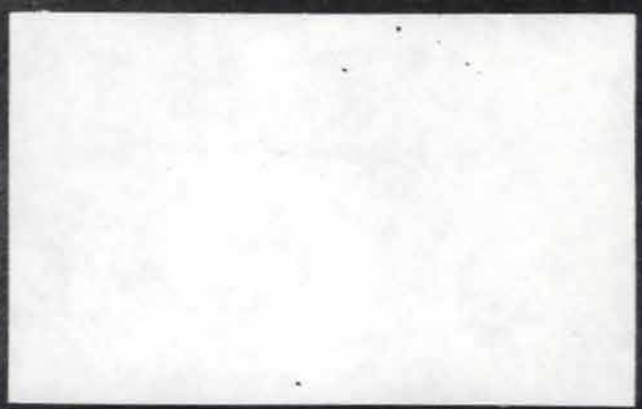
EBASCO

REM III PROGRAM

REMEDIAL PLANNING ACTIVITIES AT SELECTED UNCONTROLLED HAZARDOUS SUBSTANCE DISPOSAL SITES



EPA CONTRACT 68-01-7250

EBASCO SERVICES INCORPORATED

SDMS Document
123646

VIN 002 0557

EPA WORK ASSIGNMENT NUMBER: 37-2LB8
EPA CONTRACT NUMBER: 68-01-7250
EBASCO SERVICES INCORPORATED

VINELAND CHEMICAL COMPANY SITE
FINAL DRAFT
REMEDIAL INVESTIGATION REPORT
RIVER AREAS
VINELAND, NEW JERSEY

JUNE 1989

NOTICE

THE INFORMATION IN THIS DOCUMENT HAS BEEN FUNDED BY THE UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA) UNDER REM III CONTRACT NO. 68-01-7250 TO EBASCO SERVICES, INC. (EBASCO). THIS DOCUMENT IS A DRAFT AND HAS NOT BEEN FORMALLY RELEASED BY EITHER EBASCO OR THE USEPA. AS A DRAFT, THIS DOCUMENT SHOULD NOT BE CITED OR QUOTED, AND IS BEING CIRCULATED ONLY FOR COMMENT.

VIN 002 0558

EPA WORK ASSIGNMENT NUMBER: 37-2LB8
EPA CONTRACT NUMBER: 68-01-7250
EBASCO SERVICES INCORPORATED

VINELAND CHEMICAL COMPANY SITE
FINAL DRAFT
REMEDIAL INVESTIGATION REPORT
RIVER AREAS
VINELAND, NEW JERSEY

JUNE 1989

Prepared by:

Raymond Nowak
Site Manager
Ebasco Services Incorporated

Approved by:

Dev R. Sachdev, PhD, PE
Regional Manager-Region II
Ebasco Services Incorporated

6241b

VIN 002 0561

TABLE OF CONTENTS

VIN 002 0562

TABLE OF CONTENTS

Section	Title	Page
LIST OF TABLES		vi
LIST OF FIGURES		x
LIST OF ACRONYMS		xii
EXECUTIVE SUMMARY		E-1
1.0	INTRODUCTION	1-1
1.1	REMEDIAL INVESTIGATION OBJECTIVES	1-1
1.2	BACKGROUND INFORMATION	1-5
1.2.1	Site Description	1-5
1.2.2	Site History	1-14
1.2.3	Permit Actions	1-16
1.2.4	Previous Investigations	1-16
1.2.5	Community Concerns	1-20
1.3	REMEDIAL INVESTIGATION STUDY	1-21
1.3.1	Initial Activities	1-21
1.3.2	Field Investigation	1-21
1.3.3	Bench-Scale Treatability Studies	1-23
1.3.4	Risk Assessment	1-24
1.4	OVERVIEW OF THE REMEDIAL INVESTIGATION REPORT	1-24
2.0	STUDY AREA INVESTIGATIONS	2-1
2.1	SITE FEATURES INVESTIGATION	2-1
2.1.1	Demography	2-1
2.1.2	Land Use	2-2
2.1.3	Natural Resources	2-4
2.1.4	Climatology	2-5
2.1.5	Cultural Resources	2-7
2.2	SURFACE WATER INVESTIGATION	2-7
2.2.1	Phase I	2-10
2.2.1.1	Sampling Locations	2-10
2.2.1.2	Sampling Methods	2-10
2.2.2	Phase II	2-13
2.2.2.1	Sampling Locations	2-13
2.2.2.2	Sampling Methods	2-13

VIN 002 0563

TABLE OF CONTENTS (Cont'd)

Section	Title	Page
2.3	SEDIMENT INVESTIGATION	2-19
2.3.1	Phase I	2-19
2.3.1.1	Sampling Locations	2-19
2.3.1.2	Sampling Methods	2-19
2.3.2	Phase II	2-20
2.3.2.1	Sampling Locations	2-20
2.3.2.2	Sampling Methods	2-20
2.3.3	Supplemental Sampling	2-26
2.4	BIOTA INVESTIGATION	2-26
2.4.1	Phase II	2-26
2.4.1.1	Sampling Locations	2-26
2.4.1.2	Sampling Methods	2-31
2.5	QUALITY ASSURANCE AND QUALITY CONTROL	2-31
2.5.1	Decontamination Procedures	2-31
2.5.2	QA/QC Samples	2-32
2.5.3	Field Audits	2-32
2.5.4	Data Validation	2-36
3.0	PHYSICAL CHARACTERISTICS OF STUDY AREA	3-1
3.1	SURFACE WATER	3-1
3.1.1	Surface Water Flow	3-1
3.1.2	Water Balance	3-4
3.1.3	Vineland and Millville Water Use	3-11
3.1.4	Flood Plain Delineation	3-12
3.2	SEDIMENT	3-16
3.2.1	Grain Size Distribution	3-16
3.3	BIOTA	3-17
3.3.1	Species Investigated	3-17
4.0	NATURE AND EXTENT OF CONTAMINATION	4-1
4.1	SURFACE WATER	4-1
4.2	SEDIMENT	4-13

VIN 002 0564

TABLE OF CONTENTS (Cont'd)

Section	Title	Page
	4.2.1 Supplemental Sediment Sampling	4-22
	4.3 BIOTA	4-24
	4.4 BLANKS	4-24
5.0	FATE AND TRANSPORT OF ARSENIC	5-1
	5.1 GENERAL GEOCHEMISTRY OF ARSENIC	5-1
	5.1.1 Aqueous Speciation	5-1
	5.1.2 Precipitation/Dissolution	5-6
	5.1.3 Adsorption/Desorption	5-6
	5.1.4 Partitioning to Sediments	5-8
	5.1.5 Gas Transfer From Soils	5-8
	5.2 ARSENIC IN THE MAURICE RIVER WATERSHED	5-8
	5.2.1 Arsenic Input to the Watershed	5-9
	5.2.2 Arsenic Transport in the Maurice River Watershed	5-19
	5.2.3 Arsenic Chemistry in the Maurice River Watershed	5-26
	5.2.4 Arsenic Inventory in the Maurice River Watershed Sediments	5-38
	5.2.5 Future Arsenic Transport	5-48
6.0	BASELINE RISK ASSESSMENT	6-1
	6.1 PUBLIC HEALTH EVALUATION - BLACKWATER BRANCH AND MAURICE RIVER NORTH OF UNION LAKE	6-1
	6.1.1 Risk Assessment Methodology	6-1
	6.1.1.1 Chemical Contaminants of Concern	6-1
	6.1.1.2 Exposure Assessment	6-9
	6.1.1.3 Toxicity Assessment	6-11
	6.1.1.4 Exposure Model and Risk Assessment Results	6-17
	6.1.1.5 Summary of Risk Estimates	6-29
	6.1.1.6 Uncertainty in Risk Estimates	6-35
	6.2 PUBLIC HEALTH EVALUATION - MAURICE RIVER SOUTH OF UNION LAKE	6-39
	6.2.1 Risk Assessment Methodology	6-39
	6.2.1.1 Chemical Contaminants of Concern	6-40
	6.2.1.2 Toxicity Assessment	6-40

VIN 002 0565

TABLE OF CONTENTS (Cont'd)

Section	Title	Page
	6.2.1.3 Exposure Assessment	6-40
	6.2.2 Risk Characterization	6-46
6.3	ENVIRONMENTAL ASSESSMENT	6-46
	6.3.1 Blackwater Branch and Maurice River North of Union Lake	6-46
	6.3.1.1 Mammals	6-49
	6.3.1.2 Birds	6-49
	6.3.1.3 Terrestrial Plants and Crops	6-50
	6.3.1.4 Environmental Response Branch Biological Assessment	6-50
	6.3.2 Maurice River South of Union Lake	6-51
	6.3.2.1 Aquatic Life	6-51
	6.3.2.2 Mammals	6-51
	6.3.2.3 Birds	6-52
7.0	BENCH-SCALE TREATABILITY TESTS	7-1
7.1	SEDIMENT FIXATION TEST	7-1
	7.1.1 Objectives	7-1
	7.1.2 Description of Test	7-2
	7.1.3 Results	7-4
	7.1.4 Conclusions	7-5
7.2	ARSENIC EXTRACTION FROM SEDIMENT TEST	7-5
	7.2.1 Objectives	7-5
	7.2.2 Description of Test	7-6
	7.2.3 Results	7-7
	7.2.4 Conclusions	7-7
8.0	SUMMARY AND CONCLUSIONS	8-1
8.1	SUMMARY	8-1
	8.1.1 Nature and Extent of Contamination	8-1
	8.1.2 Contaminant Fate and Transport	8-2
	8.1.3 Risk Assessment	8-3
8.2	CONCLUSIONS	8-5
	8.2.1 Data Limitations	8-5
	8.2.2 Recommendations for Future Work	8-6
	8.2.3 Recommended Remedial Action Objectives	8-7
REFERENCES		8-10

VIN 002 0566

APPENDICES

Appendix A	Chemical Results for Phase I Sampling
Appendix B	Chemical Results for Phase II Sampling
Appendix C	Water Balance Calculations
Appendix D	Stream Flow Rate Calculations
Appendix E	Risk Assessment Calculations For Arsenic
Appendix F	Treatability Studies for Chemical Fixation of Arsenic and Solidification of Sediment
Appendix G	Treatability Studies for Extraction of Arsenic From Soil Collected From the Vineland Chemical Site
Appendix H	Toxicity Profiles
Appendix I	Surface Water and Sediment Station Cross-Sections and Arsenic Results
Appendix J	Vineland Sediment Analyses: Grain Size and Chemical Parameters
Appendix K	City of Millville and City of Vineland Public Water Supply Analyses
Appendix L	Environmental Response Branch Biological Assessment of the Blackwater Branch and the Upper Maurice River
Appendix M	NJDEP 1979 Sampling Effort

VIN 002 0567

LIST OF TABLES

Table Number	Title	Page
1-1	RI and FS Reports Prepared for the Vineland Chemical Company Site	1-2
1-2	Chemicals Used, Manufactured or Stored at Vineland Chemical Plant	1-6
2-1	Threatened and Endangered Species Maurice River Basin	2-6
2-2	Historic Structures and Sites	2-8
2-3	Phase I Sample Summary for Samples Collected From Blackwater Branch, Maurice River, Little Robin Branch, Parvin Branch and Mill Creek	2-12
2-4	Water Sample Analytical Summary for the Blackwater Branch: Phase II	2-14
2-5	Water Sample Analytical Summary for the Upper Maurice River: Phase II	2-17
2-6	Water Sample Analytical Summary for the Lower Maurice River: Phase II	2-18
2-7	Sediment Sample Analytical Summary for the Blackwater Branch: Phase II	2-21
2-8	Sediment Sample Analytical Summary for the Upper Maurice River: Phase II	2-22
2-9	Sediment Sample Analytical Summary for the Lower Maurice River: Phase II	2-25
2-10	Biota Sample Analytical Summary for the Upper Maurice River: Phase II	2-29
2-11	Biota Sample Analytical Summary for the Lower Maurice River: Phase II	2-30
2-12	Duplicate Sample and Analysis Summary for the Blackwater Branch: Phase II	2-33
2-13	Duplicate Sample and Analysis Summary for the Upper Maurice River: Phase II	2-34

VIN 002 0568

LIST OF TABLES (Cont'd)

Table Number	Title	Page
2-14	Duplicate Sample and Analysis Summary for the Lower Maurice River: Phase II	2-35
3-1	Stream Flow Rate Calculations	3-2
3-2	Summary of Estimated Water Balance-Maurice River Watershed	3-5
3-3	Groundwater Discharge From Upper Sand to the Blackwater Branch	3-8
3-4	100-Year Flood Plain Boundary Maurice River	3-15
4-1	Surface Water Arsenic Analyses Phase I and II	4-2
4-2	Summary of Chemicals Detected Surface Water: Phase II	4-9
4-3	Surface Water Quality Field Tests: Phase I	4-10
4-4	Surface Water Quality Field Tests: Phase II	4-11
4-5	Mean Surface Sediment Arsenic Concentrations: Phases I and II	4-14
4-6	Summary of Chemicals Detected in Surface Sediments 0-1 Ft. Samples: Phase II	4-20
4-7	Summary of Chemicals Detected in Field Blank Samples: Phase II	4-27
4-8	Summary of Chemicals Detected in Trip Blank Samples: Phase II	4-28
5-1	Solubility Products for Arsenates	5-3
5-2a	Ebasco Arsenic Concentrations and Loadings Downstream from the Blackwater Branch	5-11
5-2b	Ebasco Arsenic Concentrations and Loadings in the Other Tributaries to the Upper Maurice River	5-12
5-3	USGS Dissolved Arsenic Concentrations and Loadings in the Maurice River at Norma, NJ[a]	5-16

VIN 002 0569

LIST OF TABLES (Cont'd)

Table Number	Title	Page
5-4	Total, Dissolved and Suspended Arsenic Concentrations in the Contaminated Region of the Maurice River	5-20
5-5	KD of Lake Sediments Under Anaerobic and Aerobic Laboratory Conditions	5-29
5-6	Arsenic Speciation in Union Lake Sediments	5-32
5-7	Speciation of Water Samples from the Blackwater Branch at Mill Road[a]	5-34
5-8	Total Nonextractable Arsenic in the Maurice River Watershed[b]	5-35
5-9	Mean Arsenic Concentrations in the Sediment Cores from Union Lake	5-43
5-10	Arsenic Concentrations in Lake Sediments Greater Than 10 Feet Below the Surface of Union Lake	5-44
5-11	Arsenic Inventories in the Maurice River Watershed	5-46
6-1	Summary of Occurrence of Contaminants in The Blackwater Branch	6-3
6-2	Summary of Occurrence of Contaminants in The Upper Maurice River	6-4
6-3	Background Concentrations in Soil and Surface Water for Metals Found in The Maurice River	6-5
6-4	Water Quality Regulatory Criteria for Contaminants in Blackwater Branch and Upper Maurice River	6-7
6-5	Critical Toxicity Values for Contaminants in Blackwater Branch and Upper Maurice River	6-14
6-6	Summary of Equations Used to Calculate Chronic Daily Intakes For River Areas	6-19
6-7	Parameters for Recreational Exposures to Blackwater Branch and Maurice River Water and Sediment	6-21

VIN 002 0570

LIST OF TABLES (Cont'd)

Table Number	Title	Page
6-8	Arsenic Levels in Foods[a]	6-27
6-9	Summary of Cancer Risks From Exposure Pathways in Blackwater Branch	6-30
6-10	Summary of Cancer Risks From Exposure Pathways in Upper Maurice River	6-31
6-11	Summary of Cancer Risks from Major Exposure Pathways at Almond Road Beach	6-32
6-12	Summary of Worst Case Chronic Hazard Indices from Exposure to Noncarcinogens in Blackwater Branch	6-33
6-13	Summary of Worst Case Chronic Hazard Indices from Exposure to Noncarcinogens in Upper Maurice River	6-34
6-14	Acceptable Arsenic Concentrations in Sediments for Sediment Exposure Pathways in Blackwater Branch and Upper Maurice River	6-41
6-15	Water Quality Regulatory Criteria for Contaminants in Lower Maurice River	6-42
6-16	Critical Toxicity Values for Contaminants in Lower Maurice River	6-43
7-1	Summary of Treatability Tests for the Chemical Fixation and Solidification of Arsenic on Sediment	7-3
7-2	Summary of Treatability Tests for the Extraction of Arsenic from Sediment	7-8
8-1	Calculated Risk from Sediments at Various Arsenic Concentrations	8-8

VIN 002 0571

LIST OF FIGURES

Figure Number	Title	Page
1-1	River Study Area Regional Location Map	1-3
1-2	Vineland Chemical Company One Mile Radius	1-4
1-3	Vineland Chemical Company Site Plan	1-8
1-4	Blackwater Branch	1-10
1-5	Maurice River North of Union Lake	1-11
1-6	Maurice River South of Union Lake	1-12
2-1	Surface Water and Sediment Stations North of Union Lake: Phase I	2-11
2-2	Surface Water and Sediment Stations North of Union Lake: Phase II	2-15
2-3	Surface Water and Sediment Stations South of Union Lake: Phase II	2-16
2-4	Biota Sampling Investigations North of Union Lake: Phase II	2-27
2-5	Biota Sampling Locations South of Union Lake: Phase II	2-28
3-1	Blackwater Branch and Upper Maurice River Flow Rate Values	3-3
3-2	Water Table Elevations	3-9
3-3	Generalized Water Levels in the Cohansey-Kirkwood Aquifer	3-10
3-4	Existing Water System, City of Vineland	3-13
3-5	Existing Water System, Millville, NJ	3-14
4-1	Surface Water Arsenic Results Blackwater Branch: Phase II	4-5
4-2	Surface Water Arsenic Results North of Union Lake: Phase II	4-6
4-3	Surface Water Arsenic Results South of Union Lake: Phase II	4-7

VIN 002 0572

LIST OF FIGURES (Cont'd)

Figure Number	Title	Page
4-4	Mean Surface Sediment Arsenic Results Blackwater Branch: Phase II	4-16
4-5	Mean Surface Sediment Arsenic Results North of Union Lake: Phase II	4-17
4-6	Mean Surface Sediment Arsenic Results South of Union Lake: Phase II	4-18
4-7	Area of Blackwater Branch Flood Plain to be Remediated and Sediment Arsenic Analysis	4-23
4-8	Biota Arsenic Results North of Union Lake: Phase II	4-25
4-9	Biota Arsenic Results South of Union Lake: Phase II	4-26
5-1	Bacterial Reduction of Arsenate	5-4
5-2	The Biological Cycle for Arsenic	5-5
5-3	1987 Arsenic Concentration and Loading in the Blackwater Branch and Upper Maurice River to the Union Lake Dam	5-10
5-4	Arsenic Concentration at Mill Road: 1965-1984	5-14
5-5	USGS Station at Norma, NJ (ER-7) Dissolved Arsenic Loading	5-18
5-6	Observed Arsenic Concentrations in the Blackwater Branch at Mill Road and the Maurice River at Norma (ppm)	5-23
5-7	Eh-pH Diagram for Arsenic	5-28
5-8	Relationship Between Nonextractable Arsenic and Organic Carbon Content of Maurice River Basin Sediments	5-36
5-9	Contaminated Sediment Arsenic Concentration Vs Sample Location	5-40
5-10	Arsenic Concentration in Stream Sediments Vs Sediment Total Organic Carbon Content	5-41

VIN 002 0573

LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AIC	Acceptable Chronic Intake
ARARs	Applicable or Relevant and Appropriate Requirements
ASC	Acceptable Soil Concentration
ASTM	American Society of Testing and Materials
AWQC	Ambient Water Quality Criteria
BEHP	bis(2-ethylhexyl)phthalate
BNA	Base-Neutral/Acid Extractables
°C	Degrees Centigrade
CDI	Chronic Daily Intake
CDL	Contract Detection Limit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CLP	Contract Laboratory Program
CRAVE	Carcinogen Risk Assessment Verification Endeavor
DMAA	Dimethyl Arsenic Acid
DQO	Data Quality Objectives
ECRA	New Jersey Environmental Cleanup Responsibility Act
EDTA	Ethylenediaminetetra-acetate
EM	Electro Magnetic Conductivity Survey
EP	Extraction Procedure
EPIC	Environmental Photographic Information Center
ER	Ebasco River Sampling Station
EW	Ebasco Well
FS	Feasibility Study
GPD	Gallons Per Day
GPM	Gallons Per Minute
HEA	Health Effects Assessment
HSL	Hazardous Substances List
IDL	Instrument Detection Limit
IRIS	Integrated Risk Information System
Kd	Partitioning Coefficient
LL	Lined Lagoon
MCLGs	Maximum Contaminant Level Goals
MCLs	Maximum Contaminant Levels
MEP	Multiple Extraction Procedure
MG/KG	Milligrams Per Kilogram
MG/L	Milligrams Per Liter
MMAA	Monomethyl Arsenic Acid
MSL	Mean Sea Level
MW	Monitoring Well
NCDC	National Climatic Data Center
NCP	National Contingency Plan
NJAC	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJPDES	New Jersey Pollution Discharge Elimination System
NOAA	National Oceanic and Atmospheric Administration
ODW	Office of Drinking Water
OHEA	Office of Health and Environmental Affairs
OSHA	Occupational Safety and Health Administration
PCB	Polychlorinated Biphenyls
PMSA	Primary Metropolitan Statistical Area

VIN 002 0574

PPB	Parts Per Billion
PPM	Parts Per Million
PSI	Pounds Per Square Inch
PVC	Poly Vinyl Chloride
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RMCL	Recommended Maximum Contaminant Level
RfD	Reference Dose
SAS	Special Analytical Services
SNARL	Suggested-No-Adverse Response Level
SPDES	State Pollution Discharge Elimination System
SU	Standard Units
TCE	Trichloroethylene
TCL	Target Compound List
TOC	Top of Casing
TOL	Total Organic Carbon
UCS	Unconfined Compressive Strength
UG/L	Micrograms Per Liter
UL	Unlined Lagoon
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UV	Ultraviolet
VES	Vertical Electrical Soundings
ViChem	Vineland Chemical Company

VIN 002 0575

EXECUTIVE SUMMARY

The River Areas Remedial Investigation (RI) is one of three RIs being performed for the Vineland Chemical Company (ViChem) work assignment. The RIs include:

- The ViChem plant site proper;
- The River Areas, consisting of the Blackwater Branch upstream of the plant to its confluence with the Maurice River; the Maurice River from the Blackwater Branch to Union Lake, an approximate river distance of seven miles downstream; and the Maurice River below Union Lake to the Delaware Bay, an approximate river distance of 25 miles; and
- Union Lake, an 870-acre impoundment on the Maurice River.

The purpose of the River Areas RI was twofold. In the Blackwater Branch and the upper Maurice River above Union Lake, the purpose was to collect sufficient data to perform a semi-quantitative risk assessment and a feasibility study. For the lower Maurice River, below Union Lake, the purpose was to perform confirmational sampling at stations that had elevated arsenic concentrations in 1979, to perform a qualitative risk assessment, and to outline additional study needs if warranted.

The ViChem site is ranked among the top 10 hazardous waste sites in New Jersey, and is ranked number 42 on the National Priorities List. ViChem has manufactured organic arsenical herbicides and fungicides at this plant since 1949.

Detailed information on past use, storage, and disposal of all process materials at the plant is not available. It is known that waste salts containing arsenic were piled outdoors, and that precipitation contacting the piles flushed arsenic into the groundwater. Also, the plant previously discharged untreated process water into lagoons, and the water was allowed to percolate into the groundwater. The contaminated groundwater subsequently discharged into the Blackwater Branch and was distributed downstream in the Maurice River drainage system.

Previous investigations have shown elevated arsenic concentrations in surface waters and sediments extending approximately 26 river miles downstream of the plant to the Delaware Bay. The Maurice River was found to have the highest concentration of arsenic in sediments of any river in New Jersey.

VIN 002 0576

The field work for this RI was conducted in two phases. Phase I took place in June and July of 1986. Surface water and sediment samples were obtained from the Blackwater Branch and the upper Maurice River. Phase II took place in June, July, and August 1987. Surface water and sediment samples were obtained from the Blackwater Branch, the upper Maurice River, and the lower Maurice River below Union Lake to the Delaware Bay. Biota samples were also obtained from the upper and lower Maurice River.

In this RI extensive use was made of previous investigations and data collected by others. Previous studies prepared for the Vineland Chemical Company and for the New Jersey Department of Environmental Protection were reviewed and incorporated. Data collected by the USGS and its gaging station on the Maurice River at Norma, New Jersey (Ebasco's Station ER-7 in this report) were utilized. Groundwater data provided by the cities of Vineland and Millville were also incorporated.

Two bench-scale treatability tests, chemical fixation and extraction, were performed on sediments. The fixation test was performed to determine if arsenic in the sediments could be chemically stabilized or physically bound to the sediment such that leachable arsenic concentrations were below 5 mg/l. The extraction test was performed to determine if arsenic could be removed from the sediments to a concentration of 20 mg/kg, the background arsenic concentration of soils in New Jersey and the ECRA cleanup guidance level for arsenic in New Jersey soils.

The target cleanup standard for arsenic in sediments, 20 mg/kg, was chosen at the inception of the study. No regulatory guidance other than that mentioned above was available to determine sediment cleanup levels. As part of this RI, risk-based sediment cleanup levels were calculated both for submerged and exposed sediments.

The major findings of the River Areas RI were as follows:

- The main, and probably sole, source of arsenic into the Maurice River watershed above Union Lake is the groundwater discharge coming off the ViChem plant site. An estimated six metric tons of arsenic per year were entering the Blackwater Branch based on the 1987 data obtained by Ebasco. The arsenic flux was probably much higher previously. An estimated 500 metric tons of arsenic have been discharged from the plant to the river over time.

VIN 002 0577

- The rivers above Union Lake basically behave as a conduit, transferring the arsenic from the plant site downstream into Union Lake. Therefore if the contaminated groundwater discharge off the plant site is eliminated, the arsenic levels in the river above Union Lake should drop relatively quickly.

- Union Lake's sediment has been a sink for the arsenic discharged off the site. An estimated 140 metric tons of arsenic are presently bound to the lake sediments. This amount represents approximately 30 percent of the arsenic discharged from the plant.

- It is impossible to tell, based on the available data, whether eliminating the groundwater discharge off the site will lower the arsenic concentration in Union Lake's water. On one hand, the arsenic load in the water coming in and going out of Union Lake is relatively constant, suggesting that there is little arsenic desorption from the lake's sediments. On the other hand, based on the lake sediment partition coefficient, the sediments are in equilibrium with the water column. This suggests that arsenic desorption off the sediments controls the lake water arsenic concentration. Additional data are necessary to resolve this discrepancy.

- Below Union Lake, the arsenic concentration in the water drops steadily, moving downstream until the salt water front in the estuary is reached, at which point it drops relatively rapidly. This is probably due to complex chemical reactions or dilution occurring at this point. The total arsenic concentration in the surface water dropped below 50 ug/l approximately 21 river miles downstream from the site according to the 1987 data. In 1979, the concentration dropped below 50 ug/l approximately 26.5 river miles downstream from the site.

- The risk assessment considered a number of pathways whereby residents and recreational users could be exposed to the river water, sediment, and fish. Arsenic was found to be the main contaminant of concern. Risks were calculated on a worst-case basis, using maximum arsenic concentrations and conservative exposure assumptions, and on a most probable-basis, using mean arsenic concentrations and less conservative exposure assumptions. The total worst-case carcinogenic risk in the Blackwater Branch was estimated to be $5x10^{-3}$, with the total most probable risk estimated to be $5x10^{-5}$. In the upper Maurice River, the total worst case and most probable risks were estimated to be $1x10^{-3}$ and $1x10^{-4}$, respectively. At the Almond Road beach, a popular

VIN 002 0578

recreational area, the worst-case and most probable risks were $7x10^{-5}$ and $9x10^{-6}$, respectively. In all cases, ingestion (either sediments, water or fish) comprised the majority of the risk estimate. Direct contact with stream water and inhalation were insignificant. Noncarcinogenic risks were also generally insignificant. In the lower Maurice River, increased health risks were qualitatively determined to be relatively minor for most of the exposure pathways. Risk-based sediment cleanup levels to achieve the $1x10^{-6}$ level in the Blackwater Branch and upper Maurice River were calculated to be 2 mg/kg for the worst-case exposure scenario, and 12 mg/kg for the most probable exposure scenario. To achieve a $1x10^{-5}$ risk from sediments, the concentrations are 20 mg/kg for the worst case, and 120 mg/kg for the most probable scenario.

- The treatability studies determined that chemical fixation and extraction were both feasible methods to treat the arsenic-contaminated sediments to the target criteria of having less than 5 mg/l leachable arsenic (fixation) or having an arsenic concentration of less than 20 mg/kg (extraction). The feasibility study will evaluate both of these treatment technologies, although as discussed in detail in the feasibility study, the treatment criteria have changed from that postulated at the beginning of the study.

The Phase I and Phase II data, and the previous investigations and USGS data, were sufficient to meet the study objectives. Additional data needs were identified. These included determining the arsenic concentration and the flow coming out of Union Lake concurrently with measurements at the USGS gage at Norma; determining the form of arsenic in fish if EPA determines that this information is necessary to definitively quantify this risk estimate; and determining the rate of adsorption/desorption of arsenic from the sediments.

VIN 002 0579

VIN 002 0580

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) on May 9, 1986 authorized Ebasco Services Incorporated (Ebasco) to conduct a Remedial Investigation/Feasibility Study (RI/FS) of the Vineland Chemical Company (ViChem) site, Vineland, New Jersey. The RI/FS was performed in response to Work Assignment Number 37-2LB8 under Contract Number 68-01-7250. Preparation of this report was accomplished pursuant to the approved Work Plan for the ViChem site dated November 17, 1986 as amended in October 1987.

Three RI and three FS reports have been prepared for the ViChem site. The reports, the areas they cover, and the dates of submission to the EPA are presented in Table 1-1.

The study area is approximately 38 miles long: 11 miles of riverine environment (including two miles upstream of the plant); 2 miles of lacustrine environment; and 25 miles of estuarine environment. This report addresses the Blackwater Branch and the Maurice River above and below Union Lake. The location of the study area is shown on Figure 1-1, with the location of the ViChem plant shown on Figure 1-2.

1.1 REMEDIAL INVESTIGATION OBJECTIVES

The objective of the investigation in the Blackwater Branch and the upper Maurice River above Union Lake was to collect sufficient data to perform a semiquantitative risk assessment and a Feasibility Study. The objective of the investigation in the lower Maurice River, below Union Lake, was to collect sufficient data to perform a qualitative risk assessment, but not to perform a Feasibility Study. Specifically, the RI objectives by area were as follows:

Blackwater Branch and Upper Maurice River (above Union Lake)

- Define the extent of contamination in the sediment, surface waters and some of the biota in this portion of the study area;
- Identify the contaminants and pathways that have actual or potential impacts on public health or the environment;
- Conduct bench-scale tests to evaluate the feasibility of treating contaminated sediments, and to evaluate the impacts of the proposed remedial measures; and
- Use the above data to prepare a semiquantitative risk assessment of contaminated media on potentially exposed populations and a Feasibility Study for treating potentially contaminated sediments.

VIN 002 0581

VIN 002 0582

TABLE 1-1

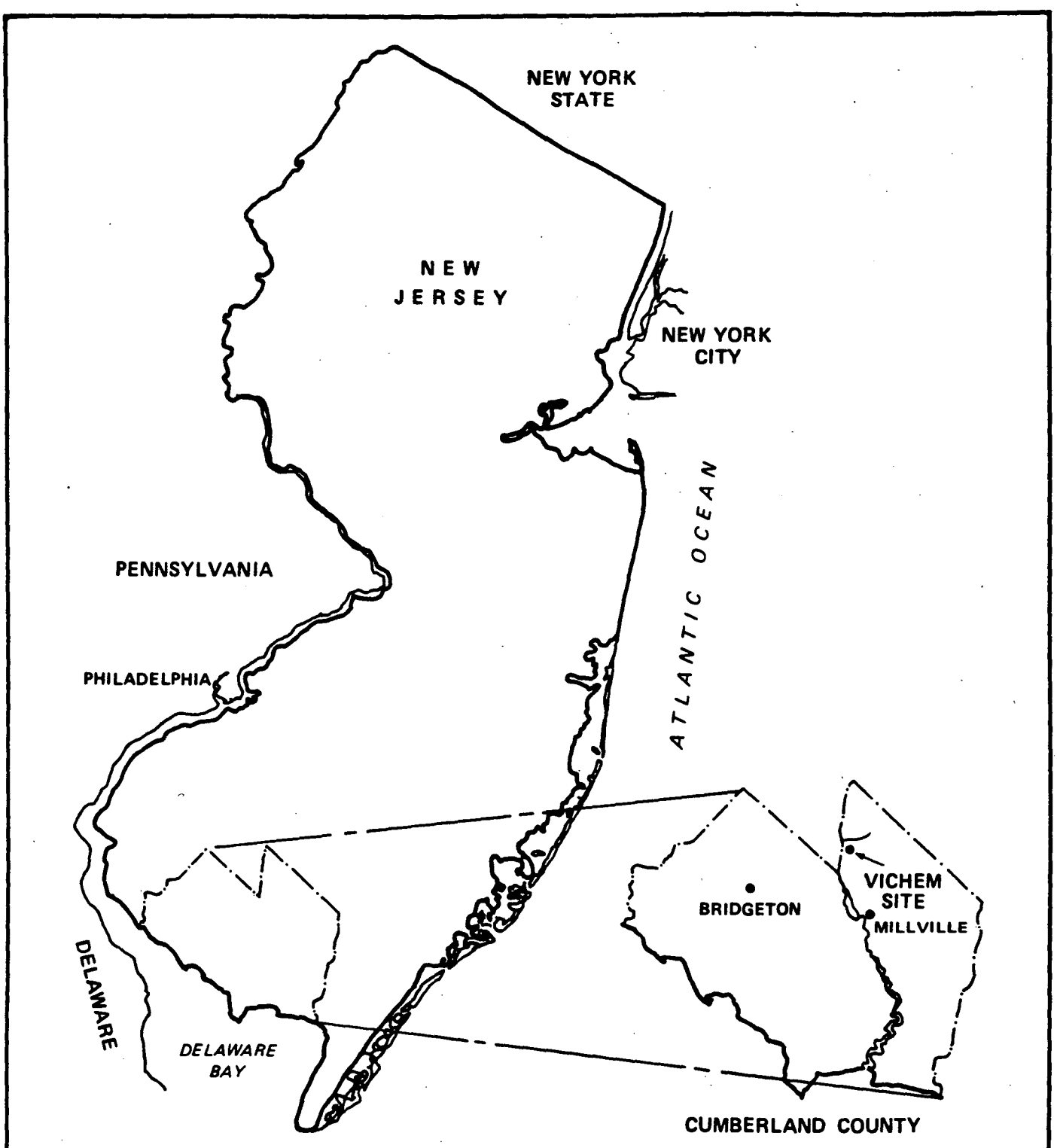
RI AND FS REPORTS PREPARED FOR THE VINELAND CHEMICAL COMPANY SITE

TITLE	AREAS	MEDIA INVESTIGATED	DRAFT	REVISED DRAFT	FINAL DRAFT
Plant Site RI	ViChem Plant Site	Soil, Groundwater	7/19/88	3/10/89	6/23/89
River Areas RI	Blackwater Branch, Maurice River between Blackwater Branch and Union Lake, Maurice River below Union Lake to Delaware Bay	Sediment, Surface Water, Biota	9/8/88	2/17/89	6/23/89
Union Lake RI	Union Lake	Sediment, Surface Water, Biota	6/21/88[2]	4/28/89	6/23/89
Plant Site FS	ViChem Plant Site	Soil, Groundwater	9/20/88	3/10/89	6/23/89
River Areas FS	Blackwater Branch,[1] Maurice River between Blackwater Branch and Union Lake	Sediment	10/5/88	2/17/89(3)	6/23/89
Union Lake FS	Union Lake	Sediment	1/18/89	4/14/89	6/23/89

1 No FS Report is being prepared for the Maurice River below Union Lake.

2 Risk assessment submitted on April 20, 1987. First Draft RI submitted on March 13, 1988. The June 21, 1988 RI incorporated the first revised risk assessment.

