GEOHYDROLOGY, SIMULATION OF GROUND-WATER FLOW, AND GROUND-WATER QUALITY AT TWO LANDFILLS, MARION COUNTY, INDIANA

By Richard F. Duwelius and Theodore K. Greeman

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CONTENTS

Page

Abstract 1

Introduction 1

- Purpose and scope 4
- Acknowledgments 4

Methods of investigation 4

- Well installation and water-level measurements 4
- Ground-water models 5
- Ground-water-quality sampling 7

Quality assurance 9

- Standard reference water samples 9
- Blank samples 9
- Duplicate samples 12
- Other quality-assurance considerations 12

Julietta landfill 13

- Site description and history 13
  - Trash disposal 15
  - Sludge disposal 17
  - Data-collection network 18
- Geohydrology 21
  - Geology 21
  - Hydrology 25
    - Ground-water levels and flow 25
    - Ground-water recharge 28
    - Hydraulic characteristics 28
    - Ground-water/surface-water relations 29
    - Streamflow 29
- Simulation of ground-water flow 31
  - Model description 31
  - Model calibration and sensitivity 34
  - Simulated water levels and flow budget 35
- Ground-water quality 38
  - General description 39
  - Aquifers 39
    - Surficial aquifer 39
    - Deep aquifer 46
  - Effects of landfill 52

Tibbs-Banta landfill 57

- Site description and history 57
  - Trash disposal 59
  - Sludge disposal 59
  - Data-collection network 60
- Geohydrology 63
  - Geology 63
  - Hydrology 65
    - Ground-water levels and flow 65
    - Ground-water recharge 68
    - Hydraulic characteristics 68
    - Ground-water/surface-water relations 69
    - Streamflow 69

CONTENTS--Continued

Page

Simulation of ground-water flow.................................. 71
  Model description... 71
  Model calibration and sensitivity............................... 74
  Simulated water levels and flow budget.......................... 75
Ground-water quality... 80
  General description... 80
  Aquifers.. 81
    Shallow aquifers.. 81
    Deep aquifers... 88
  Effects of landfill... 92
Summary and conclusions.. 96
References cited... 98

FIGURES

Figures 1-5. Maps showing:
  1. Marion County and locations of two landfills......... 3
  2. Location of the Julietta landfill in eastern Marion County.. 14
  3. Areas and types of waste disposal at the Julietta landfill.. 16
  4. Locations of observation wells and surface-water sites at the Julietta study area.................. 20
  5. Surficial geology (prelandfill) of the Julietta study area.. 22
6. Geologic section A to A', through the Julietta study area. 23
7. Geologic section B to B', through the Julietta study area. 24
8. Map showing water levels in the surficial aquifer at the Julietta study area, October 16, 1985.................. 26
9. Graph showing altitude of water level in wells EE-2 and EE-3 at the Julietta study area and precipitation at the Indianapolis southeast-side observer, March 1985 through June 1986.. 27
10. Map showing locations of streamflow measurements and streamflow for Grassy Creek and Buck Creek, October 16, 1985... 30
11. Generalized geohydrologic section showing model layers.... 32
12-14. Maps showing:
  12. Finite-difference grid used to simulate ground-water flow in the Julietta study area................... 33
  13. Simulated water levels in layer 2 and measured water levels in the surficial aquifer, October 16, 1985.. 36
  14. Dissolved-solids concentrations and Stiff diagrams of common ion concentrations in the surficial aquifer at the Julietta study area, May 1986.............. 40

FIGURES--Continued

Page

Figures 15-18. Maps showing:
- 15. Areal distribution of concentrations of dissolved ammonia in the surficial aquifer at the Julietta study area, May and June 1985........................ 54
- 16. Areal distribution of concentrations of dissolved bromide in the surficial aquifer at the Julietta study area, November 1985........................ 55
- 17. Location and surficial geology of the Tibbs-Banta landfill in southwestern Marion County............ 58
- 18. Locations of observation wells and surface-water sites at the Tibbs-Banta study area................ 61

19. Geologic section A-A', through the Tibbs-Banta study area. 64

20. Map showing water levels in the shallow aquifers at the Tibbs-Banta study area, October 17, 1985................ 66

21. Graph showing altitude of water level in wells AA-1, AA-3, and J-2 at the Tibbs-Banta study area and precipitation at the Indianapolis International Airport, January 1985 through June 1986.................................... 67

22. Map showing locations of streamflow measurements and streamflow for Little Buck Creek, October 17, 1985...... 70

23. Generalized geohydrologic section showing model layers.... 72

24-29. Maps showing:
- 24. Finite-difference grid used to simulate ground-water flow in the Tibbs-Banta study area................ 73
- 25. Simulated water levels in layer 2 and measured water levels in the shallow aquifers, October 17, 1985... 76
- 26. Simulated water levels in layer 5 and measured water levels in the deep aquifers, October 17, 1985...... 77
- 27. Dissolved-solids concentrations and Stiff diagrams of common ion concentrations in the shallow aquifers at the Tibbs-Banta study area, February 1986....... 82
- 28. Areal distribution of concentrations of dissolved ammonia in the shallow aquifers at the Tibbs-Banta study area, May 1986.............................. 94
- 29. Areal distribution of concentrations of dissolved bromide in the shallow aquifers at the Tibbs-Banta study area, May 1986.............................. 95

TABLES

Table 1. Water-quality constituents analyzed during the study and U.S. Environmental Protection Agency maximum contaminant levels for drinking water.................................... 8

2. Results of analyses of deionized water samples done by the laboratory of the Indianapolis Department of Public Works.. 11

TABLES--Continued

Page

Table 3. Trace-metal and polychlorinated biphenyl loadings resulting from sludge disposal at the Julietta landfill in 1984...... 17

4. Depth, casing type, altitude of land surface, altitude of water, and model layer for wells drilled at the Julietta study area.. 19

5. Values of selected model variables at calibration for the ground-water-flow model of the Julietta study area......... 34

6. Simulated water budget for the Julietta study area........... 37

7. Water-quality analyses of ground water at the Julietta study area.. 100

8. Summary statistics of water-quality data for shallow wells A-1, B-1, and C-2, upgradient from the Julietta landfill... 42

9. Summary statistics of water-quality data for shallow wells F-2 and H-3, beneath the Julietta landfill................. 44

10. Summary statistics of water-quality data for shallow wells DD-1, EE-1, L-2, and R-1, downgradient from the Julietta landfill.. 45

11. Summary statistics of water-quality data for the deep well C-3, upgradient from the Julietta landfill................. 48

12. Summary statistics of water-quality data for deep wells F-1, F-3, F-4, H-1, H-4, I-3, and I-4, beneath the Julietta landfill.. 49

13. Summary statistics of water-quality data for deep wells DD-2, EE-2, L-1, MN-1, and P-1, downgradient from the Julietta landfill.. 51

14. Trace-metal and polychlorinated biphenyl loadings resulting from sludge disposal at the Tibbs-Banta landfill in 1984... 60

15. Depth, casing type, altitude of land surface, altitude of water, and model layer for wells drilled at the Tibbs-Banta study area.. 62

16. Values of selected model variables at calibration for the ground-water-flow model of the Tibbs-Banta study area...... 74

17. Simulated water budget for the Tibbs-Banta study area........ 79

18. Water-quality analyses of ground water at the Tibbs-Banta study area.. 124

19. Summary statistics of water-quality data for shallow wells AA-3, FF-2, K-1, K-2, and M-1, upgradient from the Tibbs-Banta landfill.. 83

20. Summary statistics of water-quality data for shallow wells B-1 and CC-1, in the Tibbs-Banta landfill................. 85

21. Summary statistics of water-quality data for shallow wells I-2, J-2, and L-2, downgradient from the Tibbs-Banta landfill.. 87

22. Summary statistics of water-quality data for deep wells AA-1, AA-2, and F-1, upgradient from the Tibbs-Banta landfill.... 89

23. Summary statistics of water-quality data for deep wells I-1, J-1, and L-1, downgradient from the Tibbs-Banta landfill... 91

CONVERSION FACTORS AND ABBREVIATIONS

Inch-pound units in this report may be converted to metric units (International System) by using the following conversion factors:

Multiply inch-pound unit	By	To obtain metric unit
acre	0.4047	hectare
acre-foot (acre-ft)	1,234	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic yard (yd^3)	0.7646	cubic meter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon (gal)	3.785	liter
gallon per day (gal/d)	3.785	liter per day
gallon per day per foot [(gal/d)/ft]	0.0124	meters squared per day
gallon per day per square foot [(gal/d)/ft^2]	0.3516	liter per day per square meter
inch (in.)	2.54	centimeter
inch per year (in/yr)	2.54	centimeter per year
mile (mi)	1.609	kilometer
pound per acre (lb/acre)	0.1836	kilograms per hectare
square foot (ft^2)	0.09290	square meter
ton per acre (ton/acre)	2.242	megagram per hectare
ton, short	0.9072	megagram

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = (1.8\ °C) + 32$$

CONVERSION FACTORS AND ABBREVIATIONS--Continued

The following terms and abbreviations also are used in this report:

COD	Chemical oxygen demand
ft^2	Square foot
mg/L	Milligram per liter
PCB	Polychlorinated biphenol
pH	Negative log base -10 of the hydrogen ion activity, in moles per liter
PVC	Polyvinylchloride
SAS	Statistical Analysis System
SC	Specific conductance
SRWS	Standard Reference Water Sample
μg/L	Microgram per liter
μS/cm	Microsiemen per centimeter at 25° Celsius

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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by Richard F. Duwelius and Theodore K. Greeman

ABSTRACT

Geologic, hydrologic, and water-quality data were collected at the Julietta and Tibbs-Banta landfills in Marion County. Both landfills were closed in the mid-1970's, and sewage sludge mixed with dirt was spread on the landfills in the mid-1980's as part of a revegetation project.

The landfills were constructed in unconsolidated glacial sediments that consist of sand, gravel, silt, and clay. The maximum thickness of the sediments is 180 feet at Julietta and 100 feet at Tibbs-Banta. Both landfills are underlain by sand and gravel aquifers and are adjacent to gaining streams. Ground water flows toward and into the streams at each study area. Two sand and gravel aquifers were mapped at Julietta and four were mapped at Tibbs-Banta. The aquifers are separated in places by discontinuous clay layers.

Ground-water-flow models, calibrated to simulate steady-state low-flow conditions, indicate that about 19,000 gallons of water per day move through the refuse at Julietta and 42,000 gallons per day move through the refuse at Tibbs-Banta. The Julietta model also indicates that recharge through the surface of the landfill is less than in the surrounding natural areas, probably because of the addition and compaction of the sludge/soil mixture.

Concentrations of dissolved inorganic substances in ground-water samples indicate that leachate from both landfills is reaching the shallow aquifers. The effect on deeper aquifers is small because of the predominance of horizontal ground-water flow and discharge to the streams. Increases in almost all dissolved constituents were observed in shallow wells that are screened beneath and downgradient from the landfills. Several analyses, especially those for bromide, dissolved solids, and ammonia, were useful in delineating the plume of leachate at both landfills.

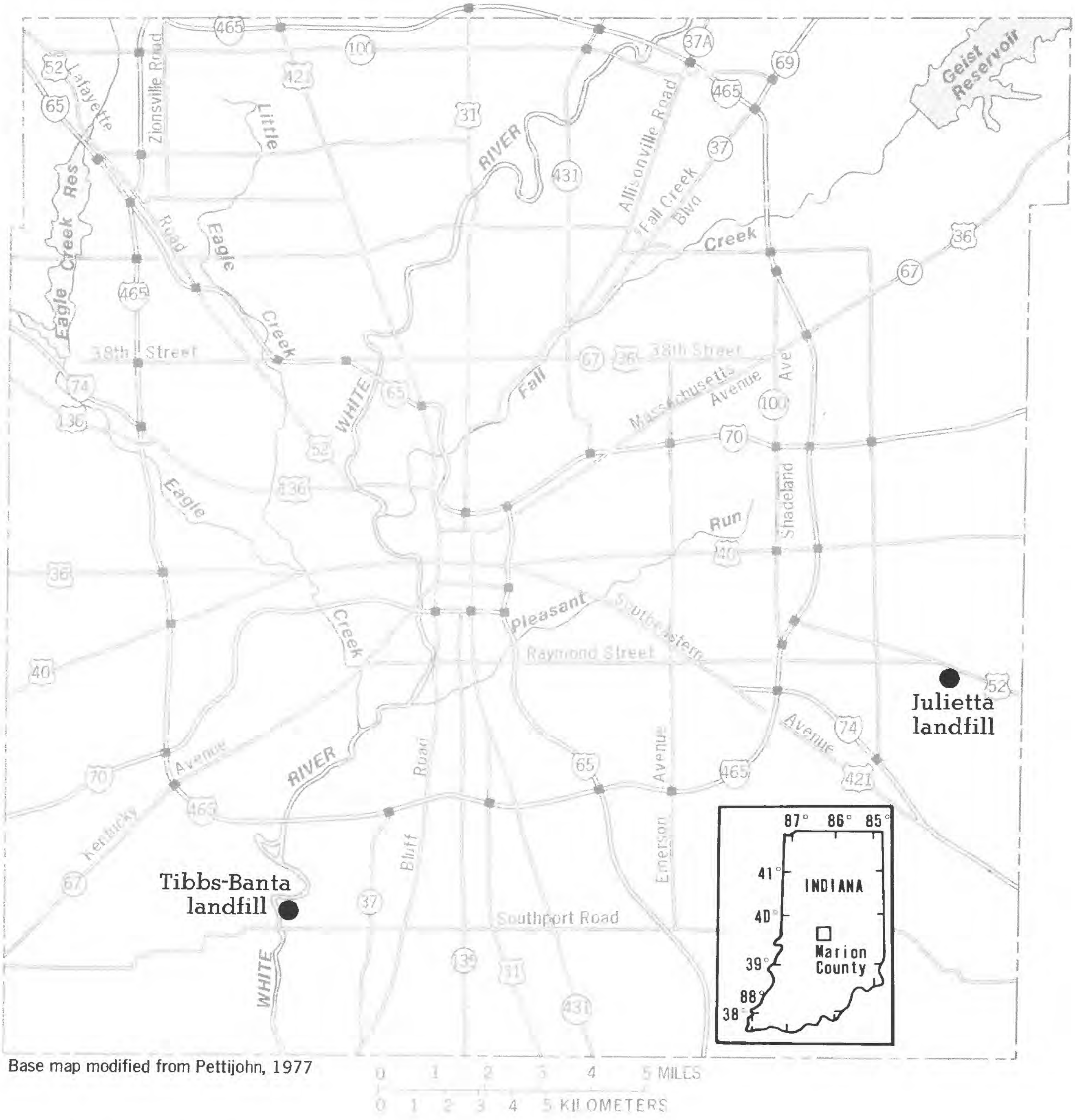
INTRODUCTION

Ground-water contamination, resulting from disposal of solid and liquid wastes in sanitary landfills, is an issue of increasing concern. Doggett and others (1980, p. 44) projected annual production of municipal refuse in the United States to be as much as 376 million short tons by the year 1990. Disposal of such large volumes of waste in landfills presents concerns, not only for the safety and health of local residents, but also for future development and management of our water resources.

Leachate from landfills is precipitation or ground water that percolates through soils or buried waste containing soluble materials. Leachate generally is characterized as having elevated concentrations of dissolved solids, nutrients, and trace elements. The solute-bearing water flows down the hydraulic gradient as a plume. If the plume is not contained and spreads from the landfill, the potential for the leachate to affect the quality of ground water with which it comes in contact is greatly increased. Assessment of the potential for ground-water contamination at a particular landfill involves careful consideration of not only the capability of leachate production, but also the relation of the ground-water flow system to other ground- and surface-water systems and to potential water users.

A 2-year study of two closed landfills in Marion County was initiated by the U.S. Geological Survey, in cooperation with the City of Indianapolis Department of Public Works, in December 1984. These landfills were selected for study because they are owned by the City of Indianapolis, and because sewage sludge from city wastewater-treatment plants had been spread on the surface of the landfills. The city wanted to know what effects the landfills had on ground-water quality and how much water was affected so that decisions could be made regarding future use of these properties.

Both landfills were included in a survey of Marion County landfills by Pettijohn (1977). In his report, the landfills are referred to as the landfill at U.S. Highway 52 and Senour Road near Julietta and the landfill at Banta Road and Tibbs Avenue near Indianapolis. In this report, they are designated as the Julietta landfill and the Tibbs-Banta landfill (fig. 1).



Base map modified from Pettijohn, 1977

Figure 1.– Marion County and locations of two landfills.

Purpose and Scope

This report presents the results of a study to (1) provide a quantitative evaluation of the ground-water flow system at the Julietta and Tibbs-Banta landfills and (2) provide a general description of the ground-water quality beneath and near the two landfills. These objectives provide the information necessary to evaluate the effects of the landfills on ground-water quality. Geologic, hydrologic, and water-quality data were collected in 1985 and 1986 at the Julietta and Tibbs-Banta landfills to fulfill the study objectives. Ground-water models were used to investigate the flow systems and estimate the volume of flow at the landfills.

This report includes descriptions of the data collection, geologic and hydrologic descriptions of the two landfills, and brief histories of trash and sludge disposal. Ground-water-flow models are described and estimates of the volume of flow are discussed. A description of the quality-assurance plan used in conjunction with the water-quality data collection and analysis is included. Water-quality data are presented with statistical summaries of ground-water quality related to well depth and position in the flow system.

Only the unconsolidated surficial deposits were investigated; therefore, this report does not include ground-water flow and quality in the underlying bedrock. Similarly, surface-water-quality data were not collected for the study; therefore, the effect of leachate on receiving streams is not discussed in detail.

Acknowledgments

Special thanks are extended to James Parks formerly of the Indianapolis Department of Public Works for providing information about the recent history of each landfill and to the laboratory of the Indianapolis Department of Public Works, managed by John Barr, for analysis of the water-quality samples. The authors also express their appreciation to private landowners for allowing access to their properties to install observation wells and to collect data.

METHODS OF INVESTIGATION

Well Installation and Water-Level Measurements

Several wells used for Pettijohn's (1977) study were still intact at each landfill and provided reliable data for this study. Additional wells were installed between December 1984 and October 1985.

The locations of the new wells were based on an analysis of Pettijohn's (1977) data. In many cases, wells were installed to replace wells from that study. The number of wells installed at each location was determined primarily by the thickness and number of unconsolidated aquifers underlying the site. In thick shallow aquifers, one well was screened near the top of the aquifer and one well was screened near the bottom of the aquifer. Where multiple aquifers are present, one well was screened above the semiconfining layer and one well was screened below the semiconfining layer. Wells were placed upgradient from each landfill to determine background water quality, and downgradient to determine the location and extent of the effects of the landfill on the ground water.

The new wells were drilled using hollow-stem augers that had 3.25-in. (inch)-inside diameters. The wells were constructed of 2-in.-diameter type 304 stainless-steel casing and 2 in. by 3 ft (feet) wire-wrapped screens. All materials were steam cleaned before use. In shallow sand and gravel aquifers, holes were augered to the required depth and the augers were removed. The casing and screen were lowered into the hole and, if necessary, were pushed to the final depth. Deeper wells were set inside the augers and were pushed into the formation before the augers were removed. Both methods allowed natural materials to collapse into the hole around the screen. The annulus was backfilled with drill cuttings. Where multiple aquifers are present, bentonite pellets were placed in the annulus between aquifers, when possible, to prevent vertical migration of water along the well bore. Concrete pads, 2 ft by 2 ft by about 6 in. thick, were poured around each well at ground level to prevent runoff of surface water from entering the well bore. Each well was equipped with a locking cap to provide security from vandalism.

The older wells were equipped similarly; however, these wells were drilled using rotary methods and were constructed using PVC (polyvinylchloride) casings and screens. All wells were developed by pumping or jetting with compressed air, or both. Levels were run to determine the altitude of each measuring point based on sea level.

Hydraulic gradients at each landfill were determined from water-level measurements. Vertical flow potential was determined by measurement of water levels at sites having two or more wells screened at different depths. In addition to ground-water levels, surface-water levels were measured from reference marks on bridges, culverts, and staff gages near the landfills. Water levels were measured monthly for 18 months, beginning in January 1985.

Ground-Water Models

Data obtained from test drilling and water-level measurements were used to construct a three-dimensional ground-water flow model of each landfill using the U.S. Geological Survey finite-difference model (McDonald and Harbaugh, 1988). The models were calibrated to match the onsite data and were used to investigate the ground-water-flow systems and to estimate the volume of flow through the refuse at the landfills. The models were not used to simulate transient conditions or contaminant transport.

Adjustments made during calibration generally involve the variables about which the least is known. For both the Julietta and the Tibbs-Banta study areas, model geometry was determined from the drilling data; however, hydraulic characteristics of the geologic materials were mostly unknown. Estimates of hydraulic conductivity for the sand and gravel aquifers, till, and clay were obtained from Morris and Johnson (1967), Cable and others (1971, p. 11), Meyer and others (1975, p. 18), and Freeze and Cherry (1979, p. 29). Hydraulic conductivity for the refuse was estimated from values of hydraulic conductivity for similar materials. Adjustments to hydraulic conductivity, recharge rates, and the stream/aquifer connection were made during calibration.

Because models are simplified versions of the real system, certain assumptions are made. Some of the assumptions that apply to the landfill models are:

1. The ground-water system is at steady state.

2. Ground-water flow in the unconsolidated sediments is three dimensional. Flow in the sand and gravel aquifers is horizontal, and flow (leakage) in the semi-confining beds (clay) between aquifers is vertical.

3. All similar geologic materials in a layer are homogeneous and horizontally isotropic and are simulated as having uniform hydraulic conductivity.

4. All shallow ground water discharges to streams.

5. Ground-water flow from the bedrock is not substantial in the total flow budget for the shallow system.

6. Streambeds are 1 ft thick, where simulated.

Assumption 1 eliminates the need for storage coefficients in the model. In addition, steady-state models generally are not as dependent on the exact simulation of boundary conditions as are models used to investigate transient conditions.

Although water may flow horizontally in the semiconfining layers, horizontal flow in the semiconfining layers is considered negligible when compared with horizontal flow in the sand and gravel aquifers. In parts of layers where there is no aquifer material, values of horizontal conductivity were assigned according to the material present. Values of vertical conductivity are assumed to be 0.1 times the horizontal conductivity value for the same material. Using aquifer-test data, William Meyer (U.S. Geological Survey, written commun., 1975) calculated this relation for glacial outwash materials in Marion County.

Assumption 4 enables the establishment of model boundaries along the major streams. The streams represent water-discharge divides for flow in the shallow unconsolidated aquifers. Because ground water does not cross the divide, no-flow boundaries were used adjacent to the major streams along the outer edge of the model. This type of boundary condition allows the flow of water to the stream but not across it.

There were no data to determine streambed thickness at the landfills; however, the volume of ground-water flow to the stream is a result not only of the streambed thickness but also the permeability of the streambed sediments. Any thickness may be assumed, and adjustments are made during calibration of the model in order to match the simulated and observed streamflows.

Ground-Water-Quality Sampling

Ground-water quality was monitored by sampling water from each of the wells every 3 months. Five samples were collected from each well during the study. The first samples were collected in May and June 1985, and the last samples were collected in May 1986. The wells were sampled with either a submersible pump, a peristaltic pump, or a bailer depending on the straightness of the well casing, the depth to water, and the pumping capacity of the well. All samples were filtered through a 0.45-micrometer membrane filter. Pumped samples were filtered directly from the pump discharge; bailed samples were put in a Teflon churn before pumping through the filter with the peristaltic pump. Samples for metals analyses were acidified and all samples were packed in ice for delivery to the lab.

Prior to sample collection, a volume of water equal to at least three times the volume of water in the well casing was removed from each well to ensure that samples were water coming from the aquifer. The discharge was monitored to verify that onsite conditions had stabilized by the time of sample collection. Onsite measurements of specific conductance (SC), pH, temperature, and dissolved oxygen were made at each sample. All equipment in contact with the samples was cleaned and rinsed with deionized water before collecting the next sample.

The constituents for which analyses were done are listed in table 1. Analysis of water samples, except for bromide analysis, was provided by the laboratory of the Indianapolis Department of Public Works at the Belmont municipal wastewater-treatment plant in Indianapolis. Samples for bromide analysis were sent to U.S. Geological Survey laboratories in Doraville, Ga., and Denver, Colo., for analysis.

The data were used to describe the ground-water quality in and near the two landfills. Maps of ionic concentrations in the horizontal and vertical directions were drawn based on the data. Statistical summaries were made to relate the variability of water samples from the same well and to assess the differences between water at upgradient and downgradient wells.

Table 1.--Water-quality constituents analyzed during the study and U.S. Environmental Protection Agency maximum contaminant levels for drinking water

[mg/L, milligram per liter; dashes (---) indicate no criteria]

Property or dissolved constituent	Maximum contaminant level
Specific conductance	[a]---
pH	[a,b]6.5-8.5 units
Temperature	[a]---
Dissolved oxygen	[a]---
Chemical oxygen demand	---
Calcium	---
Magnesium	---
Sodium	---
Potassium	---
Alkalinity, as calcium carbonate	---
Sulfate	[b]250 mg/L
Chloride	[b]250 mg/L
Bromide	---
Dissolved solids	[b]500 mg/L
Nitrate as nitrogen	[c]10 mg/L
Nitrite as nitrogen	---
Ammonia as nitrogen	---
Phosphorus	---
Arsenic	[c].05 mg/L
Barium	[c]1 mg/L
Cadmium	[c].01 mg/L
Chromium	[c].05 mg/L
Chromium, hexavalent	---
Copper	[b]1 mg/L
Iron	[b].3 mg/L
Lead	[c].05 mg/L
Manganese	[b].05 mg/L
Mercury	[c].002 mg/L
Nickel	---
Selenium	[c].01 mg/L
Zinc	[b]5 mg/L
Phenols	---

[a] Field measurement.

[b] National secondary drinking-water recommended limits (U.S. Environmental Protection Agency, 1982b).

[c] National interim primary drinking-water regulations (U.S. Environmental Protection Agency, 1982a).

QUALITY ASSURANCE

Three quality-assurance procedures were used to verify the reliability of the data. The procedures involved the analysis of Standard Reference Water Samples (SRWS), blanks, and duplicate samples. Results of quality-assurance analyses indicate inconsistencies with several constituents, including dissolved solids, chromium, lead, mercury, selenium, and phosphorus. Although the quality-assurance procedures do not resolve the inconsistencies in the data, they do indicate that results of analysis for these constituents should be used with caution.

Standard Reference Water Samples

During this study, the Indianapolis Department of Public Works participated in the SRWS Program, administered by the U.S. Geological Survey, to quantify the ability of their laboratory to analyze samples accurately. Results of SRWS analyses are compared with analyses from other laboratories around the country. Rankings for each participating laboratory are reported twice yearly in administrative reports of the U.S. Geological Survey (Janzer, V. J., U.S. Geological Survey, written commun., 1987). The laboratory of the Indianapolis Department of Public Works has participated in the SRWS program since November 1985.

Results of SRWS analyses indicate that the laboratory of the Indianapolis Department of Public Works produced acceptable results for most of the analyses during the period of this study. Occasional inconsistencies were noted in the analyses for small amounts of arsenic, barium, cadmium, chromium, and selenium. During this study, chemical oxygen demand (COD), sulfate, mercury, and phenols were not analyzed in the SRWS program. Therefore, the quality of the analyses for these four constituents is unchecked.

Blank Samples

Blank samples consisted of deionized water that was pumped through the sampling equipment and submitted for analysis with the regular samples. Blank sample analyses provide information about the quality and consistency of the sample-collection procedures and laboratory analyses. During the study, 25 blank samples were analyzed by the laboratory of the Indianapolis Department of Public Works. Ten blanks were processed through each of the two sampling pumps and five blanks were taken directly from deionized water containers used in the field.

Results of analyses of deionized water samples by the laboratory of the Indianapolis Department of Public Works are listed in table 2. Dissolved solids were detected in 21 of 25 samples. Dissolved-solids concentrations generally were small; however, concentrations were as large as 158 mg/L (milligram per liter). Other constituents commonly detected in blanks were COD, nitrate, ammonia, phosphorus, and phenols. No consistent pattern of detection was indicated by the analyses; therefore, the reason for detection of any particularly large concentration is unknown.

Deionization removes ions from the water but does not completely remove all the dissolved and suspended solids content of the water. Therefore, some of the detections in the blank samples are not unusual. The quality of deionized water may vary and is dependent on the source of the water. The deionized water used during the study came from two sources. Twenty of the blank samples were water that was purchased and five were tap water that was deionized in the laboratory.

Table 2.--Results of analyses of deionized water samples done by the laboratory of the Indianapolis Department of Public Works

[mg/L, milligram per liter; $CaCO_3$, calcium carbonate; dashes (---) indicate not detected]

Property or dissolved constituent	Number of samples	Number of detections	Median detected (mg/L)	Maximum detected (mg/L)	Detection limit (mg/L)
Chemical oxygen demand	25	12	3	8	1.0
Calcium	25	6	.14	.38	.01
Magnesium	25	3	.17	.24	.01
Sodium	25	4	.02	.32	.01
Potassium	25	5	.03	.05	.01
Alkalinity, as $CaCO_3$	25	2	2	2	1.0
Sulfate	20	6	2	3	1.0
Chloride	25	3	2	5	1.0
Dissolved solids	25	21	14	158	1.0
Nitrate as nitrogen	21	15	.01	.16	.01
Nitrite as nitrogen	21	0	---	---	.005
Ammonia as nitrogen	25	10	.035	.16	.01
Phosphorus	21	18	.02	.06	.01
Arsenic	25	0	---	---	.001
Barium	25	1	---	.01	.01
Cadmium	21	0	---	---	.01
Chromium	21	0	---	---	.01
Chromium, hexavalent	11	0	---	---	.01
Copper	21	0	---	---	.01
Iron	25	2	.015	.02	.01
Lead	21	2	.02	.02	.01
Manganese	25	0	---	---	.01
Mercury	21	1	.3	---	.0002
Nickel	21	1	.01	---	.01
Selenium	21	0	---	---	.001
Zinc	21	2	.02	.02	.01
Phenols	21	10	.0011	.004	[a].001

[a] In May 1985, the detection limit was 0.0001 mg/L. Between July 1985 and March 1986, the detection limit was 0.0005 mg/L. After March 1986, the detection limit was 0.001 mg/L.

Duplicate Samples

The final quality-assurance procedure was the collection of 46 duplicate samples. Differences in reported concentrations between duplicate samples for 19 constituents were compared using the centered signed rank test from the SAS Univariate Procedure (Statistical Analysis System Institute, 1985, p. 1187). Statistical tests were done at the 95-percent significance level.

The results indicate that differences between duplicate samples were statistically significant only for the sodium analyses. Absolute values for the difference in sodium concentrations in duplicate samples ranged from 0.02 to 2.28 mg/L. The median difference was 0.25 mg/L. The range in measured sodium concentrations for duplicate samples was from 3.1 to 125.7 mg/L.

Other Quality-Assurance Considerations

Two other discrepancies occurred during the regular sample analyses. In May 1985, 16 of 18 sequential samples indicated positive for the presence of lead. The samples included two blanks and were collected from wells located upgradient from and in the Julietta landfill. Lead was detected only once in the remaining 256 samples collected for the study; that sample was from the Tibbs-Banta landfill.

During the August 1985 sampling, mercury was detected in 22 of 67 samples. Positive indications of mercury were found in samples from both landfills. At the Julietta landfill, mercury was detected in water from wells located upgradient from, in, and downgradient from the landfill, and in one blank. At the Tibbs-Banta landfill, mercury was detected in water from two downgradient wells. Duplicate samples were collected at both wells, but only one sample from each well was found to contain mercury. Mercury was detected in only seven other samples, all collected in May 1985.

Although the analyses indicate the presence of lead and mercury in the ground water at certain times of the year, the detection of lead in sequential samples and the erratic detections in blanks and duplicate samples may indicate sample contamination, or analytical discrepancies.

JULIETTA LANDFILL

Site Description and History

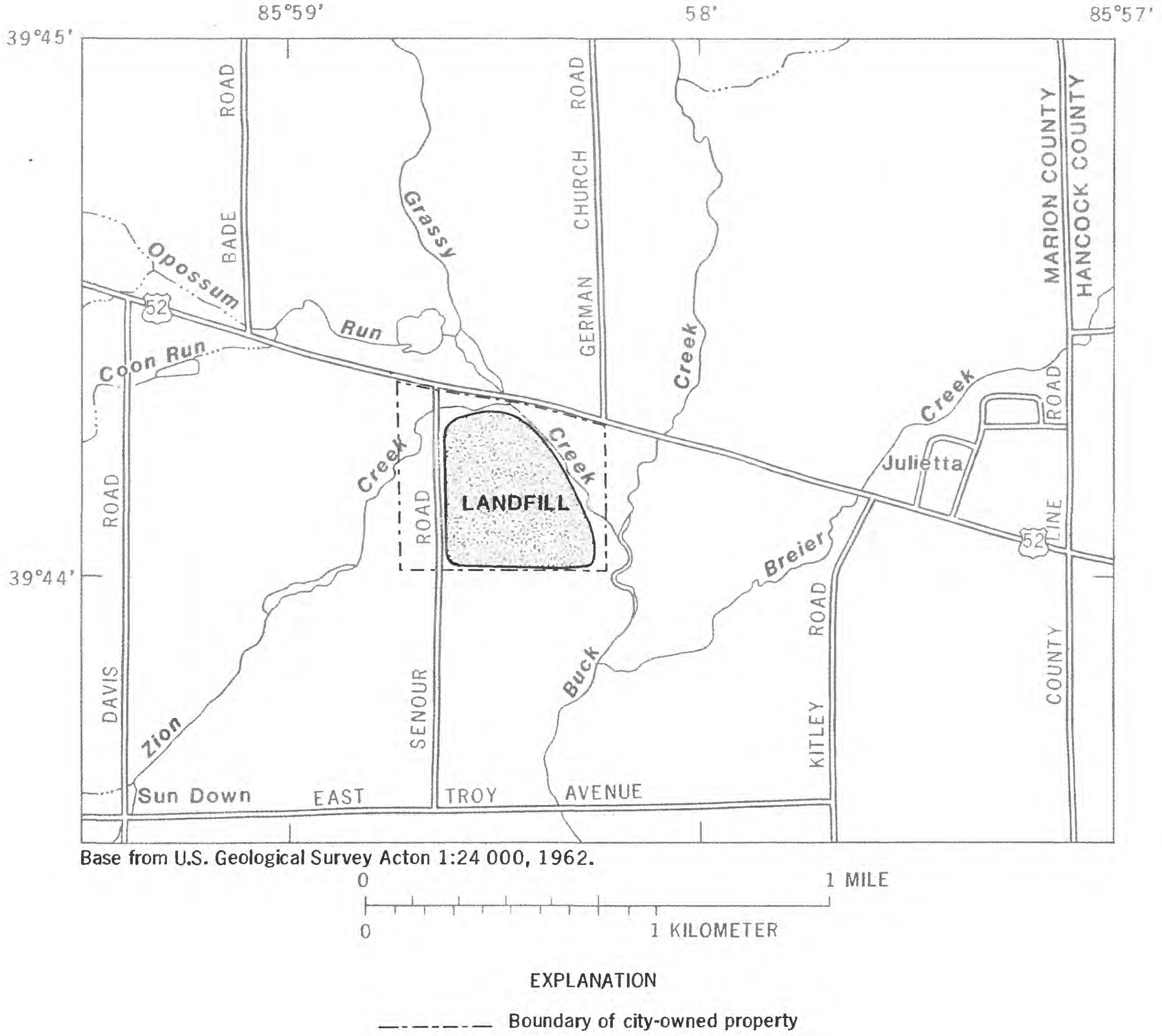
The Julietta landfill is located south of U.S. Highway 52 along Senour Road, near the town of Julietta, in eastern Marion County (fig. 2). The city-owned property that includes the landfill is about 70 acres in size and is along and west of the Buck Creek flood plain near the confluence with Grassy Creek. Zion Creek flows through the western part of the property and drains into Grassy Creek along the northern boundary of the landfill. The area receiving refuse and sludge is about 51 acres and includes only the land west of Grassy Creek and east of Senour Road.

The Julietta landfill is bordered on the west and northeast by city-owned land and on the north, south, and southeast by privately-owned land. Pay fishing lakes are located to the east between the landfill and Buck Creek. The area south of the landfill primarily is farmland. There are several homes east of Buck Creek and at least two homes and a summer camp north of U.S. Highway 52. Three homes are visible along Senour Road, south of the landfill.

Land-surface topography in the study area is moderately sloping, except in the flood plain, where the ground is nearly flat. The landfill rises abruptly west of Grassy Creek and is about 30 ft above the flood plain. The highest part of the landfill is about 10 ft higher than the land west of Senour Road. The highest local altitude is southwest of the landfill, where the land surface is about 20 ft higher than the highest part of the landfill.

Vegetative cover at the Julietta landfill primarily consists of grasses and a few trees, mostly small cottonwoods. Wheat was seeded during the revegetation project and is the most prevalent grass.

Prior to 1950, the landfill site was owned by the nearby Marion County Home and was operated as a pig farm. During the 1950's, the property was leased to a sand and gravel operation. Mining of sand and gravel resulted in several pits of various size. The largest pit was about 50 ft deep and was located in the southeastern corner of the landfill. When the sand and gravel mining ceased in the early 1960's, the abandoned pits became dumping sites for local residents (Pettijohn, 1977, p. 10).



Base from U.S. Geological Survey Acton 1:24 000, 1962.

EXPLANATION

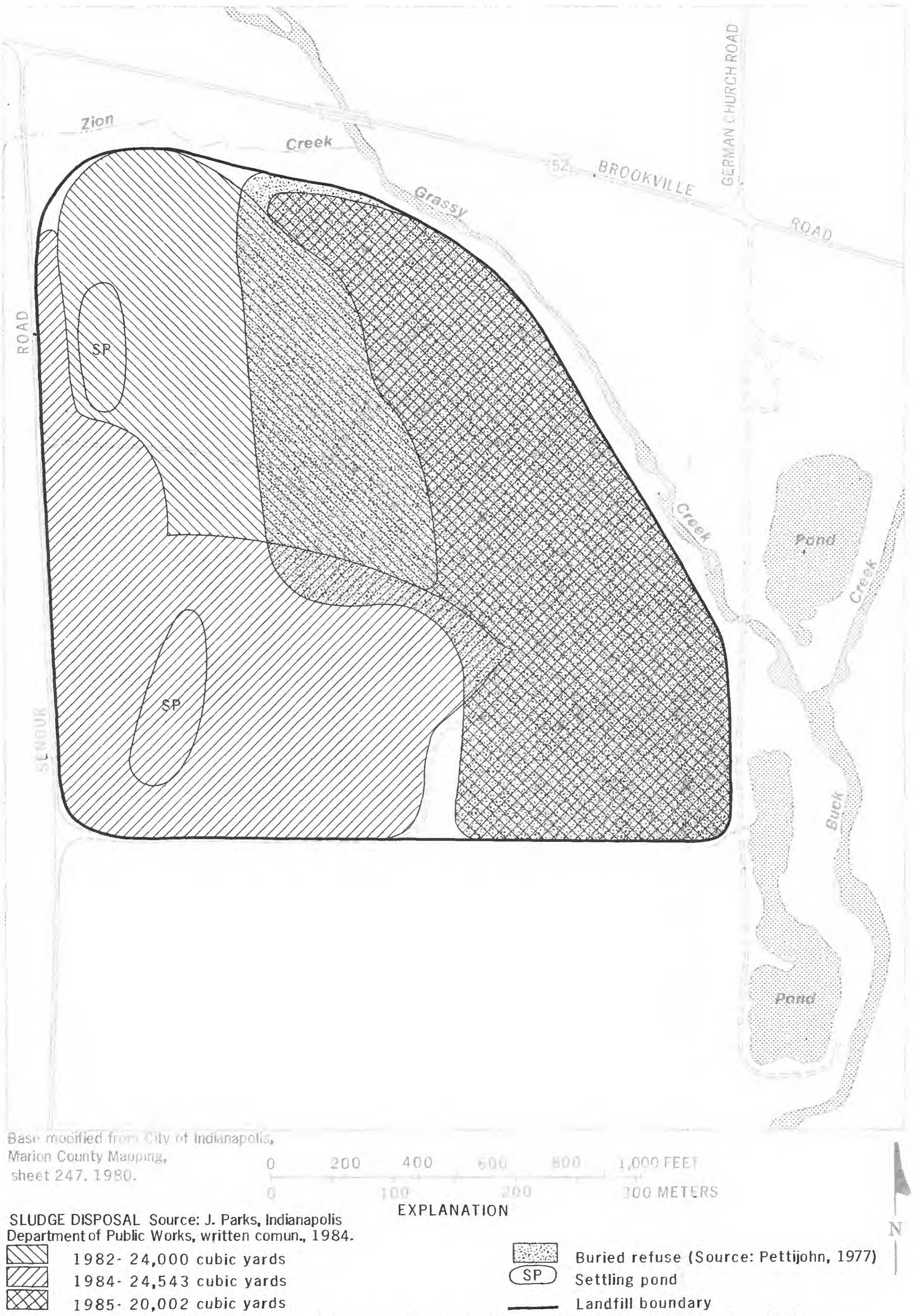
Boundary of city-owned property

Figure 2.– Location of the Julietta landfill in eastern Marion County.

Trash Disposal

During the late 1960's, the property was leased to a landfill operation, and the landfill began receiving domestic, commercial, and industrial wastes (Pettijohn, 1977, p. 10). The deep pit in the southeastern corner of the landfill was filled first, and the operation continued northward along the western edge of Grassy Creek. The fill material is composed of alternating layers of refuse and soil. Cover soil was provided onsite by removal of soil in advance of the fill. Aerial photographs, taken during this period, show several ponds along and east of Senour Road. Hazardous liquid wastes, including oil sludge, naptha, and water-soluble waste glue (Lunsford, 1986), were dumped in the ponds.

The Julietta landfill was closed in 1976. The volume of refuse buried by this time was estimated to be 2.6 million yd^3 (cubic yards) (Pettijohn, 1977, p. 10). The maximum thickness of refuse was 50 ft. The location of buried refuse is shown in figure 3. At the time of closing, the ponds were filled with dirt and demolition debris, and the landfill was covered with about 2 ft of soil (James Parks, Indianapolis Department of Public Works, oral commun., 1986).



Base modified from City of Indianapolis, Marion County Mapping, sheet 247, 1980.

EXPLANATION

SLUDGE DISPOSAL Source: J. Parks, Indianapolis Department of Public Works, written comun., 1984.

