	<0.5	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
24 cm																			
VEGETATED	8.51	345.8	9	17.8	48.3	13.4	2.7	<0.5	8.4	<0.2	1.32	<0.1	<0.02	<0.05	0.10	<0.02	<0.5	1.18	<0.05
UNVEGETATED	7.22	1917.6	2	1460.0	532.0	81.0	8.2	1.1	7.7	<0.2	<0.5	0.2	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
37 cm																			
VEGETATED	8.38	308.0	5	29.0	50.4	7.5	2.9	<0.5	7.8	<0.2	1.35	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
UNVEGETATED	4.85	1836.0	<1	1300.0	456.	81.4	6.0	0.8	10.4	6.89	6.81	10.9	0.45	<0.05	0.10	<0.02	<0.5	<0.1	<0.05
52 cm																			
VEGETATED	8.28	187.7	14	25.0	31.6	4.0	3.6	<0.5	6.1	<0.2	1.36	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
UNVEGETATED	8.21	856.8	<1	495.0	160.	36.9	3.4	<0.5	9.7	<0.2	<0.5	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
83 cm																			
VEGETATED	8.23	233.6	3	27.2	25.2	7.0	4.3	<0.5	5.6	<0.2	<0.5	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
UNVEGETATED	8.14	350.9	5	145.0	48.5	8.5	<0.3	<0.5	6.0	<0.2	0.72	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
115 cm																			
VEGETATED	8.02	170.3	2	20.2	14.4	2.6	3.4	<0.5	4.0	<0.2	<0.5	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
UNVEGETATED	8.24	389.6	9	139.0	45.4	18.2	<0.3	<0.5	7.8	<0.2	0.75	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
145 cm																			
VEGETATED	8.21	266.2	14	40.2	32.7	7.7	5.0	<0.5	3.6	0.32	<0.5	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	0.10
UNVEGETATED	3.98	1366.8	10	950.0	288.	48.0	0.6	0.5	15.3	3.19	0.88	<0.1	<0.02	<0.05	<0.10	<0.02	<0.5	<0.1	<0.05
175 cm																			
VEGETATED	4.53	2009.4	2	1580.0	636.	49.3	5.5	0.7	16.9	5.27	<0.5	<0.1	0.20	<0.05	1.13	<0.02	<0.5	1.28	<0.05
UNVEGETATED	4.05	1183.2	<1	670.0	203.	43.5	0.8	<0.5	14.8	4.67	0.70	0.5	0.03	<0.05	0.10	<0.02	<0.5	<0.1	<0.05

5. The very large difference in total dissolved salt loading for the surface samples is striking. From this it may be speculated that the two surface materials involved here differ only as to time of exposure to rainfall and leaching. Subsoil and parent material relationships could have existed for these two materials before mining took place.

Corings through the three major spoil types visually differentiated at the site

6. The most obvious difference between these three minesoils (Table I2) is their pH. The large differences in soluble salt content may reflect premining profile depths. For these 1:5 extracts it does not appear that any of the heavy metals would pose a threat to plants feeding on such a solution.

Treated vs. untreated comparisons

7. The previously presented data (esp. Table I2) offer a basis for judging the spoil in the untreated experimental plot (Table I3) to be closely related to the third (worst in terms of acidity production) spoil type characterized.

8. The treatment material seems relatively uniform with depth and areal availability, with the possible exception of Ni and Cd concentrations. Measuring Cd in only one of these extracts does not offer evidence of a Cd contribution by the dredged material, however. That single positive Cd result for the dredged material occurred in a near-surface sample that could have been contaminated by wind or water erosion of nearby spoil materials depositing over the dredged material.

9. The large Ni content in the "b" extracts represents close to 20 ppm of soluble nickel in the dredged material. The Mo concentration, which is significantly higher for the dredged material than for the mine spoil analyzed so far, may present an area of concern toward which continuing and future studies must be directed.

