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Suitability of Dredged Material for Reclamation of Surface-Mined Land

The Ottawa, Illinois, Demonstration Project

by

Wyman Harrison and Abraham Van Luik

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APPLIED GEOSCIENCE
AND ENGINEERING GROUP
ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

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SUITABILITY OF DREDGED MATERIAL FOR RECLAMATION OF SURFACE-MINED LAND

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by

Wyman Harrison and Abraham Van Luik

Energy and Environmental Systems Division

December 1979

Final Report
for the
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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 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 this study was Wyman Harrison (ANL). The coauthor, Abraham Van Luik, participated in interpretation of the results of the field and laboratory work.

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 co-workers, especially Marilyn Master, for determining the laboratory chemical parameters. Other Argonne personnel that we 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 De Kalb 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: Richard Lee, José Llopis, and Robert Peters. We express our appreciation for the technical guidance provided by WES manager Thomas Patin. Professor J. J. Jurinak, Head of the Department of Soil Science and Biometeorology at Utah State University, is thanked for his careful review of the manuscript. Eugene Perrier, Richard Lee, and Thomas Patin, all of WES, also reviewed the manuscript.

The Director of WES during conduct of this study and preparation of this report was Col. John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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

United States customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	to Obtain
cups	0.0002366	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvin*
inches	25.4	millimetres
miles (U. S. statute)	1.609349	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

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ABSTRACT

Eroding ridges of acidic coal-mine spoil in La Salle County, Illinois, were leveled to form a gently-sloped raised plateau. Four test plots were constructed: a control plot and three treatment plots that received a 0.9-m-thick cover of dredged material obtained from the Metropolitan Sanitary District of Greater Chicago. Two treatment plots received lime applications and all plots were seeded with a mixture of grasses. Pressure-vacuum soil water samplers were installed, in duplicate, at two levels in the control plot and at three levels in each treatment plot. The three levels in the treatment plots coincided with dredged material, the dredged-material mine-spoil interface, and the underlying mine spoil. Surface water, soil water, and groundwater were monitored for 29 water-quality parameters for one year. Rainfall, air temperature, runoff, and water-level elevation data were collected also. Detailed analysis of the data indicates that the dredged material used in this study does not adversely affect water quality; it supports abundant plant growth, lessens groundwater contamination, and controls acid runoff. The dredged material is judged to be a suitable material for use in reclamation of surface-mined land.

EXECUTIVE SUMMARY

This report presents the results of research conducted by Argonne National Laboratory (ANL) for the Productive Uses Project (PUP) of the Dredged Material Research Program, U. S. Army Engineer Waterways Experiment Station. A significant objective of the PUP was to promote the use of dredged material in enhancing land that is either unproductive or that has been degraded by the activities of man. During the autumn of 1977, ANL initiated a study of the PUP's Ottawa, Illinois, demonstration site where dredged material had been applied to nonproductive coal-mine spoil in an effort to:

1. Reduce acid mine drainage to, and pollution of, surrounding lands.
2. Improve the land so that some productive use could be made of it.

The Argonne effort focused upon the migration of several chemical compounds and metal ions present in the dredged material and mine spoil. This objective was accomplished by the installation of equipment for sampling soil water, local groundwater, and runoff associated with four experimental plots: a control plot of mine spoil, and three treatment plots consisting of dredged material covering mine spoil.

Runoff from each plot was gaged by a flume and water-level recorder; this assembly was placed in the downflow corner of each sloping plot. Samples of runoff water were collected from the throat of a given flume immediately following rainfall, or, when conditions premitted, three samples were collected at each flume: one shortly after inception of runoff, one during peak runoff, and one just prior to cessation of runoff.

Pressure-vacuum soil water samplers were used to collect moisture from the mine spoil and dredged material in the experimental plots. Two samplers, separated by a 45-ft (13.7-m) horizontal distance, were installed at the 2.0-, 3.0-, and 5.0-ft (0.6-, 0.9-, and 1.5-m) depths on each plot. An unexpectedly low return of soil water required combining samples from same-depth samplers on each plot and, even then, the volume of sample was often not sufficient to permit analysis of all chemical parameters.

Groundwater was scheduled to be sampled once monthly at two observation wells, located 200-300 ft (60-90 m) to either side of the experimental plots. Prior to sampling with a thief sampler, the wells were blown out with compressed air and allowed to fill up over a 30-min to 3-h period.

Rainfall at the site was measured manually during part of the monitoring study and a recording rain gage was installed about two-thirds of the way through the study. These data supplemented National Weather Service precipitation data for three nearby reporting stations.

Water sample pH was determined at the site, no more than 2 h after bulk sample collection. Following pH determination, each bulk sample was split into a number of aliquots and preservatives added according to the recommendations of the U. S. Environmental Protection Agency (EPA) or the American Public Health Association. The recommendations of these groups were followed also with respect to laboratory analysis for the following parameters: acidity, alkalinity, chloride, specific conductance, cyanide, ammonia, nitrate + nitrite, total Kjeldahl nitrogen, orthophosphate, total phosphorus, sulfate, sulfide, alkali and alkaline earth metals (Ca, Mg, Na, K, and Sr), and trace metals (Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn, and Hg).

The dynamics of pyrite oxidation were studied in the control plot that was composed of freshly graded mine spoil. Pyrite oxidation was observed to increase in the surficial material of the control plot as ambient air temperature increased. Pyrite oxidation in spoil material that had received a 0.9-m-thick cover of dredged material was found to be stabilized; no evidence of accelerated oxidation was found over the period of the study.

The dredged material/spoil interface was increasingly affected by the presence of the dredged material because interface soil water showed marked decreases in trace metal concentrations over time.

The treatment plots, in sharp contrast with the control plot, developed thick vegetation, resulting in less runoff water per station. Runoff water quality was greatly improved by dredged material treatment with respect to pH, trace metal contents, and total concentrations of dissolved constituents.

Dredged material and interface soil solutions were significantly lower in dissolved aluminum, iron, manganese, cadmium, copper, nickel, and zinc than were comparable spoil-matrix solutions. Trace constituents, for which there are published irrigation water quality criteria, were all found to be at acceptable concentrations. No use restrictions for the dredged material, or the plant growth supported by it, were indicated by any of the results of this study.

The parameters pH, Al, Fe, Mn, and SO_4 are found to be sufficient indicators of changes in pyrite oxidation in the spoil material. It is suggested that these parameters continue to be monitored in soil solutions of both the spoil and dredged material. In addition, the Ca and Mg concentrations, as well as the specific conductivity, are important indicators of rapid, large changes in spoil and dredged material matrices. It is important that these be monitored to assess the continuing ability of the dredged material to maintain its favorable pH and buffering capacity, especially in the interface zone between mine spoil and dredged material.

It is suggested that sampling be continued on a bimonthly basis and that the specified parameters be determined analytically. In addition, the suite of trace metals should be determined every 4 months, especially in the dredged material, or more often if significant declines in pH are observed within or beneath the dredged material.

I. INTRODUCTION

A. Project Description

Overview

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

The project location is on the Illinois River in La Salle County near Ottawa, Illinois (Fig. 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.

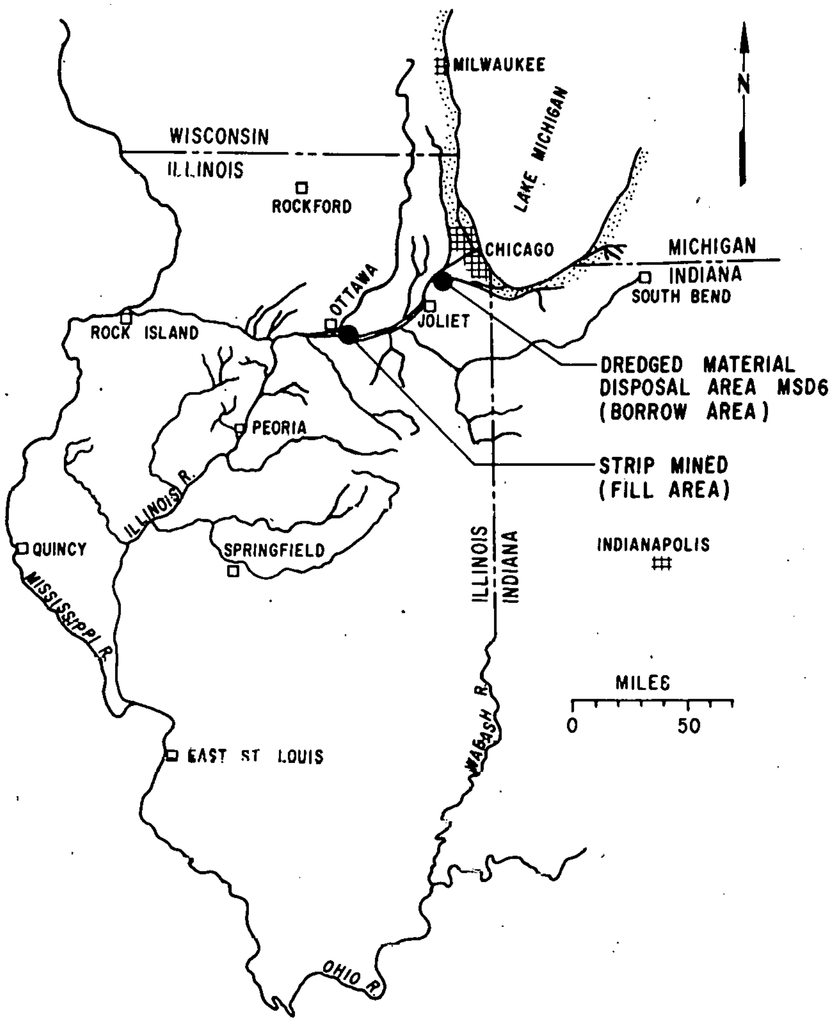

Fig. 1. Location Map

Several factors were involved in selection of the site:

1. 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.

2. 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.

3. 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).

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

5. 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 (Fig. 1) near Chicago.

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

Site Description

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 overlay 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 appendices.

Treatment Rationale

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

1. Establishment of vegetation;
2. prevention of erosion;
3. improvement of surface water quality; and
4. improvement of groundwater quality.

Perusal of the literature[1,2,3] shows 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.

Selective replacement, even if economically feasible, offers only a short-term alternative to imported cover material at this site. 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 has substantially reduced the capacity of the topsoil to neutralize the acidity that will continue to be produced in these strip-mine 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 an 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 is the purpose of this study.

Source of Dredged Material

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 of the material revealed 42 species. Approximately 3800 m^3 of the dried crust layer of natural soil consistency was removed and transported by truck to the Ottawa demonstration site.

Site Preparation

Construction of the demonstration site was under the direction of the Chicago District, Corps of Engineers. The site consisted of a series of northwest-southeast trending parallel ridges (Fig. 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 extends about 230 m south of the site to the Illinois River.

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).

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

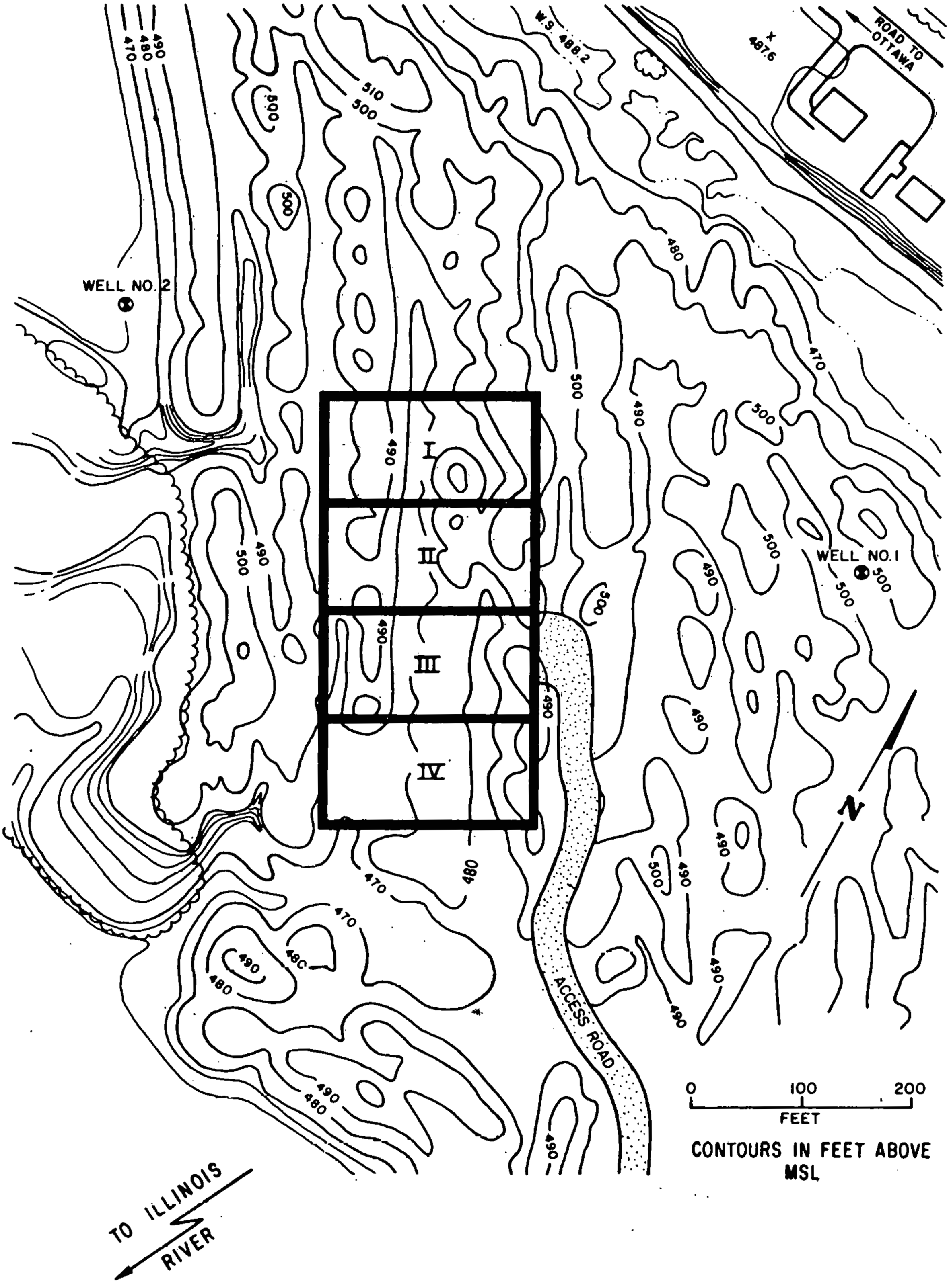

Fig. 2. Initial Site Topography, Groundwater Observation Wells, and Test Plots (Superimposed)

The four test plots are indicated by Roman numerals on Figs. 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.

Plott III: A 0.9-m-thick covering od dredged material over a zone with 22 to 34 M tons/ha of fine-grained 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 44 to 68 M tons/ha of fine-grained agricultural lime mixed into the upper 0.15 m of the mine spoil.

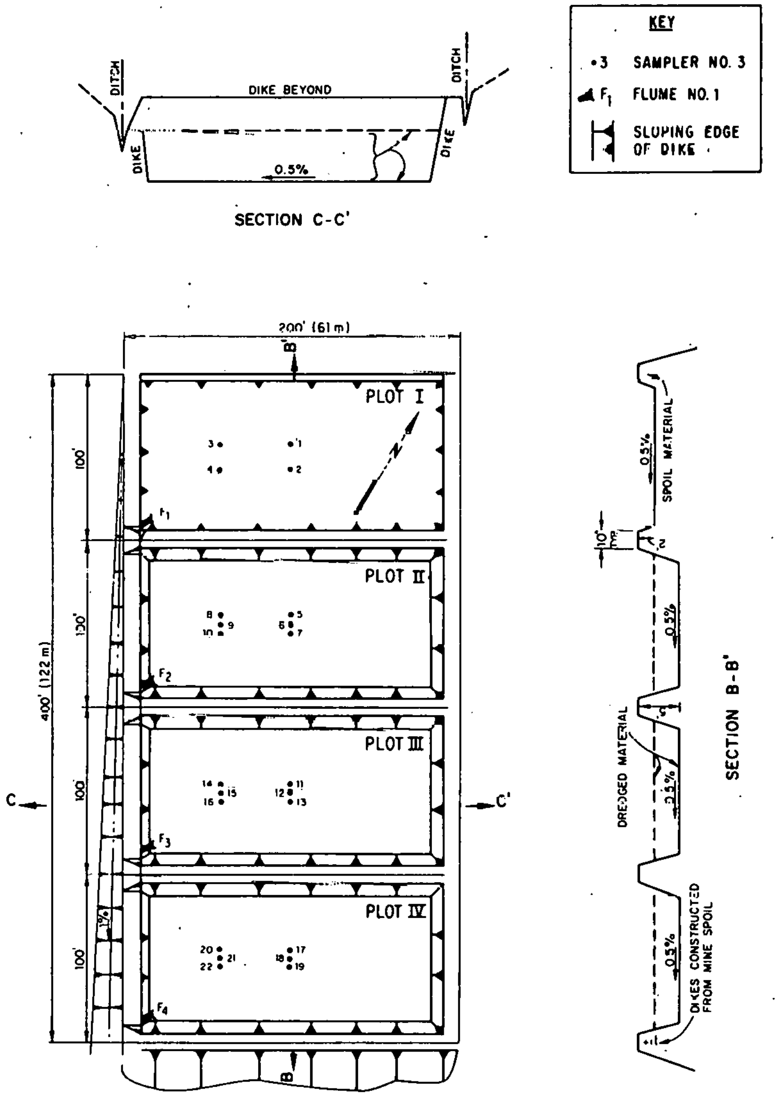

Fig. 3. Plan and Profile Views of Test Plots and Locations of Soil-water Samplers and Flumes

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

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

After seeding, wheat straw mulch was placed on each plot at a rate of 4.5 M tons/ha. The mulch was sprayed with an asphalt 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.

B. Water Quality Study

The primary objective of the water quality study was to investigate the migration of the selected chemical compounds and metals present in the dredged material. The objective was to be accomplished by a monitoring study in which samples of soil water, local groundwater, and surface runoff were 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.

II. MONITORING STUDY

A. Runoff Gaging and Sampling

Basic Plan

As seen in Fig. 3, each of the experimental plots was graded to a 0.5% slope in both southeasterly and southwesterly directions to direct runoff to flow 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

The flumes used for gaging runoff were Parshall flumes made of fiberglass-reinforced polyester by Plasti-Fab, Inc., of Tualatin, Oregon. The throat width was 9 in. (299 mm).* Each had an integral float well into which a Stevens Type F (Model 68) recorder was installed. The recorders were obtained from Leupold and Stevens Inc., Beaverton, Oregon. Each prefabricated flume was carefully leveled when emplaced in the corner of a plot; inlet wing walls were used to train the runoff into the flume.

B. Soil-water Sampling

Basic Plan

Pressure-vacuum soil water samplers (called samplers elsewhere) were chosen over groundwater-removal pits and pan collectors because of the ease of sampler installation and 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 Fig. 3. The depth of each sampler's porous ceramic cup and the material in which the cup rested are given in Table 2.

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 (2, 3, and 5 ft). 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 virgin mine spoil.

Equipment Used and Installation

Model 1920 pressure-vacuum soil water samplers were obtained from Soil-Moisture Equipment Corp. of Santa Barbara, California. These 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 aboveground with short lengths of 3/16 in. in diameter by 1/8-in. wall neoprene tubing and pinch clamps. Short pieces of tapered wooden dowel were inserted in the free ends of the neoprene tubes to prevent fouling by soil.

Two-inch-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% silica) was

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

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. 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.

TABLE 2. Details of Emplacement of Pressure-vacuum Soil-water Samplers

Sampler No.	Plot No.	Depth of Tip of Ceramic Cup Below Plot Surface		Installation Notes
		(ft/in.)	(m)	
1	I	2'0"	0.61	standing water to top hole
2	I	5'0"	1.5	hole dry; only 2' (0.61 m) from No. 1
3	I	2'0"	0.61	
4	I	5'0"	1.5	
5	II	2'0"	0.61	may have some bentonite around cup
6	II	3'3"	0.99	interface at 3'3"
7	II	4'5"	1.4	
8	II	2'2"	0.66	
9	II	3'0"	0.91	interface at 3'3" (0.99 m)
10	II	5'0"	1.5	
11	III	2'0"	0.61	interface from 2'10" to 3'4" (0.87-1.03 m)
12	III	3'0"	0.91	cup in limed layer
13	III	5'0"	1.5	
14	III	2'0"	0.61	
15	III	3'0"	0.91	cup in limed layer
16	III	5'0"	1.5	
17	IV	2'0"	0.61	
18	IV	3'5"	1.1	interface from 3'3" to 3'5" (0.99-1.05 m)
19	IV	5'1"	1.6	1.0' (0.3 m) limed layer
20	IV	2'0"	0.61	
21	IV	4'0"	1.2	
22	IV	5'2"	1.6	interface from 3'7" to 4'3" (1.08-1.30 m)
23	IV	-		replacement for no. 19

Installation of the soil water samplers was completed on November 3, 1977, and at 1300 h each sampler was filled with distilled water to moisten the cup. At 0800 h on November 4, 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 November 9 at 1400 h. Samplers were completely evacuated at each sampling. About 2.5 h was required to sample and reinstitute vacuums on each sampler.