▧ 1982- 24,000 cubic yards
▨ 1984- 24,543 cubic yards
▦ 1985- 20,002 cubic yards

░ Buried refuse (Source: Pettijohn, 1977)
(SP) Settling pond
— Landfill boundary

Figure 3.– Areas and types of waste disposal at the Julietta landfill.

Sludge Disposal

In 1982, the Julietta landfill began receiving sludge from the Belmont municipal wastewater-treatment plant in Indianapolis. About 24,000 yd^3 of digested-stabilized sludge were removed from lagoons at Belmont, dried, and spread over 17.5 acres in the northwestern part of the landfill (fig. 3). The sludge was mixed into the upper soil using a bulldozer/disc combination, and the area was seeded. Similar procedures were used in 1984 when 16 acres to the southwest were covered, and again in 1985 when the remaining 17.5 acres were covered. The mixed sludge/soil was capped in 1984 and 1985 with a layer of soil averaging about 8 in. in thickness (James Parks, Indianapolis Department of Public Works, oral commun., 1986).

An estimated 16,600 tons of dried sludge were spread at the Julietta landfill for an average loading of 325 tons of sludge per acre (James Parks, Indianapolis Department of Public Works, written commun., 1985). Analysis of the sludge contracted by the Indianapolis Department of Public Works during 1984 provided the trace-metal and polychlorinated biphenyl (PCB) loadings listed in table 3. Similar concentrations and loadings are assumed for 1982 and 1985. The loadings are larger than current standards for land designated for food-chain crops and livestock grazing; therefore, agricultural use of the property is restricted (James Parks, Indianapolis Department of Public Works, written commun., 1985).

Table 3.--Trace-metal and polychlorinated biphenyl loadings resulting from sludge disposal at the Julietta landfill in 1984[1]

[mg/kg, milligrams per kilogram; lbs/acre, pounds per acre]

Trace metal or constituent	Dry weight concentration (mg/kg)	Loading (lbs/acre)
Cadmium	84	54
Copper	1,446	932
Lead	530	342
Nickel	168	109
Zinc	3,590	2,315
Polychlorinated biphenyls	11	7.1

[1] Source: Parks, J. T., Indianapolis Department of Public Works, written commun., 1984.

Data-Collection Network

Ground-water levels and quality were monitored in 35 observation wells at 16 sites at the Julietta study area. Information about the observation wells is listed in table 4. Well locations are shown in figure 4. Well depths ranged from 16 to 170 ft below land-surface datum. Twenty-five wells from Pettijohn's (1977) study and 10 new wells were used at this site. The new wells generally were located downgradient from the landfill and, in most places, replaced damaged wells that originally were at these locations.

To avoid confusion, Pettijohn's (1977) original well numbers were maintained. Each well was labeled with an alphabetical character and with a number. The alphabetical character defines the site and the number denotes a particular well at that site. A new well, drilled to replace a damaged well, is labeled with double alphabetical characters to differentiate it from the original well at that site.

Water levels were measured monthly for 18 months in all wells (January 1985 to June 1986). Surface-water levels were measured at five locations (fig. 4). Staff gages were installed in Buck Creek and in a pond, downgradient from the landfill. Water levels in Grassy Creek and Zion Creek were measured from known altitudes on bridges and culverts. Water samples were collected every 3 months beginning in May 1985 and ending in May 1986. Five water-quality samples were collected from each well.

Table 4.--Depth, casing type, altitude of land surface, altitude of water, and model layer for wells drilled at the Julietta study area

[PVC, polyvinylchloride; SS, stainless steel; dashes (---) indicate depth of well is below bottom of model]

Well number	Depth below ground surface (feet)	Casing type	Altitude of land surface (feet)	Altitude of water 10/16/85 (feet)	Model layer
A-1	47	PVC	837	808.6	2
A-2	170	PVC	837	804.7	---
B-1	33	PVC	818	796.8	2
C-1	135	PVC	812	804.7	---
C-2	20	PVC	812	796.6	2
C-3	33	PVC	812	796.6	3
DD-1	16	SS	797	792.7	2
DD-2	31	SS	797	792.7	3
EE-1	19	SS	800	791.8	2
EE-2	42	SS	800	791.8	3
EE-3	61	SS	800	791.8	---
F-1	56	PVC	809	792.7	3
F-2	26	PVC	809	792.6	2
F-3	36	PVC	809	792.7	3
F-4	44	PVC	809	792.7	3
F-5	69	PVC	809	794.8	---
H-1	60	PVC	829	795.0	3
H-2	69	PVC	829	793.9	---
H-3	40	PVC	829	794.9	2
H-4	52	PVC	829	794.9	3
I-1	87	PVC	817	793.3	---
I-2	64	PVC	817	792.5	---
I-3	44	PVC	817	792.4	3
I-4	48	PVC	817	792.4	3
J-2	27	PVC	811	796.8	2
K-1	54	PVC	810	794.9	3
K-2	28	PVC	810	794.9	2
L-1	36	PVC	797	790.2	3
L-2	16	PVC	797	790.2	2
MN-1	36	SS	798	791.4	3
O-2	22	PVC	844	822.9	1
P-1	30	SS	797	791.2	3
R-1	43	SS	818	792.8	2
T-1	18	SS	808	794.0	2
T-2	42	SS	808	793.4	3

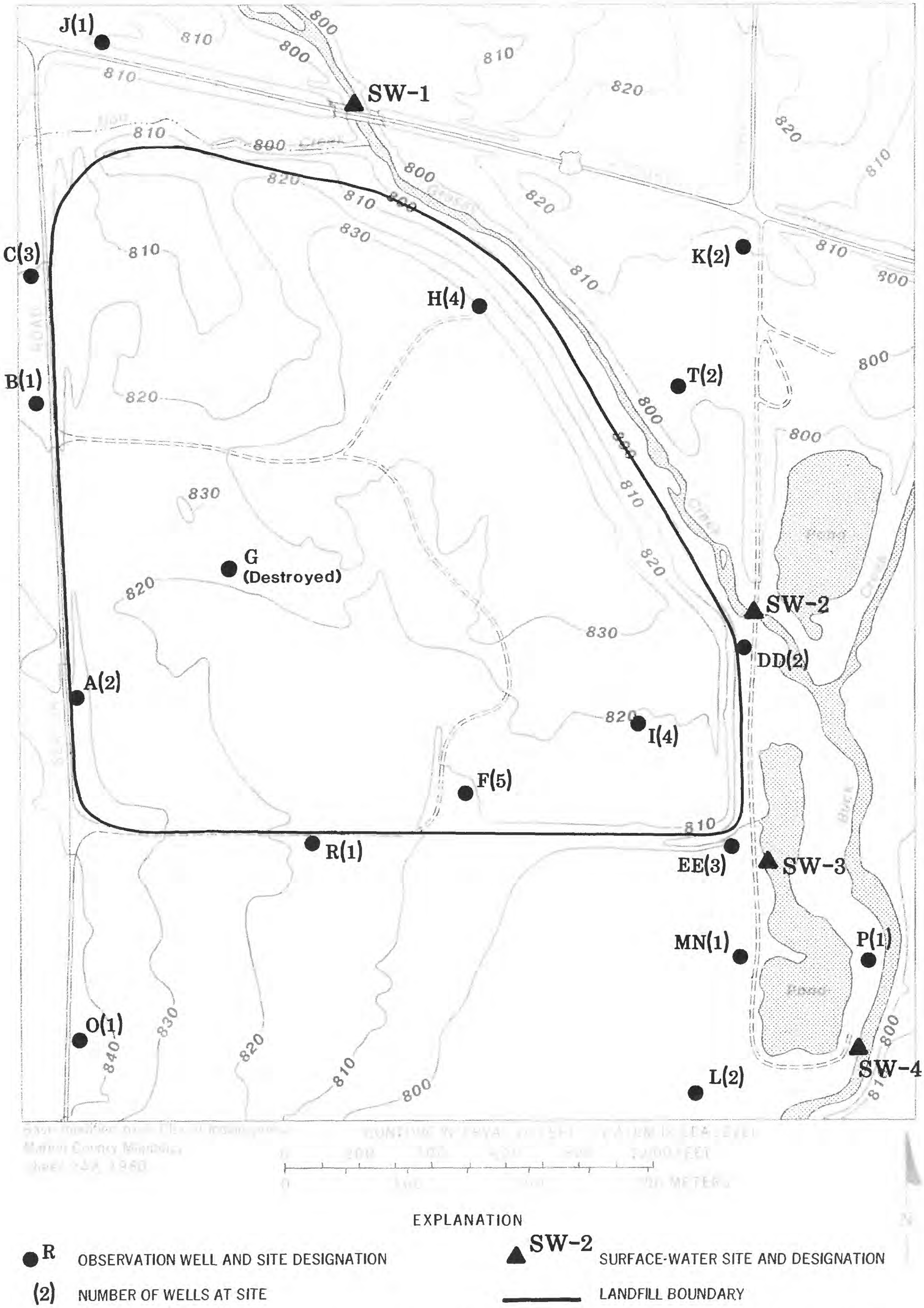


Figure 4.– Locations of observation wells and surface-water sites at the Julietta study area.

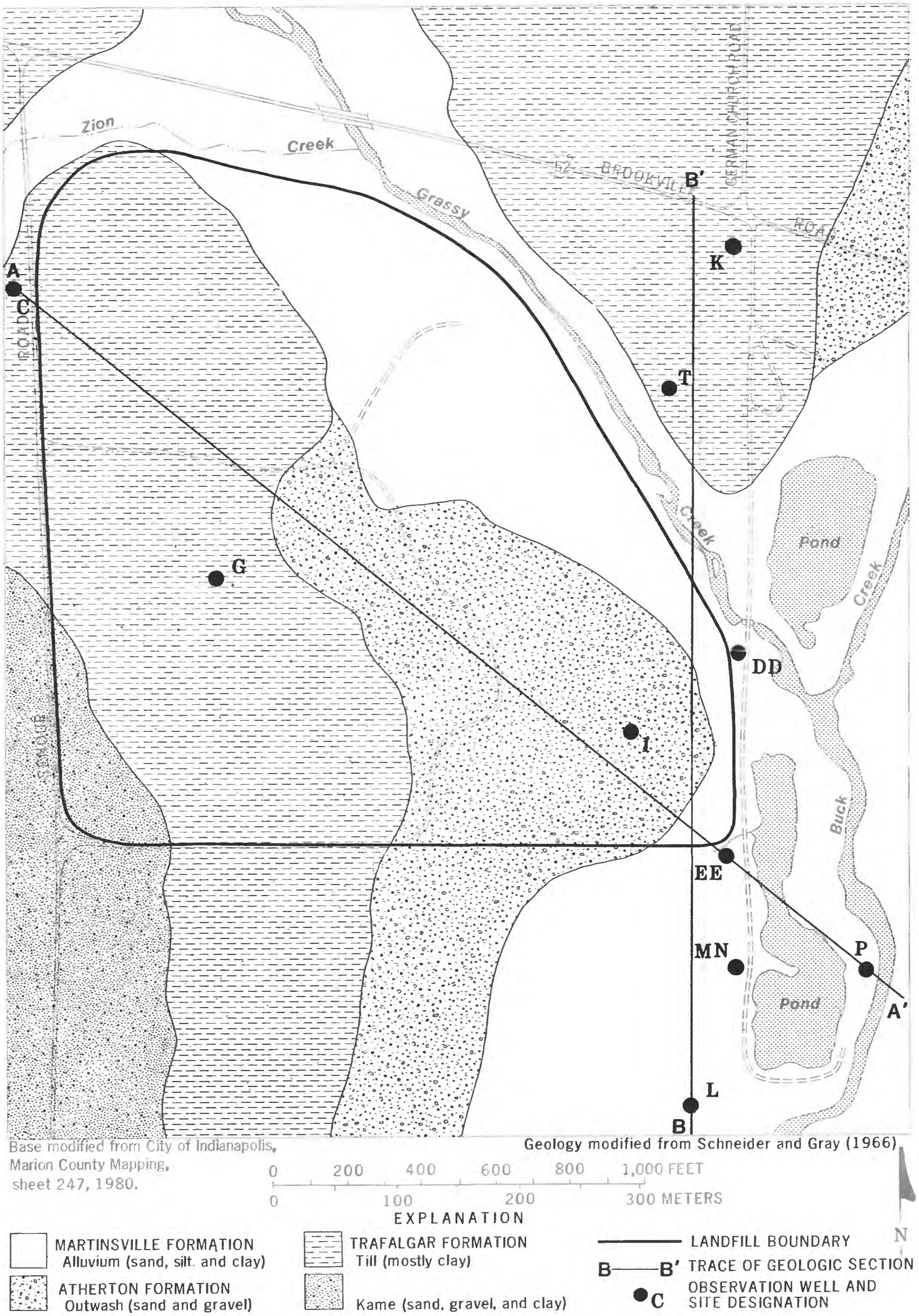
Geohydrology

Geology

The Julietta study area is underlain by limestone and dolomite bedrock of Silurian and Devonian age (Schneider and Gray, 1966, p. 28). Depth to bedrock ranges from 180 ft along Senour Road to 140 ft near the southeast corner of the landfill. The flat to gently sloping bedrock surface is within the physiographic province of the Muscatatuck Regional Slope described by Malott (1922, p. 86).

The bedrock is overlain by till, outwash, and alluvium. The unconsolidated sediments were deposited during the retreat of Wisconsin glaciation. The sediments average about 150 ft in thickness and consist of varying amounts of interbedded sand, gravel, silt, and clay. Geologic maps by Schneider and Gray (1966) show three formations in the Julietta study area (fig. 5). The Trafalgar Formation of Pleistocene age is till predominantly containing clay and silt. Interbedded sand and gravel are common in the till, but tend to be thin and discontinuous. Few layers of sand and gravel were found below 60 ft and they are usually less than 3 ft thick and are discontinuous within the study area. Southwest of the landfill is a large kame, also part of the Trafalgar Formation. The kame is comprised of large quantities of poorly sorted sand and gravel and interbedded clays (Harrison, 1963, pl. 1).

The thickest deposits of sand and gravel are in the outwash along Buck Creek and Grassy Creek. The outwash deposits are part of the Atherton Formation of Pleistocene age (Schneider and Gray, 1966, p. 13). Toward the north and the west, two apparently continuous sand and gravel layers of the Atherton Formation average about 15 ft thick and are separated by a 1- to 3-ft-thick clay. Near the southeast corner of the landfill the clay is absent, and the sand and gravel has a maximum thickness of about 40 ft. In the flood plain of Buck Creek, fine-grained sand, silt, and clay of the Martinsville Formation of Pleistocene and Holocene age (Schneider and Gray, 1966, p. 13) overlie the outwash and have a maximum thickness of about 15 ft. The relation of the area filled with refuse to the unconsolidated sediments is shown in figures 6 and 7.



Base modified from City of Indianapolis, Marion County Mapping, sheet 247, 1980.

Geology modified from Schneider and Gray (1966)

Figure 5.-- Surficial geology (prelandfill) of the Julietta study area.

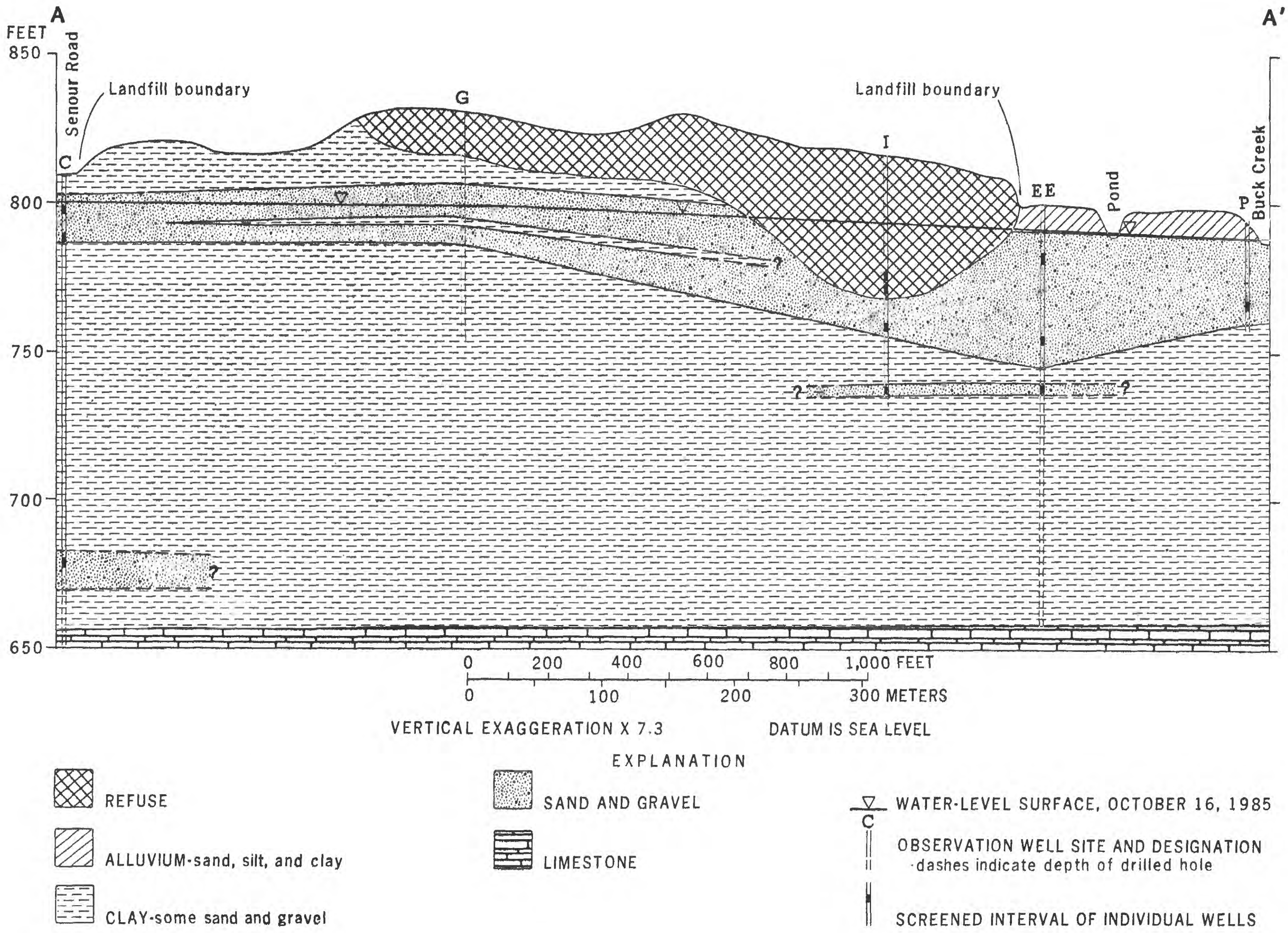


Figure 6.-- Geologic section, A to A′, through the Julietta study area.

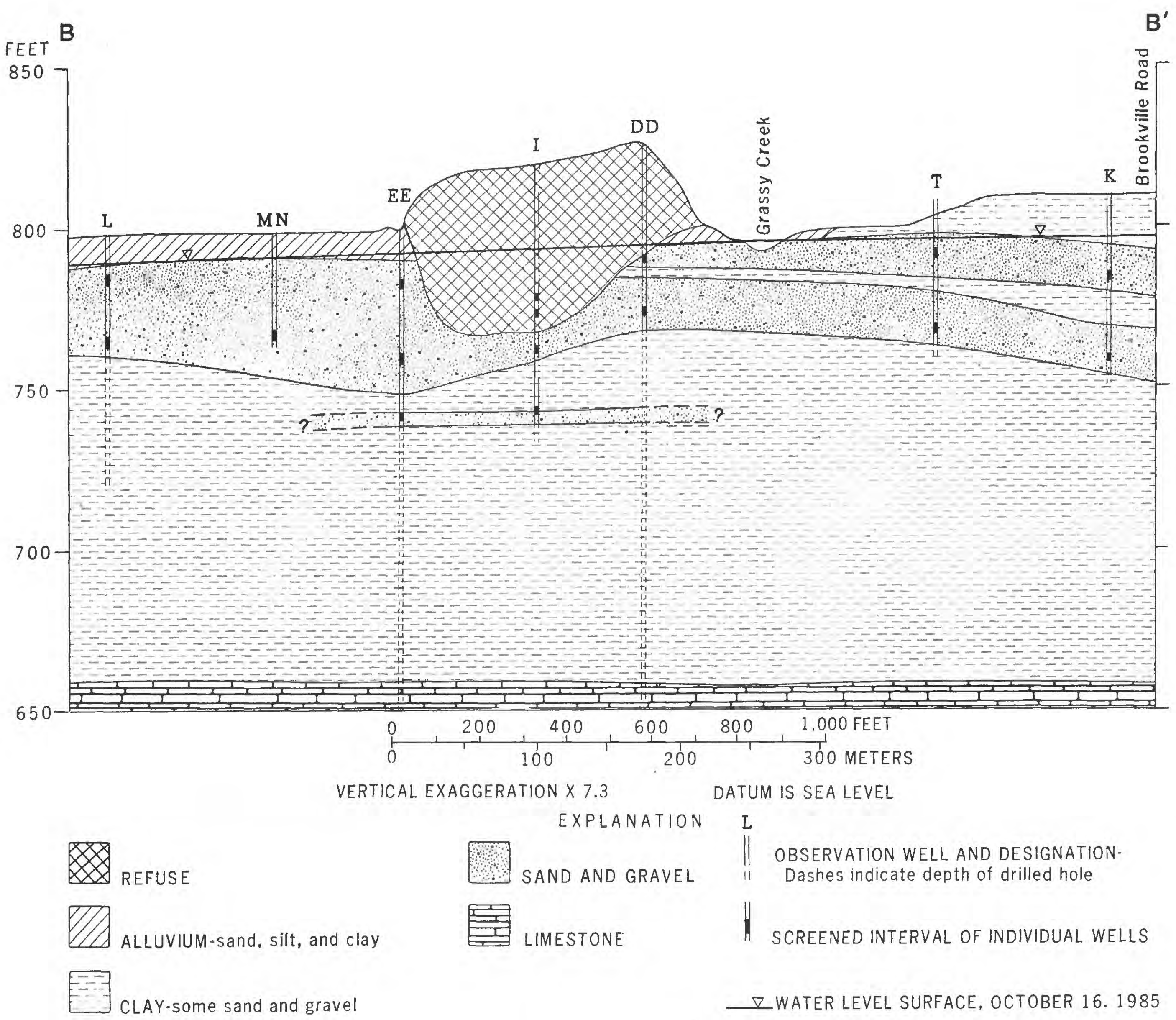


Figure 7.-- Geologic section, B to B′, through the Julietta study area.

Hydrology

The principal unconsolidated aquifers at the Julietta study area are contained in the outwash deposits. Because of their thickness and horizontal extent, the sand and gravel layers are the major conduits for ground-water flow near the landfill. Two shallow sand and gravel aquifers underlie most of the landfill. In this report, the shallowest aquifer is referred to as the surficial aquifer, and the lower aquifer is referred to as the deep aquifer. Where the two aquifers combine, shallow and deep refer to the relative position of parts of the same aquifer.

Ground-water levels and flow

Depth to water was measured in each well, and the average depth for the study area was 17.5 ft on October 16, 1985. The deepest water levels measured during the study were at well H-4, and the shallowest were at DD-2. Surface topography has a great influence on depth to water; and water levels were deepest beneath the landfill where the ground is highest. The average depth to water in wells located in the landfill was 24.2 ft on October 16, 1985. Because the thickness of refuse is as much as 50 ft, parts of the refuse were beneath the water table. The largest measured thickness of saturated refuse was 28.8 ft at site I.

Water levels measured in the shallow observation wells were used to draw a potentiometric map of equal water-level altitudes in the unconsolidated aquifers (fig. 8). Ground water flows perpendicular to the contours. The primary component of flow is to the southeast. The contours point upstream and indicate that ground water flowing through the landfill is discharged to Grassy Creek and Buck Creek.

Where multiple aquifers are present, vertical flow gradients were determined by comparing water levels in adjacent wells of different depths. Water levels in shallow and deep wells were the same throughout most of the study area, indicating that flow in the shallow aquifers primarily is horizontal. However, near the streams, vertical flow was indicated by water levels in wells at site EE. The deep well, EE-3, had a higher water level than did the shallow well, EE-2 (fig. 9). The hydrograph shows an upward flow gradient at site EE most of the time. The temporary flow reversal in November 1985 was caused by precipitation that first infiltrated the surficial aquifer.

Pettijohn (1977, p. 12) reported that a bedrock well at site EE had a static head about 6 ft above ground level. At least one private well east of Buck Creek also flows at ground surface (Joe Ketterman, Marion County Health Department, oral commun., 1987). At site C, water levels in the deep well, C-1, always were 2 to 8 ft higher than water levels in the two shallow wells at the site.

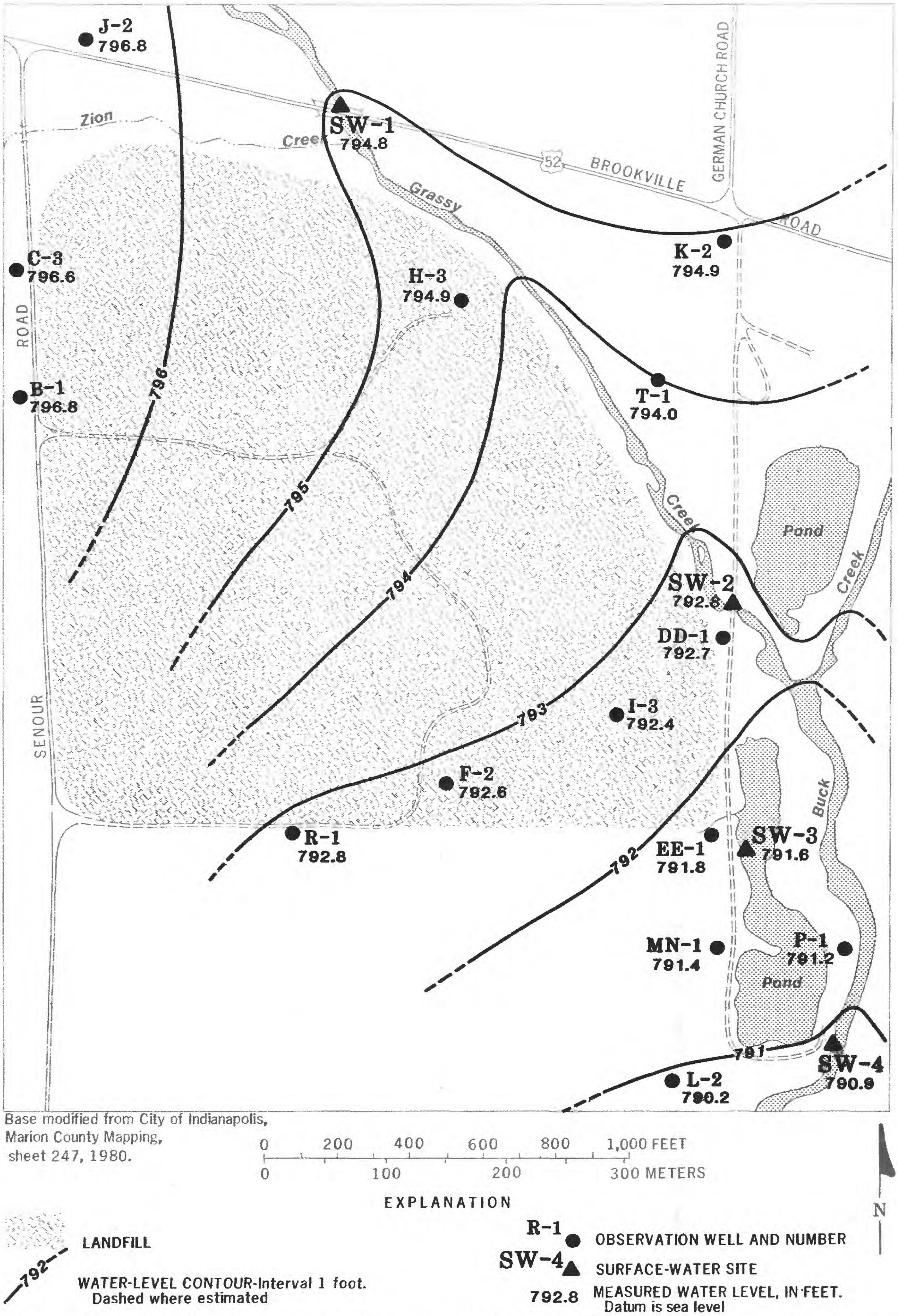


Figure 8.– Water levels in the surficial aquifer at the Julietta study area, October 16, 1985.

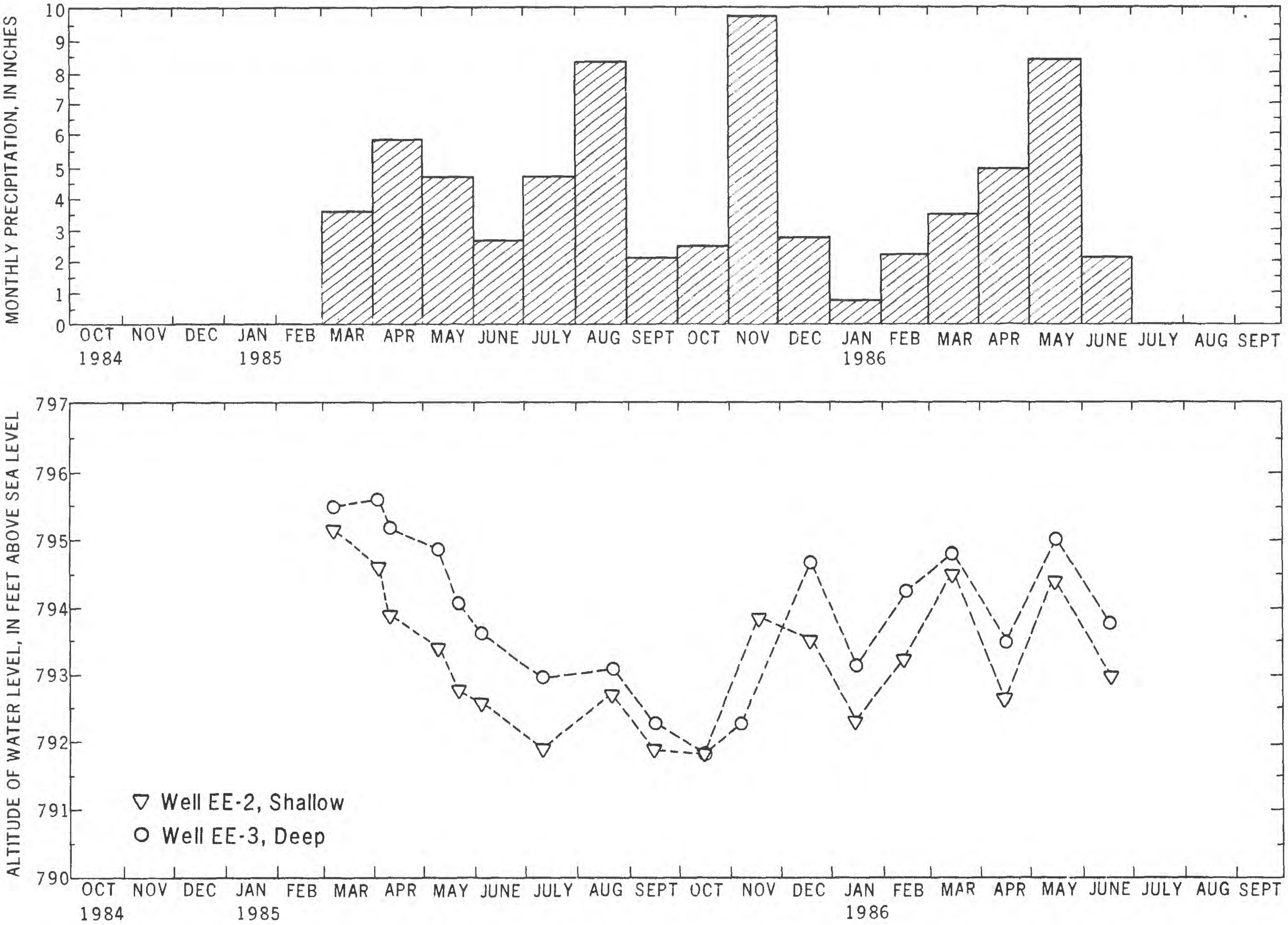


Figure 9.-- Altitude of water level in wells EE-2 and EE-3 at the Julietta study area and monthly precipitation at the Indianapolis southeast-side observer, March 1985 through June 1986.

At site A, however, water levels indicated a different pattern. The shallow well, A-1, had the highest water level, indicating a downward flow gradient. The wells at site A and the well at site O had the highest measured water levels of all wells in the study. The water levels in wells at sites A and O are affected by higher, possibly perched, water levels in sand and gravel lenses in the kame southwest of the landfill. The higher elevation of the sand and gravel in the kame may result in radial flow from the kame. Ground-water seepage was observed along the western edge of the Buck Creek valley, south of the landfill. Because the wells at sites A and O were not screened in the same aquifer as were the other landfill wells, they were not used in the water-level map (fig. 8).

Ground-water recharge

Recharge to the aquifers occurs by infiltration of precipitation. The average precipitation for Marion County is 39 in/yr (inches per year) for the period 1951-80 (National Oceanic and Atmospheric Administration, 1982). Pettijohn (1977, p. 17) estimated that recharge from infiltration of precipitation was as much as 11 in/yr before construction of the landfill. Because landfilling alters the topography and affects surface runoff, the rate of recharge probably has changed. The application and compaction of the sludge/-soil mixture at the landfill probably has decreased infiltration through the surficial material. The abundance of puddles, which remain long after rainfall has ceased, indicate a slow rate of infiltration. Vegetation at the site also decreases the rate of infiltration through evapotranspiration, and the sludge/soil mixture retains the water, making it more available for plant use.

Ground-water levels fluctuate in response to recharge. The average water-level fluctuation in all observation wells in the Julietta study area was 3.8 ft from January 1985 through June 1986. A maximum fluctuation of 6.0 ft was measured at well C-1, and a minimum fluctuation of 2.9 ft was measured at well H-1. In general, water-level fluctuations were larger in recharge areas and smaller near the streams.

Hydraulic characteristics

Horizontal hydraulic conductivity of sand and gravel aquifers in Marion County was estimated by Cable and others (1971, p. 11) to be 1,500 (gal/d)/ft^2 (gallon per day per square foot), or about 200 ft/d (feet per day). Average flow velocity at the landfill site was determined to be 1.3 ft/d by Pettijohn (1977, p. 17), using Darcy's law, a hydraulic gradient of 1.64×10^{-3}, and a 25-percent effective porosity. Assuming that the hydraulic conductivity is 200 ft/d, the transmissivity of the sand and gravel aquifers in the area of the landfill ranges from 600 to 8,000 ft^2/d (feet squared per day).

Ground-water/surface-water relations

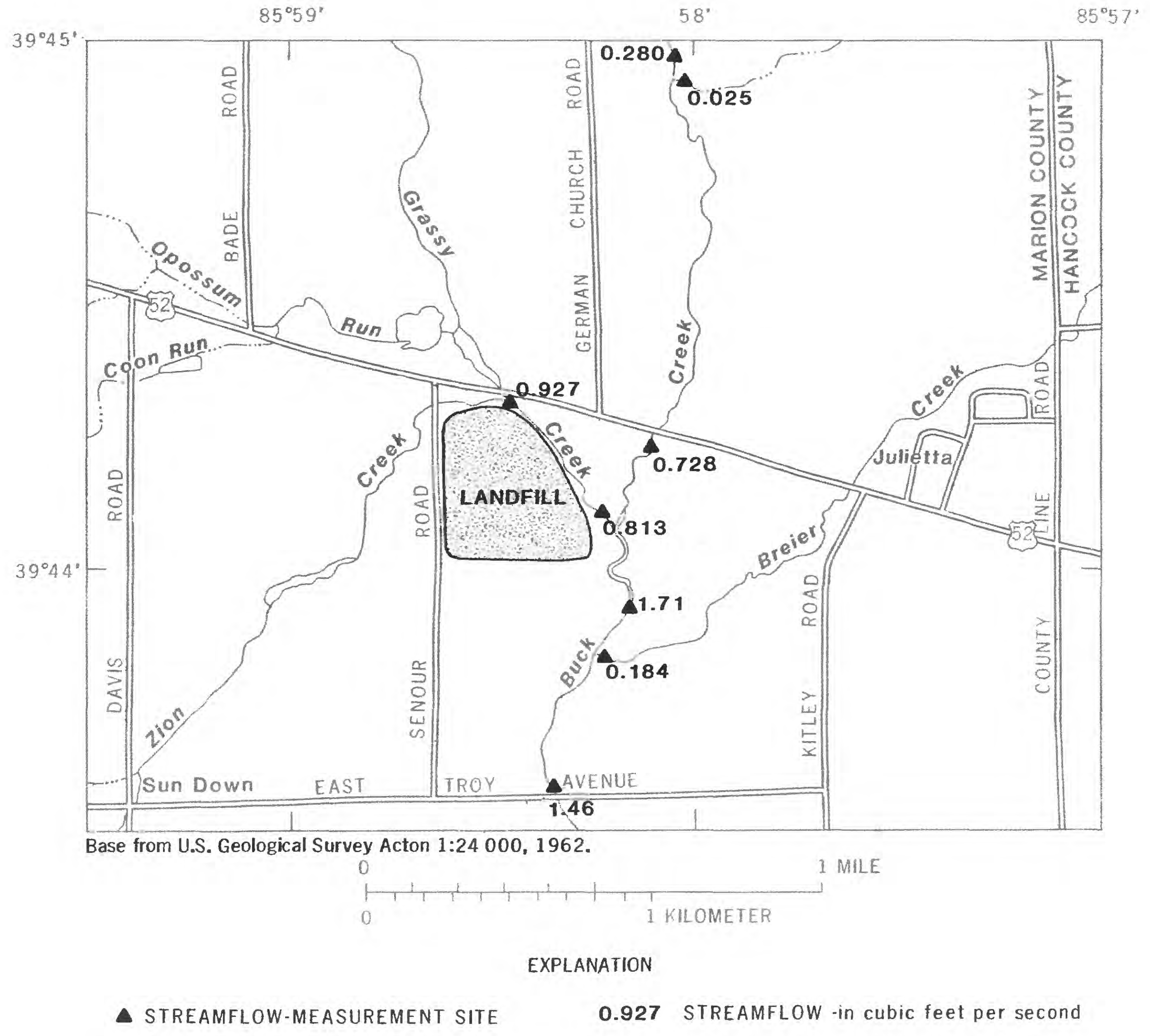
Both ground-water discharge and surface runoff contribute to flow in the three streams that drain the Julietta study area. The largest stream, Buck Creek, probably receives most of the ground-water discharge and all the surface runoff. Shallow ground-water flow is intercepted by Grassy Creek along the northeastern edge of the landfill. Flow in deep sand and gravel aquifers may move semiparallel to the streams for some distance before discharging to the streams. During normal hydrologic conditions, Grassy Creek and Buck Creek maintain flow throughout the year. Zion Creek, a small tributary to Grassy Creek, flows intermittently and receives surface runoff from the northwestern corner of the landfill and some contribution of ground water during times of high ground-water levels. Zion Creek may be dry for as many as 4 months during an average year.

Water levels in the small fishing ponds east of the landfill are maintained by ground-water flow. A staff gage in the pond near site EE indicates that the pond water levels vary in accordance with the nearby ground-water levels. On October 16, 1985, the water level was 791.8 ft in well EE-1, 791.6 ft in the pond at SW-3, 791.2 ft in well P-1, and 790.9 in Buck Creek at SW-4 (fig. 8).

Streamflow

Streamflow was measured at two locations on Grassy Creek and four locations on Buck Creek during a period of low streamflow on October 16, 1985 (fig. 10). The measurements on Grassy Creek indicated a loss of streamflow, even though ground-water levels adjacent to the stream were higher than the stream stage. The discrepancy was attributed to difficulties in measuring small changes in streamflow for short stream reaches.

Streamflow was 0.8 ft^3/s (cubic foot per second) in Grassy Creek and 0.7 ft^3/s in Buck Creek, upstream from their confluence. Downstream from the confluence, and downgradient from the landfill, discharge was 1.7 ft^3/s. The measurements were rated to be within ±10 percent of the actual value. If the upstream values are adjusted down by 10 percent and the downstream values are adjusted up by 10 percent, the resulting gain in streamflow would represent the maximum possible gain in streamflow through the study area. The maximum gain was 0.06 ft^3/s for Grassy Creek from U.S. Highway 52 to its confluence with Buck Creek, and was 0.33 ft^3/s for Buck Creek from U.S. Highway 52 to just south of the landfill, near site P.



Base from U.S. Geological Survey Acton 1:24 000, 1962.

Figure 10.-- Locations of streamflow measurements and streamflow for Grassy Creek and Buck Creek, October 16, 1985

Simulation of Ground-Water Flow

Ground-water flow through the Julietta landfill was simulated with the U.S. Geological Survey finite-difference model (McDonald and Harbaugh, 1988). Model geometry was defined by lithologic information from well logs. The model was calibrated to match the measured ground-water levels and streamflow. The sensitivity of the model to uniform changes in horizontal hydraulic conductivity, recharge, and streambed conductance was tested. The calibrated model was used to estimate the volume of ground-water flow through the refuse at the Julietta landfill.

Model Description

The Julietta model simulates steady-state flow in the two shallow sand and gravel aquifers beneath the study area. The aquifers are represented by model layers 2 and 3 (fig. 11). Layer 1, above the surficial aquifer, represents natural materials in undisturbed areas and refuse in the landfill. Thick areas of refuse extend into layers 2 and 3. A constant spacing of 123 ft was used to draw a grid containing 29 rows and 26 columns (fig. 12). The active part of the grid contains 558 grid blocks and covers an area of 193.8 acres. Buck Creek and Grassy Creek were simulated in the model. Zion Creek had no flow during the period chosen for calibration and, therefore, was not simulated.

The eastern model boundary is Buck Creek and this boundary was simulated by a no-flow boundary along the eastern edge of the stream nodes that represent Buck Creek. This arrangement of no-flow nodes and stream nodes allows the simulation of ground-water flow to or from the stream but not across it. The northern, southern, and western boundaries were simulated by constant heads. The southern two-thirds of the western boundary is along a surface-water divide between Buck Creek and Zion Creek. The aquifers are thin and become discontinuous near this boundary. A no-flow boundary might have been used along the western boundary; however, the water-level contours indicate that ground water flows across this boundary from the east. The northern and southern boundaries are arbitrary limits of the study area. The aquifers extent beyond these boundaries and water-level contours indicate that ground water flows across them. The flow of ground water across the western, northern, and southern boundaries could not be measured, whereas constant-head values for model input were easily determined from measured water levels. The top of the model was the water table, and the bottom was simulated as a no-flow boundary because of the thick clay beneath layer 3. Flow across the lower boundary is assumed to be negligible when compared to the volume of ground-water flow in the shallow aquifers.