Table I2

Chemical Data for 1:5 Soil/Water Extracts:

Comparisons Between the Three Spoil Types Visually Differentiable at the Ottawa Reclamation Site

Average Sample Depth	pH 25°C	EC μmhos/cm	Cl⁻ ppm	SO_4 ppm	Ca ppm	Mg ppm	Na ppm	Sr ppm	K ppm	Al ppm	Fe ppm	Mn ppm	Zn ppm	Cu ppm	Ni ppm	Cd ppm	Pb ppm	Cr ppm	Mo ppm
15 cm																			
I (vegetated)	8.34	326.4	<1	189.	49.7	7.4	0.3	0.5	12.9	8.05	4.53	<0.1	<0.02	<0.05	<0.1	0.02	<0.5	<0.1	<0.05
II (unvegetated)	3.40	1467.8	1	925.	323.	11.1	<0.3	<0.5	3.4	32.2	0.93	<0.1	0.12	0.10	0.10	0.07	<0.5	<0.1	<0.05
III (pyritic shale)	2.76	3348.	2	2960.	376.	170.	<0.3	<0.5	<0.1	123.	23.1	5.40	1.49	0.56	1.90	0.06	<0.5	0.97	<0.05
30 cm																			
I	8.38	308.0	4	370.	56.3	6.8	<0.3	<0.5	13.6	3.65	3.36	<0.0	<0.02	<0.05	0.10	0.03	<0.5	<0.1	<0.05
II	3.44	2119.7	2	1800.	608.	13.7	<0.3	<0.5	5.7	44.2	1.27	<0.1	0.03	0.10	1.02	<0.02	<0.5	<0.1	<0.05
III	2.67	3804.5	1	3060.	356.	210.	<0.3	<0.5	<0.1	162.	42.6	4.26	1.91	0.75	2.52	0.03	<0.5	1.71	<0.05
60 cm																			
I	7.09	225.4	<1	100.	26.5	4.2	<0.3	<0.5	6.2	0.45	<0.5	<0.1	<0.02	<0.05	<0.1	<0.02	<0.5	<0.1	<0.05
II	3.46	1670.5	1	1330.	397.	15.3	<0.3	<0.5	5.3	5.64	1.21	<0.1	0.05	<0.05	0.10	0.05	<0.5	<0.1	<0.05
III	2.73	4599.6	3	5500.	286.	398.	<0.3	<0.5	<0.1	272.	92.3	13.4	3.79	1.50	4.28	0.06	<0.5	2.08	<0.05
90 cm																			
I	4.21	258.2	1	114.	22.4	3.8	<0.3	<0.5	7.2	0.64	<0.5	<0.1	<0.02	<0.05	<0.1	0.03	<0.5	<0.1	<0.05
II	8.19	1298.1	2	1020.	350.	48.4	<0.3	<0.5	9.7	0.22	0.80	<0.1	<0.02	<0.05	0.80	0.03	<0.5	<0.1	<0.05
III	2.66	5089.6	28	7150.	253.	604.	<0.3	0.5	<0.1	374.	86.2	18.6	5.58	2.15	4.51	0.09	<0.5	2.73	<0.05
105 cm																			
I	5.60	804.4	1	555.	164.	25.2	<0.3	<0.5	7.4	<0.2	1.07	0.10	<0.02	<0.05	0.50	0.03	<0.5	<0.1	<0.05
II	7.96	346.9	1	159.	288.	22.5	<0.3	<0.5	9.7	0.82	0.73	<0.1	<0.02	<0.05	<0.1	0.04	<0.5	<0.1	<0.05
III	2.50	5840.8	4	8500.	179.	600.	<0.3	<0.6	<0.1	517.	123.	18.1	8.31	2.71	4.67	<0.02	<0.5	2.73	<0.05
115 cm																			
I	4.45	889.6	<1	575.	192.	19.1	0.3	<0.03	12.5	0.82	0.71	0.20	<0.02	<0.05	1.10	0.03	<0.5	<0.1	<0.05
no sample taken																			
no sample taken																			
145 cm																			
no sample taken																			
II	8.18	347.8	<1	134.	254.	22.9	<0.3	<0.5	15.2	<0.2	0.65	<0.1	<0.02	<0.05	0.10	<0.02	<0.5	<0.1	0.05
III	2.48	5527.8	10	2960.	190.	600.	<0.3	<0.5	<0.1	415.	143.	16.6	6.42	2.34	5.28	0.02	<0.5	1.19	<0.05

Table 13

Chemical Data for 1:5 Soil/Water Extracts: Comparisons for Cores from an Untreated Experimental Plot (I) and a Plot Receiving Dredged Material Only (II). Replications Shown Represent South Central (a) and North Central (b) Locations Within Each Plot