C. Groundwater Sampling

Groundwater was sampled once monthly at the two observation wells of Fig. 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 2.0-in.-diam (51-mm) galvanized pipe. Well 1 (Fig. 2) had a total depth of 35.7 ft (11.4 m) and terminated in a 2- by 36-in. (51- by 914-mm) screen set in clay. Well 2 had a depth of 22.5 ft (6.86 m) with the lower 10.0 ft (3.05 m) in bedrock.

When sampled for the first time (November 20, 1977), the water in Well 1 was 34 ft (10.4 m) from the top of the well pipe (pipe-top elevation = 495.3 ft [151 m]); the water level in Well 2 was 4.5 ft (1.37 m) from the top of the well pipe (pipe-top elevation = 468.8 ft [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 2½- to 3-h period and then sampled with a plastic thief sampler. Only a 600 mL sample could be obtained from Well 1 and the water was very muddy. A full litre was obtained from Well 2.

D. Ancillary Samples and Observations

An 11-in. (279-mm) Taylor, Clear Vu rain gage was installed on November 18, 1977. The gage was attended by an amateur meteorologist. A second gage, a Meteorology Research, Inc., Model 302 tipping-bucket rain gage was installed on August 9, 1978. This gage records rainfall and temperature automatically. Details of gage installation and rainfall records are described in Appendix C. The rainfall data are summarized and analyzed in Appendix B.

Four analyses of samples of mine spoil are presented in Appendix E. Appendices F, G, and H 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 I 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 appendices are used in the interpretation of water quality results obtained in the main part of the study, and are referenced in the text when so used. Figure 4 shows part of the test site as it appeared on October 25, 1978.

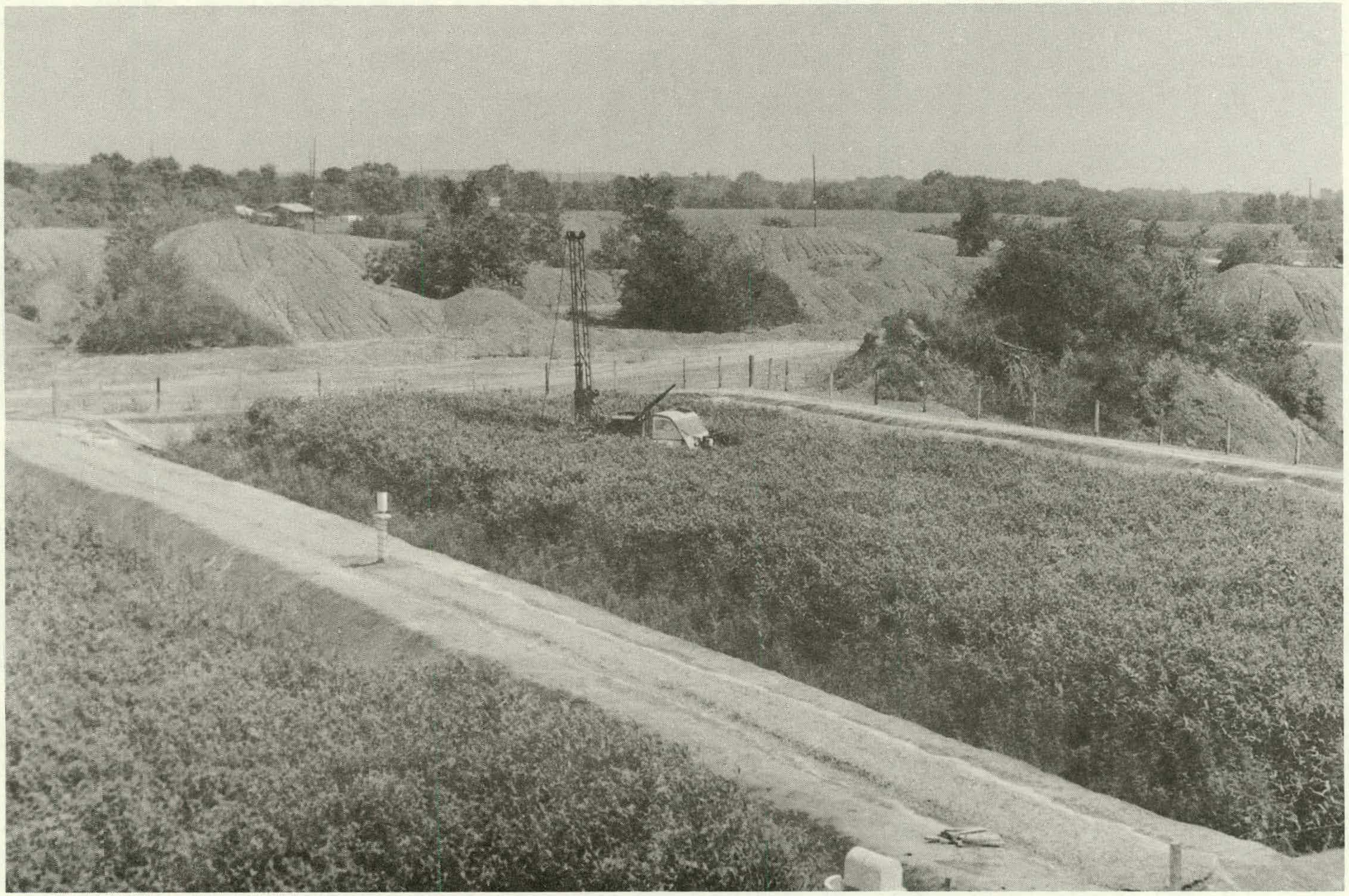

Fig. 4. Treatment Plots III and IV and Surrounding Spoil Banks. View is due east (cf. Fig. 2) and shows luxuriant growth of weeds, rain gage on center of spoil berm separating plots, flume and recorder housing in extreme foreground, and soil–boring rig in center of picture.

III. FIELD CHEMICAL WORK

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

A. Sample Handling

All samples were drawn into 1 L wide-mouth containers. Prior to use, the containers were acid washed with 10% 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 refrigerator in the coolers.

B. pH Determination

Water sample pH was determined at the site no more than 2 h after bulk sample withdrawal with a Beckman Select-Mate portable pH meter. Temperature corrections were made and recalibrations performed as necessary (see, for example, Beckman Instructions 015-082368-A).

C. Sample Preservation

Following a given 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 ~4°C for determination of acidity, alkalinity, chloride, and sulfate.)

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[a]
Zn, Cu, Cd, Pb, Cr, Ni, Al, Mn, K, Fe,	50	0.5 mL, 50% HNO_3[a]
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[a]
Total P		
Total Kjeldahl N	200	0.8 mL 0.5% $HgCl_2$ Solution
Orthophosphorus (PO_4)		
Ammonia-N	50	0.25 mL 50% H_2SO_4[a]
Sulfide	25	25 mL Sulfide anti-oxidant buffer No. 2
Cyanide	50	0.5 mL 6N NaOH

[a] A 50% solution of the concentrated acid, which is used for safety of handling in the field.

IV. LABORATORY CHEMICAL WORK

The following procedures for laboratory analysis of the water samples were adopted.

A. Nonmetals

Acidity

Cold acidity was determined using the potentiometric titration method presented in Standard Methods.[4] The selected endpoint was pH 8.3.

The precision of this method is ±1.8 mg/L $CaCO_3$.

Alkalinity

Alkalinity was determined using the potentiometric titration method presented in Standard Methods.[5] The selected endpoint was pH 4.5.

The relative standard deviation for the alkalinity analysis is ±5.0 mg/L $CaCO_3$.

Chloride

Chloride was determined using the argentometric titration method presented in Standard Methods.[6] The potassium chromate indicator was obtained from the Hach Chemical Company in a prepackaged form.

This analysis has been determined to have a detection limit of 1.0 mg/L Cl and a precision of ±4.2% Cl^-.

Specific Conductance

The electrical conductivity was determined using the method presented in Standard Methods.[7] A 4959 Electrolytic Conductivity Bridge manufactured by Leeds and Northrup was utilized for the measurements.

The precision of this test is ±3.0% of the reading.

Cyanide

The procedure used for cyanide measurements followed those outlined in Standard Methods,[8] with the exception of the type of electrode recommended. The Orion model 94-16 silver/sulfide specific ion electrode was used.[9]

This electrode may be used for cyanide measurements when $KAg(CN)_2$ indicator is added to the sample. The electrode measures the silver concentration as the ion $Ag(CN)_2^-$ dissociates. The extent of the $Ag(CN)_2^-$ dissociation is a function of the free cyanide activity. Thus, the silver ion measurement indirectly measures the free cyanide activity.

The known-addition method of analysis has a detection limit of 0.0004 mg/L CN and a precision of ±6.0% CN.

Nitrogen

Ammonia. Ammonia was determined with an Orion model 95-10, ammonia electrode. The known-addition method outlined in the Orion instruction manual was followed.[10] This procedure yields a detection limit of 0.08 mg/L NH_3-N and a precision of ±2.0% ammonia nitrogen.

Nitrate + Nitrite. The procedure to be used in the nitrate + nitrite measurements was a variation of the cadmium reduction method described in *Standard Methods*.[11] 1-Naphthylamine was replaced by chromotropic acid. A prepackaged cadmium powder and chromotropic acid indicator was obtained from the Hach Chemical Company.

Total Kjeldahl. Total Kjeldahl nitrogen will be determined using the procedures outlined in *Standard Methods*.[12]

Phosphorus

Orthophosphate. Dissolved orthophosphate was measured using the procedures outlined by the EPA.[13] This procedure is analogous to the ascorbic acid method presented in *Standard Methods*.[14]

The limit of detection of this analysis is 0.05 mg/L PO_4, and the precision is ±2.0% PO_4.

Total Phosphorus. Total phosphorus was measured using the persulfate digestion procedure outlined by the EPA.[15]

Redox Potential. The redox potential was determined with an Orion platinum redox electrode, model 96-78. The procedure followed is that outlined in the Orion instruction manual.[16]

Silica. Silica was determined using the molybdosilicate method presented in *Standard Methods*.[17] The reagents used in the test were purchased from the Hach Chemical Company in a prepackaged form.

The detection limit of this procedure is 0.5 mg/L SiO_2. The precision is ±7.0% SiO_2.

Sulfate. The procedure for the determination of sulfate was a variation of the turbidimetric method outlined in *Standard Methods*.[18] A single reagent, prepackaged by the Hach Chemical Company, was used. This reagent is a combination of the barium chloride and conditioning reagent described in *Standard Methods*.[18]

The detection limit of this analysis is 2 mg/L SO_4, and the precision is ±9.0% SO_4.

Sulfide. Free sulfide was determined with an Orion sulfide/silver ion electrode, model 94-16. The known-addition method outlined in the Orion instruction manual was followed.[19]

When using the known-addition method, the detection limit is 0.0006 mg/L S. The precision is ±2.0% S.

B. Metals

All metal analyses were performed with a Perkin-Elmer Model 603 atomic absorption spectrophotometer.

Alkali and Alkaline Earth Metals (Ca, Mg, Na, K, Sr)

The procedures used in determining these metals are described in the Perkin-Elmer methods manual.[20] The flame technique was used in assessing the metal concentrations. A lanthanum-oxide/cesium-chloride mixture was developed for use in reducing interferences during analyses.[21]

The precision of this procedure is ±10% of the concentration of the element of interest. Ideal A.A. detection limits for these metals are as follows:

Ca: 0.2 mg/L
Mg: 0.2 mg/L
Na: 0.2 mg/L
K: 0.2 mg/L
Sr: 0.5 mg/L

Trace Metals (Al, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn)

The flame analysis procedures outlined in the Perkin-Elmer methods manual[20] were used in determining the sample concentrations of these elements following an EPA "soft digestion."[22,23]

The precision of these methods is ±10% of the concentration of the metal of interest. Ideal A.A. detection limits are listed below:

Al: 0.10 mg/L
Cd: 0.02 mg/L
Mn: 0.02 mg/L
Ni: 0.05 mg/L

Cr: 0.05 mg/L
Pb: 0.05 mg/L
Cu: 0.05 mg/L
Zn: 0.05 mg/L
Fe: 0.05 mg/L

The realized detection limit for iron was 0.10 mg-Fe/L in this study.

Mercury

The EPA flameless, cold-vapor technique was used for mercury analysis.[24]

The detection limit for this procedure is 0.00010 mg/L Hg, and the precision is ±10% Hg.

V. MODEL USED FOR INTERPRETATION OF SOIL-WATER DATA

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 a saturated condition. Saturation would suggest the presence of a solid mineral phase controlling solubility for the chemical species 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.

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.

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.[25] Initially, the ionic strength μ was calculated from the molar concentrations M_i and valence Z_i for all the ionic species in solution

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

Then the activity coefficient γ_i for each ionic specie i was calculated from Stumm and Morgan[25] as

$$\log \gamma_i = -AZ_i^2\left(\mu^{\frac{1}{2}}(1 + \mu^{\frac{1}{2}}) - b\mu\right) \qquad (2)$$

where A = 0.509 for an aqueous solution at 25°C, and b has a value of 0.2. When the activity coefficients were estimated, the ion activities (M) were calculated using a mass balance approach which 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

$$M_T = [M^{2+}] + [MSO_4^0] + [MCl^+] + [MCO_3^0] + [MHPO_4^0] \qquad (3)$$

where [ ] represents concentration in moles/L and $(M_i) = \gamma_i[M_i]$, in terms of activities. Where ( ) represents activity, Eq. 3 is written

$$M_T = \frac{(M^{2+})}{\gamma_m} + \frac{(MSO_4^0)}{\gamma_{mso_4}} + \frac{(MCl^+)}{\gamma_{mcl}} + \frac{(MCO_3^0)}{\gamma_{mco_3}} + \frac{(MHPO_4^0)}{\gamma_{mhpo_4}}. \qquad (4)$$

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

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

and

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

or

$$(MX^{i-j}) = \frac{(M^{i+})(X^{j-})}{K_{MX^{i-j}}} \qquad (5)$$

where $K_{MX^{i-j}}$ is the dissociation constant for the ion pair MX^{i-j} and where i+ is the charge on cation M and j- is the charge on anion X. Making the substitution given in Eq. 5 for all complexes and rearranging Eq. 4 gives

$$(M^{2+}) = M_T\left(\frac{1}{\gamma_m} + \frac{(SO_4)}{\gamma K_{mso_4}} + \frac{(Cl)}{\gamma K_{mcl}} + \frac{(CO_3)}{\gamma K_{mco_3}} + \frac{(HPO_4)}{\gamma K_{mhpo_4}}\right)^{-1}. \qquad (6)$$

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

Each charged ion pair contributed to the ionic strength thus: the activities of all ion pairs (MX^{i-j}) were calculated from Eq. 5 after (M^{i+}) and (X^{j-}) were calculated using expressions of the form given by Eq. 6. 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 iterative DO loop until successive ionic strength values differed by less than 1 x 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.

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)	$Al_2O_3 \cdot 3H_2O$
Gypsum	$CaSO_4 \cdot 2H_2O$
Halite	$NaCl$
Hexahydrite	$MgSO_4 \cdot 6H_2O$
Hydromagnesite	$Mg_4(CO_3)_3(OH)_2$
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.

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

VI. RESULTS AND DISCUSSION

A. Presentation of Analytical and Supporting Data

The results of the chemical analyses for all runoff, soil-moisture, and well samples are presented in Appendix A. The more meaningful of these results were abstracted and tabulated for interpretation in this section of the report. Analytical results in Appendix A are given as they were obtained from the laboratory. In the present section, however, sulfate concentration values were determined by balancing the milliequivalent concentrations of cations with anion milliequivalents, assuming chloride and sulfate constituted the majority of the total anions in solution. This was done because chemical interferences were apparently encountered when the turbidimetric barium precipitation method was used with some samples. This problem was corrected to an extent by the adoption of an automated sulfate procedure toward midyear, 1978. Standard nitrate procedures were also found unsatisfactory in these solutions. A discussion of the nitrate and sulfate analytical problems appears under "Reliability of the Data" in Appendix A.

Supporting meteorological and runoff data are presented in Appendices B, C, and D. Analyses of mine-spoil samples are given in Appendix E. Descriptions of ancillary studies conducted on the chemical characteristics of surface and subsurface contact waters in spoil and dredged material are given in Appendices F, G, and H together with results and interpretations. Appendix I presents information on the geohydrology and stratigraphy of the site.

B. Quality of Runoff Water

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 to evaluation of the dredged material as a permanent cover treatment for degraded lands and are discussed in the section that follows.

Plot I: Freshly Graded Spoil

Runoff samples were obtained on six dates during the course of this study. Selected water quality parameters for these dates are presented in Table 4. On only one of these six occasions did the storm and runoff conditions allow for 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 h, allowing the collection of three well-separated samples. The collections on 6/26/78 and 7/26/78 represented the last portions of 2.28- and 0.81-in. rainstorms, respectively.

TABLE 4. Selected Water Quality Data for Treatment of 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 ← 0.89 in. → I	4/10/78 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 (ppm)	946.	1340.	236.	169.	1824.	842.	2700.
Alkalinity (ppm)	--	--	--	--	--	--	--
pH	3.90	3.34	3.72	3.50	2.98	3.30	2.40
EC (mmho)	1.98(est)**	2.45	1.05	0.82	2.90	2.41(est)**	4.13(est)**
$PO_4^{\equiv}$ (ppm)	0.13	0.03	0.01	0.05	0.05	0.08	2.60
$SO_4^{=}$ (ppm)†	1500.	2000.	650.	400.	2300.	1900.	3500.
Cl^- (ppm)	10.	<1.	<1.	<1.	3.	1.	2.
Ca^{++} (ppm)	169.	203.	86.8	57.6	120.	91.6	138.
Mg^{++} (ppm)	197.	242.	72.3	41.8	261.	235.	390.
Sr^{++} (ppm)	0.6	<0.5	<0.5	<0.5	0.9	<0.5	<0.5
Na^+	2.68	1.73	0.98	0.72	1.52	1.52	5.00
K^+	0.87	1.15	0.58	<0.50	0.70	1.10	0.93
Zn^{++}	0.92	1.64	0.39	0.26	1.06	0.78	1.85
Cu^{++} (ppm)	0.08	0.27	0.03	0.02	0.35	0.18	<0.05
Ni^{++} (ppm)	0.86	1.34	0.32	0.17	0.16	0.13	2.37
Mn^{++} (ppm)	11.4	17.0	4.60	2.29	17.6	15.6	27.6
Fe^{++} (ppm)	1.50	3.66	<0.10	<0.10	57.6	26.6	78.5
Al^{+++} (ppm)	56.5	102.	24.7	16.2	151.	125.	256.

*Standing water, 5 days since precipitation.

**Estimated by regression with total cation concentration milliequivalents/L.

†Estimated from charge balance calculation.

The trends in the values shown in Table 4 compare well with trends in the 0.6-m depth soil solution samples, as will be shown in the results and discussion of the groundwater quality portion of this study.

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 that is characteristic of the runoff process. 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. However, the large size of the 6/26/78 storm, and the samples not being collected at the onset of runoff for the 6/26/78 and 7/26/78 storms, suggests that the acidity and dissolved salts concentrations reported for these dates are conservative and that acidification is taking place in the surficial zone of Treatment Plot I with resultant increases in metals and sulfate concentration in the runoff.

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.[26] No quantitative prediction of the ultimate quality of runoff water can be made from these data.

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.[27] The result of this initial oxidation step is the direct oxidation of iron pyrite to iron sulfate.[28] After this initial step there is Fe(II) in solution which 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.[25]

The increase observed during the year in the surface acidity of study Plot I, since exposure by regrading, is not out of harmony with literature values for the kinetics of pyrite oxidation. At pH 3, half of iron in solution may be oxidized to the highly reactive but very sparingly soluble Fe(III) state over a period of a month and a half.[25] With pyrites present, but not all pervasive in the system, it may be seen that not every Fe(III) ion produced will react with a pyrite surface before it is precipitated ($Fe(OH)_3(s)$), hence it may be that steady state has not yet been reached in the system under consideration, and that further degradation of runoff waters may still occur.