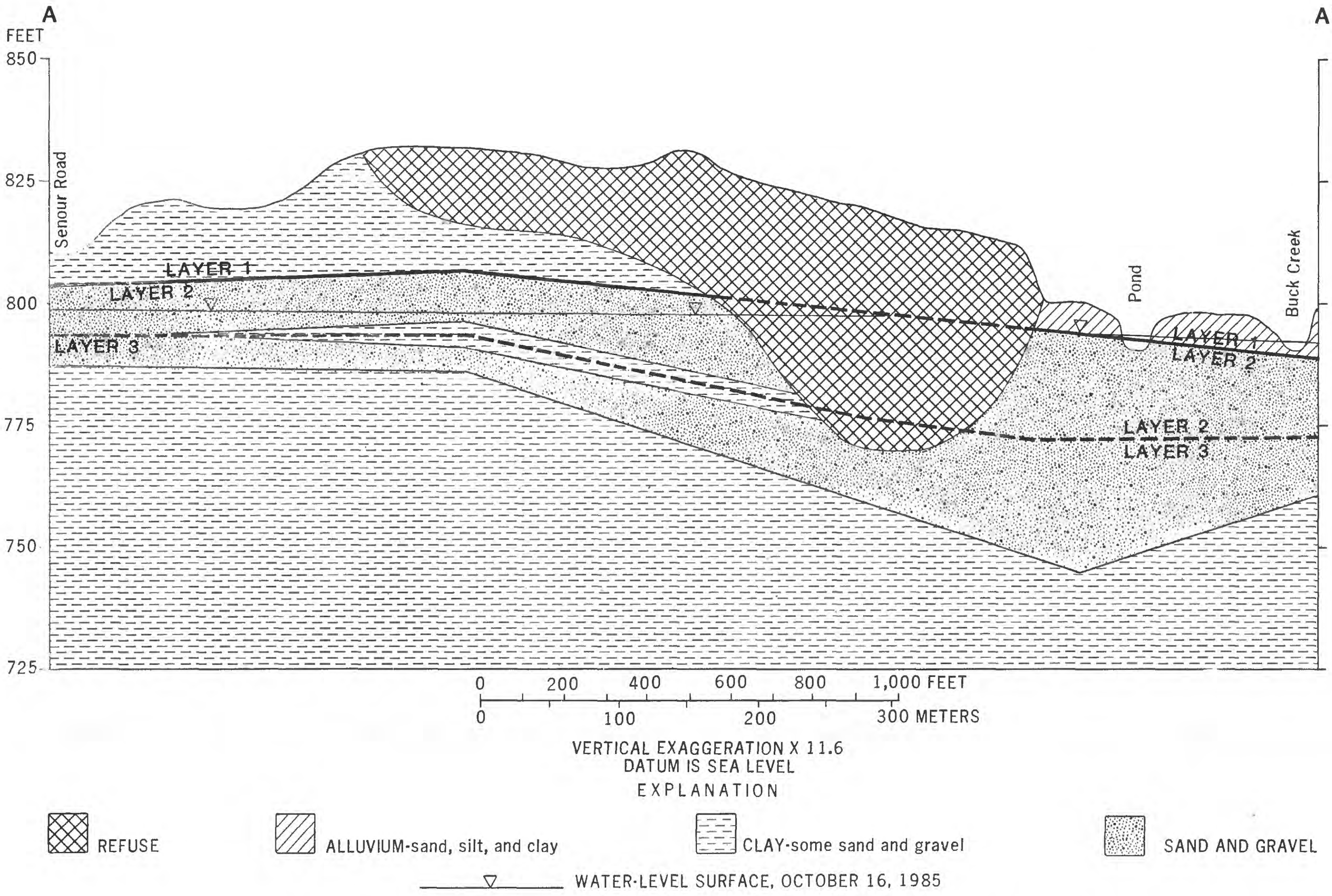


Figure 11.-- Generalized geohydrologic section showing model layers.

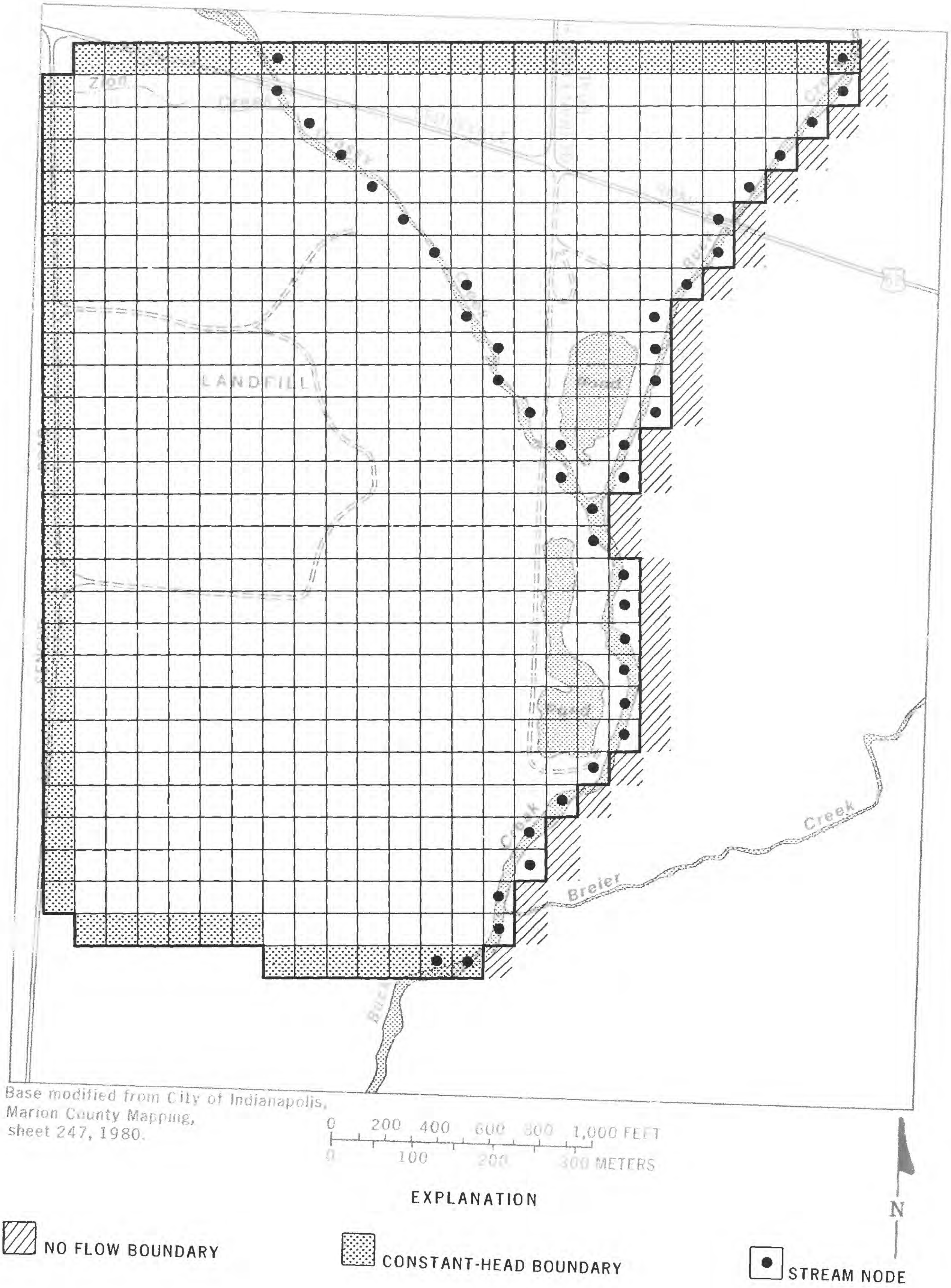


Figure 12.-- Finite-difference grid used to simulate ground-water flow at the Julietta study area.

Model Calibration and Sensitivity

The Julietta model was calibrated to water levels and streamflow measured on October 16, 1985. Values of model variables used in the calibrated model are listed in table 5. Model solutions are not unique because several combinations of values of model variables can produce similar results. The sensitivity of the Julietta model to uniform changes in horizontal hydraulic conductivity, recharge, and streambed conductivity were tested during calibration by comparing model output before and after a change was made.

Horizontal hydraulic conductivity of the sand and gravel aquifers was 150 ft/d in the calibrated model. Vertical hydraulic conductivity was assumed to be 0.1 times the horizontal hydraulic conductivity. Decreasing the hydraulic conductivity to 100 ft/d raised water levels 0.1 to 0.3 ft near the western model boundary and lowered water levels 0.1 to 0.2 ft near the streams with a reduction in streamflow of 14 percent compared to the calibrated model. Increasing the hydraulic conductivity to 300 ft/d had the opposite effect on water levels and resulted in an increase in streamflow of 26 percent compared to the calibrated model.

Table 5.--Values of selected model variables at calibration for the ground-water flow model of the Julietta study area

[ft/d, feet per day; in/yr, inches per year]

Model variable	Value at calibration
Horizontal hydraulic conductivity[1]	
Sand and gravel	150 ft/d
Alluvium	20 ft/d
Refuse	10 ft/d
Till	5 ft/d
Recharge rate	
Alluvium	6 in/yr
Refuse	3 in/yr
Till	2 in/yr
Streambed conductivity[2]	
Buck Creek	200 ft/d
Grassy Creek	50 ft/d

[1] Vertical hydraulic conductivity was assumed to be 0.01 times the value for horizontal hydraulic conductivity.

[2] For a streambed thickness assumed to be 1 ft.

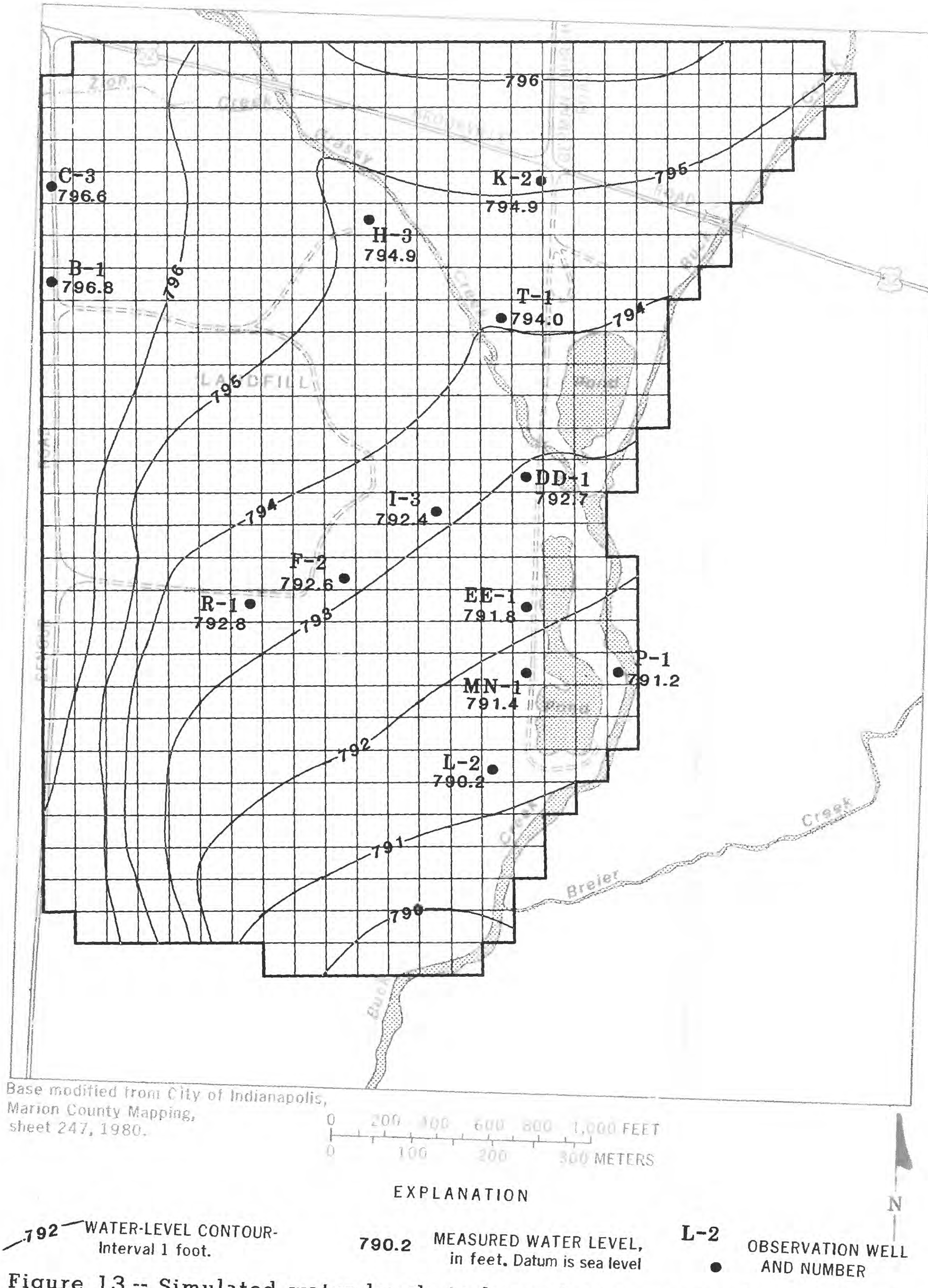
Simulated recharge rates for the calibrated model are listed in table 5. Recharge rates of one-half the calibrated values lowered water levels 0.1 to 0.2 ft throughout the model and reduced streamflow by 7 percent. Doubling the recharge rates raised water levels 0.1 to 0.3 ft and increased streamflow 17 percent.

Streambed conductivity for an assumed streambed thickness of 1 ft was 50 ft/d for Grassy Creek and 200 ft/d for Buck Creek. The larger conductivity of the Buck Creek streambed compared to that of Grassy Creek is justified because the Buck Creek streambed contains more coarse gravel than the Grassy Creek streambed. The model was not sensitive to large changes in streambed conductivity. Increasing or decreasing the streambed conductivity by two orders of magnitude did not change water levels in the model by more than 0.1 ft and did not change streamflow by more than 10 percent. A three order-of-magnitude increase in streambed conductivity resulted in an increase in streamflow of 274 percent. A three order-of-magnitude decrease in streambed conductivity raised water levels in the model as much as 0.5 ft and decreased streamflow by 32 percent.

The sensitivity analysis indicate that the Julietta model is not very sensitive to changes in values of the model variables. Streamflow was affected more than water levels by changes in horizontal hydraulic conductivity and recharge. The insensitivity is due to the constant-head boundaries that add and subtract as much water as necessary to maintain the constant water level. Moving the constant-head boundaries farther north, south, and west would increase the sensitivity of the model; however, there were no lithologic or water-level data to determine model geometry in these areas.

Simulated Water Levels and Flow Budget

Simulated water levels for layer 2 and measured water levels for the surficial aquifer on October 16, 1985, are shown in figure 13. The simulated water levels are slightly higher than the measured water levels and the differences range from no difference at well H-3 to 1.2 ft at well L-2. The average difference between simulated and measured water levels for layer 2 is 0.4 ft. Water levels in layer 3 are similar to those in layer 2; however, water levels in layer 3 are lower than those in layer 2 along the western boundary and higher near the streams. The maximum difference in water levels between layer 2 and layer 3 is 0.9 ft along the western model boundary. Simulated water levels in layer 3 are also higher than measured water levels and the differences ranged from 0.2 ft at well K-1 to 1.4 ft at well T-2, with an average difference of 0.7 ft. Much of layer 1 is above the water table and, therefore, was dry at the end of the model solution.



Base modified from City of Indianapolis, Marion County Mapping, sheet 247, 1980.

Figure 13.-- Simulated water levels in layer 2 and measured water levels in the surficial aquifer, October 16, 1985.

The model simulates two water sources--boundary inflow and recharge. Correspondingly, there are two options for discharge--boundary outflow and discharge to a stream node. Because the flow system was at steady state, input equals output, and a water budget was used to determine rates and volumes of flow. The overall budget and flow rates, in ft^3/s, for the three model layers are listed in table 6.

Table 6.--Simulated water budget for the Julietta study area

[ft^3/s, cubic feet per second; <, less than]

Inflow	Rate (ft^3/s)	Percentage of total	Outflow	Rate (ft^3/s)	Percentage of total
		Layer 1			
Recharge	0.0585	22	Leakage to streams	0.2265	85
Boundary flux	.0038	1	Boundary flux	.0012	<1
Leakage from layer 2	.2100	77	Leakage to layer 2	.0396	15
		Layer 2			
Recharge	.0296	9	Boundary flux	.1416	40
Boundary flux	.1848	52	Leakage to layer 1	.2100	59
Leakage from layer 1	.0396	11	Leakage to layer 3	.0052	1
Leakage from layer 3	.1003	28			
		Layer 3			
Boundary flux	.1384	96	Boundary flux	.0455	31
Leakage from layer 2	.0052	4	Leakage to layer 2	.1003	69
		Total			
Recharge	.0881	21	Leakage to streams	.2265	54
Boundary flux	.3313	79	Boundary flux	.1927	46
TOTAL	.4194	100	TOTAL	.4192	100

Total simulated ground-water flow in the Julietta model was 0.42 ft^3/s, or about 270,000 gal/d (gallon per day). Seventy-nine percent of the water entered the model as underflow across the northern and western boundaries. The remaining 21 percent was direct recharge. In the model, 54 percent of the ground water was discharged to streams and 46 percent was underflow across the southern boundary of the model. Because the constant head boundaries can add or subtract water, the model budget may not represent the actual ratio between recharge and boundary flow. However, because the model was calibrated to measured streamflow, the simulated volume of ground-water flow probably is reasonable.

Most of the flow in the model was in the two upper layers. Flow in layer 1 was predominantly vertical. In the model, recharge was applied to layer 2 when layer 1 was dry. Downward leakage from layer 1 to layer 2 occurred throughout most of the model. As a result, parts of layer 2 were recharged through areas of refuse in layer 1. Horizontal flow occurred through more deeply buried refuse in layers 2 and 3. Upward leakage between layers is beneath and adjacent to streams.

The simulated discharge to streams was about 0.23 ft^3/s for the entire model. Budgets for individual stream nodes indicate that 0.07 ft^3/s discharged to Grassy Creek and 0.16 ft^3/s discharged to Buck Creek. These values compared well with the seepage estimates that were made on the basis of measurements of flow in these streams on October 16, 1985. Estimates were 0.06 ft^3/s for Grassy Creek and 0.33 ft^3/s for Buck Creek. The estimate for Buck Creek includes ground water gained from both sides of the stream. Only one side of the stream is simulated; therefore, one-half of this discharge was used for calibration.

A node-by-node method was used to calculate a budget for the landfill. First, the simulated recharge through the entire area that was covered by sludge was calculated to be 0.02 ft^3/s, or about 13,000 gal/d. The area covered by sludge is larger than the area of buried refuse (fig. 3), so the recharge represents the volume of water exposed to the layer of sludge near the surface of the landfill and is independent of recharge or ground-water flow through the refuse. Second, a budget was calculated for the area of buried refuse. Total simulated ground-water flow through the buried refuse was 0.03 ft^3/s, or about 19,000 gal/d. As in the overall model budget, most of the flow was in layers 1 and 2. Flow in layer 1 predominantly was vertical. Horizontal flow through the refuse in layers 2 and 3 eventually is discharged upward to the streams.

Ground-Water Quality

Ground-water samples were collected in the Julietta study area for chemical analysis to assess the quality and to determine any effects from landfill leachate. Thirty-five wells were included in the survey. Five sets of samples were collected during the study. Wells I-2, I-3, and O-2 were not sampled every time, because these wells had damaged casings that prevented access of the submersible pump or because water levels were below the lift capability of available surface pumps. Wells J-1 and O-1 were never sampled because these wells had damaged casings or screens. The samples were analyzed to determine the concentrations of dissolved inorganic substances and phenols. Individual analyses for each well are listed in table 7 (at back of report.)

General Description

Ground water near the Julietta landfill is primarily a calcium and bicarbonate-type water. Other major cations (besides calcium) include magnesium and sodium. Chloride, and to a lesser degree, sulfate constitute the other major anions. Water in more than one-half the wells had substantial concentrations of iron and manganese, which is common in glacial sediments throughout Marion County (Cable and others, 1971, p. 33). Hardness of water (as calcium carbonate) is related directly to the concentration of polyvalent metallic ions dissolved in the water. The principal ions are calcium and magnesium (Hem, 1985, p. 158). Hardness of ground water in the Julietta study area ranged from 53 to 267 mg/L (soft to very hard) (Hem, 1985, p. 158). Water in 90 percent of the wells had a hardness concentration greater than 100 mg/L.

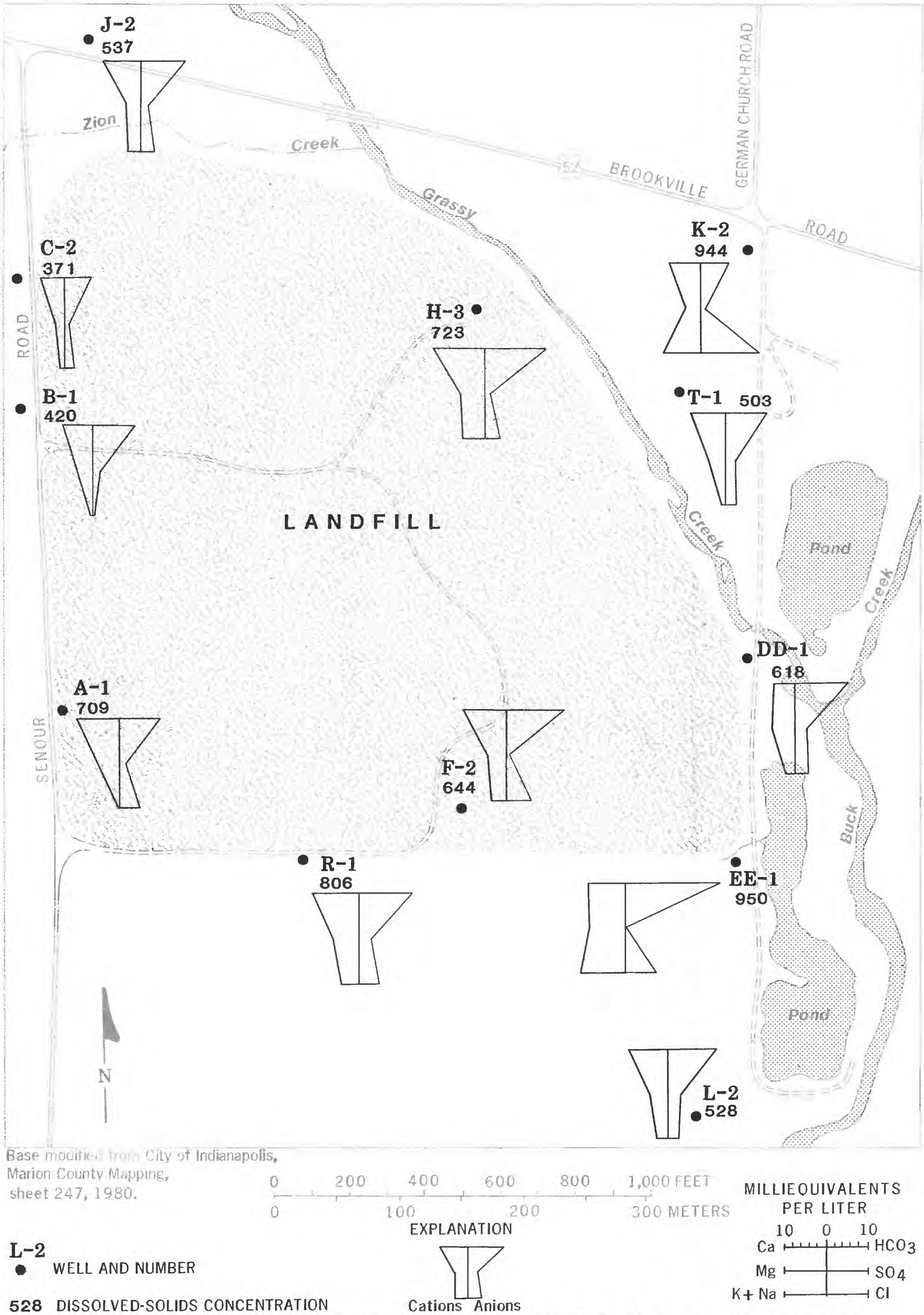
Two general trends in water quality were observed within the study area. First, a decrease in quality toward the southeast was indicated by increases in concentrations of dissolved constituents in wells screened beneath and downgradient from the landfill. Second, concentrations of dissolved constituents were smaller in water from wells that penetrate the deeper sand and gravel aquifers. Therefore, the poorest water quality seems to be confined to the surficial aquifer.

There are other potential sources of ground-water contamination near the Julietta landfill including another landfill northwest of the wells at site J and upgradient from the Julietta landfill, road salting on U.S. Highway 52, and domestic septic systems. A large-diameter interceptor sewer crosses the study area, from north to south, east of the landfill. Wells that could be affected if the sewer leaked are at sites DD, EE, L, and MN; however, ground-water quality at these wells does not indicate that such leakage has occurred. Except for well MN-1, the wells were drilled west of, or upgradient from, the sewer. This placement of the wells lessens the chance that contaminants will reach these wells. In addition, the sewer is buried below the water table along most of its course through the study area, and ground water potentially could leak into the sewer during normal sewage-flow conditions.

Aquifers

Surficial aquifer

On the basis of the previous discussion of hydrology, changes in water quality attributable to landfill leachate most likely occur beneath and downgradient from the landfill in the surficial sand and gravel aquifer. The general quality of water in the surficial aquifer is shown by Stiff diagrams in figure 14. Stiff diagrams show relative concentrations of major ions in the water. The dissolved-solids concentration also is shown and is useful in determining the overall ground-water quality.



Base modified from City of Indianapolis, Marion County Mapping, sheet 247, 1980.

Figure 14.– Dissolved-solids concentrations and Stiff diagrams of common ion concentrations in the surficial aquifer at the Julietta study area, May 1986.

The wells in the Julietta study area were grouped according to the positions of their well screens in the ground-water flow system related to the landfill to evaluate the water-quality data and to determine the effect of leachate on ground-water quality. Group 1 is upgradient, group 2 is beneath, and group 3 is downgradient from the landfill. The wells also were grouped according to whether they were screened in surficial or deep aquifers. Water-quality data are summarized by groups in tables 8 through 13. The tables list medians, interquartile ranges, minimums, and maximums for most of the measured constituents. The median for a constituent is the concentration value such that about one-half the concentrations are smaller than the median and about one-half the concentrations are larger than the median. The interquartile range provides a quick measure of the variation in the data and the minimums and maximums indicate the range.

Shallow upgradient wells are A-1, B-1, and C-2. Water from wells at sites J and O does not represent background water quality because it may be affected by other sources of contamination. Water from the shallow well, A-1, had larger concentrations of dissolved solids than did water from the other upgradient wells. Well A-1 may represent water quality in the kame southwest of the landfill.

Water from wells A-1, B-1, and C-2 represents ambient or natural water quality in the surficial aquifer before being affected by the landfill. A statistical summary of water-quality data for these wells is listed in table 8. Water in shallow upgradient wells had relatively small dissolved-solids concentrations (generally less than 500 mg/L), except at well A-1 where dissolved-solids concentrations were as large as 738 mg/L. Values of SC for water from the shallow upgradient wells ranged from 536 to 1,006 µS/cm, with a median of 638 µS/cm. The median pH was 7.2 and the median COD was 3 mg/L.

Major cations were calcium, magnesium, and, in some wells, sodium. Calcium and magnesium, respectively, had median concentrations of 87.4 and 29.3 mg/L. Sodium concentrations ranged from 4.5 to 23.0 mg/L and had a median value of 5.3 mg/L. The largest sodium concentrations were found in water from well C-2. Bicarbonate, as indicated by alkalinity, was the most abundant anion in shallow upgradient wells, with a median concentration of 290 mg/L.

Concentrations of nitrogen species generally were small in the shallow upgradient well water, except in well C-2 where concentrations of nitrate were as large as 1.9 mg/L as nitrogen. No large concentrations of nitrite or ammonia were detected.

Iron and manganese concentrations differed greatly among wells and ranged from less than 10 µg/L (micrograms per liter) for both constituents to 250 µg/L for iron and 140 µg/L for manganese. Trace elements generally were not detected, except for arsenic, which was found in water from several wells at concentrations of up to 5 µg/L, and barium whose median concentration was 240 µg/L.

Table 8.--Summary statistics of water-quality data for shallow wells A-1, B-1, and C-2, upgradient from the Julietta landfill

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of observations	Median	Interquartile range	Minimum	Maximum
Specific conductance	µS/cm	15	636	323	536	1,006
pH	units	15	7.2	.2	7.1	7.5
Temperature	°C	15	11.0	1.5	8.7	14.8
Dissolved oxygen	mg/L	15	.4	2.7	.2	6
Chemical oxygen demand	mg/L	15	3	11	1	19
Calcium	mg/L	15	87.4	39.9	60.4	126.6
Magnesium	mg/L	15	29.3	18.3	18.4	43
Sodium	mg/L	15	5.3	14.7	4.5	23.3
Potassium	mg/L	15	.8	.3	.7	1.4
Alkalinity, as $CaCO_3$	mg/L	15	290	88	190	308
Sulfate	mg/L	12	40	21.8	24.0	48
Chloride	mg/L	15	36	91.0	4.0	110
Bromide	mg/L	12	<.01	.1	<.01	.2
Dissolved solids	mg/L	15	420	265	327	738
Nitrate as nitrogen	mg/L	12	.02	1.16	<.01	1.92
Nitrite as nitrogen	mg/L	12	<.005	0	<.005	.01
Ammonia as nitrogen	mg/L	15	<.01	.05	<.01	.17
Phosphorus	mg/L	12	.01	.02	<.01	.04
Arsenic	µg/L	14	2	3	<1	5
Barium	µg/L	15	240	300	<10	580
Iron	µg/L	15	80	201	<10	250
Manganese	µg/L	15	40	111	<10	140

Wells screened beneath the landfill are at sites F, H, and I. Water from wells at these sites generally had larger concentrations of dissolved constituents than did water from the shallow upgradient wells. A statistical summary of water quality for shallow wells screened beneath the landfill is listed in table 9. Wells F-2 and H-3 are screened in the surficial aquifer and water from these wells had dissolved-solids concentrations ranging from 499 to 837 mg/L. The median concentration of dissolved solids was 665 mg/L, about 1.5 times the median concentration of water in shallow upgradient wells. Specific conductance ranged from 816 to 2,100 μS/cm. The median pH was 6.9, which is smaller than that in shallow upgradient wells. The median COD was 18 mg/L. The largest COD (35 mg/L) was found in water from well H-3.

Nitrate was detected only in small concentrations and nitrite was not detected in water from shallow wells screened beneath the landfill. Ammonia was detected in larger concentrations than in shallow upgradient wells. The largest concentration of ammonia was in water from well H-3 (8 mg/L as nitrogen). The median ammonia concentration in these wells was 1.29 mg/L as nitrogen.

Iron and manganese were detected in water from the shallow wells screened beneath the landfill in greater concentrations than those in water from the shallow upgradient wells. The median concentration of iron was 3,335 μg/L, which is more than 40 times the median concentration for the shallow upgradient wells. Manganese had a median concentration of 105 μg/L. Arsenic concentrations ranged from not detected to 12 μg/L, with a median of 2 μg/L. The same median concentration of arsenic was found in the shallow upgradient wells. Other trace elements generally were not detected.

Water in shallow downgradient wells at sites DD, EE, L, and R contained a variety of chemical constituents indicating the presence of leachate. Wells that primarily were affected by leachate were DD-1, EE-1, and R-1. A statistical summary of the shallow downgradient wells is listed in table 10. Water from these wells had a median dissolved-solids concentration of 654 mg/L, which is slightly smaller than the median concentration found in water from shallow wells screened beneath the landfill. The largest concentration of dissolved solids detected during the study was 950 mg/L in water from well EE-1. Specific conductance ranged from 891 to 1,847 μS/cm, with a median of 1,113 μS/cm. The median pH in shallow downgradient wells was 7.0 and the median COD was 15 mg/L.

The major cations included calcium, which had a median concentration of 114.6 mg/L, and magnesium, which had a median concentration of 41.6 mg/L. The median concentration of sodium was 42.0 mg/L but was as large as 124.9 mg/L in water from well EE-1. The major anion was bicarbonate as indicated by the alkalinity concentration, the largest concentration of which was detected in water from well EE-1 which had a median alkalinity concentration of 563 mg/L. The median alkalinity concentration for water from all the shallow downgradient wells was 374 mg/L. Chloride was more abundant in water from wells EE-1 and R-1, where concentrations ranged from 80 to 190 mg/L. The median chloride concentration for water from all the shallow downgradient wells was 81 mg/L.

Table 9.--Summary statistics of water-quality data for shallow wells F-2 and H-3, beneath the Julietta landfill

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of obser- vations	Median	Inter- quartile range	Minimum	Maximum
Specific conductance	µS/cm	10	1,192	249	816	2,100
pH	units	10	6.9	.2	6.7	7.0
Temperature	°C	10	13.9	2.3	12.0	15.8
Dissolved oxygen	mg/L	10	0.1	.6	0	3.0
Chemical oxygen demand	mg/L	10	18	19	7	35
Calcium	mg/L	10	120.9	41.2	12.7	157.8
Magnesium	mg/L	10	37	8.6	26.0	48
Sodium	mg/L	10	50.1	26.5	18.3	66.3
Potassium	mg/L	10	3.4	1.9	2.4	7.9
Alkalinity, as $CaCO_3$	mg/L	10	420	44	342	510
Sulfate	mg/L	8	6.5	29.0	<.01	36.0
Chloride	mg/L	10	101	62.5	30	129.0
Bromide	mg/L	7	0.4	.3	.2	1.2
Dissolved solids	mg/L	10	665	186	499	837
Nitrate as nitrogen	mg/L	8	.01	.02	.01	.04
Nitrite as nitrogen	mg/L	8	<.005	0	<.005	<.005
Ammonia as nitrogen	mg/L	10	1.29	5.75	<.01	8
Phosphorus	mg/L	8	.03	.06	<.01	.1
Arsenic	µg/L	10	2	11	<1	12
Barium	µg/L	10	300	215	200	570
Iron	µg/L	10	3,335	6,552	2,480	16,120
Manganese	µg/L	10	105	113	20	230

Table 10.--Summary statistics of water-quality data for shallow wells DD-1, EE-1, L-2, and R-1, downgradient from the Julietta landfill

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of obser-vations	Median	Inter-quartile range	Minimum	Maximum
Specific conductance	µS/cm	20	1,113	391	891	1,847
pH	units	20	7.0	.1	6.8	7.1
Temperature	°C	20	12.7	1.9	10.1	15.2
Dissolved oxygen	mg/L	20	.2	.4	0	1.5
Chemical oxygen demand	mg/L	20	15	11	6	50
Calcium	mg/L	20	114.6	15	64.1	135.6
Magnesium	mg/L	20	41.6	9.2	31.8	64.0
Sodium	mg/L	20	42	53.5	14.4	124.9
Potassium	mg/L	20	4.6	24.1	1.9	40.2
Alkalinity, as $CaCO_3$	mg/L	20	374	35	334	662
Sulfate	mg/L	16	62.5	56.3	<.01	90.0
Chloride	mg/L	20	81	73	32	190.0
Bromide	mg/L	16	.5	1	.1	2.8
Dissolved solids	mg/L	20	654	169	267	950
Nitrate nitrogen	mg/L	16	.01	.02	<.01	.13
Nitrite nitrogen	mg/L	16	<.005	0	<.005	.01
Ammonia nitrogen	mg/L	20	1.61	20.35	.34	38.04
Phosphorus	mg/L	16	.02	.04	<.01	.21
Arsenic	µg/L	20	5	15	<1	28
Barium	µg/L	20	210	155	20	480
Iron	µg/L	20	4,805	5,342	1,840	11,750
Manganese	µg/L	20	115	227	50	700

Nitrate concentrations in water from the shallow downgradient wells ranged from not detected to 0.13 mg/L as nitrogen. Nitrite generally was not detected in water from these wells. The median concentration of ammonia was 1.61 mg/L as nitrogen; this concentration is larger than those in water from upgradient wells and wells screened beneath the landfill. The largest concentration of ammonia detected during the study was about 38 mg/L in water from well EE-1.

Concentrations of iron and manganese in water from the shallow downgradient wells were larger than the concentrations in water from wells in all other groups. The median iron concentration was 4,805 µg/L and the largest concentration was 11,750 µg/L in water from well EE-1. Concentrations of manganese ranged from 50 to 700 µg/L in water from the shallow downgradient wells, with a median of 115 µg/L. The trace elements chromium, copper, nickel, and zinc were detected in small concentrations (less than 30 µg/L) in water from well EE-1 during one or more of the sampling periods. Zinc was detected in water from well DD-1 with similar frequency. Three samples from well R-1 contained zinc concentrations of 20 to 30 µg/L. Mercury also was detected in one sample from well R-1 at a concentration of 0.6 µg/L.

Water from well L-2 was not affected by leachate to the same extent as were the shallow wells along the downgradient edge of the landfill for several possible reasons. The migration of leachate probably occurs along preferential flow paths that may or may not be intercepted by the well screens. Water from well L-2 actually may represent unaffected ground water from deeper aquifers moving upward toward Buck Creek. In addition, as leachate moves through the sediments, there is an attraction between soil particles and the dissolved constituents in the leachate. Some constituents may be held by, or adsorbed onto, the sediments (Blatt and others, 1972, p. 246), causing a decrease in dissolved solids as distance from the landfill increases.

Deep Aquifer

The deep wells in the Julietta study area are screened in the lower of the two sand and gravel aquifers. Water from deep wells beneath and downgradient from the landfill generally had dissolved-solids concentrations larger than those in water from upgradient wells, but smaller than those in water from shallow downgradient wells. Although flow is mostly horizontal in the aquifers, the deep semiconfined aquifer receives some water from the overlying semiconfining unit as precipitation percolates downward. The effect of recharge by precipitation on water quality is greater in the shallow aquifer than in the deep aquifer because the downward gradient produced by percolation of precipitation is temporary, allowing little leakage through semiconfining units to occur. In addition to physically retarding the flow, the clays that separate sand and gravel aquifers can retain some of the ions in the leachate, thereby decreasing the dissolved concentration (Blatt and others, 1972, p. 246).

Well C-3 is the only deep upgradient well. A statistical summary of water quality in well C-3 is listed in table 11. Dissolved-solids concentrations in water from this well were slightly smaller than those in the shallow upgradient wells. Specific conductance of water from well C-3 ranged from 582 to 747 µS/cm, with a median of 632 µS/cm. The median pH was 7.2, which is the same as that in the shallow upgradient wells. The median COD was 8 mg/L in water from well C-3.

Except for sodium, concentrations of major cations and anions generally were slightly smaller in water from well C-3 than those in water from the shallow upgradient wells. Calcium, magnesium, and sodium, respectively, had median concentrations of 84.0, 22.6, and 19.1 mg/L. Alkalinity concentrations ranged from 236 to 272 mg/L, with a median of 248 mg/L which is slightly smaller than that found in water from the shallow upgradient wells.

Nitrogen compounds generally were not detected in water from well C-3 except for nitrate, which was detected in all but one sample from this well. Concentrations of nitrate ranged from not detected to 0.58 mg/L as nitrogen, with a median of 0.26 mg/L as nitrogen. The median nitrate concentration was about one-half that in water from well C-2, the shallow well at this site.

Concentrations of iron and manganese in water from well C-3 were similar to those in water from shallow upgradient wells B-1 and C-2, but were much less than the concentrations in water from well A-1. Iron and manganese, respectively, had median concentrations of 9 and 30 µg/L in water from well C-3. Trace elements generally were not detected except for barium, which was detected in concentrations as large as 320 mg/L. This concentration of barium was similar to concentrations detected in water from wells A-1 and B-1, but was much smaller than the concentrations detected in water from well C-2.

Wells screened in the deep aquifer beneath the landfill are F-1, F-3, F-4, H-1, H-4, I-3, and I-4. A statistical summary of water quality in these wells is listed in table 12. The deep wells generally contained water that had larger concentrations of dissolved constituents compared to water from the shallow and deep upgradient wells but had smaller concentrations of dissolved constituents compared to water from the shallower wells at the same site. Dissolved-solids concentrations ranged from 399 to 929 mg/L, with a median of 562 mg/L. The median concentration of dissolved solids was smaller in water from the deep wells than in water from the shallow wells; however, the maximum concentration was larger in the deep wells. Specific conductance was less in water from the deep wells compared to the shallow wells and ranged from 624 to 1,379 mg/L. The median pH was 7.2, which was larger than the pH of water from shallow wells screened beneath the landfill. The median COD was 9 mg/L or about one-half the concentration in water from the shallow wells.