Average Sample Depth and Identification by Treatment Plot and Location Within Plot	pH 25°C	EC µmhos/cm	Cl^- ppm	SO_4 ppm	Ca ppm	Mg ppm	Na ppm	Sr ppm	K ppm	Al ppm
9 cm										
I a	3.67	2254	<1	1850	403	210	<0.3	0.6	6.6	49.6
I b	4.09	2019	<1	1640	482	102	<0.3	<0.5	7.8	28.7
II a	7.98	1713	4	930	461	59.2	6.2	0.7	1.4	<0.2
II b	8.25	1468	5	800	403	50.2	4.9	<0.5	1.3	<0.2
24 cm										
I a	3.35	2998	<1	1940	392	324	<0.3	0.7	2.5	149
I b	3.80	2142	1	1800	482	180	0.9	<0.5	6.1	39.4
II a	8.03	1570	1	1000	407	51.8	6.0	<0.5	2.1	<0.2
II b	8.25	1570	2	930	425	50.0	4.4	<0.5	1.8	<0.2
53 cm										
I a	3.22	3488	<1	3160	413	436	<0.3	0.8	<0.1	140
I b	4.29	2488	1	1790	572	297	2.1	0.5	10.0	23.8
II a	7.88	1468	3	750	383	47.8	5.4	<0.5	4.5	<0.2
II b	8.29	1468	4	1100	383	50.2	4.8	<0.5	4.1	<0.2
85 cm										
I a	3.34	3172	<1	2620	405	401	<0.3	1.2	5.8	75.2
I b	4.64	3172	<1	2910	516	453	1.5	<0.5	6.4	38.3
II a	8.08	1305	3	670	314	33.4	3.4	<0.5	3.3	<0.2
II b	7.95	1285	<1	550	327	35.6	3.6	<0.5	3.3	1.61
115 cm										
I a	5.28	2162	<1	1700	362	172	6.1	<0.5	13.3	0.60
I b	3.54	2784	2	1870	406	318	<0.3	<0.5	<0.1	138
II a	8.13	1489	4	750	368	40.8	4.9	<0.5	2.6	<0.2
II b	7.75	1734	1	1200	479	72.3	3.0	<0.5	3.0	1.61
145 cm										
I a	8.34	534	<1	405	681	470	14.3	<0.5	16.4	<0.2
I b	4.51	2560	4	1720	575	363	2.2	<0.5	10.0	15.5
II a	4.23	3121	2	2360	511	367	<0.3	0.5	<0.1	114
II b	4.47	3406	2	3100	486	506	<0.3	<0.5	5.7	1.29
175 cm										
I a	8.19	577	4	194	443	355	16.9	<0.5	10.2	<0.2
I b	3.89	3039	3	2340	589	234	7.8	0.5	8.9	20.6
II a	4.36	3223	1	2560	480	439	<0.3	<0.5	2.5	73.2
II b	7.40	1723	2	3120	139	233	6.9	0.6	19.8	0.92

(continued)

Table I3 (Concluded)

Average Sample Depth and Identification by Treatment Plot and Location Within Plot	Fe ppm	Mn ppm	Zn ppm	Cu ppm	Ni ppm	Cd ppm	Pb ppm	Cr ppm	Mo ppm
9 cm									
I a	2.96	7.00	0.88	0.10	0.98	<0.02	<0.5	2.32	0.05
I b	0.75	4.17	0.63	<0.05	0.20	<0.02	<0.5	<0.1	0.10
II a	<0.1	<0.1	0.52	<0.05	<0.1	<0.02	<0.5	<0.1	0.13
II b	<0.1	<0.1	0.45	<0.05	4.5	0.04	<0.5	<0.1	0.19
24 cm									
I a	9.76	10.2	1.50	0.30	1.52	0.03	<0.5	1.80	<0.05
I b	1.15	5.23	0.76	0.10	0.95	<0.02	<0.5	1.52	<0.05
II a	<0.1	<0.1	0.44	<0.05	<0.1	<0.02	<0.5	<0.1	0.13
II b	<0.1	<0.1	0.35	<0.05	4.6	<0.02	<0.5	<0.1	0.21
53 cm									
I a	4.44	12.6	1.01	0.30	1.52	0.03	<0.5	<0.1	0.05
I b	1.32	10.6	0.53	<0.05	0.35	0.05	<0.5	1.85	<0.05
II a	<0.1	<0.1	0.48	<0.05	1.6	<0.02	<0.5	<0.1	0.25
II b	<0.1	<0.1	0.37	<0.05	4.7	<0.02	<0.5	<0.1	0.13
85 cm									
I a	2.25	11.0	0.74	0.20	1.40	<0.02	<0.5	<0.1	<0.05
I b	0.60	19.0	0.53	<0.05	0.56	0.05	<0.5	<0.1	<0.05
II a	<0.1	<0.1	0.29	<0.05	3.3	<0.02	<0.5	<0.1	0.29
II b	2.49	<0.1	0.74	<0.05	3.4	<0.02	<0.5	<0.1	0.10
115 cm									
I a	1.70	4.96	<0.02	<0.05	<0.05	<0.02	<0.5	1.33	<0.05
I b	34.0	10.2	3.00	0.40	2.63	0.05	<0.5	<0.1	<0.05
II a	<0.1	<0.1	0.30	<0.05	3.4	<0.02	<0.5	<0.1	0.21
II b	2.94	<0.1	0.55	<0.05	1.7	<0.02	<0.5	<0.1	0.10
145 cm									
I a	0.80	<0.1	<0.02	<0.05	<0.05	<0.02	<0.5	<0.1	<0.05
I b	0.83	11.4	0.37	<0.05	<0.05	0.05	<0.5	<0.1	<0.05
II a	15.2	12.0	3.52	0.30	5.5	<0.02	<0.5	<0.1	<0.05
II b	2.01	<0.1	0.27	<0.05	3.0	<0.02	<0.5	<0.1	<0.05
175 cm									
I a	<0.5	<0.1	<0.02	<0.05	<0.05	<0.02	<0.5	<0.1	<0.05
I b	1.29	14.0	0.20	<0.05	0.83	<0.02	<0.5	<0.1	<0.05
II a	3.22	15.0	2.20	0.10	6.1	<0.02	<0.5	<0.1	<0.05
II b	1.11	<0.1	0.59	<0.05	2.7	0.02	<0.5	<0.1	<0.05