Plots II, III, and IV: Dredged Material Treatments

Table 5 presents salient water quality characteristics for the runoff waters collected from the dredged material treatment plots. Vegetative growth on these plots was prolific and it severely reduced runoff from these plots after the April sampling. No runoff was detected from Plot II for the tail end of

TABLE 5. Selected Water Quality Data for Runoff Samples from Treatment of 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	II	II	II	III	III	III	III	III	III	IV	IV	IV	IV	IV
Sampling date	4/10/78	4/10/78	4/10/78	12/17/77	4/10/78	4/10/78	4/10/78	6/26/78	7/26/78	4/10/78	4/10/78	4/10/78	6/26/78	7/26/78
Runoff sampling time	I	M	F	F	I	M	F	F	F	I	M	F	F	F
Acidity (ppm)	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 (ppm)	47.2	23.0	23.0	32.8	37.7	21.3	23.0	16.4	--	37.7	19.7	23.0	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)	1.05	0.48	0.40	--	0.87	0.37	0.39	0.33	--	0.64	0.32	0.32	0.24	--
$PO_4^{\equiv}$ (ppm)	0.02	0.04	0.05	0.32	0.03	0.06	0.05	0.62	--	0.05	0.05	0.07	1.08	--
$SO_4^{=}$ (ppm)[a]	550.	300.	200.	700.	500.	200.	200.	100.	50.	350.	150.	150.	50.	--
Cl^{-} (ppm)	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^{-} (ppm)	58.	--	28.	0.	46.	26.	28.	--	--	46.	24.	28.	--	--
Ca^{++} (ppm)	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^{++} (ppm)	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^{+} (ppm)	4.50	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^{+} (ppm)	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^{++} (ppm)	<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^{+++} (ppm)	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

[a] Estimated by difference.

the 2.28-in. storm of 6/26/78, for example. 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 higher concentrations for sodium and potassium for these same two samples, and the lower concentrations for calcium and magnesium in relation to other runoff samples from these same plots, may be explained by the lack of contact time and the lack of dilution in this small flow. In addition, the area in which the runoff was generated was near the plastic-sheeted borders of the plots, where some contamination was evident from the separation dikes composed of mine-spoil. This condition could explain the lowered pH for the two 7/26/78 runoff samplings. Because of this suspected contamination by mine-spoil, the pH values for the 7/26/78 runoff samples from treatment Plots III and IV were not considered.

Table 6 compares trends in various parameters for treated Plots II through IV with observed trends from untreated Plot I. The quantity of data is insufficient to warrant rigorous statistical evaluation.

Based upon the limited data available, it is apparent from Table 6 that in every category the quality of the treatment plot runoff waters improved with time, in contrast with the runoff water from the untreated plot. As discussed earlier, water from the untreated plot became progressively more degraded. The phenomena of increasing pH and decreasing dissolved salt loadings in the runoff water from Plots II-IV was expected to correspond to similar trends found by Mang and others[29] in leaching studies on dredged material from five locations conducted over a period of 9 months.

The sequential runoff collections during the 4/10/78 storm also exhibited typical initial peaks in dissolved constituents, followed by decreased concentrations in the additional surface water flows, as illustrated in Table 5.

Summary

Table 7 presents high values, mean values, standard deviations, and coefficients of variation for the 4/10/78 runoff water quality parameters for the untreated and for the combined treated plots. For samples in which a parameter was not detectable by the analytical method used, the foregoing statistics were calculated using numerical values following the "less than" symbols to avoid having to use zeros. By using this procedure the means became biased in the "worst-case" direction; using zero values would have biased the means in the opposite direction. It was felt that the more conservative bias would be appropriate to the objectives of this study.

Comparison of the mean values of Table 5 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.[29,30,31]

TABLE 6. Apparent Runoff Water Quality Trends for Six Parameters, Five Collection Dates

Parameter and location (Plot #)		Date of Runoff Collection					Apparent Trend
		12/17/77	4/10/78	6/26/78	7/26/78	11/13/78	
Acidity	I	946	1340	1824	842	2700	Increasing
(ppm)	II		19.7				
	III	49.2	15.8	4.6			
	IV		11.8	0.0			
Avg.	(II-IV)	49.2	15.8	2.3			Decreasing
Alkalinity	II		47.2				
(ppm)	III	32.8	37.7	16.4			
	IV		37.7	19.7			
Avg.	(II-IV)	32.8	40.9	18.0			Decreasing
pH	I	3.90	3.34	2.98	3.30	2.40	Decreasing
	II		7.28				
	III	6.90	7.41	7.31	6.10[a]		
	IV		7.42	9.59	6.69[a]		
Avg.	(II-IV)	6.90	7.37	8.45	6.40[a]		Increasing
EC (mmho)	I	1.98	2.45	2.90	2.41	4.13	Increasing
	II		1.05				
	III		0.87	0.33			
	IV		0.64	0.24			
Avg.	(II-IV)		0.85	0.28			Decreasing
Ca (ppm)	I	169	203	120	19.6	138	Decreasing
	II		174				
	III	252	146	37.1	10.7		
	IV		115	12.1	6.51		
Avg.	(II-IV)	252	145	24.6	8.60		Decreasing
SO_4 (ppm)	I	1500	2000	2300	1900	3500	Increasing
	II		550				
	III	700	500	100	50		
	IV		350	50			
Avg.	(II-IV)	700	470	75	50		Decreasing

[a] Not considered because of probable contamination, see text.

TABLE 7. Summary of Statistical Data for Runoff Water Quality Analytical Results: The 10 April 1978 Storm

	Untreated (Plot I)				Irrigation Water Tolerances[31]		Treated (Plots II, III, and IV)			
Parameter	High value	Mean value	Std. Dev.	Coeff. of Var. %	For Continuous Use	For Short Term Use	High value	Mean value	Std. Dev.	Coeff. of Var. %
Acidity (ppm)	1340	582	658	113			19.7	16.0	3.99	25.0
Alkalinity (ppm)	--	--	--	--			47.2	28.3	9.84	34.7
pH (low value)	3.34	3.52	0.19	5.42			7.15	7.28	0.10	1.36
EC (μmho/cm)	2446	1436	882	61.5			1045	536	263	49.0
PO$_4$ (ppm)	<0.05	<0.05	0	0			0.06	<0.05*	0.00	6.52
Total-P (ppm)	0.15	0.08*	0.06	69.3			0.15	0.10	0.04	35.6
TKN (ppm)	0.85	0.65	0.18	27.7			1.80	0.95	0.45	47.8
NH$_3$ (ppm)	0.42	0.33	0.08	22.5			0.25	0.22	0.03	15.2
NO$_3$ (ppm)	3.0	2.2	1.0	48.3			0.32	0.32	--	--**
SO$_4$ (ppm)	1500	633	751	119			300	131	87	65.3
Cl (ppm)	<1	<1*	0	0			6	2*	2	100
Ca (ppm)	203	116	76.9	66.4			174	90.1	45.2	50.2
Mg (ppm)	242	119	108	90.9			43.9	17.5	12.4	71.1
Na (ppm)	1.73	1.14	0.52	45.9			4.60	2.03	1.32	64.9
K (ppm)	1.15	0.61*	0.53	86.2			4.45	1.84	1.23	66.7
Fe (ppm)	3.66	1.29*	2.06	160			1.34	0.54*	0.44	81.1
Al (ppm)	102	47.6	47.3	99.1	1.0	20	0.3	0.1*	0.0	54.5
Sr (ppm)	<0.5	<0.5	0	0			<0.5	<0.5	0	0
Mn (ppm)	17.0	7.96	7.91	95.3	2.0	20	<0.02	<0.02	0	0
Cd (ppm)	<0.02	<0.02	0	0	0.005	0.05	<0.02	<0.02	0	0
Cu (ppm)	0.27	0.12*	0.13	103	0.2	5.0	<0.05	<0.05	0	0
Cr (ppm)	<0.05	<0.05	0	0	5.0	20	<0.05	<0.05	0	0
Ni (ppm)	1.34	0.61	0.64	104	0.5	2.0	<0.05	<0.05*	0	0
Pb (ppm)	0.12	0.07*	0.04	55.1	5.0	20	<0.05	<0.05	0	0
Zn (ppm)	1.64	0.76	0.76	99.8	5.0	10	0.06	<0.05*	0.00	6.52
CN (ppm)	0.022	0.019	0.002	13.2			0.020	0.019	0.000	2.08
Hg (ppm)	**						**			
Sulfide (ppm)	0.016	0.006	0.009	144			1.68	0.19	0.56	294

* Data biased in conservative direction by using "less than" values at their numerical value.

** No data

For some or all of the runoff samples from Plot I, aluminum, copper, manganese and nickel concentrations exceeded criteria for irrigation waters as suggested in some or all of the three criteria publications consulted.[29,30,31] The pH of the runoff samples from the untreated plot fails to meet the lowest suggested pH criterion for irrigation waters. If the pH were adjusted to 5, the lowest irrigation water criteria value,[29] before discharge onto arable land, the four listed elements could be significantly reduced in concentration because their solubilities are controlled by the formation of pH-dependent solid phases.

C. Quality of Soil Water

The objective for sampling and analysis 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 means here the matrix composed of both dredged material and spoil in the treatment plots.)

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 for the analytical procedures statistical evaluation by analysis of variance for significance of 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.

Table 8 shows that the means for pH at the three different depths and for the three different treatments all differed significantly. This is due to the fact that the three depths sampled represent (1) the dredged material, (2) the dredged material and spoil material interface, and (3) the mine spoil.

The three lime treatments were designed to be: (Plot II) 0 M tons/ha added lime, (Plot III) 22-34 M tons/ha added lime, and (Plot IV) 44-68 M tons/ha added lime, respectively. The significant differences (Table 8) in mean pH for the treatment plots run counter to expectations, however, in that mean soil solution pH is less in lime treatments for Plots III and IV than in Plot II, which had no lime treatment. This trend in pH as a function of the addition of lime might be thought to reflect spatial variability in the pH of the underlying spoil material that completely masks any liming effects.

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. No interactions can be evaluated because of confounding as revealed by expected mean square analysis. Whether treatments are considered to be nested within depths, or depths to be nested inside treatments, does not affect the F-tests. Mean squares for all three variables are to be compared with the error mean square. This table uses data for the seven monthly samplings for which pH values were obtained for every sample.

Appendix A may provide one illustration of a liming effect: the 1.5-m sampling results for the highest lime application treatment reveal pH values indistinguishable from the 1.5-m spoil pH values for the November and December 1977 and March 1978 samplings. Beginning with the April 1978 samplings, however, the pH values were indistinguishable from the soil water samples from the 0.6-m depth for the other treatments. This condition may represent solution being pulled from a zone in the interface dominated originally by spoil, but after significant moisture throughflow, leached lime and/or dredged material alkalinity succeeded in neutralizing the residual acidity in the zone.

For practical purposes, however, the experimental results were examined as if there had been no lime applications. Essentially, a reduced experimental design was assumed, one that consisted of a control plot and three replications of a single dredged material application.

Results from Control Plot

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 November 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. Comparison with the chemical characteristics of the three general spoil types described in Appendix H leads to the conclusion that the acidic spoil of the control plot is underlain by a layer of (premining) topsoil. This further illustrates the spatial variability of spoil materials, a characteristic that has been referred to earlier.

The essential purpose of this study is to monitor the changes that will take place on, in, and under the dredged material that was placed over the acidic spoil material. The changes measured followed as a direct result of the impacts of air, water, and temperature over time.

A previous study calculated average acid formation rates for acid-spoil-pile surfaces as a function of total cumulative runoff acidity, surface drainage area, time, and total runoff/rainfall ratio.[33] Temperature and percolated acidity were not considered. The present study was not designed to investigate the same set of parameters; however, the rainfall, temperature, and soil water quality data that were collected do allow investigation of basic relationships between spoil acidification and environmental factors.

In Table 9, runoff water quality data for Plot I were included beside data for the closest corresponding 0.6-m soil water quality sampling date. The pH of the runoff and 0.6-m soil waters appears to be decreasing over time; however, correlation between the six corresponding pH values showed that this relationship was not significant at or above the 5% confidence level.

TABLE 9. Data (ppm) for Selected Water Quality Parameters for Soil and Runoff Waters for Plot I

		Soil Water										Runoff Water								
Depth	Date	Ca	Mg	Na	K	Sr	Al	Fe	Mn	SO_4[a]	pH	pH	Ca	Mg	Na	K	Al	Fe	Mn	SO_4
0.6 m	20 Nov	415	3660	77.4	15.8	-	68.0	31.5	202	16400	5.4									
	27 Nov	472	3650	78.2	13.0	1.0	148	14.4	216	18500	5.4									
	4 Dec	373	3390	91.7	9.5	0.7	125	4.79	182	15500	5.2	[b]								
	17 Dec	349	1070	418	7.8	1.6	173	0.56	203	7250	4.6	— 3.9	169	197	2.7	0.9	57	1.5	11	1500
	17 Apr	231	1110	201	4.9	1.2	-	-	-	5380	4.3	— 3.3	203	242	1.7	1.15	102	3.7	17	2000
	16 May	146	605	88.5	8.0	0.5	317	1.24	48.6	4180	4.1									
	13 Jun	446	1090	70.4	6.9	0.7	453	1.20	76.8	8020	3.8	— 3.0	120	261	1.5	0.7	151	58	18	2300
	20 Jul	150	998	42.3	5.8	0.6	319	2.12	39.5	6190	3.4	— 3.3	92	235	1.5	1.1	125	27	16	1900
	9 Aug	213	963	38.6	5.2	0.6	484	2.50	87.6	7150	3.5									
	6 Sep	168	1380	55.3	9.1	<0.5	474	5.79	106	8740	4.2									
	11 Oct	143	1700	50.1	7.4	<0.5	683	23.3	86.6	11000	3.8	= 3.0	141	1130	6.7	0.5	397	112	49	1300
	8 Nov	146	1820	55.4	6.7	<0.5	455	6.89	115	10300	3.5	2.4	138	390	5.0	0.9	256	79	28	3500
1.5 m	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	2.10	--	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									

[a] Sulfates estimated from charge balance calculations.

[b] Lines indicate approximate times of runoff collection with respect to times of collection of soil water.

Similar correlations between 0.6-m, and corresponding surface runoff Al and Fe concentrations, yielded r values of 0.948 and 0.842, which, at 4° of freedom, are significant at the 1 and 5% confidence levels, respectively. These correspondences are not easily interpreted because of the complexity of acid-sulfate soil pyrite oxidation reaction mechanisms and possible oxidation product translocation pathways.[34,37] It appears, however, that aluminum mobility is greater than iron mobility in this acid-sulfate soil system, assuming that pyrite oxidation is a very shallow surface phenomena here, as suggested in the literature.[33]

The runoff data (Table 9) show a definite increase in pyrite oxidation for the surface of the untreated spoil of Plot I. The 0.6-m soil water data (Table 9) show, initially, the ion concentration decreases that may be expected from leading through a freshly exposed surface. Subsequent increases in concentration, after warmer weather has set in, suggest corresponding increases in the surface pyrite oxidation rate. Relationships between 0.6-m concentrations and meteorological factors (Table 10) were investigated (Table 11).

Table 11 shows a significant negative linear relationship between calcium in the soil solution at 0.6 m and total precipitation between collection dates. Failure of sodium to behave similarly to a significant extent allows the speculation that more than simple dilution or leaching is causing this decrease in calcium. Application of the thermodynamic solubility model (described in Part V) showed that calcium sulfate, gypsum, was saturated in a number of these 0.6 m soil solutions. Formation of solid state gypsum in soils, according to the literature, is possible where the acidity produced by pyrite oxidation is neutralized by calcium carbonate,[34] and/or is leached to depths in the soil where the downward movement of water is impeded.[35] Since no water could be collected from some of the 1.5 m-depth soil water samplers for some months, it may be further speculated that there is downward water movement impedance at or above that level. Gypsum precipitation at or below the 0.6-m depth appears, therefore, a likely calcium concentration control mechanism in Plot I.

Part II of Table 11 shows that sodium, manganese, and strontium decreased as the weather got warmer. Since this is equivalent to saying they decreased over the one-year duration of this study, no new information is obtained from these correlations. Of interest, however, is the significant but opposite trend for the aluminum concentration. Laboratory oxidation in nitric acid of pyritic materials and their inclusions showed aluminum to be the second most abundant metal solubilized, after iron (see Table G.1, Appendix G). Together with the corresponding drop in pH, the aluminum results suggest accelerated pyrite oxidation in the Plot I surface with accumulation in the near subsurface. The manganese results suggest removal by leaching, similar to sodium and strontium. From Table 9, however, it may be seen that manganese does not appear in the 1.5-m soil solutions. This, it may be speculated, stems from the strongly pH-dependent nature of manganese solubility.[25] In all likelihood, manganese(II) oxide precipitation is occurring at the interface between the acidic and near neutral spoil materials, represented by the 0.6-m and 1.5-m sampling depths.

TABLE 10. Summary of Meteorological Data Presented in Appendix B

	20 Nov*	27 Nov	4 Dec	17 Dec	17 Apr	16 May	13 Jun	20 Jul	9 Aug	6 Sep	11 Oct	8 Nov
Number of rainfall events between collection dates	3	2	2	4	13	4	3	8	3	6	7	5
Cumulative inches of rainfall between collection dates	1.91**	0.58**	0.75**	1.01	4.69	5.73	0.41	5.50	2.22	1.62	5.72	1.68
Mean temperatures between collection dates, $\left(\frac{\sum \text{daily means}}{\text{days}}\right)$°F	51	28	26	24	28	54	71	76	73	76	68	53
Number of days between collections	30	7	7	13	121	29	28	37	20	28	35	28

* For preceding 30 days and date of collection.

** Estimated from Ottawa data (see Appendix B).

TABLE 11. 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	

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 (-0.764)*	11 (9)	0.05 (0.01)	0.407 (0.583)
Sr	-0.735	10	0.01	0.540
Al	0.720	10	0.01	0.518
Mn	-0.818	10	0.01	0.669
pH	-0.700	11	0.01	0.491

*Critical r values: at df = 9, α = 0.05, r = 0.602; df = 9, α = 0.01, r = 0.735;
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.

Significance for the correlation of increased iron concentrations with increased temperature was not demonstrated. This may be related to the relative ease with which iron may be precipitated, even at low pH, preventing its translocation from the surface to 60-cm depth at which these samples were taken.[34,37] Efforts to calculate Fe^{3+} to Fe^{2+} ratios from the redox status of the solution were unsuccessful due to nonequilibrium conditions and the lack of sensitivity[38,39] of the computer model to discriminate between redox couples.

Table 12 lists soil water, trace metal concentrations for the Plot I 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 penetration of nickel into the near neutral 1.5-m depth being suggested by the data. Results of a laboratory pyritic-material oxidation study (see Appendix G) indicated that chromium, cadmium, and lead were solubilized during pyrite oxidation

TABLE 12. 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	0.18	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

at measurable concentrations. There was no indication of downward movement of either chromium or cadmium in the data of Table 12, 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 12 probably represent a high lead background concentration for the spoil material. The increasing nickel and zinc concentrations, however, may be taken as a further indication of increasing pyrite oxidation in the Plot I spoil surface material.

Results from the Treatment Plots

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

Table 8, in the preceding section, 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. In Table 13, this test is repeated as a one-way analysis of variance on the pH of each sampling depth over time. One-way analysis of variance allows the inclusion of the incomplete data sets since unequal sample size is allowed.[32]

According to the results of the statistical analysis (Table 13) there was a significant variation in pH over time in the 0.6-m samples, which represent the dredged material. It becomes important, at this point, to know which means differed statistically from which other means, so Duncan's Multiple Range Test[32] was used, and the resulting nondistinguishable means were underlined in Table 13, meaning that those means not underlined by the same line may be said to differ significantly at the 99% level of confidence.

What the Duncan's Multiple Range (DMR) Test results show is that there was a significant drop in pH between winter and spring, and a significant rise in pH in midsummer which, by the end of the sampling period, was indistinguishable from the pH before the drop occurred. Thus, in Table 13, the 17 December pH of 7.92 is shown, by the dashed line, to be indistinguishable from the 8 November pH of 7.63. A pH cycle, with a drop in pH during the time of the maximum vegetative growth rate, has been documented, apparently, in the 0.6-m depth of the dredged material. That this is a normal phenomenon in mineral soils, especially under cultivation, is attested by the general soils textbook of Buckman and Brady,[41] wherein the cause is ascribed to be "due to acids produced by microorganisms." Also, higher plants, "especially with regard to acidic exudates," are given mention as a probable causative factor. The raising of pH with lowering soil temperatures is also noted.[41] 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 yr) no changes in pH have occurred that denote a radical change in the makeup of the dredged material as a soil.