Table 11.--Summary statistics of water-quality data for the deep well C-3, upgradient from the Julietta landfill

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of obser-vations	Median	Inter-quartile range	Minimum	Maximum
Specific conductance	µS/cm	5	632	139	582	747
pH	units	5	7.2	.1	7.2	7.3
Temperature	°C	5	9.4	2.3	7.8	11.3
Dissolved oxygen	mg/L	5	.2	2.9	0	5.8
Chemical oxygen demand	mg/L	5	8	8	2	13
Calcium	mg/L	5	84	16.1	72.4	91.3
Magnesium	mg/L	5	22.6	3.4	22	26.4
Sodium	mg/L	5	19.1	5.3	16.5	23.3
Potassium	mg/L	5	1	.2	1	1.2
Alkalinity, as $CaCO_3$	mg/L	5	248	28	236	272
Sulfate	mg/L	4	33	2.8	32	35
Chloride	mg/L	5	34	19.5	28	53
Bromide	mg/L	4	0	.1	0	.1
Dissolved solids	mg/L	5	414	87	361	460
Nitrate as nitrogen	mg/L	4	.26	.44	<.01	.58
Nitrite as nitrogen	mg/L	4	<.005	.01	<.005	.01
Ammonia as nitrogen	mg/L	5	<.01	0	<.01	<.01
Phosphorus	mg/L	4	.01	.02	0	.03
Arsenic	µg/L	5	<1	0	<1	<1
Barium	µg/L	5	30	185	9	320
Iron	µg/L	5	9	10	<10	20
Manganese	µg/L	5	30	10	20	30

Table 12.--Summary statistics of water-quality data for deep wells F-1, F-3, F-4, H-1, H-4, I-3, and I-4, beneath the Julietta landfill

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; μg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of observations	Median	Interquartile range	Minimum	Maximum
Specific conductance	μS/cm	31	898	367	624	1,379
pH	units	31	7.2	.2	6.8	7.5
Temperature	°C	32	14.	2.7	11	22.7
Dissolved oxygen	mg/L	32	.1	.4	0	2.9
Chemical oxygen demand	mg/L	31	9	8	1	30
Calcium	mg/L	32	98.8	34.3	76.9	193.9
Magnesium	mg/L	32	31.6	7.1	25.6	64.7
Sodium	mg/L	32	27	27	8	59.3
Potassium	mg/L	32	3	2.9	.8	33.3
Alkalinity, as $CaCO_3$	mg/L	31	328	58	298	730
Sulfate	mg/L	25	34	44	.5	58
Chloride	mg/L	32	27.5	94	4	128
Bromide	mg/L	23	.1	.1	0	.6
Dissolved solids	mg/L	31	562	230	399	929
Nitrate as nitrogen	mg/L	25	.01	.01	<.01	.6
Nitrite as nitrogen	mg/L	25	<.005	0	<.005	.01
Ammonia as nitrogen	mg/L	32	.36	.6	<.01	19.4
Phosphorus	mg/L	25	.03	.04	<.01	.61
Arsenic	μg/L	31	1	3	<1	30
Barium	μg/L	32	205	130	30	370
Iron	μg/L	32	2,225	988	1,000	11,140
Manganese	μg/L	32	30	10	10	520

Except for sulfate, the major cations and anions were detected in smaller concentrations in water from deep wells screened beneath the landfill compared to water from shallow wells at the same sites. Median concentrations of calcium, magnesium, and sodium in water from the deep wells respectively were 98.8, 31.6, and 27.0 mg/L. The median concentration of sulfate was 34.0 mg/L, which is more than five times the concentration found in water from the shallow wells screened beneath the landfill. Alkalinity concentrations were larger in water from the deep wells screened beneath the landfill compared to water from shallow and deep upgradient wells; however, the median alkalinity concentration was smaller than the median concentrations in water from shallow wells at the same sites. The median alkalinity concentration was 328 mg/L. The maximum alkalinity concentration was 730 mg/L in water from well I-3--the largest alkalinity concentration found during the study.

Nitrite generally was not detected in water from the deep wells screened beneath the landfill. Small concentrations of nitrate were detected and concentrations were as large as 0.6 mg/L as nitrogen. Concentrations of ammonia generally were smaller in water from the deep wells compared to water from the shallow wells at the same sites and compared to water from shallow and deep upgradient wells. Concentrations of ammonia ranged from not detected to 19.4 mg/L as nitrogen. The maximum concentration of ammonia was detected in water from well I-3 and is similar to the concentrations detected in water from shallow downgradient wells.

The median concentrations of iron and manganese in water from deep wells screened beneath the landfill respectively were 2,225 and 30 μg/L. These concentrations are smaller than those in water from shallow wells at the same sites. Although median concentrations of trace elements also were smaller in water from the deep wells, the largest concentration of arsenic detected during the study was 30 μg/L in water from the deep well H-3.

Because of active biodegradation of refuse at site I, shallow well I-3 was emitting gas. The presence of gas indicated anaerobic conditions in this part of the landfill. The gas was not collected for laboratory analysis, but onsite tests done in the well indicated that the gas was flammable and toxic. Tests outside the well indicated that the gas dissipated quickly after leaving the well head. The tests were done using a portable gas-detection meter used to detect toxic and combustible gas and oxygen-deficiency in the atmosphere. The gas probably is methane, but may contain hydrogen sulfide or other gases. Well I-3 is the shallowest well at site I and is near the thickest part of the refuse.

Deep, downgradient wells are DD-2, EE-2, L-1, MN-1, and P-1. A statistical summary of water quality in these wells is listed in table 13. Water in the deep downgradient wells generally had smaller concentrations of dissolved constituents than those found in water in shallow downgradient wells or water in shallow and deep wells screened beneath the landfill, but had larger concentrations than those found in water in shallow and deep upgradient wells. Dissolved-solids concentrations in water from the deep downgradient wells ranged from 411 to 642 mg/L, with a median of 513 mg/L. Specific conductance ranged from 636 to 1,076 μS/cm. The median pH was 7.2, and the median COD was 8 mg/L.

Table 13.--Summary statistics of water-quality data for deep wells DD-2, EE-2, L-1, MN-1, and P-1, downgradient from the Julietta landfill

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of observations	Median	Interquartile range	Minimum	Maximum
Specific conductance	µS/cm	25	832	206	636	1,076
pH	units	25	7.2	.1	7	7.3
Temperature	°C	25	13.2	2.4	10	15.6
Dissolved oxygen	mg/L	25	.2	.4	0	.9
Chemical oxygen demand	mg/L	25	8	10	1	36
Calcium	mg/L	25	92.8	17.7	74	111.3
Magnesium	mg/L	25	32.9	9.1	12.9	41.2
Sodium	mg/L	25	26.3	20.3	8.2	56.1
Potassium	mg/L	25	3.8	6.9	1.1	13.5
Alkalinity, as $CaCO_3$	mg/L	25	346	50	186	456
Sulfate	mg/L	20	33	18	.5	121
Chloride	mg/L	25	40	42	1	109
Bromide	mg/L	20	.3	.4	<.01	13.3
Dissolved solids	mg/L	25	513	96	411	642
Nitrate as nitrogen	mg/L	20	.01	.02	<.01	1.11
Nitrite as nitrogen	mg/L	20	<.005	0	<.005	.01
Ammonia as nitrogen	mg/L	25	2.47	3.32	.07	8.48
Phosphorus	mg/L	20	.01	.01	<.01	.03
Arsenic	µg/L	25	<1	0	<1	2
Barium	µg/L	25	350	290	100	1,070
Iron	µg/L	25	3,150	2,130	5	5,760
Manganese	µg/L	25	50	30	20	100

Concentrations of major cations and anions in water from deep downgradient wells were much smaller than those found in water from shallow wells screened beneath the landfill and those found in water from shallow downgradient wells, but were only slightly smaller than the concentrations found in water from the deep wells screened beneath the landfill. The median concentrations of calcium, magnesium, and sodium in water from deep downgradient wells respectively were 92.8, 32.9, and 26.3 mg/L. Alkalinity concentrations ranged from 186 to 456 mg/L, with a median of 346 mg/L.

Nitrite generally was not detected in water from the deep downgradient wells. Nitrate concentrations ranged from not detected to 1.11 mg/L as nitrogen. The maximum nitrate concentration was found in water from deep well DD-2 and was much smaller than the concentrations in water from shallow downgradient wells or wells screened beneath the landfill. This concentration of nitrate is similar to the concentrations in some of the shallow upgradient wells. The median concentration of ammonia was 2.47 mg/L as nitrogen, which is larger than the median concentration in water from wells in the other groups; however, the maximum concentration of ammonia in water from deep downgradient wells is only about one-fourth the maximum concentration in water from shallow downgradient wells and is about one-half the maximum concentration in water from deep wells screened beneath the landfill.

Median concentrations of iron and manganese in deep downgradient wells respectively were 3,150 and 50 µg/L. Except for barium, trace elements were not detected in large concentrations. Barium concentrations ranged from 100 to 1,070 µg/L, the largest concentration detected during the study. The median barium concentration was 350 µg/L.

Effects of Landfill

Leachate is caused by the decomposition and dissolution of materials in the landfill and the transport of soluble substances by ground water. At the Julietta study area, ground water moves in a southeasterly direction toward Buck Creek. Larger concentrations of almost all dissolved constituents were detected in water from wells screened in the surficial aquifer beneath and downgradient from the landfill compared to water from wells in other groups. Water from wells DD-1, EE-1, F-2, H-3, I-3, I-4, and R-1 generally had larger concentrations of dissolved solids, sodium, chloride, and ammonia than did water from other wells. These substances are indicative of leachate from municipal landfills (Lu and others, 1985, p. 108). Another indicator is low pH. The pH ranged from 7.1 to 7.5 in water from wells upgradient from the landfill and from 6.7 to 7.1 in water from the wells beneath and downgradient from the landfill. The pH of soil moisture or leachate in refuse may be even lower (Lu and others, 1985, p. 108). Alkalinity concentrations, which increase beneath and downgradient from the landfill, buffer the leachate and preclude extremely low pH values.

Water from well EE-1, a 19-ft-deep well immediately downgradient from the thickest part of the refuse, consistently had the largest concentrations of substances that indicate the presence of leachate during all sampling periods, which indicates the general direction of leachate movement.

Although ground water moving through the Julietta landfill has larger concentrations of minerals and nutrients than the ambient ground water, the levels of enrichment did not exceed current U.S. Environmental Protection Agency (USEPA) maximum contaminant levels (U.S. Environmental Protection Agency, 1982a). The applicable levels are listed in table 1. Only the November 1985 sample from well P-1 had a barium concentration of 1,070 µg/L. Secondary drinking-water recommended limits (U.S. Environmental Protection Agency, 1982b), which relate to esthetics rather than health, were exceeded regularly for dissolved solids, magnesium, and iron. For example, concentrations of iron were more than the secondary recommended limits in water from 28 of the 35 wells, including shallow and deep wells upgradient, beneath, and downgradient from the landfill.

Concentrations of individual constituents were plotted for each well location, and contour maps indicating relative concentrations were drawn. As a result, several indicators of landfill leachate were delineated. Water from shallow wells beneath and downgradient from the landfill had larger concentrations of almost all constituents analyzed for compared to water from wells upgradient from the landfill. Concentrations of dissolved solids, sodium, chloride, and iron had similar distributions when mapped regardless of location with respect to the landfill. Ammonia and bromide, on the other hand, seem to be good indicators of leachate in the Julietta study area.

Concentrations of ammonia in water from wells screened in the surficial aquifer are shown in figure 15. Relatively small concentrations of ammonia in water from site F and large concentrations in water from well R indicate the presence of two plumes or, at least, a separation of the plume near site F. This pattern was noted when many of the other constituents were mapped. Smaller concentrations at site F may indicate that landfill material upgradient from this location is not readily leachable. The wells at site F simply may not intercept parts of the plume with the largest concentrations because of vertical variation in concentration. The data also may indicate that the hydraulic conductivity and therefore the likelihood of contaminant transport is lower near site F compared to sites E or R.

The distribution of bromide concentrations in water from wells screened in the surficial aquifer is shown in figure 16. The distribution is similar to that for ammonia in figure 15. The approximate location of the contaminant plume of these substances at the Julietta study area is shown in both figures.

Plume boundaries and concentrations varied between sampling periods, which indicates the transient nature of the plume. Concentrations of bromide varied more than did concentrations of ammonia. Although not generally stable in nature, concentrations of ammonia consistently produced almost identical patterns for each sampling period when mapped. In addition to these indicators, SC, which is measurable onsite, provides a quick overall view of the extent of the landfill's effect on ground-water quality.

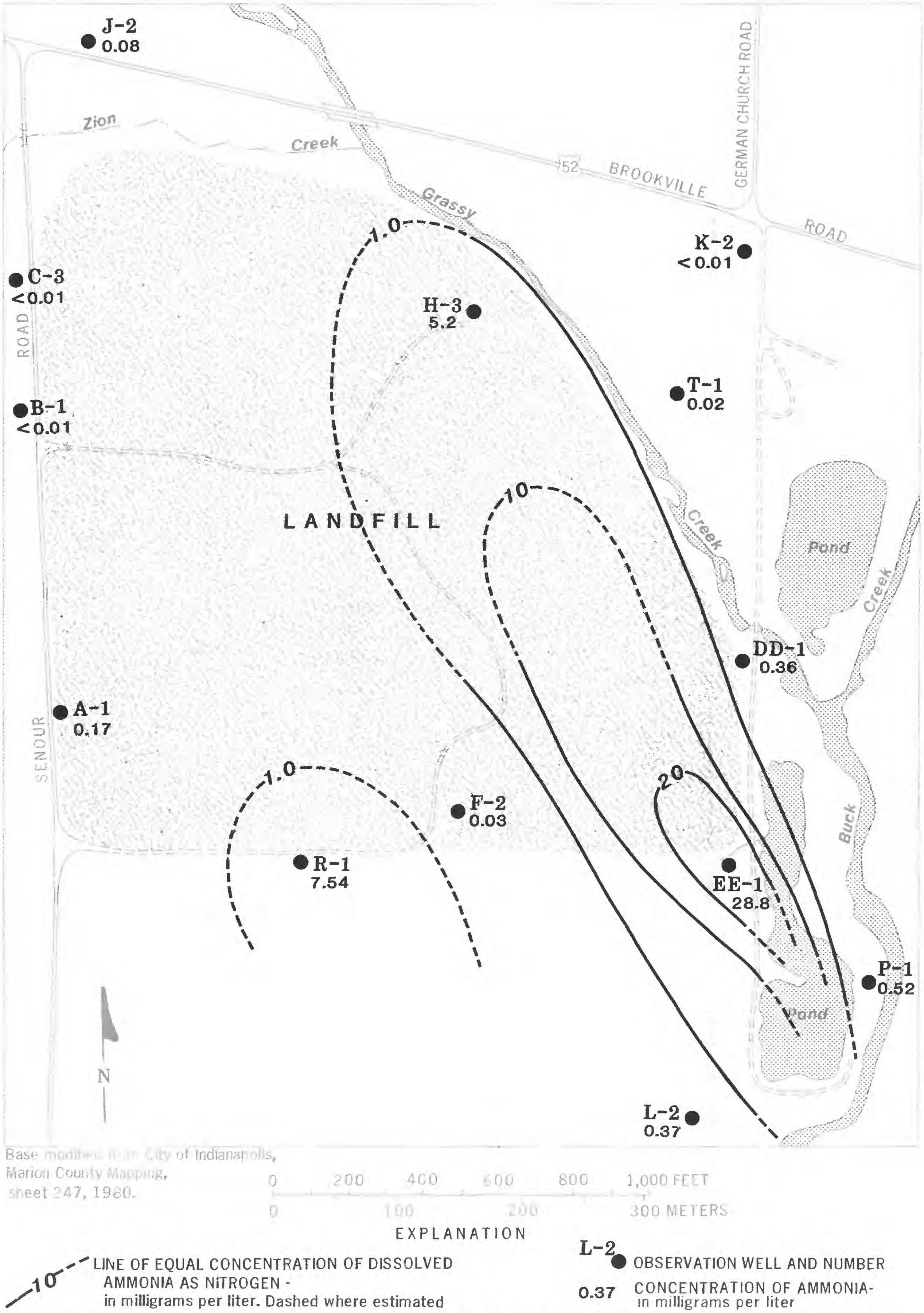
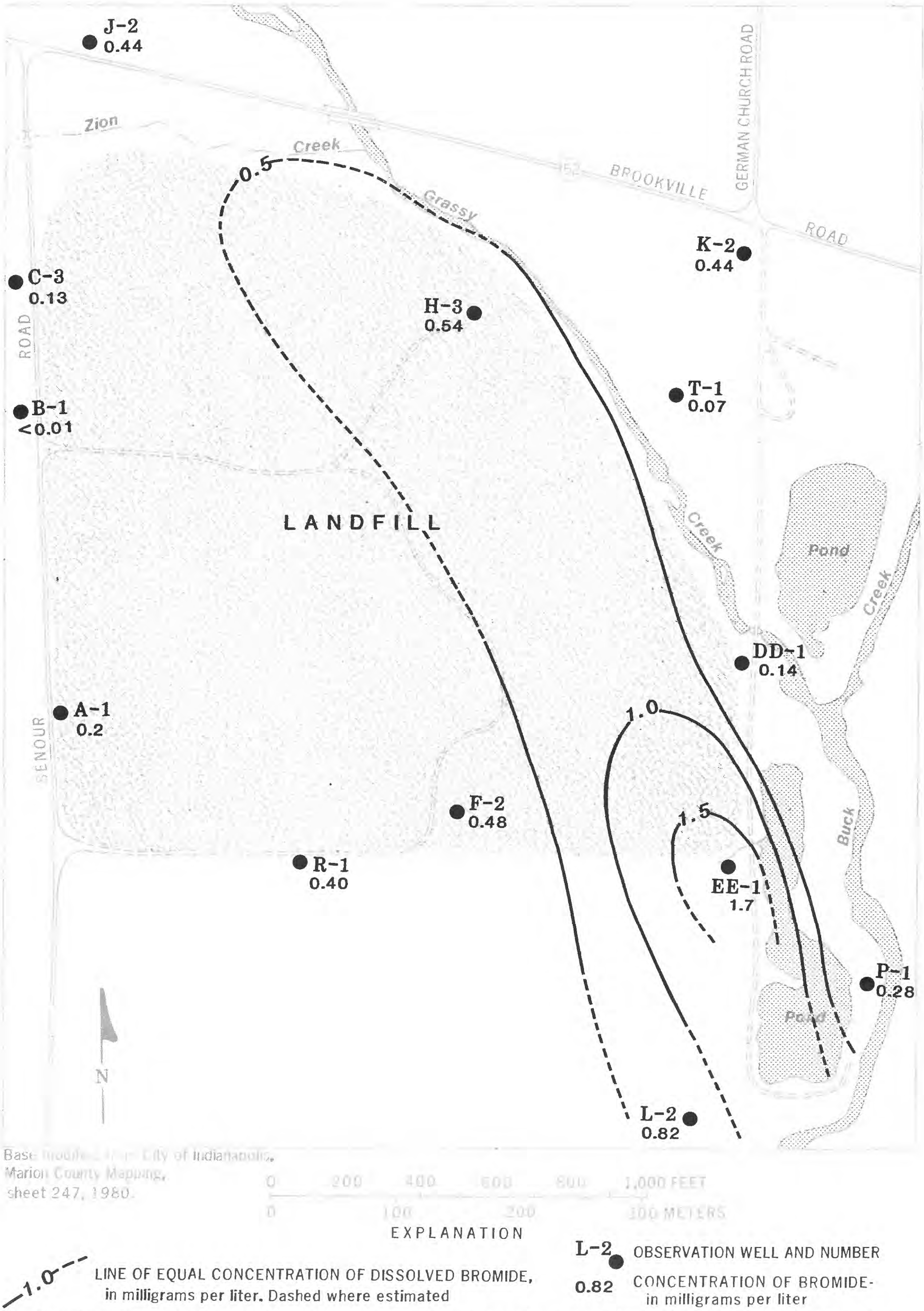


Figure 15.-- Areal distribution of concentrations of dissolved ammonia in the surficial aquifer at the Julietta study area, May and June 1985.



Base modified from City of Indianapolis, Marion County Mapping, sheet 247, 1980.

Figure 16.-- Areal distribution of concentrations of dissolved bromide in the surficial aquifer at the Julietta study area, November 1985.

Ground water and, therefore, any contaminant plume from the landfill, probably discharges to Buck Creek. Ground water also discharges to Grassy Creek, which flows into Buck Creek. The discharge measurements for Grassy Creek and Buck Creek and the model analysis indicate that the ground-water contribution to the streams along the edge of the landfill is small (about 1:10) in comparison with streamflow contributions upstream. Therefore, the effect of leachate on the surface water probably is not measurable. In addition to the effects of dilution, certain ionic species (such as iron and manganese) may form oxides or hydroxides and may precipitate from solution in the more oxidized environment of the surface water. Oxidation also could be occurring in other surface-water bodies, such as the fishing ponds west of Buck Creek. Because the ground water discharges into Buck Creek, the leachate probably does not cross the stream.

TIBBS-BANTA LANDFILL

Site Description and History

The Tibbs-Banta landfill is located near the intersection between Tibbs Avenue and Banta Road, in southwestern Marion County (fig. 17). The landfill is on the eastern flood plain of the White River downstream from Indianapolis and is near a sharp bend in the river immediately upstream from the confluence with Little Buck Creek. During the 1930's, flood-control levees were constructed along this section of the White River and were extended upstream along Little Buck Creek. The 50-acre landfill occupies the area north of Little Buck Creek, between the levees and the White River.

The Tibbs-Banta landfill is bordered on the south by city-owned land, on the east and northeast by privately-owned land, and on the west and northwest by the White River. The land to the south is occupied by the Southport Road municipal wastewater-treatment plant which is operated by the Indianapolis Department of Public Works. The area north of the landfill is farmland and several homes are located along Banta Road to the east of the landfill.

The surface of the landfill is flat to moderately sloping, except near the White River, where the ground surface drops abruptly. Because the landfill was placed between 10-ft-high levees, the top of the landfill is about 10 ft higher than the surrounding area. A linear depression, trending from northwest to southeast through the west-central part of the landfill, corresponds to the location of a buried petroleum pipeline.

Base from U.S. Geological Survey, Maywood 1:24 000, 1963.

Geology modified from Harrison, 1963

Figure 17.-- Location and surficial geology of the Tibbs-Banta landfill in southwestern Marion County.

Trash Disposal

The Tibbs-Banta landfill was used first as a public landfill in late 1968. The landfill was operated by the Indianapolis Department of Public Works, and was used to dispose of residential trash from neighborhood collection routes, and large trash items hauled in pickup trucks and in cars. The Tibbs-Banta landfill was not used for disposal of industrial or commercial wastes.

No trash was placed along the route of the buried petroleum pipeline; therefore, it provides a division between two areas of the landfill. Twenty acres that are east of the pipeline and between the levees were filled first. Cover material was derived onsite from surficial deposits of silty sand. After the area between the levees was filled, the area west of the pipeline, which is between the levee and the White River, was filled. Additional silty sand was mined from the river bed and used for cover. Bulldozers were used to cover and compact the trash.

Sludge Disposal

Landfilling at Tibbs-Banta ended in 1974 (Bastable, T. A., Indianapolis Department of Public Works, written commun., 1984). When the landfill was closed, the required 12 in. of cover soil was not spread over the filled area. Since then, the landfill has had two applications of municipal wastewater lagoon sludge. Sludge from the Southport Road municipal wastewater-treatment plant was spread on the landfill surface in 1983 and 1984. Applied as a semiliquid, the sludge was dried on the landfill surface, then stockpiled. More wet sludge was hauled in, and the process was repeated. Later, the stockpile was spread over the landfill surface. In 1983, a total of 6,940 tons of dried sludge was spread over 28 acres west of the pipeline. The following year, 5,480 tons of dried sludge were applied on 17 acres to the east. During drying and moving, the sludge was mixed with large volumes of soil, until the final mixture had a 1:4.2 sludge-to-soil ratio (Bastable, T. A., Indianapolis Department of Public Works, written commun., 1984). Sludge/soil applications have raised the land surface more than 1 ft. Trace-metal and PCB loadings, resulting from sludge disposal at the Tibbs-Banta landfill in 1983 and 1984, are listed in table 14.

Table 14.--Trace-metal and polychlorinated biphenyl loadings resulting from sludge disposal at the Tibbs-Banta landfill in 1984[1]

[mg/kg, milligrams per kilogram; lbs/acre, pounds per acre]

Trace metal or constituent	Dry weight concentration (mg/kg)	Loading (lbs/acre)
Cadmium	131	123
Copper	2,803	2,627
Lead	525	429
Nickel	295	276.5
Zinc	8,984	8,418
Polychlorinated biphenyls	27	25.3

[1] Source: Parks, J. T., Indianapolis Department of Public Works, written commun., 1984.

Data-Collection Network

A network of 18 observation wells was used to monitor ground-water levels and quality at the Tibbs-Banta study area. Well locations are shown in figure 18. Well depths ranged from 13 to 69 ft below land-surface datum. Two wells, B-1 and F-1, were drilled in 1974 for Pettijohn's (1977) study of seven landfills. Well B-1 was drilled into the fill and is the only well screened in refuse at the landfill. Most of the wells drilled for Pettijohn's (1977) study were destroyed during sludge-spreading operations.

New wells are designated by double-alphabetical characters, AA through FF, and replaced wells drilled for Pettijohn's (1977) study. FF was used at site F to represent a well that was replaced at that site. Wells, at sites I through N, were drilled at new locations. Well N-1 was constructed of black iron, and was not used for water-quality analysis. A large-diameter well, located near the effluent pumping station at the Southport Road treatment plant, was used to collect water-level data. More information about the observation well network is listed in table 15.

Water levels were measured monthly for 18 months (January 1985 through June 1986). Water levels also were measured at two surface-water sites in the study area. The water surface of Little Buck Creek was measured from a reference mark on the Tibbs Avenue bridge at the eastern end of the landfill. The White River was measured at a staff gage near site J. Water samples were collected every 3 months, beginning in May 1985 and ending in May 1986. Five water-quality samples were collected from each well.

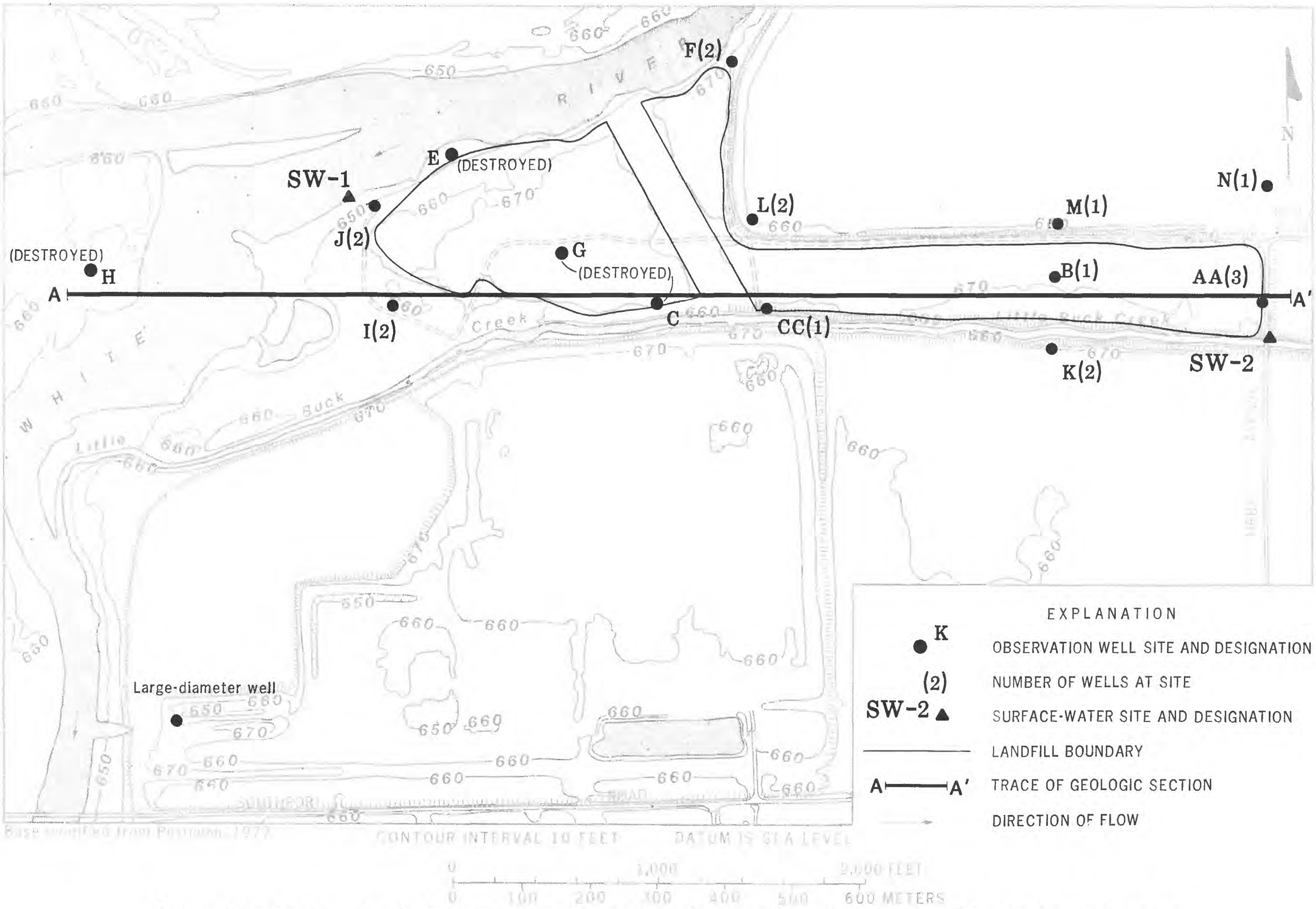


Figure 18.-- Locations of observation wells and surface-water sites at the Tibbs-Banta study area.

Table 15.--Depth, casing type, altitude of land surface, altitude of water, and model layer for wells drilled at the Tibbs-Banta study area

[SS, stainless steel; PVC, polyvinylchloride; BI, black iron; dashes (---) indicate well is outside of modeled area]

Well number	Depth below ground surface (feet)	Casing type	Altitude of land surface (feet)	Altitude of water 10/17/85 (feet)	Model layer
AA-1	69	SS	670	658.0	5
AA-2	56	SS	670	657.6	4
AA-3	25	SS	670	657.7	2
B-1	17	PVC	671	656.1	2
CC-1	27	SS	666	653.7	2
F-1	59	PVC	672	650.2	4
FF-2	29	SS	672	[a]650.7	2
I-1	41	SS	660	649.7	4
I-2	21	SS	660	649.7	3
J-1	42	SS	659	649.3	4
J-2	15	SS	659	649.2	2
K-1	36	SS	661	656.1	3
K-2	13	SS	660	656.2	2
L-1	44	SS	661	652.2	4
L-2	22	SS	661	653.3	2
M-1	16	SS	663	655.9	2
N-1	24	BI	664	[b]657.6	2
Large-diameter well	30	BI	662	648.3	---

[a] Water level measured 10/22/85.
[b] Water level measured 10/18/85.

Geohydrology

Geology

The Tibbs-Banta study area is underlain by shale and limestone of Late Devonian and Early Mississippian age. The oldest bedrock unit is the upper member of the New Albany Shale, a carbonaceous, brown to black fissile shale of Late Devonian and Early Mississippian age (Shaver and others, 1970, p. 115). Conformably overlying the New Albany Shale is the Rockford Limestone of Early Mississippian age (Shaver and others, 1970, p. 140). Although only 3 ft thick in this area, the Rockford Limestone is the most resistant unit in a 600-ft, or more, vertical section of shales. Because of its greater resistance, the Rockford Limestone often forms ledges and protects the underlying New Albany Shale from erosion. Bedrock altitudes are 30 to 50 ft higher where the buried Rockford Limestone is present in subcrop. The Borden Group of Mississippian age overlies the Rockford Limestone (Shaver and others, 1970, p. 22). At the study area, the Borden Group is a gray argillaceous shale. All the bedrock units are almost horizontal, dipping to the southwest at about 0.5 degrees. The degree of dip was estimated by altitude differences of the Rockford Limestone recorded on area water-well logs. Depth to bedrock ranges from about 100 ft at the eastern edge of the landfill to about 20 ft beneath the White River along the western edge of the landfill.

Overlying the bedrock are deposits of Pleistocene age comprised of glacial outwash containing clay, silt, sand, and gravel. Gravel, as large as cobble size, was found when drilling many of the wells. The medium to large particle size of the sand and gravel is indicative of deposition by a river that had moderately high velocity. The outwash deposits form a broad valley ranging from 3 to 5 mi (miles) wide in Marion County. Overlying and reworked from the outwash deposits are alluvial sediments of Holocene age. The alluvium forms a low-relief valley almost 2 mi wide.

Lithologic logs for drilled holes indicate as many as four sand and gravel layers, separated in places by thin discontinuous layers of clay or till (fig. 19). The lowest layer is dirty sand and gravel containing much silt and clay, probably from erosion of the shale bedrock. Extensive reworking of older, unconsolidated materials during each successive glaciation is indicated by the discontinuous clay and till. Determining the origin of the sediments was beyond the scope of this report; therefore, for practical purposes, similar textures were grouped together, regardless of their origin.

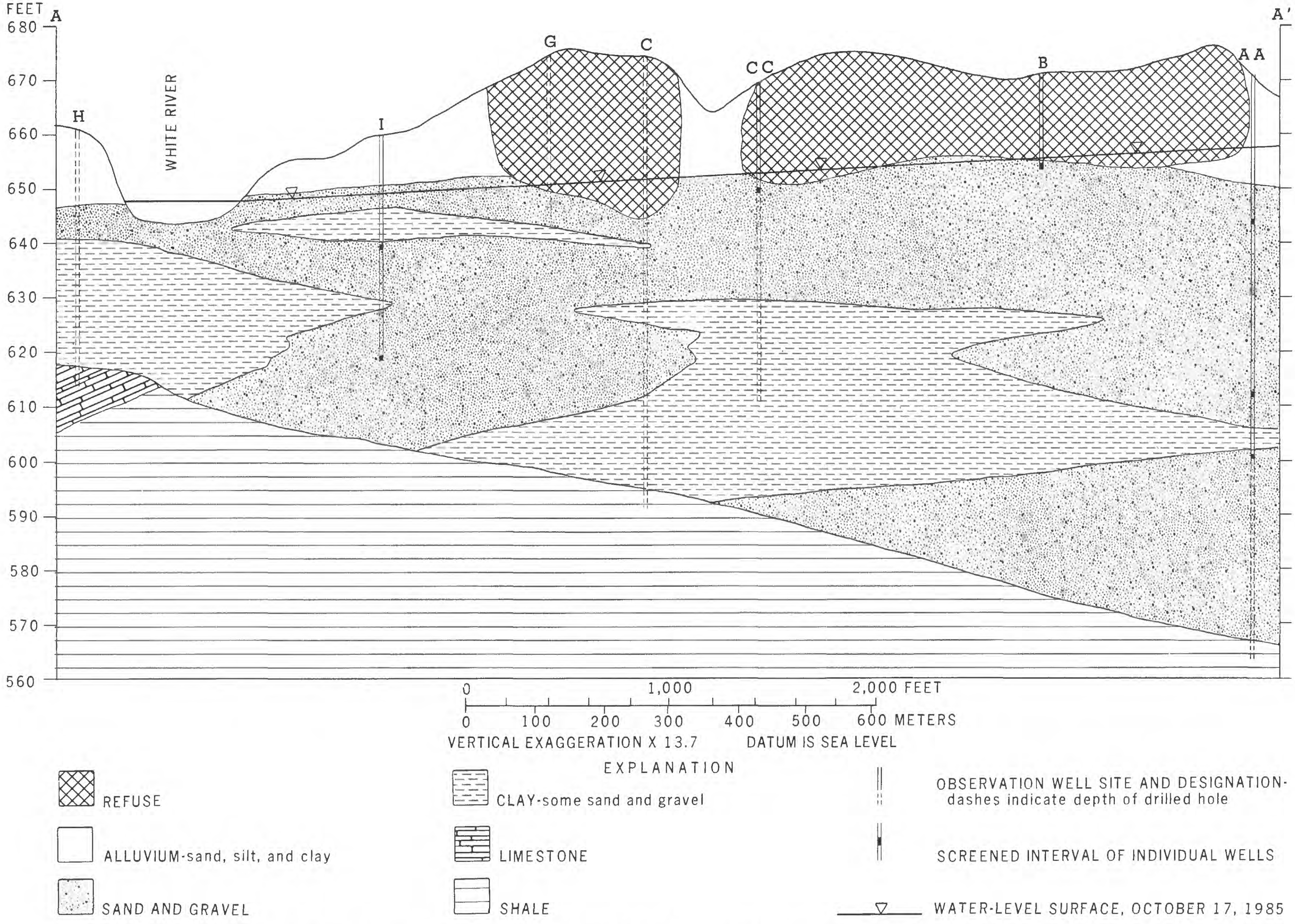


Figure 19.-- Geologic section A-A' through the Tibbs-Banta study area.

Hydrology

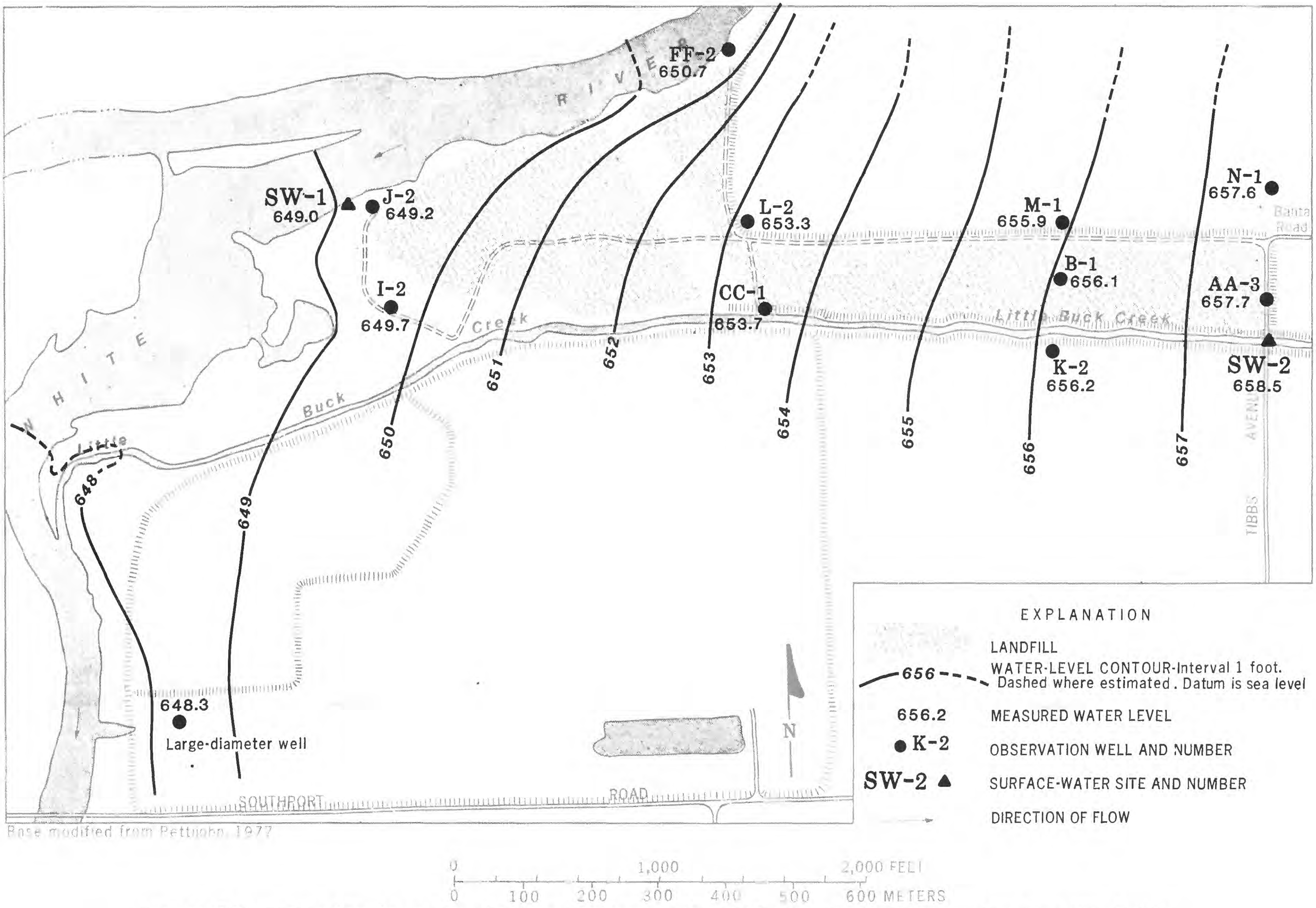
The outwash aquifer system of the White River, a small part of which underlies the Tibbs-Banta study area, contains the most extensive sand and gravel deposits in Marion County (Harrison, 1963, p. 55). Discontinuous clay lenses within the outwash separate the sand and gravel into layers. Well logs at the study area indicate that as few as two layers and as many as four layers of sand and gravel underlie the landfill. In this report, the two shallowest sand and gravel layers are referred to as the shallow aquifers and the two deepest sand and gravel layers are referred to as the deep aquifers.

Ground-water levels and flow

Depth to water was measured in each well and the average depth to water for the study area was 10.5 ft on October 17, 1985. The deepest water level measured during the study was 21.8 ft in well F-1 and the shallowest was 3.9 ft in well K-2. Water levels in well B-1 indicate that the water table is in the refuse. The largest thickness of saturated refuse measured during the study was 5.5 ft.

Horizontal-flow directions were determined by the areal distribution of water-level altitudes (fig. 20). Ground-water flow predominantly is from east to west. The water table slopes toward the river and has a steeper gradient near the river in the northwestern part of the landfill.

Water levels at sites having more than one well indicate that vertical flow components generally are small. For example, there were practically no differences between water levels in shallow and deep wells at sites I and K. The discontinuous clay layers can affect the vertical distribution of water levels and cause localized vertical flow. Water levels in well AA-1, the deep well at site AA, were always higher than water levels in the shallow well at this site (fig. 21) indicating the potential for upward flow from the deep semiconfined aquifer. Potential for upward flow also was indicated by most of the water levels measured in shallow and deep wells at sites F and J. At site L, a slight downward flow potential was indicated by the water-level data.



Base modified from Pettijohn, 1977

Figure 20 -- Water levels in the shallow aquifers at the Tibbs-Banta study area, October 17, 1985.