Conclusions

10. From the three data tables presented, it may be concluded that acid production by oxidation of pyrite and other reduced sulfur minerals presents the single most important problem for the reclamation of this site.

11. Addition of an 0.9-m dredged material cover allows plant growth and provides a surface of above neutral pH, with a higher Mo content than was observed in the spoil (see Table I3). If the land after dredged material covering becomes a grazing area, the Mo elevation in the soil solution could present a problem.

APPENDIX J: SITE GEOHYDROLOGY

by

T. A. Bannister and T. R. West*

Site Location and Background

1. The study site is an abandoned coal and clay strip mine located in the SE¼ and center of section 7, and the SW¼ and center of section 8, T33N, R4E, Rutland Township, approximately 1.5 miles east of Ottawa, Illinois.

2. One of the main reasons for mining coal at this location was its location on a river-cut terrace. There is no till at this site and the overburden consists of a low refractory shale, the Francis Creek shale that could be of minor use in industry.

3. The Wilmington Coal Company initiated mining at this site in 1936. Operations were somewhat erratic through the years and mining ceased by 1942. In addition, the National Fireproofing Company had an interest in the area because of the underclay directly beneath the coal. This clay is generally of high refractory value (except where pyrite-rich) and it proved to be much more valuable than the Francis Creek shale that makes up the overburden to the coal.[24]** Unfortunately, the material in the stratigraphic section that was left behind as waste by the coal and clay companies is also the material that causes the most environmental problems. On the basis of field observation, it is concluded that the waste piles in approximately the northwest quarter of the area shown on Figure J1 contain waste fireclay (underclay) and hence the underclay was mined out there to a large extent. The bottom of the mine is only a thin remnant of this underclay, overlying the St. Peter

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** Raised numerals refer to similarly numbered items at the end of the main text.