TABLE 13. One-way Analysis of Variance Comparing pH Variation with Time of Sampling for Treatment of Plots II, III, and IV Soil Solution Data at Three Profile Depths

Sample Depth (m)	Plot	Time of Sampling 20 Nov	17 Dec	17 Apr	16 May	13 Jun	20 Jul	9 Aug	6 Sep	11 Oct	8 Nov
0.6	II	8.00	8.10	6.89	6.80	6.70	6.80	7.02	-	7.45	7.70
	III	8.00	7.85	7.02	6.80	6.85	6.70	7.40	-	7.60	7.50
	IV	8.05	7.80	6.36	6.75	6.80	6.79	7.60	-	7.65	7.70
	Means	8.02	7.92	6.92	6.78	6.78	6.76	7.34	-	7.57	7.63
0.9	II	7.95	7.00	-	6.70	6.60	6.79	7.08	-	7.30	8.00
	III	7.85	7.10	6.88	6.68	6.65	6.65	6.90	-	7.10	6.80
	IV	5.70	4.90	6.32	6.65	6.60	6.20	6.69	-	7.25	7.20
	Means	7.07	6.33	6.60	6.68	6.62	6.55	6.89	-	7.22	7.33
1.5	II	5.40	-	4.15	4.85	5.80	5.89	5.77	-	5.85	4.80
	III	2.50	-	2.00	3.18	2.90	2.46	2.40	3.10	3.35	2.60
	IV	4.65	-	-	3.90	3.90	3.65	3.78	4.10	4.45	4.00
	Means	4.18	-	3.08	3.98	4.20	4.00	3.98	3.60	4.55	3.80

Note: DMR test result on means (see text). Means underlined by the same line are not significantly different at the 99% confidence level.

Analysis of Variance, Time vs pH Change at Each Depth

Sample Depth, m	Sums of Squares		df	Mean Squares	F-Value	Significance and α Level
0.6	Total	6.43	26			
	Sampling Time	6.12	8	0.77	44.57	Significant at α = 0.005
	Error	0.31	18	0.02		
0.9	Total	10.50	26			
	Sampling Time	2.99	8	0.37	0.89	Nonsignificant
	Error	7.51	18	0.42		
1.5	Total	33.78	24			
	Sampling Time	3.27	8	0.41	0.21	Nonsignificant
	Error	30.51	16	1.91		

The result that no significant differences in pH were demonstrated for the 0.9-m depth soil solutions tends to confirm the above conclusion as to the cause of the surface pH lowering. It is not to be expected that microorganisms or plant roots would have as marked an effect on the soil matrix at 0.9 m as at 0.6 m.

The lack of significant pH changes for the (0.9-m) dredged material/ spoil interface, and in the (1.5-m) spoil underlying the dredged material was encouraging. The increased pyrite oxidation rate suggested by the surface data for Plot I, as discussed, was contraindicated for the spoil surfaces in the three treated plots by this lack of significant pH change.

It may be useful, at this point, to review some of the literature pertinent to understanding the complexity of the reactions that may constitute what has thus far been referred to as "pyrite oxidation." It is especially important, in a short review of this literature, to determine what effect placing a dredged material cover may have on pyrite oxidation rates in underlying spoil. It must not be supposed, for example, that a dredged material cover would completely halt pyrite oxidation in underlying spoil. Even if a cover were a totally effective oxygen barrier, acid release would not be prevented altogether, although it would be slowed down. The continuation of acid production under controlled oxygen exclusion conditions has been demonstrated experimentally,[42,43] as well as described mechanistically.[25] After initial oxidation of pyrite has taken place, further oxidation may take place by reaction with ferric iron, which is rapidly reduced by iron pyrite.[25] Ferrous iron released by iron pyrite oxidation may be oxidized to ferric iron by microbial activity, or by oxygen directly. The hydrolysis of the resulting ferric ion to the sparingly soluble hydrous oxide form ensures a future supply of ferric ion in solution in case the oxygen supply is cut off by a seal over the spoil. In the complete absence of oxygen, depending on the oxidation-reduction status of the medium, either water will be used as the sulfide-to-sulfate oxidation oxygen source, or metallic sulfur will be produced. Metallic sulfur production has been observed.[44] Aluminum, manganese, and copper also play roles in specific parts of the complete oxidation of iron pyrite to ferric hydroxide and sulfuric acid. Oxides of manganese may be an oxidizing agent,[45] while copper[46] and aluminum hydroxide[47] act as catalysts. Whether or not these laboratory study results are relatable to field conditions at the Ottawa site is not known. They do illustrate, however, the complexity of the possible reactions that may contribute to the "pyrite oxidation" process.

The application of the dredged material may not altogether stop acid production in the underlying spoil material, but certain concrete and beneficial results in relation to the groundwater quality may be expected:

1. Reduction of mean temperature; oxidation of iron pyrite has a temperature dependence that is eightfold for every 10° increase between 5 and 25°C.[46]

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

3. 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.

4. 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.

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

The net result of these five major beneficial processes will be the eventual approach of a very low steady state of pyrite oxidation that may have no significant impact on the environment beyond the boundaries of the presently degraded (surface and subsurface) area.

Table 14 presents data for the 1.5-m minesoil water to show that the rate of acidification, as measured by the aluminum, iron, and manganese

TABLE 14. Concentrations (ppm) of Aluminum, Iron, and Manganese in the Soil-water Extracts of the 1.5-m Sampling Depth of Plots II, III, and IV Analyzed for Significant Variations over Time

		Time of Sampling									
	Plot	20 Nov	4 Dec	17 Apr	16 May	13 Jun	20 Jul	9 Aug	6 Sep	11 Oct	8 Nov
Aluminum	II	113	91.5	204	14.8	14.1	1.96	0.57	1.20	0.20	17.9
	III	-	-	136	412	449	60.9	769	790	336	403
	IV	-	537	-	169	480	311	196	294	119	47.5
Iron	II	14.6	7.36	1.00	<0.10	3.40	0.30	<0.10	0.32	<0.10	<0.10
	III	-	-	396	87.8	237	146	489	786	245	296
	IV	-	485	-	5.94	14.6	14.8	6.40	7.42	1.70	<0.10
Managanese	II	32.5	29.8	46.1	16.9	10.0	8.89	7.95	8.24	7.93	13.8
	III	-	-	20.5	62.3	58.5	27.1	90.3	99.7	38.6	74.1
	IV	-	192	-	74.6	148	58.4	69.7	97.0	44.9	36.5
Cumulative Days between Sampling Centered about Zero		-177	-164	-28	0	+27	+65	+85	+113	+148	+176

Trend-line analysis using cumulative number of days between samplings, centered about zero, as the fixed variable and the concentration as the random variable:

			Interpretation:
Aluminum:	II r = -0.646 df = 9	Decreasing trend:	95% significance level.
	III r = 0.320 df = 7	Increasing trend:	non-significant
	IV r = -0.797 df = 7	Decreasing trend:	95% significance level.
Iron:	II r = -0.830 df = 9	Decreasing trend:	99% significance level.
	III r = 0.243 df = 7	Increasing trend:	non-significant.
	IV r = -0.847 df = 7	Decreasing trend:	99% significance level.
Manganese:	II r = -0.714 df = 9	Decreasing trend:	95% significance level.
	III r = 0.414 df = 7	Increasing trend:	non-significant.
	IV r = -0.853 df = 7	Decreasing trend:	99% significance level.

concentrations, has not accelerated under the dredged material cover as it has in the control plot. (The lack of a pH decrease over time has been demonstrated in Table 13.) Trend analyses were performed using the cumulative number of days between samplings, centered about zero to minimize bias, as the fixed variable and the concentrations as the random variable. The results (Table 14) show that in Plots II and IV the concentrations of these metals are decreasing, while in Plot III no significant trend is evidenced. The missing values for Plot III, at the beginning of the study, caused the trend analyses to be biased, giving undue weight to the later values and inflating the positive r values somewhat.

Trend analyses were also performed for those parameters which, judging from the Plot I data, seemed indicative of acidification. These parameters were specific conductivity, acidity, aluminum, iron, manganese, nickel, zinc, magnesium, and calcium. The results, in Table 15, revealed the following (at ≥ 95% significance level):

1. In the dredged material (0.6 m), over the one-year period of the study.

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

    b. In Plot II, aluminum concentration decreased; in Plot II, acidity decreased.

2. 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.

3. 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 in this report.

The magnitudes of the trace metal concentrations in the dredged material and the interface soil solutions were computed for those values that, over the year of the study, were measurable. The results appear in Table 16. It is suggested that the number of observations above detection limits divided by the total number of observations might be multiplied against the given mean values if an overall mean for the year is desired. The values in parentheses represent irrigation water tolerances for long-term and short-term use. The reason that water quality criteria for long-term use are lower than those for short-term use is that trace metals tend to be retained in the soil, resulting in a buildup over time. Because we are dealing with an in situ soil solution that is irrigated only be rainwater, however, applying the short-term use criterion is conservative-justified. In view of the trends in the results of Table 15, it may be concluded that trace metal concentrations in the dredged material do not present any cause for alarm.

TABLE 15. Trend Analyses: 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
Spec. Cond.	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
Aluminum†	II	-0.821,9**	-0.625,7	-0.646,9*
	III	-0.501,7	-0.673,8*	0.320,7
	IV	0.239,7	-0.757,9**	-0.797,7*
Iron†	II	-0.492,8	-0.011,8	-0.830,9**
	III	0.215,8	-0.283,9	0.243,7
	IV	0.320,7	-0.852,9**	-0.847,7**
Manganese†	II	-0.426,8	-0.002,8	-0.714,9*
	III	-0.297,7	-0.662,9*	0.414,7
	IV	-0.437,7	-0.889,9**	-0.853,7**
Nickel†	II	0.114,8	0.190,8	-0.633,9*
	III	0.071,7	-0.612,9*	0.311,7
	IV	0.473,7	-0.906,9**	-0.801,7**
Zinc	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**
Calcium	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
Magnesium	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% significance level.
** Significant at 99% significance level.
† Using "less than" data at numerical value.

TABLE 16. Trace Components in the Soil Obtained from the Dredged Material (0.6 m) and Dredged Material Spoil Interface (0.9 m) Zone: A Combined Statistical Summary for the Three Treatment Plots

Trace Component	Number of Observations		Number Above Detection Limits		Mean Concentration of Component in Number Above Detection Limits (mg/l)		Coefficient of Variation (%) for Detected Values	
	0.6 m	0.9 m	0.6 m	0.9 m	0.6 m	0.9 m	0.6 m	0.9 m
Al	26	27	8	12	0.21 (1.0, 20)*	7.66	28.9	179
Fe	25	28	22	19	5.62 (- -)	46.3	166	189
Mn	25	28	23	28	4.18 (2.0, 20)	16.0	21.8	107
CN	14	18	14	17	0.019 (- -)	0.016	52.2	40.8
Mg	18	22	15	17	0.00655 (- -)	0.00708	231	222
Cd	26	28	8	10	0.03 (.005, 05)	0.03	35.6	46.7
Cr	25	28	3	3	0.06 (5.0, 20)	0.09	10.2	26.6
Cu	25	28	18	17	0.14 (0.2, 5.0)	0.21	98.6	134
Ni	25	27	20	26	0.23 (0.5, 2.0)	1.27	62.3	127
Pb	25	28	10	12	0.13 (5.0, 20)	0.14	43.9	30.3
Zn	25	30	25	30	2.88 (5.0, 10)	2.92	45.7	46.6

*Trace element tolerances for irrigation waters (for continuous use, for short-term use); bar indicates no tolerance has been set (from Reference 31).

There is evidence that the comparing of soil solution trace metal concentrations to irrigation water criteria may be too conservative for realistic risk assessment. Divalent ions such as calcium and magnesium, for example, will reduce potential plant uptake of a divalent trace metal such as cadmium because of mass action.[48]

The mean values given in Table 16 for the dredged material and dredged material/spoil interface may profitably be compared with the mean values for the same parameters from the spoil solutions under the treatments. The means for these solutions were calculated the same as the means given in Table 16 and are presented in Table 17. It is easily seen that considerably

TABLE 17. Trace Components (ppm) in the Soil Solutions of the Spoil Materials at 1.5 m in the Dredged-material Treatment Plots*

Trace Component	Number of Observations	Number Above Detection Limits	Mean of Detected Values	Coeff. of Var. % For Detected Values
Al	25	25	236	101
Fe	24	20	162	139
Mn	25	25	47.3	76.0
CN	21	10	0.015	64.7
Kg	19	17	0.00619	213
Cd	26	16	0.07	73.8
Cr	24	14	0.44	170
Cu	23	21	0.66	115
Ni	24	24	3.25	75.5
Pb	24	22	0.19	64.2
Zn	25	25	3.49	75.4

*Calculated in same manner as in Table 16.

smaller aluminum, iron, manganese, cadmium, copper, nickel, and zinc concentrations exist in the dredged material soil solutions as compared with the spoil solutions. The Table 17 comparison is a more conservative comparison than the comparison with control plot trace metal concentrations since these were previously shown to have increased with the demonstrated accelerations of pyrite oxidation that followed surface exposure.

TABLE 18. Water Quality Comparison for Wells 1 and 2

Parameter (ppm)	Well 1		Well 2	
	$\bar{x}$	C.V. %	$\bar{x}$	C.V. %
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[a]	245	2.6[a]	143
Fe	99[a]	278	217[a]	36.9
Mn	3.96[a]	142	8.20	35.0
Cu	0.12[a]	143	<0.05	--
Cr	0.14[a]	135	<0.05	--
Cd	0.07[a]	204	<0.02	--
Ni	0.22[a]	153	0.64	30.2
Pb	0.34[a]	126	0.13	63.4
Zn	193[a]	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
Tot. -P	0.08	84.4	0.05	--
PO_4-P	0.05	--	0.05	--
$S^=$	7.65[a]	297	5.57[a]	251

[a] Values initially very high, then rapidly decreasing, usually to the limit of detection.

D. Quality of Groundwater

The Appendix A data for Wells 1 and 2, as summarized in Table 18, show two relatively stable and uniform groundwaters that reflect the fact that Well 1 was completed in the underclay and Well 2 in the St. Peter sandstone (see Appendix I).

The trace metal content and sulfide content for both wells was initially very high, but tapered off rapidly for most species to near below detection limits for the remainder of the sampling period. This trend probably reflects initial contamination related to well drilling. Zinc contamination (Table 18) from the well casings was expected.

Well 1 ended in the underclay and Well 2 in the St. Peter sandstone (Appendix I). It may be inferred from the well-water data that leachates from the overlying spoil have not contaminated groundwater at these depths and locations.

APPENDIX A

Water Quality Data for 9 November 1977-13 November 1978

Data Tables

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

Acidity	A.1
Alkalinity	A.2
pH	A.3
Chloride	A.4
Specific Conductance	A.5
Cyanide	A.6
Ammonia Nitrogen	A.7
Nitrate + Nitrite Nitrogen	A.8
Total Kjeldahl Nitrogen	A.9
Orthophosphate	A.10
Total Phosphorus	A.11
Silica	A.12
Sulfate	A.13
Sulfide	A.14
Calcium	A.15
Magnesium	A.16
Sodium	A.17
Potassium	A.18
Strontium	A.19
Aluminum	A.20
Cadmium	A.21
Chromium	A.22
Copper	A.23
Iron	A.24
Manganese	A.25
Nickel	A.26
Lead	A.27
Zinc	A.28
Mercury	A.29

Data Reliability

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

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.

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:

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

2. Near-neutral well samples (W1 and W2) tended to be an average of 10% 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.

3. Acid spoil samples, 26 in all, were an average of 10% low on the measured values; 72% 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:

$$\text{calc. } SO_4 = 958 + 0.78 (\text{meas. } SO_4) \tag{A.1}$$

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

4. 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:

$$\text{calc. } SO_4 = 1626 + 0.43 (\text{meas. } SO_4) \tag{A.2}$$

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

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% uncertainty of the method. (<u>Standard Methods</u>[11] described a 9.7% relative standard deviation for 19 laboratory determinations of sulfate, for a sample that required a 1/10 dilution).

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 ethylenediaminetretraacetic 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.

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% or less for most of the calculated coefficients of variation.

Examples of Symbols Used in This Appendix

L1 = soil water sampler No. 1

W1 = observation well No. 1

$F1_I$ = initial runoff sample at flume No. 1

$F1_M$ = midpoint or peak runoff sample at flume No. 1

$F1_F$ = final runoff sample at flume No. 1

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

Note: See Fig. 3 for location of soil-water samplers, etc.

TABLE A.1. 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.	3620.		194.		3670.	2,780.	10,000.	3,610.	
L2 + L4								156.	sample	175.		121.		47.5	185.	150.	73.6	
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				550.	822.	823.				759.		851.		389.	601.	842.	536.	
$F1_I$					945.		1340.											
$F1_M$							236.										3,700.	
$F1_F$							169.				1820.		842.					2,700.
$F2_I$							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 A.2. 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								183.		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								152.		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	
$F1_I$					--		--											
$F1_M$							--										--	
$F1_P$							--				--		--					--
$F2_I$							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											
$F4_M$							19.6											
$F4_P$							22.9				19.7		13.8					
R							--											

TABLE A.3. 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	3C 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	5.93		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 A.4. 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	25 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 A.5. 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 A.6. 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	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
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		0.0843	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 A.7. 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 1978
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											
$F1_M$							0.29										0.24	
$F1_F$							0.29				2.34		INTERF.					0.24
$F2_I$							0.26											
$F2_M$							0.23											
$F2_F$							0.19											
$F3_I$					0.09		0.24											
$F3_M$							0.24											
$F3_F$							0.25				0.44		1.25					
$F4_I$							0.17											
$F4_M$							0.18											
$F4_F$							0.25				0.48		0.60					
R							0.30											

TABLE A.8. 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 A.9. 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	7.30	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	3.55	3.00	3.85	
L20																		
L21																		
L22																		
L23																		
W_		3.20		1.55		4.4			2.15	4.25		8.25		2.75	1.50	2.20	2.00	
W:		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 A.10. 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	0.43	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 A.11. Total Phosphorous (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								<0.05	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	<0.05	
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											
$F1_F$							<0.05				3.50		0.40					
$F2_I$							0.05											
$F2_M$							0.10											
$F2_F$							0.05											
$F3_I$					0.10		0.15											
$F3_M$							0.10											
$F3_F$							0.10				0.40		0.20					
$F4_I$							0.15											
$F4_M$							0.10											
$F4_F$							0.10				0.35		0.35					
R							<0.05											

TABLE A.12. 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														
L14	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 A.13. 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		2,500				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 A.14. Sulfide (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
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 A.15. 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	505			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 A.16. 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	26 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			134	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	
$F1_I$					197		242.											
$F1_M$							72.3										1,130	
$F1_F$							41.8				261		235					390
$F2_I$							43.9											
$F2_M$							17.3											
$F2_F$							12.2											
$F3_I$					35		31.7											
$F3_M$							9.63											
$F3_F$							9.63				6.33		2.62					
$F4_I$							17.7											
$F4_M$							8.10											
$F4_F$							7.49				2.62		2.07					
R							24.1											

TABLE A.17. 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	8 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 A.18. 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	25 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		1.21		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 A.19. 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	27 NOV 1977	4 DEC 1977	17 DEC 1977	30 MAR 1973	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			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	2.4	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	4.7	
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										<0.5	
$F1_F$							<0.5				0.9		<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 A.20. 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		1.95		0.57	1.20	0.20	17.9	
L8																		
L9																		
L10																		
L11 + L14		0.14			0.21			0.23	<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 A.21. 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 A.22. 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	1[illegible] 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 A.23. 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															
L2 + 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		0.10		<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	
$F1_I$					0.08		0.27											
$F1_M$							<0.05										0.25	
$F1_F$							<0.05				0.35		0.18					<0.05
$F2_I$							<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	[illegible]				
$F4_I$							<0.05											
$F4_M$							<0.05											
$F4_F$							<0.05				<0.05		<0.05					
R							<0.05											

TABLE A.24. 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 A.25. 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	6.03	
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		6.21	5.53	9.24			13.6	9.03		10.4		8.09	10.89	6.27	6.88	
$F1_I$					11.4		17.0											
$F1_M$							4.60										47.8	
$F1_F$							2.29				17.6		15.6					27.6
$F2_I$							<0.02											
$F2_M$							<0.02											
$F2_F$							<0.02											
$F3_I$					0.09		<0.02											
$F3_M$							<0.02											
$F3_F$							<0.02				0.04		0.04					
$F4_I$							<0.02											
$F4_M$							<0.02											
$F4_F$							<0.02				<0.02		<0.02					
R							<0.02											

TABLE A.26. 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	10.4	
L2 + L4		0.05			<0.05			0.32	0.50	0.55		0.20		0.20	0.37	0.26	0.37	
L3			6.66															
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				0.08	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	0.71	0.39	0.40	
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	0.64			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 A.27. 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	0.10	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	0.15	
L7																		
L7 + L10		<0.05		0.11				0.15	0.19	0.05		0.05		<0.05	0.28	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		0.16	0.19	
L13																		
L13 + L16								0.17	0.19	0.05		0.05		0.10	0.47	0.20	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	0.26	
$F1_I$					0.05		0.12											
$F1_M$							<0.05										0.26	
$F1_F$							<0.05				0.05		0.05					0.13
$F2_I$							<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 A.28. 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	0.09														
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		123.	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	
$F1_F$							0.25				1.06		0.78					1.85
$F2_I$							0.06											
$F2_M$							0.04											
$F2_F$							<0.05											
$F3_I$					0.21		<0.05											
$F3_M$							<0.05											
$F3_F$							<0.05				0.08		0.06					
$F4_I$							<0.05											
$F4_M$							<0.05											
$F4_F$							<0.05				<0.05		0.06					
R							<0.05											

TABLE A.29. 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

Meteorological Data

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.