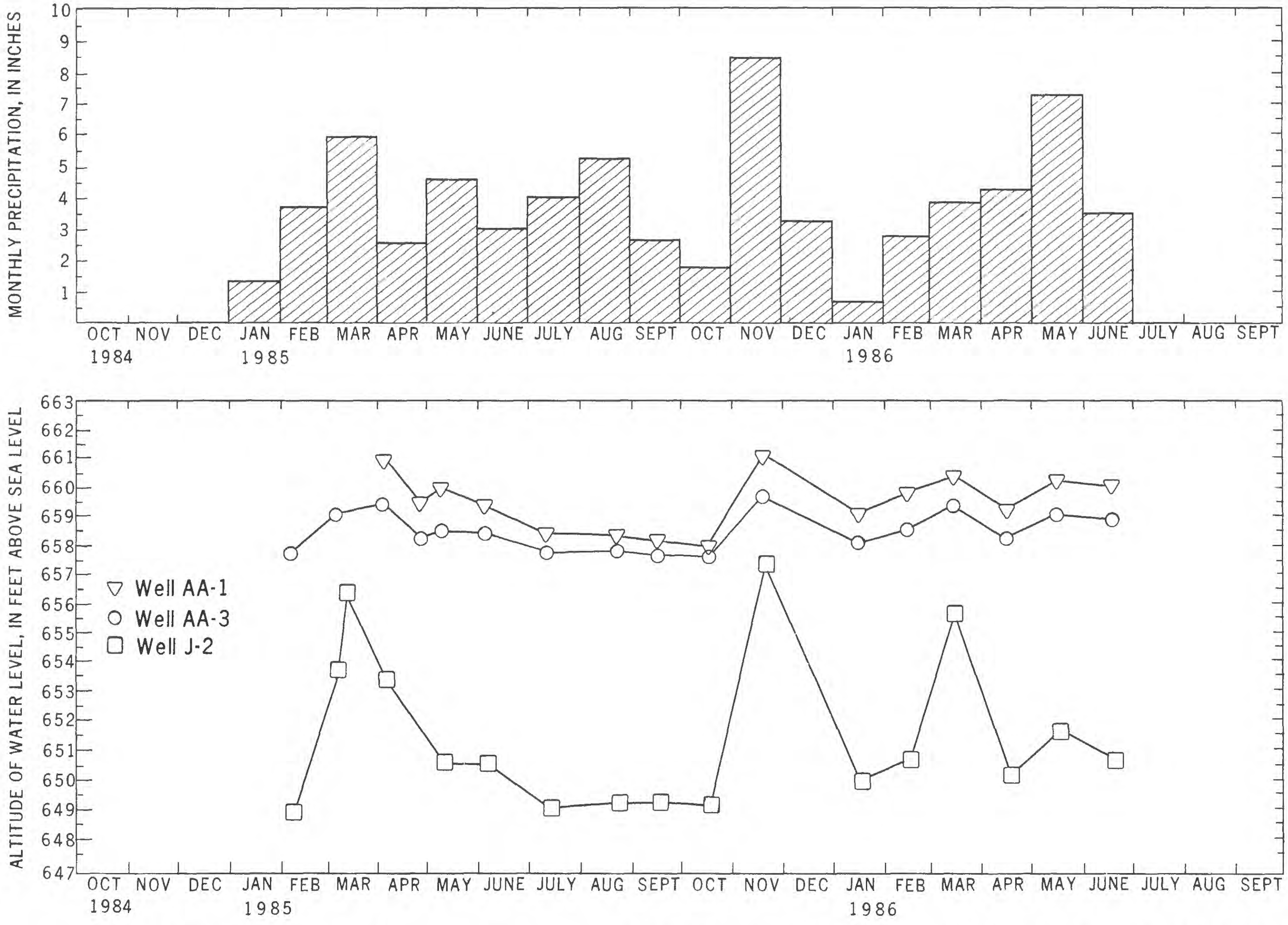


Figure 21.-- Altitude of water levels in wells AA-1, AA-3, and J-2 at the Tibbs-Banta study area and monthly precipitation at the Indianapolis International Airport, January 1985 through June 1986.

Ground-water recharge

Recharge to the ground-water system occurs by infiltration of precipitation. The average precipitation for Marion County is 39 in/yr for the period 1951-80 (National Oceanic and Atmospheric Administration, 1982). From 10 to 15 in. of this precipitation may actually recharge the outwash aquifer (Smith, 1983, p. 23). The remaining precipitation is returned to the atmosphere by evapotranspiration or runs off as surface water.

Ground-water levels fluctuate in response to recharge from precipitation. Hydrographs of instantaneous water levels in wells AA-1, AA-3, and J-2, and monthly precipitation are shown in figure 21. Precipitation was measured at the National Weather Service station located at the Indianapolis International Airport, 4 mi northwest of the Tibbs-Banta landfill. The general relation of precipitation to ground-water levels for most months is evident when the hydrographs are compared with precipitation. Direct comparisons of instantaneous and monthly data are not possible. Water-level fluctuations during the period of measurement averaged 3.83 ft for all wells, but ranged from 1.49 to 8.31 ft. The largest fluctuations were in wells located near the White River. The seven wells nearest the White River had average water-level fluctuations of 6.57 ft. The 11 wells farthest from the river had average water-level fluctuations of 2.09 ft. Fluctuations of ground-water levels as a result of precipitation temporarily can alter horizontal and vertical gradients to the extent that a reversal of flow may occur.

The large fluctuations in well J-2 (fig. 21), which is near the river, are caused by a process called temporary bank storage and are related to the interconnection between the aquifer and the river. Excessive rainfall will increase runoff and cause flooding. Ground-water levels close to the river will begin to rise because of a temporary flow reversal created by the higher stage of the river. The rise in ground-water levels seems to be almost simultaneous with the river at 50- and 75-ft distances, as measured in the shallow wells at sites F and J.

Hydraulic characteristics

Transmissivity mapping done by Meyer and others (1975, p. 20) indicates that transmissivity near the Tibbs-Banta study area ranges from 100,000 to 150,000 (gal/d)/ft, or about 14,000 to 21,000 ft^2/d. An aquifer test done by the U.S. Geological Survey in the outwash aquifer, about 3,000 ft north of the study area, indicated a transmissivity of 16,000 ft^2/d (William Meyer, U.S. Geological Survey, written commun., 1975). At the test site, saturated thickness of the sand and gravel was 45 ft; therefore, the average horizontal hydraulic conductivity was estimated to be about 356 ft/d.

Ground-water/surface-water relations

The White River has the lowest water-level altitude at the Tibbs-Banta study area. As a result, ground water moving through the landfill is discharged to the river during normal flow conditions. Other authors, who studied various stretches of undisturbed river channel in Marion and adjacent counties, have reported that measured ground-water seepage to the White River ranged from 2.0 to 5.5 ft^3/s per mile of river (Meyer and others, 1975, p. 28; Gillies, 1976, p. 13; Bailey and Imbrigiotta, 1982, p. 19; Smith, 1983, p. 22).

Streamflow

Streamflow measurements were made at four locations along Little Buck Creek (fig. 22) on October 17, 1985, during a period of low streamflow. The measurements indicate that Little Buck Creek begins losing water to the outwash aquifer shortly after entering the flood plain, more than 2 mi upstream from the study area. Bailey and Imbrigiotta (1982, p. 19) reported that this relation also occurs for some smaller tributaries to the White River in Johnson County, south of the study area. The loss of water may be seasonal and may be related to periods of low ground-water levels. Measured loss of flow in Little Buck Creek, from the eastern edge of the study area to the mouth of the creek, was about 0.8 ft^3/s. Measurements along Little Buck Creek were rated to be accurate within ±5 percent.

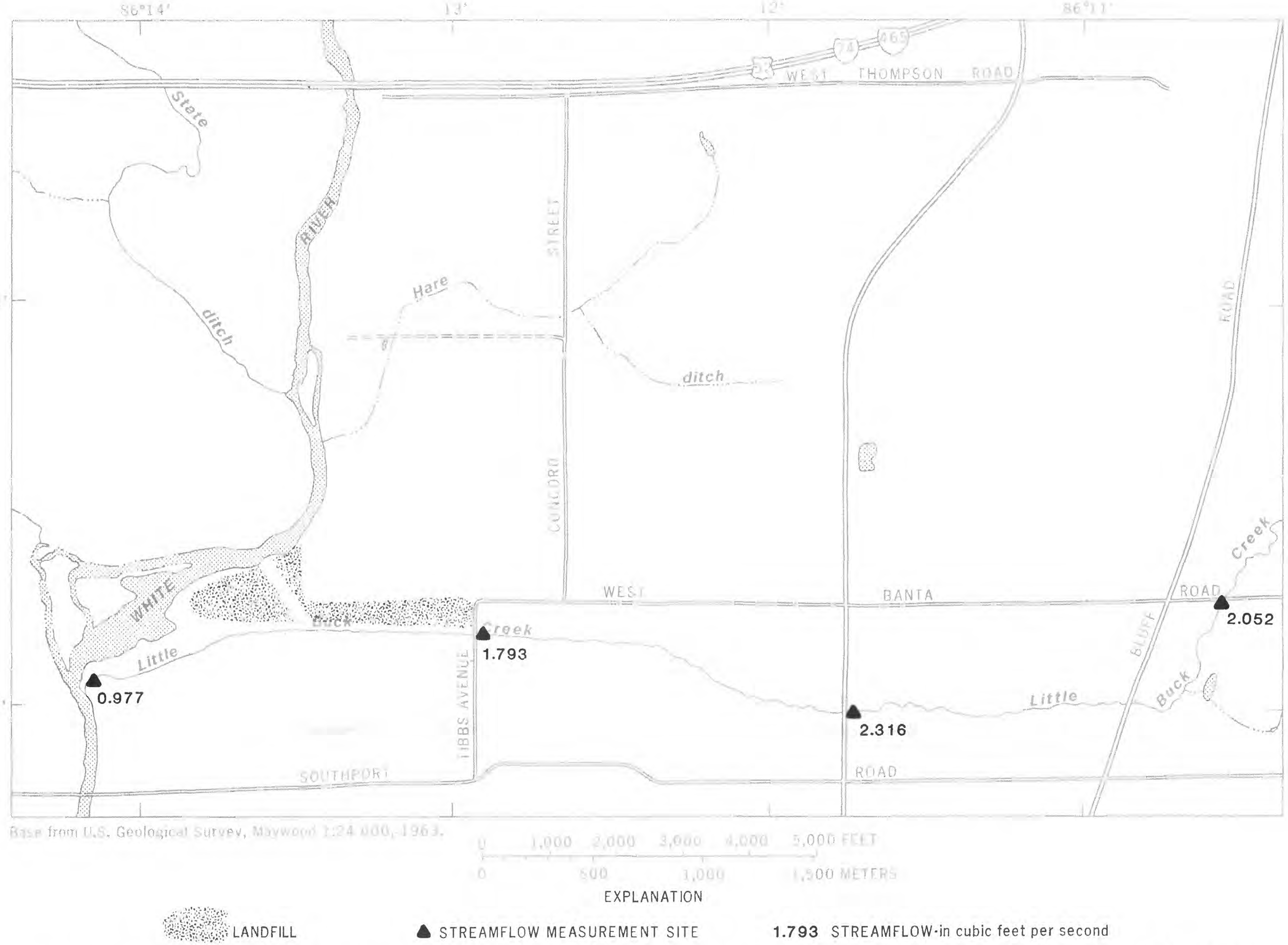


Figure 22.-- Locations of streamflow measurement sites, and streamflow for Little Buck Creek, October 17, 1985.

Simulation of Ground-Water Flow

Ground-water flow through the Tibbs-Banta landfill was simulated with the U.S. Geological Survey finite-difference model (McDonald and Harbaugh, 1988). Model geometry was defined by lithologic information from well logs. The model was calibrated to match the measured ground-water levels and streamflow. The sensitivity of the model to uniform changes in horizontal hydraulic conductivity, recharge, and streambed conductance was tested. The calibrated model was used to estimate the volume of ground-water flow through the refuse at the Tibbs-Banta landfill.

Model Description

The Tibbs-Banta model simulates steady-state flow in the four sand and gravel aquifers beneath the study area. The aquifers are represented by model layers 2, 3, 4, and 5 (fig. 23). Layer 1, which is above the upper aquifer, contains the refuse. The Tibbs-Banta model uses a variable grid spacing. The grid has 31 rows and 21 columns, and covers a total of 356 acres, of which 295 acres are simulated in the model (fig. 24). All rows are 200 ft wide. Columns 1 through 17 are 100 ft wide, and columns 18 through 21 are 200 ft wide. The smaller grid spacing was used in areas where more detail was needed. The White River and Little Buck Creek were simulated as river nodes approximating the configuration of the streams.

Model boundaries were based on the observed flow system. The eastern boundary was simulated by constant heads. Constant-head values for the eastern boundary were determined from measured water levels. The northern and southern boundaries of the model area approximately parallel the ground-water flow direction. Therefore, these boundaries were simulated as no-flow boundaries because little or no water crosses them. The White River is the western model boundary and this boundary was simulated by a no-flow boundary along the western edge of the stream nodes that simulate the White River. This arrangement of stream nodes and no-flow nodes allowed the simulation of ground-water flow to and from the stream but not across it. The top of the model was the water table, which was below the top of layer 2 in most areas. The lower boundary of the model was bedrock, which rises to the west and underlies layers 5, 4, and 3 (fig. 23). Ground-water flow to or from the bedrock is small in comparison with the volume of water in the unconsolidated flow system and therefore was ignored.

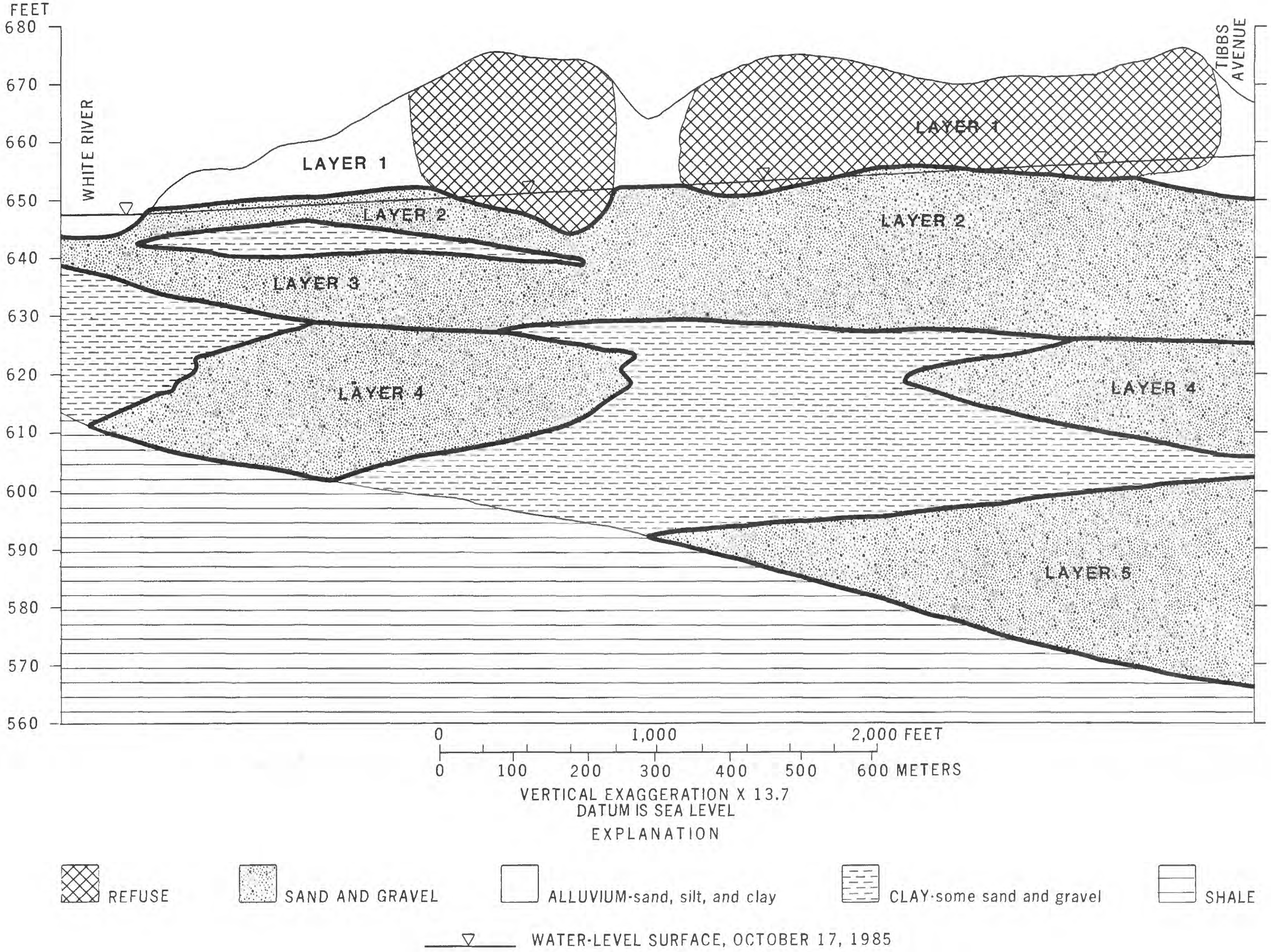
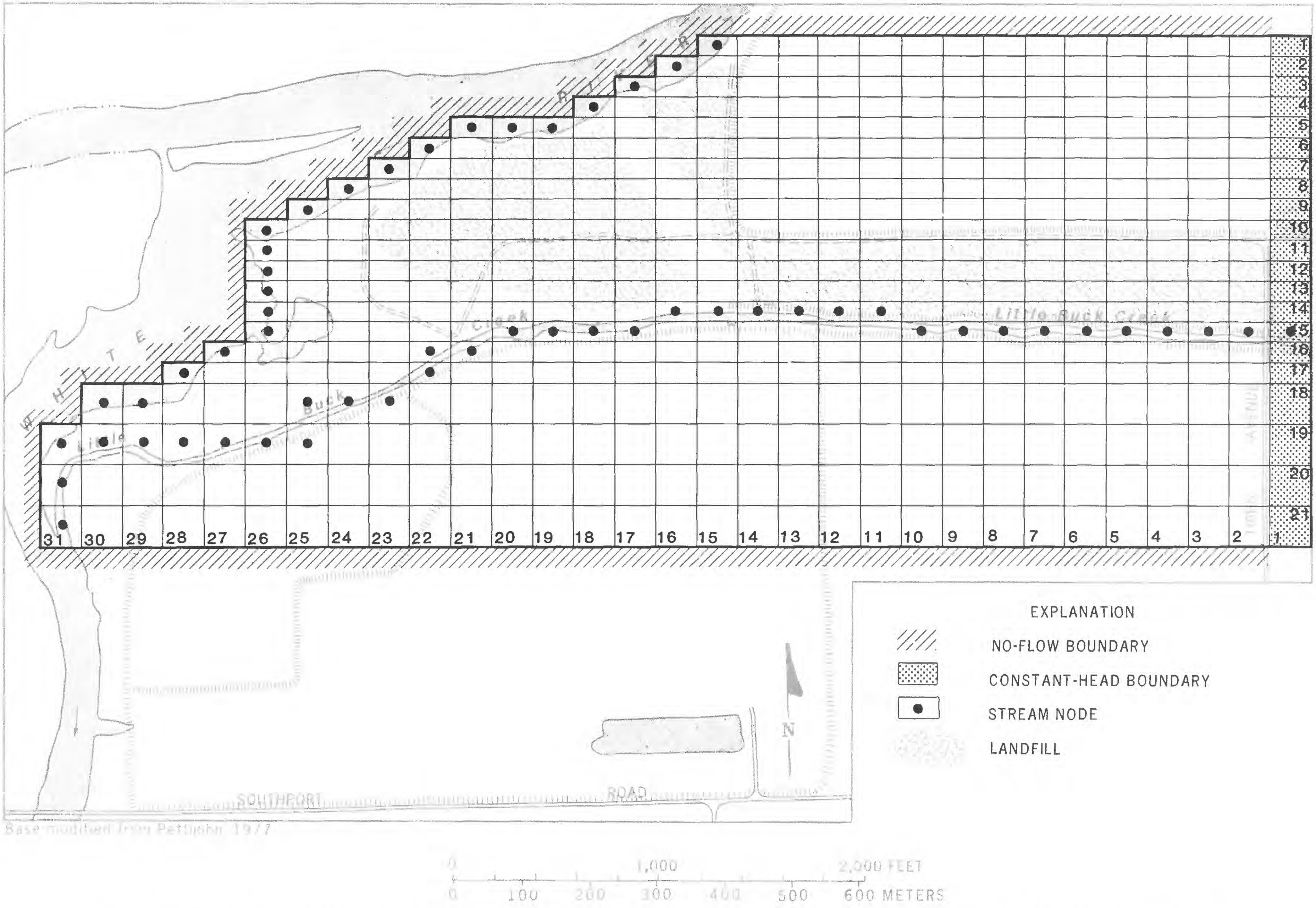


Figure 23.-- Generalized geohydrologic section showing model layers.



Base modified from Pettijohn 1977

Figure 24.– Finite-difference grid used to simulate ground-water flow at the Tibbs-Banta study area.

Model Calibration and Sensitivity

The Tibbs-Banta model was calibrated to correspond to water-level and streamflow measurements made on October 17, 1985. The average flow in the White River on October 17 was 411 ft^3/s at the gage near Centerton, about 23 mi downstream from the study area (Glatfelter and others, 1987, p. 148). Streamflow data from 1948 to 1986 indicate that flow in the White River equaled or exceeded 411 ft^3/s for 89 percent of the time; therefore, flow in the White River on October 17 probably was from ground-water seepage rather than from precipitation runoff.

Values of model variables used in the calibrated model are listed in table 16. Model solutions are not unique because several combinations of values of model variables can produce similar results. The sensitivity of the Tibbs-Banta model to uniform changes in horizontal hydraulic conductivity, recharge, and streambed conductivity were tested during calibration by comparing model output before and after a change was made.

Table 16.--Values of selected model variables at calibration for the ground-water-flow model of the Tibbs-Banta study area

[ft/d, feet per day; in/yr, inches per year]

Model variable	Value at calibration
Horizontal hydraulic conductivity[1]	
Sand and gravel	[2]50 to 700 ft/d
Alluvium	1 ft/d
Refuse	50 ft/d
Recharge rate	10 in/yr
Streambed conductivity[3]	
Little Buck Creek	240 ft/d
White River	400 ft/d

[1] Vertical hydraulic conductivity was assumed to be 0.01 times the value for horizontal hydraulic conductivity.

[2] Horizontal hydraulic conductivity of sand and gravel was 700 ft in model layer 2, 500 ft/d in model layers 3 and 4, and 50 ft/d in model layer 5.

[3] For a streambed thickness assumed to be 1 ft.

Horizontal hydraulic conductivity values for the sand and gravel aquifers in the calibrated model ranged from 50 to 700 ft/d. Vertical hydraulic conductivity was assumed to be 0.1 times the horizontal hydraulic conductivity. Decreasing the horizontal hydraulic conductivity to one-half the calibrated values raised water levels 0.1 to 0.2 ft near the White River, reduced leakage from Little Buck Creek by 27 percent, and reduced leakage to the White River by 27 percent compared to the calibrated model. Doubling the hydraulic conductivity raised water levels 0.1 to 0.2 ft in the west-central part of the model, increased leakage from Little Buck Creek by 82 percent, and increased leakage to the White River by 80 percent compared to the calibrated model.

The recharge rate in the calibrated Tibbs-Banta model was 10 in/yr. Similar recharge rates were used by Gillies (1976, p. 18), and Bailey and Imbrigiotta (1982, p. 30) in studies of the White River outwash aquifer. Decreasing recharge rates from 10 to 0.1 in/yr resulted in an average lowering of ground-water levels by 0.03 ft. Increasing recharge from 10 to 40 in/yr raised water levels 0.10 ft.

The Tibbs-Banta model was very sensitive to changes in the surface-water/ground-water connection. The volume of surface water entering the ground-water system from Little Buck Creek and the volume of ground water discharging to the White River were difficult to simulate. Hydraulic conductivity of the streambed sediments was calibrated at 400 ft/d for the White River and 240 ft/d for Little Buck Creek. Decreasing the streambed hydraulic conductivity to 1/100th of the calibrated value improved the correlation between simulated and measured water levels, but ground-water seepage to streams was too small. Increasing the hydraulic conductivity of the streambed by one order of magnitude caused too much seepage to the White River.

Simulated Water Levels and Flow Budget

Simulated water levels for layer 2 and measured water levels for the shallow aquifers on October 17, 1985, are shown in figure 25. The simulated and measured values are in reasonable correlation and have a maximum difference of 0.91 ft near the White River at well J-2. Water levels in layers 3 and 4 were almost identical to those in layer 2 and the maximum difference between the layers was less than 1.0 ft. Simulated water levels in layers 3, 4, and 5 were within 2.1 ft of the measured water levels. Parts of layer 1 were above the water table; therefore, many of the nodes were dry at the end of the simulation.

Water levels in layer 5, the deep layer, were different from water levels in the shallow layers. The simulated water levels in layer 5 are shown in figure 26. Layer 5 thins to the west and no longer exists near the center of the model. Ground water in layer 5 is confined below a till layer that impedes upward flow to the White River. At the eastern edge of the model, water levels in layer 5 are only 0.5 ft higher than those in shallower layers. Along the northern boundary, near the White River, water levels in layer 5 are 5.0 ft higher than those in the shallower layers.

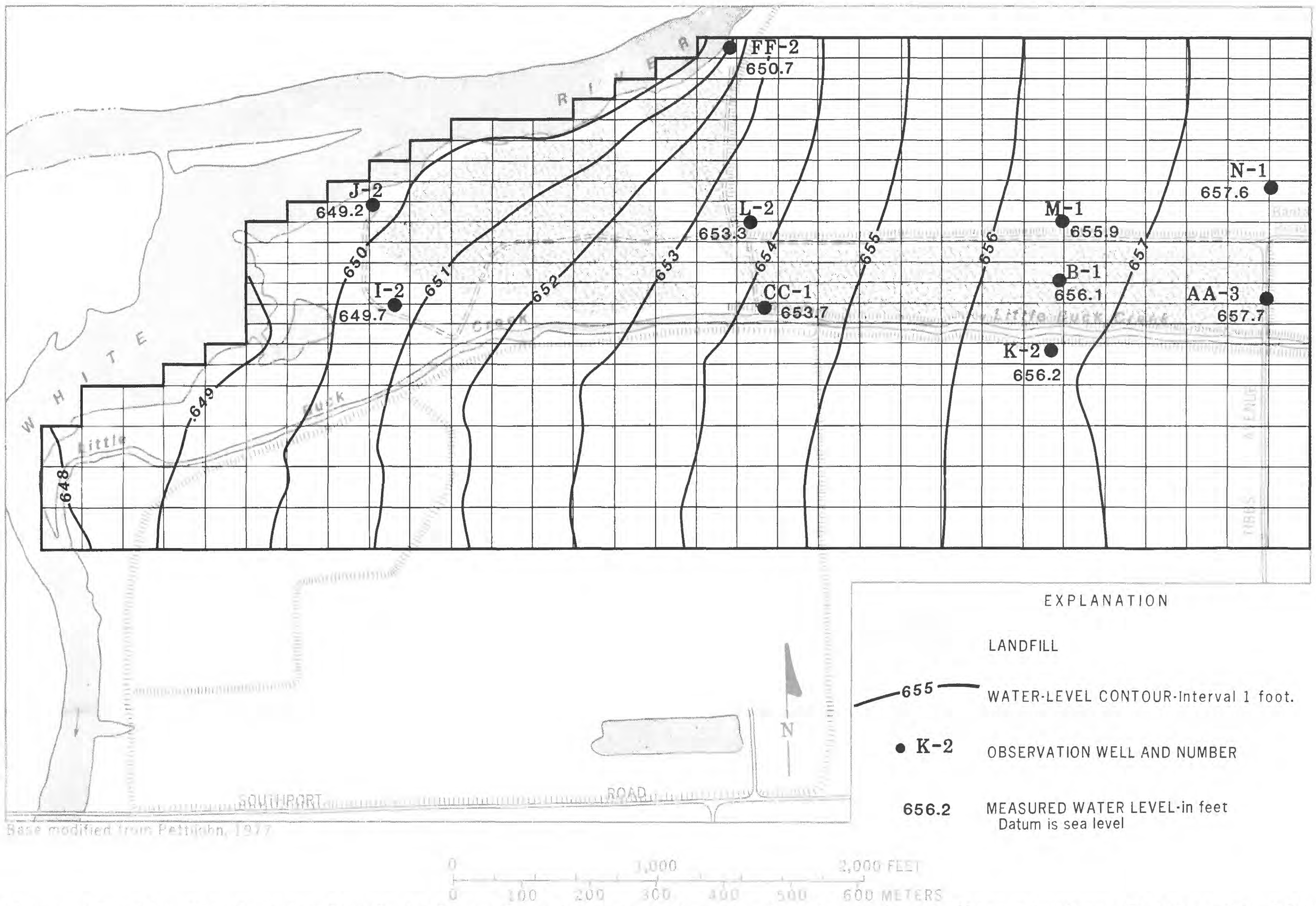


Figure 25.-- Simulated water levels in layer 2 and measured water levels in the shallow aquifers, October 17, 1985.

Figure 26.-- Simulated water levels in layer 5 and measured water levels in the deep aquifer, October 17, 1985.

The model simulates three water sources--boundary inflow, recharge, and leakage from streams. There are two options for discharge--boundary outflow and discharge to a stream node. Because the flow system was at steady state, input equals output and a water budget was used to determine rates and volumes of flow. The overall budget and flow rates in ft^3/s for the five model layers are listed in table 17.

Total ground-water flow in the Tibbs-Banta model was 1.9 ft^3/s, or about 1.24 million gal/d. Thirty-two percent of the total is inflow across the constant-head boundary. Seventeen percent is recharge. The remaining 51 percent of the inflow is leakage from Little Buck Creek. Because the constant head boundary can add or subtract water, the model budget may not represent the actual ratio between recharge and boundary flow. However, because the model was calibrated to measured streamflow, the simulated volume of flow probably is reasonable.

In the model, recharge was applied to layer 2 when layer 1 was dry. Layer 1 was dry adjacent to most of the Little Buck Creek channel, was dry under the field north of the landfill, and was dry under the western part of the landfill. In the Tibbs-Banta model, about 30 percent of the recharge was applied to layer 1 and about 70 percent of the recharge was applied to layer 2.

The Tibbs-Banta model budget (table 17) indicates that most of the ground-water flow was in layers 2 and 3. Layers 4 and 5 had less flow than layers 2 and 3 because layers 4 and 5 are not in direct connection with the White River. Water flows horizontally in layers 2 and 3 and is discharged to the White River. Layer 1 had less flow than layers 2 and 3 because large parts of layer 1 are dry.

In the Tibbs-Banta model, ground-water is discharged to the White River. The simulated discharge to the White River was 1.8 ft^3/s. There are 4,560 linear ft of river channel in the model and only one-half of the river is simulated, so the discharge simulated by the model represents a seepage rate of 4.2 ft^3/s per mile of river channel. This rate of seepage is within the range of measured seepage rates reported by previous investigators. Meyer and others (1975, p. 28) and Gillies (1976, p. 13) calculated seepage rates of 2.6 and 2.5 ft^3/s per mile of channel for sections of the White River upstream from the study area. Bailey and Imbrigiotta (1982, p. 19) calculated a seepage rate of 5.5 ft^3/s per mile of channel for the White River downstream of the study area.

The model simulated seepage to and from Little Buck Creek. Analysis of individual stream nodes indicated that Little Buck Creek lost 0.79 ft^3/s to the ground-water flow system. Little Buck Creek was a losing stream in rows 1 through 25 and lost 0.83 ft^3/s. In rows 26 through 30, Little Buck Creek is a gaining stream, receiving 0.04 ft^3/s. The simulated seepage rates correspond to the streamflow measurements made for Little Buck Creek.

A node-by-node method was used to calculate a water budget for the landfill. Recharge for the landfilled area was 0.064 ft^3/s, or about 41,400 gal/d. Another 0.001 ft^3/s, about 650 gal/d, flows westward through the refuse from the eastern boundary and upward from layer 2. Therefore, a total of about 42,050 gal/d of water are exposed to refuse and sludge in layer 1 of the landfill.

Table 17.--Simulated water budget for the Tibbs-Banta study area

[ft^3/s, cubic feet per second; <, less than]

Inflow	Rate (ft^3/s)	Percentage of total	Outflow	Rate (ft^3/s)	Percentage of total
Layer 1					
Recharge	0.0931	24	Leakage to streams	0.1697	47
Boundary flux	.0001	<1	Leakage to layer 2	0.1943	53
Leakage from layer 2	.1823	47			
Leakage from streams	.1084	28			
Layer 2					
Recharge	.2267	8	Leakage to streams	1.6792	62
Boundary flux	.3643	13	Leakage to layer 1	0.1823	7
Leakage from layer 1	.1943	7	Leakage to layer 3	0.8286	31
Leakage from layer 3	1.0786	40			
Leakage from streams	.8664	32			
Layer 3					
Boundary flux	.1280	9	Leakage to layer 2	1.0786	74
Leakage from layer 2	.8286	57	Leakage to layer 4	0.3733	26
Leakage from layer 4	.4953	34			
Layer 4					
Boundary flux	.0758	15	Boundary flux	0.0001	<1
Leakage from layer 3	.3733	75	Leakage to layer 3	0.4953	99
Leakage from layer 5	.0467	10	Leakage to layer 5	0.0004	<1
Layer 5					
Boundary flux	.0463	99	Leakage to layer 4	0.0467	100
Leakage from layer 4	.0004	1			
Total					
Recharge	.3198	17	Leakage to streams	1.8489	100
Boundary flux	.6145	32	Boundary flux	0.0001	<1
Leakage from streams	.9748	51			
TOTAL	1.9091	100	TOTAL	1.8490	100

Ground-Water Quality

Water samples were collected from the observation-well network in the Tibbs-Banta study area to determine the effect of the landfill on local ground-water quality. Sixteen wells were included in the survey. Five sets of samples were collected during the study. Well FF-2 was drilled after the collection of sample 2 and, consequently, there are only partial data for that well. Except for well B-1, all wells were sampled using a submersible pump. Well B-1 was drilled for Pettijohn's (1977) study, and is the only well screened in the refuse. Because of compaction of the refuse and vandalism, the well casing no longer is straight or round enough for the use of a submersible pump. Samples from well B-1 were collected with a peristaltic pump. Ground-water samples were analyzed to determine concentrations of dissolved inorganic substances and phenols. Individual analyses for each well are listed in table 18 (at back of report).

General Description

Ground water in the Tibbs-Banta study area is a calcium bicarbonate type. Other major cations (besides calcium) include magnesium and sodium. Chloride and sulfate are the other major anions. Iron and manganese commonly were present in relatively large concentrations, and the concentrations were even larger beneath the landfill.

In the study area, two general trends in water quality were observed. First, the concentrations of dissolved constituents were largest in water from wells that are in or near the landfill or that receive ground-water flow that has passed through the landfill. The large concentrations indicate leaching of soluble substances in the refuse by percolating precipitation and ground water. Second, concentrations of dissolved solids were smaller in wells that penetrate the deep sand and gravel aquifers compared to the shallow aquifers. Therefore, leachate from the landfill seems to be confined to the shallow aquifers.

Water from the shallow upgradient well, AA-3, contains substances unrelated to the landfill. The concentrations of dissolved solids in water from this well were larger than those in well B-1, the next well along the flow path or in well AA-2, the next deepest well at site AA. The analyses of water from these wells indicated that water from well AA-3 contained as much as 93 mg/L of sodium and 154 mg/L of chloride, almost twice the concentrations found in water from well B-1. The large concentrations of sodium and chloride probably are related to the use of road salt along Tibbs Avenue during winter months.

Aquifers

Shallow aquifers

General water quality of the shallow aquifers is shown by Stiff diagrams in figure 27. The Stiff diagrams show relative concentrations of seven major ions in the ground water. Concentrations of dissolved solids also are shown and are useful in determining the overall ground-water quality.

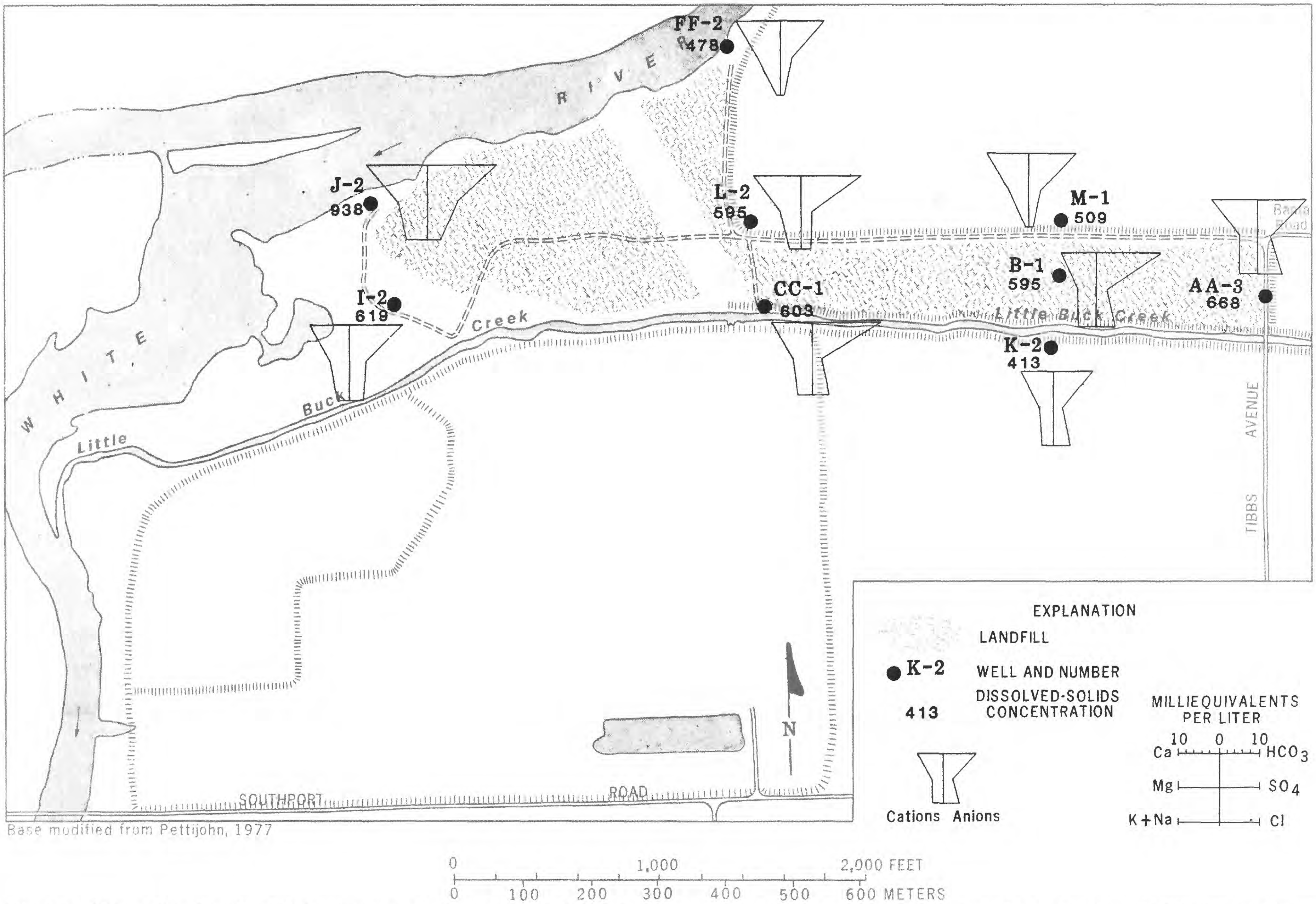
Water-quality differences between wells in three different positions along the ground-water flow path were compared to evaluate the water-quality data from the Tibbs-Banta study area. The positions were upgradient from the landfill, in the landfill, and downgradient from the landfill. In addition to position, wells were grouped by depth. In this report, the two shallowest sand and gravel layers are referred to as the shallow aquifers, and the two deepest sand and gravel layers are referred to as the deep aquifers.

Shallow upgradient wells are AA-3, FF-2, K-1, K-2, and M-1. A statistical summary of water quality for the shallow upgradient wells is listed in table 19. Well AA-3 was included even though its water contained relatively large concentrations of sodium and chloride. Water from shallow upgradient wells had smaller concentrations of dissolved solids (typically less than 550 mg/L) than did wells located in or downgradient from the landfill. Specific conductance for the five upgradient shallow wells ranged from 693 to 1,297 µS/cm, with a median value of 787 µS/cm. The median pH was 7.1, and values ranged from 6.9 to 7.3. Median COD was 8 mg/L.

The most abundant anion in water from shallow upgradient wells was bicarbonate, as indicated by the alkalinity concentration; median alkalinity for water from the shallow upgradient wells was 282 mg/L. Major cations were calcium, magnesium, and sodium, median concentrations of which respectively were 98, 27, and 25 mg/L.

Concentrations of nitrogen species generally were small in water from shallow upgradient wells, except in well M-1 where relatively large concentrations of nitrate (3.5 mg/L) were detected. The reason for the large concentrations of nitrate in water from well M-1 is unknown. The landfill probably was not the source, because concentrations of nitrate were smaller everywhere else in the study area. Agricultural fertilizers may be the source, inasmuch as well M-1 is adjacent to agricultural land and large concentrations of nitrate in ground water have been reported in association with agricultural areas (Hem, 1985, p. 125). No substantial concentrations of ammonia were detected in water from the shallow wells upgradient from the landfill.

Iron and manganese concentrations differed greatly among wells and ranged from not detected to 1,290 µg/L for iron and 790 µg/L for manganese. Except for barium, trace elements mostly were undetected in water from the shallow upgradient wells. Barium was detected in water from all wells in concentrations ranging from not detected to 230 µg/L. The median barium concentration in water from the shallow upgradient wells was 110 µg/L.



Base modified from Pettijohn, 1977

Figure 27.-- Dissolved solids concentrations and Stiff diagrams of common ion concentrations in the shallow aquifers at the Tibbs-Banta study area, February, 1986.

Table 19.--Summary statistics of water-quality data for shallow wells AA-3, FF-2, K-1, K-2, and M-1, upgradient from the Tibbs-Banta landfill

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of obser- vations	Median	Inter- quartile range	Minimum	Maximum
Specific conductance	µS/cm	23	787	139	693	1,297
pH	units	23	7.1	.2	6.9	7.3
Temperature	°C	23	13.5	4.2	8.9	18.7
Dissolved oxygen	mg/L	23	.2	.3	0	1.7
Chemical oxygen demand	mg/L	23	8	11	<1	24
Calcium	mg/L	23	98	28	78	134
Magnesium	mg/L	23	27	4	24	32
Sodium	mg/L	23	25	30.7	3.2	93
Potassium	mg/L	23	2.1	1.6	1	3.2
Alkalinity, as $CaCO_3$	mg/L	23	282	46	240	336
Sulfate	mg/L	19	58	20	38	87
Chloride	mg/L	23	56	40	16.0	154
Bromide	mg/L	19	.065	.03	<.01	.3
Dissolved solids	mg/L	23	524	137	375	813
Nitrate as nitrogen	mg/L	18	.12	.82	<.01	3.5
Nitrite as nitrogen	mg/L	18	<.005	0	<.005	.02
Ammonia as nitrogen	mg/L	23	.04	.12	<.01	.21
Phosphorus	mg/L	18	.01	.01	<.01	.05
Arsenic	µg/L	23	<1	0	<1	2
Barium	µg/L	23	110	110	<10	230
Iron	µg/L	23	130	1,100	<10	1,290
Manganese	µg/L	23	130	100	<10	790

Shallow wells that were located in the landfill are B-1 and CC-1. A statistical summary of the water-quality data collected from these wells is listed in table 20. Well B-1 is screened in the refuse and water from this well indicated the largest effect of landfill leachate of all wells in the Tibbs-Banta study area. Well CC-1 is screened in sand and gravel near refuse. Water from well CC-1 does not indicate as much effect from leachate as does well B-1 and the effect is intermittent. Well CC-1 intercepts landfill leachate when ground-water flow is west or southwest. A small change in flow direction to the northwest would make well CC-1 an upgradient well. A loss of streamflow was measured in Little Buck Creek on October 17, 1985. Water seeping from the stream into the aquifer near well CC-1 would lessen the effect of leachate on water from this well.