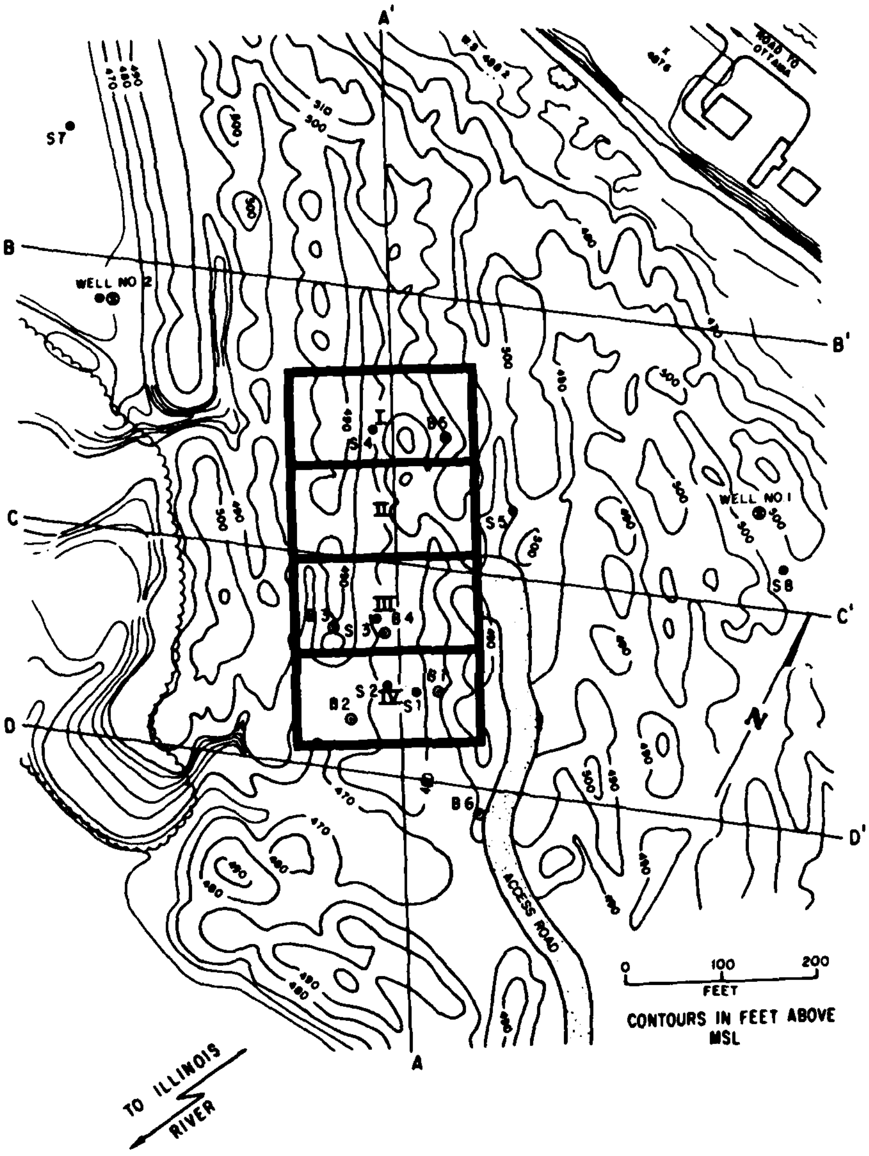

Figure J1. Initial site topography, cross section lines A-A' through D-D' (Figure J2), groundwater observation wells, and test plots (superimposed). Boring locations are indicated by B1 through B6; electrical soundings indicated by S1 through S8