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.

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.

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.

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

From these considerations it may be seen, however, that rainfall values reported for a total event would overcome this 8-h 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.

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.

Table B.1 gives the daily reported precipitation amounts for rain gages at Marseilles Lock, Ottawa, Illinois, 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.

Table B.2 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 B.3, together with data from the recording gage at the demonstration site that came on line in August 1978.

Per event rainfall totals for all five stations are given in Table B.4.

From Tables B.1 and B.4, one may infer that there were some omissions in Mr. Johnston's reports. In particular, the December 1, 1977, and January 1, 1978, storms appear to have been missed, as well as August 16 and October 18 storms of 1978.

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 B.5.

From Table B.5 it may be seen that 97% 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.)

TABLE B.1. Total Daily Precipitation, Marseilles Lock/Ottawa/Utica-Starved Rock, Illinois

Day	77 Oct	77 Nov ↓	77 Dec	78 Jan	78 Feb	78 Mar	78 Apr	Day
1	1.43/1.46/1.02	.35/ .38/ .42	.60/ .50/ .35	.31/.28/.52	↓T			1
2		.77/ .20/ .54	T/ / T	.01/ /.01	.01/ T/.02	.05/	.17/ .35/ .34	2
3		.01/ / T			.02/	.12/ .07/ .13	.22/ / .01	3
4					.03/.06/.01		T/ .05/ T	4
5	.05/ .02/ .02		/ .12/ T		.05/.02/.04		.05/ T/ .03	5
6			.24/ .16/ .35	T/ /			1.15/1.17/ .98	6
7	/ .47/	.12/ .14/ .13		T/.05/	T/ / T		.04/ / .02	7
8	.98/ .57/1.04	T/ / .03	T/ .36/	.09/.02/.02	T/ /		T/ .04/ .03	8
9		.03/ .04/ .04	.40/ / .35	T/ T/ T			.02/1.06/	9
10	T/ .18/	.05/ / .01	T/				.51/ .01/ .87	10
11	.15/ / .16	.01/ / T					.55/ / .53	11
12				/.12/				12
13			T/ / T	.16/.08/.14	.36/ /			13
14		.02/ / .01	T/ / T	.05/.05/.07	.51/.02/.37	.10/ .33/ .25		14
15	T/ .06/				T/ / T	T/ / .01		15
16	.06/ T/ T			T/	T/ / T	/ / T		16
17		.19/ / .01	.02/ / .01	T/				17
18			/ .01/				.75/ .71/ .90	18
19				T/.01/ T			.03/ .01/ .01	19
20		.10/ .26/ .02	.56/ .58/ .26	.04/.06/.03			.03/ /	20
21		T/ / .01	.38/ .13/ .08	T/ /.01	T/ / T	.25/ .22/ .15	.13/ .14/ .10	21
22	/ .07/		.03/ / T					22
23	.03/ .13/ .11	.03/ / .05			.02/.01/.01		.07/ .05/ .05	23
24	.17/ .04/ .18	.04/ / .01		.01/.10/.01	T/ /.01		.01/ .03/ .06	24
25	.73/ .60/ .81	.21/ .32/ .15		T/ /.04		.22/ .51/ .19	.55/ .50/ .46	25
26		.01/ / T		.24/.23/.03		.25/ .10/ .28		26
27		.15/ .25/ .04		.12/ /.03		.04/ / .04		27
28		.15/ / .08	T/ T/ T	T/ /				28
29								29
30								30
31	↓/ .31/			↓.01/ T/ .01				31
Totals	3.60/3.91/3.39	2.24/1.59/1.55	2.23/1.86/1.40	1.04/.98/.92	.62/.49/.46	.98/1.28/1.05	4.28/4.12/4.39	Totals

Day	78 May	78 Jun	78 Jul ↓	78 Aug ↓	78 Sep	78 Oct	78 Nov	Day
1			.03/ / .04	.03/				1
2			.69/ .31/ .22	T/ .02/ T				2
3			.03/ / .02	T/ /		.52/ .46/ .38		3
4	.32/	T/ /	T/ /					4
5	.61/ .29/ .67					.06/ .12/ .13		5
6	.08/ .02/ .06					.05/ .02/ .03	.46/ .74/ .60	6
7	.61/1.02/ .71	.02/ .02/ T	T/ / T				.06/ / T	7
8	.72/ .17/ .58	.19/ .37/ .32	.08/ .08/					8
9	.01/	/ / .01	/ / .11	T/ .20/ .02				9
10	T/ / T					.03/ .08/ .01		10
11	.02/ .70/ .05		/ .05/	.24/ .33/ .34	/ T	.04/ / .03		11
12	.98/ .48/1.38						T/ .01/ T	12
13	.64/ .97/1.20		1.01/ .95/1.88		.03/ .20/ .23	.03/ .09/ .03	.28/ .44/ .43	13
14	.42/ .09/ .58		T/ /		T/ .27/ .16	.02/ .01/	.09/ / .06	14
15	.04/ .02/ .05				.12/ / .06	.01/ / T		15
16		/ .65/ .04	.06/1.00/ .95	.05/ .67/ .34		T/ / .01	/ T/	16
17		1.10/ .45/ .71	.11/ / .04		2.37/2.46/3.09		.47/ .57/ .49	17
18		.11/ .09/ .13		.50/ .49/ .27	1.50/1.91/3.26	/ .20/	.08/ / .04	18
19			/ / .01	.03/ .03/ .05	.43/ / .48	.19/ / .16		19
20		/ .51/	.03/ / .01				T/ .03/	20
21		.71/ .01/ .30	.02/ .35/ .27		.12/ .10/ .53		.03/ .05/ .03	21
22			.30/ T/ .42		.03/ /		T/ / .01	22
23	.06/ .04/ .04		.14/ .60/ .55			.52/ .50/ .60	.48/ .50/ .48	23
24	.06/ / .06			.03/ .38/ .28				24
25		/2.33/		.18/ / .07		.03/ .51/ .07		25
26		3.11/ .48/1.95	/ .89/			.44/ / .54	/ .02/	26
27		.06/ .02/ .04	1.19/ / .44	T/ .02/ T			.34/ .33/ .39	27
28		.01/ / .03		/ / T			.03/ T/ .03	28
29			/ .04/				T/	29
30	T/ .09/	.05/ .15/ .04	.07/ / .15		.44/ .40/ .36		T/ / .01	30
31		↓	↓					31
Totals	4.25/4.21/5.38	5.36/4.70/3.57	3.76/4.27/5.11	1.03/2.17/1.37	5.04/5.34/6.17	1.94/1.99/1.99	2.32/2.67/2.56	Totals

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

TABLE B.2. Water Equivalents for Snowfalls at the Ottawa Weather Service Gage

Day	Nov 1977		Dec 1977		Jan 1978		Feb 1978		Mar 1978	
	Snow	H_2O	Snow	H_2O	Snow	H_2O	Snow	H_2O	Snow	H_2O
1					4.0	0.28[a]	0.3	T		
2			2.0	0.50[a]			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[a]			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[a]		
15										
16										
17										
18										
19					0.5	0.01				
20			2.5	0.58[a]	1.0	0.06				
21			1.5	0.13						
22										
23							0.3	0.01		
24					0.5	0.10[a]				
25	3.5	0.32[a]							0.9	0.51[a]
26					3.0	0.23			0.3	0.10[a]
27	2.5	0.25								
28			0.2	T						
29										
30										
31					0.3	T				

[a] Temps. at or above 32°F during the day, numbers not used.

TABLE B.3. 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[a]					0.48	0.07			/MISDA	1
2												0.43/0.46	/MISDA	2
3					0.01[a]	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[a]					0.06						T/MISDA	6
7			0.17			0.05		0.31	0.04				/MISDA	7
8		0.47[a]				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[a]				1.43		1.05		0.19/0.19	/0.01	0.29/0.03	12
13		0.03	0.12[a]	0.35[a]			1.21				0.15/		/0.32	13
14				0.03[a]	0.25						/0.25			14
15				T						0.45/0.54			0.16/0.06	15
16		0.16[a]					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[a]	0.09[a]					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[a]				0.22	0.46		2.21				0.39/0.45		25
26			0.20[a]					0.07	0.81				/0.07	26
27	0.31[a]				0.02								/0.14	27
28		0.04[a]						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[a]										/MISDA	record	31

[a] Water equivalent = $\frac{\text{"snow"}}{12.8}$.

TABLE B.4. 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	

T = Trace Reported

* = End of Report: Missing Data or No Rainfall

() =Estimated Amounts

TABLE B.5. Three-way Linear Correlation for Stations* A, B, and C of Table B.4

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

---

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

**Significant at the 99% confidence level.

†$S_{xy} = \frac{1}{n-1} (\sum_i x_i y_i \quad \frac{1}{n} \sum x_i y_i)$. Symmetrical in x and y.

Data of Table B.5 imply that valid event comparisons may be made for precipitation totals over relatively short periods of time using linear statistical relationships.

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 B.6.

TABLE B.6. Three-way Linear Correlation for Stations* A, B, and D of Table B.4

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

---

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

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

Table B.6 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 B.5.

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.

A comparison of data in Tables B.1 and B.3 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 B.4 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.

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 B.7.

Comparison 1 in Table B.7 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 B.7 shows that for the 20 events during which Mr. Johnston recorded rainfall, his data correlated almost perfectly with the combined Marseilles and Ottawa gages. Data from the demonstration site gate did not compare as well over the same period, however. Inspection of the data in Table B.4 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.

The regression equations for the precipitation values from Marseilles Lock and Ottawa gages versus Mr. Johnston's gage (Table B.6 and Comparison 3 of Table B.7) 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 B.4 for each questioned event.

TABLE B.7. 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

$R^2 = 0.96$

$E = 0.14 - 0.01A + 0.59B$

Table B.4 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 taken as max + min/2, and daily highs at or below 32°F; and daily means at or below 32°F determined freezing or near-freezing days for the purposes of this study. For missing values in the Ottawa record, values for Peru, Illinois, 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 B.8.

Use was made also of the daily evaporation rate at the Hennepin Power Plant, about 32 miles southwest of Ottawa. Pan evaporation is a function of temperature, relative humidity, and wind. Using Hennepin Power Plant pan evaporation rates 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 B.9.

TABLE B.8. Mean Daily and Monthly Temperatures for Ottawa, Illinois

	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[a]	14[b]	24[a]	59	46	77	80	73	74	59	48	1
2	65	35	9[b]	14[b]	23[b]	42	48	70	80	76	75	61	55	2
3	64	25[a]	14[b]	14[b]	23[b]	59	50	67	74	71	79	63	59	3
4	58	24[b]	27[a]	13[b]	12[b]	64	53	68	74	69	70	59	(65)	4
5	55	33[a]	35	15[b]	14[b]	47	44	70	76	70	74	59	64	5
6	58	13[b]	33	8[b]	30[a]	57	49	75	80	71	77	51	55	6
7	59	7[b]	36	13[b]	30[a]	58	52	78	80	74	80	50	43	7
8	60	17[b]	21[a]	18[b]	32[a]	56	61	68	76	71	81	49	46	8
9	55	9[b]	0[b]	21[b]	28[a]	58	60	(67)	76	79	81	59	(53)	9
10	39	-1[b]	3[b]	20[b]	35	56	59	67	67	73	(78)	63	53	10
11	35	6[b]	(9)[b]	20[b]	(36)	52	67	78	68	75	82	57	49	11
12	32[a]	27[a]	14[b]	26[a]	39	59	70	80	(70)	77	80	59	45	12
13	(31)[a]	38	19[b]	26[b]	35	48	61	63	78	78	83	52	54	13
14	(44)	33	22[b]	27[a]	37	46	46	66	72	79	80	48	46	14
15	53	35	12[b]	23[b]	37	49	55	73	78	83	72	48	36	15
16	47	40	13[b]	14[b]	33	47	58	75	74	78	78	50	38	16
17	42	50	17[b]	11[b]	30[a]	44	60	80	76	74	74	47	47	17
18	43	44	18[b]	12[b]	32[a]	52	66	79	78	82	75	52	45	18
19	42	38	25[b]	12[b]	42	51	68	71	81	78	82	50	38	19
20	51	29[a]	23[b]	17[b]	43	41	73	76	(83)	69	82	58	32[a]	20
21	38	24[b]	14[b]	16[b]	44	45	(64)	67	82	69	67	66	29[b]	21
22	(32)[a]	23[b]	12[b]	14[b]	51	44	60	70	81	77	59	(59)	32[a]	22
23	(37)	33	23[a]	26[b]	48	59	67	74	76	(74)	61	(59)	38	23
24	35	31[a]	28[a]	33	40	56	67	77	70	78	65	47	35	24
25	24[a]	15[b]	26[b]	32[a]	31[b]	55	74	80	73	75	63	55	31[a]	25
26	11[b]	11[b]	17[b]	21[b]	33	53	80	80	77	(77)	62	50	35	26
27	22[b]	7[b]	6[b]	23[b]	39	54	80	83	74	78	62	52	35	27
28	18[b]	19[b]	9[b]	29[a]	50	58	77	73	71	79	58	49	29[a]	28
29	21[b]	31[a]	7[b]		46	60	79	79	76	72	62	(53)	31[a]	29
30	25[a]	25[a]	9[b]		46	50	76	81	67	73	67	(56)	26[a]	30
31		30[a]	12[b]		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	

[a] Denotes a "near freezing day," a mean at or below 32°F but a high above 32°F.
[b] Denotes a freezing day, with a high at or below 32°F.
NOTE: ()=estimated value, using Peru, IL, data

TABLE B.9. 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 C

Liquid Precipitation and Air Temperature at the Ottawa Site as Measured by the Argonne Instrument Package, August-November 1978

by

L. S. Van Loon*

Argonne's Instrument Package

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

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).** The recording package is described later.

The rain gage (Fig. C.1) 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, tamperproof housing for the electronic recording package used with the rain gage. The pipe is 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 (Fig. C.1) to keep a moderate temperature within the pipe containing the recording package.

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

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**L. S. Van Loon, A. A. Frigo, and R. A. Paddock, 1978, Argonne National Laboratory's Thermal Plume Measurements: Instruments and Techniques, Argonne National Laboratory Report ANL/WR-77-4, 63 pp.

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 three months unattended operation at the 8-min sampling interval. The cassette tape is usually replaced monthly to ensure that the system is operating properly.

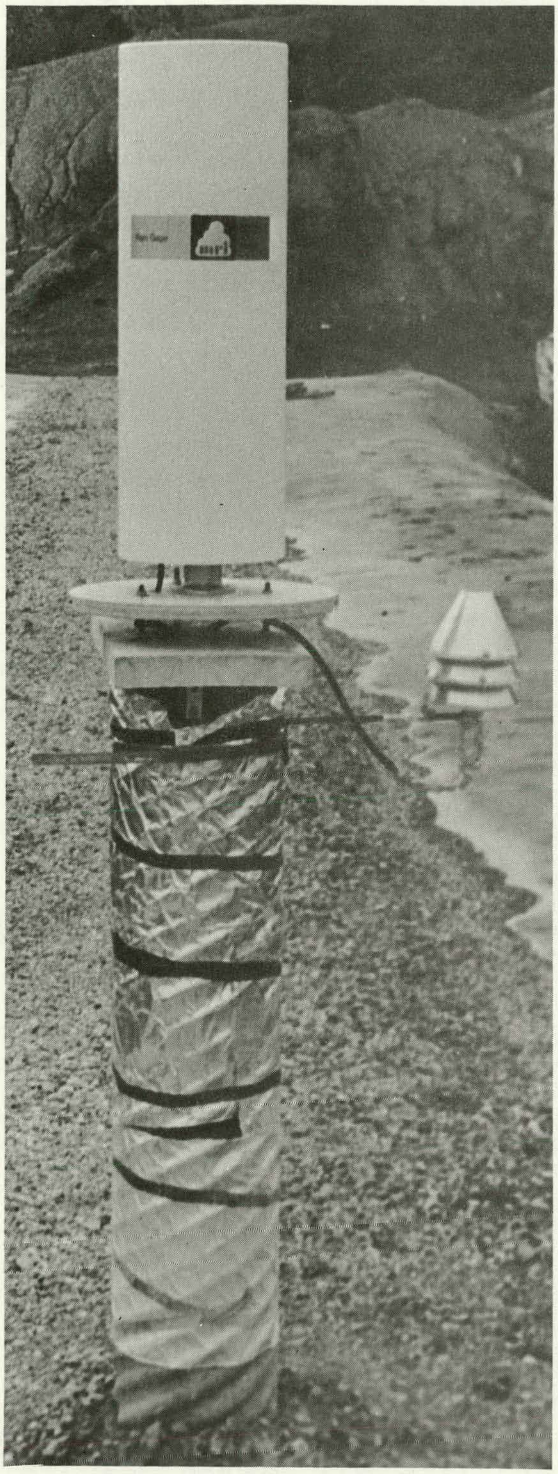

Fig. C.1. Rain Gage Atop Mounting Pipe and Thermistor Fixture to Right-hand Side

A cylindrical, polyvinyl chloride (PVC) waterproof vessel of 6-in. (152-mm) diam 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 (Fig. C.1).

Data Reduction and Display

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 h period (midnight-to-midnight) in which a rainfall event is recorded.

Temperature and rainfall data for the period 9 August 1978-20 November 1978 are available from the authors of this report. The temperature data are displayed as a continuous record (cf. Fig. C.2); rainfall data are presented only for those days that rainfall occurred (cf. Fig. C.3). (All of the rainfall data are plotted in Appendix D.)