3 This report was reissued on April 27, 1989 containing a revised action level for the sediments.



U.S. ENVIRONMENTAL PROTECTION AGENCY

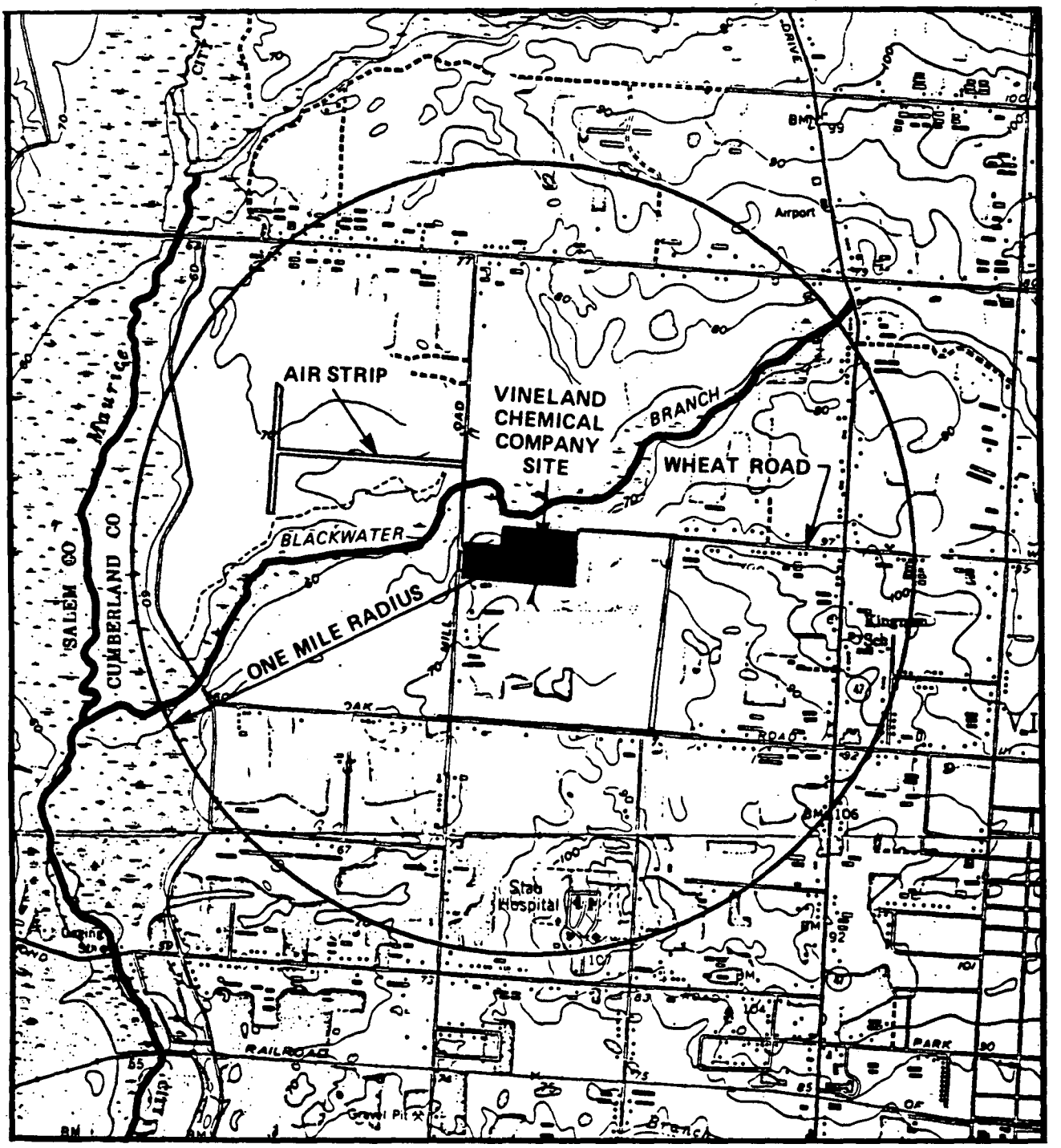
VINELAND CHEMICAL COMPANY SITE

FIGURE 1-1

RIVER STUDY AREA
REGIONAL LOCATION MAP

EBASCO SERVICES INCORPORATED

USN 002



SCALE 1:24000

0 1 MILE

BASE MAP PREPARED BY U.S.G.S., 1977

U.S. ENVIRONMENTAL PROTECTION AGENCY
VINELAND CHEMICAL COMPANY SITE
FIGURE 1–2 VINELAND CHEMICAL COMPANY ONE MILE RADIUS
EBASCO SERVICES INCORPORATED

VIN008
0584

Lower Maurice River (below Union Lake)

- Repeat the NJDEP's 1979 sampling in this portion of the study area at locations where the arsenic concentration in sediments exceeded 23 mg/kg, the level detected in the Maurice River above the Blackwater Branch (the receiving stream for groundwater from the ViChem plant) at that time; and

- Use this and other data to prepare a qualitative risk assessment, identify hot spots, and make recommendations for future work as warranted.

The data base to meet these objectives was obtained from field work performed by Ebasco in 1986 and 1987. Specific elements of the field program are described in Subsection 1.3.2 and in Section 2. In addition, treatability studies were performed to evaluate potential treatment technologies for contaminated sediments, as outlined in Section 7. Also, some use was made of previous studies conducted for the Vineland Chemical Company, previous studies conducted for the NJDEP, and USGS data. This overall data base provided the information to meet the study objectives outlined above.

1.2 BACKGROUND INFORMATION

1.2.1 Site Description

The ViChem plant is located in a residential/industrial area in the northwest corner of the City of Vineland in Cumberland County, New Jersey. The plant location is shown on Figure 1-2.

The plant is bordered on the north by Wheat Road and the Blackwater Branch, a tributary to the Maurice River. Residential areas border the plant to the east, west and south.

ViChem has produced organic herbicides and fungicides at this location since approximately 1949. ViChem currently produces two major herbicidal chemicals, disodium methanearsonate and monosodium methanearsonate. Table 1-2 lists chemicals used, manufactured, or known to be stored at the ViChem plant.

The ViChem plant site is shown on Figure 1-3. The plant consists of several manufacturing and storage buildings, a laboratory, a worker change facility, a wastewater treatment plant and several lagoons. The manufacturing and parking areas shown on Figure 1-3 are paved. The lagoon area is unpaved and is devoid of vegetation. This area is dominated by loose sandy soils. The remainder of the site is covered by trees, grass, or shrubs.

The site is situated in a residential/industrial area. Twelve residences are shown on Figure 1-3 in the immediate vicinity of the plant. A number of other residences are located close to the plant along Wheat, Orchard, Oak, and Mill Roads.

VTN 002 0585

TABLE 1-2

CHEMICALS USED, MANUFACTURED OR STORED
AT VINELAND CHEMICAL PLANT

INORGANIC METALS AND SALTS

Arsenic
Mercury
Mercury (II) chloride
Mercury (I) chloride
Cadmium
Cadmium chloride

FLOCCULANTS

Aluminum
Iron

METAL ORGANIC ARSENIC COMPOUNDS

Disodium methane arsonate
Dodecyl and octylammonium methane-arsonate
Monosodium acid methane arsonate
Calcium acid methane-arsonate
Dimethylarsonic acid (Cacodylic acid)

ORGANIC MERCURY COMPOUNDS

Phenyl mercury dimethyldithiocarbamate
Phenyl mercuric acetate

HERBICIDES

Sodium 2,4-dichlorophenoxy acetate (2,4D)
2-4-dichlorophenoxy acetic acid
2(4-chloro-2-methyl phenoxy) propanoic acid (MCPP)

bis(dimethylthio-carbonyl)disulfide (thiram)

1,4-bis (bromoacetoxy)-2-butene
2,3-dibromopropionaldehyde

Alkylarylpolyether alcohol

SOLVENTS AND GENERAL ORGANIC CHEMICALS

Benzyl alcohol
Xylene
2,3 Benzofuran

Methanol
Epichlorolydrin
Acrolein
Isopropyl alcohol

Methyl chloride
Methylene chloride
Trichloroethane
Trichloroethylene

Tetrachloroethylene
Bromochloromethane

Methylene-bis-thiocymate
Hydrobromic acid

Tetrabutyl ammonium bromide
Bromo acetic acid

VIN 002 0586

TABLE 1-2 (Cont'd)

CHEMICALS USED, MANUFACTURED OR STORED
AT VINELAND CHEMICAL PLANT

Glycerine
Triton X-100
Formaldehyde
Butanediol

Gasoline
Kerosene

POSSIBLE CHEMICALS FROM MANUFACTURING

Phenol
Chlorophenols
Chloroacetic acid
Chlorides
Arsenic trioxide
Arsenic pentoxide
Methyl chloride
Methanol
Sodium hydroxide
Calcium oxides, chlorides, sulfates
Mercury oxides
Cadmium salts

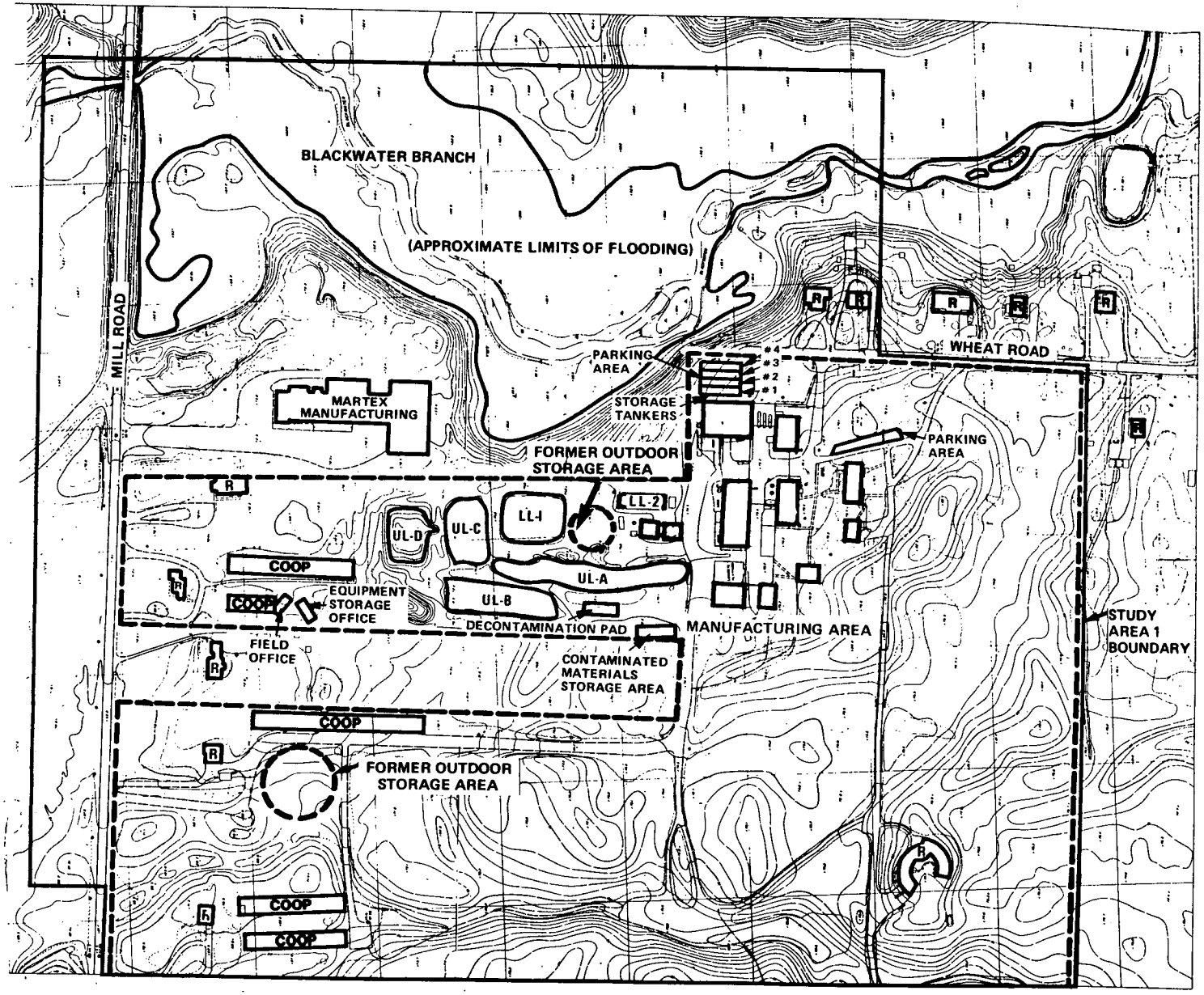
Compiled from:

1) Miller, F., NJDEP Memo, Vineland Chemical Ground Water Pollution Problem, May 24, 1985

2) Sittig, M., Pesticide Manufacturing and Toxic Materials Control Encyclopedia, Noyes Data Corp., Park Ridge NJ (1980)

VIN 002 0581

VIN 002 0584



TOPOGRAPHIC BASE PREPARED FOR U.S. ARMY CORPS OF ENGINEERS BY KUCERA INTERNATIONAL, JANUARY 1986.

U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 1-3

VINELAND CHEMICAL COMPANY SITE PLAN

EBASCO SERVICES INCORPORATED

VIN 002 0584

The Martex Manufacturing facility is loc
and west of the ViChem lagoon area. Mart
packaging materials, although little info
the materials used or manufactured at this

The Blackwater Branch is immediately nor
as shown in Figure 1-4. This stream f
discharges into the Maurice River approxi
downstream from the plant. The upper M
Figure 1-5, then flows approximately
downstream into Union Lake, which is a
long. The Maurice River then flows appro
downstream from the lake into the Dela
Figure 1-6.

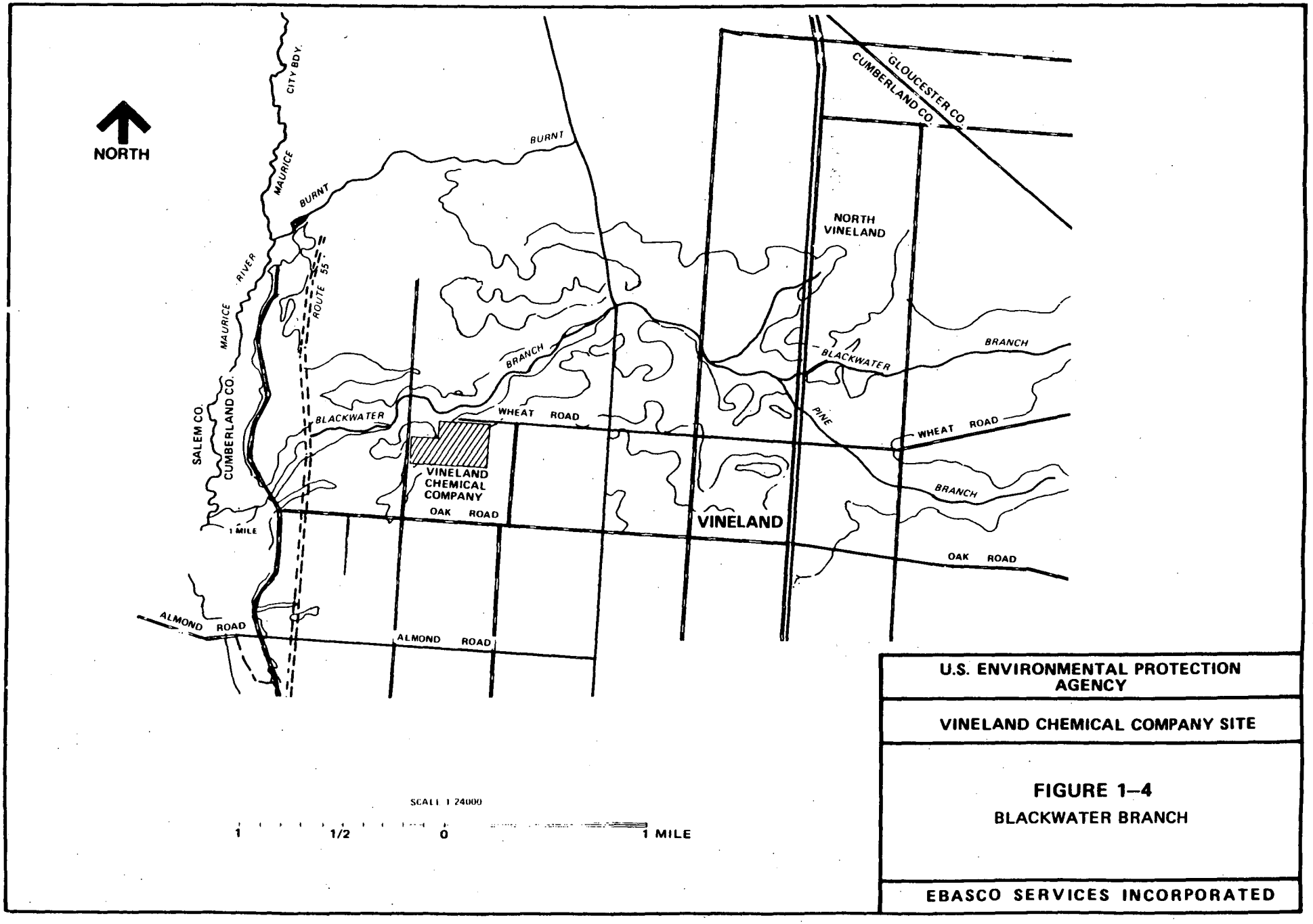
Some time between April 1985 and June 198
a dam on the Blackwater Branch just downst
bridge. The dam flooded the Blackwater Br
extent shown in Figure 1-3. The dam was
to allow for construction of a new bridge.
is now flowing in its normal channel and
been drained.

A wastewater treatment system is in op
plant site. The system has a design cap
25 gallons per minute (gpm), or 36,000
assuming 24-hours of operation. The s
treat between 2,000 and 5,000 gpd of pro
gpd of groundwater, which was to be pu
water table, and storm runoff water as ne
provisions were made to collect up to 60,
cooling water in the event that a mechani
and mixed the non-contact cooling water
process water.

The wastewater treatment system consists o
vator, filters and ancillary equipment. F
to the first mix tank and caustic soda is
mix tank to promote flocculation. The wa
the reactivator where it is mixed with a pc
then passes through a flocculation compart
particles settle to the bottom and are r
lined tank. The reactivator effluent is
filter before discharge. The slurry in th
pumped into a vacuum filter and the dry s
a dumpster for off-site disposal. An
discharge requirements is reportedly recir

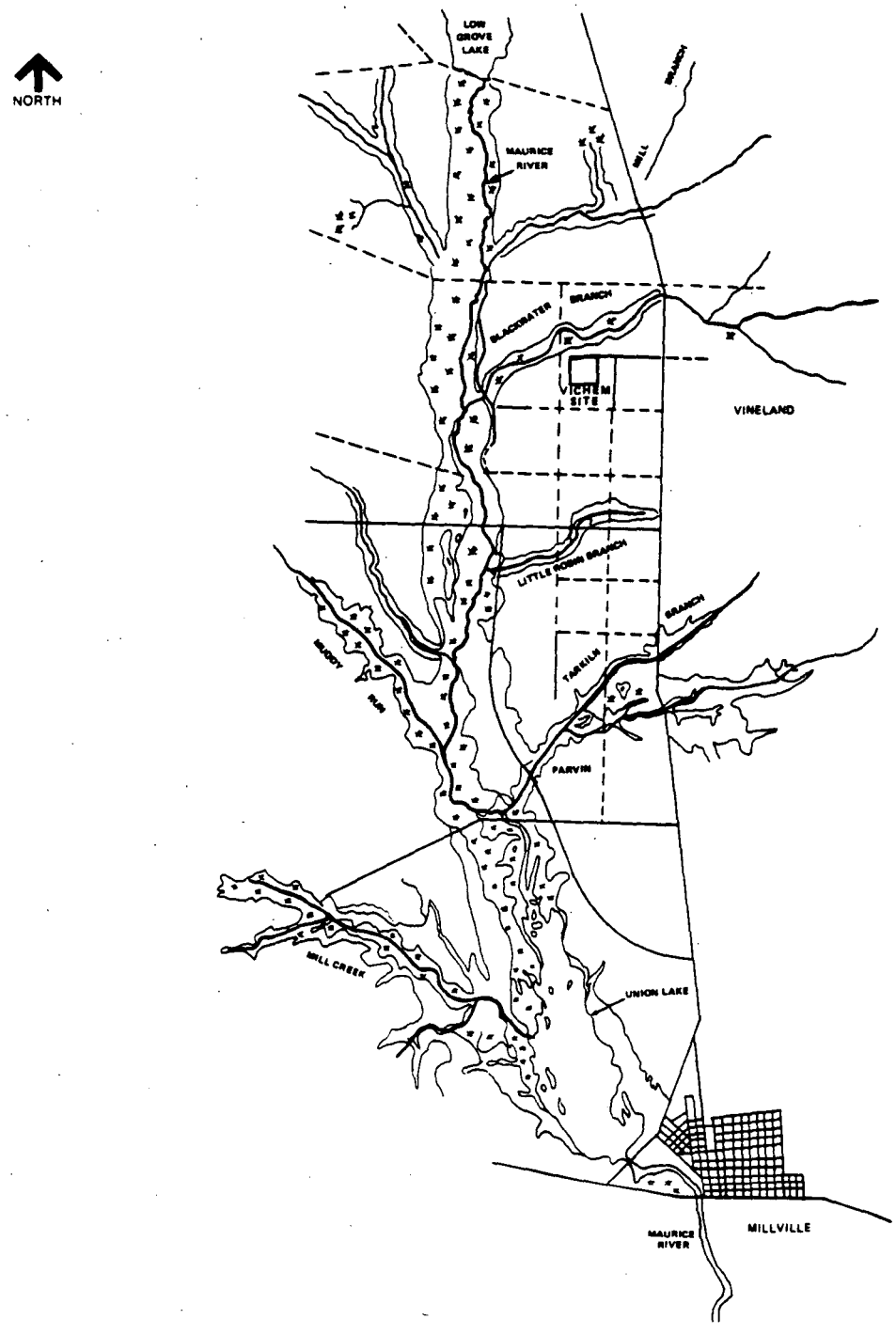
Some of the lagoons shown in Figure 1-3
water treatment system. Lagoon LL-1 is
490,000 gallon capacity. This lagoon was
cess water, groundwater, and storm water
treatment. Water can be pumped from

VIN 002 05-89

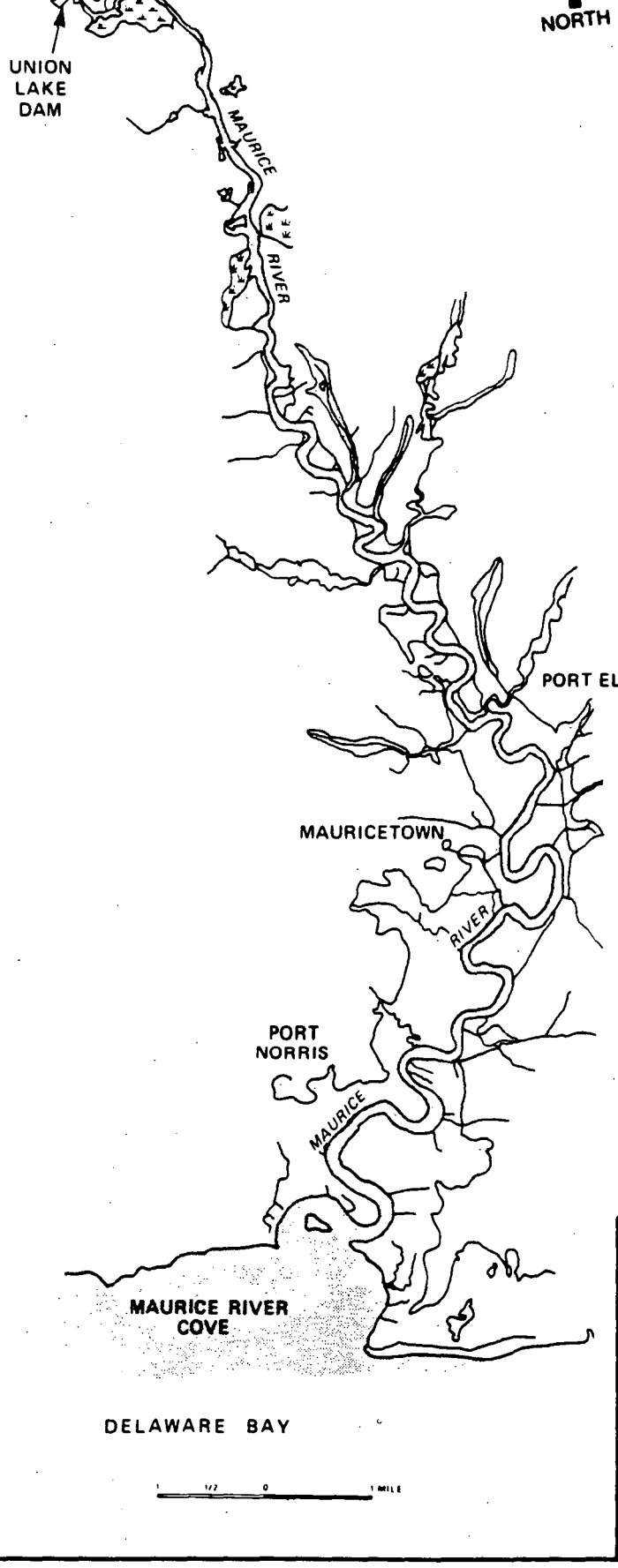


U.S. ENVIRONMENTAL PROTECTION AGENCY
VINELAND CHEMICAL COMPANY SITE
FIGURE 1–4 BLACKWATER BRANCH
EBASCO SERVICES INCORPORATED

obso 000NIN



U.S. ENVIRONMENTAL PROTECTION AGENCY
VINELAND CHEMICAL COMPANY SITE
FIGURE 1–5 MAURICE RIVER NORTH OF UNION LAKE
EBASCO SERVICES INCORPORATED



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 1–6

MAURICE RIVER SOUTH OF UNION LAKE

EBASCO SERVICES INCORPORATED

VIN 002 0592

wastewater treatment plant at 25 gpm. Lagoon LL-2 is also a lined lagoon, but it has a concrete base. This lagoon was designed to hold the sludge prior to disposal. It now holds water to be recirculated for retreatment. Lagoon UL-A is an unlined lagoon. This lagoon receives the non-contact cooling water and the treated discharge from the treatment plant. Because the site soils are sandy and this lagoon is unlined, inflow to the lagoon rapidly infiltrates the groundwater.

The remaining lagoons shown in Figure 1-3, UL-B, UL-C, and UL-D, are all unlined and are not currently used in the water treatment system. However, aerial photographs provided by the USEPA's Environmental Photographic Information Center (EPIC) showed that in the past these lagoons were connected to lagoon UL-A. Photographs from USEPA's Site Analysis, Vineland Chemical Company (Simpson, 1988) show that UL-A, UL-B, UL-C, UL-D and LL-1 (which was previously unlined) were connected to one another in the past. The photographs show that all of the lagoons were filled with liquid.

The two lined lagoons, LL-1 and LL-2, are regulated by RCRA. The wastewater treatment plant and the unlined lagoon, UL-A, are regulated under the NJPDES program. Other active solid waste management units at the plant site include: trailers/tote bins used to store waste salts and the treatment plant sludge; septic system and leach field; and the soil beneath the floors of the production buildings, where past operating procedures reportedly produced spillage. Inactive/abandoned solid waste management units are basically areas where waste salts were improperly stored in the past, including the waste salt piles, sludge piles, chicken coops, and outdoor drum storage areas.

The treatment plant was designed to produce an effluent with an arsenic concentration of 0.05 milligrams per liter (mg/l). ViChem initially had difficulties achieving this level, therefore an interim standard of 0.7 mg/l was agreed to and ordered by NJDEP in December 22, 1981, with the understanding that the 0.05 mg/l level would eventually be met. In-house analytical results performed on a daily basis by ViChem indicate that the effluent has been reduced below the interim standard, but the levels are still greater than 0.05 mg/l at times. The levels are still greater than 0.05 mg/l when the influent concentrations are high, but are less than 0.05 mg/l when the influent concentrations are low.

ViChem reports that it no longer treats either groundwater or process water. Reportedly all of the water used in manufacturing the herbicides is consumed by the process and is included as inherent moisture in the product. ViChem ceased pumping and treating groundwater in July 1987 with the consent of the NJDEP. The wastewater treatment plant now reportedly treats only storm water runoff on an intermittent basis.

VIN 002 0543

The herbicide manufacturing process produces approximately 1,107 tons of waste by-product salts each year. These wastes have an EPA hazardous waste number of K 031 and are neither treated nor disposed of at the site, nor stored on-site for more than 90 days. The salts are transported by licensed shippers to licensed facilities in Ohio and Michigan for disposal.

1.2.2 Site History

ViChem began manufacturing organic arsenical herbicides and fungicides at this plant in approximately 1949. In addition to arsenical herbicides, the company also produced cadmium-based herbicides and used other inorganics such as lead and mercury. Table 1-2 presented a list of chemicals used, manufactured, or stored at the ViChem plant.

As early as 1966, the NJDEP observed the discharge of untreated wastewaters with unacceptable arsenic concentrations (67 mg/l) into the unlined lagoons. An unknown quantity of arsenic rapidly infiltrated the groundwater from the lagoons. On February 8, 1979, ViChem was ordered to install and provide industrial wastewater treatment and/or disposal facilities. The wastewater treatment works did not become operational until March 1980.

Waste salts from the herbicide production process were stored on site in uncontrolled piles on the soil, in the concrete lagoon LL-2 (which at the time was unlined), and in abandoned chicken coops on the plant property. The storage of salts in piles was observed in April 1970 and in the coops in April 1973. These salts reportedly contained one to two percent arsenic (Woodward-Clyde, 1985). As these salts have a high solubility, precipitation contacting these piles rapidly dissolved the salts, carrying an unknown quantity of arsenic into the groundwater.

Between 1975 and 1976, ViChem was "fixating" the waste salts for disposal at the Kin-Buc Landfill. The process involved mixing the dried salts with ferric chloride and soda ash, reportedly reducing the solubility. The process was stopped in 1976 when the Kin-Buc Landfill voluntarily stopped accepting all chemical wastes, the fixated salts included. ViChem then resumed piling the untreated waste salts on the soil surface at the plant site.

A court order issued on January 26, 1977 required ViChem to containerize the waste salts from the chicken coops and piles, then store the drums in a warehouse off-site. In June 1979, another order was issued for the disposal of the stored drums in an approved landfill. Removal and disposal of these drums were not completed until June 30, 1982.

Currently, the waste salts and the sludge from the wastewater treatment systems are stored in large-capacity trailers and tote bins. The tote bins are filled at the point of generation

in the manufacturing buildings, and then emptied into the trailers. The NJDEP believes that releases from this system are unlikely. The salts and sludge are transported to the licensed facilities mentioned above. During peak production, as many as four or five trailers are filled and removed per week.

Aerial photographs provided by the USEPA's Environmental Photographic Information Center (EPIC) and conversations with ViChem employees indicated several possible locations of past contamination. The cleared area in the southwest corner of the site shown as a "former outdoor storage area" on Figure 1-5 used to be occupied by two chicken coops. Sometime between November 1975 and March 1979, both coops were destroyed. These coops were reportedly used to store process chemicals and/or waste. The materials stored in the coops may have percolated into the groundwater. This area is now devoid of vegetation. Photographs show many locations containing mounded material and/or drums. These were observed in the lagoon area and along the plant road. The waste salts wee reportedly mounded so high at times in lagoon LL-2 that the salts spilled over onto the soil in the lagoon area.

It is alleged that the floors of the manufacturing buildings have been leaking arsenic compounds into the underlying sands for years. The original floors of the buildings were brick and were reportedly in need of repairs several years ago. Allegedly, when the old bricks were removed, the soil contained crystalline waste from the previous spills. It is not known whether the soils were removed when the floors were replaced, although in Ebasco's Phase II investigation the soils below building number 9 were sampled and had high arsenic concentrations (Ebasco, 1989a). The floor of this building was solid and in good repair during Ebasco's 1987 investigation.

In response to a series of Administrative Consent Orders issued by the NJDEP, ViChem instituted some cleanup actions and modified the production process. The cleanup actions included stripping the surface soils in the manufacturing area, piling these soils in the clearing by well cluster EW-15, and paving the manufacturing area; installing a storm water runoff collection system; removing the piles of waste salts; and installing a groundwater pump and treat system, including the wastewater treatment plant. Modifications to the production process included modifying the water system where mixing of process water and non-contact cooling water was unlikely, lining two of the lagoons used in the wastewater treatment system, and properly disposing of the waste salts.

Evidence suggested that a serious groundwater contamination problem existed at the ViChem site, and that the groundwater was discharging into the streams and degrading the downstream water quality. Therefore, this RI/FS was undertaken to investigate the extent of the groundwater contamination and to evaluate remedial alternatives for rehabilitating the groundwater and downstream sediments and surface waters.

VIN 002 0545

1.2.3 Permit Actions

On December 2, 1985, the USEPA informed ViChem that its interim status for the lined RCRA impoundments was terminated as a matter of law on November 8, 1985 because of failure to comply with Section 3005(e)2 of RCRA. The USEPA determined that the company (a) failed to certify compliance with the applicable financial assurance requirements for closure and post-closure care, (b) failed to certify that required liability insurance was ever actually obtained, and (c) failed to certify the preparation of a groundwater monitoring program meeting the requirements applicable to interim facilities. The company was to cease placing hazardous waste into the two lined lagoons.

ViChem submitted applications for RCRA and NJPDES permits. The RCRA permit application was for storage of hazardous wastewaters in the two lined lagoons. The NJPDES discharge to groundwater permit application was for discharge to the unlined lagoon UL-A.

In April 1986, the NJDEP advised ViChem of its intent to deny both the RCRA and NJPDES permits. The technical and administrative bases for the tentative decision to deny the NJPDES permit are: (a) the discharge of 200,000 gallons per day (gpd) of non-contact cooling water into the unlined lagoons increased hydraulic gradients, thereby forcing contaminanted groundwater deeper into the aquifer and further off-site; and (b) the treatment works were unable to meet the discharge criterion of 0.05 mg/l for arsenic. The technical bases for denying the RCRA permit application were inadequate closure, post-closure, and liability assurance requirements, and an inadequate groundwater monitoring program. The administrative basis for denial was the failure to submit a complete hazardous waste facility permit application given adequate time to do so. The NJPDES permit has been denied, but is being appealed by ViChem.

1.2.4 Previous Investigations

Since 1978, a number of studies have been performed by or for the NJDEP Office of Science and Research in the Maurice River watershed and at the ViChem plant site. ViChem itself has also conducted some investigations into the groundwater plume at the plant.

In 1979 and 1980, the NJDEP initiated a sampling program in the Blackwater Branch and the Maurice River downstream from the site. The results showed that the sediment arsenic concentrations in the Maurice River were the highest observed anywhere within the State of New Jersey. The study showed that the Almond Road weir, the submerged dam in Union Lake, the lower main dam in Union Lake, and the tidal creeks of the Maurice River estuary below Union Lake stored arsenic-contaminated sediments. Elevated arsenic concentrations were found in sediments as far from the site as the Delaware Bay, approximately 36 river miles downstream. Also, the arsenic

UIN 002 0546

concentration in the surface water decreased downstream from the site but did not reach the Federal Primary Drinking Water Standard for arsenic, 0.05 mg/l or 50 ug/l, until 26.5 river miles downstream from the ViChem site.

In 1978, ViChem commissioned a surface geophysical survey of the site at the direction of the NJDEP. The survey noted areas of probable contamination being the lagoon area, the area north of the lagoons to the Blackwater Branch, the former outdoor storage area shown on Figure 1-3, and along the plant road between the former outdoor storage area and the lagoons. The report also contended that the probable groundwater contamination was shallow and recommended locations for installing extraction wells.

In 1979, NJDEP sampled soils in the ViChem plant area. Samples were taken at the surface and at depth. The study showed arsenic concentrations ranging from undetected to 864 mg/kg at various locations in the plant area.

In 1981, the NJDEP performed a surface geophysical survey of the plant area. The study identified two areas of probable groundwater contamination, one northwest of the lagoons toward the Blackwater Branch and the other near the former outdoor storage area. The study estimated that the probable maximum depth of the contaminant plume was approximately 40 feet.

In 1982, ViChem commissioned a groundwater investigation of the site. In this study, previous investigations were reviewed and a scheme to remove arsenic from the contaminated aquifer was proposed. This study included several sets of water quality data. Approximately four and a half years of monthly arsenic concentrations at ViChem well MW-1 were presented along with data from ViChem wells MW-6 and MW-10. These data showed a marked drop in the arsenic concentration in the groundwater between 1978 and 1981. The study also presented monthly levels of arsenic in the Blackwater Branch at Mill Road and in the Maurice River at the Almond Road weir. The study postulated that the arsenic load at Mill Road was very similar to the arsenic load at Almond Road, implying that the river system was essentially a conduit for arsenic transport into Union Lake. The study reviewed processes for arsenic cleanup at the site and recommended a groundwater pump and treat program along with controlled soil leaching.

In 1982, an employee of ViChem was diagnosed as having subacute arsenic poisoning. The New Jersey Department of Health then conducted a "Cross-Sectional Evaluation of Arsenic Exposure and Toxicity at the Vineland Chemical Company." The study revealed that employees had elevated arsenic concentrations in their hair and urine, but only exhibited minor symptoms associated with arsenic trioxide dust on the skin and mucous membranes. As a result of this survey, the arsenic handling practices in the production facility had improved.

Two studies were conducted by the NJDEP and Rutgers University from 1980 to 1982 in Union Lake. The studies showed that Union Lake is chemically stratified during the summer. This stratification creates seasonal anaerobic conditions in the bottom sediments, which are conducive to the formation of toxic arsenical compounds from the contaminated sediments (NJDEP, 1986). The Rutgers University work included sampling and analysis of water and sediments, as well as speciation of arsenic [trivalent (As III), pentavalent (As V), monomethyl arsenic acid (MMAA) and dimethyl arsenic acid (DMAA)(Faust, 1983)]. This study concluded that the waters and bottom sediments were highly contaminated with substantial quantities of arsenic, and that total arsenic concentrations in all lake water samples exceeded the NJDEP and EPA drinking water standard of 50 ug/l. In sediments, the order of predominance of the four arsenic species (in descending order) was: As (V), As (III), MMAA, DMAA. In four of the sediment samples, the inorganic arsenate was between 73% and 88% of the total arsenical species. In water, the order of predominance was MMAA, As (III), As (V), DMAA. The results of the sampling efforts revealed a seasonal pattern of arsenic concentrations within the lake water with the greatest concentrations occurring during the summer. Additional NJDEP sediment sampling near the spillway area of Union Lake in April 1986 again showed arsenic contamination within the sediments and indicated that contamination within the sediments was a surficial phenomenon.

In a 1983 to 1985 study by Rutgers University (Winka, 1985), it was shown that arsenic may exist in many species in the watershed, and that these species may be transformed by changes in physical condition and season. Results indicated that within the water column the inorganic arsenic species may be one half of the total arsenic. Arsenic was not easily solubilized under aerobic conditions. The concern raised by these findings was that when an anaerobic condition develops on the bottom of Union Lake, the arsenic would be readily converted into the more toxic As (111) and As (V) forms. The more toxic forms could then be released to the water column upon seasonal turnover of the stratified layers. However, as these compounds are extremely insoluble, they were expected to precipitate back to the lake bottom within a relatively short period of time.

In 1982, ViChem commissioned a pumping test to be performed on the shallow aquifer underlying the lagoon area. The pumping test estimated a transmissivity in the shallow aquifer of approximately 50,000 gpd/ft, and a storage coefficient of between 0.1 and 0.04.

In 1985, ViChem's RCRA Part B permit application was submitted to the NJDEP. The application included a description of the wastewater and groundwater handling, and a description of the wastewater treatment process and facility design. The application also included data on the production rates at the plant and the toxicity of the wastes generated. Arsenic concentrations in the Blackwater Branch through time were also presented.

VTN 004 0548

In 1986, ViChem commissioned a pumping test to be performed in the deeper groundwater below the site. The plant's production well, screened from 130 to 165 feet below the ground, was used as the pumping well and a deep monitoring well was installed in the lagoon area. The pumping test was conducted for 24 hours, with water levels measured in the deep monitoring well and several shallow monitoring wells near the discharge in the lagoon area. The report concluded that the "clay layer," reportedly encountered from 120 to 135 feet below the ground and which the production well is screened below, acts as a confining layer and prevents downward migration from the overlying aquifer. However, Ebasco's review of this pumping test data revealed that there was significant leakage across this "clay layer" during the pumping test.