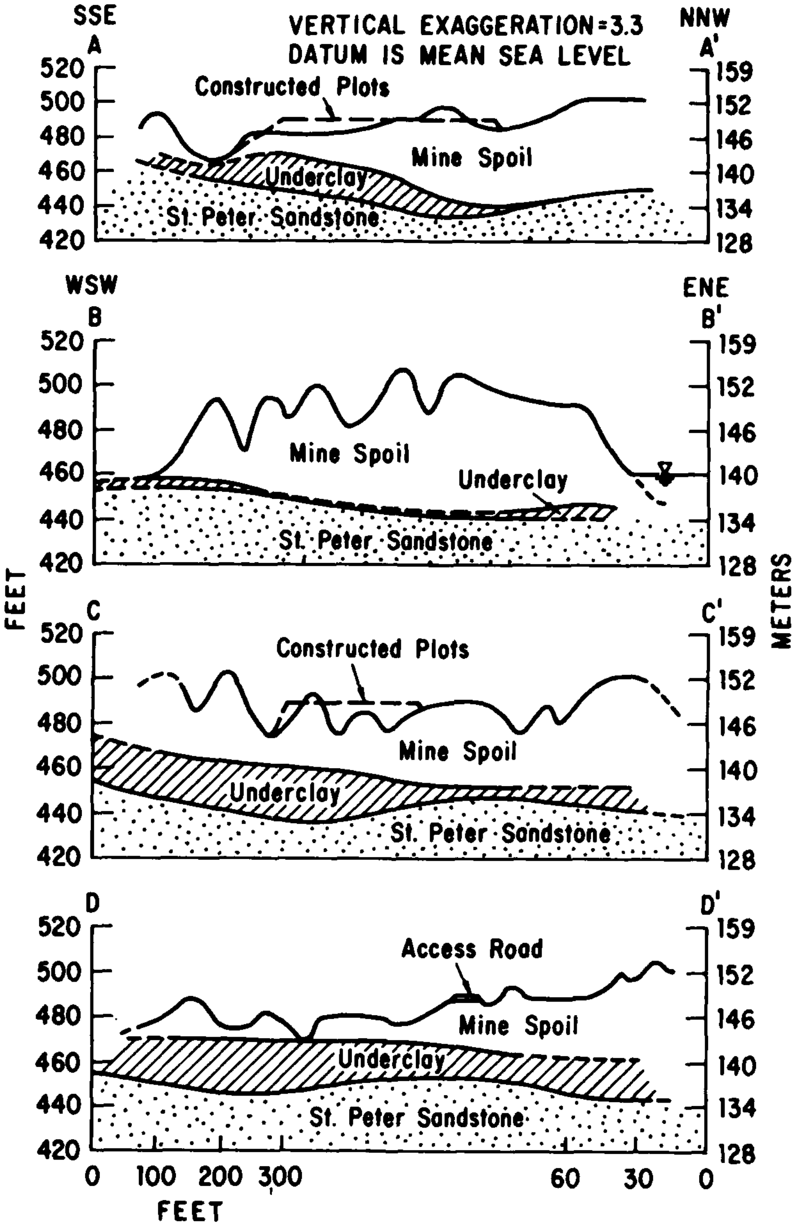

Figure J2. Cross sections A-A' through D-D' of Figure J1 sandstone. On the other hand, the area covered by the southeast quarter of Figure J1 has only been worked for the coal. The underclay is still intact below the waste piles.

Drilling, Sampling, and Electrical Resistivity Sounding Program

4. A commercial engineering firm was hired to do the drilling, and sampling was accomplished on 18, 21, and 22 August 1978.

5. Figure J1 shows the locations of the six borings that were made. An all-terrain-vehicle (ATV) was used to facilitate movement over the steep berms that separated the test plots and to navigate the rugged strip-mined terrain. Borings were advanced with a 10-in., hollow-stem auger. Sampling was accomplished with a standard split-spoon sampler and a pushed, thin-walled steel cylinder (Shelby tube).

6. The following schedule lists the samples taken at each boring location (Figure J1):

B1 through B3: Continuous split-spoon samples (1.5-ft intervals to a depth of 13.5 ft. (N-values and percent recovery recorded for each sampling.) Two undisturbed samples were taken with a Shelby tube sampler at depths of 1 to 3 ft and 5 to 7 ft (except for B3; second Shelby tube sample taken 7 to 9 ft).

B4: Continuous split-spoon samples to a depth of 9.0 ft. Split-spoon samples at depths 10.5 to 12.0 ft, 14.5 to 16.0 ft, 19.5 to 21.0 ft, 24.5 to 26.0 ft, and 28.5 to 30.0 ft. One Shelby tube sample taken at a depth of 5.0 to 7.0 ft.

B5: Continuous split-spoon samples to a depth of 12.0 ft. Two Shelby tube samples taken at 1.0 to 3.0 and 5.0 to 7.0 ft.

B6: Split-spoon samples taken at 4.5 to 6.0 ft, 9.5 to 11.0 ft, and 13.5 to 15.0 ft. Water intercepted at 14.0 ft; polyvinyl chloride (PVC) pipe observation well set at 14.5 ft.

7. Information that was immediately gathered from the above program included standard penetration N-values and descriptions of the material encountered in each boring. Soil logs for each boring are given in Bannister's thesis.[25]

8. Earth electrical resistivity soundings were made at points S1 through S8 (Figure J1) around the site. The original purpose of the soundings was to delineate the free (phreatic) water surface. Subsequent interpretation led to the conclusion that the free surface was not discernable with this method. However, the data permitted delineation of the surface of the St. Peter sandstone and, to some extent, the bottom of the mine.

9. Details of the interpretations of the borings and resistivity data are given by Bannister.[25] Figure J2 presents four cross sections of the site (along the cross section lines of Figure J1) that summarize the major stratigraphic interpretations of the boring and resistivity data.

Natural Moisture Contents

10. The first tests performed were to determine the natural moisture contents of the samples. Results in Figures J3-J5 are plotted versus depth to give a picture of the vertical variations in moisture content. The moisture contents were determined for the split-spoon samples (disturbed specimens). Since natural moisture contents are typically not derived from disturbed samples (unless immediately after sample collection), the relative moisture contents are of primary interest here. A trend emerges from the data of Figures J3-J5. The moisture contents generally decrease with depth, except for localized points of higher or lower moisture.