Dissolved-solids concentrations in water from shallow wells in the landfill were slightly larger than those in water from shallow upgradient wells and ranged from 394 to 611 mg/L. Specific conductance ranged from 700 to 1,345 µS/cm. The median SC of water from these wells was 1,144.5 µS/cm which is much larger than the SC of water from the shallow upgradient wells. Values of pH of water from wells B-1 and CC-1 ranged from 6.6 to 7.5, with a median value of 6.95. Median COD was 16.5 mg/L in water from both wells but was largest in water from well B-4 which had a median COD of 48 mg/L.

Concentrations of major cations and anions in water from shallow wells in the landfill were similar to those in water from shallow upgradient wells. Median values for calcium, magnesium, sodium, and potassium respectively were 90, 29.5, 34.5, and 21 mg/L. The median alkalinity was 442 mg/L. Median concentrations of sulfate, chloride, and bromide respectively were 28, 63, and 0.17 mg/L. The largest concentration of bromide in water from shallow wells in the landfill was 0.7 mg/L in well B-1. This concentration of bromide is more than twice the largest concentration found in water from the shallow upgradient wells.

Concentrations of ammonia in water from shallow wells in the landfill were much larger compared to the concentrations in shallow upgradient wells. Ammonia concentrations ranged from 0.83 to 39.03 mg/L as nitrogen, with a median concentration of 18.51 mg/L as nitrogen. Concentrations of nitrate in water from wells B-1 and CC-1 were slightly smaller than the concentrations in water from the shallow upgradient wells and concentrations of nitrite were similar in water from wells in both groups.

Iron concentrations were much larger in water from shallow wells in the landfill compared to the concentrations in water from the shallow upgradient wells. The median iron concentration was 9,880 mg/L. No difference in concentrations of manganese between shallow upgradient wells and shallow wells was observed. Trace elements, except for arsenic and barium, were not detected in water from shallow wells in the landfill. Arsenic concentrations were large in these wells compared to the shallow upgradient wells and ranged from 6 to 49 µg/L, with a median of 19 µg/L. The median concentration of barium was 350 µg/L.

Table 20.--Summary statistics of water-quality data for shallow wells B-1 and CC-1, in the Tibbs-Banta landfill

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; μg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of obser-vations	Median	Inter-quartile range	Minimum	Maximum
Specific conductance	μS/cm	10	1,144.5	364.2	700	1,345
pH	units	10	6.95	.32	6.6	7.5
Temperature	°C	9	15	2.9	12.5	17.7
Dissolved oxygen	mg/L	10	.3	.25	0	1.6
Chemical oxygen demand	mg/L	10	16.5	35.5	5	55
Calcium	mg/L	10	90	16.8	62	130
Magnesium	mg/L	10	29.5	7.2	18	36
Sodium	mg/L	10	34.5	19.8	22	52
Potassium	mg/L	10	21	8.6	2.9	32
Alkalinity, as $CaCO_3$	mg/L	10	442	179	234	558
Sulfate	mg/L	8	28	31.2	22	60
Chloride	mg/L	10	63	32.5	40	89
Bromide	mg/L	8	.17	.4	.1	.72
Dissolved solids	mg/L	10	593	89.2	394	611
Nitrate as nitrogen	mg/L	8	.015	.02	.01	.31
Nitrite as nitrogen	mg/L	8	<.005	0	<.005	.01
Ammonia as nitrogen	mg/L	10	18.51	20.95	.83	39.03
Phosphorus	mg/L	8	.08	.09	.03	.15
Arsenic	μg/L	10	19	29.2	6	49
Barium	μg/L	10	350	360	190	620
Iron	μg/L	10	9,880	24,882	530	40,230
Manganese	μg/L	10	130	77.5	80	230

Wells I-2, J-2, and L-2 are shallow downgradient wells. A statistical summary of water quality in the shallow downgradient wells is listed in table 21. Well J-2 is closest to the leachate plume, and water from this well was most affected by leachate from the landfill. The median dissolved solids concentration for the shallow downgradient wells was 619 mg/L, and concentrations ranged from 466 to 1,106 mg/L. Compared to the shallow wells in other groups, the dissolved-solids concentrations in shallow downgradient wells were larger. Specific conductance ranged from 772 to 1,611 µS/cm, with a median value of 1,013 µS/cm. The pH ranged from 6.8 to 7.3, with a median of 7.0. Chemical oxygen demand ranged from 3 to 57 mg/L with a median of 17 mg/L.

Major cations were detected in larger concentrations in water from the shallow downgradient wells compared to shallow wells in other groups. Calcium concentrations ranged from 96.6 to 189.9 mg/L with a median of 121.3 mg/L. Median concentrations of magnesium and sodium respectively were 32.6 and 36.9 mg/L. Alkalinity concentrations were smaller in water from shallow downgradient wells than those in water from shallow wells in other groups. The median alkalinity concentration was 356 mg/L. The median chloride concentration was 68 mg/L--about the same as that detected in water from shallow well B-1 in the landfill. The median sulfate concentration in water from shallow downgradient wells was 78 mg/L which is larger than the concentrations found in water from shallow wells in other groups. Concentrations of bromide were slightly larger in water from shallow downgradient wells compared to shallow wells in other groups. The median bromide concentration was 0.2 mg/L and the largest bromide concentration detected in water from shallow downgradient wells was 0.9 mg/L at well J-2.

The median nitrate concentration in water from shallow downgradient wells was 0.01 mg/L as nitrogen. Nitrite was detected in only two samples from shallow downgradient wells. The median concentration of ammonia was 3.14 mg/L as nitrogen in water from shallow downgradient wells. This concentration of ammonia is larger than the concentrations found in water from shallow upgradient wells but is smaller than the concentrations found in shallow wells in the landfill. This may indicate that ammonia was being reduced anaerobically (denitrification) to nitrogen gas (Hammond, 1973, p. B-80) although no gas emissions were observed.

Iron concentrations were larger in water from shallow downgradient wells than in water from shallow upgradient wells but were smaller than the concentrations in water from shallow wells in the landfill. The median iron concentration was 1,990 µg/L in shallow downgradient wells. The median manganese concentration in water from shallow downgradient wells was more than twice the median manganese concentration for all other well groups. Manganese concentrations ranged from 30 to 1,500 µg/L in the shallow downgradient wells, with a median value of 300 µg/L.

Table 21.--Summary statistics of water-quality data for shallow wells I-2, J-2, and L-2, downgradient from the Tibbs-Banta landfill

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of obser-vations	Median	Inter-quartile range	Minimum	Maximum
Specific conductance	µS/cm	15	1,013	197	772	1,611
pH	units	15	7	.3	6.8	7.3
Temperature	°C	14	12.6	2.8	9.9	16.7
Dissolved oxygen	mg/L	14	.3	.5	0	1.6
Chemical oxygen demand	mg/L	15	17	19	3	57
Calcium	mg/L	15	121.3	20.2	96.6	189.9
Magnesium	mg/L	15	32.6	9.7	26.1	50.9
Sodium	mg/L	15	36.9	30.5	14.4	87.3
Potassium	mg/L	15	6.7	5.4	2.8	11.3
Alkalinity, as $CaCO_3$	mg/L	15	356	84	300	534
Sulfate	mg/L	12	78	43.5	56	198
Chloride	mg/L	15	68	28	26	134
Bromide	mg/L	12	.2	.2	.06	.9
Dissolved solids	mg/L	15	619	141	466	1,106
Nitrate as nitrogen	mg/L	12	.01	.07	<.01	.26
Nitrite as nitrogen	mg/L	12	<.005	0	<.005	.01
Ammonia as nitrogen	mg/L	15	3.14	2.93	1.41	7.13
Phosphorus	mg/L	12	.04	.15	<.01	.19
Arsenic	µg/L	15	2	29	<1	59
Barium	µg/L	15	240	150	30	610
Iron	µg/L	15	1,990	12,490	<10	22,850
Manganese	µg/L	15	300	790	30	1,500

Several trace elements were detected in water from the shallow downgradient wells that were not detected in water from other shallow wells; however, the frequency of detection was irregular. Mercury and nickel were detected in water from well J-2 on different sampling dates. Mercury was detected in duplicate samples at concentrations of 0.6 and 1.3 µg/L during August 1985. A nickel concentration of 20 µg/L was detected during February 1986. Other than barium and arsenic, trace elements were not detected in other samples. Arsenic concentrations in the shallow downgradient wells ranged from not detected to 59 µg/L, with a median of 2 µg/L. The median concentration of barium in shallow downgradient wells was 240 µg/L.

Deep aquifers

The deep aquifers at the Tibbs-Banta landfill consist of the lower two of the four sand and gravel layers. Ground-water flow in the deep aquifers generally is horizontal, especially in the eastern part of the study area. Between Tibbs Avenue and the White River, the bedrock surface rises about 70 ft, terminating the deep layers and causing water to move upward into the shallow aquifers and into the river.

Deep upgradient wells are AA-1, AA-2, and F-1. A statistical summary of the ground-water quality in the deep upgradient wells is listed in table 22. Dissolved-solids concentrations in water from these wells were much smaller than those in water from shallow upgradient wells. Dissolved-solids concentrations ranged from 299 to 511 mg/L, with a median of 380 mg/L. The SC ranged from 563 to 755 µS/cm, with a median of 596 µS/cm. Values of pH ranged from 7.2 to 7.5, with a median of 7.4. The median COD concentration was 3 mg/L, which is smaller than that in water from shallow upgradient wells.

Major cations and anions also were detected in smaller concentrations in water from the deep upgradient wells compared to water from shallow upgradient wells. The median concentrations of calcium and magnesium respectively were 80.7 and 24.8 mg/L--only slightly smaller than the concentrations in water from shallow upgradient wells. The median concentrations of sodium and potassium respectively were 4.1 and 0.8 mg/L--much smaller than in water from shallow upgradient wells. The median alkalinity concentration was 254 mg/L in water from the deep upgradient wells. Sulfate concentrations ranged from 30.0 to 64.0 mg/L, with a median of 51.5 mg/L. The median chloride concentration was 4.0 mg/L, and chloride concentrations ranged from not detected to 53.0 mg/L.

Both nitrate and nitrite were detected in smaller concentrations in water from the deep aquifers compared to water from the shallow aquifers. Nitrate was detected in 8 of the 12 samples from the deep upgradient wells. Water from well AA-2 was found to contain measurable concentrations of nitrate in only one of four analyses, and that concentration was 0.01 mg/L as nitrogen, the detection limit. The median concentration of nitrate in all three wells was less than 0.01 mg/L as nitrogen. Nitrite was detected once in 12 analyses at a concentration of 0.01 mg/L as nitrogen. Concentrations of ammonia differed among deep upgradient wells but were smallest in water from wells AA-1 and AA-2 which had a median concentration of 0.05 mg/L as nitrogen and largest in water from well F-1 which had a median concentration of 0.85 mg/L as nitrogen.

Table 22.--Summary statistics of water-quality data for deep wells AA-1, AA-2, and F-1, upgradient from the Tibbs-Banta landfill

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of obser-vations	Median	Inter-quartile range	Minimum	Maximum
Specific conductance	µS/cm	15	596	116	563	755
pH	units	15	7.4	.1	7.2	7.5
Temperature	°C	15	12.1	1	12	14.5
Dissolved oxygen	mg/L	15	.2	.2	0	.5
Chemical oxygen demand	mg/L	15	3	9	1	25
Calcium	mg/L	15	80.7	7.7	72.9	87
Magnesium	mg/L	15	24.8	3.9	22.4	30.8
Sodium	mg/L	15	4.1	12.6	2.2	18.2
Potassium	mg/L	15	.8	1.1	.6	2.1
Alkalinity, as $CaCO_3$	mg/L	15	254	16	251	282
Sulfate	mg/L	12	51.5	20.8	30	64
Chloride	mg/L	15	4	36	<1	53
Bromide	mg/L	12	.03	.04	<.01	.07
Dissolved solids	mg/L	15	380	71	299	511
Nitrate as nitrogen	mg/L	12	<.01	0	<.01	.15
Nitrite as nitrogen	mg/L	12	<.005	0	<.005	.01
Ammonia as nitrogen	mg/L	15	.08	.69	<.01	1.01
Phosphorus	mg/L	12	.025	.04	<.01	.1
Arsenic	µg/L	15	3	5	<1	9
Barium	µg/L	15	220	200	<10	440
Iron	µg/L	15	2,080	1,160	790	2,360
Manganese	µg/L	15	60	60	30	110

The median iron concentration in water from the deep upgradient wells was 2,080 µg/L, which is larger than the concentrations in water from shallow upgradient wells but smaller than those in water from shallow wells in other groups. The median manganese concentration was 60 µg/L, about one-half the median concentration measured in the shallow upgradient wells. Arsenic and barium were detected in the deep upgradient wells in larger concentrations than in shallow upgradient wells. Median concentrations of arsenic and barium in the deep upgradient wells respectively were 3 and 220 µg/L. Lead and nickel also were detected; however, concentrations were equal or slightly more than the detection limit.

Wells I-1, J-1, and L-1 are located in the deep aquifers downgradient from the landfill. A statistical summary of water quality in samples from the deep downgradient wells is listed in table 23. Water from well J-1 had a much different water chemistry than did water from the other two wells in this group. Samples from well J-1 were similar to those from shallow downgradient wells. A possible connection between the shallow and deep aquifers near site J could explain the similarity. Dissolved-solids concentrations in deep downgradient wells ranged from 278 to 803 mg/L, with a median concentration of 327 mg/L. The median SC was 517 µS/cm, but ranged from 445 to 1,288 µS/cm. The median pH was 7.6, and the median COD concentration was 7 mg/L.

Median calcium and magnesium concentrations were smaller in water from the deep downgradient wells than in water from the deep upgradient wells, whereas concentrations of sodium and potassium were larger. Median concentrations of calcium, magnesium, sodium, and potassium respectively were 48.3, 22.7, 31.4, and 2.5 mg/L. The median alkalinity concentration in water from deep downgradient wells was 264 mg/L, which is slightly larger than in water from the deep upgradient wells. The median sulfate concentration was 2.5 mg/L, which is much smaller than in water from the deep upgradient wells. The median chloride concentration was 9.0 mg/L.

Differences in nitrogen species and concentrations also indicated that water from well J-1 was different than water from the other two wells in the deep downgradient group. Ammonia was the primary indicator of this difference. The median ammonia concentration in water from well J-1 was 16 times the median concentration in water from deep downgradient wells I-1 and L-1. Median concentrations of ammonia and nitrate in water from the deep downgradient wells respectively were 0.47 and 0.01 mg/L as nitrogen. Nitrite concentrations were similar in water from all the deep downgradient wells and the median concentration was less than the detection limit of 0.005 mg/L as nitrogen.

Median iron and manganese concentrations in water from the deep downgradient wells were smaller than the median concentrations in water from the deep upgradient wells. Median concentrations of iron and manganese respectively were 1,640 and 40 µg/L. Arsenic and barium were detected in water from deep downgradient wells; median concentrations respectively were 1 and 430 µg/L. In the deep aquifers, median barium concentrations were larger downgradient than upgradient from the landfill.

Table 23.--Summary statistics of water-quality data for deep wells I-1, J-1, and L-1, downgradient from the Tibbs-Banta landfill

[μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; μg/L, micrograms per liter; <, less than]

Property or constituent	Unit	Number of obser- vations	Median	Inter- quartile range	Minimum	Maximum
Specific conductance	μS/cm	15	517	718	445	1,288
pH	units	15	7.6	.5	7	7.7
Temperature	°C	14	13.2	2.4	10.3	16.5
Dissolved oxygen	mg/L	12	.2	.3	0	2.3
Chemical oxygen demand	mg/L	15	7	30	1	46
Calcium	mg/L	15	48.3	76.5	40.4	139.8
Magnesium	mg/L	15	22.7	13.7	20	39.5
Sodium	mg/L	15	31.4	47.4	11	74.1
Potassium	mg/L	15	2.5	6.8	2	10.2
Alkalinity, as $CaCO_3$	mg/L	15	264	154	232	434
Sulfate	mg/L	12	2.5	95.5	.5	114
Chloride	mg/L	15	9	85	.5	109
Bromide	mg/L	12	.1	.6	.02	1
Dissolved solids	mg/L	15	327	463	278	803
Nitrate as nitrogen	mg/L	12	.01	0	<.01	.1
Nitrite as nitrogen	mg/L	12	<.005	0	<.005	.01
Ammonia as nitrogen	mg/L	15	.47	5.06	.31	8.83
Phosphorus	mg/L	12	.03	.06	<.01	.16
Arsenic	μg/L	15	1	10	<1.0	15
Barium	μg/L	15	430	360	40	800
Iron	μg/L	15	1,640	1,080	1,000	3,770
Manganese	μg/L	15	40	210	20	250

Effects of Landfill

The effect of landfilling on the ground-water quality of an area is largely dependent on ground water, or infiltrating precipitation, moving through and dissolving materials in the refuse. At the Tibbs-Banta landfill, ground-water levels are above the base of the refuse in some areas. At well B-1, the well screen is at the base of the refuse, just below the lowest measured water level. Water-level fluctuations in well B-1 were slightly greater than 3 ft; although not a large fluctuation, it is enough to wet and drain the base of the refuse. If all 50 acres of the landfill have similar water-level fluctuations within the refuse, a 3-ft rise in water level would represent a 150-acre-ft increase in the amount of saturated refuse.

Ground water flows in a west-northwesterly direction under the Tibbs-Banta study area. As it moves, the water dissolves and carries materials from the refuse. The largest concentrations of dissolved constituents were detected in water from the shallow aquifers, in and downgradient from the landfill. The leachate typically has larger concentrations of dissolved solids, SC, and COD than the ambient ground water, although the presence of large concentrations of these constituents alone are not conclusive evidence of leachate production. Another indicator of landfill leachate is low pH. Water from shallow upgradient wells had a median pH of 7.1, whereas the median pH of water in wells in and downgradient from the landfill respectively was 6.8 and 7.0. Alkalinity increased along the flow path in the shallow aquifers and buffered the water, mitigating the decrease in pH. In the deep aquifers, alkalinity concentrations and pH values were slightly larger in water from the downgradient wells compared to water from the upgradient wells. The median pH was 7.4 in water from deep upgradient wells and 7.6 in water from deep downgradient wells, indicating that some water-quality changes in the deep aquifer in the downgradient direction may not be related to the landfill.

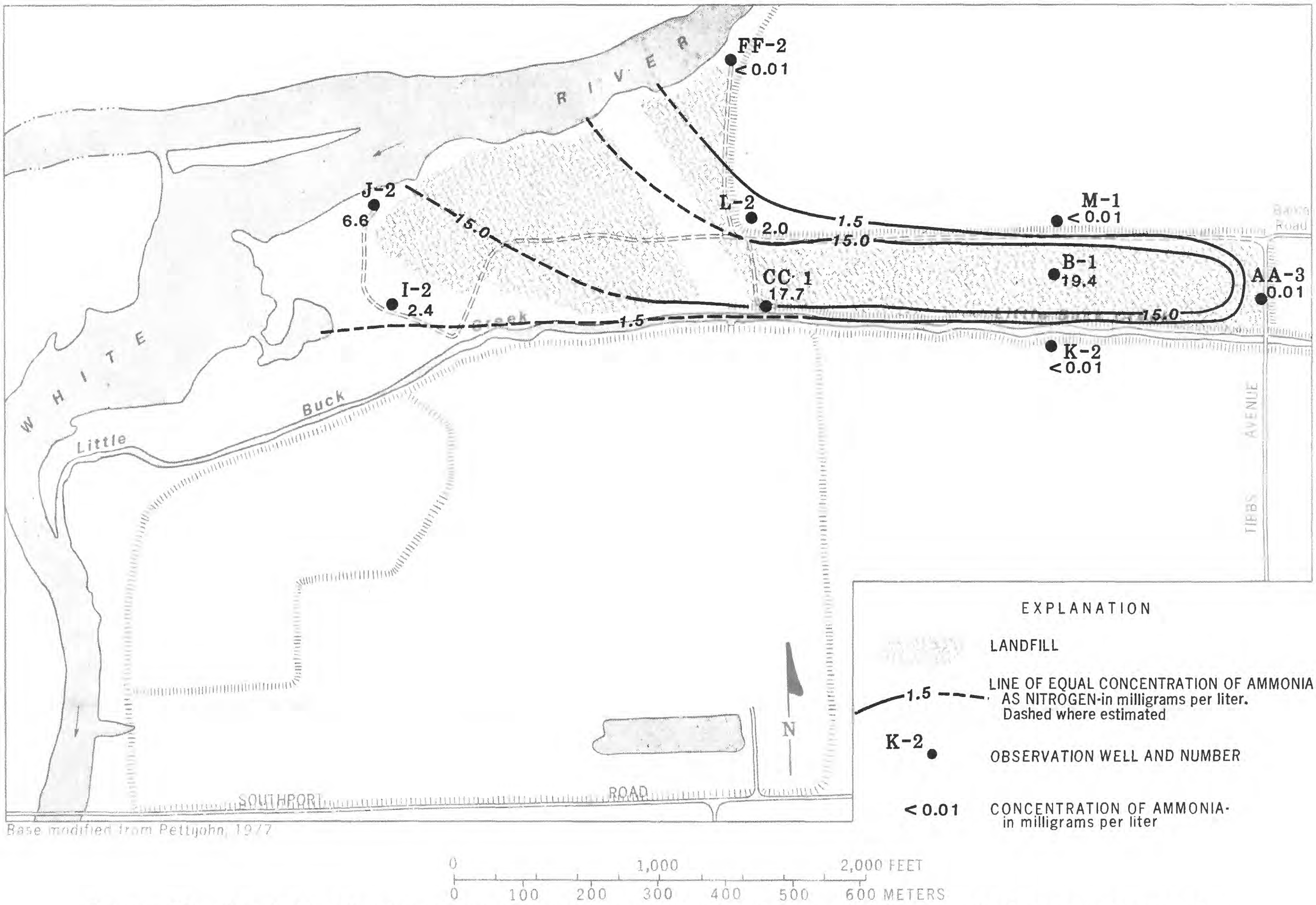
Water from the shallow downgradient wells consistently had larger concentrations of almost all constituents. Ground water from well J-2 appears to have been most affected by landfill leachate. The Tibbs-Banta landfill model was used to estimate a ground-water-discharge rate to the White River of 1.8 ft^3/s. Because the 41-year (1930-31 and 1946-86) average discharge for the White River at the Centerton gage was 2,446 ft^3/s (Glatfelter and others, 1987, p. 148), the ground-water discharge is negligible compared to the streamflow and landfill leachate would be diluted in the river.

Concentrations of individual constituents were plotted on a map and the points were contoured to indicate their areal distribution. As a result, several constituents were found to be good indicators of leachate at the Tibbs-Banta landfill. Not all constituents were good indicators because of their irregular distribution or frequency of detection in the ground water. Iron, for example, is present in leachate, but its irregular distribution in outwash deposits may cause misidentification of leachate contamination.

Ammonia, bromide, chloride, potassium, sodium, and sulfate were among the best indicators of the presence and direction of leachate flow. Concentrations of ammonia, bromide, chloride, potassium, and sodium were larger in water from downgradient wells than in water from wells in other groups. Sulfate concentrations were smaller in water from downgradient wells than in water from wells in other groups indicating that sulfate may be the source of oxygen for reducing reactions in the landfill. Distribution of ammonia concentrations in water from shallow wells in the study area is shown in figure 28. Ammonia concentrations were largest in the landfill. Movement of the ammonia plume to the river was assumed, although ammonia is unstable and may not reach the river in this chemical form.

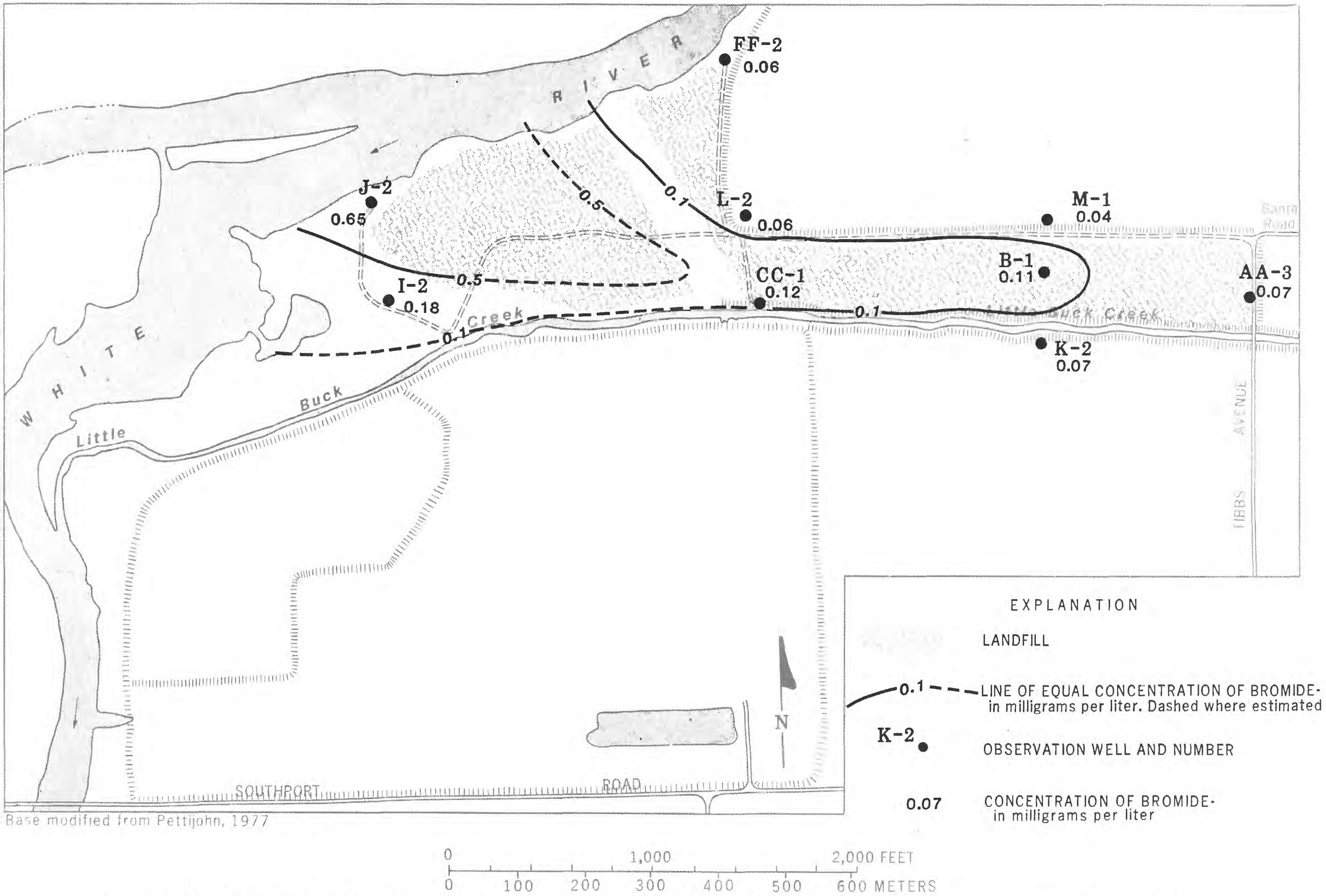
The distribution of bromide, chloride, sodium, and potassium in the plume was similar to that for ammonia. Sodium, potassium, and chloride may have sources other than the landfill--for example, road-salting along Tibbs Avenue. Bromide is a better indicator of leachate because its presence commonly is anthropogenic (Hem, 1985, p. 146). Distribution of bromide concentrations in the shallow aquifers in the Tibbs-Banta study area is shown in figure 29.

Plume boundaries and constituent concentrations changed between sampling dates, which indicates the variability of the leachate plume. Bromide concentrations varied less than did concentrations of ammonia and were the best indicator of leachate from the Tibbs-Banta landfill. Specific-conductance measurements also provided a quick indication of the extent of the effect of the landfill on ground-water quality.



Base modified from Pettijohn, 1977

Figure 28.-- Areal distribution of concentrations of dissolved ammonia in the shallow aquifers at the Tibbs-Banta study area, May 1986.



Base modified from Pettijohn, 1977

Figure 29.-- Areal distribution of concentrations of dissolved bromide in the shallow aquifers at the Tibbs-Banta study area, May 1986.

SUMMARY AND CONCLUSIONS

Ground-water flow and quality were investigated at two landfills in Marion County. The two sites are referred to as the Julietta and the Tibbs-Banta landfills. The Julietta landfill is adjacent to the flood plain of Buck Creek in southeastern Marion County. The Tibbs-Banta landfill is located in southwestern Marion County in the flood plain of the White River, the largest stream in the county. Both landfills contain municipal trash and garbage. The Julietta landfill is reported to have received industrial wastes, including hazardous materials. The landfills were closed in the mid-1970's; however, sewage sludge from Indianapolis wastewater-treatment plants was applied to the surface of the landfills in the mid-1980's during a revegetation program.

The landfills are underlain by unconsolidated glacial deposits containing sand, gravel, clay, and silt. The sediments are as much as 180 ft thick in the Julietta study area and as much as 100 ft thick in the Tibbs-Banta study area. Layers of sand and gravel within the glacial sediments form aquifers and provide pathways for shallow ground-water flow.

At the Julietta study area, two sand and gravel aquifers, averaging 15 ft in thickness, are separated by about 1 to 3 ft of sandy clay beneath most of the study area. To the southeast, the clay is absent and the aquifers merge into one unit. Beneath the Tibbs-Banta study area, four sand and gravel aquifers were identified. The lower two aquifers thin from east to west and are separated from above by layers of till consisting mostly of clay. The lower aquifers are absent in the western part of the study area. The upper two aquifers are thicker and more continuous than the lower aquifers, but are separated, in places, by discontinuous clay layers of variable thickness.

Static water levels, measured in observation wells, indicate that water in the aquifers flows toward, and discharges into, the adjacent streams. Ground-water flow primarily is horizontal, except near the streams where vertical gradients increase. Higher water levels in the deep aquifers compared to the shallow aquifers near the streams indicate the potential for upward flow of ground water to the streams.

Ground-water contamination occurs when ground water or percolating precipitation comes in contact with soluble materials in the refuse. At both landfills, the refuse is exposed to water from two sources: (1) recharge from precipitation and (2) horizontal flow through the buried refuse. To some degree, recharge occurs everywhere through the surface of the landfills. Horizontal flow occurs in areas of saturated refuse, which were found in both landfills. Fluctuations of water levels caused by infiltration of precipitation can change the thickness and extent of the refuse that is saturated.

Models of ground-water flow were used to provide estimates of the volume of water affected by the landfills. The models simulated low-flow steady-state conditions in the sand and gravel aquifers beneath the landfills and were calibrated by matching ground-water levels and streamflow amounts, measured onsite. The sand and gravel aquifers were modeled as layers; therefore, the Julietta model has two aquifer layers and the Tibbs-Banta model has four aquifer layers. The area of refuse was included as an additional top layer so that ground-water flow and recharge through the refuse could be simulated. Water budgets for the areas of refuse indicate that about 19,000 gal/d of water flows through the Julietta landfill and 42,000 gal/d flows through the Tibbs-Banta landfill.

Five sets of ground-water samples were collected from observation wells at the two landfills during the study. Samples were collected from shallow and deep wells that were screened upgradient, beneath, and downgradient from the landfills. Concentrations of dissolved inorganic materials and phenols were determined for each sample. Onsite measurements of SC, pH, temperature, and dissolved oxygen were made during sample collection. The data were used to define the ground-water quality at the two landfills.

Analyses of the ground-water samples indicate larger concentrations of almost all constituents in water from wells screened beneath and downgradient from the landfills. In addition, water from the deep wells generally contained smaller concentrations of dissolved materials than did water from the shallow wells.

Maps of concentrations of specific ions provided an indication of the extent of leachate migration in the ground water. Although most ionic concentrations could be similarly mapped, two of these (bromide and ammonia) were among the best indicators of leachate migration at the two study areas. Specific conductance, measured onsite, also was useful for quick determination of the extent of the leachate from the landfills.

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Table 7.--Water-quality analyses of ground water at the Julietta study area

[μS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; μg/L, micrograms per liter; ---, no data; A or B, duplicate samples; <, less than]

Well number	Sample date	Specific conductance, field (μS/cm)	pH, field (units)	Water temperature (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L as $CaCO_3$)
A-1	5/30/85A	909	7.1	14.2	0.0	9	119	40	5	0.9	290
A-1	5/30/85B	909	7.1	14.2	.0	5	122	41	5	.9	250
A-1	8/14/85	937	7.1	11.5	.2	19	116	38	4	.8	288
A-1	11/13/85	947	7.2	11.0	.5	17	115	38	5	.8	292
A-1	2/20/86	1,006	7.1	12.0	.2	19	114	40	4	.8	284
A-1	5/12/86	947	7.2	12.2	.6	4	126	43	6	.9	291
A-2	5/30/85	677	7.6	13.9	.0	9	59	34	37	1.0	334
A-2	8/14/85	685	7.6	12.5	1.3	10	56	33	38	1.0	338
A-2	11/18/85	671	7.6	12.0	1.0	6	57	30	39	1.0	336
A-2	2/20/86	711	7.6	12.0	.0	10	59	32	36	.9	334
A-2	5/12/86	663	7.7	11.9	.7	4	59	33	39	1.0	338
B-1	5/28/85	629	7.2	11.6	.3	1	90	32	5	.8	300
B-1	8/8/85	664	7.2	12.0	.3	<1	86	29	6	.8	300
B-1	11/7/85	634	7.2	10.5	.4	1	89	29	5	.7	306
B-1	2/12/86	654	7.2	10.8	.3	3	87	27	5	.7	308
B-1	5/12/86	615	7.2	10.7	.3	2	86	30	5	.8	294
C-1	5/28/85	665	7.5	12.2	.5	4	56	32	37	1.4	334
C-1	8/8/85	680	7.5	12.8	.4	<1	54	31	38	1.4	336
C-1	11/13/85	658	7.5	11.0	.2	8	56	30	38	1.4	332
C-1	2/19/86	651	7.5	10.6	.2	3	58	32	37	1.4	326
C-1	5/13/86	658	7.4	10.8	.3	2	59	33	39	1.5	346
C-2	5/28/85	536	7.4	9.1	6.0	3	63	20	19	1.4	190
C-2	8/7/85	540	7.4	8.7	3.9	3	60	18	22	1.3	202
C-2	11/20/85	638	7.2	11.6	4.0	13	78	22	23	1.0	240
C-2	2/19/86A	549	7.4	10.9	2.5	9	69	19	16	1.2	212
C-2	2/19/86B	549	7.4	10.9	2.5	9	69	20	16	1.2	212
C-2	5/13/86A	582	7.3	7.8	5.8	2	75	19	20	1.0	196
C-2	5/13/86B	582	7.3	7.8	5.8	2	72	19	20	1.0	198
C-3	5/28/85	605	7.3	9.4	.0	4	72	22	18	1.0	236
C-3	8/7/85	632	7.2	9.0	.2	8	74	23	19	.9	246
C-3	11/13/85	747	7.2	10.0	.2	8	87	25	23	1.2	266
C-3	2/19/86	717	7.2	11.3	.3	13	91	26	22	1.1	272
C-3	5/13/86	614	7.2	9.0	.4	2	84	23	16	1.0	248

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Specific conduct-ance, field (µS/cm)	pH, field (units)	Water tempera-ture (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L as $CaCO_3$)
DD-1	5/22/85	954	6.8	12.9	1.5	8	120	45	16	2.4	396
DD-1	8/5/85	915	7.2	13.0	.4	10	115	37	14	2.1	366
DD-1	11/20/85	905	7.0	12.4	1.0	10	112	37	17	2.2	360
DD-1	2/10/86	939	7.1	11.9	.4	14	117	38	21	1.9	376
DD-1	5/19/86	1,001	7.0	11.4	.2	8	64	45	36	2.3	368
DD-2	5/21/85	677	7.2	13.2	.0	<1	83	37	8	1.4	326
DD-2	8/5/85	681	7.3	13.5	.4	3	86	31	8	1.1	326
DD-2	11/18/85	772	7.2	11.8	.5	16	104	27	11	2.0	266
DD-2	2/10/86	775	7.2	10.0	.4	12	107	26	12	2.0	280
DD-2	5/19/86	690	7.2	12.2	.1	2	100	33	9	1.4	316
EE-1	5/21/85	1,680	6.8	13.4	.0	43	98	61	106	34	630
EE-1	8/1/85A	1,362	7.0	14.8	.0	81	76	43	98	32	528
EE-1	8/1/85B	1,362	7.0	14.8	.0	41	75	42	98	32	536
EE-1	11/20/85	1,538	6.9	15.2	.0	48	89	54	91	34	372
EE-1	2/11/86	1,716	6.9	13.9	.1	50	103	58	104	32	870
EE-1	5/19/86A	1,847	6.9	12.7	.1	44	111	64	125	40	662
EE-1	5/19/86B	1,847	6.9	12.7	.1	43	109	62	126	39	672
EE-2	5/21/85	712	7.2	15.6	.0	4	80	32	16	3.6	326
EE-2	8/1/85	865	7.3	15.0	.0	7	95	35	19	3.8	360
EE-2	11/18/85A	761	7.2	15.5	.8	7	85	30	20	4.2	346
EE-2	11/18/85B	761	7.2	15.5	.8	7	85	30	20	4.1	346
EE-2	2/11/86	826	7.1	15.2	.2	8	91	32	28	3.8	364
EE-2	5/19/86	693	7.3	14.9	.1	2	91	32	16	3.0	320
EE-3	5/21/85	458	7.8	15.5	.0	7	31	25	41	1.6	240
EE-3	8/5/85A	478	7.2	15.3	.0	12	31	19	39	1.4	250
EE-3	8/5/85B	478	7.2	15.3	.0	10	30	20	39	1.5	250
EE-3	11/7/85	468	7.8	14.8	.0	1	32	20	40	1.4	250
EE-3	2/11/86	471	7.8	14.9	.3	13	31	19	39	1.2	246
EE-3	5/19/86	471	7.8	14.9	.1	8	35	22	43	1.4	254
F-1	5/29/85	956	7.2	15.3	.0	5	106	35	36	4.5	364
F-1	8/13/85A	898	7.2	14.8	.0	11	98	33	36	4.5	344
F-1	8/13/85B	898	7.2	14.8	.0	10	100	32	35	4.4	346
F-1	11/4/85	987	7.3	13.2	.5	6	95	30	38	4.1	328
F-1	2/18/86	1,040	7.2	13.7	.2	19	108	39	39	4.4	407
F-1	5/14/86	936	7.2	14.8	.2	5	106	34	40	4.6	344

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Specific conductance, field (µS/cm)	pH, field (units)	Water temperature (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L as $CaCO_3$)
F-2	5/29/85	1,113	6.8	15.7	0.0	10	126	37	48	3.0	412
F-2	8/12/85A	1,229	6.8	14.0	.1	20	127	42	53	2.7	430
F-2	8/12/85B	1,229	6.8	14.0	.1	20	129	43	52	2.8	436
F-2	11/5/85A	1,289	6.8	13.8	.1	16	142	47	53	2.6	510
F-2	11/5/85B	1,289	6.8	13.8	.1	20	142	47	52	2.6	524
F-2	2/18/86	1,154	6.9	14.0	.1	26	119	40	52	3.7	436
F-2	5/14/86A	1,106	6.9	14.3	.2	9	136	37	53	4.2	404
F-2	5/14/86B	1,106	6.9	14.3	.2	8	138	37	54	4.2	402
F-3	5/29/85	964	7.1	15.6	.0	9	119	31	33	3.2	330
F-3	8/13/85A	1,054	7.0	14.2	.0	12	120	40	35	3.3	346
F-3	8/13/85B	1,054	7.0	14.2	.0	13	119	32	35	3.3	344
F-3	11/5/85	1,160	7.1	14.0	.0	11	134	33	45	3.3	416
F-3	2/18/86	1,041	7.1	13.9	.1	29	115	32	45	3.5	390
F-3	5/14/86	982	7.1	14.0	.1	3	125	30	43	3.8	360
F-4	5/29/85A	1,014	7.2	15.6	.0	5	120	38	35	3.9	368
F-4	5/29/85B	1,014	7.2	15.6	.0	12	119	37	35	4.6	356
F-4	8/13/85	1,014	7.1	14.0	.0	12	114	46	34	4.1	334
F-4	11/5/85	1,039	7.2	13.9	.0	9	112	35	36	3.9	334
F-4	2/18/86	1,172	7.2	13.8	.1	30	131	42	42	4.2	412
F-4	5/14/86	1,216	7.1	13.9	.2	11	147	43	59	5.0	438
F-5	5/29/85	557	7.5	14.8	3.0	9	49	27	36	1.7	282
F-5	8/13/85	571	7.4	13.8	.8	15	47	22	38	2.1	284
F-5	11/5/85	566	7.5	13.5	.6	20	45	22	41	2.4	286
F-5	2/18/86	552	7.6	13.6	.3	9	47	23	36	1.6	288
F-5	5/14/86	556	7.5	13.7	.2	8	48	22	39	1.8	255
H-1	5/20/85	657	7.2	13.7	2.9	18	81	36	8	1.2	300
H-1	7/30/85	680	7.4	12.2	.2	<1	81	30	10	1.5	302
H-1	11/25/85	632	7.2	11.0	.8	6	85	30	9	.8	300
H-1	2/13/86	689	7.4	12.1	.2	6	84	30	9	1.0	298
H-1	2/13/86	689	7.4	12.1	.2	3	87	32	9	.9	300
H-1	5/21/86	659	7.4	12.1	.2	5	85	30	10	1.2	304
H-2	5/20/85A	806	7.3	13.4	3.2	7	86	34	22	1.3	298
H-2	5/20/85B	806	7.3	13.4	3.2	7	86	35	22	1.3	300
H-2	7/30/85	703	7.4	12.2	.3	2	83	30	12	1.2	302
H-2	11/25/85	627	7.4	12.0	.8	6	84	30	9	.8	302
H-2	2/13/86	693	7.4	12.1	.2	5	84	31	9	1.1	300
H-2	5/21/86	661	7.4	12.0	.1	4	86	32	11	1.2	300