The USEPA's Environmental Photographic Information Center (EPIC) produced a report in March 1988 on the ViChem site. The report presents an aerial photographic analysis of the ViChem plant and surrounding area. The first photograph presented was taken in March 1951 and the last was taken in November 1987. A total of 11 photographs are presented.

Among other things, the analysis of the photographs shows areas of "Vegetation Damage" and "Vegetation Stress" along the Blackwater Branch beginning with a September 1979 photograph. None of the prior photographs show vegetation damage or stress, and all of the later photographs show some vegetation damage and/or stress.

Some of the damaged areas are in the portion of the Blackwater Branch that was inundated with water from the beaver dam. However, the beaver dam was not constructed until some time after April 1985, much later than the first indication of vegetation damage/stress. A topographic base map for the site that was flown in April 1985 shows the Blackwater Branch flowing in its normal channel at that time. It should be pointed out that the damaged/stressed areas are coincident with the contaminated groundwater plume coming off the ViChem site.

In 1988, the USEPA's Environmental Response Branch prepared a bioassessment on the Blackwater Branch and the upper Maurice River. The report concluded that there was an adverse impact to the benthic communities in the Blackwater Branch downstream from the ViChem plant. The impact takes the form of lower species diversity and a toxic response in bioassay tests done with the sediments. The adverse impact on the Maurice River is less, however, probably resulting from dilution. This report is presented as Appendix L to this report.

In addition to the above studies, Ebasco, under contract with the USEPA, prepared RI reports for two portions of the ViChem site: the ViChem Plant Site and Union Lake. (Ebasco, 1989a and 1989e). Pertinent findings from these RI reports to the river areas are as follows:

V IN 002 0549

- o There is a heavily contaminated arsenic plume in the shallow groundwater underneath the site, within an aquifer termed the upper sand in the plant RI report. No arsenic contamination was seen below the base of the upper sand, ranging from 40 to 70 feet below the ground surface. A unit termed the banded zone, which contains clay laminae, was found at the base of the upper sand and apparently prevents the downward migration of arsenic.

- o The groundwater in the upper sand discharges into the Blackwater Branch and thus provides the arsenic flux into this stream and the Maurice River.

This is based on several observations:

(1) There is an upward hydraulic gradient on both sides of the Blackwater Branch.

(2) The groundwater flow direction is from the plant area toward the Branch.

(3) The groundwater between the plant and the Branch is contaminated with arsenic, but no arsenic contamination is seen in the groundwater across the Branch from the site.

(4) The Blackwater Branch shows elevated arsenic concentrations below the plant, but virtually undetected concentrations above it.

- o Union Lake is contaminated with substantial quantities of arsenic. The mean dissolved arsenic concentration in the water is approximately 56 ug/l, which is above the Federal Primary Drinking Water Standard for arsenic, 50 ug/l. The mean arsenic concentration in the sediment is approximately 74 mg/kg, which is significantly higher than the background arsenic concentration in the Maurice River above the confluence with the Blackwater Branch. The highest arsenic concentration detected in the sediments was over 1,200 mg/kg.

1.2.5 Community Concerns

In 1984, after the ViChem site was added to the National Priorities List, EPA implemented a community relations program to inform area residents about the Superfund related activities and obtain their input. Community concern increased from moderate to relatively high and also became more specific. The involvement of organized environmental groups generated media attention and increased public awareness of the site.

As a result of EPA's community relations activities, five major community concerns were identified:

- Human health risks from exposure to contaminated groundwater because some of the residents relied on groundwater for potable water;
- Human health risks from exposure to contaminated surface water because local rivers and lakes are used for recreation;
- Frustration over the perceived lack of remedial action at the site;
- A perceived lack of cooperation on behalf of ViChem during the remedial response process; and
- A perception of inadequate information from NJDEP.

1.3 REMEDIAL INVESTIGATION STUDY

1.3.1 Initial Activities

The initial tasks of this Work Assignment were the development of a Work Plan Memorandum, a Work Plan, and a Field Operations Plan (for both Phase I and II) for the RI/FS. The Work Plan Memorandum presented the scope of the program and the estimated schedule and budget to perform these initial tasks.

Prior to the preparation of project plans, a site walk-through was performed to familiarize the investigators with the site, determine possible sampling locations, and obtain information for developing the Health and Safety Plan. Existing information and prior reports prepared by ViChem and the NJDEP were also reviewed. Following the site visit and the evaluation of the existing data, potential remedial alternatives were identified in order to scope out the field sampling and analyses program and to specify the appropriate levels of data quality required.

1.3.2 Field Investigation

Ebasco's field investigation in the River Areas was conducted in two phases. Phase I was conducted in June and July of 1986. Surface water and sediment samples were obtained from the Blackwater Branch and the upper Maurice River above Union Lake, with limited sampling performed below Union Lake. Phase II was conducted in June, July, and August of 1987. Surface water and sediment samples were again obtained from the Blackwater Branch and the upper Maurice River, and in addition surface water and sediment samples were obtained from the lower Maurice River, below Union Lake, to the Delaware Bay. Limited biota sampling was conducted in both the upper and lower Maurice River. The sampling programs are discussed below and in Section 2.

Phase I

The main objective of the Phase I investigation was to repeat sampling at stations in the Blackwater Branch and the upper Maurice River that showed elevated sediment arsenic concentrations in the 1979 sampling effort by the NJDEP. The locations of the NJDEP's 1979 samples, and the analytical results, are presented in Appendix M. Additional objectives included determining background arsenic concentrations, broadening the data base, and testing equipment and field procedures to plan the Phase II effort.

Surface water and sediment samples were obtained from a total of 14 sampling stations in Phase I. The design of the program was to obtain core samples from most stations, however limited sample recovery at depth was realized. Therefore the field methods were modified for Phase II.

Phase II

The objective of the Phase II field program was to obtain sufficient data to perform a semiquantitative risk assessment and a feasibility study for potentially contaminated sediments in the Blackwater Branch and the upper Maurice River. In the lower Maurice River, the objective was to obtain sufficient data to perform a qualitative risk assessment. Samples were obtained at stations that had elevated arsenic concentrations in sediments in the NJDEP 1979 study. The sampling methodology differed between the two portions of the study area according to the differing data needs:

- Blackwater Branch and Upper Maurice River

  (1) Sediment core samples were obtained from the Phase I stations and from several additional stations to estimate the depth and spatial distribution of contamination in the sediments for the FS. In most cases two cores were obtained from each station, with samples obtained from 0-1, 1-2, and 2-3 feet within the sediment column from each core. In many of the upper Maurice River stations more cores were obtained, up to seven at a station, to improve the quantity estimates of potentially contaminated sediments.

  (2) Surface water flows were obtained concurrently with surface water sampling to estimate the arsenic load in the system, and were measured on a single day to determine the relative flow magnitudes within the basin.

  (3) Fish samples were obtained to provide data for the fish ingestion pathway for the semiquantitative risk assessment.

- Lower Maurice River

  (1) Sediment grab samples were obtained with a dredge to determine the surface sediment arsenic concentration at stations that had elevated arsenic concentrations in 1979. The sampling was confirmational, not designed to give detailed estimates of contamination quantity.

  (2) Surface water samples were obtained concurrently with the sediment samples, but flows were not obtained. Surface water samples were taken with a Kemmerer sampler to determine the water quality at depth in the water column. Surface water samples were obtained at the surface in the Blackwater Branch and the upper Maurice River because the water was shallow (less than 3 feet deep).

  (3) Fish samples were obtained, as were samples of crabs and oysters, because the latter two are common in this estuarine system.

All Phase II sediment and water samples were split with ViChem. ViChem personnel declined to participate in or observe the sampling procedures. All splits were prepared in the field by Ebasco personnel, who filled the appropriate ViChem-supplied bottles with the appropriate sample aliquots. Ebasco logged and labeled the samples, and transferred custody to ViChem periodically. ViChem declined to receive split samples of the fish, crabs, or oysters. ViChem did not receive split samples in Phase I.

1.3.3 Bench-Scale Treatability Studies

To evaluate the applicability and suitability of technologies for remedial action, two bench-scale treatability tests were performed. The first was chemical fixation of arsenic in sediment. The second was chemical extraction of arsenic from sediment.

The sediment fixation test was performed to confirm whether the arsenic in the sediment could be chemically stabilized or physically bound to the sediment, such that total leachable arsenic was reduced to a level below the EP RCRA Toxicity Test threshold of 5 mg/l. At the time the tests were performed it was assumed that the arsenic contaminated sediment would be considered nonhazardous and could be suitable for disposal in a nonhazardous waste landfill if they achieved this level. A description of these tests and their results are presented in Section 7.1.

The chemical extraction tests were performed to obtain performance data on the extraction of arsenic oxides and methylated arsenic oxides from sediment. The performance criterion established for the tests required that the treated

sediment contain a total arsenic concentration below 20 mg/kg, which is considered to be the background arsenic concentration in New Jersey soil. At the time the tests were performed it was assumed that if the sediments achieved this level, the treated sediments would be considered nonhazardous and could be suitable for disposal in a nonhazardous waste landfill. The extraction tests and results are described in Section 7.2.

Subsequent to these tests, the USEPA issued guidance on the criteria for nonhazardous disposal of the treated sediments (fixated or extracted). These criteria are discussed in detail in the River Areas FS (Ebasco, 1988d).

1.3.4 Risk Assessment

A risk assessment was performed using the basic methodology described in the Superfund Public Health Evaluation Manual (USEPA, 1986). Data from field sampling (see Section 2 for details) were used to evaluate exposure estimates for local residents and recreational users of the rivers. Exposure pathways and assumptions used are described in detail in Subsection 6.3.

Two types of risk assessments were performed. In the Blackwater Branch and the upper Maurice River, a semiquantitative assessment of the health risks to potentially exposed populations was prepared. This method attempts to quantify risks to exposed populations and compares them to known standards. In the lower Maurice River, a qualitative risk assessment was performed. Risk calculations were not performed, but exposure pathways and contaminant levels were evaluated to qualitatively evaluate the potential health risks to exposed populations.

1.4 OVERVIEW OF THE REMEDIAL INVESTIGATION REPORT

This RI report is comprised of eight sections. The Introduction, Section 1.0, provides background information regarding site location and physiography, facility history and operation, waste discharges, and community concerns. The nature and extent of the problem, as identified through previous studies, is presented in this section. A summary of the RI, identifying the activities of each major component, is also provided.

Section 2.0, Study Area Investigations, provides a detailed description of the river areas field investigation and general information of the demography, land use, climatology and cultural resources in the vicinity of the Maurice River.

Section 3.0, Physical Characteristics of the Study Area, provides a discussion of the surface water flow characteristics of the Maurice River, presents a water balance and discusses the river's flood plain, presents a summary of the grain sizes of the sediments and the types of soil near the river, and identifies the types of biota sampled during the investigation.

VIN 009 0009

Section 4.0, Nature and Extent of Contamination, describes the types and levels of contaminants found in the various media sampled during the RI.

Section 5.0, Fate and Transport of Arsenic, describes the geochemistry and other factors that influence the movement of the main contaminants found in the river system.

Section 6.0, Baseline Risk Assessment, presents the risks calculated for various scenarios of exposure to the sediment, surface water, and fish in the Blackwater Branch and the upper Maurice River and qualitatively discusses potential health risks to exposed populations from the lower Maurice River.

Section 7.0, Bench-Scale Treatability Tests, presents the results of the treatability studies performed on the sediments.

Section 8.0, Summary and Conclusions, presents a brief summary of each major component of the RI, discusses the limitations of the data, makes recommendations for future work, and recommends remedial response objectives.

This report contains 12 appendices:

Appendix A presents the chemical analytical data from Ebasco's Phase I field investigations.

Appendix B presents the Phase II analytical data.

Appendix C presents water balance calculations.

Appendix D presents the Phase II stream flow rate calculations.

Appendix E presents the risk assessment calculations for arsenic.

Appendix F presents the laboratory results of the sediment fixation treatability tests.

Appendix G presents the laboratory results of the sediment extraction treatability studies.

Appendix H presents toxicity profiles and general fate and transport information for the main contaminants found in the river areas.

Appendix I presents stream cross-sections showing the sediment core arsenic concentrations.

Appendix J presents statistical analyses of the correlations between arsenic, iron, TOC, and grain size within the sediment samples obtained in the river areas.

VIN 002 0605

Appendix K presents some water quality analyses performed for the City of Millville's public water supply system.

Appendix L presents the biological assessment of the Blackwater Branch and the upper Maurice River prepared by the USEPA's Environmental Response Team.

Appendix M presents the NJDEP's 1979 surface water and sediment data from the Blackwater Branch and the Maurice River.

VIN 082 0606

UIN 002 0607

2.0 STUDY AREA INVESTIGATIONS

2.1 SITE FEATURES INVESTIGATIONS

The Blackwater Branch flows approximately one and a half miles from the ViChem Plant to the Maurice River. The Maurice River then flows approximately 7 miles south to Union Lake which is approximately 2 miles long. The Maurice River flows approximately 25 miles south from the Union Lake dam to Delaware Bay. The total drainage basin area of the Maurice River above the Delaware Bay is approximately 380 square miles.

The focus of the site features investigation for this RI was on towns and villages in proximity to the Maurice River. Following a detailed evaluation of 1980 census data, the lack of block statistics for individual towns caused the investigation to include the entirety of Census Tract 101, Maurice River Township and Census Tract 102, Commercial Township.

2.1.1 Demography

Maurice River Township is located southeast of the Vineland - Millville metropolitan area and is bordered by the Maurice River on the west, Atlantic and Cape May Counties on the east and Delaware Bay on the south. The township encompasses a total land area of approximately 94.7 square miles, making it the largest township division in Cumberland County, and has a total population of 4,577 (U.S. Bureau of Census, 1980). This number represents a 22.3% increase in population over the 1970 census. Maurice River Township encompasses 18.9% of total Cumberland County land area and 3.4% of total county population, making Maurice River Township the second least densely populated township within Cumberland County (U.S. Bureau of Census 1980). There are a total of 1202 households within Maurice River township, and 100% of the township is classified as rural (U.S. Bureau of Census, 1980).

Approximately 80% of the population reside within one mile of the Maurice River in, or in proximity to, the towns of Port Elizabeth, Bricksboro, Dorchester, Leesburg, and Heislerville. Block Statistics were not available for the aforementioned towns.

Commercial Township, Census Tract 102, is located southwest of the Vineland-Millville metropolitan area and is bordered by the Maurice River on the east, Downe Township on the west, and Maurice River Cove on the south. The township encompasses a total area of approximately 34.0 square miles, making it the fifth largest township division within Cumberland County, and

IN002 0608

has a total population of 4,674 (U.S. Bureau of Census 1980). This number represents a 27.5% increase in population over the 1970 census. These figures represent 6.8% of total county land area and 3.5% of total county population, respectively, making Commercial Township one of the most densely populated divisions within Cumberland County. There are 1,583 households within the township, with 67.4% of the township classified as rural and 32.6% classified as urbanized (U.S. Bureau of Census, 1980). Approximately 80% of the population live within one mile of the Maurice River in, or in proximity to, the towns of Brickshutem, Mauricetown, Port Norris, and Bivalve.

2.1.2 Land Use

Maurice River Township and Commercial Township are located in the southernmost portion of Cumberland County. The townships are bordered by Vineland and Millville to the north, the Delaware Bay to the south, Cape May and Atlantic Counties to the east, and Downe Township to the west. Maurice River and Commercial Township are separated by the Maurice River, with Maurice River Township located to the east of the river.

Maurice River Township is comprised of approximately 25% Public (P) and 20% Conservation (C) land, according to the Maurice River Township Zoning Ordinance No. 303, July 1982. Principal uses for land zoned as Public and Conservation are: water, forest, and wildlife conservation areas; agricultural or forestry research centers; parks and playgrounds; and other similar recreational uses. The following is a list of these areas throughout Maurice River Township.

Heislerville Fish and Wildlife Management Area - situated in the southern portion of the township bordering the Maurice River and Delaware Bay. The area consists of approximately 2682 acres of wooded bay shore land and is dedicated to hunting, fishing, hiking, and wildlife preservation.

Corson Fish and Wildlife Management Area - situated on the Delaware Bay adjacent to the Heislerville Fish and Wildlife Management Area. The area consists of approximately 461 acres, which are divided into woodland and wetland parcels.

Peaslee Fish and Game Tract - situated in northeast Maurice River Township. The tract encompasses approximately 9,555 acres, which are dedicated to hunting, fishing, hiking, wildlife protection and water conservation.

VIN002 0607

Belleplain State Forest, Cape May County - situated in the eastern portion of Maurice River Township and in adjacent Cape May County. The area consists of approximately 508 acres of undeveloped forest in Maurice River Township dedicated to hunting and fishing.

Other land use zone districts, comprising a lesser portion of Maurice River Township, includes Residential (R-1, minimum lot size 1 acre), Residential (R-5, minimum lot size 3 acres), General Industry (M-3, minimum lot size 3 acres), Light Industry (M-2, minimum lot size 2 acres), and Resource Industry (M-1, minimum lot size 5 acres). The Bayshore State Prison Farm, located outside of Leesburg, is zoned as Public (P) land according to the July 1982 ordinance, and encompasses a land area of over 1,000 acres.

Commercial Township is located immediately adjacent to the Maurice River on the west. According to the Commercial Township Zoning Ordinance No. 79-190, February 1979, the township is comprised of approximately 60% Residential Agriculture (R-A, minimum lot size of 1 acre for Single Family units, and 5 acres for Farm uses), and 26% Commercial Recreation (CR, minimum lot size 3 acres).

Commercial Township has two major Commercial Recreation (CR) areas. They are:

Turkey Point Fish and Wildlife Management Area - Bayshore Wetlands - located in the southern portion of Commercial Township on the Delaware Bay. The area consists of approximately 1,611 acres of undeveloped fish, game, and wildlife preserve.

Edward C. Bevan Fish and Wildlife Management Area - this area comprises portions of Lawrence, Downe, Millville, and Commercial Townships with approximately 4,000 acres located in Commercial Township. The Edward C. Bevan Fish and Wildlife Management Area is one of the largest fish and game areas in the state. This mostly wooded area is used primarily for hunting and fishing.

Land use zone districts comprising the remaining (14%) of the township include Residential R-1 (minimum lot size 0.5 acres), Residential R-2 (Garden Apartments and Townhouses, minimum lot size 15 acres), Business District (B-1, minimum lot size 0.5 acres), and Industry-General (I-G, minimum lot size 5 acres).

Overall, Maurice River Township and Commercial Township comprise approximately 82,368 acres, of which 16,698 acres (20.3%) are dedicated to fish and wildlife management. Approximately 10% of these 16,698 acres have been classified as either brackish or fresh water wetlands, and are included within the State of New Jersey Coastal Area Facilities Review Act (CAFRA) boundaries.

In addition, approximately 90% of the land in Maurice River Township zoned as Residential (R-5), General Industry (M-3), Light Industry (M-2), and Resource Industry (M-1), as well as land in Commercial Township zoned as Residential (R-1, R-2), Business (B-1), and Industry-General (I-G), lie within one mile of the 19.2-mile stretch of the Maurice River from Laurel Lake south to the mouth of Delaware Bay.

Both Maurice River and Commercial Townships are served by one principal arterial, NJ State Route 47, as well as a network of principal county roads. This network connects with other major and minor arterials to serve the areas directly north consisting of Vineland-Millville-Bridgeton, which provide major transportation links to other major north-south transportation corridors in the Philadelphia-Camden area.

Rail service is provided in Commercial Township by Conrail and in Millville by the Pennsylvania-Reading Seashore line. Limited private and commercial air service is provided by the Millville Airport, located north of Commercial Township, just south of the Millville Central Business District.

2.1.3 Natural Resources

In May 1987, federal legislation was enacted authorizing the study of the Maurice River, as well as other Cumberland County rivers, as potential additions to the National Wild and Scenic Rivers System.

The 1968 Wild and Scenic Rivers Act (Public Law 90-542) establishes a framework whereby the nation's outstanding rivers are protected. As eligibility requirements, the river must be relatively free-flowing, comparatively undeveloped, and possess at least one outstanding natural, scenic, recreational or historical value.

As previously discussed, approximately 20.3% of the land in Commercial and Maurice Townships is zoned as Commercial Recreation (CR), Public (P), and Conservation (C). These areas are defined as open space by the New Jersey Coastal Management Program maintained by federal, state, county, and municipal agencies, and nonprofit groups; and wetlands as delineated by the U.S. Department of Interior, National Wetlands Inventory (NWI).

The watershed open space and wetland zones contain intertwined upland and hardwood swamp forests and freshwater nontidal wetlandsm with the forested areas consisting of broad-leaved

UIN002 0611

deciduous trees, broad-leaved evergreen, and needle-leaved evergreen; and the emergent areas consisting of broad and narrow-leaved persistent and nonpersistent species, with soils predominantly sandy with organic horizons.

The drainage basin open space and wetland zones of intertidal marshes ranging from freshwater to brackish consist of a blend of persistent and nonpersistent, and vegetated and nonvegetated, pioneer species.

Maurice River and Commercial Townships, specifically the open space and wetland areas in contact with the Maurice River and its drainage basin, support a vast array of vegetation, wildlife, animal and reptile species, and fishery resources. Many species are listed on the Federal and State threatened or endangered lists. Table 2-1 provides a list of threatened and endangered species that are confirmed to inhabit or have historically inhabited the Maurice River and its watershed.

Just north of Mauricetown, in the Muskee Creek area, is New Jersey's largest single stand of wild rice, Zinzania aquatica, which is an important area for migratory stopover and overwintering of waterfowl. Between there and Mauricetown, the wetlands gradually change from freshwater to brackish. South of this area, the marshes include a mixture of plants dominated by salt meadow grass, Spartina peltantra virginica. In addition, the river's vast tidal mud flats, marshes, and high water quality support the single-largest concentration of shore birds in North America which gather enroute to the Arctic.

The lower Maurice River is considered to be the most reliable oyster setting bed in New Jersey. The oyster, Crassostrea virginica, is a shellfish, which historically supported a major industry in the area. Oyster production severely declined in 1956 when an oyster blight severely curtailed production. However, the area continues to be a major spawning and production area. Fish species historically inhabiting the area include the American sturgeon, the short-nose sturgeon, and the American Shad. The Maurice River is a key nursery and spawning area for most of the recreationally important species of the Delaware Bay.

2.1.4 Climatology

Available climatological data were obtained from cooperative weather stations maintained by the National Weather Service in Vineland (precipitation and wind) and Bridgeton (temperature). The Vineland station has accumulated data since 1885, while the Bridgeton station has data dating back to 1894.

Vineland receives approximately 45 inches of rainfall per year. Monthly averages range from 3.46 inches in April to 5.21 inches in August. During an average year, Vineland can expect 77 days

VIN 002 0612

TABLE 2-1

THREATENED AND ENDANGERED SPECIES
MAURICE RIVER BASIN

FLORA	STATUS
Sensitive joint vetch, *Aeschynomene virginica*	Federal endangered
Parker's pipework, *Eriocaulon parkeri*	Federal endangered
Sedge, *Carex barrattii*	Federal endangered
Boneset, *Eupatorium resinoeum*	Federal endangered
Bur marigold, *Bidens bidenoids*	Federal endangered
Butterfly pea, *Clitoria marine*	Federal endangered
FAUNA	
Bald Eagle, *Haliaetus eucocephalus*	Federal & State Endangered
Pergrene Falcon, *Falco peregrinus*	Federal & State Endangered
Pied-billed Grebe, *Podilymbus podiceps*	State endangered
Least Tern, *Sterna albifrons*	State endangered
Cooper's Hawk, *Accipter cooporii*	State endangered
Northern Harrier, *Circus cyaneys*	State endangered
Osprey, *Pandion haliaetus*	State threatened
Barred Owl, *Strix varia*	State threatened
Red-Headed Woodpecker, *Melanerpes erythroephalus*	State threatened
Red-Shouldered Hawk, *Buteo lineatus*	State threatened
Boblink (Reedbirds), *Dolichonyz orzlvorus*	State threatened
Great Blue Haron, *Ardea herodias*	State threatened
REPTILES	
Pine Snake, *Pituophis mananoleucus*	State threatened
Corn Snake, *Elaphequttata*	State endangered
Pine Barrens Treefrog, *Hyla andersonii*	State endangered
Southern Gray Treefrog, *Hyla chrysoscelis*	State endangered
Eastern Tiger Salamander, *Amboystoma tigrinum*	State endangered
FISH	
Atlantic Sturgeon, *Acipenser fulvescens*	State threatened
Short-nose sturgeion, *Acipenser brevirostrum*	Federal endangered
American Shad, *Alosa pseudoharengus*	State threatened

VIN 0082 0615

of precipitation in excess of 0.1 inches, with 30 of those days exceeding 0.5 inches. Mean snowfall amounts to 18.6 inches, with the maximum occurring in February (6.4 inches).

No temperature data are available for Vineland proper, but Bridgeton (12 miles WSW of Vineland) has a mean annual temperature of 54.7 degrees Fahrenheit. The mean maximum and minimum annual temperature are 65.0 and 44.6 degrees Fahrenheit, respectively, and the lowest temperature was -12 degrees Fahrenheit. The average growing season is 170 days, and the average dates of the last and first killing frosts are April 15 and October 25, respectively.

Although detailed wind information is not available for the site, the predominant wind flow from October through April is from the northwest. From May through August the dominant flow is out of the southwest, and during September the wind is from the southeast.

2.1.5 Cultural Resources

Commercial Township is home to numerous sites of cultural/historical significance. There are 34 structures from Mauricetown listed on the Cumberland County Register of Historical Structures and Sites. However, only one of these structures is listed in the official New Jersey Register of Historical Places and the National Register of Historical Places. Table 2-2 lists historical structures recognized by Cumberland County and the National Register of Historic Places.

There are numerous sites in Maurice River Township with historical/cultural significance that are on the Cumberland County Register. However, none of these structures are listed on the National Register of Historic Places. Of particular interest is the Port Elizabeth Friend's Cemetery. A church built prior to 1709 no longer exists, but the cemetery is the resting place of the founder of Port Elizabeth, Quaker Elizabeth Bodley.

2.2 SURFACE WATER INVESTIGATION

The field investigation was conducted in two phases. Phase I took place in June and July of 1986. Phase II took place in June, July, and August of 1987. The Phase I analytical results are presented in Appendix A, with the Phase II results presented in Appendix B. Appendix I presents cross sections of the stations sampled in Phase II showing the water depth.

The primary objective of the surface water investigation was to repeat sampling at stations previously sampled by the NJDEP in 1979. Secondary objectives were to obtain data for the Public Health Evaluations, and to obtain data to determine the arsenic load in the surface water system.

VIN 002 0647

TABLE 2-2

HISTORIC STRUCTURES AND SITES

National Register of Historic Places	Year Constructed
Ceasar Hoskins Cabin, Mauricetown	Circa 1700
Cumberland County Register of Historic Sites and Structures	
Mauricetown Academy, Mauricetown	1860
Birthplace of Dallas Lone Sharp - Naturalist, Mauricetown	1862
Marines Memorial Window, Mauricetown United Methodist Episcopal Church, Mauricetown	1980
Site of Revolutionary War Battle of Dallas's Landing, Mauricetown	1781
Captain Charles Sharp House, Mauricetown	Circa 1862
Cashier "Oyster" Boat, Port Norris	1849
Iron Bridge, Mauricetown	1888
George Compton House, Mauricetown	Circa 1820
Captain Samuel Sharp House, Mauricetown	Circa 1862
David Compton House, Mauricetown	1815
Captain Isaac Peterson House, Mauricetown	Circa 1868
Benjamin Tomlin House, Mauricetown	Circa 1880
Samuel Compton House, Mauricetown	Circa 1822
Mauricetown Methodist Episcopal Church	1880
Mosie Bateman/T. Buckaloo House, Mauricetown	1828/1862
Seth Bowne House, Mauricetown	Circa 1860
The Farry House/Patty's Place, Buckshutem	1830
J.E. Avis House, Mauricetown	1861
William Henry Phillips House, Mauricetown	1963
Vashti Sharp House, Mauricetown	Circa 1872

TABLE 2-2 (Cont'd)

HISTORIC STRUCTURES AND SITES

National Register of Historic Places	Year Constructed
Port Elizabeth Friend's Cemetery, Port Elizabeth	1709
David Lorn House, Mauricetown	Circa 1862
George Fagen House and Store, Mauricetown	Circa 1862
Mauricetown Post Office	1862-1876
Samuel Butcher House, Mauricetown	1799
Captain Charles Haley House, Mauricetown	Circa 1862
Captain Abel Haley House, Mauricetown	Circa 1876
Captain Alfred Haley House, Mauricetown	Circa 1870
J. Melton Compton House, Mauricetown	1880
Samuel Cobb House, Mauricetown	1853
John Bowen House, Mauricetown	Circa 1862
Daniel B. Compton House, Mauricetown	1857
Ichabod Compton, Jr. House, Mauricetown	1812

VIN 002 0616

2.2.1 Phase I

2.2.1.1 Sampling Locations

In Phase I, 19 surface water samples were taken from the sampling locations labeled as ER-__ and shown in Figure 2-1. Table 2-3 lists the types of samples obtained and the analyses performed.

Sampling was conducted at stations that showed elevated arsenic concentrations in the 1979 sampling conducted by the NJDEP. The criterion was to obtain samples at those locations where the sediment arsenic concentration exceeded that observed at station ER-6 on the Maurice River upstream from the Blackwater Branch confluence.

Samples were obtained from the Blackwater Branch upstream and downstream of ViChem Plant and from the Maurice River upstream of the Blackwater Branch to slightly below Union Lake. Samples were also obtained from several Maurice River tributaries, including Little Robin Branch, Parvin Branch, and Mill Creek.

2.2.1.2 Sampling Methods

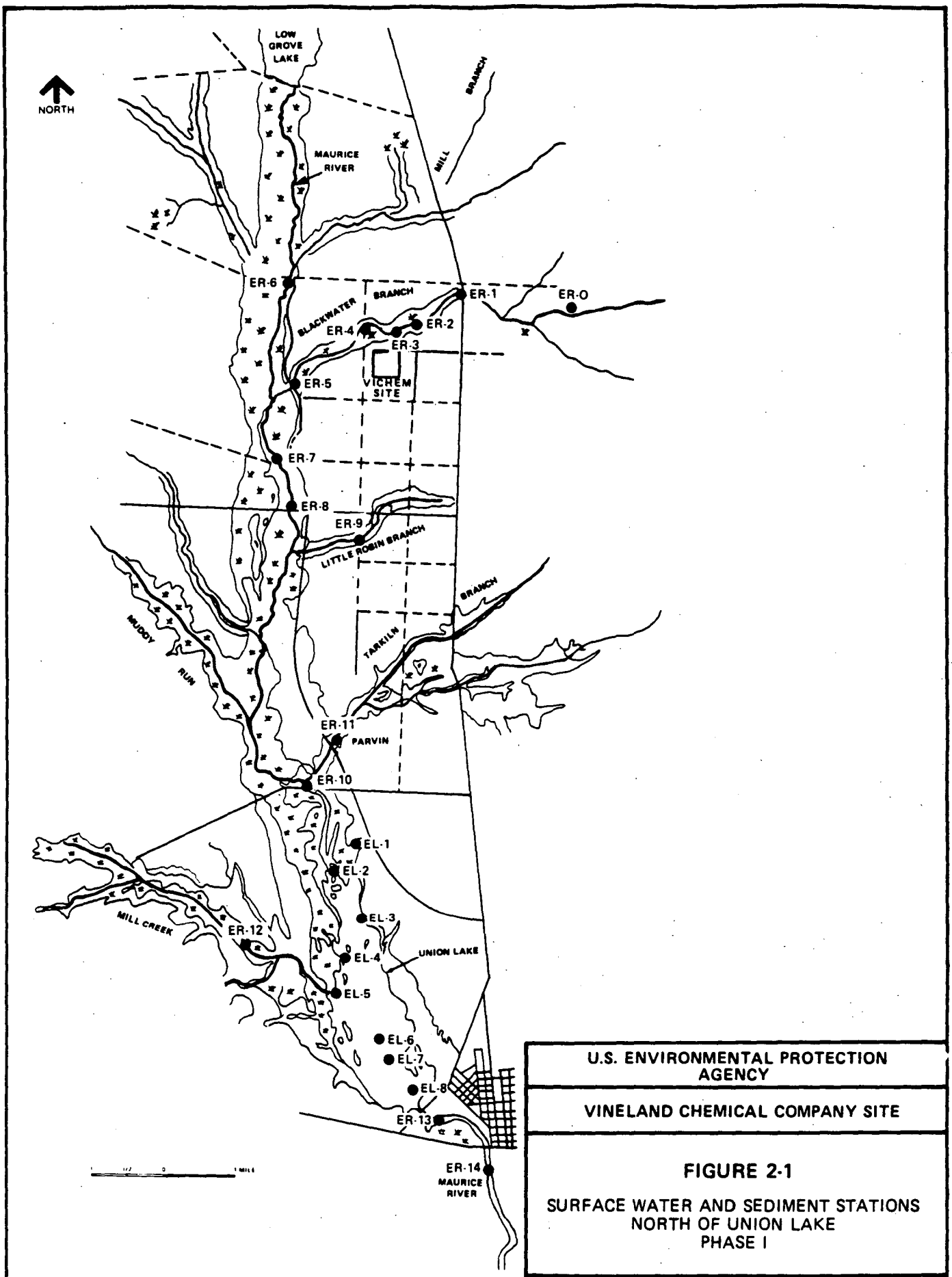
Samples were obtained either at the surface of the water column or at depth as shown in Table 2-3. In general the water was shallow (less then three feet deep), particularly in the tributaries to the Maurice River, so most samples were taken at the surface.

Surface samples were taken with stainless steel buckets or beakers. Aliquots for the various analyses were poured from these containers.

Water samples at depth were taken with Kemmerer samplers. The water depth at the station was measured, the opened sampler was lowered to the desired sampling depth, then the messenger was sent to close the sampler and obtain the sample from the desired interval. Aliquots for the various analyses were poured from these samplers.

The Phase I samples were analyzed for particulate and dissolved arsenic and iron. Some samples were also analyzed for inorganics and volatiles on the Hazardous Substance List (HSL).

The aliquots analyzed for particulate and dissolved arsenic and iron were filtered through a filter with 0.45 um pores in the field. The first 20 milliliters (ml) of filtrate passed through each filter were discarded. The remainder of the filtrate was preserved with nitric acid to a pH of 2 or less. Both the filtrate and the filter were sent to a CLP laboratory for total arsenic and iron analyses.



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 2-1

SURFACE WATER AND SEDIMENT STATIONS
NORTH OF UNION LAKE
PHASE I

EBASCO SERVICES INCORPORATED

UIN 002 0618

TABLE 2-3

PHASE I SAMPLE SUMMARY FOR SAMPLES COLLECTED FROM BLACKWATER BRANCH, MAURICE RIVER, LITTLE ROBIN BRANCH, PARVIN BRANCH AND MILL CREEK

		Sediment Samples			Water Samples		
			Analyses			Analyses	
Surface Stream	Sample Location	Description of Samples (all 0-1 Foot)	Total As, Fe & TOC	HSL Metals & VOAs	Description Of Samples	Particulate & Dissolved As & Fe	HSL Metals & VOAs
Blackwater Branch	ER-0	3 colocates	3		1 triplicate surface	3	
	ER-1	2 colocates	2	2	1 surface	1	
	ER-2	1 sample	1	1	1 surface	1	1
	ER-3	1 sample	1		1 surface	1	
	ER-4	3 colocates	3	3	3 surface colocates	3	3
	ER-5	1 sample	1		1 surface	1	
Maurice River	ER-6	1 sample	1	1	2 colocated surface, 1 bottom	3	2
	ER-7	2 colocates	2		1 surface, 1 bottom	2	2
	ER-8	1 sample	1		1 split sample (bottom)	2	
Little Robin Branch	ER-9	1 split sample	2		1 surface	1	
Maurice River	ER-10	1 sample	1		2 colocated surface, 1 bottom	3	2
Parvin Branch	ER-11	2 colocates	2	2	1 surface	1	1
Mill Creek	ER-12	2 colocates	2		1 surface	1	
Maurice River	ER-13	not sampled			1 surface	1	1
	ER-14	not sampled			1 surface	1	1
	TOTAL	21 sediments	22	9	19 water	25	13

The aliquots analyzed for total HSL inorganics and volatiles were not filtered. The aliquots were poured directly from the sampling devices into the appropriate sample bottles. The total HSL inorganics aliquots were preserved with nitric acid to a pH of 2 or less, while the VOA aliquots were preserved with sodium thiosulfate.

Certain field tests were performed on the Phase I water samples. These included pH, Eh, specific conductance, dissolved oxygen, salinity, and temperature. These are discussed in Section 5.0, Fate and Transport of Arsenic.

2.2.2 Phase II

2.2.2.1 Sampling Locations

Water samples were taken from 40 stations in Phase II. Ten stations are on the Blackwater Branch, shown in Figure 2-2 and summarized in Table 2-4. Thirteen stations are on the Maurice River and tributaries north of Union Lake, shown in Figure 2-2 and summarized in Table 2-5. The remaining 17 stations are on the lower Maurice River south of Union Lake to the Delaware Bay, shown in Figure 2-3 and summarized in Table 2-6.

The majority of these sampling stations were previously sampled by NJDEP. Three upstream stations, ER-0A, ER-0B, and ER-0C were added to yield additional upstream data. In addition, ER-6A, -9A, -9B, -9C, -9D, -9E, -9F, and -10A were sampled to provide additional data for the FS. Station ER-9B was dry and was therefore not sampled during Phase II.

2.2.2.2 Sampling Methods

The water samples were collected upstream from Union Lake by dipping the appropriate sample bottle into the stream, except for the dissolved arsenic aliquot. This was obtained with a stainless steel beaker, with the aliquot poured from the beaker into the filtering apparatus.

The water samples downstream from Union Lake were taken with a Kemmerer sampler by the same procedure mentioned previously. All aliquots were poured from the Kemmerer sampler.

The water samples collected upstream from Union Lake were all analyzed for dissolved arsenic, total (unfiltered) HSL inorganics, and HSL volatiles. Some samples were also analyzed for HSL extractable organics and pesticides/PCBs, as shown in Tables 2-4 and 2-5. The water samples collected downstream from Union Lake were all analyzed for dissolved arsenic and total (unfiltered) HSL inorganics.