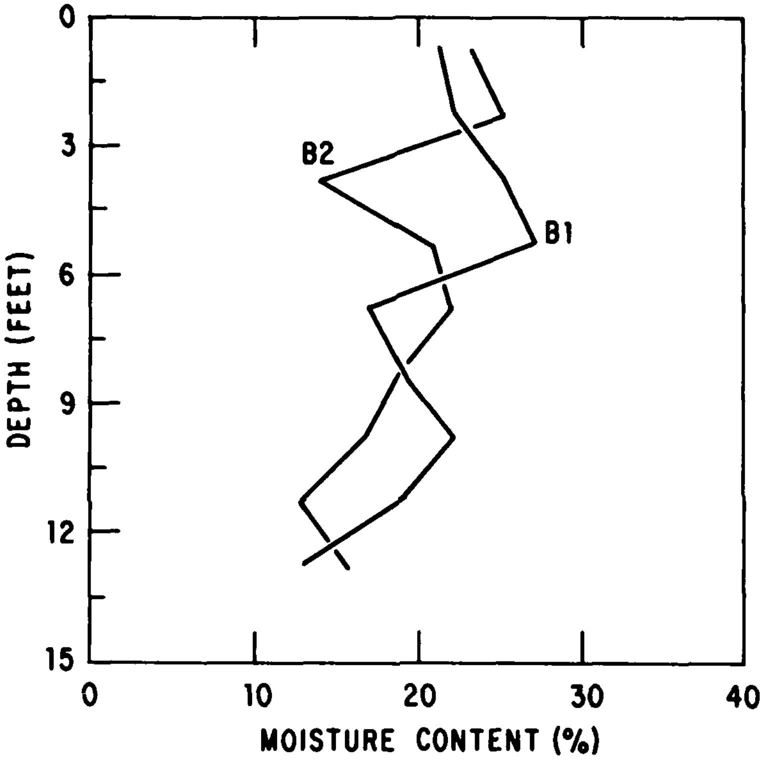

Figure J3. Natural moisture content as a function of depth in borings B1 and B2

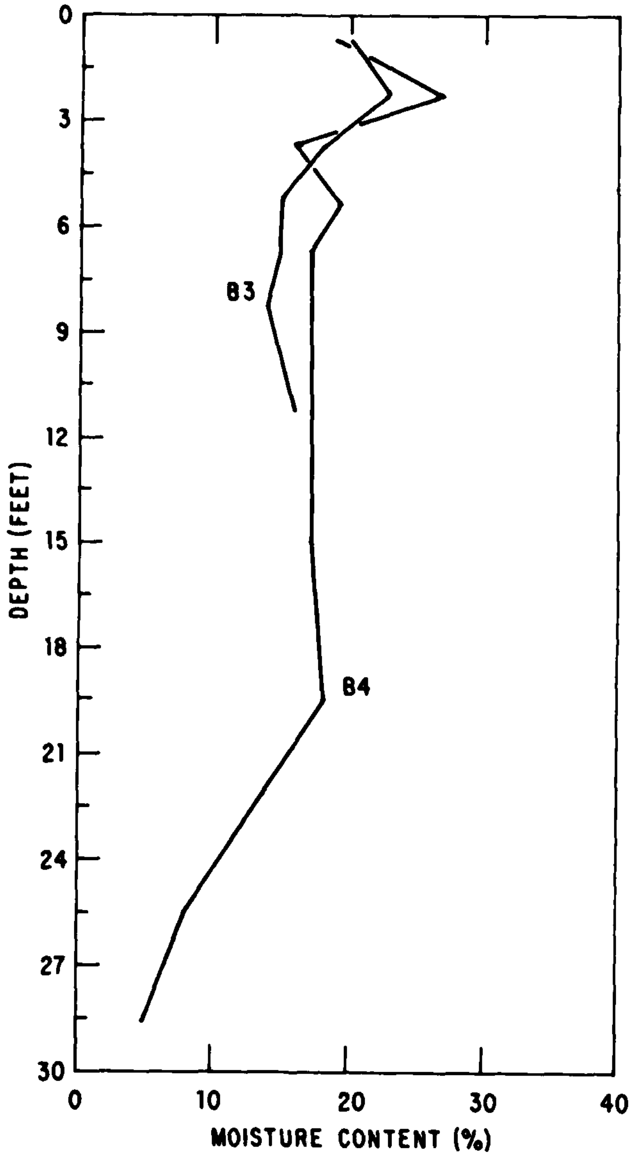

Figure J4. Natural moisture content as a function of depth in borings B3 and B4

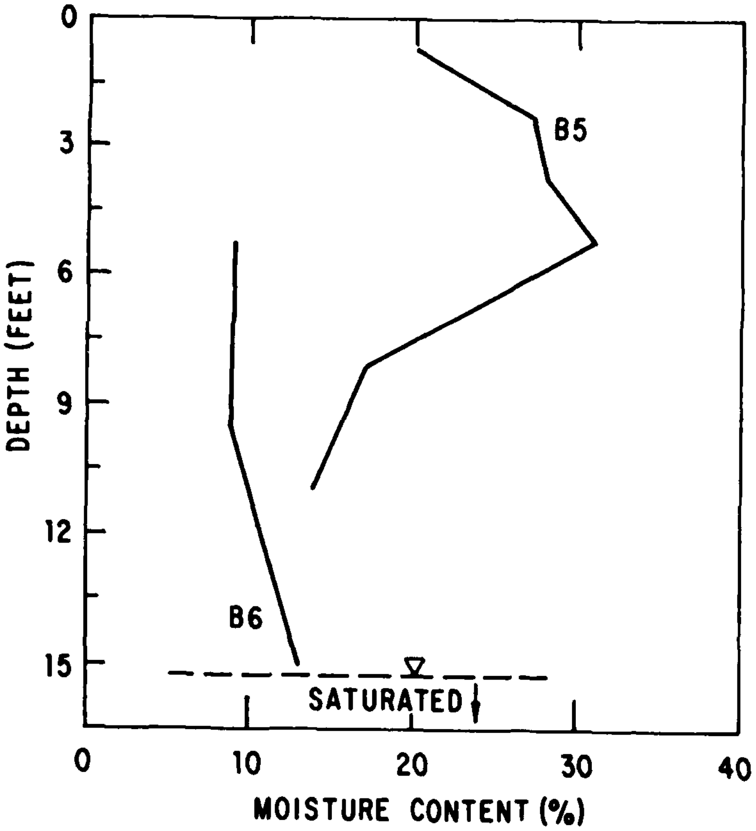

Figure J5. Natural moisture content as a function of depth in borings B5 and B6

Site Hydrology

11. The Illinois River, only 300 ft (91 m) away from the site, will have a major influence on local hydrology. The river's normal pool elevation is 460 ft (140 m) above mean sea level, with its maximum high at 472 ft (144 m) and minimum low at 452 ft (138 m). The pond marking the final cut on the east border of the site usually stands at an elevation of about 460 ft (140 m), the same elevation as the Illinois River. Another controlling factor is the permeability of the mine waste material which, with a relatively impermeable surface crust, prohibits infiltration.

12. Water level elevations were monitored in three wells (Figure J1) during the period 23 August 1978 through 12 April 1979. Well No. 1 and boring B6 ended in the underclay; Well No. 2 ended in the St. Peter sandstone. Thus, complete hydrologic continuity between the wells was not ensured, and a contour map of the piezometric surface based on these three points would be meaningless. It should be mentioned, however, that in Well No. 1 and boring B6, water was not observed until the hole was advanced well into the intact underclay. Thus, no saturated surface was encountered in the overlying spoil material.

13. Analysis of the well water level data leads to the following conclusions:

- a. The water level in Well No. 2 is determined by the elevation of the Illinois River.