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Specific conductance, field (µS/cm)	pH, field (units)	Water temperature (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L as $CaCO_3$)
H-3	5/20/85	845	7.0	15.8	3.0	7	93	35	19	2.8	342
H-3	7/30/85	816	6.9	13.4	1.5	8	98	26	18	2.4	344
H-3	11/25/85	1,231	7.0	12.0	.4	34	123	36	42	5.9	432
H-3	2/13/86A	1,293	7.0	12.2	.2	26	112	31	29	3.8	406
H-3	2/13/86B	1,293	7.0	12.2	.2	28	107	34	30	4.0	406
H-3	5/21/86	2,100	6.7	12.4	.0	35	158	48	66	8.0	428
H-4	5/20/85	689	7.2	14.4	.0	7	82	31	9	1.1	302
H-4	7/30/85	716	7.5	12.5	.4	2	85	31	11	1.2	306
H-4	11/25/85	624	7.5	11.8	.7	13	85	32	9	1.4	308
H-4	2/13/86	708	7.4	12.1	.2	6	87	33	9	1.0	306
H-4	5/21/86	672	7.3	12.3	.1	<1	84	31	11	1.0	306
I-1	5/23/85	584	7.5	14.9	2.4	12	47	30	42	1.7	282
I-1	8/12/85	612	7.5	15.4	.2	14	49	25	42	2.0	286
I-1	11/6/85	594	7.4	14.2	.4	10	45	24	46	1.7	290
I-1	2/12/86A	1,222	7.2	15.1	.1	42	138	48	41	2.8	302
I-1	2/12/86B	1,222	7.2	15.1	.1	66	135	48	39	2.8	306
I-1	5/22/86	1,029	7.1	14.8	.1	35	139	35	41	3.8	310
I-2	6/3/85A	596	7.3	18.5	1.4	2	56	30	30	1.8	284
I-2	6/3/85B	596	7.3	18.5	1.4	7	55	29	30	1.8	282
I-2	5/22/86	548	7.4	15.3	.2	4	52	24	35	1.8	288
I-3	5/30/85	1,379	6.8	22.7	2.8	28	194	65	31	1.6	730
I-3	5/22/86A	1,218	6.7	15.7	.0	18	147	42	23	11	584
I-3	5/22/86B	1,218	6.7	15.7	.0	16	145	42	23	11	566
I-4	5/23/85A	651	7.3	15.9	2.7	14	82	26	12	1.8	300
I-4	5/23/85B	651	7.3	15.9	2.7	5	81	32	12	1.7	300
I-4	8/12/85	686	7.3	15.2	.0	18	86	26	13	2.7	306
I-4	11/6/85	663	7.3	15.5	.6	12	77	26	11	1.8	314
I-4	2/12/86	673	7.4	15.4	.1	12	88	30	10	1.5	308
I-4	5/22/86	669	7.0	15.5	.1	5	99	29	13	1.9	310
J-2	6/3/85A	1,315	6.9	13.2	.1	7	152	40	63	2.7	350
J-2	6/3/85B	1,315	6.9	13.2	.1	10	148	40	62	2.7	350
J-2	8/14/85	811	6.6	12.2	.4	19	115	28	56	2.5	340
J-2	11/5/85	985	7.0	13.0	.5	3	110	27	49	2.3	326
J-2	2/20/86	1,026	7.0	12.5	.4	13	104	28	50	2.4	320
J-2	5/15/86	898	6.9	11.6	.4	4	113	27	44	2.1	304

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Specific conductance, field (µS/cm)	pH, field (units)	Water temperature (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L as $CaCO_3$)
K-1	5/28/85	789	7.2	13.0	0.0	3	102	36	12	1.2	348
K-1	8/7/85	804	7.1	12.0	.2	6	95	37	12	1.2	346
K-1	11/4/85	787	7.2	11.9	.4	4	89	33	11	1.2	354
K-1	2/19/86	757	7.2	12.3	.3	3	94	34	11	1.1	342
K-1	5/12/86	793	7.2	12.5	.6	1	100	39	13	1.2	350
K-2	5/28/85	965	7.4	11.7	7.1	13	74	20	91	1.6	220
K-2	8/7/85	1,362	7.0	12.1	.2	28	144	42	59	1.8	324
K-2	11/4/85	1,290	7.1	12.0	.4	2	127	37	56	2.0	328
K-2	2/19/86	1,047	7.4	12.2	1.6	19	78	22	98	1.8	284
K-2	5/12/86	1,364	7.3	10.7	6.8	2	99	28	118	1.8	198
L-1	5/22/85	1,076	7.1	12.5	.0	26	97	38	56	9.3	402
L-1	8/6/85A	1,060	7.1	12.0	.4	13	93	34	46	9.9	364
L-1	8/6/85B	1,060	7.1	12.0	.4	15	94	34	45	10.0	362
L-1	11/20/85	912	7.1	12.0	.9	31	101	33	33	5.6	330
L-1	2/10/86	1,048	7.2	12.7	.4	23	100	34	51	7.4	374
L-1	5/20/86	1,039	7.1	12.1	.2	8	107	37	47	7.2	352
L-2	5/22/85A	909	7.0	11.7	.5	12	113	36	28	4.8	334
L-2	5/22/85B	909	7.0	11.7	.5	9	103	36	25	4.3	332
L-2	8/6/85	1,167	7.0	12.5	.1	16	126	37	47	6.0	398
L-2	11/18/85	1,000	7.1	13.8	.5	16	108	32	38	4.6	360
L-2	2/10/86	1,030	7.1	11.2	.2	20	118	37	35	3.5	386
L-2	5/20/86	891	7.0	10.1	.2	6	118	34	29	3.2	342
MN-1	5/21/85	805	7.2	14.2	.0	<1	74	35	26	12	354
MN-1	8/1/85	963	7.2	15.5	.0	11	85	36	37	14	416
MN-1	11/7/85	1,046	7.1	14.0	.0	36	87	41	44	13	456
MN-1	2/10/86A	862	7.2	14.2	.3	18	80	34	32	11	378
MN-1	2/10/86B	862	7.2	14.2	.3	21	80	34	32	11	392
MN-1	5/13/86	921	7.0	13.7	.2	12	91	37	35	9.2	398
O-2	6/3/85	1,717	7.0	12.0	7.8	16	167	56	94	1.5	314
O-2	8/8/85	1,613	6.9	12.0	6.3	47	153	49	99	1.6	308
O-2	2/20/86	1,740	7.1	11.9	5.6	35	154	49	88	1.5	302
O-2	5/20/86	2,060	7.0	10.5	6.4	6	183	57	148	1.5	318

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Specific conductance, field (µS/cm)	pH, field (units)	Water temperature (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity (mg/L as $CaCO_3$)
P-1	5/22/85	636	7.4	12.0	0.0	10	83	13	20	2.2	186
P-1	8/1/85	832	7.2	12.8	.8	6	106	16	27	2.6	344
P-1	11/7/85	861	7.1	12.8	.0	13	111	22	25	3.5	366
P-1	2/11/86	711	7.2	13.3	.2	8	100	20	25	3.6	282
P-1	5/15/86A	838	7.1	12.5	.4	8	111	23	29	3.8	320
P-1	5/15/86B	838	7.1	12.5	.4	6	107	24	30	3.9	326
R-1	5/20/85	1,103	6.9	14.3	.1	11	114	42	44	11	384
R-1	8/7/85	1,123	6.9	14.0	.5	18	115	39	42	5.4	366
R-1	8/7/85	1,123	6.9	14.0	.5	19	115	40	42	5.2	360
R-1	11/4/85A	1,249	7.0	12.3	.4	15	121	42	46	4.6	368
R-1	11/4/85B	1,249	7.0	12.3	.4	12	121	41	45	4.6	364
R-1	2/12/86	1,209	7.0	12.3	.2	18	125	45	42	3.9	362
R-1	5/12/86	1,175	7.0	12.8	.2	8	136	46	52	4.0	388
T-1	5/22/85	677	7.2	11.3	.0	4	90	29	8	1.1	272
T-1	8/6/85	744	7.1	12.8	.1	13	95	28	8	1.1	282
T-1	11/6/85A	676	7.2	13.5	.0	2	86	25	9	1.1	276
T-1	11/6/85B	676	7.2	13.5	.0	6	85	27	9	1.1	280
T-1	2/11/86	665	7.2	11.6	.2	5	91	28	6	1.0	254
T-1	5/15/86	741	7.1	10.2	.2	1	105	32	7	1.1	280
T-2	5/23/85	631	7.2	13.1	.0	4	86	32	9	1.1	334
T-2	8/6/85	703	7.2	11.5	.3	2	88	32	9	1.0	336
T-2	11/6/85	689	7.3	12.5	.0	4	84	32	10	1.1	338
T-2	2/11/86	696	7.2	11.6	.2	4	91	32	10	.9	342
T-2	5/15/86	718	7.1	11.5	.2	2	94	34	12	1.1	330

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nitrogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
A-1	5/30/85A	---	92	---	639	0.01	<0.005	0.17	0.03
A-1	5/30/85B	---	98	---	621	.01	<.005	.17	.03
A-1	8/14/85	44	110	0.10	738	.02	<.005	.07	.04
A-1	11/13/85	---	97	.20	645	.34	<.005	.06	.02
A-1	2/20/86	46	102	.10	615	.01	<.005	.13	<.01
A-1	5/12/86	46	106	.11	709	---	---	.06	---
A-2	5/30/85	---	12	---	437	.01	.01	1.39	.17
A-2	8/14/85	14	13	.11	412	<.01	<.005	1.46	.18
A-2	11/18/85	---	14	.03	408	.02	<.005	1.01	.16
A-2	2/20/86	14	11	.05	393	.02	<.005	2.16	.15
A-2	5/12/86	16	22	.05	421	---	---	1.38	---
B-1	5/28/85	---	6	---	437	.03	<.005	<.01	.01
B-1	8/8/85	48	9	.01	422	.01	<.005	<.01	.03
B-1	11/7/85	---	4	<.01	414	.01	<.005	<.01	.01
B-1	2/12/86	47	4	.02	396	.01	<.005	<.01	.01
B-1	5/12/86	46	5	<.01	420	---	---	.01	---
C-1	5/28/85	---	11	---	435	.02	<.005	1.78	.06
C-1	8/8/85	---	10	.10	441	.01	<.005	1.74	.05
C-1	11/13/85	---	10	.08	479	<.01	<.005	2.81	.05
C-1	2/19/86	14	12	.09	389	.01	<.005	1.74	.01
C-1	5/13/86	14	10	.05	372	---	---	1.89	---
C-2	5/28/85	---	36	---	374	1.92	<.005	.02	.01
C-2	8/7/85	25	35	.01	327	1.51	<.005	<.01	.02
C-2	11/20/85	---	57	.22	405	.86	.01	<.01	.01
C-2	2/19/86A	24	30	<.01	335	1.28	<.005	<.01	<.01
C-2	2/19/86B	24	32	---	340	1.28	<.005	<.01	.01
C-2	5/13/86A	24	44	.12	371	---	---	<.01	---
C-2	5/13/86B	18	48	---	367	---	---	.04	---
C-3	5/28/85	---	31	---	414	.58	<.005	<.01	.01
C-3	8/7/85	34	34	.04	366	.25	<.005	<.01	.03
C-3	11/13/85	---	53	.13	460	<.01	.01	<.01	.02
C-3	2/19/86	35	45	<.01	440	.27	<.005	<.01	<.01
C-3	5/13/86	32	28	.02	361	---	---	<.01	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nitrogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
DD-1	5/22/85	---	34	---	638	0.13	<0.005	0.36	0.02
DD-1	8/5/85	73	32	0.17	607	.01	<.005	.34	.01
DD-1	11/20/85	---	42	.14	591	<.01	.01	.72	.01
DD-1	2/10/86	73	52	.30	593	.01	<.005	.55	<.01
DD-1	5/19/86	63	63	.28	618	---	---	.68	---
DD-2	5/21/85	---	6	---	450	.03	<.005	.32	.02
DD-2	8/5/85	43	5	.04	434	.03	<.005	.26	.01
DD-2	11/18/85	---	18	.08	536	1.08	<.005	.13	.01
DD-2	2/10/86	116	22	.02	523	1.11	<.005	.07	<.01
DD-2	5/19/86	52	9	.03	429	---	---	.17	---
EE-1	5/21/85	---	189	---	923	.02	<.005	28.8	.05
EE-1	8/1/85A	8	126	1.50	742	.03	<.005	25.4	.06
EE-1	8/1/85B	9	128	---	728	.01	<.005	25.1	.02
EE-1	11/20/85	---	160	1.70	777	<.01	.01	25.4	.01
EE-1	2/11/86	6	190	1.60	870	.12	<.005	32.3	.05
EE-1	5/19/86A	<1	162	2.80	950	---	---	38.0	---
EE-1	5/19/86B	<1	167	---	928	---	---	29.9	---
EE-2	5/21/85	---	14	---	454	.01	<.005	1.56	.03
EE-2	8/1/85	33	40	.24	521	.01	<.005	2.48	.02
EE-2	11/18/85A	---	19	.21	466	.02	<.005	1.74	.02
EE-2	11/18/85B	---	17	---	478	.01	<.005	1.34	.01
EE-2	2/11/86	35	32	.21	469	<.01	<.005	2.54	<.01
EE-2	5/19/86	42	10	.06	411	---	---	1.16	---
EE-3	5/21/85	---	4	---	287	.01	<.005	.64	.01
EE-3	8/5/85A	4	4	.09	301	.03	<.005	.55	.01
EE-3	8/5/85B	4	4	---	309	.01	<.005	.56	.01
EE-3	11/7/85	---	4	.07	302	<.01	<.005	.70	.01
EE-3	2/11/86	<1	4	<.01	237	.03	<.005	.72	<.01
EE-3	5/19/86	<1	3	.03	271	---	---	.73	---
F-1	5/29/85	---	93	---	562	.01	<.005	.29	.01
F-1	8/13/85A	6	95	.12	581	.01	<.005	.22	.02
F-1	8/13/85B	6	95	---	573	.08	<.005	.23	.03
F-1	11/4/85	---	87	.16	609	.01	<.005	.22	.04
F-1	2/18/86	1	103	.15	643	.01	<.005	.35	.01
F-1	5/14/86	<1	88	.11	569	---	---	.33	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nitrogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
F-2	5/29/85	---	117	---	676	0.01	<0.005	0.03	0.02
F-2	8/12/85A	4	129	0.43	790	.01	<.005	.01	.03
F-2	8/12/85B	6	134	---	763	.01	<.005	.05	.03
F-2	11/5/85A	---	116	.48	837	.01	<.005	<.01	.07
F-2	11/5/85B	---	118	---	822	.01	<.005	.03	.04
F-2	2/18/86	3	128	.24	711	.04	<.005	.05	<.01
F-2	5/14/86A	9	116	.20	644	---	---	.06	---
F-2	5/14/86B	<1	103	---	645	---	---	.04	---
F-3	5/29/85	---	92	---	618	.01	<.005	.02	.01
F-3	8/13/85	8	124	.27	685	.04	<.005	.02	.02
F-3	8/13/85	8	114	---	642	.01	<.005	<.01	.04
F-3	11/5/85	---	128	.34	720	.01	<.005	<.01	.03
F-3	2/18/86	<1	110	.10	629	.03	<.005	.02	<.01
F-3	5/14/86	5	95	.12	580	---	---	<.01	---
F-4	5/29/85A	---	98	---	656	.01	<.005	.04	.01
F-4	5/29/85B	---	100	---	650	.01	<.005	.02	.01
F-4	8/13/85	34	102	.15	674	.01	<.005	.03	.04
F-4	11/5/85	---	106	.44	662	.01	<.005	<.01	.03
F-4	2/18/86	24	119	.15	746	.01	<.005	.10	<.01
F-4	5/14/86	<1	120	.22	709	---	---	.27	---
F-5	5/29/85	---	3	---	324	.01	<.005	.47	.01
F-5	8/13/85	10	3	.52	361	.09	<.005	.47	.06
F-5	11/5/85	---	4	.54	353	.02	<.005	.54	.29
F-5	2/18/86	9	4	.17	341	.01	<.005	.57	.01
F-5	5/14/86	8	4	.11	322	---	---	.50	---
H-1	5/20/85	---	6	---	444	.02	<.005	.68	.03
H-1	7/30/85	54	6	---	426	.03	<.005	.41	.02
H-1	11/25/85	---	5	.09	427	.01	<.005	.38	.05
H-1	2/13/86A	52	6	.08	407	.01	<.005	.59	<.01
H-1	2/13/86B	52	6	---	413	.01	<.01	.46	.02
H-1	5/21/86	52	7	.14	546	---	---	.45	---
H-2	5/20/85A	---	46	---	521	.02	<.005	.41	.19
H-2	5/20/85B	---	47	---	534	.02	<.005	.43	.05
H-2	7/30/85	55	13	---	445	.01	<.005	2.65	.03
H-2	11/25/85	---	6	.11	435	.01	<.005	.31	.05
H-2	2/13/86	55	8	.07	410	.01	<.005	.43	.01
H-2	5/21/86	52	7	.13	571	---	---	.44	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nitrogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
H-3	5/20/85	---	34	---	512	0.02	<0.005	5.21	0.10
H-3	7/30/85	36	30	---	499	.02	<.005	2.53	.03
H-3	11/25/85	---	86	0.54	653	.01	<.005	8.00	.07
H-3	2/13/86A	32	65	.31	568	.03	<.005	7.48	<.01
H-3	2/13/86B	31	62	---	561	.03	<.005	6.97	<.01
H-3	5/21/86	29	71	1.20	723	---	---	4.44	---
H-4	5/20/85	---	10	---	458	.01	<.005	.38	.03
H-4	7/30/85	57	13	---	437	.21	<.005	.35	.01
H-4	11/25/85	---	6	.21	444	.02	<.005	.49	.15
H-4	2/13/86	58	6	.04	422	<.01	.01	.44	<.01
H-4	5/21/86	56	8	<.01	478	---	---	.46	---
I-1	5/23/85	---	7	---	374	.01	<.005	.73	.02
I-1	8/12/85	27	3	.31	388	.01	<.005	.58	.05
I-1	11/6/85	---	4	.23	375	.02	<.005	.67	.05
I-1	2/12/86A	303	13	<.01	846	.01	<.005	.79	.11
I-1	2/12/86B	303	13	---	850	.02	<.005	.84	.09
I-1	5/22/86	222	11	.14	763	---	---	.71	---
I-2	6/3/85A	---	7	---	392	.01	<.005	.46	.03
I-2	6/3/85B	---	4	---	394	.17	<.005	.46	.01
I-2	5/22/86	15	4	<.01	328	---	---	.49	---
I-3	5/30/85	---	34	---	929	.60	<.005	19.4	.61
I-3	5/22/86A	20	21	<.01	644	---	---	10.1	---
I-3	5/22/86B	20	21	---	588	---	---	10.3	---
I-4	5/23/85A	---	12	---	414	.01	<.005	.87	.04
I-4	5/23/85B	---	13	---	423	.01	<.005	.94	.04
I-4	8/12/85	39	8	.62	424	.01	<.005	7.66	.11
I-4	11/6/85	---	4	.23	416	.01	<.005	.83	.22
I-4	2/12/86	39	7	.04	399	<.01	<.005	.79	.05
I-4	5/22/86	40	15	<.01	414	---	---	.83	---
J-2	6/3/85A	---	162	---	922	.02	<.005	.08	.02
J-2	6/3/85B	---	170	---	970	.01	<.005	.07	.02
J-2	8/14/85	69	96	.06	637	.05	<.005	.06	.03
J-2	11/5/85	---	101	.44	640	.12	<.005	.12	.02
J-2	2/20/86	69	81	.07	548	.01	<.005	.10	.01
J-2	5/15/86	44	64	.08	537	---	---	.02	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nitrogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
K-1	5/28/85	---	26	---	569	0.02	<0.005	0.24	0.01
K-1	8/7/85	50	57	0.04	479	.01	<.005	.28	.05
K-1	11/4/85	---	13	<.01	472	<.01	<.005	.34	.04
K-1	2/19/86	44	17	.04	481	<.01	.01	.50	.03
K-1	5/12/86	49	30	.05	537	---	---	.27	---
K-2	5/28/85	---	153	---	609	.54	<.005	<.01	.02
K-2	8/7/85	59	214	.34	944	.02	<.005	.02	.04
K-2	11/4/85	---	164	.44	754	.01	<.005	<.01	.06
K-2	2/19/86	35	142	.07	611	.61	<.005	<.01	<.01
K-2	5/12/86	24	289	.06	944	---	---	<.01	---
L-1	5/22/85	---	109	---	642	.01	<.005	3.65	.01
L-1	8/6/85A	28	96	.50	638	<.01	<.005	4.31	.01
L-1	8/6/85B	27	95	---	615	.01	<.005	4.45	.01
L-1	11/20/85	---	78	.25	559	.03	.01	1.23	.01
L-1	2/10/86	25	106	.28	591	.02	<.005	3.29	<.01
L-1	5/20/86	33	102	.28	607	---	---	2.89	---
L-2	5/22/85A	---	53	---	597	.01	<.005	.37	.04
L-2	5/22/85B	---	51	---	599	.02	<.005	.37	.05
L-2	8/6/85	49	101	.78	733	.04	<.005	.70	.04
L-2	11/18/85	---	74	.82	607	.02	<.005	.65	.03
L-2	2/10/86	62	80	.51	643	.01	<.005	.58	.02
L-2	5/20/86	75	42	.25	528	---	---	.51	---
MN-1	5/21/85	---	29	---	472	.01	<.005	6.53	.02
MN-1	8/1/85	12	50	.53	529	.01	<.005	8.48	.01
MN-1	11/7/85	---	65	.30	591	<.01	<.005	6.07	.02
MN-1	2/10/86A	24	43	.51	463	.03	<.005	6.48	<.01
MN-1	2/10/86B	24	42	---	473	.01	<.005	6.80	<.01
MN-1	5/13/86	20	51	.31	519	---	---	4.68	---
O-2	6/3/85	---	330	---	1,203	5.31	<.005	.01	.02
O-2	8/8/85	58	291	.24	1,162	3.28	<.005	<.01	.05
O-2	2/20/86	68	328	.05	1,077	5.20	<.005	.11	<.01
O-2	5/20/86	56	404	.12	1,275	---	---	<.01	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nitrogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
P-1	5/22/85	---	106	---	448	0.01	<0.005	0.52	0.03
P-1	8/1/85	32	40	0.39	512	.01	<.005	.79	.02
P-1	11/7/85	---	39	.28	529	<.01	<.005	2.75	.01
P-1	2/11/86	45	49	.17	439	.03	<.005	2.11	.01
P-1	5/15/86A	44	48	.28	513	---	---	2.47	---
P-1	5/15/86B	43	50	---	499	---	---	3.48	---
R-1	5/20/85	---	80	---	702	.01	<.005	7.54	.21
R-1	8/7/85A	85	82	.52	664	.01	<.005	4.23	.03
R-1	8/7/85B	85	84	---	663	.03	<.005	4.24	.03
R-1	11/4/85A	---	123	.40	794	.03	.01	4.35	.02
R-1	11/4/85B	---	118	---	803	<.01	<.005	4.13	.04
R-1	2/12/86	83	116	.46	733	.01	<.005	2.76	<.01
R-1	5/12/86	90	109	.36	806	---	---	2.51	---
T-1	5/22/85	---	33	---	449	.02	<.005	.02	.01
T-1	8/6/85	56	35	.05	496	.01	<.005	.25	.01
T-1	11/6/85A	---	26	.07	441	.01	<.005	<.01	.01
T-1	11/6/85B	---	26	---	428	<.01	.01	<.01	.01
T-1	2/11/86	53	34	.03	391	.01	<.005	.02	<.01
T-1	5/15/86	54	41	.06	503	---	---	.12	---
T-2	5/23/85	---	8	---	441	.01	<.005	.38	.01
T-2	8/6/85	40	6	.04	458	<.01	<.005	.26	.02
T-2	11/6/85	---	6	.03	444	<.01	.01	.26	.01
T-2	2/11/86	38	7	.08	400	.01	<.005	.28	.01
T-2	5/15/86	43	15	.04	462	---	---	.27	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
A-1	5/30/85A	---	400	<10	<10	<10	<10	210	10	140
A-1	5/30/85B	---	410	<10	<10	<10	<10	180	20	120
A-1	8/14/85	5	280	<10	<10	<10	<10	220	<10	130
A-1	11/13/85	4	580	<10	<10	---	<10	240	<10	130
A-1	2/20/86	4	410	<10	<10	---	<10	250	<10	120
A-1	5/12/86	3	310	---	---	---	---	210	---	110
A-2	5/30/85	---	190	<10	<10	<10	<10	490	<10	40
A-2	8/14/85	2	210	<10	<10	<10	<10	550	<10	40
A-2	11/18/85	2	280	<10	<10	---	<10	450	<10	50
A-2	2/20/86	2	250	<10	<10	---	<10	480	<10	40
A-2	5/12/86	1	170	---	---	---	---	580	---	30
B-1	5/28/85	<1	110	<10	<10	<10	<10	40	<10	40
B-1	8/8/85	2	260	<10	<10	<10	<10	70	<10	50
B-1	11/7/85	2	250	<10	<10	---	<10	90	<10	50
B-1	2/12/86	2	240	<10	<10	---	<10	110	<10	40
B-1	5/12/86	2	170	---	---	---	---	80	---	30
C-1	5/28/85	<1	160	<10	<10	<10	<10	600	20	70
C-1	8/8/85	1	150	<10	<10	<10	<10	660	<10	60
C-1	11/13/85	<1	350	<10	<10	---	<10	670	<10	70
C-1	2/19/86	<1	260	<10	<10	---	<10	660	<10	60
C-1	5/13/86	<1	240	---	---	---	---	770	---	60
C-2	5/28/85	<1	<10	<10	<10	<10	<10	<10	<10	<10
C-2	8/7/85	3	<10	<10	<10	<10	<10	<10	<10	<10
C-2	11/20/85	<1	<10	<10	<10	---	<10	<10	<10	<10
C-2	2/19/86	<1	50	<10	<10	---	<10	<10	<10	<10
C-2	2/19/86	<1	60	<10	<10	---	<10	10	<10	<10
C-2	5/13/86A	<1	10	---	---	---	---	<10	---	<10
C-2	5/13/86B	<1	10	---	---	---	---	<10	---	<10
C-3	5/28/85	<1	<10	<10	<10	<10	<10	<10	<10	20
C-3	8/7/85	<1	20	<10	<10	<10	<10	20	<10	30
C-3	11/13/85	<1	320	<10	<10	---	<10	<10	<10	30
C-3	2/19/86	<1	80	<10	<10	---	<10	10	<10	30
C-3	5/13/86	<1	30	---	---	---	---	<10	---	20

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
DD-1	5/22/85	8	160	<10	<10	<10	<10	2,350	<10	700
DD-1	8/5/85	5	160	<10	<10	<10	<10	2,440	<10	570
DD-1	11/20/85	16	150	<10	<10	---	<10	3,140	<10	470
DD-1	2/10/86	15	180	<10	<10	---	<10	3,270	<10	400
DD-1	5/19/86	18	20	---	---	---	---	4,690	---	360
DD-2	5/21/85	1	170	<10	<10	<10	<10	40	<10	100
DD-2	8/5/85	1	210	<10	<10	<10	<10	610	<10	60
DD-2	11/18/85	<1	340	<10	<10	---	<10	<10	<10	50
DD-2	2/10/86	<1	240	<10	<10	---	<10	<10	<10	40
DD-2	5/19/86	<1	100	---	---	---	---	10	---	80
EE-1	5/21/85	22	400	<10	<10	<10	30	10,360	<10	100
EE-1	8/1/85A	17	230	<10	<10	<10	<10	7,650	<10	60
EE-1	8/1/85B	17	240	<10	<10	<10	<10	7,200	<10	50
EE-1	11/20/85	28	400	<10	20	---	<10	7,700	<10	70
EE-1	2/11/86	16	480	<10	<10	---	<10	8,500	<10	50
EE-1	5/19/86A	25	320	---	---	---	---	11,750	---	80
EE-1	5/19/86B	28	350	---	---	---	---	11,590	---	80
EE-2	5/21/85	2	380	<10	<10	<10	<10	3,110	<10	30
EE-2	8/1/85	<1	370	<10	<10	<10	<10	4,180	<10	30
EE-2	11/18/85A	<1	570	<10	<10	---	10	3,350	<10	30
EE-2	11/18/85B	<1	620	<10	<10	---	<10	3,590	<10	30
EE-2	2/11/86	<1	500	<10	<10	---	<10	3,410	<10	20
EE-2	5/19/86	<1	230	---	---	---	---	3,250	---	30
EE-3	5/21/85	11	690	<10	<10	<10	<10	870	<10	<10
EE-3	8/5/85A	6	580	<10	<10	<10	<10	940	<10	<10
EE-3	8/5/85B	5	550	<10	<10	<10	<10	960	<10	<10
EE-3	11/7/85	12	760	<10	<10	---	<10	950	<10	<10
EE-3	2/11/86	11	694	<10	<10	---	<10	900	<10	<10
EE-3	5/19/86	14	600	---	---	---	---	940	---	10
F-1	5/29/85	<1	330	<10	<10	<10	<10	3,120	20	30
F-1	8/13/85A	2	290	<10	<10	<10	<10	3,140	<10	30
F-1	8/13/85B	3	250	<10	<10	<10	<10	3,030	<10	30
F-1	11/4/85	<1	370	<10	<10	---	<10	3,160	<10	30
F-1	2/18/86	<1	350	<10	<10	<10	<10	3,070	<10	30
F-1	5/14/86	<1	190	---	---	---	---	2,800	---	10

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
F-2	5/29/85	<1	200	<10	<10	<10	<10	3,150	<10	50
F-2	8/12/85A	1	230	<10	10	<10	<10	3,260	<10	60
F-2	8/12/85B	<1	240	<10	10	<10	<10	3,250	<10	60
F-2	11/5/85A	<1	310	<10	<10	<10	<10	3,700	<10	60
F-2	11/5/85B	<1	320	<10	<10	<10	<10	3,640	<10	60
F-2	2/18/86	<1	250	<10	<10	<10	<10	2,640	<10	50
F-2	5/14/86A	<1	290	---	---	---	---	2,790	---	20
F-2	5/14/86B	<1	270	---	---	---	---	2,710	---	30
F-3	5/29/85	<1	180	<10	<10	<10	<10	2,440	10	30
F-3	8/13/85A	1	250	<10	10	<10	<10	2,350	<10	30
F-3	8/13/85B	1	160	<10	<10	<10	<10	2,440	<10	30
F-3	11/5/85	1	350	<10	<10	<10	<10	2,850	<10	30
F-3	2/18/86	<1	200	<10	<10	<10	<10	2,480	<10	20
F-3	5/14/86	<1	140	---	---	---	---	2,270	---	10
F-4	5/29/85A	<1	170	<10	<10	<10	<10	2,100	20	30
F-4	5/29/85B	---	160	<10	<10	<10	<10	3,040	20	30
F-4	8/13/85	1	340	<10	10	<10	<10	2,000	<10	30
F-4	11/5/85	<1	210	<10	<10	<10	<10	2,040	<10	20
F-4	2/18/86	<1	200	<10	<10	<10	<10	2,450	<10	20
F-4	5/14/86	<1	120	---	---	---	---	2,210	---	20
F-5	5/29/85	---	270	<10	<10	<10	<10	430	10	30
F-5	8/13/85	5	250	<10	10	<10	<10	460	<10	30
F-5	11/5/85	2	360	<10	30	<10	<10	440	<10	30
F-5	2/18/86	4	250	<10	<10	<10	<10	450	<10	30
F-5	5/14/86	2	240	---	---	---	---	280	---	20
H-1	5/20/85	6	230	<10	<10	<10	<10	2,540	10	60
H-1	7/30/85	4	140	<10	<10	<10	<10	1,010	<10	40
H-1	11/25/85	4	230	<10	<10	---	<10	1,620	<10	40
H-1	2/13/86A	3	240	<10	<10	---	<10	1,730	<10	30
H-1	2/13/86B	3	220	<10	<10	---	<10	1,840	<10	30
H-1	5/21/86	2	120	---	---	---	---	1,970	---	30
H-2	5/20/85A	4	230	<10	<10	<10	<10	1,620	20	40
H-2	5/20/85B	4	220	<10	<10	<10	<10	1,640	20	40
H-2	7/30/85	5	90	<10	<10	<10	<10	1,710	<10	30
H-2	11/25/85	4	220	<10	<10	---	<10	1,930	<10	30
H-2	2/13/86	4	240	<10	<10	---	<10	1,880	<10	30
H-2	5/21/86	2	130	---	---	---	---	2,060	---	30

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
H-3	5/20/85	11	340	<10	<10	<10	<10	3,410	<10	160
H-3	7/30/85	12	290	<10	<10	<10	<10	2,480	<10	150
H-3	11/25/85	12	490	<10	<10	---	<10	10,340	<10	170
H-3	2/13/86A	11	450	<10	<10	---	<10	8,960	<10	150
H-3	2/13/86B	12	460	<10	<10	---	<10	9,370	<10	150
H-3	5/21/86	4	570	---	---	---	---	16,120	---	230
H-4	5/20/85	6	150	<10	<10	<10	<10	1,720	<10	40
H-4	7/30/85	4	100	<10	<10	<10	<10	1,290	<10	30
H-4	11/25/85	4	180	<10	<10	---	<10	2,170	<10	40
H-4	2/13/86	3	230	<10	<10	---	<10	2,240	<10	30
H-4	5/21/86	2	130	---	---	---	---	2,430	---	30
I-1	5/23/85	6	90	<10	<10	<10	<10	750	<10	40
I-1	8/12/85	4	90	<10	<10	<10	<10	390	<10	40
I-1	11/6/85	4	130	<10	<10	---	<10	650	<10	30
I-1	2/12/86A	2	60	<10	<10	---	<10	440	<10	170
I-1	2/12/86B	2	70	<10	<10	---	<10	420	<10	160
I-1	5/22/86	1	130	---	---	---	---	730	<10	160
I-2	6/3/85A	---	420	<10	<10	<10	<10	1,290	30	20
I-2	6/3/85B	---	380	<10	<10	<10	<10	1,430	30	20
I-2	5/22/86	2	350	---	---	---	---	1,220	---	20
I-3	5/30/85	---	250	<10	<10	<10	<10	11,140	20	520
I-3	5/22/86A	<1	30	---	---	---	---	7,950	---	350
I-3	5/22/86B	<1	40	---	---	---	---	8,030	---	350
I-4	5/23/85A	2	180	<10	<10	<10	<10	1,000	<10	40
I-4	5/23/85B	2	170	<10	<10	<10	<10	1,560	<10	40
I-4	8/12/85	2	320	<10	<10	<10	<10	1,150	<10	40
I-4	11/6/85	4	330	<10	<10	---	<10	1,820	<10	30
I-4	2/12/86	2	230	<10	<10	---	<10	1,800	<10	40
I-4	5/22/86	1	150	---	---	---	---	1,640	---	40
J-2	6/3/85A	---	370	<10	<10	<10	<10	1,780	30	100
J-2	6/3/85B	---	400	<10	<10	<10	<10	1,780	20	100
J-2	8/14/85	3	190	<10	10	<10	<10	1,630	<10	80
J-2	11/5/85	2	320	<10	<10	<10	<10	1,500	<10	70
J-2	2/20/86	3	270	<10	<10	---	<10	1,190	<10	70
J-2	5/15/86	2	130	---	---	---	---	1,250	---	50

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
K-1	5/28/85	2	330	<10	<10	<10	<10	2,640	<10	70
K-1	8/7/85	1	340	<10	<10	<10	<10	2,760	<10	70
K-1	11/4/85	6	480	<10	<10	---	<10	2,790	<10	60
K-1	2/19/86	4	430	<10	<10	---	<10	2,550	<10	60
K-1	5/12/86	4	380	---	---	---	---	2,310	---	50
K-2	5/28/85	<1	<10	<10	<10	<10	<10	<10	<10	<10
K-2	8/7/85	<1	90	<10	<10	<10	<10	20	<10	20
K-2	11/4/85	<1	160	<10	<10	---	<10	30	<10	10
K-2	2/19/86	<1	80	<10	<10	---	<10	<10	<10	<10
K-2	5/12/86	<1	130	---	---	---	---	<10	---	<10
L-1	5/22/85	<1	250	<10	<10	<10	<10	2,530	<10	30
L-1	8/6/85A	<1	330	<10	<10	<10	<10	2,440	<10	30
L-1	8/6/85B	<1	320	<10	<10	<10	<10	2,430	<10	30
L-1	11/20/85	<1	250	<10	<10	---	<10	2,110	<10	30
L-1	2/10/86	<1	250	<10	<10	---	<10	2,360	<10	20
L-1	5/20/86	1	130	---	---	---	---	2,740	---	80
L-2	5/22/85A	<1	170	<10	<10	<10	<10	1,840	<10	150
L-2	5/22/85B	1	260	<10	<10	<10	<10	1,860	20	140
L-2	8/6/85	<1	250	<10	<10	<10	<10	1,950	<10	130
L-2	11/18/85	2	350	<10	<10	---	<10	1,890	<10	130
L-2	2/10/86	1	310	<10	<10	---	<10	1,900	<10	140
L-2	5/20/86	<1	170	---	---	---	---	1,890	---	160
MN-1	5/21/85	1	350	<10	<10	<10	<10	4,240	<10	60
MN-1	8/1/85	<1	370	<10	<10	<10	<10	5,280	<10	70
MN-1	11/7/85	<1	630	<10	<10	---	<10	5,760	<10	70
MN-1	2/10/86A	<1	380	<10	<10	---	<10	4,300	<10	50
MN-1	2/10/86B	<1	410	<10	<10	---	<10	4,290	<10	40
MN-1	5/13/86	<1	310	---	---	---	---	4,150	---	50
O-2	6/3/85	---	70	<10	<10	<10	<10	<10	20	<10
O-2	8/8/85	1	<10	<10	<10	<10	<10	<10	<10	<10
O-2	2/20/86	1	100	<10	<10	---	<10	<10	<10	190
O-2	5/20/86	<1	120	---	---	---	---	20	---	30

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
P-1	5/22/85	<1	420	<10	<10	<10	<10	1,960	<10	60
P-1	8/1/85	<1	620	<10	<10	<10	<10	3,180	<10	60
P-1	11/7/85	2	1,070	<10	<10	---	<10	4,230	<10	60
P-1	2/11/86	<1	850	<10	<10	---	<10	3,150	<10	40
P-1	5/15/86A	<1	870	---	---	---	---	4,010	---	50
P-1	5/15/86B	<1	840	---	---	---	---	3,850	---	50
R-1	5/20/85	5	180	<10	<10	<10	<10	4,920	<10	80
R-1	8/7/85A	<1	230	<10	<10	<10	<10	5,640	<10	90
R-1	8/7/85B	<1	230	<10	<10	<10	<10	5,730	<10	90
R-1	11/4/85A	2	260	<10	<10	---	<10	6,240	<10	90
R-1	11/4/85B	2	300	<10	<10	---	<10	6,210	<10	90
R-1	2/12/86	2	190	<10	<10	---	<10	5,320	<10	90
R-1	5/12/86	3	140	---	---	---	---	6,620	---	90
T-1	5/22/85	1	120	<10	<10	<10	<10	1,030	<10	70
T-1	8/6/85	<1	250	<10	<10	<10	<10	1,050	<10	70
T-1	11/6/85A	1	260	<10	<10	---	<10	1,020	<10	60
T-1	11/6/85B	3	310	<10	<10	---	<10	1,040	<10	70
T-1	2/11/86	2	210	<10	<10	---	<10	840	<10	60
T-1	5/15/86	1	250	---	---	---	---	1,080	---	50
T-2	5/23/85	3	290	<10	<10	<10	<10	2,340	<10	50
T-2	8/6/85	<1	330	<10	<10	<10	<10	2,460	<10	50
T-2	11/6/85	3	530	<10	<10	---	<10	2,550	<10	40
T-2	2/11/86	3	410	<10	<10	---	<10	2,440	<10	30
T-2	5/15/86	3	310	---	---	---	---	2,490	---	30