UIN 008 0680

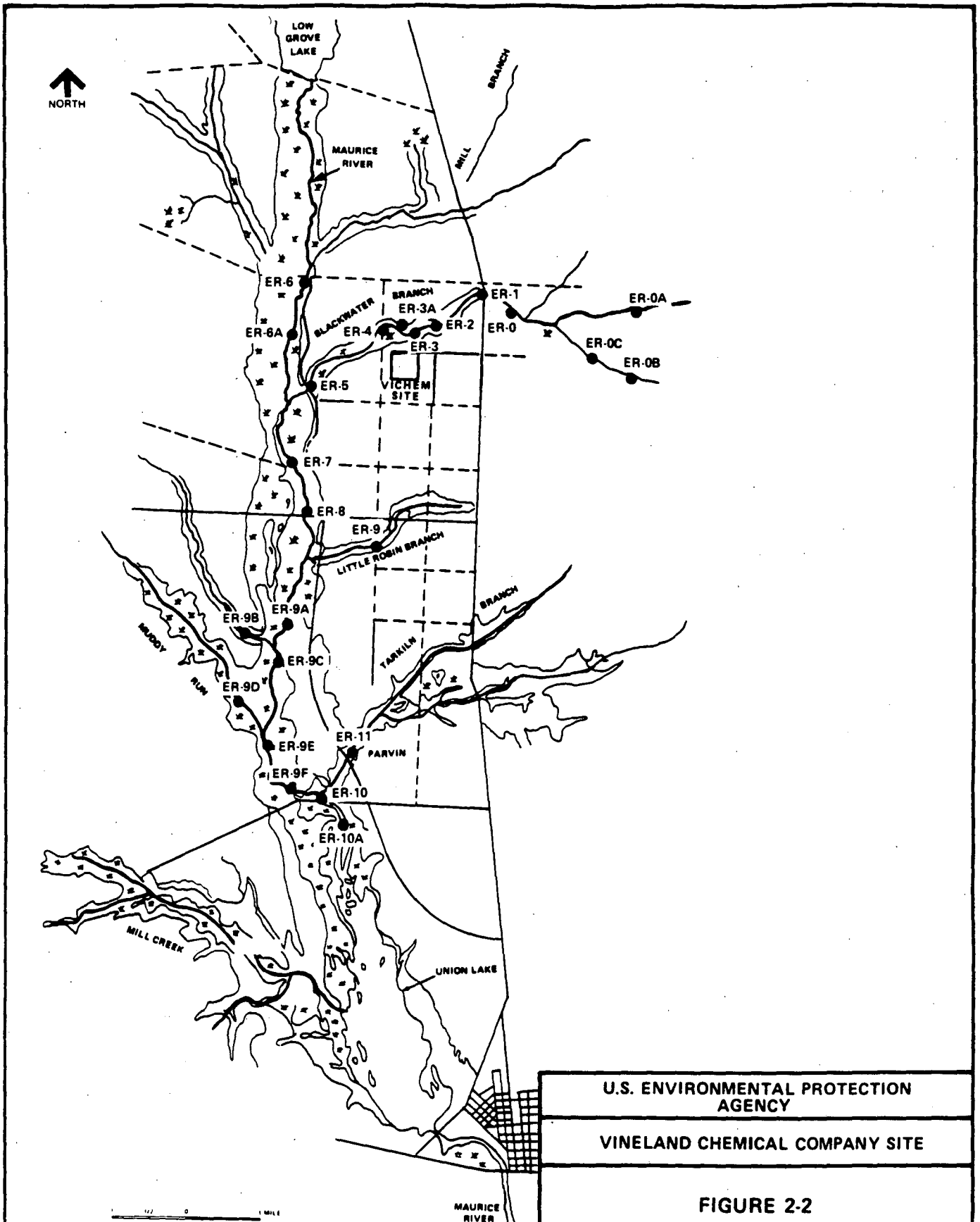
TABLE 2-4

WATER SAMPLE ANALYTICAL SUMMARY FOR THE
BLACKWATER BRANCH PORTION OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION
PHASE II

STATION NUMBER	SAMPLE ID	LOCATION	DISSOLVED ARSENIC	HSL POLLUTANTS			
				EXTRACTABLE	INORGANIC	VOA	PES/PCB
ER-0	ER0-W	Blackwater Branch - Upstream	1	1	1	1	1
ER-0A	ER0A-W	Blackwater Branch - Upstream	1	1	1	1	1
ER-0B	ER0B-W	Blackwater Branch - Upstream	1	1	1	1	1
ER-0C	ER0C-W	Blackwater Branch - Upstream	1	1	1	1	1
ER-1	ER1-W	Blackwater Branch - Upstream	1	1	1	1	1
ER-2	ER2-W	Blackwater Branch - Upstream	2*		1	1	
ER-3	ER3-W	Blackwater Branch - Upstream	1		1	1	
ER-3A	ER3A-W	Blackwater Branch At Site	1	1	1	1	1
ER-4	ER4-W	Blackwater Branch At Mill Road	1	1	1	1	1
ER-5	ER5-W	Blackwater Branch - Downstream	1		1	1	
			11	7	10	10	7

Notes: * Includes 1 duplicate sample.

1990 -700 NIA



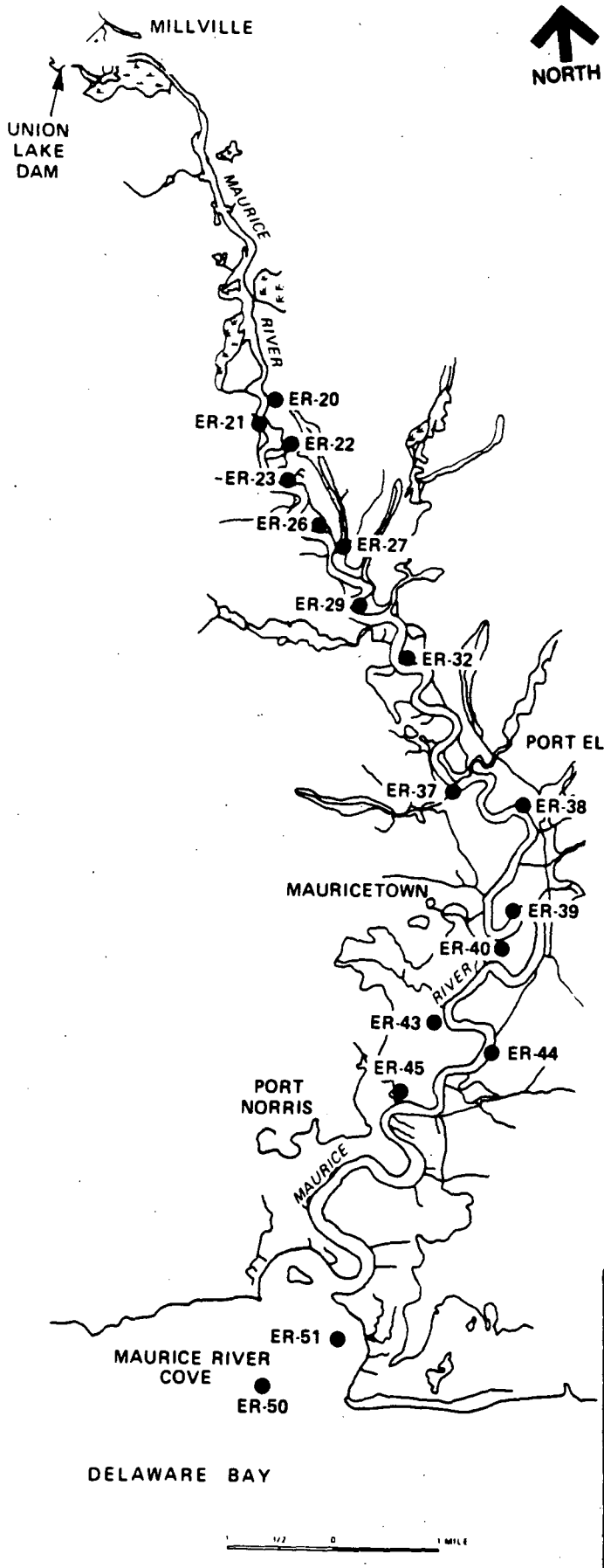
U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 2-2

SURFACE WATER AND SEDIMENT STATIONS
NORTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 2-3

SURFACE WATER AND SEDIMENT STATIONS
SOUTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED

UIN 002 0625

TABLE 2-5

WATER SAMPLE ANALYTICAL SUMMARY FOR THE
UPPER MAURICE RIVER PORTION OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION

PHASE II

STATION NUMBER	SAMPLE ID	LOCATION	DISSOLVED ARSENIC	HSL EXTRACTABLE	HSL INORGANIC	HSL VOA	PES/PCB
ER-6	ER6-W	Maurice River-Upstream	1		1	1	
ER-6A	ER6A-W	Maurice River-Upstream	2*	2*	2*	2*	2*
ER-7	ER7-W	Maurice River-Almond Road	1	1	2*	2*	1
ER-8	ER8-W	Maurice River-Garden Road	1		1	1	
ER-9	ER9-W	Little Robin Branch	1	1	1	1	1
ER-9A	ER9A-W	Maurice River-Downstream	1		1	1	
ER-9C	ER9C-W	Maurice River-Downstream	1	1	1	1	1
ER-9D	ER9D-W	Muddy Run	1	1	1	1	1
ER-9E	ER9E-W	Maurice River-Downstream	1	1	1	1	1
ER-9F	ER9F-W	Maurice River-Downstream	1		1	1	
ER-10	ER10-W	Maurice River-Downstream	1		1	1	
ER-10A	ER10A-W	Maurice River-Downstream	1	1	1	1	1
ER-11	ER11-W	Parvin Branch	1	1	1	1	1
			14	9	15	15	9

Notes: * Includes 1 duplicate sample.

TABLE 2-6

WATER SAMPLE ANALYTICAL SUMMARY FOR THE
LOWER MAURICE RIVER PORTION OF THE
VINELAND CHEMICAL COMPANY SITE

PHASE II

STATION NUMBER	LOCATION	HSL POLLUTANTS	
		DISSOLVED ARSENIC	INORGANIC
ER-20	Lower Maurice River	1	1
ER-21	Lower Maurice River	1	1
ER-22	Lower Maurice River	1	1
ER-23	Lower Maurice River	1	1
ER-26	Lower Maurice River	1	1
ER-27	Lower Maurice River	1	1
ER-29	Lower Maurice River	1	1
ER-32	Lower Maurice River	2*	2*
ER-37	Lower Maurice River	1	1
ER-38	Lower Maurice River	1	1
ER-39	Lower Maurice River	1	1
ER-40	Lower Maurice River	1	1
ER-43	Lower Maurice River	1	1
ER-44	Lower Maurice River	1	1
ER-45	Lower Maurice River	1	1
ER-50	Delaware Bay	1	1
ER-51	Delaware Bay	1	1
		18	18

Notes: * Includes 1 duplicate sample.

The dissolved arsenic aliquots were filtered in the field and preserved with nitric acid. Only the filtrate was analyzed. Single-use, disposable plastic filter apparatuses were used in Phase II, elminating the need to discard a portion of the filtrate. The total inorganics aliquots were not filtered, and were preserved with nitric acid. The remaining aliquots were not preserved. All aliquots were iced prior to shipment.

Certain field tests were performed on the water samples. These included pH, specific conductance, dissolved oxygen, salinity and temperature. These results are discussed in Section 5, Fate and Transport of Arsenic.

The flows at certain stations were measured during Phase II. The flows were measured twice; once when a water sample was taken and once on a single day when the flows were all determined relative to one another. These measurements are discussed in Subsection 3.1.1.

2.3 SEDIMENT INVESTIGATION

2.3.1 Phase I

2.3.1.1 Sampling Locations

Phase I sediment samples were obtained from stations on the Blackwater Branch and the Maurice River upstream of Union Lake. The locations are shown in Figure 2-1, with the analytical summary presented in Table 2-3.

Phase I samples were taken from stations sampled by NJDEP in 1979. The same upstream samples were obtained, ER-0, -1, -2, and -6. The downstream stations sampled were those that displayed arsenic concentrations greater than 23 mg/kg, the arsenic concentration of ER-6 in 1979.

The Phase I analytical results are shown in Appendix A, while the Phase II results are shown in Appendix B. Appendix I presents cross sections showing the stream geometry, depth of sediment, and arsenic concentrations at each sediment sampling station.

2.3.1.2 Sampling Methods

The samples were obtained with a WILCO corer with a stainless steel liner or a stainless steel split-spoon. The corer or split-spoon was pushed or hammered into the sediment to obtain the maximum depth of penetration.

The samples were removed from the liner or split-spoon, placed in stainless steel mixing bowls, then described visually. The cores were homogenized and samples were put into containers for TOC, total arsenic and iron, and HSL inorganics analysis, as necessary. Volatile samples were obtained from the cores before they were homogenized.

VIN 004 0026

The design of the Phase I program was to analyze samples from 0-1 feet and from 2-3 feet within the sediment column. This proved to be impractical because the sampler could not penetrate and hold samples at depth even in soft sediments. Therefore, the Phase I results represent sediment from approximately 0-1 feet within the sediment column.

2.3.2 Phase II

2.3.2.1 Sampling Locations

A total of 309 sediment samples were obtained from 40 stations in Phase II. The locations are shown in Figure 2-3. Tables 2-7, 2-8, and 2-9 display the analyses performed on the samples from the Blackwater Branch, Maurice River upstream of Union Lake, and Maurice River downstream of Union Lake, respectively.

The majority of the stations were previously sampled by the NJDEP in 1979. Three additional upstream stations, ER-0A, ER-0B, and ER-0C were added to obtain additional background data. Seven additional stations, ER-6A, -9A, -9C, -9D, -9E, -9F, and -10A, were added to aid in estimating the volume of contaminated sediments for the FS.

2.3.2.2 Sampling Methods

Sediment core samples were obtained upstream of Union Lake. Surface sediment grab samples were obtained downstream of Union Lake.

The core samples were obtained with a hand auger. In most cases two cores were obtained per station, one from each side of the stream. In some cases more cores were obtained to estimate the sediment volume for the FS. Each core taken was given a letter designation in Tables 2-7 and 2-8.

Three samples were obtained from each core; one from 0-1 foot, one from 1-2 foot, and one from 2-3 foot. The samples were obtained by augering to the design depth, removing the auger from the hole, and transferring the sediment to a stainless steel beaker. Then the auger was replaced in the hole and the next sample was obtained. In some cases less than three samples were obtained because of poor recovery at depth, as shown in Tables 2-6 and 2-7.

The sediment aliquots for arsenic and iron, grain size, TOC, HSL inorganics, extractables and pesticides/PCPs were homogenized before being placed into the sample bottles. The aliquots for HSL volatiles were taken before homogenizing.

The sediment samples taken from the Maurice River below Union Lake were taken with an Eckman dredge from the surface. One grab sample was obtained from each station. These samples were analyzed for arsenic and iron, TOC, and grain size, as indicated in Table 2-9.

VIN002-0627

TABLE 2-7

SEDIMENT SAMPLE ANALYTICAL SUMMARY FOR THE
BLACKWATER BRANCH PORTON OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION
PHASE II

STATION NUMBER	SAMPLE ID	CORE	SAMPLES PER CORE	DEPTH OF CORE (FT)	As/Fe	T.O.C	GRAIN SIZE	E.P. TOXICITY	HSL POLLUTANTS EXTRACTABLE	INORGANIC	VOA	PES/PCB
ER-0	ER0-A0,A1,A2	A	3	3	3	3	3	1				
	ER0-B0,B1,B2	B	3	3	4*	4*	4*		1	1	1	1
ER-0A	ER0A-A0,A1,A2	A	3	3	4*	4*	4*		1	1	1	1
	ER0A-B0,B1,B2	B	3	3	3	3	3					
ER-0B	ER0B-A0,A1,A2	A	3	3	3	3	3	1				
	ER0B-B0,B1,B2	B	3	3	2	3	3		1	1	1	1
ER-0C	ER0C-A0,A1,A2	A	3	3	2	3	3		2*	2*	2*	2*
	ER0C-B0,B1,B2	B	3	3	3	3	3	1				
ER-1	ER1-A0,A1,A2	A	3	3	2	3	3		1	1	1	1
	ER1-B0,B1,B2	B	3	3	3	3	3					
ER-2	ER2-A0,A1,A2	A	3	3	4*	4*	4*					
	ER2-B0,B1,B2	B	3	3	4	3	3					
ER-3	ER3-A0,A1,A2	A	3	3	4*	4*	4*	1				
	ER3-B0,B1,B2	B	3	3	3	3	3					
ER-3A	ER3A-A0,A1,A2	A	3	3	3	3	3	1				
	ER3A-B0,B1,B2	B	3	3	3	3	3					
ER-4	ER4-A0,A1,A2	A	3	3	2	3	3					
	ER4-B0,B1	B	2	2	2	2	2		1	1	1	1
	ER4-C0,C1,C2	C	3	3	3	3	3	1				
ER-5	ER5-A0,A1,A2	A	3	3	3	3	3					
	ER5-B0,B1	B	2	2	2	2	2					
			61		62	65	65	6	7	7	7	7

Notes: * Includes 1 duplicate sample.

7999b

TABLE 2-8

SEDIMENT SAMPLE ANALYTICAL SUMMARY FOR THE
UPPER MAURICE RIVER PORTON OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION
PHASE II

STATION NUMBER	SAMPLE ID	CORE	SAMPLES PER CORE	DEPTH OF CORE (FT)	As/Fe	T.O.C.	GRAIN SIZE	E.P. TOXICITY	HSL POLLUTANTS EXTRACTABLE	INORGANIC	VOA	PES/PC
ER-10	ER10-A0,A1,A2	A	3	3	3	3	3					
	ER10-B0,B1,B2	B	3	3	4*	4*	4*					
ER-10A	ER10A-A0,A1,A2	A	3	3	3	3	3	1				
	ER10A-B0,B1,B2	B	3	3	3	3	3					
	ER10A-C0,C1	C	2	2	2	2	2					
	ER10A-D0	D	1	1	1	1	1					
	ER10A-E0	E	1	1	1	1	1					
	ER10A-F0	F	1	1	1	1	1					
	ER10A-G0,G1,G2	G	3	3	3	3	3					
	ER10A-H0,H1,H2	H	3	3	4*	4*	4*					
	ER10A-I0,I1,I2	I	3	3	2	3	3	1	1	1	1	1
ER-11	ER11-A0,A1,A2	A	3	3	2	3	3	1	1	1	1	1
	ER11-B0,B1,B2	B	3	3	3	3	3					
ER-6	ER6-A0,A1,A2	A	3	3	2	3	3	1	1	1	1	1
	ER6-B0,B1,B2	B	3	3	3	3	3					
ER-6A	ER6A-A0,A1,A2	A	3	3	4*	4*	4*					
	ER6A-B0,B1,B2	B	3	3	3	3	3	2*	1	1	1	1
			44		44	47	47	6	4	4	4	4

Notes: * Includes 1 duplicate sample.

TABLE 2-8 (Cont'd)

SEDIMENT SAMPLE ANALYTICAL SUMMARY FOR THE
UPPER MAURICE RIVER PORTON OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION
PHASE II

STATION NUMBER	SAMPLE ID	CORE	SAMPLES PER CORE	DEPTH OF CORE (FT)	As/Fe	T.O.C.	GRAIN SIZE	E.P. TOXICITY	HSL POLLUTANTS EXTRACTABLE	INORGANIC	VOA	PES/PCB
ER-7	ER7-A0,A1,A2	A	3	3	3	3	3	1				
	ER7-B0,B1,B2	B	3	3	3	3	3		1	1	1	1
	ER7-C0,C1,C2	C	3	3	4*	4*	4*					
ER-8	ER8-A0,A1,A2	A	3	3	3	3	3	1				
	ER8-B0,B1,B2	B	3	3	3	3	3					
ER-9	ER9-A0,A1,A2	A	3	3	3*	4*	4*		1	1	1	1
	ER9-B0,B1,B2	B	3	3	3	3	3	2*				
ER-9A	ER9A-A0,A1,A2	A	3	3	3	3	3					
	ER9A-B0,B1,B2	B	3	3	3	3	3					
	ER9A-C0,C1	C	2	2	2	2	2					
	ER9A-D0,D1	D	2	2	2	2	2					
	ER9A-E0,E1,E2	E	3	3	3	3	3	1				
ER-9C	ER9C-A0,A1,A2	A	3	3	3	3	3	1				
	ER9C-B0,B1,B2	B	3	3	3	3	3					
	ER9C-C0,C1	C	2	2	2	2	2					
	ER9D-D0,D1,D2	D	3	3	3	3	3					
	ER9E-E0,E1,E2	E	3	3	2	3	3		1	1	1	1
ER-9D	ER9D-A0,A1,A2	A	3	3	3	3	3		1	1	1	1
	ER9D-B0,B1.B2	B	3	3	3	3	3	1				
			54		54	56	56	7	4	4	4	4

Notes: * includes 1 duplicate sample.

TABLE 2-8 (Cont'd)

SEDIMENT SAMPLE ANALYTICAL SUMMARY FOR THE
UPPER MAURICE RIVER PORTON OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION
PHASE II

STATION NUMBER	SAMPLE ID	CORE	SAMPLES PER CORE	DEPTH OF CORE (FT)	As/Fe	T.O.C.	GRAIN SIZE	E.P. TOXICITY	HSL POLLUTANTS EXTRACTABLE	INORGANIC	VOA	PES/PC
ER-9E	ER9E-A0,A1,A2	A	3	3	2	3	3		1	1	1	1
	ER9E-B0,B1,B2	B	3	3	3	3	3					
	ER9E-C0	C	1	1	1	1	1					
	ER9E-D0,D1	D	3	3	3	3	3					
	ER9E-E0,E1,E2	E	3	3	3	3	3	1				
ER-9F	ER9F-A0,A1,A2	A	3	3	3	3	3					
	ER9F-B0,B1	B	2	2	2	2	2	1				
	ER9F-C0,C1	C	2	2	2	2	2					
	ER9F-D0,D1	D	2	2	2	2	2					
	ER9F-E0,E1	E	2	2	2	2	2					
	ER9F-F0,F1,F2	F	3	3	3	3	3					
	ER9F-G0,G1,G2	G	3	3	3	3	3					
			30	30	29	30	30	2	1	1	1	1

1890 000 NIA

TABLE 2-9

SEDIMENT SAMPLE ANALYTICAL SUMMARY FOR THE LOWER MAURICE RIVER PORTION OF THE VINELAND CHEMICAL COMPANY SITE [a]
PHASE II

STATION NUMBER	LOCATION	As/Fe	T.O.C	GRAIN SIZE
ER-20	Lower Maurice River	1	1	1
ER-21	Lower Maurice River	1	1	1
ER-22	Lower Maurice River	1	1	1
ER-23	Lower Maurice River	1	1	1
ER-26	Lower Maurice River	1	1	1
ER-27	Lower Maurice River	1	1	1
ER-29	Lower Maurice River	1	1	1
ER-32	Lower Maurice River	2*	2*	2*
ER-37	Lower Maurice River	1	1	1
ER-38	Lower Maurice River	1	1	1
ER-39	Lower Maurice River	1	1	1
ER-40	Lower Maurice River	1	1	1
ER-43	Lower Maurice River	1	1	1
ER-44	Lower Maurice River	1	1	1
ER-45	Lower Maurice River	1	1	1
ER-50	Delaware Bay	1	1	1
ER-51	Delaware Bay	1	1	1
		18	18	18

Notes:

(a) Sediment samples are grab samples.

* Includes 1 duplicate sample.

8213b

VIN 0020632

2.3.3 Supplemental Sampling

Additional sediment sampling was performed in the Blackwater Branch in January 1988. The purpose was to aid in delineating the volume of contaminated sediments in the flood plain remaining after the beaver dam was breached. The sampling locations and results are presented in Section 4.0.

A total of 22 borings were conducted on an approximate 200x200-foot grid. Samples were obtained with a hand auger over approximate two-foot depth intervals. Samples were obtained through the depth of sediment (black, organic soil) until sand was reached. The well installation and soil boring program conducted at the ViChem plant site indicated that the natural material expected below the recent sediments was a clean, well-sorted sand. When this material was reached, the soil borings were terminated.

The samples were obtained using hand augers and compositing the two-foot depth intervals by the same methods as outlined above. All samples were analyzed for total arsenic only.

2.4 BIOTA INVESTIGATION

2.4.1 Phase II

Biota samples were obtained during Phase II in July and August 1987. The results were used to characterize the potential health risks associated with the ingestion of fish caught in the upper and lower Maurice River. Biota sampling locations are shown in Figures 2-4 and 2-5, with analyses presented in Appendix B. Tables 2-10 and 2-11 summarize the biota sample analyses for the upper and lower Maurice River.

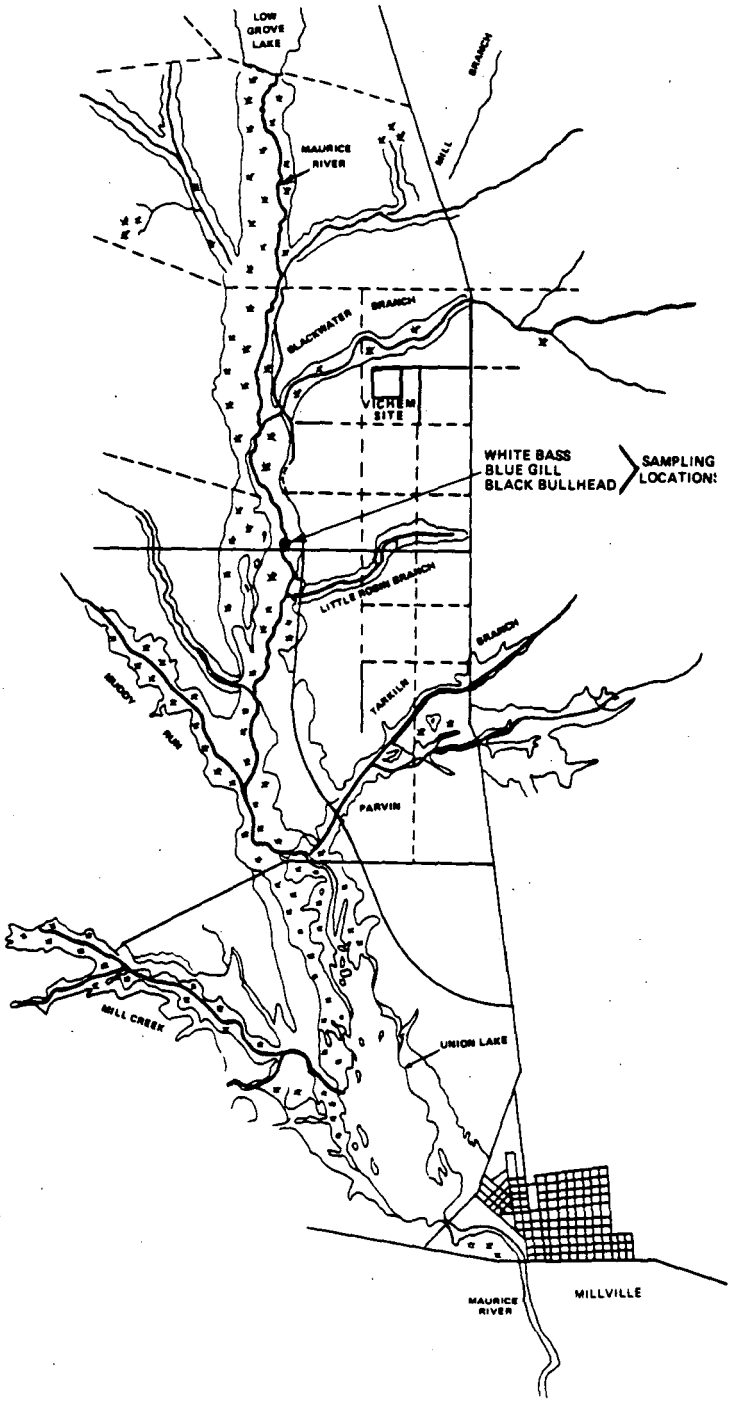
2.4.1.1 Sampling Locations

Three fish samples were obtained on the Maurice River upstream of Union Lake. White Bass, Blue Gill and Black Bullhead species were analyzed for total arsenic and pesticides. Pesticides are the most likely class of the HSL pollutants to accumulate in fish tissue.

Five biota samples were obtained from the Maurice River between Union Lake and the Delaware Bay. At the two northern stations shown in Figure 2-5, trammel nets were installed and a variety of specimens were caught, of which yellow perch, catfish, and approximately 12 blue crabs were retained for analysis. At the two southern stations shown in Figure 2-5, oysters were obtained and the muscle tissue was sent for analysis. In addition, approximately two dozen blue crabs were bought from local fishermen in Port Norris and were combined with the 12 blue crabs for analysis.

All of the biota samples from the Maurice River between Union Lake and the Delaware Bay were analyzed for total arsenic. The results are presented in Appendix B.

VLN 002 0633



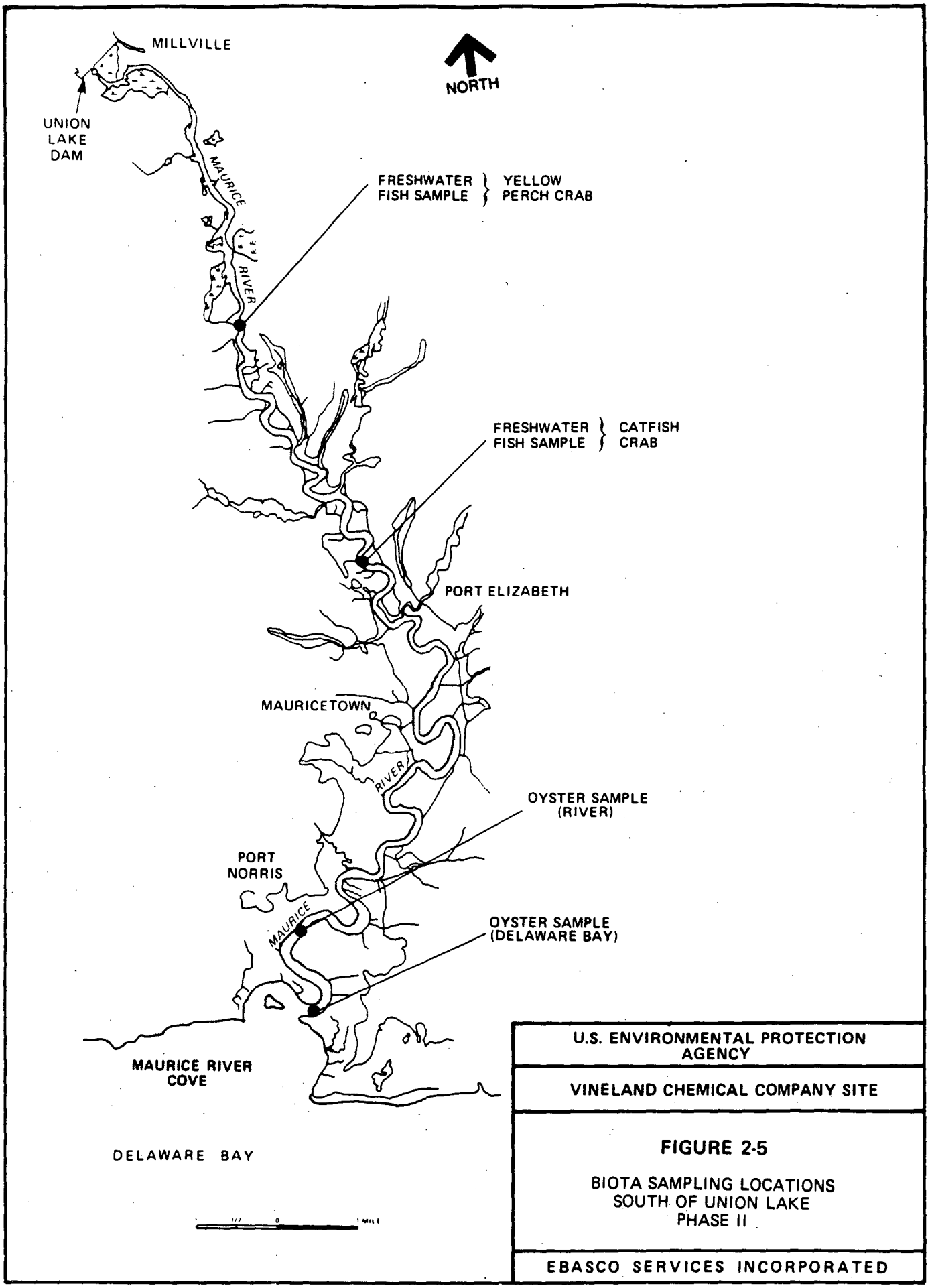
U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 2-4

BIOTA SAMPLING LOCATIONS
NORTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 2-5

BIOTA SAMPLING LOCATIONS
SOUTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED

VIN 002 0635

TABLE 2-10

BIOTA SAMPLE ANALYTICAL SUMMARY FOR THE
UPPER MAURICE RIVER PORTION OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION

PHASE II

BIOTA SPECIES	LOCATION DESCRIPTION	NUMBER OF ANALYSES PES/PCB	TOTAL As
White Bass	ER-8		1
Blue Gill	ER-8		1
Black Bullhead	ER-8		1
Field Blank	ER-8		1
Catfish	ER-8	1	
Black Bullhead	ER-8	1	
Black Bullhead	ER-8	1	
Field Blank	ER-8	1	
		4	4

9890 000 NIA

TABLE 2-11

BIOTA SAMPLING ANALYTICAL SUMMARY FOR THE
LOWER MAURICE RIVER PORTION OF THE
VINELAND CHEMICAL COMPANY SITE

PHASE II

BIOTA SPECIES	LOCATION DESCRIPTION	TOTAL ARSENIC
Catfish	Lower Maurice	1
Crab Backfin	Lower Maurice	1
Crab Hepatopancreas	Lower Maurice	1
American Oyster	Delaware Bay	1
American Oyster	Lower Maurice	1
Yellow Perch	Lower Maurice	1
Field Blank	Lower Maurice	1
		7

C890 700 NIA

2.4.1.2 Sampling Methods

The upper Maurice River samples, the White Bass, Blue Gill and Black Bullhead, were obtained utilizing a rod and reel with natural bait and artificial lures. Once the specimens were collected the scales were removed. While keeping the fish tissue intact, approximately 250 g. of muscle tissue was removed from both the right and left sides of the fish, and transferred into a wide-mouthed glass jar. The samples were then placed on ice and shipped to a CLP laboratory to be analyzed for total arsenic and pesticides. Originally only the left sides of the fish were to be sent for analysis, but due to the small size of the fish, and the low quantity of fish caught, both the right and left sides were sent for analysis.

The two fish samples and 12 of the blue crabs from the lower Maurice River were caught in trammel nets. The nets were installed along the river bank and the catch was retrieved the next day.

The fish were scaled and the muscle tissue from the left side (with the skin on) was sent for analysis.

The crabs caught in the trammel nets were combined with approximately two dozen crabs bought from local fishermen in Port Norris. It should be noted that field personnel observed numerous crab traps in the lower Maurice River and the Delaware Bay during the field work. The hepatopancreas and the backfin muscle from each crab was removed. The combined backfin muscles from all of the crabs comprised one sample, while the combined hepatopancreases comprised the other sample.

The oyster samples were obtained from oyster beds by personnel from the Rutgers University Shellfish Research Station in Bivalve. One bushel of American Oysters, Crassostrea Virginica, was obtained from each of the locations shown in Figure 2-5. Ebasco personnel shucked the oysters and put the flesh in sample bottles for total arsenic analyses.

2.5 QUALITY ASSURANCE AND QUALITY CONTROL

2.5.1 Decontamination Procedures

To ensure that the chemical analyses were reflective of the actual concentrations present at sampling locations, the equipment involved in sampling activities was decontaminated prior to use. Decontamination was also performed to minimize the potential for cross-contamination between sampling locations and the transfer of contamination off site.

Prior to sampling, all surface water and sediment sampling equipment was decontaminated using the following procedures:

- Potable water rinse
- Alconox or liquid detergent wash

VIN002 0638

- Potable water rinse
- Distilled/deionized water rinse
- Nitric acid rinse
- Distilled/deionized water rinse
- Acetone rinse
- Distilled/deionized water rinse

After being cleaned, small equipment was wrapped in aluminum foil or butcher paper to minimize contamination prior to utilization.

The knives used for preparation of the fish samples were initially decontaminated and then decontaminated after the preparation of each sample of each species. Field monitoring equipment such as volatile organic analyzers and combustible gas meters were wiped down with clean paper towels.

The sediment and water sampling equipment used in the lower Maurice River was decontaminated using deionized water. It was felt that this was preferable to using chemical solutions on the sampling boat.

2.5.2 QA/QC Samples

A trip blank was prepared for each day of field sampling when volatiles samples were obtained in advance of initiating the sampling on that day. The trip blank was filled with deionized, organic free water and was used to determine if any cross-contamination occurred between samples during shipment. The trip blanks were analyzed for volatiles only. The trip blank results are presented in Appendix B.

A field blank was taken for each medium sampled at a frequency of approximately one field blank per 20 samples. The field blank was composed of deionized organic free water that was poured through decontaminated sampling equipment. During the biota investigation, the knives used to prepare the fish samples were rinsed for field blanks. The field blank results are presented in Appendix B.

A duplicate sample was obtained for each of 20 samples of a similar matrix. The results of the duplicate sample analyses provide information concerning sample homogeneity, analytical precision and accuracy, and the effect of the sample matrix on the analytical methodology. Tables 2-12, 2-13 and 2-14 indicate the duplicate sample analysis summary for the three river areas.