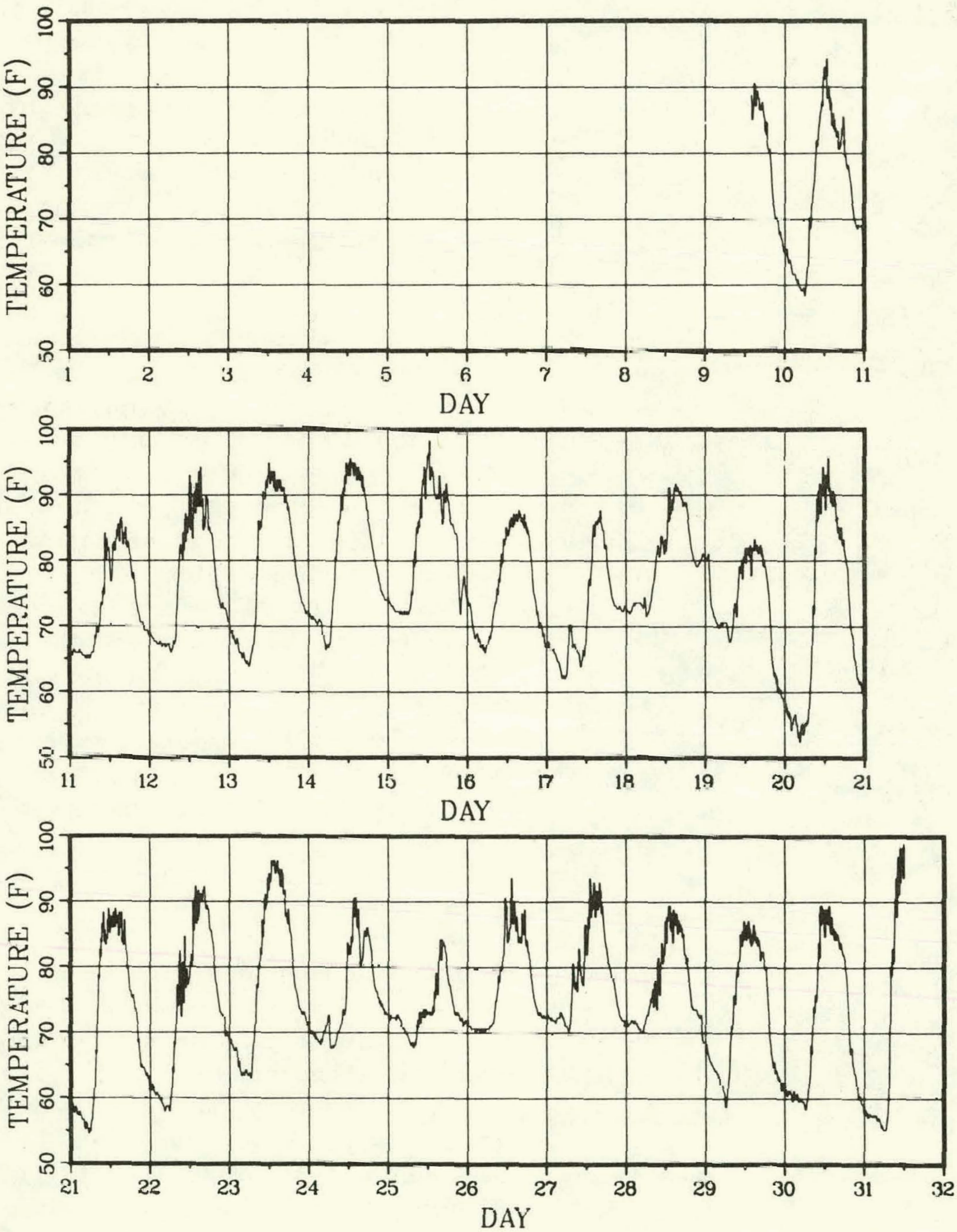

Fig. C.2. Temperature Record for August 1978

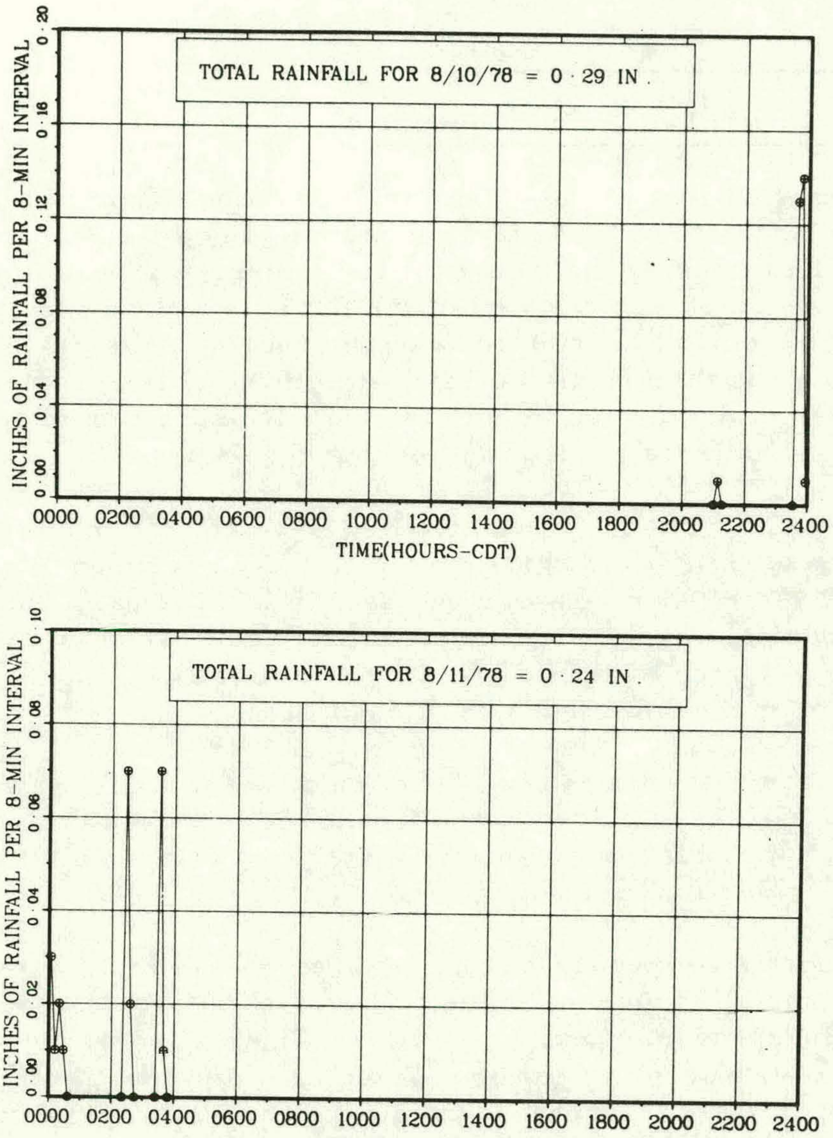

Fig. C.3. Rainfall Records for August 10 and 11, 1978

APPENDIX D

Equipment and Methods for Monitoring Runoff and Rainfall/Runoff Data for the Period April-November 1978

by

Conrad Tome*

Description of Runoff Monitoring Equipment

The Parshall flume** 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.

Four Parshall flumes were installed, leveled, and backfilled on two sides to make them an integral part of the dikes surrounding Plots I-IV. Later a 3-ft (0.9-m) 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 (Fig. D.1) to prevent erosion on the downflow side of each flume.

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.

To facilitate continuous monitoring, Stevens Type F water level recorders† were installed on each flume. They are self-contained, 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 eight days while the chart permitted recording changes of as little as 0.01 ft.†† 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.

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*Engineering Assistant, EES Division, Argonne National Laboratory.

**Manning Environmental Corp., 120 DuBois St., P.O. Box 1356, Santa Cruz, California, 95061, Publication No. FL-778.

†Leupold and Stevens, Stevens Resources Data Book, Second Edition, Revised June 1975, pp. 45-57.

††Stevens Type F Water Level Recorder Spec. Sheet, Bulletin 24, 17th Edition.

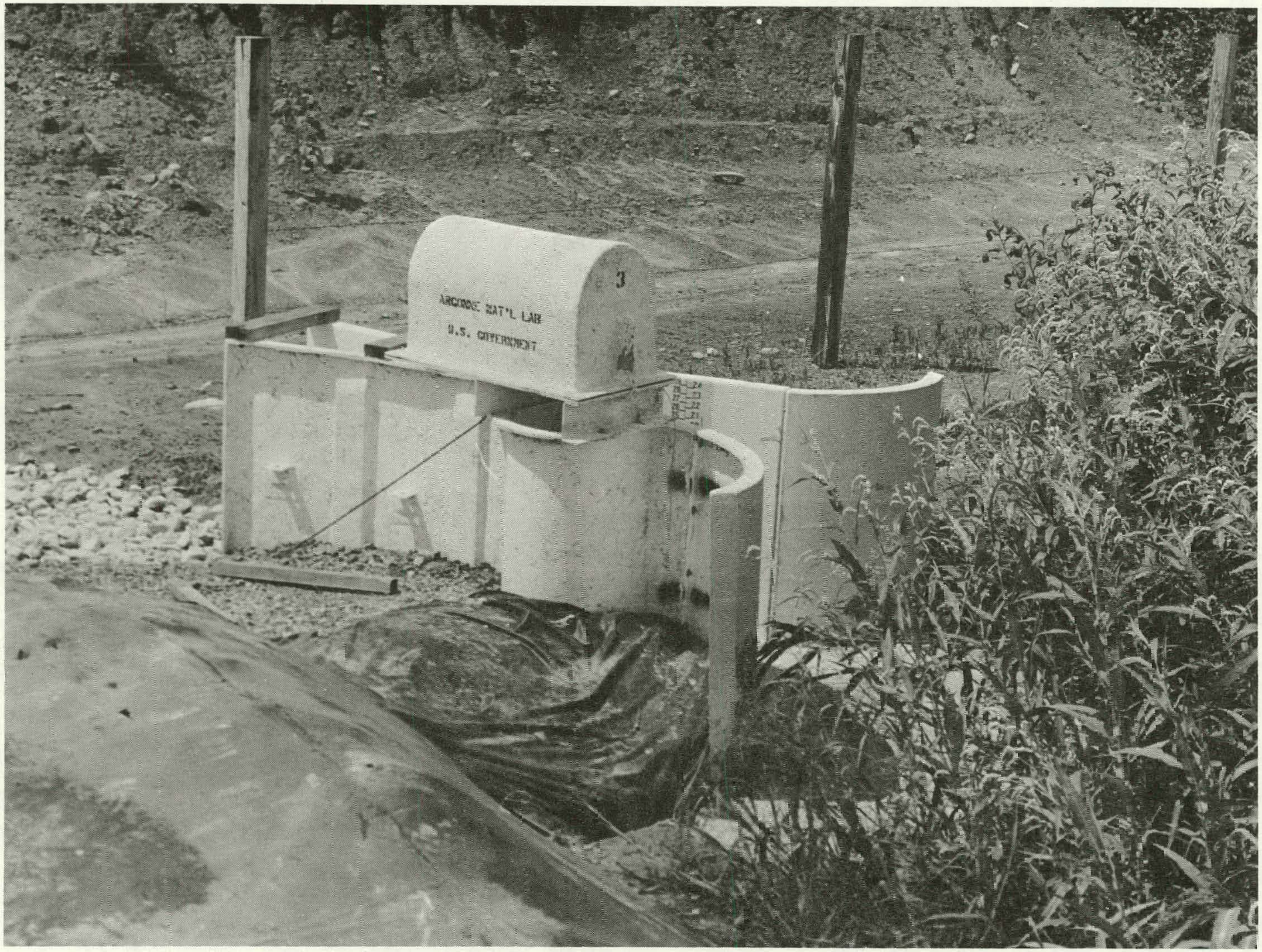

Fig. D.1. Flume at South Corner of Plot III. Water flow from right to left. Stevens recorder under housing.

Data Reduction and Presentation

Chart data were reduced by measuring the length of the spike in each runoff record and comparing this value to the table* 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 two 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, in Figs. D.1-D.9.

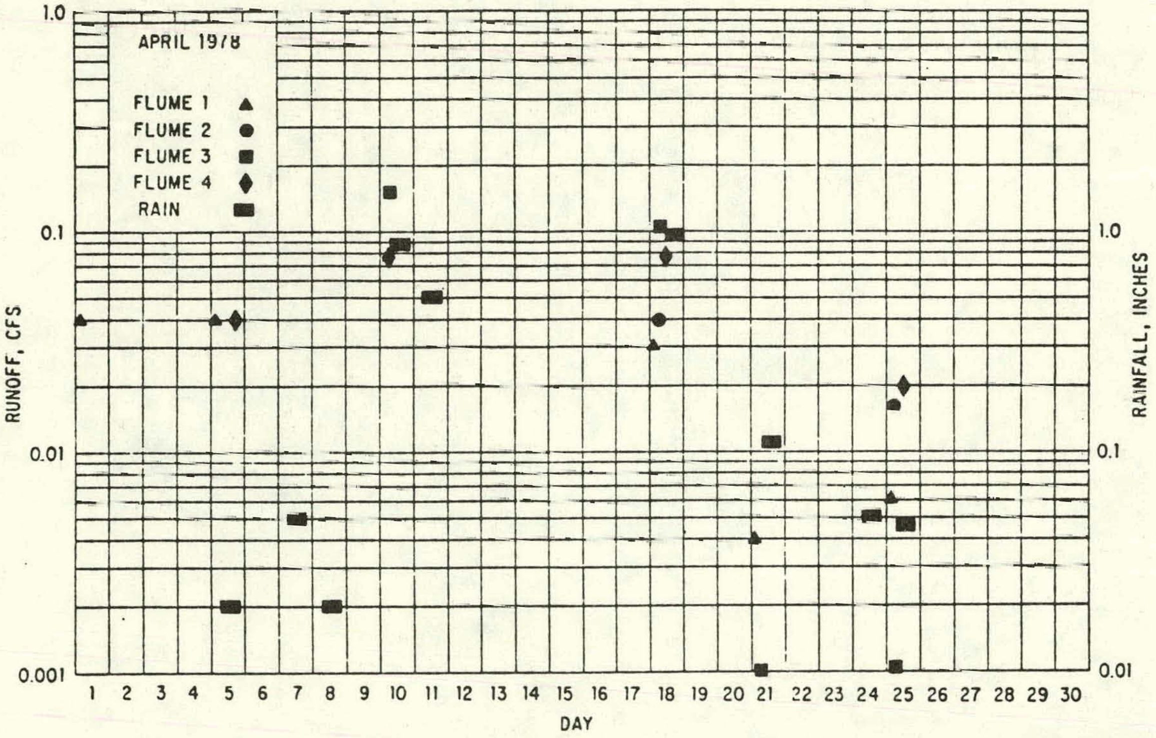

Fig. D.2. Rainfall and Runoff Data, April 1978

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*See third footnote on p. 92.