- b. The water levels in Well No. 1 and boring B6 probably reflect the position of the premining groundwater surface, their elevations coinciding roughly with the elevations of the local bedrock surface (given an allowance for excess pore pressure commonly found in very impermeable clays).

14. In summary, the mine spoil piles are unsaturated below the surficial crust and the saturated water surface occurs just below the top of the underclay in the southern and eastern portions of the site (Figure J1) at an elevation slightly in excess of that expected from hydrostatic pressure considerations. The saturated water surface in

the northern and western portions of the site is found in the St. Peter sandstone and is about the same elevation as that of the Illinois River, being determined by the river's elevation. Practically all precipitation is converted to runoff.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Harrison, Wyman
Suitability of dredged material for reclamation of surface-mined land; Ottawa, Illinois, Demonstration Project / by Wyman Harrison, Abraham Van Luik, Applied Geoscience and Engineering Group, Energy and Environmental Systems Division, Argonne National Laboratory, Argonne, Ill. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
50, [96] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; EL-80-7)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Interagency Agreement WESRF-77-197.
References: p.49-50.

1. Acid mine water. 2. Dredged material. 3. Groundwater quality. 4. Land reclamation. 5. Mine wastes. 6. Mine waters. 7. Monitoring. 8. Soil water. 9. Spoil. 10. Surface mining. 11. Surface waters. 12. Water analysis.

(Continued on next card)

Harrison, Wyman
Suitability of dredged material for reclamation of surface-mined land ... 1980. (Card 2)

13. Water quality. I. Van Luik, Abraham, joint author. II. United States. Argonne National Laboratory, Lemont, Ill. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; EL-80-7.
TA7.W34 no.EL-80-7