2.5.3 Field Audits

Several audits were performed to determine that the field work was conducted within the procedures presented in the approved Field Operations Plan (Ebasco, 1986b) for the site and in accordance with accepted USEPA and NJDEP protocols. Audits and/or inspections were performed by the following personnel on the following days:

VIN002 0634

TABLE 2-12

DUPLICATE SAMPLE AND ANALYSIS SUMMARY FOR THE
BLACKWATER BRANCH PORTION OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION
PHASE II

	NUMBER OF DUPLICATES								
MEDIUM SAMPLED	As & Fe	TOC	GRAIN SIZE	DISSOLVED ARSENIC	EPTOX	HSL EXTRACTABLES	PEST/PCB	VOA	TOTAL
Sediment	4	4	4		1	1	1	1	16
Water				1					1
	4	4	4	1	1	1	1	1	17

0790 -00 NIA

TABLE 2-13

DUPLICATE SAMPLE AND ANALYSIS SUMMARY FOR THE
UPPER MAURICE RIVER PORTION OF THE
VINELAND CHEMICAL COMPANY INVESTIGATION
PHASE II

MEDIUM SAMPLED	NUMBER OF DUPLICATES									
	As & Fe	TOC	GRAIN SIZE	DISSOLVED ARSENIC	EPTOX	HSL EXTRACTABLE	HSL INORG	PES/PCB	VOA	TOTAL
Sediment	5	5	5		2					17
Surface Water				1		1	2	1	2	7
	5	5	5	1	2	1	2	1	2	24

TABLE 2-14

DUPLICATE SAMPLE AND ANALYSIS SUMMARY FOR THE
LOWER MAURICE RIVER PORTION OF THE
VINELAND CHEMICAL COMPANY SITE
PHASE II

	NUMBER OF DUPLICATES					
MEDIUM SAMPLED	TOTAL	As & Fe	TOC	GRAIN SIZE	DISSOLVED ARSENIC	HSL INORGANIC
Sediment		1	1	1		
Surface Water					1	1

1490 t00 NIA

DATE	COMPANY/AGENCY
6/25/1986	Ebasco QA (Phase I)
5/5/1987	NJDEP
5/13/1987	NJDEP
5/14/1987	Ebasco QA
5/27/1987	USEPA
6/2/1987	USEPA
7/1/1987	USEPA
7/16/1987	Ebasco QA

2.5.4 Data Validation

Data Quality Objective (DQO) Level 4 analyses were performed by the CLP laboratories for this RI/FS. This is the highest level of analytical QA/QC, designed to provide data of sufficient quality to withstand court scrutiny.

Only analytical data that withstood this rigorous QA/QC procedure, that is only data that were not rejected in the validation process, were considered valid and usable for this RI/FS. Throughout this report and in the Appendices, an analysis marked with an "X" was considered rejected. This analysis was therefore not used to draw conclusions about contaminant concentrations, and did not factor into calculated averages and means.

Owing to the large size of the analytical data base for the RI/FS, the reason for rejecting an individual analysis is not reported here. This information is available and can be provided if requested.

VTN 002 06414

VIN002 0642

3.0 PHYSICAL CHARACTERISTICS OF STUDY AREA

The Maurice River drains an area of approximately 380 square miles (sq mi) above its mouth at Delaware Bay. About 284 sq mi are in Cumberland County. The U.S. Geological Survey maintains a stream-gaging station on the Maurice River at Norma (Ebasco sampling station ER-7; see Figure 2-1) which measures runoff from a 113 sq mi drainage area, of which about 100 sq mi are in Salem and Gloucester Counties, and about 13 sq mi are in Cumberland County. According to the Water Resources Data Report for 1986, the average annual discharge of the Maurice River at Norma between 1932 and 1961 was 0.98 mgd (million gallons per day) per square mile or approximately 168 cfs (cubic feet per second). Assuming that uniform hydrologic conditions exist throughout the basin, the 100 sq mi area in Salem and Gloucester Counties contributes an average of 98 mgd of surface-water inflow to Cumberland County at the Norma gaging station. Additional surface-water inflow, estimated as 44 mgd from Salem County and flowing in the Maurice River below the gage, comes from an area of about 45 sq mi that is drained by the Muddy Run tributary. Therefore, the estimated total inflow contributed by the Maurice River to the water-supply gains of Cumberland County is about 142 mgd. This is equal to about 6 inches of water over the 502 square mile area of the county.

3.1 SURFACE WATER

3.1.1 Surface Water Flow

Stream Flow Rate Calculations

Approach

Stream flow rate measurements were obtained by Ebasco personnel from the Maurice River and various tributaries during Phase II. The flows were measured twice; once when a chemical sample was obtained and once on a single day when all flows were measured relative to one another. Table 3-1 shows the volumetric flow rates for all of the stream stations. The flow stations are shown in Figure 3-1. Appendix D contains the stream flow rate calculations.

The flows were measured to determine the arsenic flux in the watershed. Knowing the contaminant concentration and flow at a location makes it possible to calculate the contaminant flux. Knowing the flows at one point in time throughout a watershed makes it possible to determine dilution factors and the relative flows at different stations.

Flow Rate Methods

The stream flow rates were measured using a Pygmy Meter, which measures the stream flow velocity. Ten velocity measurements were performed across the stream perpendicular to the flow. The flow velocity was measured three times within each section by

VIN002 0645

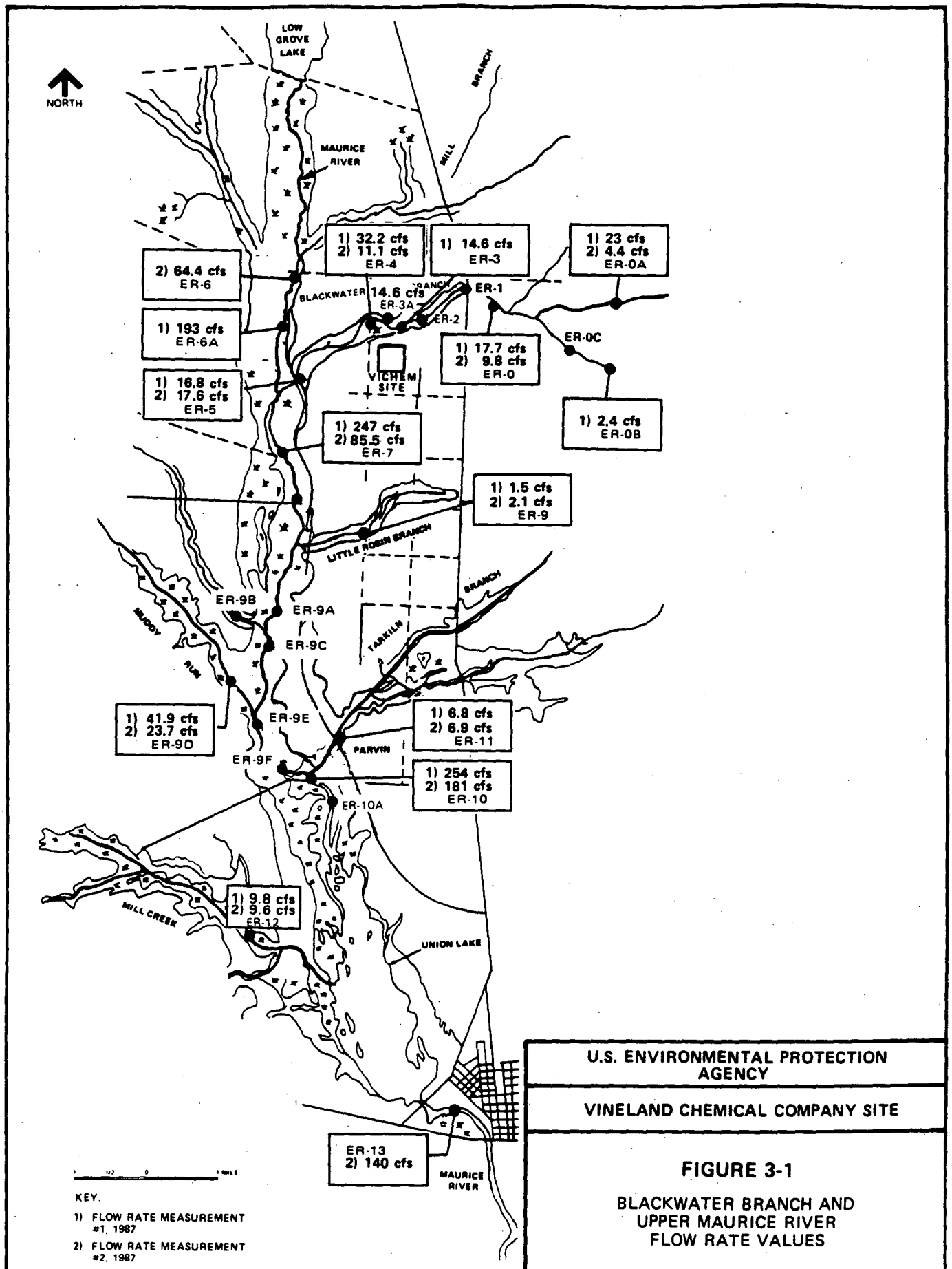
TABLE 3-1

STREAM FLOW RATE CALCULATIONS

Stream Station	Measurement Date	Volumetric Flow Rate of Stream (cfs)
ER-O (Blackwater Branch)	1) 7/14/87	17.7
	2) 7/30/87	9.8
ER-OA (Blackwater Branch)	1) 7/15/87	23.0
	2) 7/30/87	4.4
ER-OC (Pine Branch)	1) 7/20/87	2.4
ER-3* (Blackwater Branch)	1) 7/13/87	14.6
ER-4 (Blackwater Branch)	1) 7/13/87	32.2
	2) 7/30/87	11.1
ER-5 (Blackwater Branch)	1) 6/25/87	16.8
	2) 7/30/87	17.6
ER-6 (Maurice River)	2) 7/30/87	64.4
ER-6A (Maurice River)	1) 7/16/87	193
ER-7 (Maurice River)	1) 7/15/87	247
	2) 7/30/87	85.5
ER-9 (Little Robin Branch)	1) 7/1/87	1.5
	2) 7/30/87	2.1
ER-9D (Muddy Run)	1) 6/30/87	41.9
	2) 7/30/87	23.7
ER-10 (Maurice River)	1) 7/9/87	254
	2) 7/30/87	181
ER-11 (Tarklin Branch)	1) 6/23/87	6.8
	2) 7/30/87	6.9
ER-12 (Mill Creek)	1) 7/16/87	9.8
	2) 7/30/87	9.6
ER-13 (Maurice River)	2) 7/30/87	140

* Measurement may be inaccurate due to swampy conditions.

VINO02 0644



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 3-1

BLACKWATER BRANCH AND UPPER MAURICE RIVER FLOW RATE VALUES

EBASCO SERVICES INCORPORATED

VIN002 0645

counting the number of revolutions made by a wheel on the current meter over time, including any conversion factors unique to the current meter. The average section velocity was determined from the average of the three readings. The velocity of each subsection was multiplied by the area (i.e., depth times width) to determine the volumetric flow rate in each subsection. After the volumetric flow rates were calculated for each subsection, they were added together to equal the total volumetric flow for the stream (see Appendix D for subsection measurements).

If a section's average depth was less than 2.5 feet, the velocity was measured at six-tenths (0.6) of the depth from the surface (six-tenths method). If the section's average depth was greater than 2.5 feet, the velocity was measured at two-tenths (0.2) and eight-tenths (0.8) of the depth and these two readings were averaged.

The flow rate of the Blackwater Branch ranged between 4.4 cfs and 32.2 cfs. The flow rate on the upper Maurice River ranged between 64.4 and 254 cfs. Four stations on tributaries had the following flow rates: ER-0C (Pine Branch) had 2.4 cfs; ER-9, (Little Robin Branch) had 1.5 and 2.1 cfs; ER-9D, (Muddy Run), had 41.9 and 23.7 cfs; and ER-11, (Tarklin Branch) had 6.8 and 6.9 cfs.

3.1.2 Water Balance

A water balance was calculated to determine the amount of groundwater recharge in the Maurice River drainage basin using stream flow data from the gaging station at Norma (Ebasco station ER-7) and rainfall data. The water balances calculated for the years 1981-1982, 1982-1983 and 1983-1984 are shown in Table 3-2. Appendix C shows the plots and calculations.

The water balance was estimated using the following simple relationship:

$$\text{Inflow} = \text{Outflow} \pm \text{change in storage}$$

where: Inflow = precipitation
Outflow = total surface water flow (base flow plus surface runoff) plus evapotranspiration

Assuming that all of the water inflow to the drainage basin is from precipitation, that all of the precipitation appears as surface water flow in the stream (base flow plus runoff) or is lost to evapotranspiration, and that there is no net change in surface water or groundwater storage within the basin, then the simple relationship above may be rewritten as:

$$\text{Precipitation} = \text{Base Flow} + \text{Surface Runoff} + \text{Evapotranspiration}$$

U IN002 0646

TABLE 3-2

SUMMARY OF ESTIMATED AVERAGE WATER BALANCE
MAURICE RIVER WATERSHED

ITEM	1981-1982 INCHES/YEAR	1982-1983 INCHES/YEAR	1983-1984 INCHES/YEAR	AVERAGE OF 1981-1984 INCHES/YEAR
Water Gains				
Precipitation	38.6	40.9	52.8	44.1
Water Losses				
Evapotranspiration	23.6	20.7	24.3	22.9 (52%)
Surface Runoff	5.5	11.0	13.1	9.9 (22%)
Groundwater Base Flow	9.5	9.2	15.4	11.4 (26%)

V.IN 002 0071

The water balance was estimated by first plotting the mean daily flow recorded at the Norma gaging station for each month of the water year on arithmetic graph paper. It was assumed that this represented the total surface water flow, which is comprised of two components: (1) base flow (groundwater recharge to the stream), and (2) surface runoff. The base flow was then estimated by drawing an arbitrary base flow line on the graph that mimicked the total flow line. By converting units, the volume of the total flow and the volume of the base flow were determined. The base flow was then subtracted from the total flow to estimate the volume of the surface runoff. The rainfall in the basin was determined from precipitation records. The evapotranspiration was estimated by subtracting the total surface water flow from the precipitation. Finally, the three components of outflow (base flow, surface runoff, and evapotranspiration) were compared to the rainfall to determine the overall water balance.

This method for determining a water balance is fairly crude and makes many assumptions, among them:

(1) That there is no net gain or loss in the surface water or groundwater storage within the basin;

(2) That all rainfall in the basin appears as surface runoff, groundwater base flow to the stream, or is lost to evapotranspiration (no undetected groundwater discharge out of the basin around the stream gage); and

(3) That the rainfall records from one station are representative of the entire basin for that water year.

Despite the crudeness of this method, the water balance calculated in this manner can give a general idea of the hydrologic characteristics within a basin. As shown in Table 3-2, slightly more than half (52%) of the available rainfall is assumed to be lost to evapotranspiration, while slightly less less one quarter (22%) appears in the stream as surface runoff and slightly more than one quarter (26%) recharges the groundwater and appears in the stream as base flow.

The base flow or groundwater discharge per unit area of the drainage basin was also calculated. The total mean base flow was divided by the basin area, 112 sq mi. In water years 1981-1982 and 1982-83, the groundwater discharge was 0.7 cfs/sq mi. In water year 1983-1984, the groundwater discharge was 1.1 cfs/sq mi.

The water balance estimated by the above methods was compared with other estimates prepared previously.

In a study prepared for ViChem (Lennon, 1982) the average base flow for the drainage basin that includes the plant site was estimated to be approximately 0.7 cfs/sq. mile. According to

VIN002 0648

the Cumberland County Groundwater Resources report (Rooney, 1971), the average long-term annual precipitation in Cumberland County is about 44 inches and the average evapotranspiration is approximately 29 inches per year. These values are in general agreement with the values calculated for 1981-1984.

Of interest in surface water contamination investigations is the determination of whether a surface water body is effluent or influent; that is, whether the groundwater recharges the surface water or whether the surface water recharges the groundwater. While detailed information along the length of the Maurice River is not available, the data obtained for the ViChem RI reports suggest, at least indirectly, that the surface water is probably recharged by the groundwater. The pertinent observations are outlined below.

First, in the Draft RI report for the ViChem Plant site, it was estimated that groundwater from the contaminated upper sand aquifer recharged the Blackwater Branch. This was based on measurements showing an upward gradient between the groundwater and the stream, and on the fact that arsenic contamination was seen in the groundwater below the plant and in the surface water downstream of the plant, but not in the surface water upstream of the plant or the groundwater across the stream from the plant (Ebasco, 1989a). Table 3-3 presents the estimated groundwater flowrates off the plant site to the Blackwater Branch, with the groundwater flow directions shown in Figure 3-2.

Second, the water balance calculated above suggests a significant component of base flow into the Maurice River, approximately one quarter of the rainfall in the basin. This indicates that the groundwater recharges the stream and not vice versa.

Third, the USGS flow data collected at the Norma gaging station shows that the lowest mean daily flow recorded during the period of record (since 1932) is 23 cfs. If the Maurice River were a losing stream, recharging the groundwater, it would be expected that during drought periods the flow would drop to zero. Since this has not occurred since 1932, it is reasonable to assume that there is a component of groundwater discharge to the stream.

Lastly, the Cumberland County Water Resources Report from 1971 shows the generalized water levels in the Cohansey-Kirkwood Aquifer (Rooney, 1971). These are presented in Figure 3-3. The generalized groundwater flow lines are shown pointing toward the Maurice River, indicating that the groundwater flow is toward the river and that the river is probably recharged by the groundwater.

In the absence of site-specific data, it is impossible to determine whether the Maurice River is inffluent or efluent at all points along its length. However, the data do suggest that the river is recharged by the groundwater and not vice versa.

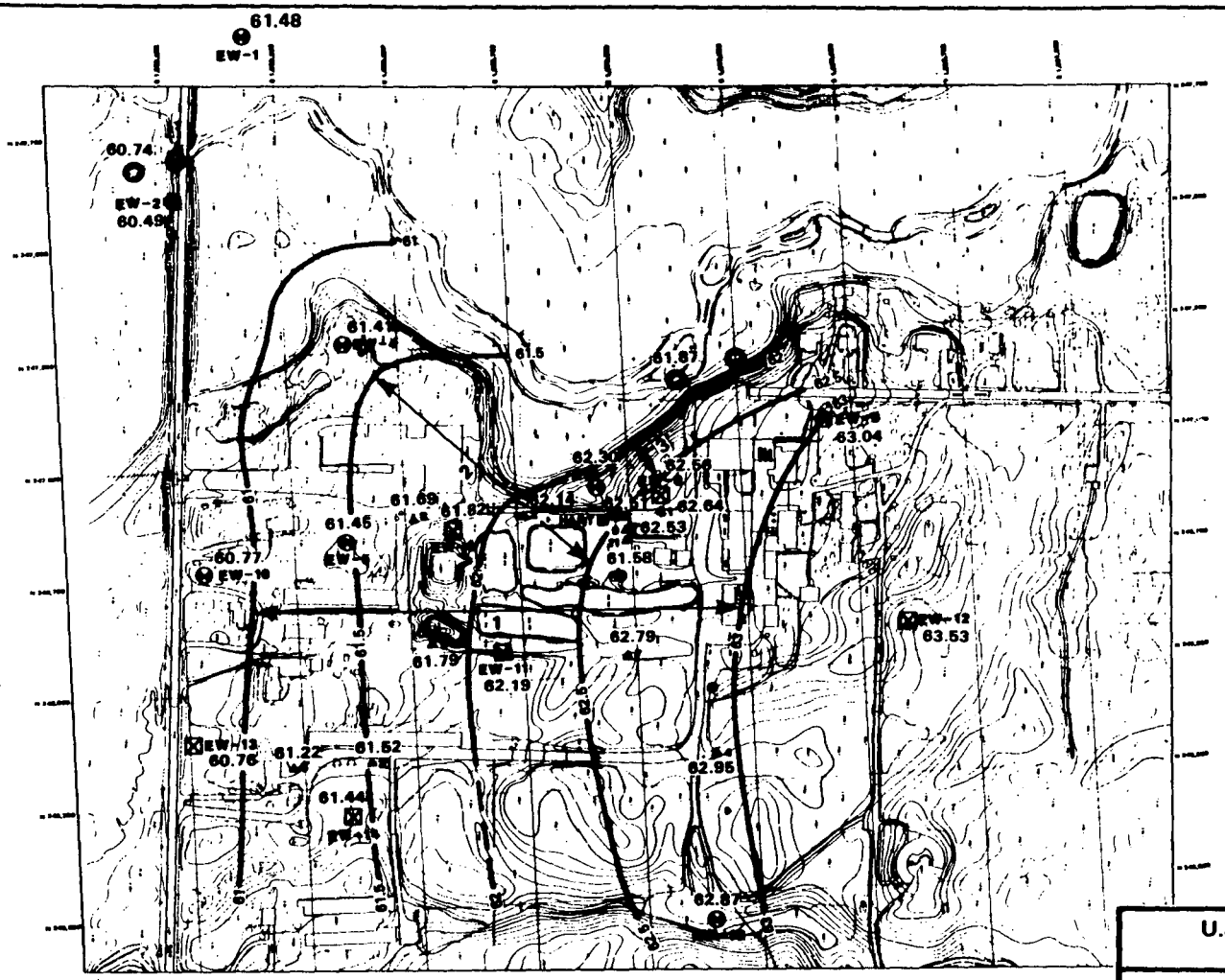
VIN002 0644

TABLE 3-3

GROUNDWATER DISCHARGE FROM THE UPPER SAND TO THE BLACKWATER BRANCH

Date	Q_1*	Q_2*	Q_3*	Total
10/19/87	158,922	70,753	261,241	490,916
11/21/87	150,093	70,753	146,295	367,141
1/27/88	158,922	94,337	365,738	618,997
Average	156,000	78,000	258,000	492,000

* All flows are in gallons per day.



U.S. ENVIRONMENTAL PROTECTION AGENCY

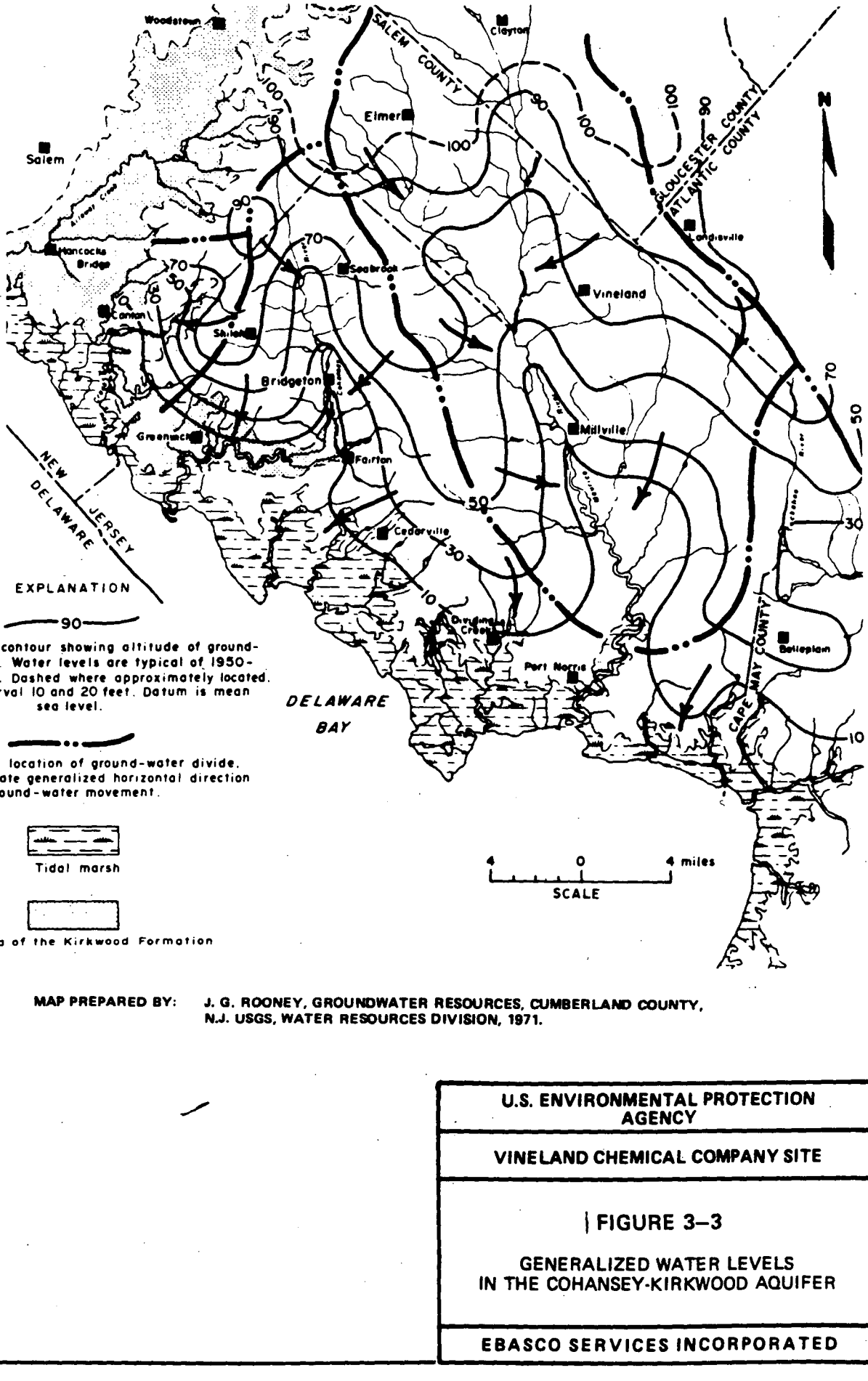
VINELAND CHEMICAL COMPANY SITE

FIGURE 3-2

WATER TABLE ELEVATIONS – 10/19/87
SHALLOW MW's & STREAM GAUGES

EBASCO SERVICES INCORPORATED

1590 FOONIA



MAP PREPARED BY: J. G. ROONEY, GROUNDWATER RESOURCES, CUMBERLAND COUNTY, N.J. USGS, WATER RESOURCES DIVISION, 1971.

U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 3–3

GENERALIZED WATER LEVELS IN THE COHANSEY-KIRKWOOD AQUIFER

EBASCO SERVICES INCORPORATED

VIN 008 C008

As a final note on the surface water hydrology, in the Plant Site RI report the amount of arsenic entering the Blackwater Branch from groundwater discharge off the plant site was estimated. This was done by combining the groundwater flow rate off the site with the mean arsenic concentration in the groundwater. It was estimated that between 2 and 11 metric tons of arsenic were entering the Blackwater Branch each year from the plant site, with the best estimate placed at 6 metric tons per year (Ebasco, 1988). This will be discussed in detail in Section 5, Fate and Transport of Arsenic.

3.1.3 Vineland and Millville Water Use

Figures 3-4 and 3-5 show the municipal water supply systems for the cities of Vineland and Millville. Both cities derive their municipal water supplies from groundwater wells, not the surface water bodies in the Maurice River systems.

From the information gathered in the Plant Site RI report (Ebasco 1989b), it appeared that none of Vineland's water supply wells were downgradient of the Vichem plant. The closest water supply well, #7, is approximately 6,500 feet south of the plant, and approximately one mile east of the Maurice River. All of Vineland's water supply wells are reportedly screened below a dark grey marker bed, which contains clay at some locations. It is believed that this marker bed is the same dark grey material seen at the base of the middle sand at the ViChem plant site. Very little arsenic contamination was seen at this depth on the plant site.

The City of Vineland commissioned an investigation into the hydrologic regime near its wells #7 and #10. The purpose was to determine the source(s) of TCE contamination in these wells and to recommend technologies to remove the TCE.

As part of this investigation, a pumping test was conducted on well #7. The distance-drawdown plot revealed a cone of influence extending approximately 5,200 feet from the well under apparently steady-state conditions after pumping for 48 hours at 1,000 gpm. The report estimated that the capture zone, the distance that the well would draw contamination back to it, was approximately 2,250 feet downgradient and approximately 3.14 times this distance parallel to the gradient. The estimated capture zone is shown in Figure 3-4.

As shown in the figure, the estimated capture zone does not extend to the Maurice River. The capture zone does, however, extend up to the ViChem plant site. It must be recalled that the pumping well is screened in an aquifer that is stratigraphically below the contaminated upper sand aquifer at the ViChem plant site.

VIN 004 0053

Millville's water supply wells are shown in Figure 3-5. As shown in this figure, five of these wells are situated close to the Maurice River near the southern end of town. Four of these wells are screened approximately 100 feet below the ground while the fifth is screened approximately 300 feet below the ground.

While it is not known whether the groundwater recharges the river or vice versa, the cities of Vineland and Millville both periodically monitor their water distribution systems for arsenic. Recent results from both municipalities are presented in Appendix K. In Millville, arsenic was undetected at the concentration level of 0.005 mg/l (5 ug/l). In Vineland, arsenic was undetected at the level of 0.05 mg/l.

3.1.4 Flood Plain Delineation

Table 3-4 outlines the distance of the 100-year flood boundary from the Maurice River at each surface water and sediment sampling station along the Maurice River. The 100-year flood boundary shows the predicted highest extent of flooding that may occur once in a 100-year period. The information was obtained from the NJDEP Division of Coastal Resources.

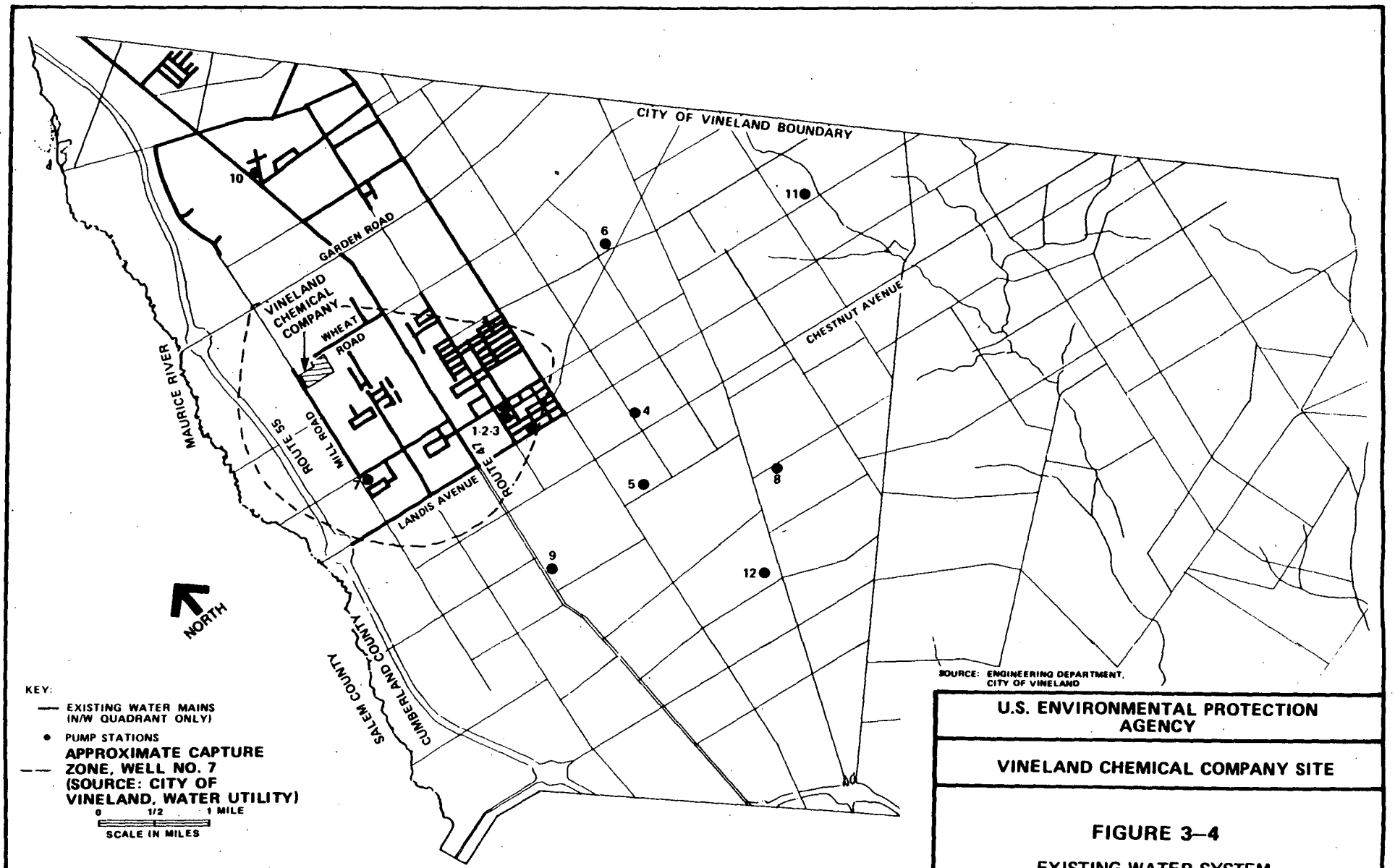
In the Blackwater Branch, immediately adjacent to the site by stations ER-3, -3A and 4, the flood boundary is affected by the topography. The 100-year flood plain is at the 66- to 67- foot elevation. The boundary therefore very closely approximates the limit of flooding in the branch caused by the beaver dam, shown previously in Figure 1-3.

Between sampling stations ER-5 and ER-9D, along the Upper Maurice River, the maximum distance between the banks of the river and the 100 year flood boundary ranges between 200 and 700 feet. Just north of Union Lake, at stations ER-9E, ER-9F, ER-10 and ER-10A, the maximum distance between the banks of the river and the 100 year flood boundary ranged between 1,200 and 2,000 feet from the Maurice River.

Around the banks of Union Lake, the 100-year flood boundary lies approximately 200 feet or less from the lake. In most places the boundary is on the lake's edge. At ER-13 and ER-14, immediately south of the Union Lake dam, the boundary is less than 500 feet and less than 900 feet, respectively, from the Maurice River.

At stations ER-20 through ER-37, the 100-year flood boundary varies between approximately 1,100 feet wide near ER-20 to approximately 3,600 feet wide at EA-37. At some points the 100-year flood boundary is coincident with one bank of the stream (the west bank) and extends almost entirely to the east. At other locations, the river channel is closer to the middle of the 100-year flood plain, which extends out along both banks of the river. The maps that cover stations ER-38 through ER-50 further south on the Maurice River are not available. It may be assumed that the flood plain is approximately the same size or larger than the flood plain at ER-37.

VIN 002 0654



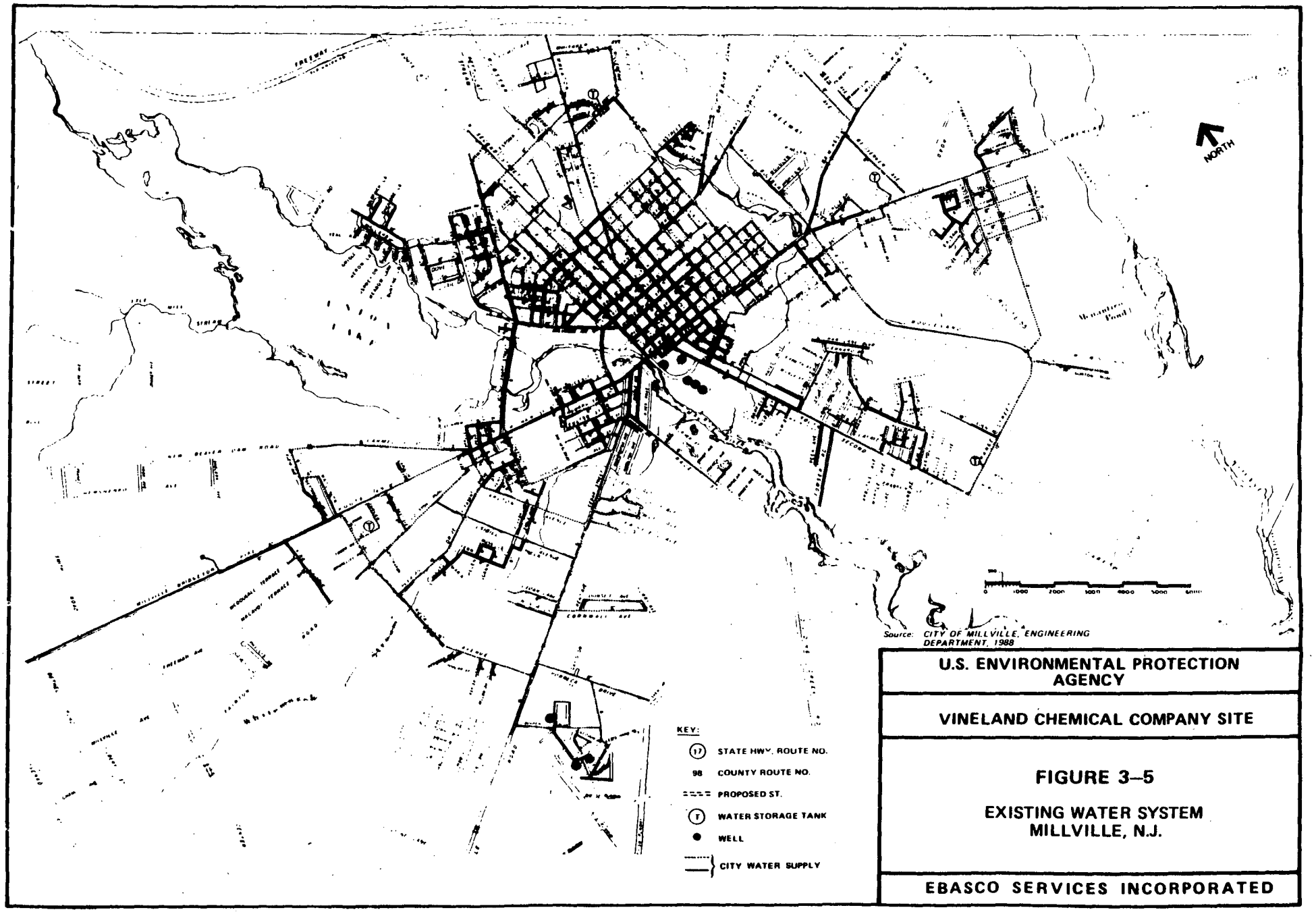
U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 3–4

EXISTING WATER SYSTEM, CITY OF VINELAND

EBASCO SERVICES INCORPORATED



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 3–5

EXISTING WATER SYSTEM MILLVILLE, N.J.