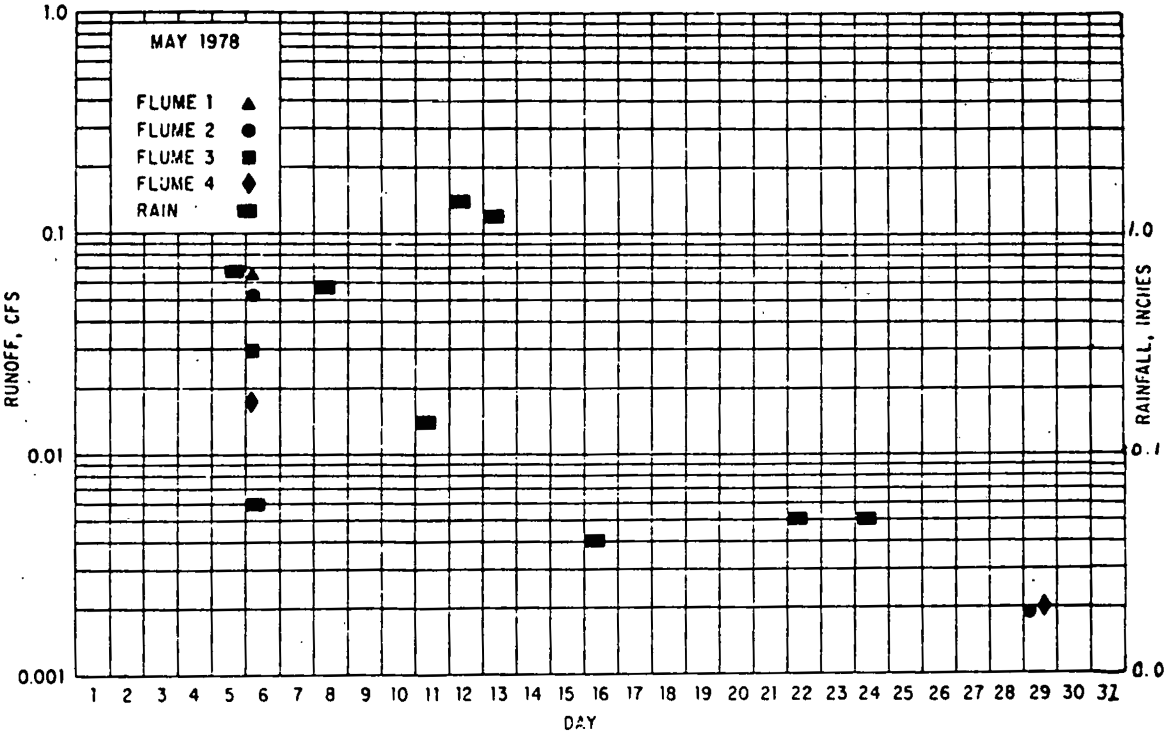

Fig. D.3. Rainfall and Runoff Data, May 1978

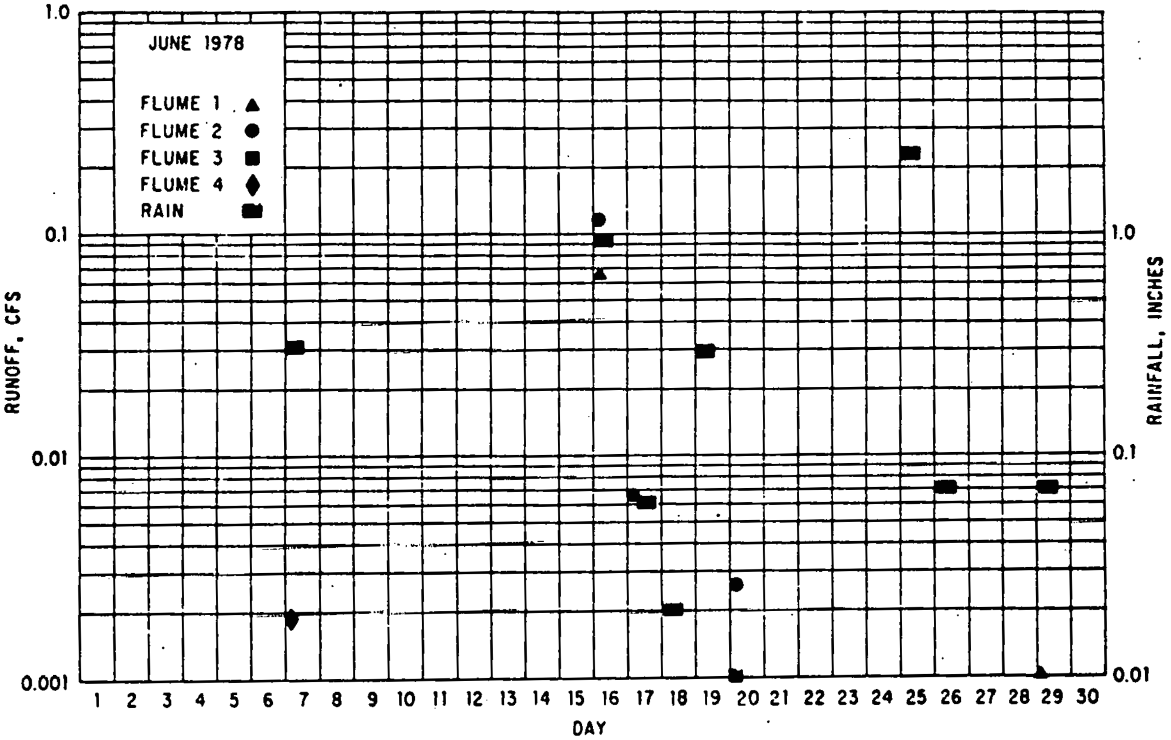

Fig. D.4. Rainfall and Runoff Data, June 1978

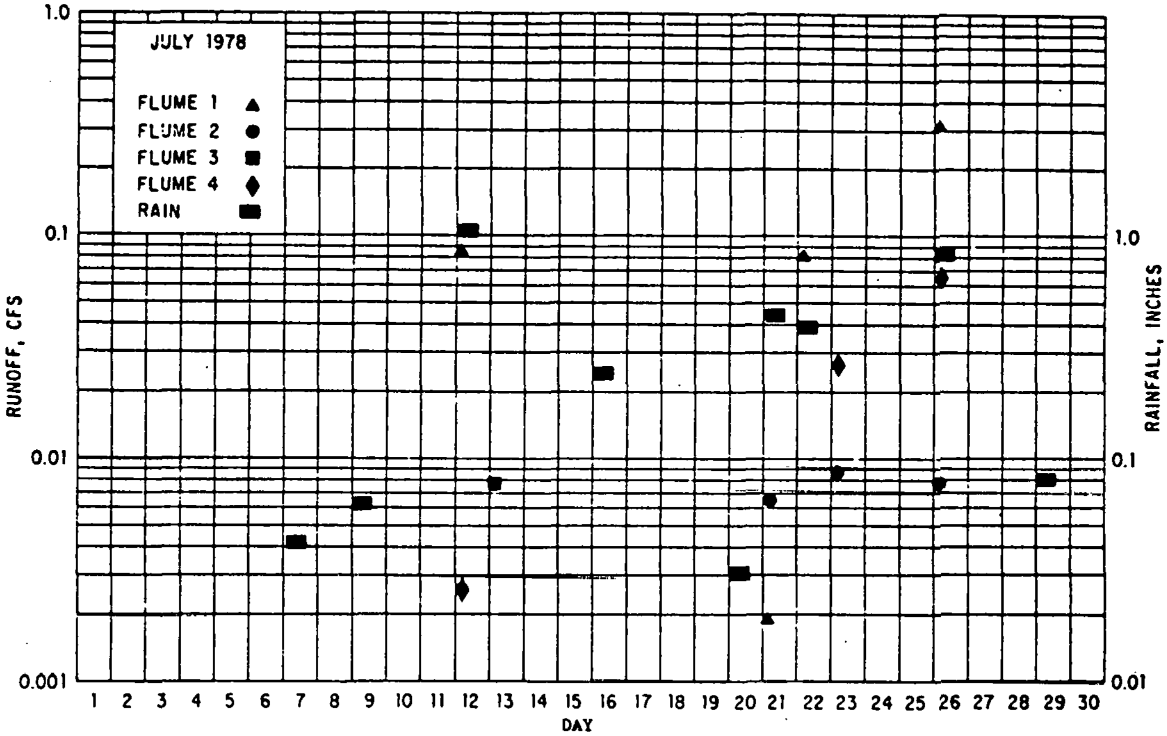

Fig. D.5. Rainfall and Runoff Data, July 1978

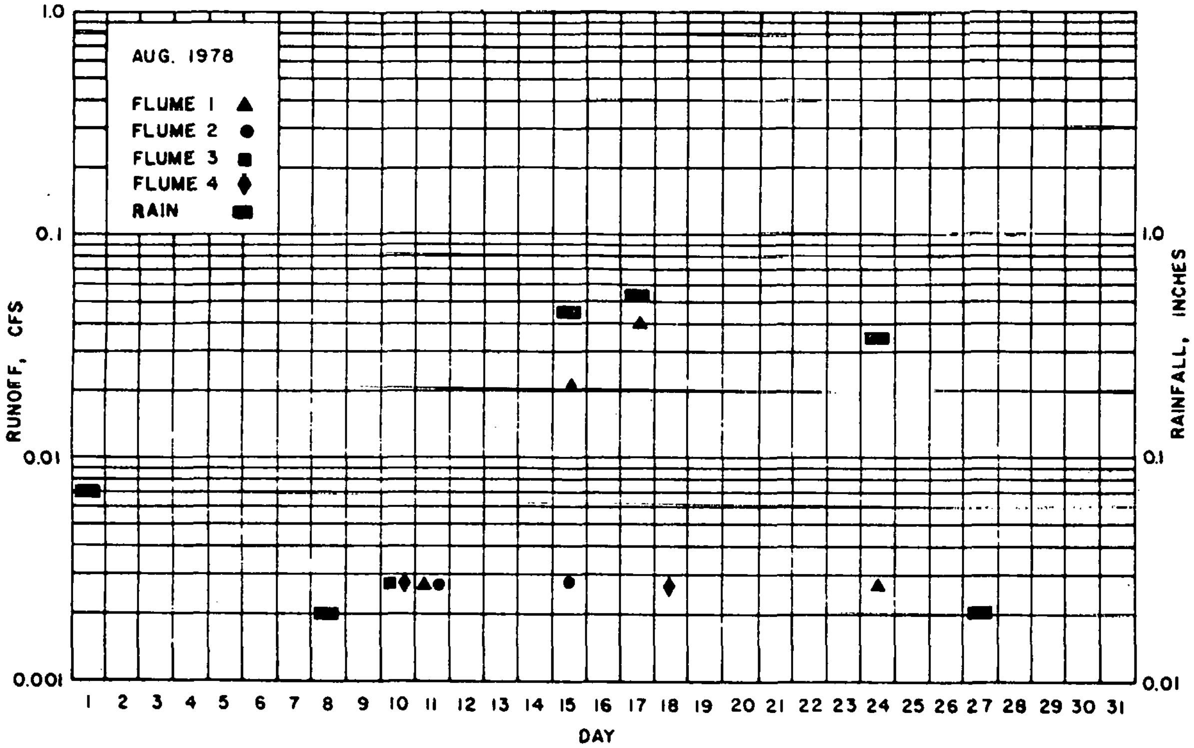

Fig. D.6. Rainfall and Runoff Data, August 1978

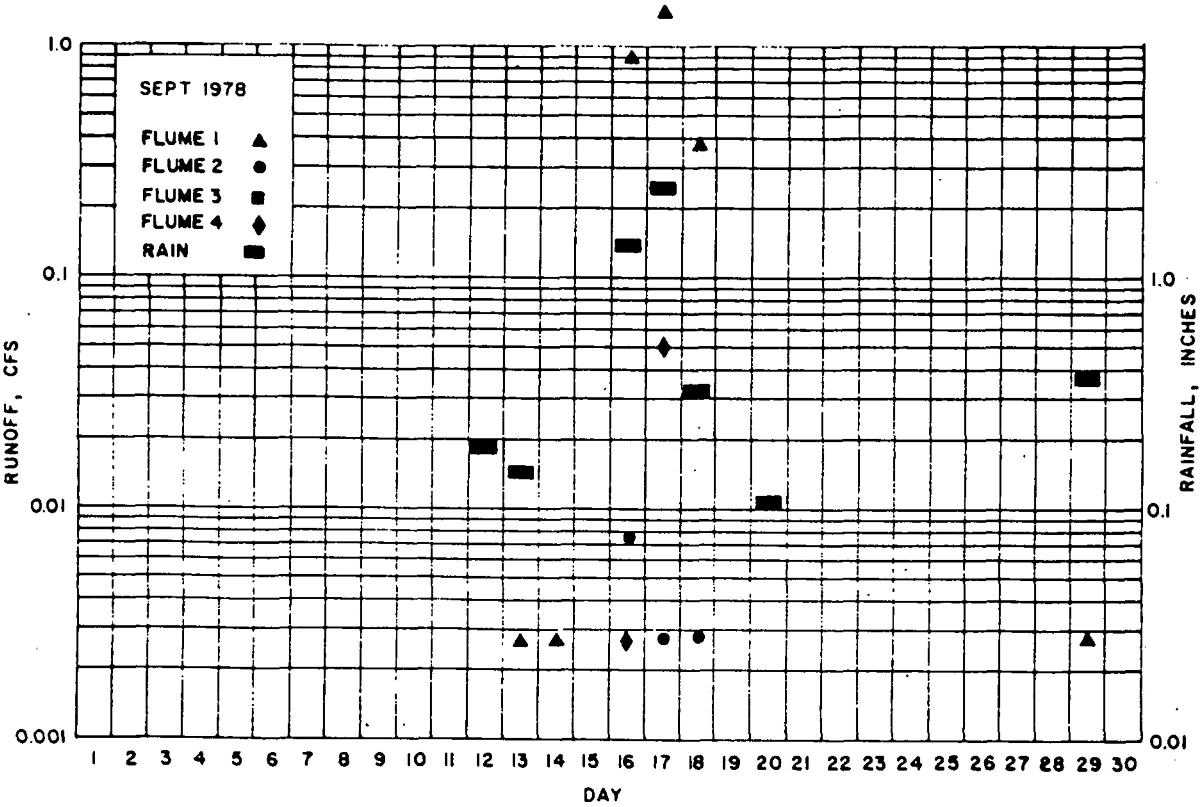

Fig. D.7. Rainfall and Runoff Data, September 1978

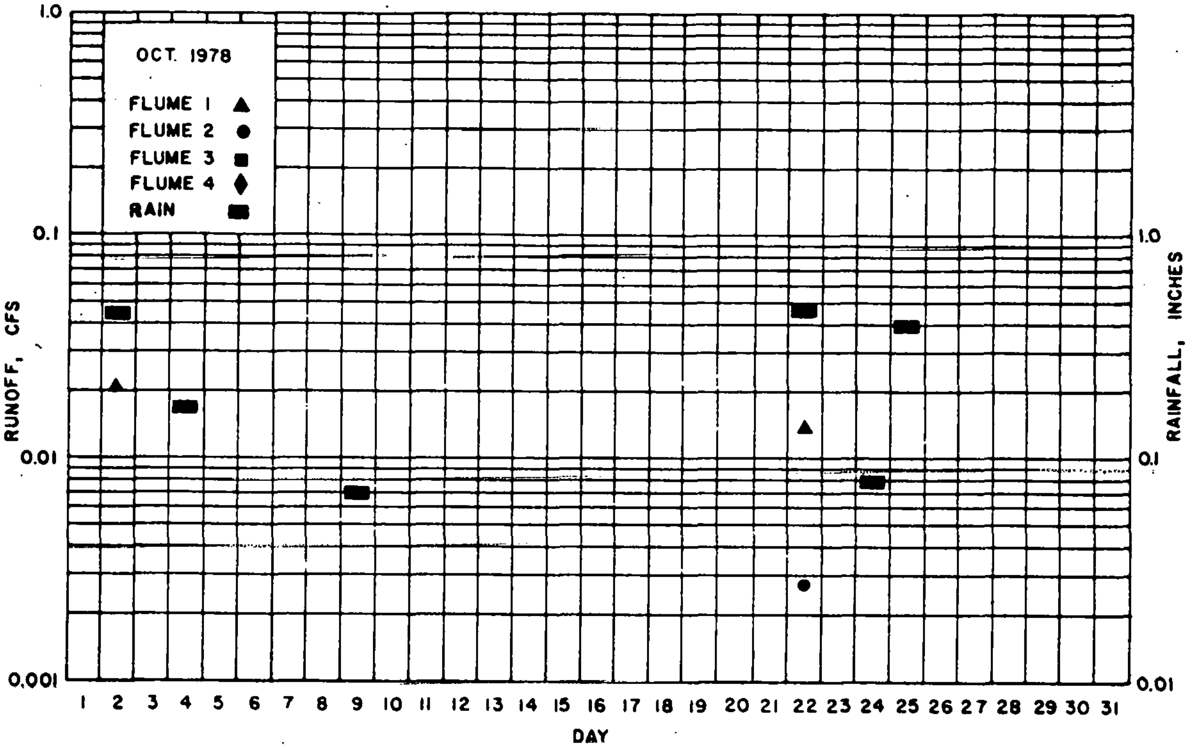

Fig. D.8. Rainfall and Runoff Data, October 1978

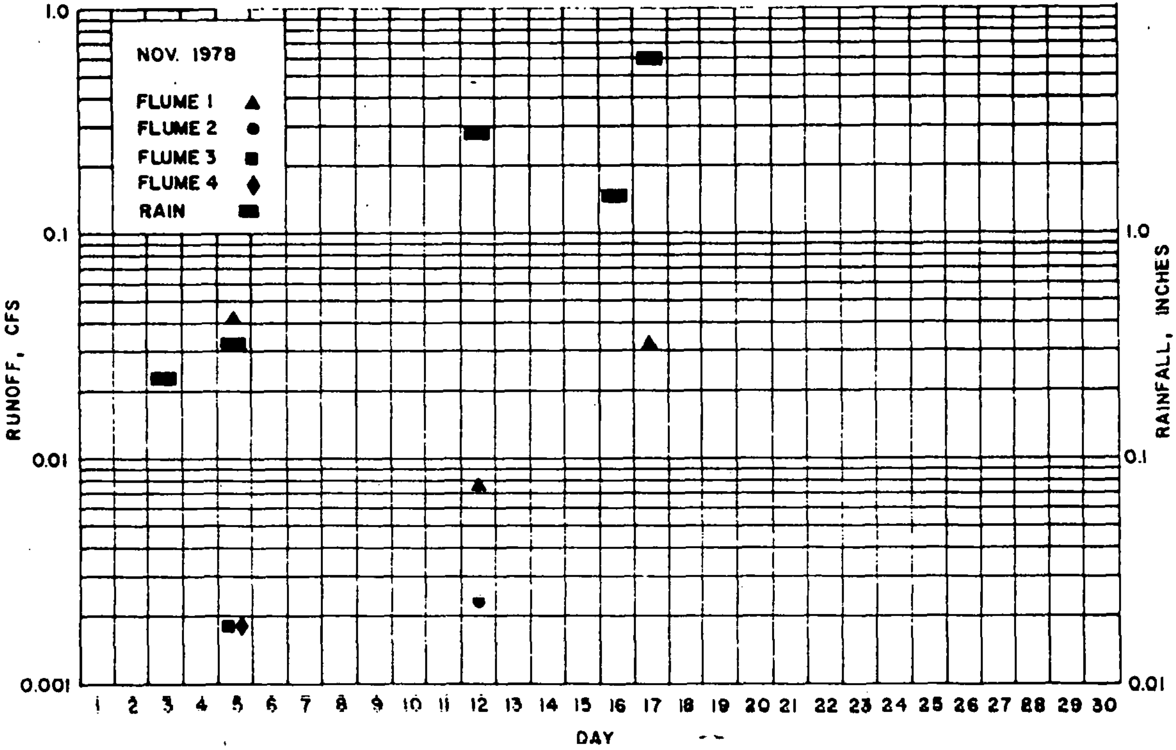

Fig. D.9. Rainfall and Runoff Data, November 1978

APPENDIX E

Analysis of Mine Spoil Samples, by the Purdue University Soil Survey Laboratory

Particle-size Distribution (mm), Percent 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

					(Meq/100 g)						
	pH (1:1)**	KCl	CaCl$_2$	Ca	Mg	Na	K	Ext. Acid	CEC† (Sum)	Base Sat. (%)	Org. C (%)
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 No. 2.
672 Fresh material with some lignitic coal, mostly gray shale, from cut in spoil banks ≈15 ft below surface.
673 Fresh material from ≈15 ft below surface in another spoil bank.
674 Weathered material from hilltop.

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

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

†Cation exchange capacity.

APPENDIX F

Chemistry of Mine-spoil Surface Water Before and After Treatment with Dredged Material

Objective

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

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 has 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.

A sampling was made at nine points (Fig. F.1) 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 1 basin, directly in line with Plot III.
5. A seep into the drainage directly west of Plot I.

6-9. Standing waters in treatment Plots I through IV, respectively.

Results

The kinds of analyses made and the values obtained are reported in Table F.1.

Discussion

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 F.1) for waters at these points show clearly that they are of poor quality in terms of constituents and acidity.

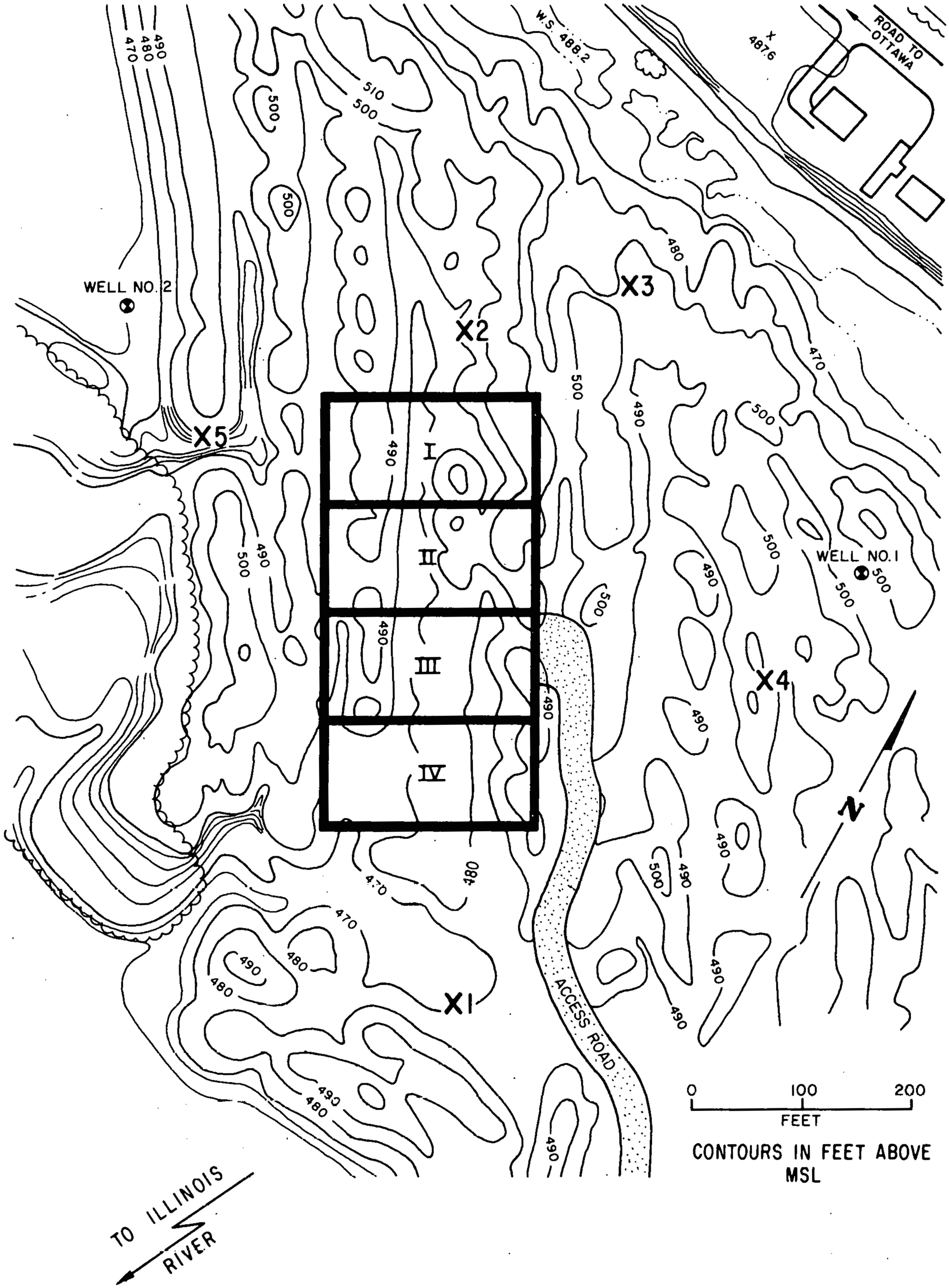

Fig. F.1. Surface Water Sampling Points

TABLE F.1. Chemical Data for Duplicate Samples from Collection Sites 1-9 (Fig. F.1)

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	754	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	2.52	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
$PO_4^{\equiv}$ (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	103	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	0.5	<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	<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	3.50	8.76	5.59	5.44	9.73	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	11.5	32.8	366.	383.	5.94	8.24	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Al (ppm)	135.	133.	34.0	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

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.

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.

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 7a,b through 9a,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.

Conclusions

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.

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 G

Soil Moisture, Acidity, and Variations in Plant Growth on the Mine Spoil

Objective

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

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 h.

Results

Visual Reconnaisance

Three types of surficial mine spoil could be described visually:

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

2. 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.

3. 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

Soil moisture sampling was done in two areas:

1. A hill west of the demonstration site, where adjacent vegetated and nonvegetated areas were cored. Results, presented in Fig. G.1, 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.

2. Experimental Plots I and II were cored to 180 cm in two places each. Results, with standard deviation for the two cores, are presented in Fig. G.2. The dredged material has significantly more water than the mine

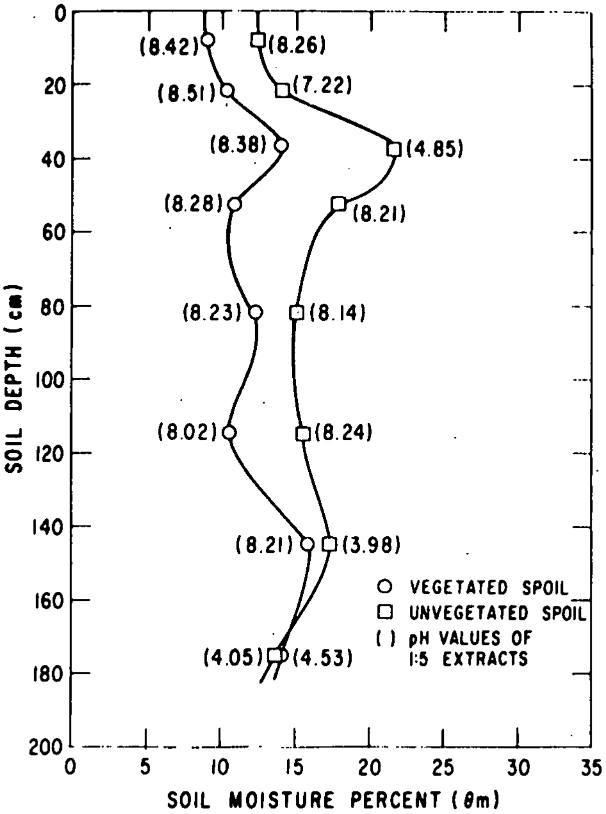

Fig. G.1

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

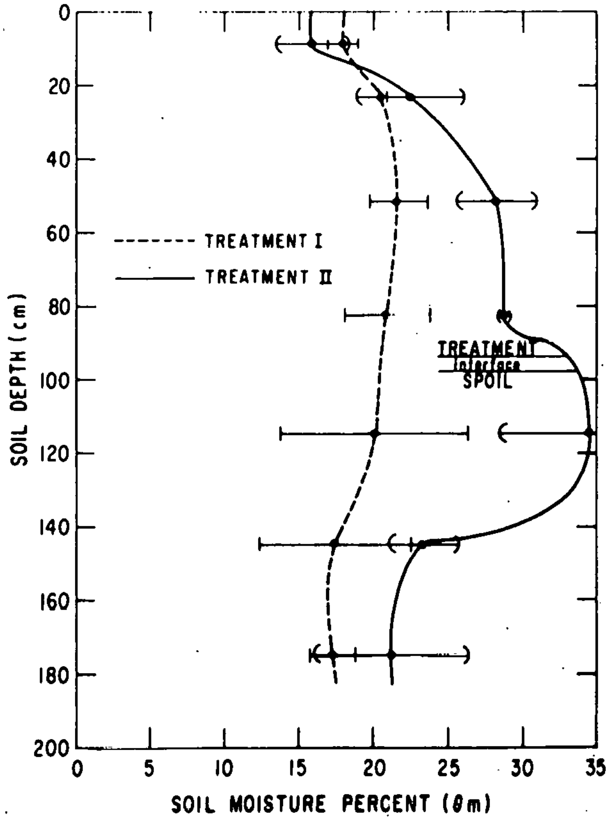

Fig. G.2

Soil Moisture Curves for Treatments I and II. Average of two cores, ± standard deviation.