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
A-1	5/30/85A	0.3	<10	---	<10	<0.0001
A-1	5/30/85B	<.2	<10	---	<10	<.0001
A-1	8/14/85	<.2	<10	<1	<10	.0024
A-1	11/13/85	<.2	<10	<1	<10	<.0005
A-1	2/20/86	<.2	<10	<1	<10	<.001
A-1	5/12/86	---	---	---	---	---
A-2	5/30/85	<.2	<10	---	<10	<.0001
A-2	8/14/85	<.2	<10	<1	<10	<.0005
A-2	11/18/85	<.2	<10	<1	<10	<.0005
A-2	2/20/86	<.2	<10	<1	<10	<.001
A-2	5/12/86	---	---	---	---	---
B-1	5/28/85	<.2	<10	<1	<10	<.0001
B-1	8/8/85	.3	<10	<1	<10	<.0005
B-1	11/7/85	<.2	<10	<1	<10	.0024
B-1	2/12/86	<.2	<10	<1	<10	<.001
B-1	5/12/86	---	---	---	---	---
C-1	5/28/85	<.2	<10	<1	<10	.0052
C-1	8/8/85	.3	<10	<1	<10	<.0005
C-1	11/13/85	<.2	<10	<1	<10	<.0005
C-1	2/19/86	<.2	<10	<1	<10	.001
C-1	5/13/86	---	---	---	---	---
C-2	5/28/85	<.2	<10	<1	<10	.0003
C-2	8/7/85	.7	<10	<1	<10	.0006
C-2	11/20/85	<.2	<10	<1	<10	<.0005
C-2	2/19/86A	<.2	<10	<1	<10	<.001
C-2	2/19/86B	<.2	<10	<1	<10	<.001
C-2	5/13/86A	---	---	---	---	---
C-2	5/13/86B	---	---	---	---	---
C-3	5/28/85	<.2	<10	<1	<10	.0006
C-3	8/7/85	.4	<10	<1	<10	<.0005
C-3	11/13/85	<.2	<10	<1	<10	<.0005
C-3	2/19/86	<.2	<10	<1	<10	<.001
C-3	5/13/86	---	---	---	---	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
DD-1	5/22/85	<0.2	<10	<1	20	0.0002
DD-1	8/5/85	<.2	<10	<1	20	.0012
DD-1	11/20/85	<.2	<10	---	<10	<.0005
DD-1	2/10/86	<.2	<10	<1	<10	<.001
DD-1	5/19/86	---	---	---	---	---
DD-2	5/21/85	<.2	<10	<1	<10	<.0001
DD-2	8/5/85	<.2	<10	<1	<10	.0006
DD-2	11/18/85	<.2	<10	<1	<10	<.0005
DD-2	2/10/86	<.2	<10	<1	<10	<.001
DD-2	5/19/86	---	---	---	---	---
EE-1	5/21/85	<.2	<10	<1	20	.0028
EE-1	8/1/85A	<.2	<10	<1	<10	.0010
EE-1	8/1/85B	.3	<10	<1	<10	<.0005
EE-1	11/20/85	<.2	<10	<1	<10	<.0005
EE-1	2/11/86	<.2	<10	<1	<10	<.001
EE-1	5/19/86A	---	---	---	---	---
EE-1	5/19/86B	---	---	---	---	---
EE-2	5/21/85	.2	<10	<1	<10	<.0001
EE-2	8/1/85	.4	<10	<1	<10	.0008
EE-2	11/18/85	<.2	<10	<1	<10	<.0005
EE-2	11/18/85	<.2	<10	<1	<10	<.0005
EE-2	2/11/86	<.2	<10	<1	<10	<.001
EE-2	5/19/86	---	---	---	---	---
EE-3	5/21/85	<.2	<10	<1	<10	<.0001
EE-3	8/5/85A	.6	<10	<1	<10	.0006
EE-3	8/5/85B	<.2	<10	<1	<10	<.0005
EE-3	11/7/85	<.2	<10	<1	<10	<.0005
EE-3	2/11/86	<.2	<10	<1	<10	<.001
EE-3	5/19/86	---	---	---	---	---
F-1	5/29/85	<.2	<10	<1	<10	.0018
F-1	8/13/85A	<.2	<10	<1	<10	<.0005
F-1	8/13/85B	<.2	<10	<1	<10	.0012
F-1	11/4/85	<.2	<10	<1	<10	.0028
F-1	2/18/86	<.2	<10	<1	<10	.001
F-1	5/14/86	---	---	---	---	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
F-2	5/29/85	<0.2	<10	<1	<10	<0.0001
F-2	8/12/85A	.3	<10	<1	<10	.0010
F-2	8/12/85B	.4	<10	<1	<10	.0010
F-2	11/5/85A	<.2	<10	<1	<10	<.0005
F-2	11/5/85B	<.2	<10	<1	<10	<.0005
F-2	2/18/86	<.2	<10	<1	<10	<.001
F-2	5/14/86A	---	---	---	---	---
F-2	5/14/86B	---	---	---	---	---
F-3	5/29/85	<.2	<10	<1	<10	<.0001
F-3	8/13/85A	<.2	<10	<1	<10	<.0005
F-3	8/13/85B	.2	<10	<1	<10	.0042
F-3	11/5/85	<.2	<10	<1	<10	.0058
F-3	2/18/86	<.2	<10	<1	<10	<.001
F-3	5/14/86	---	---	---	---	---
F-4	5/29/85	.2	<10	<1	<10	<.0001
F-4	5/29/85	<.2	<10	---	<10	.0002
F-4	8/13/85	<.2	<10	<1	<10	.0006
F-4	11/5/85	<.2	<10	<1	<10	<.0005
F-4	2/18/86	<.2	<10	<1	<10	.001
F-4	5/14/86	---	---	---	---	---
F-5	5/29/85	.4	<10	---	<10	.0036
F-5	8/13/85	.3	<10	<1	<10	<.0005
F-5	11/5/85	<.2	<10	<1	<10	.0008
F-5	2/18/86	<.2	<10	<1	<10	<.001
F-5	5/14/86	---	---	---	---	---
H-1	5/20/85	.5	<10	<1	10	.0032
H-1	7/30/85	<.2	<10	<1	<10	.0016
H-1	11/25/85	<.2	<10	<1	<10	<.0005
H-1	2/13/86A	<.2	<10	<1	<10	<.001
H-1	2/13/86B	<.2	<10	<1	<10	<.001
H-1	5/21/86	---	---	---	---	---
H-2	5/20/85A	<.2	<10	<1	<10	.0084
H-2	5/20/85B	<.2	<10	<1	<10	.0012
H-2	7/30/85	<.2	<10	<1	<10	.0006
H-2	11/25/85	<.2	<10	<1	<10	<.0005
H-2	2/13/86	<.2	<10	<1	<10	<.001
H-2	5/21/86	---	---	---	---	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
H-3	5/20/85	0.3	<10	<1	<10	0.0018
H-3	7/30/85	<.2	<10	<1	<10	.0016
H-3	11/25/85	<.2	<10	<1	<10	<.0005
H-3	2/13/86A	<.2	<10	<1	<10	<.001
H-3	2/13/86B	<.2	<10	<1	<10	<.001
H-3	5/21/86	---	---	---	---	---
H-4	5/20/85	<.2	<10	<1	<10	.0012
H-4	7/30/85	<.2	<10	<1	<10	.0040
H-4	11/25/85	<.2	<10	<1	<10	<.0005
H-4	2/13/86	<.2	<10	<1	<10	<.001
H-4	5/21/86	---	---	---	---	---
I-1	5/23/85	<.2	<10	<1	<10	.0004
I-1	8/12/85	.3	<10	<1	<10	.0018
I-1	11/6/85	<.2	<10	<1	<10	<.0005
I-1	2/12/86A	<.2	<10	<1	<10	<.001
I-1	2/12/86B	<.2	<10	<1	<10	<.001
I-1	5/22/86	---	---	---	---	---
I-2	6/3/85A	<.2	<10	---	<10	.0002
I-2	6/3/85B	<.2	<10	---	<10	.0006
I-2	5/22/86	---	---	---	---	---
I-3	5/30/85	<.2	<10	---	<10	.0008
I-3	5/22/86A	---	---	---	---	---
I-3	5/22/86B	---	---	---	---	---
I-4	5/23/85A	<.2	<10	<1	<10	<.0001
I-4	5/23/85B	<.2	<10	<1	<10	<.0001
I-4	8/12/85	<.2	<10	<1	<10	.0056
I-4	11/6/85	<.2	<10	<1	<10	<.0005
I-4	2/12/86	<.2	<10	<1	<10	<.001
I-4	5/22/86	---	---	---	---	---
J-2	6/3/85A	<.2	<10	---	<10	<.0001
J-2	6/3/85B	<.2	<10	---	<10	<.0001
J-2	8/14/85	<.2	<10	<1	<10	.0018
J-2	11/5/85	<.2	<10	<1	<10	<.0005
J-2	2/20/86	<.2	<10	<1	<10	.001
J-2	5/15/86	---	---	---	---	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
K-1	5/28/85	<0.2	<10	<1	<10	0.0008
K-1	8/7/85	.4	<10	<1	<10	<.0005
K-1	11/4/85	<.2	<10	<1	<10	.0020
K-1	2/19/86	<.2	<10	<1	<10	<.001
K-1	5/12/86	---	---	---	---	---
K-2	5/28/85	<.2	<10	<1	<10	<.0001
K-2	8/7/85	.5	<10	<1	<10	<.0005
K-2	11/4/85	<.2	<10	<1	<10	.0026
K-2	2/19/86	<.2	<10	<1	<10	<.001
K-2	5/12/86	---	---	---	---	---
L-1	5/22/85	<.2	<10	<1	<10	.0002
L-1	8/6/85A	<.2	<10	<1	<10	<.0005
L-1	8/6/85B	<.2	<10	<1	<10	.0006
L-1	11/20/85	<.2	<10	<1	<10	<.0005
L-1	2/10/86	<.2	<10	<1	<10	.002
L-1	5/20/86	---	---	---	---	---
L-2	5/22/85A	<.2	<10	<1	<10	<.0001
L-2	5/22/85B	<.2	<10	<1	<10	.0028
L-2	8/6/85	<.2	<10	<1	<10	<.0005
L-2	11/18/85	<.2	<10	<1	<10	<.0005
L-2	2/10/86	<.2	<10	<1	<10	<.001
L-2	5/20/86	---	---	---	---	---
MN-1	5/21/85	<.2	<10	<1	<10	<.0001
MN-1	8/1/85	.5	<10	<1	<10	<.0005
MN-1	11/7/85	<.2	<10	<1	<10	.0024
MN-1	2/10/86A	<.2	<10	<1	<10	<.001
MN-1	2/10/86B	<.2	<10	<1	<10	<.001
MN-1	5/13/86	---	---	---	---	---
0-2	6/3/85	<.2	<10	---	<10	<.0001
0-2	8/8/85	.6	<10	<1	<10	<.0005
0-2	2/20/86	<.2	<10	<1	<10	<.001
0-2	5/20/86	---	---	---	---	---

Table 7.--Water-quality analyses of ground water at the Julietta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
P-1	5/22/85	<0.2	<10	<1	<10	0.0001
P-1	8/1/85	.2	<10	<1	<10	.0006
P-1	11/7/85	<.2	<10	<1	<10	<.0005
P-1	2/11/86	<.2	<10	<1	<10	<.001
P-1	5/15/86A	---	---	---	---	---
P-1	5/15/86B	---	---	---	---	---
R-1	5/20/85	<.2	30	<1	<10	<.0001
R-1	8/7/85A	.6	20	<1	<10	<.0005
R-1	8/7/85B	.6	20	<1	<10	<.0005
R-1	11/4/85A	<.2	20	<1	<10	.0010
R-1	11/4/85B	<.2	30	<1	<10	<.0005
R-1	2/12/86	<.2	<10	<1	<10	<.001
R-1	5/12/86	---	---	---	---	---
T-1	5/22/85	<.2	<10	<1	<10	.0014
T-1	8/6/85	<.2	<10	<1	<10	<.0005
T-1	11/6/85A	<.2	<10	<1	<10	.0006
T-1	11/6/85B	<.2	<10	<1	<10	<.0005
T-1	2/11/86	<.2	<10	<1	<10	<.001
T-1	5/15/86	---	---	---	---	---
T-2	5/23/85	<.2	<10	<1	<10	.0016
T-2	8/6/85	<.2	<10	<1	<10	.0010
T-2	11/6/85	<.2	<10	<1	<10	.0020
T-2	2/11/86	<.2	<10	<1	<10	<.001
T-2	5/15/86	---	---	---	---	---

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area

[µS/cm, microsiemens per centimeter at 25 °C; °C, degree Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; ---, no data; A or B, duplicate samples; <, less than]

Well number	Sample date	Specific conductance, field (µS/cm)	pH, field (units)	Water temperature (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, (mg/L as $CaCO_3$)
AA-1	5/16/85	574	7.4	12.2	0.4	12	77	28	3	0.8	254
AA-1	8/21/85	610	7.3	12.0	.1	24	76	24	2	.8	254
AA-1	11/19/85	590	7.4	13.3	.0	2	81	25	3	.7	260
AA-1	2/6/86	596	7.4	12.3	.2	10	83	25	3	.7	254
AA-1	5/6/86	585	7.4	12.0	.2	1	81	23	4	1.1	255
AA-2	5/15/85	659	7.4	12.5	.0	5	84	31	12	2.0	252
AA-2	8/20/85	690	7.2	12.0	.0	6	81	25	16	1.9	252
AA-2	11/14/85	727	7.4	12.0	.3	11	86	27	16	1.9	254
AA-2	2/6/86A	755	7.3	12.1	.2	25	87	26	18	1.8	252
AA-2	2/6/86B	755	7.3	12.1	.2	13	86	26	19	1.8	252
AA-2	5/6/86	719	7.3	12.0	.2	3	86	26	17	2.1	251
AA-3	5/15/85A	1,149	7.0	12.1	.0	5	117	31	71	1.6	298
AA-3	5/15/85B	1,149	7.0	12.1	.0	1	118	31	70	1.7	300
AA-3	8/20/85A	857	7.0	13.0	.1	14	107	27	22	1.9	282
AA-3	8/20/85B	857	7.0	13.0	.1	10	107	26	20	1.9	288
AA-3	11/19/85	1,019	6.9	15.8	.0	15	102	26	61	2.2	286
AA-3	2/5/86	1,109	7.0	12.8	.2	20	116	29	54	1.6	326
AA-3	5/6/86	1,297	7.0	9.7	.1	10	134	31	93	1.8	336
B-1	5/16/85A	1,345	6.9	14.1	.3	43	90	36	39	32	558
B-1	5/16/85B	1,345	6.9	14.1	.3	38	89	36	39	32	566
B-1	8/21/85A	1,310	6.8	13.7	.4	48	85	33	52	24	464
B-1	8/21/85B	1,310	6.8	13.7	.4	57	86	31	52	25	476
B-1	11/19/85A	1,289	6.6	15.9	.0	55	90	28	30	25	542
B-1	11/19/85B	1,289	6.6	15.9	.0	58	89	28	30	25	524
B-1	2/4/86	1,188	7.0	---	.0	5	95	33	43	23	428
B-1	5/5/86	1,145	6.6	12.5	.3	50	130	27	22	18	500
CC-1	5/13/85A	985	7.0	15.7	1.6	17	84	25	22	22	356
CC-1	5/13/85B	985	7.0	15.7	1.6	10	84	30	22	23	358
CC-1	8/20/85	700	7.3	17.7	.2	10	62	18	35	8.5	234
CC-1	11/12/85	816	7.5	16.5	.3	16	74	26	44	2.9	258
CC-1	2/4/86	1,144	7.0	15.0	.4	15	108	33	34	19	456
CC-1	5/7/86	968	6.9	12.9	.3	14	92	31	24	20	378

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Specific conductance, field (µS/cm)	pH, field (units)	Water temperature (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alkalinity, (mg/L as $CaCO_3$)
F-1	5/14/85	618	7.3	14.5	<0.2	3	80	29	3.4	0.9	282
F-1	8/21/85	591	7.4	12.0	.2	2	78	22	3.1	.9	268
F-1	11/12/85	570	7.5	12.0	.3	1	73	23	4.1	.8	268
F-1	2/4/86	565	7.5	13.0	.5	2	75	24	3.8	.6	270
F-1	5/5/86	563	7.4	13.6	.3	3	76	22	4.7	.8	266
FF-2	5/14/85	---	---	---	---	---	---	---	---	---	--
FF-2	8/21/85	---	---	---	---	---	---	---	---	---	--
FF-2	11/12/85	748	7.0	13.8	.6	3	109	27	3.9	1.2	302
FF-2	2/4/86A	739	7.1	12.0	.5	4	108	29	3.2	1.0	300
FF-2	2/4/86B	739	7.1	12.0	.5	3	111	30	3.1	1.0	296
FF-2	5/5/86A	733	7.0	10.9	.2	5	115	27	4.9	1.2	292
FF-2	5/5/86B	733	7.0	10.9	.2	5	113	29	4.6	1.2	294
I-1	5/14/85	517	7.6	16.1	.1	4	48	21	37	2.6	266
I-1	8/19/85	517	7.6	12.2	.2	7	47	21	32	2.4	264
I-1	11/21/85	508	7.5	12.4	.0	3	49	20	29	2.5	260
I-1	2/3/86	525	7.7	12.2	---	46	48	20	28	2.3	270
I-1	5/5/86	516	7.4	12.3	.2	2	55	22	31	2.5	260
I-2	5/14/85	1,094	7.2	16.7	1.2	8	123	38	33	3.7	346
I-2	8/19/85A	1,020	7.4	12.3	.2	17	113	32	38	3.1	322
I-2	8/19/85B	1,020	7.4	12.3	.2	20	111	31	37	3.1	316
I-2	11/19/85	937	7.2	14.2	1.4	20	97	28	37	3.4	300
I-2	2/3/86A	1,013	7.2	12.1	.3	20	116	33	34	2.8	354
I-2	2/3/86B	1,013	7.2	12.1	.3	20	114	32	34	2.8	354
I-2	5/5/86	1,060	6.9	12.1	.2	10	133	38	40	3.6	406
J-1	5/14/85	1,226	7.1	16.5	---	10	130	34	68	9.5	386
J-1	8/20/85A	1,288	7.2	14.2	2.0	46	123	35	74	10	416
J-1	8/20/85B	1,288	7.2	14.2	2.0	40	129	35	74	9.8	416
J-1	11/14/85	1,260	7.0	14.0	.3	33	121	35	68	9.2	408
J-1	2/5/86A	1,172	7.1	14.0	.4	43	124	36	62	9.7	392
J-1	2/5/86B	1,172	7.1	14.0	.4	37	122	33	61	9.6	392
J-1	5/7/86	1,173	7.2	14.1	2.3	18	140	39	56	9.1	434
J-2	5/13/85	1,611	6.8	16.3	1.6	57	162	43	87	8.3	534
J-2	8/19/85A	1,134	6.9	15.5	.2	29	121	33	55	5.6	394
J-2	8/19/85B	1,134	6.9	15.5	.2	28	123	32	54	5.7	390
J-2	11/21/85	945	7.0	14.0	.0	19	99	26	46	6.0	322
J-2	2/3/86	1,426	6.9	12.0	.4	53	156	40	53	7.1	478
J-2	5/7/86	1,464	6.8	13.0	.3	43	190	51	55	8.2	508

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Specific conduct-ance, field (µS/cm)	pH, field (units)	Water tempera-ture (°C)	Dissolved oxygen (mg/L)	Chemical oxygen demand (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Alka-linity, (mg/L as $CaCO_3$)
K-1	5/15/85	731	7.2	15.6	0.0	8	86	30	11	2.8	256
K-1	8/15/85	803	7.3	13.9	.4	24	85	28	30	3.1	244
K-1	11/14/85	765	7.3	14.8	.3	8	80	25	31	3.0	248
K-1	2/6/86	747	7.3	15.0	.1	15	85	25	25	2.6	254
K-1	5/8/86A	749	7.2	15.2	.2	1	93	28	20	2.8	256
K-1	5/8/86B	749	7.2	15.2	.2	2	94	29	20	2.7	250
K-2	5/15/85	886	7.2	16.1	.4	1	90	32	34	3.0	268
K-2	8/15/85	853	7.0	18.7	.3	14	90	27	39	3.2	276
K-2	11/14/85	771	7.2	18.4	.2	13	78	24	31	2.7	240
K-2	2/6/86	820	7.2	13.5	.2	13	85	26	36	2.2	260
K-2	5/8/86A	847	7.1	14.2	.2	<1	94	30	38	2.7	260
K-2	5/8/86B	847	7.1	14.2	.2	2	96	29	38	2.6	260
L-1	5/14/85	453	7.6	14.4	.0	1	40	22	11	2.2	237
L-1	8/15/85	463	7.7	---	---	10	44	24	14	2.6	232
L-1	11/12/85	455	7.7	10.3	.3	3	46	22	13	2.5	238
L-1	2/5/86	455	7.7	10.8	.4	5	47	23	13	2.0	242
L-1	5/6/86	445	7.6	10.9	.2	3	48	25	15	2.2	238
L-2	5/14/85	981	7.0	13.6	.1	5	123	34	23	9.1	358
L-2	8/15/85	810	7.1	---	---	13	105	26	18	11	308
L-2	11/12/85A	884	7.1	10.8	.3	14	113	27	20	9.5	356
L-2	11/12/85B	884	7.1	10.8	.3	14	114	27	20	9.6	354
L-2	2/5/86	976	7.0	11.0	.5	15	127	33	24	9.0	396
L-2	5/6/86	772	7.0	9.9	.2	3	113	29	14	6.7	308
M-1	5/16/85	693	7.2	11.0	1.7	3	94	24	3.4	1.2	276
M-1	8/19/85	781	7.1	8.9	.2	6	98	26	11	1.6	302
M-1	11/14/85	928	7.0	12.0	.4	10	121	27	22	2.1	332
M-1	2/5/86	787	7.1	9.9	.4	7	111	30	7.3	1.1	304
M-1	5/6/86	702	7.0	9.0	.5	<1	114	28	4.6	1.1	294

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nittogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
AA-1	5/16/85	---	38	---	351	0.02	<0.005	<0.01	0.01
AA-1	8/21/85	54	4	0.010	380	.15	<.005	.09	.05
AA-1	11/19/85	50	3	.028	385	.01	<.005	.05	.02
AA-1	2/6/86	55	<1	.028	299	.01	<.005	.08	<.01
AA-1	5/6/86	53	3	.035	360	---	---	.08	---
AA-2	5/15/85	---	37	---	511	.01	<.005	.04	.02
AA-2	8/20/85	64	28	.050	423	<.01	<.005	.04	.06
AA-2	11/14/85	48	46	<.01	475	<.01	<.005	.12	.01
AA-2	2/6/86A	60	53	.071	395	<.01	<.005	<.01	.01
AA-2	2/6/86B	62	52	---	387	<.01	<.005	.06	.01
AA-2	5/6/86	64	41	.061	479	---	---	<.01	---
AA-3	5/15/85A	---	141	---	770	.05	<.005	.04	.02
AA-3	5/15/85B	---	148	---	786	.02	<.005	.02	.03
AA-3	8/20/85A	71	56	<.010	572	<.01	<.005	.06	<.01
AA-3	8/20/85B	72	55	<.010	565	<.01	<.005	.01	<.01
AA-3	11/19/85	49	118	.060	613	<.01	<.005	.01	.03
AA-3	2/5/86	79	109	.044	668	.03	<.005	.13	<.01
AA-3	5/6/86	87	154	.071	813	---	---	.01	---
B-1	5/16/85A	---	71	---	611	.02	<.005	4.49	.15
B-1	5/16/85B	---	71	---	613	.01	<.005	4.77	.15
B-1	8/21/85A	24	86	.72	591	.01	<.005	27.12	.15
B-1	8/21/85B	22	85	---	591	.01	<.005	25.57	.16
B-1	11/19/85A	23	55	.54	606	.01	.010	39.03	.08
B-1	11/19/85B	22	55	---	596	<.01	.010	39.26	.08
B-1	2/4/86	60	74	.47	595	.02	<.005	25.97	.05
B-1	5/5/86	29	40	.11	601	---	---	19.35	---
CC-1	5/13/85A	---	46	---	537	.01	<.005	25.10	.04
CC-1	5/13/85B	---	43	---	544	.01	<.005	26.50	.05
CC-1	8/20/85	22	60	.100	394	.31	<.005	5.58	.08
CC-1	11/12/85	27	89	.150	517	.01	<.005	.83	.08
CC-1	2/4/86	44	66	.190	603	.04	<.005	14.96	.03
CC-1	5/7/86	58	40	.120	507	---	---	17.68	---

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nitrogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
F-1	5/14/85	---	2	---	409	<0.01	<0.005	1.01	0.05
F-1	8/21/85	38	2	0.020	363	<.01	<.005	.84	.10
F-1	11/12/85	30	2	.020	352	<.01	<.005	.84	.05
F-1	2/4/86	38	2	.031	344	<.01	<.005	.86	.03
F-1	5/5/86	36	4	.061	367	---	---	.72	---
FF-2	5/14/85	---	---	---	---	---	---	--	---
FF-2	8/21/85	---	---	---	---	---	---	--	---
FF-2	11/13/85	61	19	<.010	525	.63	<.005	<.01	.01
FF-2	2/4/86A	76	19	.049	477	1.02	<.005	.09	<.01
FF-2	2/4/86B	75	19	---	478	1.08	<.005	.02	<.01
FF-2	5/5/86A	70	18	.062	506	---	---	<.01	---
FF-2	5/5/86B	70	18	---	504	---	---	<.01	---
I-1	5/14/85	---	8	---	327	.01	<.005	.53	.03
I-1	8/19/85	4	18	.070	426	.01	<.005	.38	.04
I-1	11/21/85	1	9	.061	314	<.01	<.005	.31	.01
I-1	2/3/86	<1	8	.062	320	<.01	<.005	.48	.01
I-1	5/5/86	<1	11	.067	329	---	---	.45	---
I-2	5/14/85	---	82	---	466	.01	<.005	2.61	.03
I-2	8/19/85A	73	75	.31	621	.01	<.005	1.41	.04
I-2	8/19/85B	73	76	---	622	.01	<.005	1.38	.04
I-2	11/19/85	61	75	.21	572	<.01	<.005	1.69	.05
I-2	2/3/86A	86	65	.24	619	<.01	<.005	2.32	.01
I-2	2/3/86B	86	66	---	636	<.01	<.005	2.38	<.01
I-2	5/5/86	91	53	.18	676	---	---	2.35	---
J-1	5/14/85	---	104	---	770	<.005	.01	8.83	.06
J-1	8/20/85A	114	109	.98	803	<.01	.01	7.21	.16
J-1	8/20/85B	108	108	---	808	.01	<.005	7.13	.22
J-1	11/14/85	96	101	.83	766	.01	<.005	5.32	.08
J-1	2/5/86A	96	86	.67	710	<.01	.01	5.46	.13
J-1	2/5/86B	97	86	---	703	.02	.01	4.92	.17
J-1	5/7/86	98	88	.52	748	---	---	6.72	---
J-2	5/13/85	---	134	---	1,106	.01	<.005	7.13	.18
J-2	8/19/85A	108	68	.26	713	.04	<.005	3.14	.19
J-2	8/19/85B	---	69	---	710	.10	<.005	3.11	.20
J-2	11/21/85	60	68	.20	582	.05	<.005	1.52	.16
J-2	2/3/86	192	77	.95	938	<.01	<.005	5.08	.17
J-2	5/7/86	198	68	.65	969	---	---	6.57	---

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Bromide, dissolved (mg/L)	Dissolved solids (mg/L)	Nitrate, dissolved as nitrogen (mg/L)	Nitrite, dissolved as nitrogen (mg/L)	Ammonia, dissolved as nitrogen (mg/L)	Phosphorus, dissolved (mg/L)
K-1	5/15/85	---	46	---	524	0.01	<0.005	0.21	0.01
K-1	8/15/85	58	70	0.080	554	.03	<.005	.15	.04
K-1	11/14/85	46	54	.110	470	.01	<.005	.13	.01
K-1	2/6/86	56	50	.065	375	.03	<.005	.19	<.01
K-1	5/8/86A	54	54	.069	481	---	---	.13	---
K-1	5/8/86B	54	52	---	478	---	---	.11	---
K-2	5/15/85	---	74	---	620	2.17	.01	.03	.02
K-2	8/15/85	51	67	.080	530	.66	.01	<.01	.05
K-2	11/14/85	38	65	.130	480	.55	.02	<.01	.01
K-2	2/6/86	38	68	.057	413	.83	.01	<.01	<.01
K-2	5/14/86A	58	75	.069	534	---	---	<.01	---
K-2	5/14/86B	58	74	---	519	---	---	<.01	---
L-1	5/14/85	---	1	---	278	.01	<.005	.47	.03
L-1	8/15/85	4	4	.050	292	.01	<.005	.40	.07
L-1	11/12/85	<1	3	.020	284	.10	<.005	.35	.03
L-1	2/5/86	<1	2	.045	285	.09	<.005	.41	<.01
L-1	5/6/86	<1	<1	.027	279	---	---	.41	---
L-2	5/14/85	---	47	---	652	.08	.010	4.66	.19
L-2	8/15/85	83	33	.110	523	.26	.010	4.89	.03
L-2	11/12/85A	56	48	.350	581	.01	<.005	4.82	.02
L-2	11/12/85B	56	45	---	591	.01	<.005	4.48	.01
L-2	2/20/86	66	42	.160	595	.15	<.005	3.80	<.01
L-2	5/6/86	60	26	.058	533	---	---	1.96	---
M-1	5/16/85	---	24	---	455	3.50	<.005	.04	.01
M-1	8/19/85	84	21	.110	519	.19	<.005	<.01	.02
M-1	11/14/85	64	56	.300	631	.01	<.005	.14	<.01
M-1	2/5/86	66	24	.047	509	2.44	<.005	<.01	<.01
M-1	5/6/86	54	16	.045	476	---	---	<.01	---

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
AA-1	5/16/85	3	270	<10	<10	<10	<10	2,050	<10	60
AA-1	8/21/85	3	60	<10	<10	<10	<10	2,230	20	70
AA-1	11/19/85	3	360	<10	<10	---	<10	2,360	<10	70
AA-1	2/6/86	3	280	<10	<10	---	<10	2,080	<10	50
AA-1	5/6/86	3	50	---	---	---	---	2,150	---	60
AA-2	5/15/85	1	160	<10	<10	<10	<10	790	<10	110
AA-2	8/20/85	<1	<10	<10	<10	<10	<10	840	<10	100
AA-2	11/14/85	<1	190	<10	<10	---	<10	930	<10	100
AA-2	2/6/86A	<1	170	<10	<10	---	<10	1,020	<10	80
AA-2	2/6/86B	<1	150	<10	<10	---	<10	1,000	<10	70
AA-2	5/6/86	<1	300	---	---	---	---	1,040	---	100
AA-3	5/15/85A	<1	140	<10	<10	<10	<10	710	<10	740
AA-3	5/15/85B	<1	150	<10	<10	<10	<10	690	<10	740
AA-3	8/20/85A	2	<10	<10	<10	<10	<10	830	<10	710
AA-3	8/20/85B	1	<10	<10	<10	<10	<10	800	<10	710
AA-3	11/19/85	1	170	<10	<10	---	<10	840	<10	650
AA-3	2/5/86	1	140	<10	<10	---	<10	940	<10	770
AA-3	5/6/86	1	150	---	---	---	---	1,190	---	790
B-1	5/16/85A	49	610	<10	20	10	<10	25,350	<10	130
B-1	5/16/85B	47	620	<10	20	10	<10	23,470	<10	130
B-1	8/21/85A	39	510	<10	<10	<10	<10	14,310	<10	80
B-1	8/21/85B	42	480	<10	<10	<10	<10	15,270	<10	80
B-1	11/19/85A	21	230	<10	<10	---	<10	39,800	<10	110
B-1	11/19/85B	21	230	<10	<10	---	<10	39,620	<10	110
B-1	2/4/86	42	220	<10	<10	<10	<10	13,830	<10	180
B-1	5/5/86	20	310	---	---	---	---	40,230	---	200
CC-1	5/13/85A	12	620	<10	<10	<10	<10	5,840	<10	130
CC-1	5/13/85B	<1	560	<10	20	<10	<10	5,940	<10	120
CC-1	8/20/85	6	190	<10	<10	<10	<10	1,680	<10	100
CC-1	11/12/85	6	390	<10	<10	<10	<10	530	<10	120
CC-1	2/4/86	12	580	<10	<10	<10	<10	4,880	<10	230
CC-1	5/7/86	18	260	---	---	---	---	5,930	---	130

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
F-1	5/14/85	5	400	<10	10	<10	<10	1,990	<10	50
F-1	8/21/85	9	220	<10	<10	<10	<10	2,310	30	40
F-1	11/12/85	7	440	<10	<10	<10	<10	2,180	<10	40
F-1	2/4/86	6	390	<10	<10	<10	<10	2,130	<10	40
F-1	5/5/86	7	170	---	---	---	---	2,100	---	30
FF-2	11/12/85	<1	180	<10	<10	<10	<10	<10	<10	80
FF-2	2/4/86A	<1	160	<10	<10	<10	<10	130	<10	120
FF-2	2/4/86B	<1	130	<10	<10	<10	<10	110	<10	110
FF-2	5/5/86A	<1	230	---	---	---	---	250	---	80
FF-2	5/5/86B	<1	220	---	---	---	---	260	---	90
I-1	5/14/85	<1	310	<10	<10	<10	<10	1,140	<10	30
I-1	8/19/85	2	170	<10	<10	<10	<10	2,040	<10	50
I-1	11/21/85	<1	260	<10	<10	---	<10	1,130	<10	40
I-1	2/3/86	<1	320	<10	<10	---	<10	1,100	<10	30
I-1	5/5/86	<1	200	---	---	---	---	1,600	---	40
I-2	5/14/85	<1	200	<10	<10	<10	<10	2,060	<10	200
I-2	8/19/85A	2	250	<10	<10	<10	<10	1,990	<10	180
I-2	8/19/85B	2	250	<10	<10	<10	<10	2,160	<10	180
I-2	11/19/85	<1	330	<10	<10	---	<10	1,870	<10	210
I-2	2/3/86A	<1	310	<10	<10	---	<10	1,400	<10	240
I-2	2/3/86B	<1	320	<10	<10	---	<10	1,370	<10	230
I-2	5/5/86	<1	30	---	---	---	---	2,140	---	300
J-1	5/14/85	1	430	<10	10	<10	<10	1,640	<10	240
J-1	8/20/85A	2	350	<10	<10	<10	<10	1,000	<10	250
J-1	8/20/85B	2	330	<10	<10	<10	<10	980	<10	250
J-1	11/14/85	<1	720	<10	<10	---	<10	3,770	<10	220
J-1	2/5/86A	<1	510	<10	<10	---	<10	3,060	<10	240
J-1	2/5/86B	<1	480	<10	<10	---	<10	3,110	<10	220
J-1	5/7/86	<1	40	---	---	---	---	1,160	---	250
J-2	5/13/85	28	610	<10	<10	<10	<10	14,020	<10	1,500
J-2	8/19/85A	30	240	<10	<10	<10	<10	12,510	<10	1,000
J-2	8/19/85B	33	210	<10	<10	<10	<10	12,120	<10	1,010
J-2	11/21/85	36	270	<10	<10	---	<10	11,830	<10	910
J-2	2/3/86	51	510	<10	<10	---	<10	22,850	<10	1,500
J-2	5/7/86	59	70	---	---	---	---	21,770	---	1,480

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Arsenic, dissolved (µg/L)	Barium, dissolved (µg/L)	Cadmium, dissolved (µg/L)	Chromium, dissolved (µg/L)	Chromium, hexavalent dissolved (µg/L)	Copper, dissolved (µg/L)	Iron, dissolved (µg/L)	Lead, dissolved (µg/L)	Manganese, dissolved (µg/L)
K-1	5/15/85	<1	160	<10	<10	<10	<10	1,170	<10	170
K-1	8/15/85	<1	60	<10	<10	<10	<10	1,290	<10	150
K-1	11/14/85	<1	190	<10	<10	---	<10	1,170	<10	150
K-1	2/6/86	<1	150	<10	<10	---	<10	1,110	<10	130
K-1	5/8/86A	<1	70	---	---	---	---	1,290	---	140
K-1	5/8/86B	<1	60	---	---	---	---	1,290	---	140
K-2	5/15/85	<1	60	<10	<10	<10	<10	<10	<10	100
K-2	8/15/85	<1	<10	<10	<10	<10	<10	10	<10	130
K-2	11/14/85	<1	160	<10	<10	---	<10	<10	<10	120
K-2	2/6/86	<1	20	<10	<10	---	<10	30	<10	70
K-2	5/8/86A	<1	20	---	---	---	---	<10	---	160
K-2	5/8/86B	<1	20	---	---	---	---	<10	---	160
L-1	5/14/85	11	540	<10	10	<10	<10	1,750	<10	20
L-1	8/15/85	12	510	<10	<10	<10	<10	1,190	<10	30
L-1	11/12/85	11	800	<10	<10	<10	<10	2,790	<10	50
L-1	2/5/86	15	620	<10	<10	---	<10	2,220	<10	20
L-1	5/6/86	13	620	---	---	---	---	1,760	---	20
L-2	5/14/85	4	240	<10	10	<10	10	10	<10	340
L-2	8/15/85	1	120	<10	10	<10	<10	20	<10	30
L-2	11/12/85A	2	270	<10	<10	<10	<10	<10	<10	280
L-2	11/12/85B	<1	300	<10	<10	<10	<10	<10	<10	290
L-2	2/5/86	<1	180	<10	<10	---	<10	20	<10	280
L-2	5/6/86	<1	160	---	---	---	---	10	---	330
M-1	5/16/85	<1	110	<10	<10	<10	<10	10	<10	<10
M-1	8/19/85	1	<10	<10	<10	<10	<10	<10	<10	<10
M-1	11/14/85	<1	110	<10	<10	---	<10	<10	<10	<10
M-1	2/5/86	<1	50	<10	<10	---	<10	<10	<10	<10
M-1	5/6/86	<1	60	---	---	---	---	<10	---	<10

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
AA-1	5/16/85	<0.2	<10	<1	<10	0.0028
AA-1	8/21/85	<.2	<10	<1	<10	<.0005
AA-1	11/19/85	<.2	<10	<1	<10	<.0005
AA-1	2/6/86	<.2	<10	<1	<10	<.001
AA-1	5/6/86	---	---	---	---	---
AA-2	5/15/85	<.2	<10	<1	<10	<.0001
AA-2	8/20/85	<.2	<10	<1	<10	<.0005
AA-2	11/14/85	<.2	<10	<1	<10	<.0005
AA-2	2/6/86A	<.2	20	<1	<10	<.001
AA-2	2/6/86B	<.2	20	<1	<10	<.001
AA-2	5/6/86	---	---	---	---	---
AA-3	5/15/85A	<.2	<10	<1	<10	.0004
AA-3	5/15/85B	<.2	<10	<1	<10	<.0001
AA-3	8/20/85A	<.2	<10	<1	<10	<.0005
AA-3	8/20/85B	<.2	<10	<1	<10	<.0005
AA-3	11/19/85	<.2	<10	<1	<10	<.0005
AA-3	2/5/86A	<.2	<10	<1	<10	<.001
AA-3	5/6/86	---	---	---	---	---
B-1	5/16/85A	<.2	<10	<1	<10	.0006
B-1	5/16/85B	.2	<10	<1	10	.0018
B-1	8/21/85A	<.2	<10	<1	<10	<.0005
B-1	8/21/85B	<.2	20	<1	<10	<.0005
B-1	11/7/85A	<.2	<10	---	<10	<.0005
B-1	11/7/85B	<.2	<10	---	<10	<.0005
B-1	2/4/86	<.2	<10	<1	<10	<.001
B-1	5/5/86	---	---	---	---	---
CC-1	5/13/85A	<.2	<10	<1	20	.0050
CC-1	5/13/85B	<.2	<10	<1	<10	.0027
CC-1	8/20/85	<.2	<10	<1	<10	<.0005
CC-1	11/12/85	<.2	<10	<1	<10	<.0005
CC-1	2/4/86	<.2	<10	<1	<10	<.001
CC-1	5/7/86	---	---	---	---	---

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
F-1	5/14/85	<0.2	<10	<1	<10	<0.0005
F-1	8/21/85	<.2	<10	<1	<10	<.0005
F-1	11/12/85	<.2	<10	<1	<10	<.0005
F-1	2/4/86	<.2	<10	<1	<10	<.001
F-1	5/5/86	---	---	---	---	---
FF-2	5/14/85	---	---	---	---	---
FF-2	8/21/85	---	---	---	---	---
FF-2	11/12/85	<.2	<10	<1	<10	<.0024
FF-2	2/4/86A	<.2	<10	<1	<10	<.001
FF-2	2/4/86B	<.2	<10	<1	<10	<.001
FF-2	5/5/86A	---	---	---	---	---
FF-2	5/5/86B	---	---	---	---	---
I-1	5/14/85	<.2	<10	<1	<10	.0124
I-1	8/19/85	<.2	<10	<1	<10	<.0005
I-1	11/21/85	<.2	<10	<1	<10	<.0005
I-1	2/3/86	<.2	<10	<1	<10	<.001
I-1	5/5/86	---	---	---	---	---
I-2	5/14/85	<.2	<10	<1	20	.0022
I-2	8/19/85A	.6	<10	<1	<10	.0032
I-2	8/19/85B	<.2	<10	<1	<10	<.0005
I-2	11/19/85	<.2	<10	<1	<10	<.0005
I-2	2/3/86A	<.2	<10	<1	<10	<.001
I-2	2/3/86B	<.2	20	<1	<10	<.001
I-2	5/5/86	---	---	---	---	---
J-1	5/14/85	<.2	<10	<1	<10	<.0001
J-1	8/20/85A	<.2	20	<1	<10	.0010
J-1	8/20/85B	<.2	20	<1	<10	.0016
J-1	11/14/85	<.2	<10	<1	<10	.0006
J-1	2/5/86A	<.2	<10	<1	<10	<.001
J-1	2/5/86B	<.2	<10	<1	<10	<.001
J-1	5/7/86	---	---	---	---	---
J-2	5/13/85	<.2	<10	<1	<10	.0068
J-2	8/19/85A	1.3	<10	<1	<10	.0022
J-2	8/19/85B	.6	<10	<1	<10	.0018
J-2	11/21/85	<.2	<10	<1	<10	<.0005
J-2	2/3/86	<.2	20	<1	<10	<.001
J-2	5/7/86	---	---	---	---	---

Table 18.--Water-quality analyses of ground water at the Tibbs-Banta study area--Continued

Well number	Sample date	Mercury, dissolved (µg/L)	Nickel, dissolved (µg/L)	Selenium, dissolved (µg/L)	Zinc, dissolved (µg/L)	Phenols, total (µg/L)
K-1	5/15/85	<0.2	<10	<1	<10	0.0008
K-1	8/15/85	<.2	<10	<1	<10	.0024
K-1	11/14/85	<.2	<10	<1	<10	<.0005
K-1	2/6/86	<.2	<10	<1	<10	<.001
K-1	5/8/86A	---	---	---	---	---
K-1	5/8/86B	---	---	---	---	---
K-2	5/15/85	<.2	<10	<1	<10	<.0006
K-2	8/15/85	<.2	<10	<1	<10	.0016
K-2	11/14/85	<.2	<10	<1	<10	<.0005
K-2	2/6/86	<.2	<10	<1	<10	<.001
K-2	5/8/86A	---	---	---	---	---
K-2	5/8/86B	---	---	---	---	---
L-1	5/14/85	<.2	<10	<1	<10	<.0001
L-1	8/15/85	<.2	<10	<1	<10	.0024
L-1	11/12/85	<.2	<10	<1	<10	<.0005
L-1	2/5/86	<.2	<10	<1	<10	<.001
L-1	5/6/86	---	---	---	---	---
L-2	5/14/85	<.2	<10	<1	<10	.0016
L-2	8/15/85	<.2	<10	<1	<10	<.0005
L-2	11/12/85A	<.2	<10	<1	<10	<.0005
L-2	11/12/85B	<.2	<10	<1	<10	<.0005
L-2	2/5/86	<.2	<10	<1	<10	<.001
L-2	5/6/86	---	---	---	---	---
M-1	5/16/85	<.2	<10	<1	<10	.0004
M-1	8/19/85	<.2	<10	<1	<10	.0018
M-1	11/14/85	<.2	<10	<1	<10	<.0005
M-1	2/5/86	<.2	<10	<1	<10	<.001
M-1	5/6/86	---	---	---	---	---