EBASCO SERVICES INCORPORATED

9590-600 NIA

TABLE 3-4

100-YEAR FLOOD PLAIN BOUNDARY
MAURICE RIVER

	STATION NUMBER	APPROXIMATE FLOOD PLAIN DISTANCE - 100 YEAR FLOOD BOUNDARY
	ER-5	<200 feet from the Maurice River
U	ER-6	<200 feet from the Maurice River
P	ER-7	<600 feet from the Maurice River
P	ER-8	<400 feet from the Maurice River
E	ER-9	On Little Robin Branch-Not Available
R	ER-9A	<200 feet from the Maurice River
	ER-9B	<200 feet from the Maurice River
M	ER-9C	<700 feet from the Maurice River
A	ER-9D	<200 feet from the Maurice River
U	ER-9E	<2000 feet from the Maurice River
R	ER-9F	<1200 feet from the Maurice River
I	ER-10	<1200 feet from the Maurice River
C	ER-10A	<1200 feet from the Maurice River
E	ER-11	On Parvin Branch-Not Available
	ER-12	On Mill Creek-Not Available
	ALL EL's	In Union Lake-Less than 200 feet from Union Lake, mostly on banks
	ER-13	<500 feet from Maurice River
	ER-14	<900 feet from Maurice River
L O W E R	ER-20-37	Varies between approximately 1,600 feet wide at north end of the Lower Maurice River to approximately 3,600 feet wide farther south near EA-37
M A U R I C E	ER-38-50	Assumed to be similar to ER-37, Maps Not Available

All "less than signs": One side of the river has 100 year Flood Boundary this distance from the river and the other side is the same or closer.

Source: Floodway Flood Boundary and Floodway Map, National Flood Insurance Program, NJDEP, Division of Coastal Resources, Trenton, NJ, 1982-1985.

UTN 082 0651

3.2 SEDIMENT

According to the Soil Survey of Cumberland County (USDA, 1978) the soils within the Blackwater Branch and the Maurice River flood plains are classified under two soil associations, the Muck-Atson-Berryland association and the Tidal Marsh association.

The soils on the banks of the Blackwater Branch and on the banks of the Maurice River north of Union Lake are mostly Muck soils in the Muck-Atson-Berryland association. These are lowland, nearly level, poorly drained organic and sandy soils. These soils are predominantly wooded, with Atlantic white-cedar being most dominant. The water table is high for six months or more in these soils, which causes severe limitations for most uses. If drained, these soils have low available water capacities. Muck soils have low bearing capacities, and, if drained, subside severely.

The soils on the banks of the Maurice River south of Union Lake and on the banks of the Maurice River Cove on the Delaware Bay are within the Tidal Marsh association. These are lowland soils, nearly level, very poorly drained, silty or mucky tidal flats that are subject to daily flooding. This association is one half mile to about six miles wide in most areas, but along the Cohansey Creek and the Maurice River, it extends inland 12 miles. Tidal Marsh normally supports a strand of grasses that can tolerate salts from tidal water and daily flooding. This association has severe limitations for all urban uses. Some areas have been partially drained and diked so that salt hay can be harvested. When drained, areas of the Tidal Marsh oxidize upon drying and remaining sulfur prevents plant growth (USDA, 1978).

3.2.1 Grain Size Distribution

Each sediment sample was analyzed for grain size distribution. The grain size analyses were classified in phi units, which are proportional to the grain diameters found in a particular sample. The phi units correspond to grains in a sample larger than sand (less than 1), sand (-1 to 4) silt (4 to 8) and clay (more than 8). These results are presented in Appendix B.

About two-thirds of the stream sediments were comprised of 80-100% sand size particles. Less than one-third were comprised of 60-80% sand size particles, and the remainder contained less than 60% sand size particles. Most of the sediments south of Union Lake had less than 60% sand size particles. About half of the Blackwater Branch and the Upper Maurice River sediments were between 60 and 80% sand size, and about half were between 80 and 100% sand size. Most of the samples had less than 10% silt and less than 10% clay.

3.3 BIOTA

3.3.1 Species Investigated

Three types of fish were sampled from the Maurice River north of Union Lake, white bass, blue gill and black bullhead catfish. The white bass was 10 inches long, the blue gill sample came from an 8 inch fish and a 7-inch fish and the black bullhead catfish was 10 inches long.

Two fish samples were obtained below Union Lake, yellow perch and catfish. A number of other fish were caught in the nets but were discarded. The crabs sampled were of the species Callinectes apidus (blue crabs). The oysters obtained from the river and the Delaware Bay were of the species Crassostrea virginica (American Oyster).

VIN002 0654

VIN 002 0660

4.0 NATURE AND EXTENT OF CONTAMINATION

4.1 SURFACE WATER

Surface water samples were obtained in Phases I and II. In Phase I, samples were obtained from the Blackwater Branch and the Maurice River above Union Lake. In Phase II, water samples were taken in the Blackwater Branch, the Maurice River above Union Lake, and the Maurice River below Union Lake. The analytical results for Phase I are presented in Appendix A, while the results for Phase II are presented in Appendix B. The total and dissolved arsenic concentrations from Phase I and II are presented in Table 4-1.

Phase I

The arsenic concentrations in the Blackwater Branch upstream from the ViChem Plant were low to undetected in Phase I, based on the results from ER-0, -1, and -2. The arsenic concentration downstream from the plant in the Blackwater Branch was much higher, ranging from approximately 300 ug/l at ER-4 at the Mill Road Bridge to almost 700 ug/l at ER-5, approximately 1.5 miles downstream of the plant.

The arsenic concentration in the Maurice River above the confluence with the Blackwater Branch was below detection limit (10 ug/l) at ER-6. The concentration below the confluence was higher, approximately 130 to 160 ug/l at ER-7. The concentration decreased steadily downstream to approximately 70 ug/l at ER-10 just above Union Lake. The concentrations just below Union Lake at stations ER-13 and ER-14 were similar to the concentration entering the lake at ER-10, 67 and 62 ug/l.

The arsenic concentrations were also determined in several tributaries entering the Maurice River. Arsenic concentrations were very low to undetected in the Little Robin Branch, Pine Branch, and Mill Creek sampled at stations ER-9, -11, and -12, respectively.

Other inorganics detected in stations downstream of the ViChem plant that were not detected upstream included copper (6.4 ug/l), lead (9.3 ug/l), mercury (0.3 ug/l) and silver (5.1 ug/l).

Three volatile compounds were detected in the surface water samples: acetone, dichloroflouromethane, and 2-butanone. Of these, acetone was detected most frequently. Acetone was used in the decontamination of sampling equipment and was also found in some field blanks. The latter two compounds were found in one sample each.

Phase II

The total arsenic concentrations for each station sampled in Phase II are shown in Figures 4-1 through 4-3. Table 4-1

VIN002 0661

TABLE 4-1

SURFACE WATER ARSENIC ANALYSES
PHASES I AND II

	PHASE I			PHASE II	
STATION	DISSOLVED[a] ARSENIC (ug/l)	PARTICULATE[b] ARSENIC (ug/l)	TOTAL[c] ARSENIC (ug/l)	DISSOLVED[a] ARSENIC (ug/l)	TOTAL[c] ARSENIC (ug/l)
ER-0	10a 10u 10u	4.5x 2.4x 1.4x		4u	10x
ER-0A				4u	2.2J
ER-0B				4u	6u
ER-0C				4u	6u
ER-1	10u	0.5u		5.5J	6u
ER-2	10x	0.5u		4u	2.5J
ER-2 Dup				4u	
ER-3				4.8J	61
ER-3A	206x	39		2790	6200
ER-4	250x 208 215x	35.5 38.5 43	330 290 280	202	153
ER-5	698	118		460	570J
ER-6	10u 10u 10u	0.5u 0.5u 0.5u		4u	6u
ER-6A				4u	4.5J
ER-6A Dup				4u	4.4J
ER-7	124 128	13 13	134 160	91	10X 10x

8259b

0990 —000 NIA

TABLE 4-1 (Cont'd)

SURFACE WATER ARSENIC ANALYSES
PHASES I AND II

STATION	PHASE I DISSOLVED[a] ARSENIC (ug/l)	PHASE I PARTICULATE[b] ARSENIC (ug/l)	PHASE I TOTAL[c] ARSENIC (ug/l)	PHASE II DISSOLVED[a] ARSENIC (ug/l)	PHASE II TOTAL[c] ARSENIC (ug/l)
ER-8	114x 106x	14.7 11.0		46.8	10x
ER-9	10u	5u		4u	6u
ER-9A				65	123
ER-9C				56	150
ER-9D				4.4J	6u
ER-9E				48	146
ER-9F				36	105
ER-10	56x 58x 51x	16 12.8 17.3	70 70	32	125
ER-10A				28	102
ER-11	10x	0.79		8.2	5u
ER-12	10x	0.5u			
ER-13	58	5.54	67		
ER-14	43	8.6	62		
ER-20				39	79.7
ER-21				37	91
ER-22				32	89
ER-23				26	10x

8259b

TABLE 4-1 (Cont'd)

SURFACE WATER ARSENIC ANALYSES
PHASES I AND II

STATION	PHASE I DISSOLVED[a] ARSENIC (ug/l)	PHASE I PARTICULATE[b] ARSENIC (ug/l)	PHASE I TOTAL[c] ARSENIC (ug/l)	PHASE II DISSOLVED[a] ARSENIC (ug/l)	PHASE II TOTAL[c] ARSENIC (ug/l)
ER-26				27	73
ER-27				26	82
ER-29				17	50
ER-32				16	52
ER-32 Dup				15	44
ER-37				7.2J	18
ER-38				5.8J	12
ER-39				7.1J	25
ER-40				10	18
ER-43				10	13
ER-44				5u	12
ER-45				8.4J	8J
ER-50				5.3J	2.8J
ER-51					2.7J

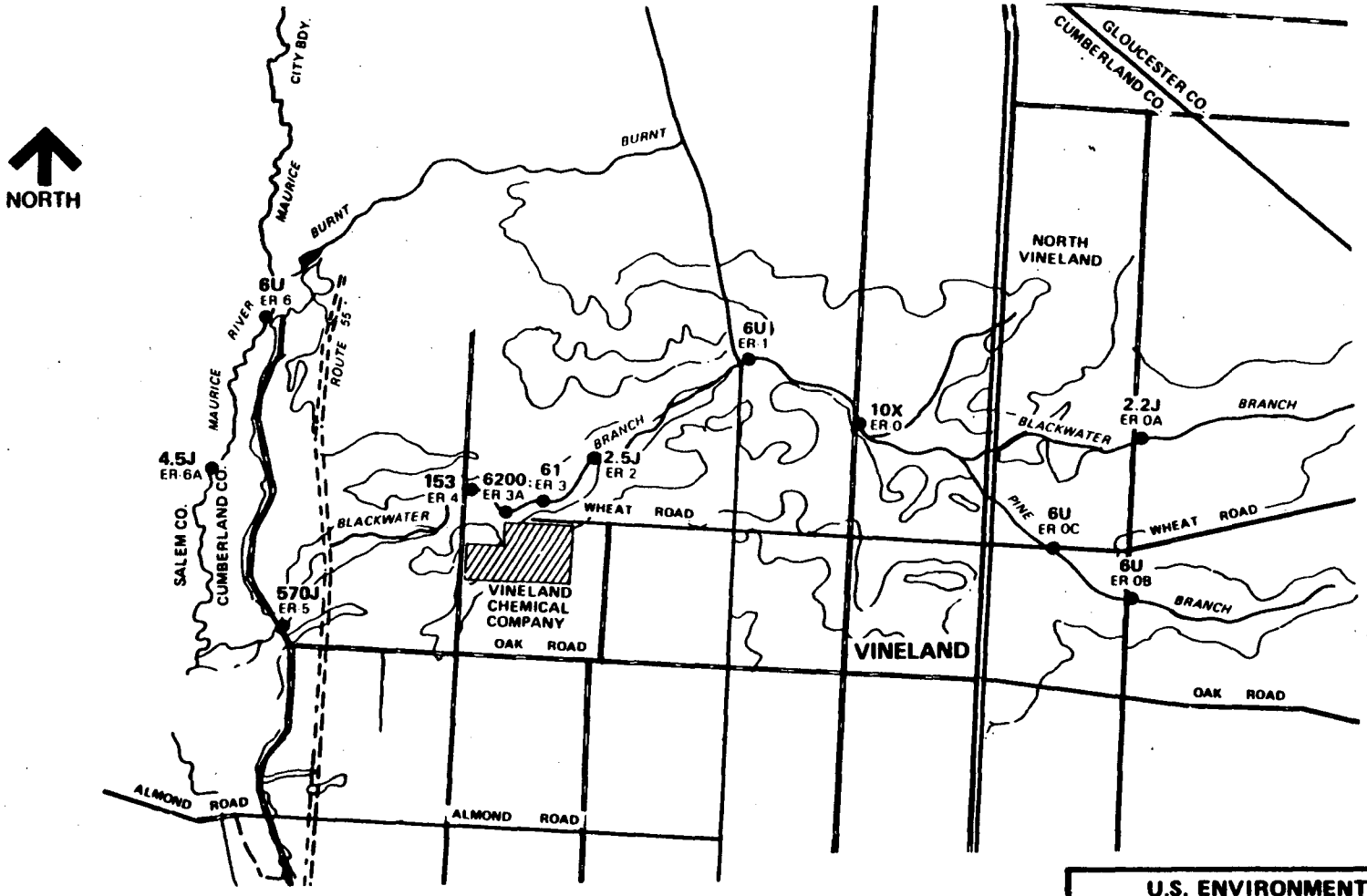
(a) - Filtrate of sample filtered in the field.
(b) - Results of analysis of filter paper - expressed as ug per filter. Approximately 1 litre of water filtered per sample.
(c) - Unfiltered in field.

Explanation of Codes

u - Undetected at given detection limit
x - Rejected
J - Estimated concentration

8259b

VIN 002 0664



U.S. ENVIRONMENTAL PROTECTION AGENCY

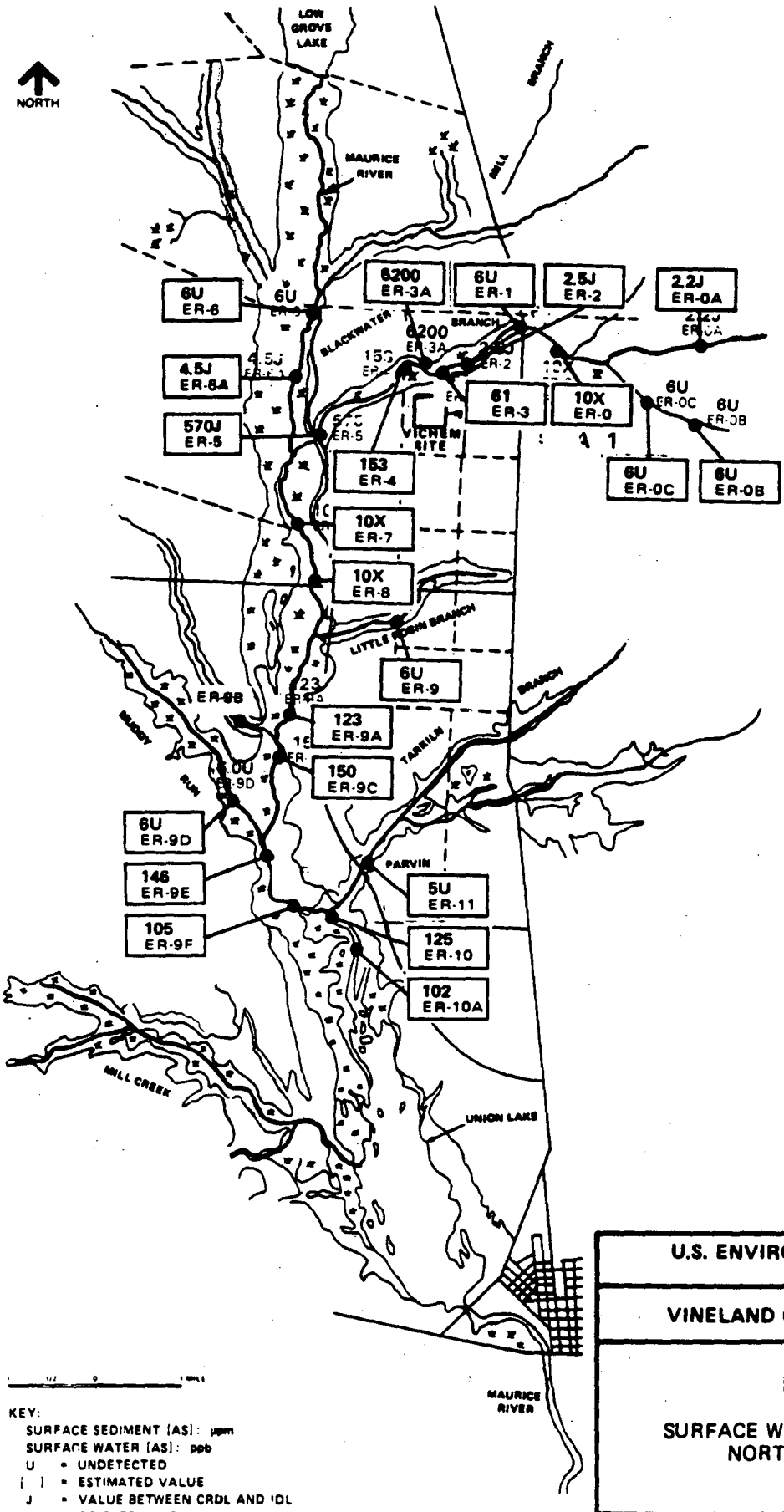
VINELAND CHEMICAL COMPANY SITE

FIGURE 4-1

SURFACE WATER ARSENIC RESULTS
BLACKWATER BRANCH
PHASE II

EBASCO SERVICES INCORPORATED

VIN 002 0665



U.S. ENVIRONMENTAL PROTECTION AGENCY

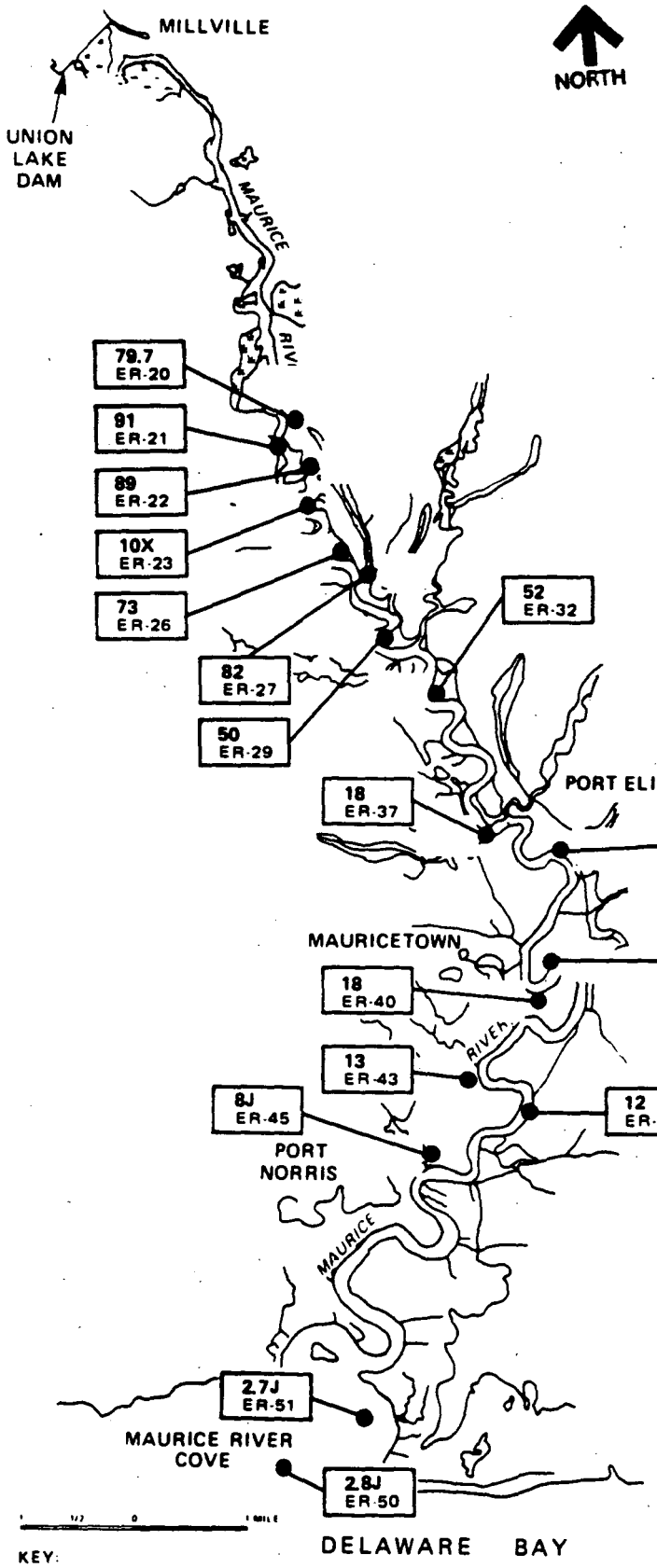
VINELAND CHEMICAL COMPANY SITE

FIGURE 4-2

SURFACE WATER ARSENIC RESULTS
NORTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED

VIN 002 0666



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 4-3

SURFACE WATER ARSENIC RESULTS
SOUTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED

VIN 002 0667

presents the arsenic concentration from Phase II, while Table 4-2 presents a summary of all of the compounds detected in the surface water in Phase II.

The stations on the Blackwater Branch upstream of the ViChem site again showed low to undetected arsenic concentrations. Near the plant, the concentrations increased to as much as 6,200 ug/l at ER-3A. At the time of sampling, this station was in the swamp caused by the beaver dam. Further downstream from the plant on the Blackwater Branch, the total arsenic concentrations were 153 and 570 ug/l at stations ER-4 and ER-5, respectively.

The arsenic concentration in the Maurice River above the confluence with the Blackwater Branch was low to undetected. Below the confluence, the concentrations ranged from 91 ug/l (dissolved) at ER-7 to 28 ug/l (dissolved) at ER-10A just above Union Lake.

The total arsenic concentrations in the Maurice River below Union Lake decreased progressively downstream. The highest concentrations were seen at the stations closest to the lake (91 ug/l total) with the lowest seen in the Delaware Bay (2.8 ug/l total). The concentration of total arsenic dropped below 50 ug/l somewhere between stations ER-32 and ER-37. In the 1979 sampling conducted by the NJDEP, the total arsenic concentration dropped below 50 ug/l somewhat further south, between stations ER-40 and ER-43 shown in Figure 4-3.

In Phase I, most of the arsenic detected in the water samples taken north of Union Lake was dissolved. In Phase II, the dissolved arsenic comprised much less of the total arsenic. This is shown in Table 4-1, and is discussed in Section 5, Fate and Transport of Arsenic.

Very few organics were detected in the water samples taken in the Blackwater Branch and the Maurice River above Union Lake. Pesticide/PCB compounds were not detected. The only volatile compounds detected were trans-1,2-dichloroethene at 9 ug/l and trichloroethene at 11 ug/l, both at station ER-8. No semivolatile compounds were definitively detected, although some compounds were tentatively identified at 108 ug/l or less.

Field Water Quality Tests

Certain field water quality tests were performed in Phases I and II. Temperature, pH, Eh, specific conductance, and dissolved oxygen were measured at all stations in both Phases. Salinity was measured at all stations in Phase I, and was measured only at the stations below Union Lake in Phase II. Table 4-3 presents the water quality tests for Phase I, while Table 4-4 presents the results for Phase II.

VIN 002 0668

TABLE 4-2

SUMMARY OF CHEMICALS DETECTED
SURFACE WATER
PHASE II

COMPOUND	NO. OF OCCUR.	NO. OF ANALYSES	MINIMUM DETECTED CONCENTRATION	MAXIMUM DETECTED CONCENTRATION	NO. OF ESTIM. VALUES	NO. OF REJECTED VALUES
**CLASS: VOLATILES (ug/l)						
Methyl Chloride	1	19	4.0	4.0	1	6
Trans-1,2-Dichloroethene	1	24	9.0	9.0	0	1
Trichloroethene	3	24	2.0	11.0	2	1
Benzene	1	24	4.0	4.0	1	1
4-Methyl-2-Pentanone	2	24	3.0	4.0	2	1
Di-n-Butylphthalate	1	14	2.0	2.0	1	0
Bis[2-Ethlhexyl]Phthalat	3	10	0.6	6.0	3	3
Di-n-Octyl Phthalate	1	14	8.0	8.0	1	0
Gamma-BHC	1	14	0.004	0.004	1	0
**CLASS: INORGANICS (ug/l)						
Aluminum	38	43	132.0	1110.0	7	0
Antimony	3	43	18.0	38.0	1	0
Arsenic	61	80	2.2	6200.0	17	5
Barium	39	41	32.0	148.0	39	2
Beryllium	2	43	2.4	2.4	2	0
Cadmium	1	25	4.6	4.6	1	18
Calcium	34	34	3170.0	207000.0	12	9
Chromium	12	43	7.7	56.0	3	0
Cobalt	2	43	51.0	66.0	0	0
Copper	22	43	11.0	87.0	16	0
Iron	34	34	124.0	3660.0	16	9
Lead	16	29	2.3	29.4	6	14
Magnesium	43	43	1600.0	591000.0	41	0
Manganese	43	43	18.3	129.0	4	0
Mercury	11	43	0.2	0.8	0	0
Nickel	10	42	7.9	112.0	3	1
Potassium	41	43	405.0	232000.0	25	0
Selenium	4	23	0.5	2.4	4	20
Silver	8	43	9.6	35.0	1	0
Sodium	34	34	3580.0	6092000.0	4	9
Thallium	2	22	0.6	1.3	2	21
Vanadium	13	43	6.5	60.0	12	
Zinc	7	7	8.0	74.1	4	

VIN 002 0669

TABLE 4-3

SURFACE WATER QUALITY
FIELD TESTS
PHASE I

SURFACE WATER STATION	DESCRIPTION	FIELD TESTS TEMPERATURE (°C)	pH (S.U.)	Eh (mV)	SPECIFIC CONDUCTANCE (umhos/cm)	DISSOLVED OXYGEN (mg/l)	SALINITY (%)
ER-0	Surface*	20	4.8			6.8	
ER-0	Surface	21	6.5	5.7		7.0	
	Sediment			6.7			
ER-1	Surface	18	6.0	6.0		6.3	
ER-2	Surface	23	6.8	5.4		8.0	
ER-3	Surface	24	6.2	5.5		7.4	
	Sediment					9.5	
ER-4	Surface	23	6.2	6.0		2.6	
ER-5	Surface	17.3	6.0			7.8	
	Bottom	17.3	5.9			7.6	
	Sediment			0.15-0.20			
ER-6	Surface	23	5.6	6.6		6.5	
	Sediment			4.7			
ER-7	Surface	20,21	4.1		52	8.1	5.0
	Bottom	18,20	4.15		55	8.1	5.0
ER-8	Surface	21	6.1			7.8-8.2	
ER-9	Surface	19.5	4.5		55	10	0
	Bottom	20	4.5		150	9.4	0
ER-10	Surface	25	7.2	5.8		8.2	
	Bottom	25	7.0	5.9		7.9	
	Sediment			5.7			
ER-11	Surface	19	6.5	8.2		3.7	
	Sediment			8.4,8.6			
ER-12	Surface	15	6.8	4.5	40	9.5	0
ER-13	Surface	25	6.8	0.72	85	7.6	0
ER-14	Surface	24	6.2	0.60	90	7.6	0

* Test performed after rainfall

VIN 002 0670

TABLE 4-4

SURFACE WATER QUALITY
FIELD TESTS
PHASE II

SURFACE WATER STATION	FIELD TESTS					
	TEMPERATURE (°C)	pH (S.U.)	Eh (mV)	SPECIFIC CONDUCTANCE (umhos/cm)	DISSOLVED OXYGEN (mg/l)	SALINITY (%)
ER-O	22	6.1	+170	40	5.8	
ER-OA	21	4.8	+240	70	4.4	
ER-OB	30	7.4	+100	20	5.8	
ER-OC	24	6.8		100	7.9	
ER-1	27	6.8	+160	50	5.6	
ER-2	23	6.8	+137	60	6.7	
ER-3						
ER-3A	25	6.5	+150	90	8.0	
ER-4	24.5	5.4	+140	65	6.2	
ER-5	22	5.2	+160	80	7.6	
ER-6	25.5	7.4	+150	80	7.4	
ER-6A	22.5	6.4	+155	65	6.4	
ER-7	24	7.0	+120	60	6.2	
ER-8	27	7.4	+130	40	8.0	
ER-9	26	6.8	+125	20	8.2	
ER-9A	25	7.0	+140	80	8.0	
ER-9C	25	6.8	+150	35	6.8	
ER-9D	27.5	7.5	+ 90	65	7.5	
ER-9E	27	6.8	+135	90	7.8	
ER-9F	27	6.7	+140	60	7.6	
ER-10	28	6.8	+140	100	7.8	
ER-10A	27.5	7.8	+150	110	7.6	
ER-11	25	6.9	+150	460	4.0	
ER-20	28	6.2	+150	98	6.2	0
ER-21	275	6.6	+140	119	7.2	0
ER-22	27	6.2	+150	95	4.7	0
ER-23	28	6.5	+140	95	7.2	0
ER-26	28	6.7	+130	115	6.9	0
ER-27	28	6.6	+130	121	6.6	0
ER-29	28	6.8	+120	308	6.4	0.2
ER-32	28	6.9	+115	710	4.9	0.5
ER-37	28.5	6.9	+105	6500	5.1	4.7
ER-38	28.5	7.0	+100	10,100	5.2	4.9
ER-39	29	6.5	+135	4,400	5.9	2.8
ER-40	29.5	6.7	+130	5,800	4.9	3.2
ER-43	29	6.7	+120	9,900	3.8	5.5
ER-44	28	6.8	+120	16,000	3.1	9.0
ER-45	28	6.9	+110	23,000	3.2	13.5
ER-50	28	7.5	+ 80	27,000	4.2	16
ER-51	28	7.2	+ 90	32,500	5.2	19

VIN 002 0671

The pH varied between a low of 4.1 on the upper Maurice River at ER-7 to a high of 7.5 at station ER-50 in the Delaware Bay. There were no systematic pH variations observed in the watershed.

The Phase I Eh measurements ranged between 0.60 just south of Union Lake at ER-14 to 8.2 on the Parvin Branch, with most values between 4 and 6. In Phase II, the Eh values were much higher, generally over 100 mV. It is believed that some instrumentation problems were experienced in Phase I, since the results are unreasonable for a surface water body, while the Phase II results are considered more representative of the surface water system.

The specific conductance in the upper Maurice River and the Blackwater Branch was low, generally less than 100 umhos/cm. The specific conductance was slightly elevated at station ER-11 (460 umhos/cm) on the Parvin Branch, which presumably produces the specific conductance increase observed between ER-9F and ER-10. The Parvin Branch enters the Maurice River between these two stations.

The specific conductance in the lower Maurice River increased downstream toward the Delaware Bay. In Table 4-3, a large increase in specific conductance was observed between stations ER-32 and ER-37, with an accompanying increase in salinity. This probably represents the tidal saltwater front in the estuary at the time of sampling. The data show that the conductance and the salinity at stations ER-39, -40, and -43 were lower than at station ER-38, further upstream. This is probably a result of sampling times. Stations ER-20 through ER-38 were all sampled sequentially on one day, while stations ER-39 through ER-51 were sampled on another day. The tidal front was not necessarily in the same place on separate days.

The data on Figure 4-3 showed that the arsenic concentration in the lower Maurice River dropped below 50 ug/l in between stations ER-32 and -37. The data in Table 4-3 show a large specific conductance increase between these same two stations. As discussed in Section 5, arsenic may be precipitated out of solution in saline waters, which may explain these two observations.

Literature Values

According to the Cumberland County Water Resources Data Report (Rooney, 1971), the following water quality results were observed at the Norma gaging station (ER-7) on the Maurice River in 1986. The specific conductance of the river ranged between 60 and 79 umhos/cm, the pH ranged between 5.8 and 6.7, the dissolved oxygen ranged between 81 and 88 percent saturation, and the biological oxygen demand ranged between 0.4 and 1.7 mg/l. The dissolved arsenic ranged between 50 and 93 ppb. The water quality results obtained in Phases I and II are in general agreement with these values.

VIN 002 0672

4.2 SEDIMENT

Sediment samples were obtained in Phases I and II. In Phase I, sediment samples from approximately 0 to 1 foot were obtained from stations in the Blackwater Branch and upper Maurice River. In Phase II, sediment core samples from 0 to 3 feet were obtained in the Blackwater Branch and the upper Maurice River, while surface sediment dredge samples were obtained from the lower Maurice River. The Phase I analytical results are presented in Appendix A, while the Phase II results are presented in Appendix B. Table 4-5 presents the mean arsenic concentration in the top one foot of sediment of Phase I and II samples.

Phase I

The arsenic results of the Phase I sediment samples show basically the same pattern as that observed for the surface water samples. Arsenic was detected at very low concentrations (5 mg/kg) in the background samples (ER-0, ER-1, and ER-6). The highest concentration of arsenic was found at ER-3A near the ViChem site (331 mg/kg) and the concentrations decreased to 70 mg/kg at ER-10, where the Maurice River enters Union Lake. Arsenic was detected at very low concentrations in the sediments of Little Robin Branch, Parvin Branch or Mill Creek. The only parameter detected near the ViChem site that was not detected in the background samples was cadmium at 8.0 mg/kg. Chromium was detected at 30 mg/kg at ER-1 (background sample) and decreased in concentration to below detectable levels near the ViChem site. Chromium was also found in the Maurice River background sample (ER-6) at 16 mg/kg.

Several volatile compounds were detected in sediments. These included acetone, toluene, several unknown compounds detected in the library search, dichlorodifluoromethane, 2-butanone, and tetrachloroethene. Acetone was detected most frequently and was also found in several field blanks. Acetone was used to decontaminate the sampling equipment. Toluene was found only at ER-1. This sample was collected near a road and its presence is probably due to runoff from the road. The unknown compounds (also found in two field blanks and one trip blank) were believed to be breakdown products of runoff from roads in the area and/or laboratory contaminants such as photolytic inhibitors used in laboratory reagents. Dichlorodifluoromethane, 2-butanone, and tetrachloroethene are common laboratory contaminants and were found in some of the laboratory reagent blanks.

Phase II

Figures 4-4, 4-5 and 4-6 show the sediment arsenic concentrations in the top one foot of sediment (0-1 foot) for stations in the Blackwater Branch, the upper Maurice River and the lower Maurice River, respectively. These values are

VIN 002 0673

TABLE 4-5

MEAN SURFACE SEDIMENT ARSENIC CONCENTRATIONS
PHASES I AND II

STATION	PHASE I MEAN ARSENIC CONCENTRATION[a] (mg/kg)	PHASE II MEAN ARSENIC CONCENTRATION[a] (mg/kg)
ER-0	5	1.0uJ
ER-0A		1.0uJ
ER-0B		6.0uJ
ER-0C		3.3
ER-1	5	8.0
ER-2	5	5.8
ER-3		410
ER-3A	331	2300
ER-4	55	91
ER-5	74	37
ER-6	5	2.7u
ER-6A		1.5u
ER-7	70	7.1J
ER-8	104	14J
ER-9	5	2.2uJ
ER-9A		71
ER-9C		45
ER-9D		3.2
ER-9E		130
ER-9F		180
ER-10	70	460
ER-10A		68
ER-11	5	8.7
ER-12	5	
ER-20		9.9
ER-21		25
ER-22		234

VIN 002 0674

TABLE 4-5 (Cont'd)

MEAN SURFACE SEDIMENT ARSENIC CONCENTRATIONS
PHASES I AND II

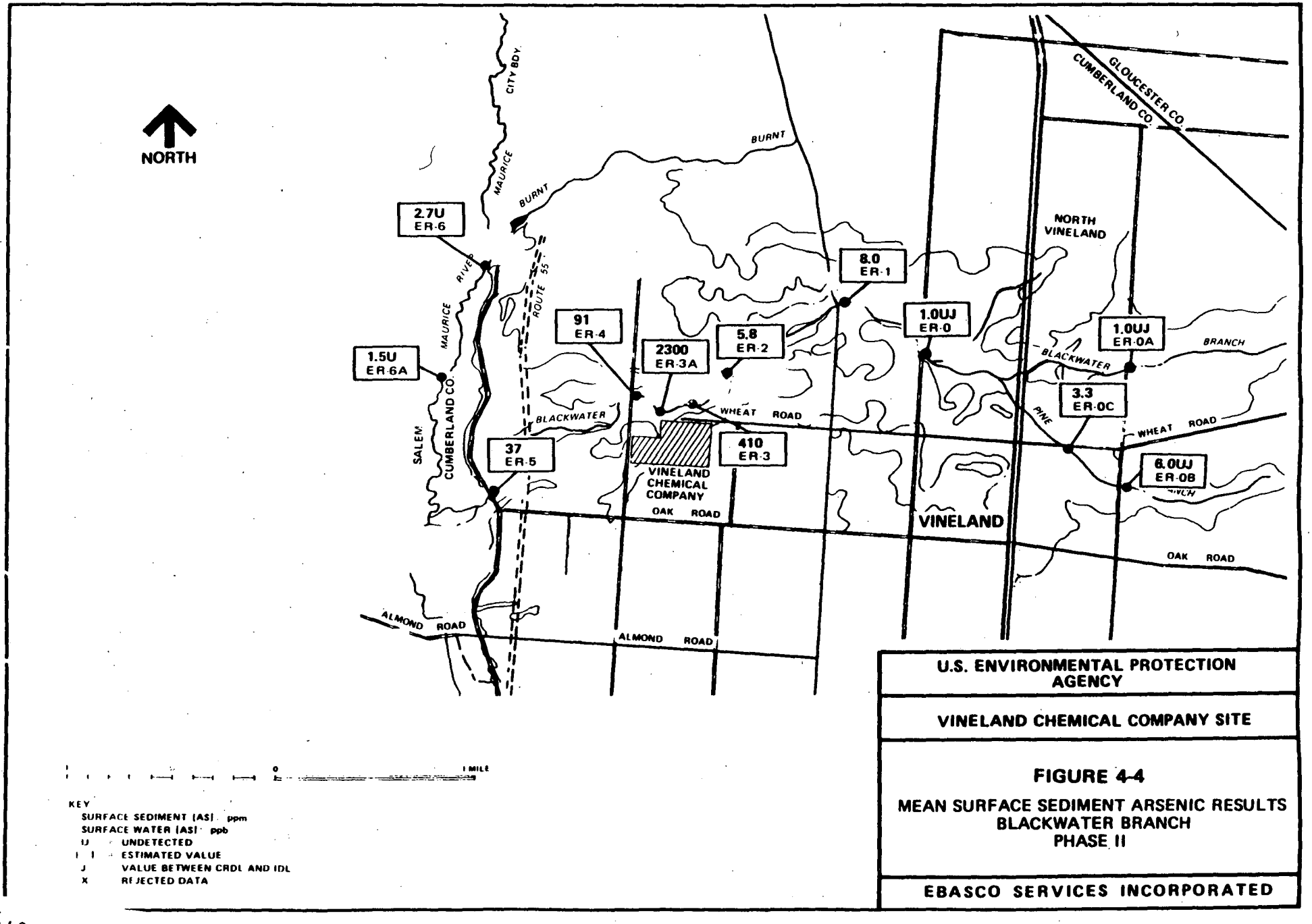
STATION	PHASE I MEAN ARSENIC CONCENTRATION[a] (mg/kg)	PHASE II MEAN ARSENIC CONCENTRATION[a] (mg/kg)
ER-23		21
ER-26		35
ER-27		93
ER-29		16
ER-32		59
ER-32 Dup		12
ER-37		136
ER-38		41
ER-39		9.2
ER-40		19
ER-43		11
ER-44		32
ER-45		27
ER-50		20

(a) - Mean of all 0-1' sediment samples or sediment dredge samples taken at this station. If only one sample obtained, that value is reported.