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 (Fig. G.2) where moisture content would be controlled by the increased suction below the interface.

Chemical Characterization

Soil water extractions of 1:5 were performed on the above mentioned cores as well as on cores taken from the hill just north of Well 1 (Fig. 2, of main text) where the three spoil types occur side by side, as described previously. Since the species which 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.

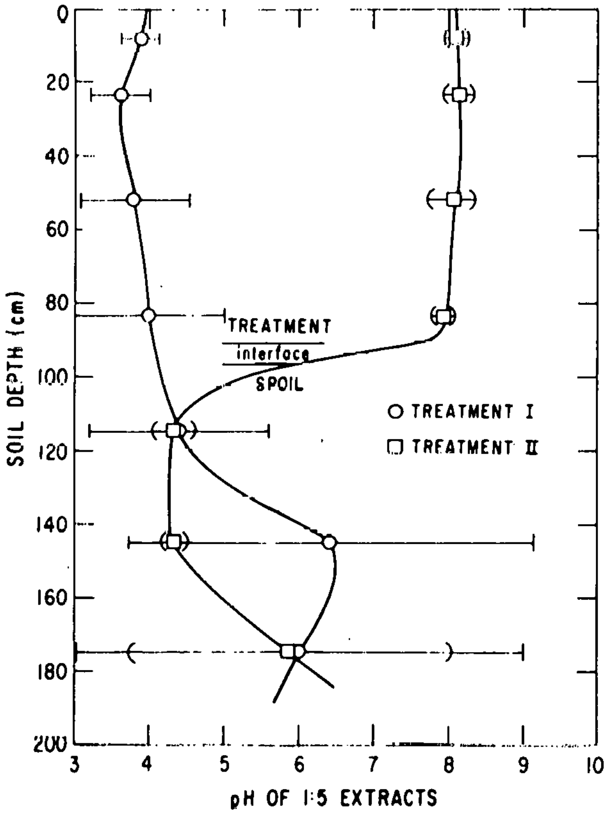

Fig. G.3. pH Variation with Depth for 1:5 Soil/Water Extracts. Treatment Plots I and II.

Figure G.3 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 h at room temperature.

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 G.4 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.

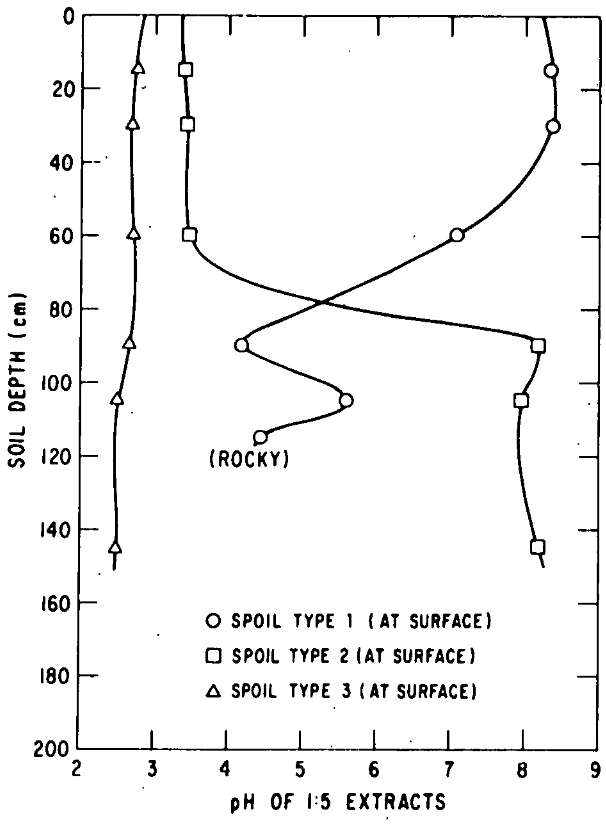

Fig. G.4

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

Table G.1 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% 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 G.1. 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.

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 versus the cubic form of pyrite.

Conclusions

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 Figs. G.1 and G.2. A cursory examination of these figures shows:

1. A general increase in profile moisture content for the spoil of treatment Plot I as compared with the nontreatment plot spoils.
2. An apparent "perching" effect below the treatment application zone.

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 H

Chemical Characteristics of Contact Waters on Spoil and Dredged Material

Objective

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

Investigative Method

The extracts described in Appendix G of this subproject were separated from the soil solid phase by centrifugation and analyzed for pH, specific-conductance, chloride, sulfate, and the metals Ca, Mg, Na, K, Sr, Al, Fe, Mn, Zn, Cu, Ni, Cd, Pb, Mo and Cr.

Results

Results are given in Tables H.1, H.2, and H.3.

Discussion

Table H.1. Vegetated and Unvegetated Status of Adjacent Minesoils of Similar Appearance

The results of this table 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.

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.

Table H.2. Corings through the Three Major Spoil Types Visually Differentiated at the Site

The most obvious difference between these three minesoils 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.

TABLE H.1. 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	355.2	<1	27.0	59.2	12.3	3.3	0.6	13.6	<0.2	0.33	<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	31.0	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	356.8	<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

TABLE H.2. 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	7.56	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.	178.	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	3.19	<0.05

Table H.3. Treated versus Untreated Comparisons

The previously presented data (esp. Table H.2) offer a basis for judging the spoil in the untreated experimental plot to be closely related to the third (worst in terms of acidity production) spoil type characterized.

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 nearsurface sample that could have been contaminated by wind or water erosion of nearby spoil materials depositing over the dredged material.

The large, but consistently appearing, 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.

Conclusions

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.

Addition of a 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 II.3.) If the land after dredged material covering becomes a grazing area, the Mo elevation in the soil solution could present a problem.

TABLE H.3. 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

TABLE H.3 (Contd.)

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	4.90	<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

APPENDIX I

Site Geohydrology

by

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

Site Location and Background

The study site is an abandoned coal and clay strip mine located in the southeast quarter and center of Section 7, and the southwest quarter and center of Section 8, T33N, R4E, Rutland Township, approximately 1.5 miles east of Ottawa, Illinois.

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.

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 which makes up the overburden to the coal.** 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 Fig. I.1 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 sandstone. On the other hand, the area covered by the southeast quarter of Fig. I.1 has only been worked for the coal. The underclay is still intact below the waste piles.

Drilling, Sampling, and Electrical Resistivity Sounding Program

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

Figure I.1 shows the locations of the six borings that were made. An all-terrain-vehicle (ATV) was used to facilitate movement over the steep

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**H. B. Willman and J. Norman Payne, Geology and Mineral Resources of the Marseilles, Ottawa, and Streator Quadrangles, Illinois Geological Survey Bulletin No. 66, Urbana, Illinois, 1942.

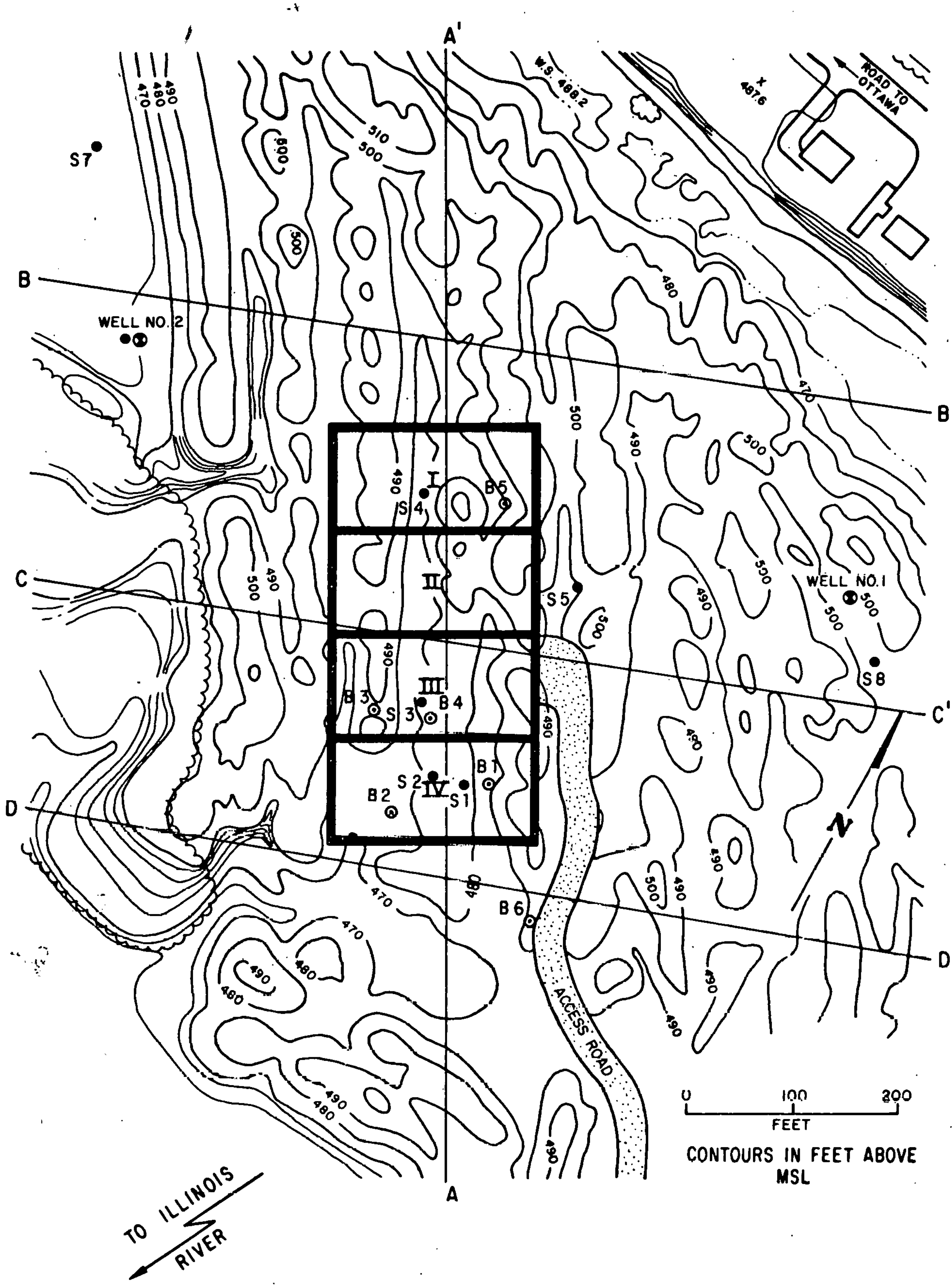

Fig. I.1. Initial Site Topography, Cross-section Lines A–A' through D–D' (Fig. I.5), Groundwater Observation Wells, and Test Plots (Superimposed). Boring locations are indicated by B–1 through B–6; electrical soundings indicated by S–2 through S–4.

berms that separate 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).

The following schedule lists the samples taken at each boring location (Fig. I.1):

B-1 through B-3: 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 1-3 ft and 5-7 ft (except for B-3; second Shelby tube sample taken 7-9 ft).

B-4: Continuous split-spoon samples to a depth of 9.0 ft. Split-spoon samples at depths 10.5-12.0 ft, 14.5-16.0 ft, 19.5-21.0 ft, 24.5-26.0 ft, and 28.5-30.0 ft. One Shelby tube sample taken at a depth of 5.0-7.0 ft.

B-5: Continuous split-spoon samples to a depth of 12.0 ft. Two Shelby tube samples taken at 1.0-3.0 ft and 5.0-7.0 ft.

B-6: Split-spoon samples taken at 4.5-6.0 ft, 9.5-11.0 ft, and 13.5-15.0 ft. Water intercepted at 14.0 ft; PVC pipe observation well set at 14.5 ft.

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 T. Bannister's thesis.*

Earth electrical resistivity soundings were made at points S-1 through S-8 (Fig. I.1) 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.

Details of the interpretations of the borings and resistivity data are given by Bannister.* Figure I.5 presents four cross sections of the site (along the cross-section lines of Fig. I.1) that summarize the major stratigraphic interpretations of the boring and resistivity data.

Natural Moisture Contents

The first tests performed were to determine the natural moisture contents of the samples. Results in Figs. I.2-I.4 are plotted versus depth to

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*T. Bannister, Engineering Geology Assessment for an Abandoned Strip Mine, Master's Thesis, Purdue University, 1979.

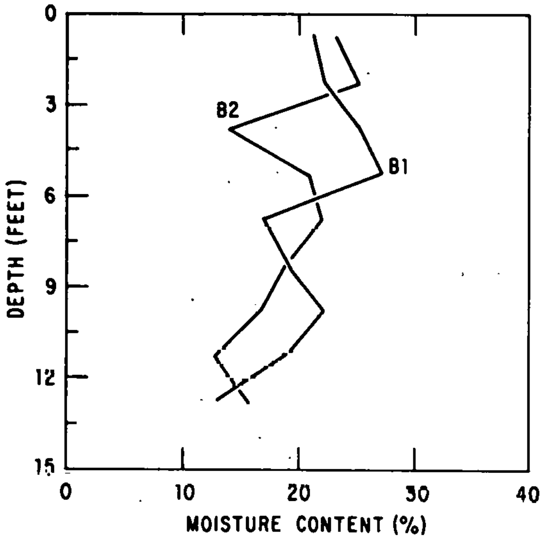

Fig. I.2. Natural Moisture Content as a Function of Depth in Borings B-1 and B-2

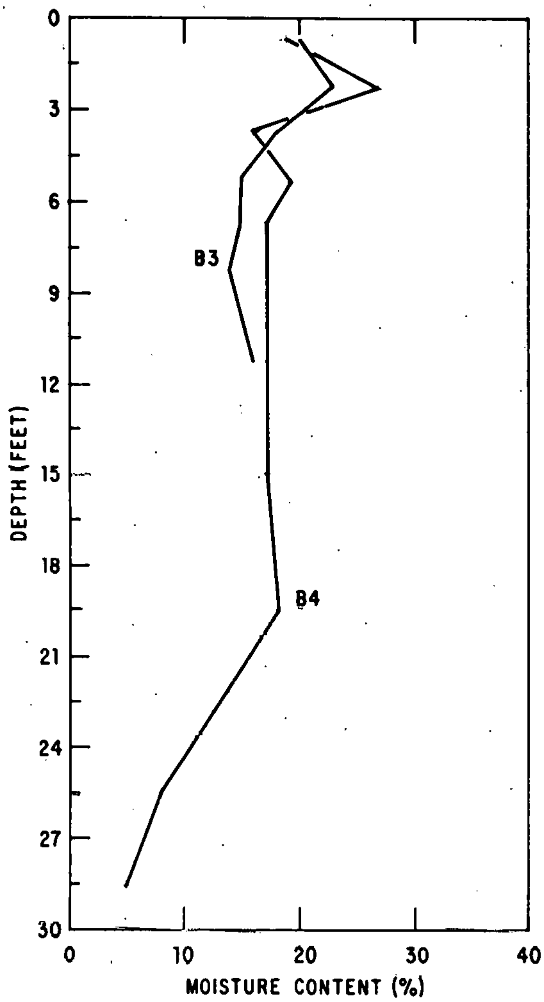

Fig. I.3. Natural Moisture Content as a Function of Depth in Borings B-3 and B-4

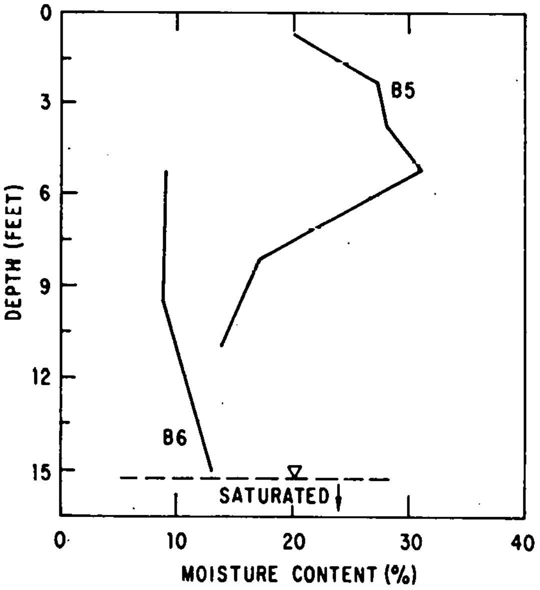

Fig. I.4

Natural Moisture Content as a Function of Depth in Borings B-5 and B-6

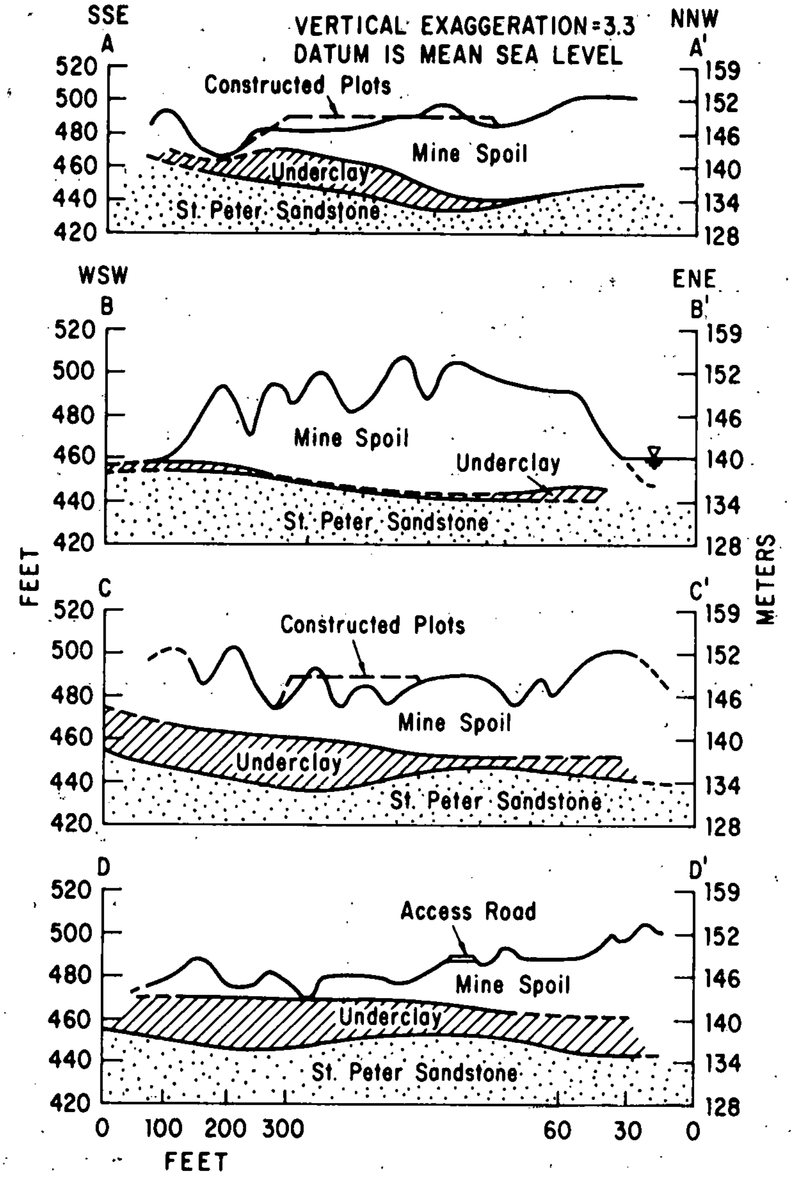

Fig. I.5. Cross-sections A–A'—D–D' of Fig. I.1

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 Figs. I.2-I.4. The moisture contents generally decrease with depth, except for localized points of higher or lower moisture.

Site Hydrology

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 MSL, 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.

Water-level elevations were monitored in three wells (Fig. I.1) during the period 23 August 1978 through 12 April 1979. Wells 1 and B-6 ended in the underclay; Well 2 ended in the St. Peter sandstone. Thus, complete hydrologic continuity between the wells was not assured, and a contour map of the piezometric surface based on these three points would be meaningless. It should be mentioned, however, that in Wells 1 and B-6, 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.

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

1. The water level in Well 2 is determined by the elevation of the Illinois River.

2. The water levels in Wells 1 and B-6 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).

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 (Fig. I.1) 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.

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