Explanatory Notes

u - Undetected at given concentration
J - Estimated value

VIN 002 0675



U.S. ENVIRONMENTAL PROTECTION AGENCY

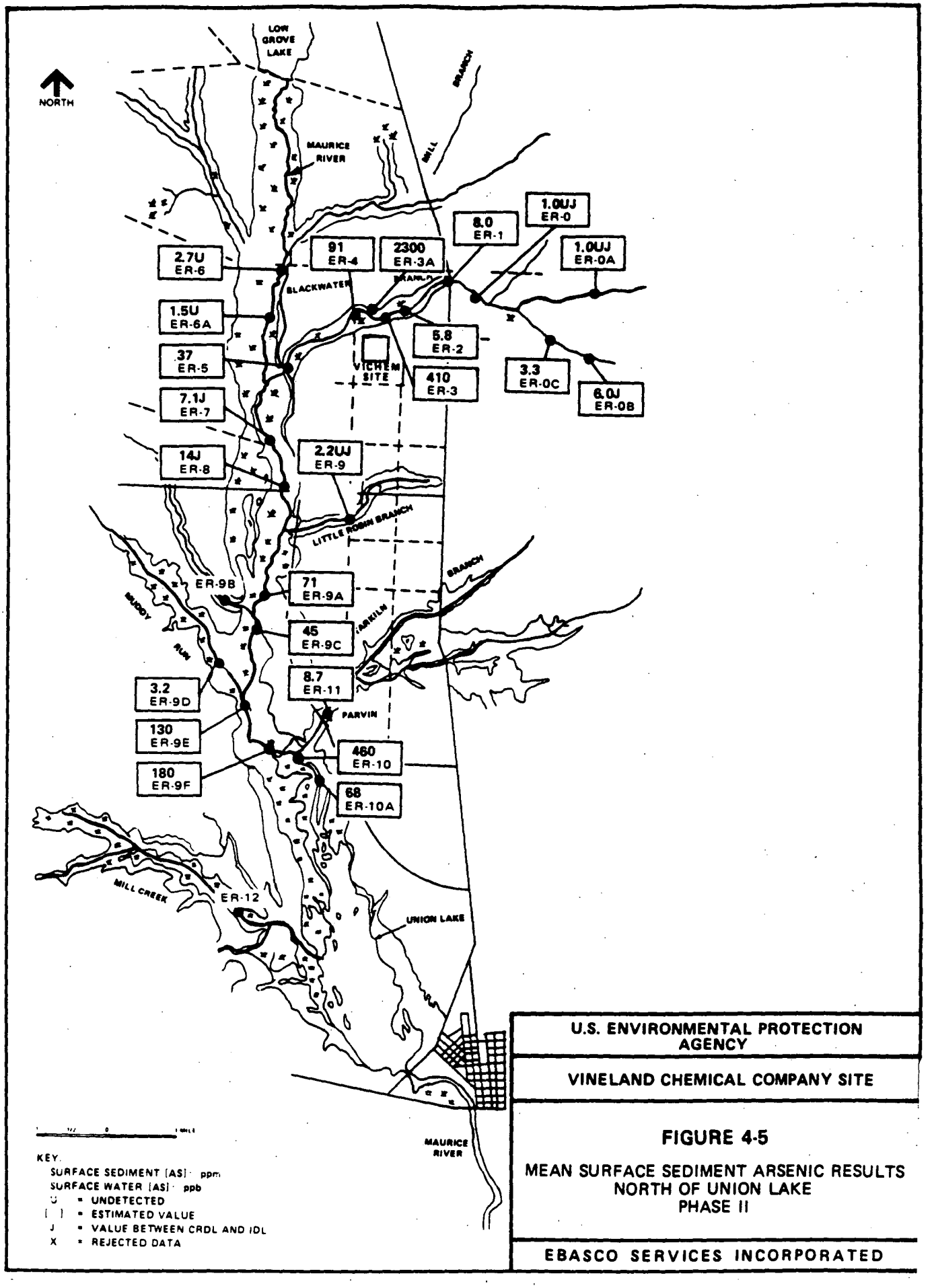
VINELAND CHEMICAL COMPANY SITE

FIGURE 4-4

MEAN SURFACE SEDIMENT ARSENIC RESULTS
BLACKWATER BRANCH
PHASE II

EBASCO SERVICES INCORPORATED

VIN 002 0676



U.S. ENVIRONMENTAL PROTECTION AGENCY

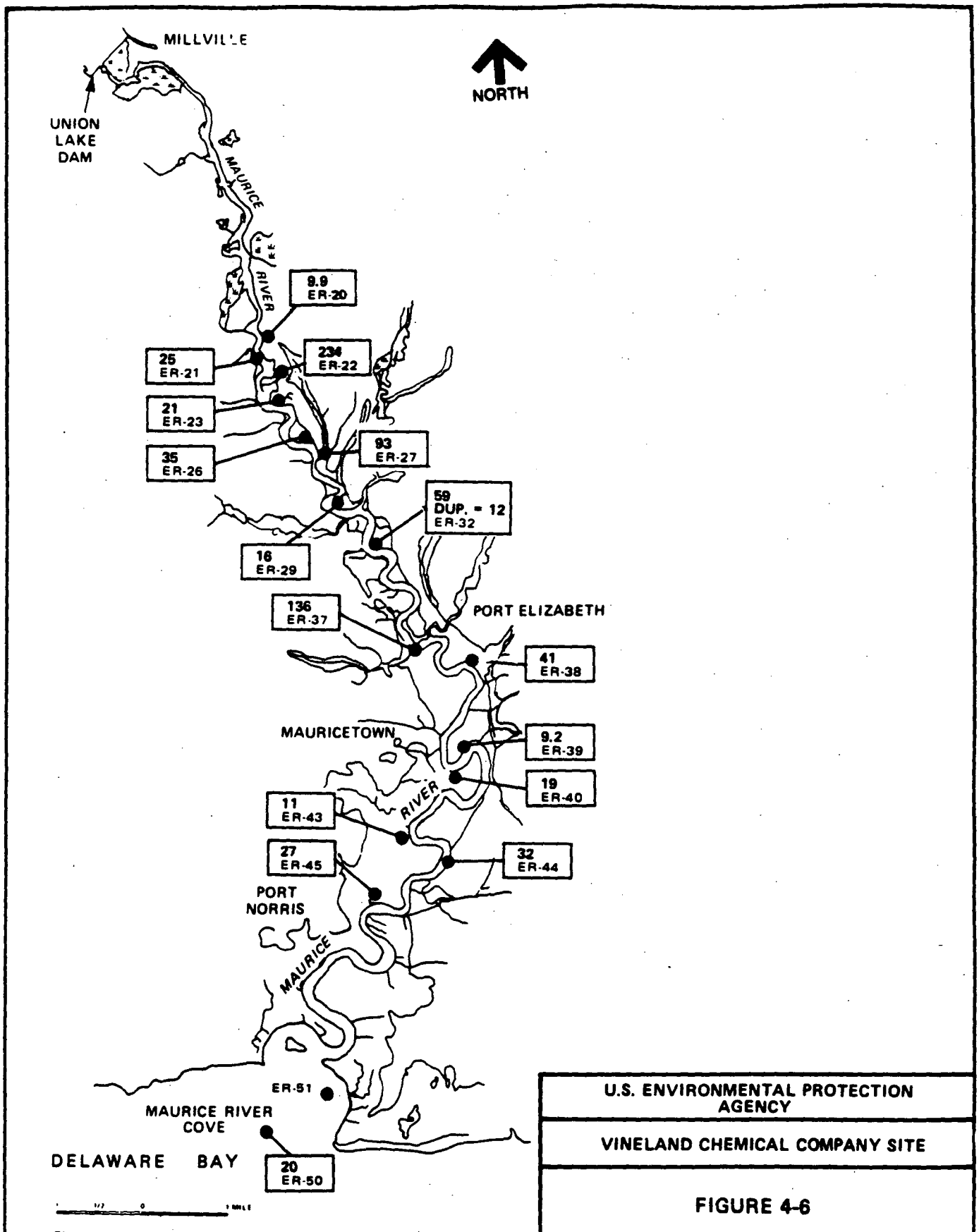
VINELAND CHEMICAL COMPANY SITE

FIGURE 4-5

MEAN SURFACE SEDIMENT ARSENIC RESULTS
NORTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED

VIN 002 0677


MILLVILLE
NORTH
UNION LAKE DAM
MAURICE RIVER
9.9 ER-20
25 ER-21
234 ER-22
21 ER-23
35 ER-26
93 ER-27
59 DUP. = 12 ER-32
16 ER-29
136 ER-37
PORT ELIZABETH
41 ER-38
MAURICETOWN
9.2 ER-39
19 ER-40
11 ER-43
RIVER
27 ER-45
32 ER-44
PORT NORRIS
MAURICE
ER-51
MAURICE RIVER COVE
DELAWARE BAY
20 ER-50
KEY:
SURFACE SEDIMENT (AS) = ppm
U = UNDETECTED
[ ] = ESTIMATED VALUE
J = VALUE BETWEEN CRDL AND IDL
X = REJECTED DATA
U.S. ENVIRONMENTAL PROTECTION AGENCY
VINELAND CHEMICAL COMPANY SITE
FIGURE 4-6
SURFACE SEDIMENT ARSENIC RESULTS
SOUTH OF UNION LAKE
PHASE II
EBASCO SERVICES INCORPORATED

VIN 002 0678

tabulated in Table 4-5. Cross sections showing the arsenic concentration in each core sample with depth are presented in Appendix I. Table 4-6 summarizes the chemicals detected in the 0-1 foot samples from each core.

The arsenic concentrations in the surface sediments (0-1 ft) in the Blackwater Branch in Phase II showed the same pattern as seen in Phase I. The arsenic was very low to undetected upstream from the ViChem plant and was higher downstream from the plant. The highest mean surface sediment concentration was seen at station ER-3A in the swamp by the plant, approximately 2300 mg/kg. The mean surface arsenic concentrations at ER-4 and ER-5 were 91 and 37 mg/kg, respectively.

Upstream from the Blackwater Branch, the Maurice River showed very low to undetected arsenic concentrations. The concentrations were higher downstream with stations ER-9A, -9E, -9F, 10 and 10A all displaying mean surface sediment arsenic concentrations above 50 mg/kg. The highest mean concentration was seen at ER-10, approximately 460 mg/kg.

The tributaries sampled in Phase II, Little Robin Branch, Parvin Branch, and Muddy Run, all displayed very low to undetected arsenic concentrations.

There were no consistent patterns of arsenic concentration with depth in the core samples shown in Appendix I. Some stations, such as ER-5, -8, -10 and -10A, showed higher arsenic concentrations at the surface than at depth. Others, such as ER-3A and ER-9A, showed higher concentrations at depth than at the surface. Still others displayed no pattern, having higher concentations at depth in one core and higher concentrations at the surface in another. There data may indicate that the sediments are subject to mixing and overturning in the stream beds.

The sediment arsenic concentrations below Union Lake varied from less than 10 to over 200 mg/kg. There was no discernible pattern of arsenic distribution in the sediments along this section of the Maurice River.

The TOC results shown in Appendix A displayed a wide variation. Above Union Lake, the lowest concentrations observed were less than 1,000 mg/kg, usually in the Maurice River just above Union Lake. The highest concentration was at ER-3A in the swamp by the plant, 349,000 mg/kg. Below Union Lake, most samples were above 10,000 mg/kg, with the peak of 102,000 mg/kg at station ER-22.

VIN 002 0679

TABLE 4-6

SUMMARY OF CHEMICALS DETECTED IN
SURFACE SEDIMENTS; 0-1 FT. SAMPLES
PHASE II

COMPOUND	NO. OF OCCUR.	NO. OF ANALYSES	MINIMUM DETECTED CONCENTRATION	MAXIMUM DETECTED CONCENTRATION	NO. OF ESTIM. VALUES	NO. OF REJECTED VALUES
**CLASS: VOLATILES (ug/kg)						
Methyl Chloride	1	1	3	3	1	13
Carbon Disulfide	1	14	4	4	1	1
2-Butanone	2	7	3	13	2	8
Toluene	7	12	3	260	3	3
**CLASS: BNA (ug/kg)						
Bis[2-Chloroethyl]Ether	1	15	860	860	1	1
Benzoic Acid	1	15	310	310	1	1
Acenaphthylene	2	15	67	83		
Acenaphthene	1	15	450	450	0	1
Dibenzofuran	1	15	350	350	1	1
Diethylpthalate	2	15	42	67	2	1
Fluorene	1	15	620	620	0	1
Phenanthrene	4	15	150	2100	3	1
Anthracene	4	15	170	350	4	1
Di-n-Butylphthalate	2	9	42	67	2	5
Fluoranthrene	7	15	30	1100	6	1
Pyrene	7	15	32	1200	6	1
Benzo[a]Anthracene	3	15	110	200	3	1
Chrysene	4	15	190	670	3	1
Benzo[b]Fluoranthene	2	15	210	370	1	1
Benzo[a]Pyrene	2	15	150	170	2	1
Indeno[1,2,3-CD]Pyrene	1	15	83	83	1	1
Benzo[G,H,I]Perylene	1	15	83	83	1	1
** CLASS: PEST/PCB (ug/kg)						
Gamma-BHC	1	14	230	230	0	2
4-4-DDD	3	13	13	45	2	3
Endosulfan Sulfate	1	15	23	23	1	1
4-4-DDT	1	14	32	32	0	2

VIN 002 0680

TABLE 4-6 (Cont'd)

SUMMARY OF CHEMICALS DETECTED IN
SURFACE SEDIMENTS; 0-1 FT. SAMPLES
PHASE II

COMPOUND	NO. OF OCCUR.	NO. OF ANALYSES	MINIMUM DETECTED CONCENTRATION	MAXIMUM DETECTED CONCENTRATION	NO. OF ESTIM. VALUES	NO. OF REJECTED VALUES
**CLASS: INORGANICS (mg/kg)						
Aluminum	16	23	262	25965	0	0
Arsenic	79	112	1	3760	14	4
Barium	32	36	9	810	22	0
Beryllium	1	23	1.6	1.6	1	0
Cadmium	10	36	1.2	12.0	1	0
Calcium	13	23	10.0	5480.0	10	0
Chromium	4	23	3.1	6.8	4	0
Cobalt	9	23	6.0	119.0	1	0
Iron	90	98	80.0	39000.0	1	4
Lead	21	24	1.9	337.0	0	2
Magnesium	8	23	64.0	1440.0	8	0
Manganese	9	16	7.2	102.0	1	7
Mercury	7	36	0.2	2.7	0	0
Nickel	6	23	1.5	17.0	4	0
Potassium	1	23	380.0	380.0	0	0
Silver	1	36	4.4	4.4	1	0
Sodium	4	23	337.0	846.0	4	0
Vanadium	9	23	4.1	49.9	7	0
Zinc	16	23	4.1	162.0	1	0

VIN 002 0681

Various other inorganic compounds were analyzed for above Union Lake. Antimony, selenium and thallium were not detected at any of the river stations. Cadmium was detected at 1.21-3.9 mg/kg, iron at 134-21,300 mg/kg, and lead at 1.95-314 mg/kg.

The volatile compounds detected in the surface sediments north of Union Lake were toluene, acetone, 2-butanone, methyl chloride, and a tentatively identified compound. Toluene was detected at 4 ug/kg in ER0-B0, at 250 and 260 ug/kg in ER0C-A0, at 130 ug/kg in ER4-B0, at 100 ug/kg in ER6-A0 and at 15 ug/kg in ER9C-E0. Acetone was detected at 4 ug/kg in ER9D-A0, methyl chloride was detected at 3 ug/kg in ER11-A0 and 2-butanone was detected at 3 ug/kg at ER6-A0. The tentatively identified compound was detected at 13 ug/kg in ER9E-A0.

Several semivolatile compounds were detected in the surface sediments north of Union Lake. Most of the compounds were found in sediments from stations ER-0B, ER-10A, ER-1 and ER-9. The following semivolatile compounds were detected: acenapthalene, diethylphthalate, acenaphthene, dibenzofuran, fluorene, phenanthrene, anthracene, benzoic acid, ideno[1,2,3-cd]pyrene, di-n-butylphthalate, bis[2-chloroethyl]ether, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, and benzo[a]pyrene.

Four pesticide/PCB compounds were detected in the surface sediments north of Union Lake. Gamma-BHC was found in ER0B-B0 at 230 ug/kg and 4-4-DDD was found in ER9-A0 at 18 ug/kg, in ER9C-E0 at 45 ug/kg, and in ER10A-I0 at 13 ug/kg. Endosulfan sulphate was found in ER10A-I0 at 23 ug/kg and 4-4-DDT was found in ER9-A0 at 32 ug/kg.

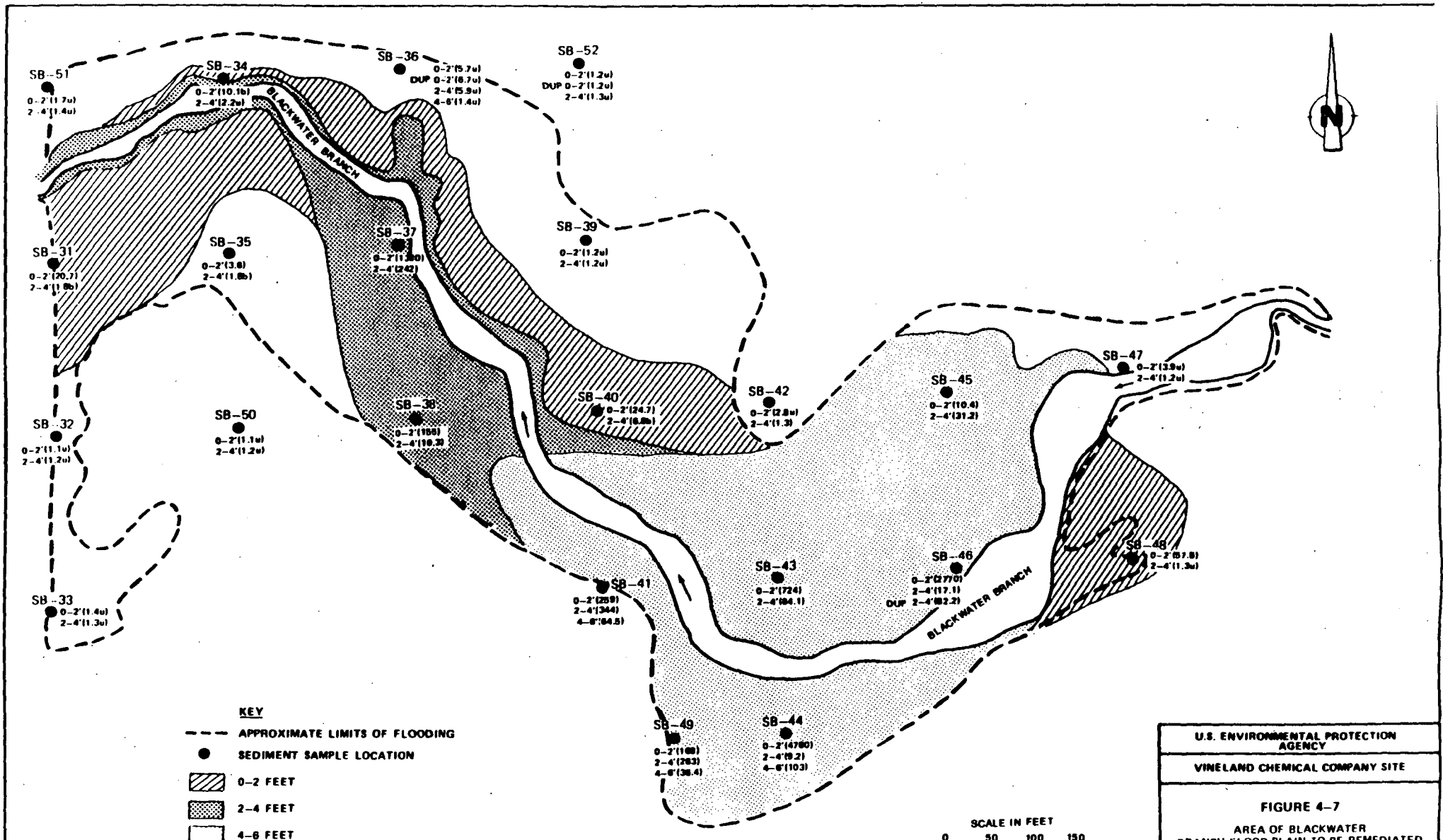
Six compounds were detected in the EP toxicity analysis of the stream sediments. Arsenic was detected at 19-240 ug/l, barium at 9-810 ug/l, calcium at 7-12 ug/l, chromium at 7.8-10 ug/l, lead at 6.7-300 ug/l and mercury at 2.1 and 2.7 ug/l.

4.2.1 Supplemental Sediment Sampling

Figure 4-7 presents the sampling locations and the results of supplemental samples taken in the Blackwater Branch flood plain. These samples were taken to estimate the volume of contaminated sediments in this area. Sampling was conducted in Novmember 1988, approximately one year after the beaver dam had been breached and the area allowed to drain. Samples were analyzed for total arsenic only.

The results show that most of the sediments in the area that had been submerged by the flood waters had elevated arsenic concentrations. Very few samples had undetected arsenic levels as observed upstream of the flooded area in the Blackwater Branch.

VIN 002 0682


SB-51
0-2'(1.7u)
2-4'(1.4u)
SB-34
0-2'(10.1b)
2-4'(2.2u)
SB-36
0-2'(5.7u)
DUP 0-2'(6.7u)
2-4'(5.9u)
4-6'(1.4u)
SB-52
0-2'(1.2u)
DUP 0-2'(1.2u)
2-4'(1.3u)
BLACKWATER BRANCH
SB-31
0-2'(20.7)
2-4'(1.8b)
SB-35
0-2'(3.8)
2-4'(1.8b)
SB-37
0-2'(1.2u)
2-4'(242)
SB-39
0-2'(1.2u)
2-4'(1.2u)
SB-47
0-2'(3.9u)
2-4'(1.2u)
SB-45
0-2'(10.4)
2-4'(31.2)
SB-42
0-2'(2.8u)
2-4'(1.3)
SB-40
0-2'(24.7)
2-4'(6.8b)
SB-38
0-2'(156)
2-4'(10.3)
SB-50
0-2'(1.1u)
2-4'(1.2u)
SB-32
0-2'(1.1u)
2-4'(1.2u)
SB-48
0-2'(57.8)
2-4'(1.3u)
SB-46
0-2'(2770)
2-4'(17.1)
DUP 2-4'(82.2)
SB-43
0-2'(724)
2-4'(84.1)
SB-41
0-2'(259)
2-4'(344)
4-6'(84.5)
SB-33
0-2'(1.4u)
2-4'(1.3u)
SB-49
0-2'(188)
2-4'(263)
4-6'(36.4)
SB-44
0-2'(4760)
2-4'(9.2)
4-6'(103)
KEY
APPROXIMATE LIMITS OF FLOODING
SEDIMENT SAMPLE LOCATION
0-2 FEET
2-4 FEET
4-6 FEET
b - ARSENIC DETECTED IN BLANK AS WELL
u - UNDETECTED
SCALE IN FEET
0 50 100 150
N
U.S. ENVIRONMENTAL PROTECTION AGENCY
VINELAND CHEMICAL COMPANY SITE
FIGURE 4-7
AREA OF BLACKWATER BRANCH FLOOD PLAIN TO BE REMEDIATED AND SEDIMENT ARSENIC ANALYSES
ERASCO SERVICES INCORPORATED

VIN 002 0683

The maximum depth of arsenic contamination found was approximately six feet. However, samples deeper than this were not taken here, since the purpose of the sampling was to estimate volumes of sediments for removal. Excavation would not be considered practical for materials in the flood plain much deeper than this.

Figure 4-7 also presents the approximate limits of flooding caused by the beaver dam in the Blackwater Branch flood plain. This was determined by observing a topographic map of the area, and by surveying the flood plain on foot to determine obvious signs of flooding.

4.3 BIOTA

The three fish samples taken above Union Lake were analyzed for total arsenic and pesticides/PCBs. The samples taken in the lower Maurice River, two fish, one crab backfin, one crab hepatopancreas, and two oysters, were analyzed for total arsenic. Figures 4-8 and 4-9 display the arsenic results from the upper and lower Maurice River stations, respectively. All of the analytical data are presented in Appendix A.

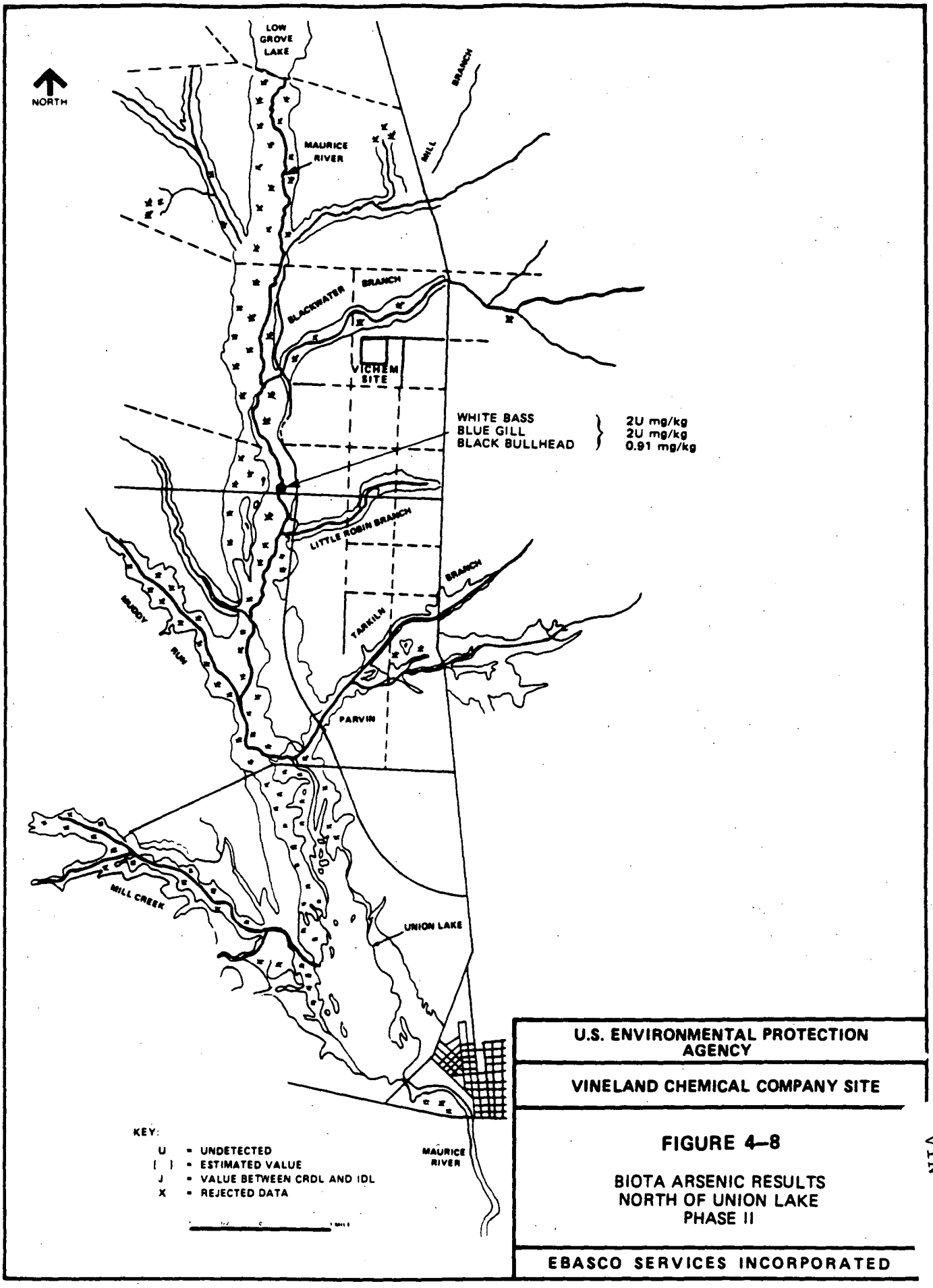
The results for the fish samples from the upper Maurice River showed undetected pesticide/PCB values. The white bass and blue gill showed undetected arsenic values. The black bullhead showed an arsenic concentration of 0.91 mg/kg.

The catfish and yellow perch sampled in the lower Maurice River also showed undetected arsenic values. The crab backfin, crab hepatopancreas and the American oyster from the river showed 1.5, 1.6 and 1.3 mg/kg arsenic, respectively. The American oyster taken in the Delaware Bay displayed an arsenic concentration of 1.2 mg/kg.

4.4 BLANKS

Table 4-7 summarizes the chemicals detected in the field blank samples from the Phase II sampling program and Table 4-8 summarizes the chemicals detected in the trip blank samples. Methyl chloride, acetone, 2-butanone and toluene were detected in some of the field and trip blanks. The only semivolatile detected was bis-[2-ethylhexyl]pthalate at 0.3 ug/l. Metals were detected in the field blanks only. Arsenic was detected in 2 out of 23 field blanks at 1.4J and 7.8 J ug/l.

VIN 002 0684



U.S. ENVIRONMENTAL PROTECTION AGENCY

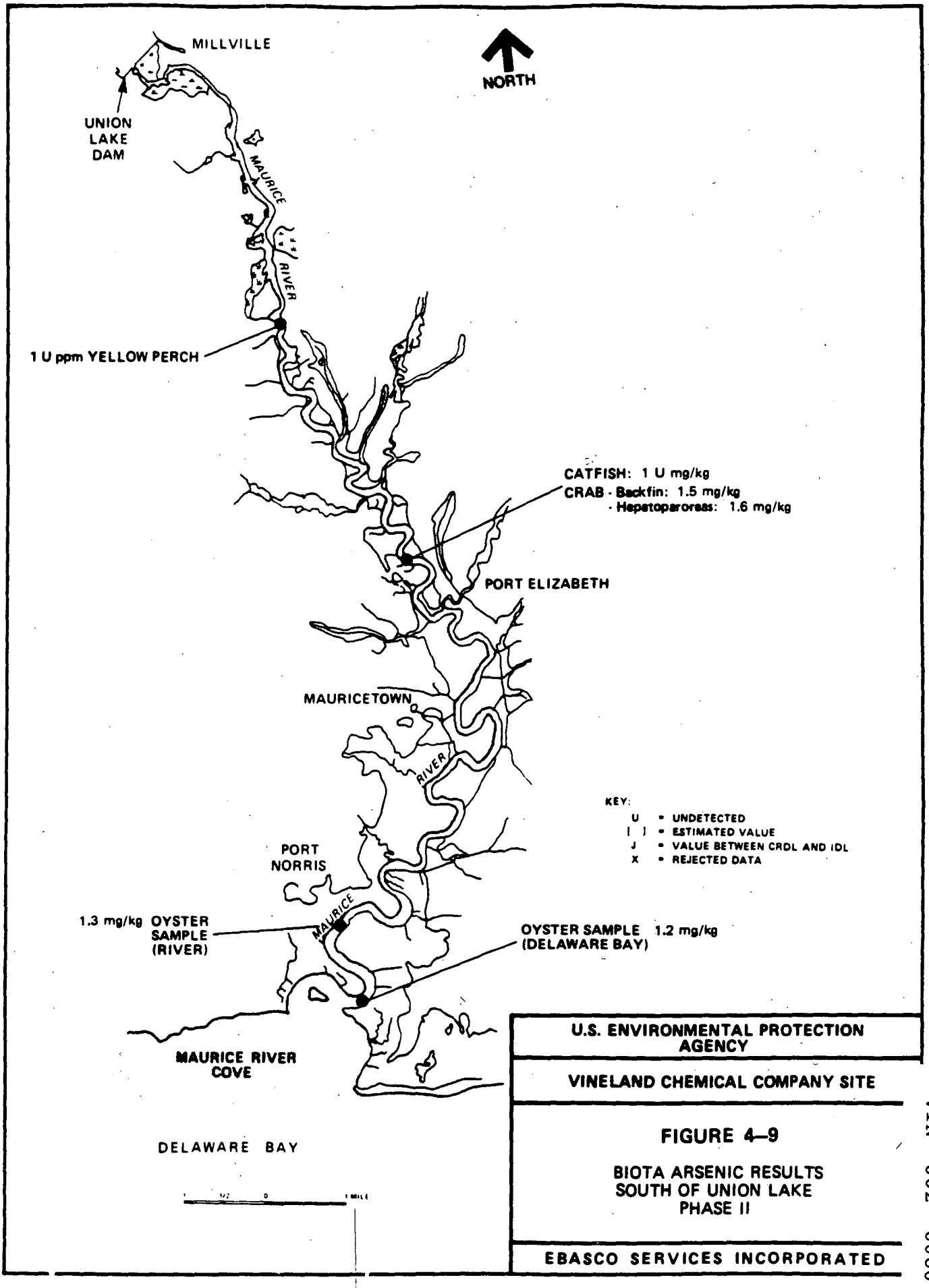
VINELAND CHEMICAL COMPANY SITE

FIGURE 4–8

BIOTA ARSENIC RESULTS
NORTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED

VIN 002 0685



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 4–9

BIOTA ARSENIC RESULTS
SOUTH OF UNION LAKE
PHASE II

EBASCO SERVICES INCORPORATED

VIN 002 0686

TABLE 4-7

SUMMARY OF CHEMICALS DETECTED
FIELD BLANK SAMPLES
PHASE II

COMPOUND	NO. OF OCCUR.	NO. OF ANALYSES	MINIMUM DETECTED CONCENTRATION	MAXIMUM DETECTED CONCENTRATION	NO. OF ESTIM. VALUES	NO. OF REJECTED VALUES
**CLASS: VOLATILES (ug/l)						
Methyl Chloride	3	5	3.0	16.0	3	0
Toluene	2	5	12.0	21.0	2	0
**CLASS: BNA (ug/l)						
Bis[2-Ethylhexyl]Phthalate	1	4	0.3	0.3	1	0
**CLASS: INORGANICS (ug/l)						
Aluminum	1	7	100.0	100.0	1	0
Arsenic	2	23	1.4	7.8	2	0
Barium	2	7	1.3	1.9	2	0
Calcium	2	7	893.0	974.0	2	0
Copper	2	7	12.0	17.0	2	0
Iron	11	16	24.0	347.0	3	0
Lead	3	6	1.6	5.8	2	1
Magnesium	3	7	53.0	182.0	3	0
Manganese	1	7	3.0	3.0	1	0
Mercury	7	36	0.1	2.7	0	0
Nickel	2	7	8.3	23.0	2	0
Selenium	1	5	2.7	2.7	1	2
Sodium	3	7	1490.0	2240.0	3	0
Zinc	3	6	4.5	172.0	2	1

VIN 002 0687

TABLE 4-8

SUMMARY OF CHEMICALS DETECTED
TRIP BLANK SAMPLES
PHASE II

COMPOUND	NO. OF OCCUR.	NO. OF ANALYSES	MINIMUM DETECTED CONCENTRATION	MAXIMUM DETECTED CONCENTRATION	NO. OF ESTIM. VALUES	NO. OF REJECTED VALUES
**CLASS: VOLATILES						
Methyl Chloride	4	7	3.0	58.0	4	8
Acetone	2	4	31.0	3300.0	0	5
2-Butanone	6	11	3.0	86.0	4	4
Toluene	4	11	2.0	32.0	4	4

VIN 002 0688

VIN 002 0689

5.0 FATE AND TRANSPORT OF ARSENIC

5.1 GENERAL GEOCHEMISTRY OF ARSENIC

Arsenic is ubiquitous in the earth's crust at low concentrations, generally below 5 mg per kg (USEPA, 1976). It occurs in four oxidation states: the -3 state, the metallic (0) state, and the +3 and +5 states. The metallic state can be found in certain types of mineral deposits; the +3 and +5 states are common in a variety of complex minerals and in dissolved salts in natural waters. The -3 state is present in gaseous AsH_3 (arsine). Arsenic occurs most frequently in nature in the pentavalent (+5) state as arsenate.

In soil, arsenic is present at concentrations from 0.1 ppm to more than 1,000 ppm, depending on the soil's particular geological history (Ehrlich, 1981). Analysis of 1,577 US surface waters showed arsenic to be present in 87 samples with concentrations ranging from 5 to 336 ug/l, and a mean level of 64 ug/l, (Kopp, 1969). In addition, large amounts of arsenic have been introduced into the environment in various chemical forms. Inorganic arsenic compounds such as sodium arsenite, lead arsenate and calcium arsenate have been used in agriculture; arsenic pentoxide is used as both a herbicide and a pesticide. Organic arsenic compounds such as monomethylarsenic acid ($CH_3AsO(OH)_2$) and dimethylarsenic acid ($(CH_3)_2AsOOH$ (also known as cacodylic acid) and their salts have been widely used as herbicides and pesticides. In addition, smelting operations and coal burning power plants have been sources of arsenic emissions into the environment.

Arsenic is mobile in the environment. Both natural and manmade arsenic can be cycled within the air, water, and soil by mechanisms such as oxidation/reduction, adsorption/desorption, precipitation/dissolution, and biological methylation and demethylation.

5.1.1 Aqueous Speciation

Arsenic occurs in natural waters as arsenate (+5), arsenite (+3) and methylated species. Arsenic acid (H_3AsO_4) and arsenious acid (H_3AsO_3) are formed from arsenate and arsenite, respectively. Arsenious acid is formed from the dissolution of arsenious trioxide in water, whereas arsenic acid is formed from the dissolution of arsenic pentoxide in water.

Under the pe (log standard oxidation-reduction potential) and pH conditions typical of natural surface waters, the arsenate species ($H_2AsO_4^-$ and $HAsO_4^{2-}$) predominate. Under moderately reducing (lower pe) aquatic conditions, the arsenite species ($H_3AsO_3^0$ and $H_2AsO_3^-$) are likely to predominate.

VIN 002 0690

Of the two inorganic forms of arsenic, As^{+5} is the more soluble (Weast, 1977). In solution it forms an oxyacid, H_3AsO_4, whose properties very closely resemble those of H_3PO_4. Its solubility is 302 gm/100 cc water (Weast, 1977) at 12.5°C as $H_3AsO_4.1/2H_2O$. As (V) forms insoluble salts with many cations (Arsenic, 1984). Table 5-1 lists the solubility products for a range of arsenates.

As^{+3} has a solubility of 0.103M (41.6 gm/l as As_2O_6). Its behavior in solution is similar to that of boric acid, $B(OH_3)$ (Arsenic, 1984).

Evidence suggests that the arsenite (+3) form of arsenic is four to ten times more mobile in soil pore waters (and probably sediment pore waters) than is the arsenate (+5) species (Deuel and Swoboda, 1972). This is due to the formation of arsenate (As^{+5}) salts on the surface of sediment and soil materials. In many systems, this results from the presence of iron and manganese hydroxides, which readily absorb As^{+5} into their matrices. The larger As^{+3} ion is probably not as readily absorbed in these structures. This suggests that under reducing pore-water conditions, redox reactions may result in increases in total arsenic concentrations in the aqueous phase.

In addition to direct effects on the solubility of arsenic itself, reducing conditions may indirectly increase arsenic concentrations through the reduction of ferric (+3) to ferrous (+2) iron, and the accompanying dissolution of amorphous iron oxides. The importance of iron redox reactions to arsenic cycling (similar to that of phosphorus) has been postulated by a number of authors, including Deuel and Swoboda (1972) and Ferguson and Gavis (1972). This is of particular importance in the sandy soils of the Maurice River drainage basin since high iron levels are present.

Evidence indicates that aqueous speciation of arsenic is also controlled by biological methylation and demethylation. Biomethylation of arsenicals is generally thought to occur in the anaerobic environment of the sediment. McBride & Wolfe (1971) showed that an anaerobic bacterium, Methanobacterium strain M.O.H could methylate arsenic, and produced dimethylarsine (DMA) from As (V), As (III), and monomethylarsenic acid (MMAA). The cell extracts or whole cells of Methanobacterium required adenosine triphosphate, hydrogen, and methyldonors with methylcobalamine (CH_3-B_{12}) (Ridley et al., 1977). This biomethylation and reduction process is shown in Figure 5-1. Moreover, three species of fungi, Candidate humicola, Gliocladium species and a Penicillum species, were found to form trimethylarsine from methylated arsenic substrates at neutral or acid pH. The Candidate was able to methylate dimethylarsenic acid, monomethyl arsenic acid, arsenate, and arsonite (Cox and Alexander, 1973). The trimethyl arsine and dimethylarsine formed can be released into the air. Figure 5-2 shows the

VIN 002 0691

TABLE 5-1

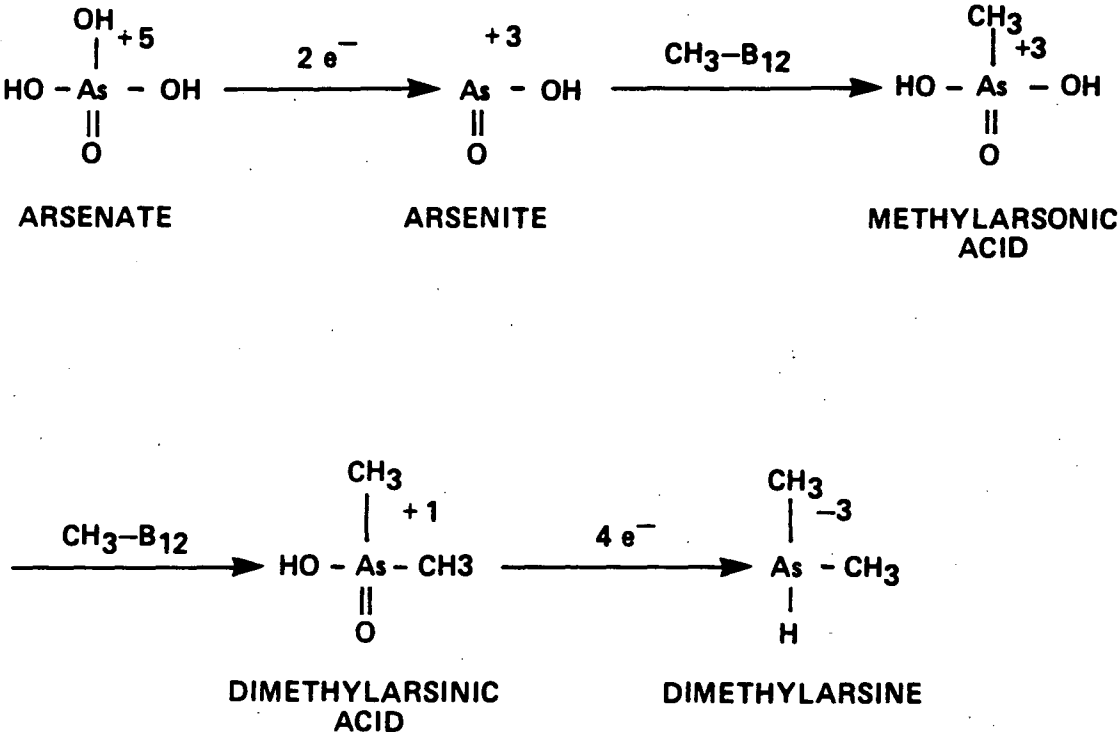
SOLUBILITY PRODUCTS FOR ARSENATES [1]

Arsenate	K_{sp}
$AlAsO_4$	-15.8
$Ba_3(AsO_4)_2$	-50.11
$Ca_3(AsO_4)_2$	-18.16
$Cd_3(AsO_4)_2$	-32.6
$Co_3(AsO_4)_2$	-28.1
$Cu_3(AsO_4)_2$	-35.1
$Cr\ AsO_4$	-20.1
$Fe\ AsO_4$	-20.2
$Mg_3(AsO_4)_2$	-19.6
$Ni_3(AsO_4)_2$	-25.5
$Pb(AsO_4)_2$	-34.4
$Sr_3(AsO_4)_2$	-18.1
$Zn(AsO_4)_2$	-27.4
$Mn_3(AsO_4)_2$	-28.7

Where, for example $K_{sp_{FeAsO_4}} = [Fe^{+3}]\ [AsO_4^{-3}]$

1 From Frankenthal, R.P., 1963, "Equilibrium constants." In: Handbook of Analytical Chemistry, 1st Edition (edited by Meites, L.) P1-13 to 1-19, McGraw Hill, Toronto.

VIN 002 0692



SOURCE: McBride & Wolfe, 1971

U.S. ENVIRONMENTAL PROTECTION AGENCY

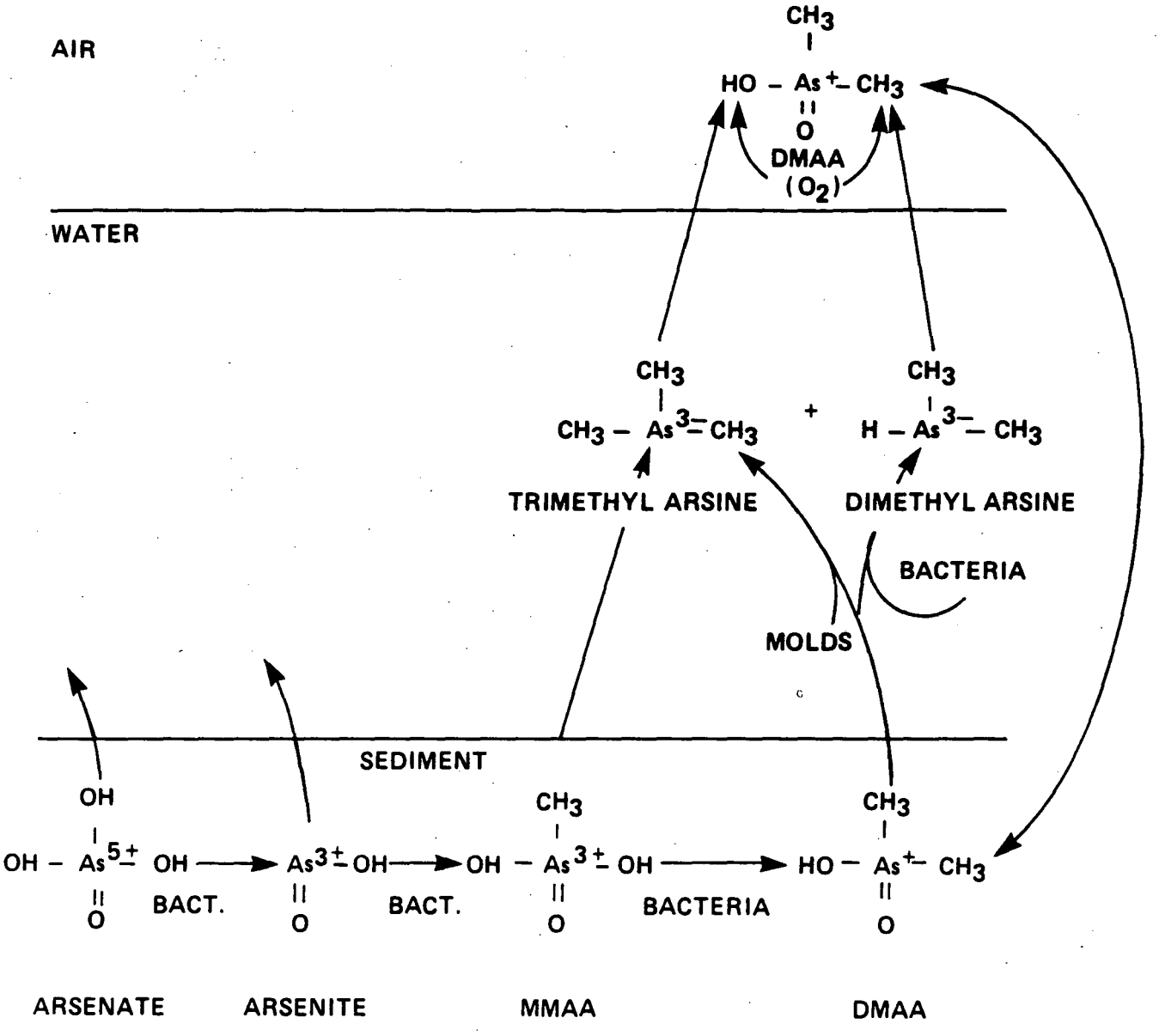
VINELAND CHEMICAL COMPANY SITE

FIGURE 5-1

BACTERIAL REDUCTION OF ARSENATE

EBASCO SERVICES INCORPORATED

VIN 002 0693



SOURCE: WOOD, 1974

U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 5-2

THE BIOLOGICAL CYCLE FOR ARSENIC

EBASCO SERVICES INCORPORATED

VIN 002 0694

biological cycle for arsenic. In addition, Andreae (1979) proposed that biological demethylation is responsible for the regeneration of inorganic arsenic from methylated arsenicals.

5.1.2 Precipitation/Dissolution

Arsenic can form insoluble precipitates with calcium, sulfur, iron, aluminum and barium compounds in natural waters. These reactions have been proposed as controls on aqueous phase arsenic concentrations (Deuel and Swoboda, 1972). Arsenic sulfide (As_2S_3) is suggested as being of particular importance under reducing conditions. However, since the nucleation and growth rate of the arsenical precipitates are slow, soluble arsenic species are more likely to be adsorbed on the surface of inorganic and organic substrates.

5.1.3 Adsorption/Desorption

Arsenic occurs in soil/sediment predominantly in an insoluble or adsorbed form. Arsenic has been shown to be adsorbed by a variety of sediment solid phase components including hydrous iron, aluminum and calcium oxides, clays and soil organic matter. In most geologic environments, evidence suggests the importance of soil iron oxides in adsorbing negatively charged anions, such as arsenate, preferentially. Woolson et al. (1971) found that most of the arsenic residue from soil with a history of arsenic applications was found as Fe-As. Other forms, Al-As and Ca-As, may predominate if the amount of "reactive" Al or Ca is high and reactive Fe is low. Arsenic adsorption appears to be better correlated to the clay content of the soil than to soil organic carbon content (Jacobs et al., 1970 and Wauchope, 1975). The reason for this relationship is that the hydrous iron and aluminum oxide contents of soils usually vary directly with the clay content of the soil.

However, for certain organic arsenate compounds, soil organic content may be a significant factor in overall mobility (Clement and Faust, 1981). Hydrous oxides also appear to be more effective adsorbers of arsenic on a surface area basis than are layer silicate components of clays. The adsorption process appears to be dependent upon both system pH and reduction-oxidation (redox) conditions. Maximum adsorption of arsenic as arsenate (+5) occurs under acidic or neutral pH conditions, with decreasing adsorption with increasing pH over the pH 7-9 range. The maximum adsorption of arsenic as arsenite (+3) on hydrous oxides appears to occur in the pH 7-9 range (Rai and Zachara, 1984). Also, Gupta and Chen (1978) showed that the rate of adsorption decreases with increasing salinity and that pentavalent species have a greater adsorption affinity than do trivalent species. These data show that adsorption will be most important in aerobic, fresh water. As conditions become more reducing, alkaline, and/or saline, arsenic is less likely to be adsorbed and more likely to remain dissolved.

VIN 002 0695

The relationships between the concentration of arsenic sorbed (adsorbed or desorbed) to solid phase soils or sediments and the aqueous phase arsenic concentration may be expressed in terms of a partition or distribution coefficient (K):

$$K = X/C \quad (1)$$

where:

X = amount of arsenic adsorbed to the solid phase in mg/kg, and
C = aqueous arsenic concentration in mg/l.

Factors that have been demonstrated to influence the magnitude of K for a constituent such as arsenic include:

- o the experimental aqueous concentration range studied;
- o the form and valence of arsenic;
- o solution pH, and
- o solid/solution ratios.

Experimentally measured arsenic partition coefficients have been reported by a number of researchers for both sediments and soils of differing chemical composition.

Partition coefficient (K) values for arsenic adsorption (as arsenate) to three different U.S. soils have been estimated from the linear portions of Langmuir isotherms of data reported by Jacobs et al., (1970) and are found to be 8-28 l/kg. Estimated partition coefficients have been calculated from data reported for the adsorption of arsenic (as arsenate) to sediment (Wauchope and McDowell, 1984), and are estimated to be 19-102 l/kg.

Wauchope (1975) also observed that the partitioning of two organic arsenic herbicide compounds (methanearsonate - $H_2AsO_3CH_3$ and cacodylate - $HAsO_2(CH_3)_2$) was generally similar to that of inorganic arsenic. For equivalent initial solution arsenic concentrations (2.5×10^{-3} M), maximum calculated K values (methanearsonate, K=75; cacodylate, K=46) are less than the maximum K values calculated for inorganic arsenate.

Available evidence indicates that the adsorption of arsenic to soils/sediment is not entirely reversible. Elkhatib et al., (1984) and Winka (1985) reported that isotherms of arsenite desorption from soils were strongly hysteritic. That is, for comparable experimental time frames, a fraction of previously adsorbed arsenic appeared to be irreversibly bound to the soil phase. In general, partition coefficients for desorption (K_d) were significantly greater than the analogous K values for adsorption. This suggests that the use of partition coefficients based on measured adsorption may not appropriately describe the current mobility of arsenic at sites of past

contamination. Arsenic migration in most field systems is predominantly controlled by arsenic desorption from the solid phase. Therefore, it is the magnitude of K_d that is most appropriately applied to environmental fate studies.

Available information indicates that K_d for soil desorption is:

- o Significantly greater than K for adsorption;
- o A function of soil chemical composition, including soil pH and iron oxide concentration, and
- o Strongly affected by the soil redox levels.

5.1.4 Partitioning to Sediments

The partitioning of arsenic between natural waters and sediments may be controlled by both precipitation and adsorption processes. At low aqueous phase arsenic concentrations, sediment-water partitioning may be predominantly controlled by adsorption/desorption processes rather than by direct precipitation (Clement and Faust, 1981).

In general, when runoff occurs, dissolved arsenic is accumulated in the sediment by three interrelated processes: sediment loading, solute adsorption onto the sediment, and "entrapment" in adsorbed solute as heavier sediment particles are left behind. The adsorption of arsenic to sediment is not an entirely reversible process and the sediment usually acts as a sink for arsenic. Winka (1985) has shown that the arsenic concentrations in sediment at the bottom of Union Lake were as much as three orders of magnitude higher than in the overlying waters.

5.1.5 Gas Transfer From Soils

A study by Woolson and Kearny (1972) showed that significant amounts of cacodylic acid (dimethyl arsenic acid) can be volatilized in the soil via biological activity. Any of the biological processes that produce dimethyl or trimethyl arsines provide a means for gas exchange flux from the soils. However, quantifying this flux is quite difficult since the reaction rates are not well known.

5.2 ARSENIC IN THE MAURICE RIVER WATERSHED

In this section the transport and fate of arsenic in the Maurice River basin will be examined. An understanding of arsenic transport and inventories in the basin is essential in determining populations at risk, remedial alternatives, and the effects of remediation on the basin, if remediation is required. In the next five subsections several important topics on arsenic in the basin will be discussed. These include:

1. An estimation will be made of the instantaneous release rate of arsenic from the site, based on Ebasco data from 1986 and 1987. The historic record of arsenic release will

VIN 002 0697

be examined and the total amount of arsenic released to the basin will be calculated. These data will also be used to establish the ViChem site as the only significant source of arsenic to the basin.

2. The transport of arsenic within each subsection of the basin (i.e. the Blackwater Branch and upper Maurice River, Union Lake, and the lower Maurice River) will be examined using water concentrations and flow rate measurements where available. Where the flow information is not available, it will be estimated based on drainage area. Each subsection will be examined to determine if it is a sink or a conduit for arsenic from the site.

3. The chemistry of arsenic in the waters and sediments of the basin will be examined. In particular, arsenic speciation and the desorption coefficient (K_d) will be examined for their spacial variations and dependence upon sediment organic carbon content, iron content, particle size distribution, and sediment redox conditions. The K_d values will be used to examine the relationship between the lake water and sediments. The potential for arsenic release from the sediments will also be examined.

4. The sediments of the basin will be inventoried where possible. These data will be used to show the fate of the arsenic released from the site and clearly identify the arsenic sinks. This information will be compared with the results of the two previous subsections.

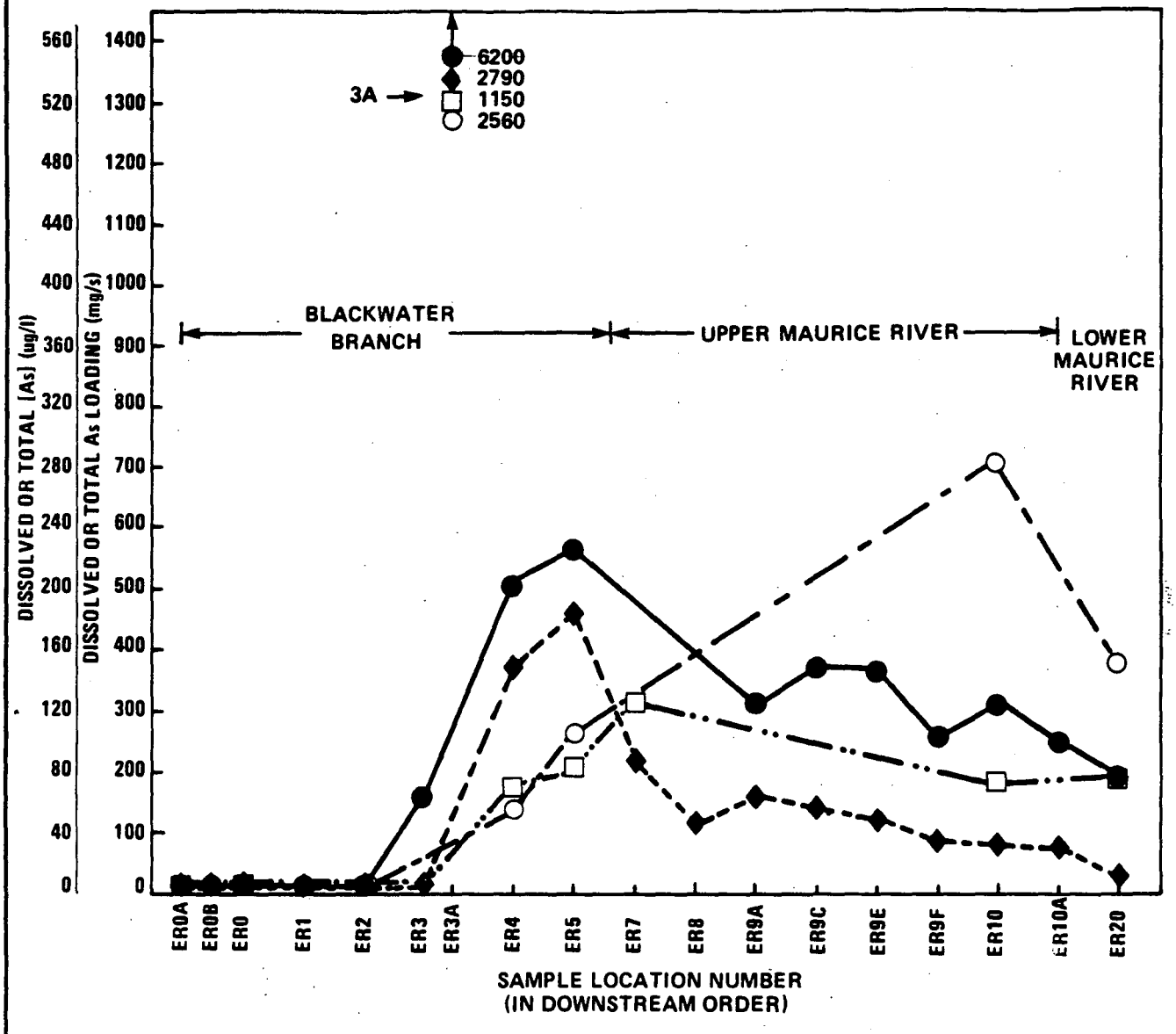
5. The possibility of predicting future water column arsenic levels will be examined, particularly in reference to the MCL for arsenic of 50 ug/l. This section will also include a summary of the previous results.

5.2.1 Arsenic Input to the Watershed

In this section, estimates for the instantaneous arsenic flux from the ViChem site will be calculated, discussed and compared. The history of arsenic release from the site will also be discussed and a net arsenic input to the Maurice River basin will be calculated.

Arsenic concentrations in the sediments and surface waters of the Blackwater Branch upstream of the ViChem site were very low to undetected. Downstream of the site (ER-3 and below), the concentrations were elevated. Similarly, arsenic concentrations in the water and sediment of the Maurice River were undetected above the confluence with the Blackwater Branch and were elevated below the confluence. This is shown graphically in Figure 5-3, which presents the arsenic concentrations and loads at various points in the Maurice River. It is clear from this figure and from the analytical data in Tables 5-2a and 5-2b that the ViChem Plant is the source of arsenic into the watershed.

VIN 002 0698



DISSOLVED As (ug/l)

TOTAL As (ug/l)

DISSOLVED As LOAD (mg/s)

TOTAL As LOAD (mg/s)

U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 5-3

1987 ARSENIC CONCENTRATION AND LOADING IN THE BLACKWATER BRANCH AND UPPER MAURICE RIVER TO THE UNION LAKE DAM

EBASCO SERVICES INCORPORATED

VIN 002 0699

TABLE 5-2a

EBASCO ARSENIC CONCENTRATIONS AND LOADINGS DOWNSTREAM FROM THE BLACKWATER BRANCH

1987

Location	Date	Station Number	Stream Flow (ft^3/s)	Arsenic Concentration (ug/l) Diss[c]	Arsenic Concentration (ug/l) Total	Arsenic Load (mg/s) Diss[c]	Arsenic Load (mg/s) Total	Arsenic Load (metric tons/yr) Diss[c]	Arsenic Load (metric tons/yr) Total
Blackwater Branch	7/15/87	ER-0A	23.0	4U	2.2J	1.3	1.4	0.041	0.044
	6/30/87	ER-0B		4U	6U				
	7/14/87	ER-0	17.7	4U		1.0			
	6/29/87	ER-1		5.5J	6U				
	7/16/87	ER-2		4U	2.5J				
	7/10/87	ER-3		4.8J	61				
Blackwater at ViChem Site	7/29/87	ER-3A	14.6	2790	6200	1150	2560	36	81
Blackwater at Mill Road	7/13/87	ER-4	32.3	202	153	185	140	5.8	4.4
	6/25/87	ER-5	16.5	460	570J	215	266	6.8	8.4
Upper Maurice River	7/15/87	ER-7	246.9	91		636		20	
	6/27/87	ER-8		46.8					
	7/9/87	ER-9A		65	123				
	7/9/87	ER-9C		56	150				
	7/10/87	ER-9E		48	146				
	7/6/87	ER-9F		36	105				
	7/9/87	ER-10	203.9	32	125	185	721	5.8	22.7
Upper Maurice River just above Union Lake	7/9/87	ER-10A		28	102				
Median 1987 Arsenic Load between Mill Road (ER-4) and Union Lake (ER-10A)						200	266	6.3	8.4

1986

Blackwater at Mill Road	7/9/86	ER-4	7.9[b]	208		46		1.5	
Uppr Maurice River at Norma	7/10/86	ER-7	61	126		220		6.9	
Median Arsenic Load between Mill Road (ER-4) and Union Lake (ER-10A) for all Ebasco data						200		6.3	

a) For non-detect measurements the load is calculated using 1/2 of the detection limit.
b) Flow = $\frac{14}{112}$ x Flow at Norma. See text for ratio explanation.
c) Dissolved arsenic.

VIN 002 0700

TABLE 5-2b

EBASCO ARSENIC CONCENTRATIONS AND LOADINGS IN THE OTHER TRIBUTARIES TO THE UPPER MAURICE RIVER

Location	Date	Station Number	Stream Flow (ft^3/s)	Arsenic Concentration (ug/l) Diss[c]	Arsenic Concentration (ug/l) Total	Arsenic Load[a] (mg/s) Diss[c]	Arsenic Load[a] (mg/s) Total	Arsenic Load[b] (metric tons/yr) Diss[c]	Arsenic Load[b] (metric tons/yr) Total
Upper Maurice River above the Blackwater Branch	6/29/87	ER-6		4U	6U				
	7/15/87	ER-6A	193.2	4U	4.5J	10.9	12.3	0.34	0.39
Little Robin Branch	7/1/87	ER-9	1.5	4U	6U	0.84	1.26	0.026	0.040
Muddy River	6/30/87	ER-9D	41.9	4.4J	6U	2.6	3.6	0.082	0.11
Parvin Branch	6/23/87	ER-11	6.8	8.2UJ	5U	0.79	0.48	0.025	0.015

a) These loads were calculated using 1/2 of the non-detect level.
b) This is the annual rate at the instantaneous load.
c) Dissolved arsenic.

VIN 002 0701

The quantity of arsenic released to the watershed has been estimated several ways. In the RI report for the ViChem plant site, the instantaneous arsenic input was estimated based on the groundwater flow and groundwater arsenic concentration, and based on the flow and arsenic concentration in the Blackwater Branch (Ebasco, 1989a). Various studies were performed for ViChem, which estimated the arsenic load in the Blackwater Branch at station ER-4 (just below the site at Mill Road), and at the USGS stream gaging station in Norma (station ER-7). Additional information is available to estimate the load from the Norma station as well.

In the RI report for the ViChem plant (Ebasco, 1989a), the groundwater flow from beneath the ViChem site was estimated to be 492,000 gpd or 0.76 cfs. Using the mean arsenic concentration along the groundwater flow vectors, this produced an estimated arsenic load in the groundwater flowing off-site of between 2 and 11 metric tons per year at the time of sampling, summer 1987. Since there was an upward hydraulic gradient between the contaminated aquifer and the Blackwater Branch, and since no contamination was seen across the Branch from the site, it was assumed that all of the contaminated groundwater discharged into the Blackwater Branch.

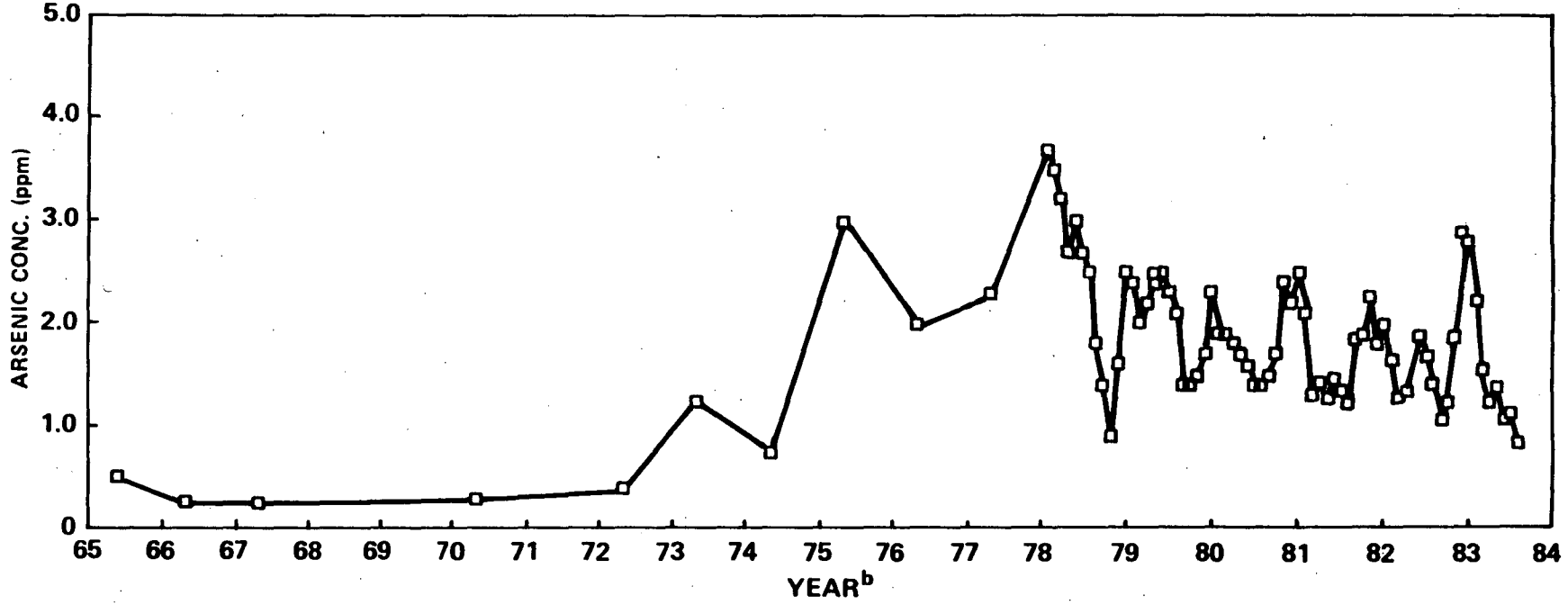
The flow and arsenic concentrations in the Blackwater Branch downstream of the ViChem plant were also determined in the summer of 1987 at stations ER-4 and ER-5. Multiplying the flow by the concentrations yielded estimates of 4.3 and 8.2 metric tons of arsenic passing stations ER-4 and ER-5 per year, respectively (Ebasco, 1988b).

These independently derived estimates for the summer of 1987 compared favorably with each other. It was therefore concluded that approximately 6 metric tons of arsenic per year were entering the Blackwater Branch from contaminated groundwater discharged from beneath the ViChem site.

In a study prepared for ViChem in 1982, the arsenic load in the Blackwater Branch was estimated using the flow and arsenic concentration at station ER-4 (Lennon & Johnson, 1982). It were estimated that approximately 6.8 metric tons of arsenic per year were flowing past station ER-4, which is in agreement with the Ebasco 1987 estimates.

The historical arsenic input to the Maurice River watershed was estimated using the arsenic concentrations of the Blackwater Branch at Mill Road, Ebasco site ER-4. These data were collected by ViChem and were reported in their RCRA permit application (Woodward-Clyde, 1985). Figure 5-4 is a plot of the arsenic concentration versus time from 1965 to 1984.

VIN 002 0702



a. COLLECTED AND MEASURED BY VINELAND CHEMICAL CO. FROM WOODWARD-CLYDE, 1985.

b. THE TICK MARK ON THE BOTTOM AXIS FOR EACH YEAR REPRESENTS AUGUST 1.

U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 5-4

ARSENIC CONCENTRATION AT MILL ROAD[a]
1965 TO 1984

EBASCO SERVICES INCORPORATED

VIN 00.2 0703

To calculate the total arsenic flux using these data, a water flow rate was estimated from the USGS flow gauging station at Norma, NJ (Station ER-7). The mean daily flow at this location was 168 cfs (4.76 m^3/s) based on 53 years of records. The drainage area to this point is 112 sq. mi. The Blackwater Branch is included in this drainage area. The drainage area of the Blackwater Branch at Mill Road was estimated by Lennon and Johnson (1982) to be 14 sq mi. Assuming that the flow per unit area in the basin is relatively constant, the flow in the Blackwater Branch was estimated by multiplying the ratio of the drainage areas (14/112) by the flow at the gaging station. This yielded a mean annual flow at Mill Road of 21 cfs (0.59 m^3/s).

The total mass of arsenic passing station ER-4 was determined by integrating the area under the curve in Figure 5-5 and multiplying this by the mean annual flow. This yielded a total mass flux of 500 metric tons of arsenic passing this point over 18 years or, on an annual basis, 28 metric tons/yr (890 mg/s).

This agrees well with the annual production of arsenic wastes at ViChem. Woodward-Clyde (1985) described the annual solid waste production to be 1,170 tons of waste salts containing 1 to 2% arsenic by weight. This yields 10 to 20 metric tons of arsenic per year with an additional unknown and potentially larger arsenic flux to the aquifer via the previously untreated process water discharge. The short-term variations (less than 1 year) seen in Figure 5-4 are probably the result of seasonal hydrologic variations in the Maurice River basin and do not represent variations in the input at the site.

The history of the arsenic release given by the ViChem records can be checked against the USGS records from Norma, NJ. Table 5-3 presents the dissolved arsenic concentrations, flows, and loads determined at the USGS gaging station in Norma since 1979. The arsenic loading data are plotted in Figure 5-5.

The data show that the load has significantly decreased from 1979 to the present, primarily as a result of decreased dissolved arsenic concentrations. Recall that a number of actions were taken by ViChem since 1979 as a result of Administrative Consent Orders issued by NJDEP, including removing waste salt piles and not discharging untreated process waters. This data set agrees well with the ViChem data, showing a similar pattern of minima and maxima, as well as a similar range of arsenic loadings (0 to 2.0 gm/s for the USGS data vs 0.5 to 2.2 gm/s for the ViChem data).

In conclusion, the arsenic input to the Maurice River watershed has been monitored by several independent means. A total of about 500 metric tons has entered the watershed below Mill Road on the Blackwater Branch between 1965 and 1984. The history of this release shows significant short-term variations (less than

VIN 002 0704

TABLE 5-3

USGS DISSOLVED ARSENIC CONCENTRATIONS AND LOADINGS IN THE MAURICE RIVER AT NORMA, NJ[a]

Date	Flow (cfs)	Flow (m3/s)	Dissolved Arsenic (ug/l)	Dissolved Arsenic Load[b] (mg/s)	Dissolved Arsenic Load[b] (metric ton/yr)	Geometric Mean Annual Load[d] (metric ton/yr)
6/79	390	11.0	180	2000	62	
8/79	170	4.8	170	820	26	
11/79	240	6.8	240	1600	51	
12/79	215	6.1	240	1500	46	44
1/80	215	6.1	180	1100	35	
2/80	165	4.7	160	750	24	
3/80	230	6.5	160	1000	33	
4/80	180	5.1	300	1500	48	
5/80	155	4.4	360	1600	50	
8/80	120	3.4	280	950	30	
9/80	65	1.8	460	850	27	
11/80	101	2.9	220	630	20	32
1/81	61	1.7	8*	14*	0.4*	
5/81	104	2.9	320	940	30	
7/81	73	2.1	130	270	8.5	
11/81	98	2.8	160	440	14	15
1/82	126	3.6	280	1000	32	
5/82	108	3.1	200	610	19	
9/82	55	1.6	190	300	9.3	
11/82	82	2.3	150	350	11.0	16
1/83	149	4.2	66	280	8.8	
5/83	293	8.3	160	1300	42	
9/83	81	2.3	160	370	11.5	
11/83	228	6.5	96	620	20	17
1/84	168	4.8	96	460	14	
5/84	248	7.0	1*	7*	0.22*	
9/84	125	3.5	37	130	4.1	
11/84	121	3.4	61	210	6.6	7.2
5/85	193	5.5	60	330	10.3	NA

* These data may be questionable since they are so different from the rest of the data trend. They are not included in the geometric mean calculation.

VIN 002 0705

TABLE 5-3 (Cont'd)

USGS DISSOLVED ARSENIC CONCENTRATIONS AND LOADINGS IN THE MAURICE RIVER AT NORMA, NJ[a]

Date	Flow (cfs)	Flow (m3/s)	Dissolved Arsenic (ug/l)	Dissolved Arsenic Load[b] (mg/s)	Dissolved Arsenic Load[b] (metric ton/yr)	Geometric Mean[d] Annual Load (metric ton/yr)
1/86	117	3.3	90	300	9.4	
2/86	249	7.1	50	350	11	
8/86	54	1.5	93	140	4.5	
11/86	108	3.1	41	125	3.9[c]	6.5
3/87	178	5.0	45	230	7.2[c]	
5/87	164	4.6	58	270	8.5[c]	
9/87	83	2.4	31	73	2.3[c]	5.2

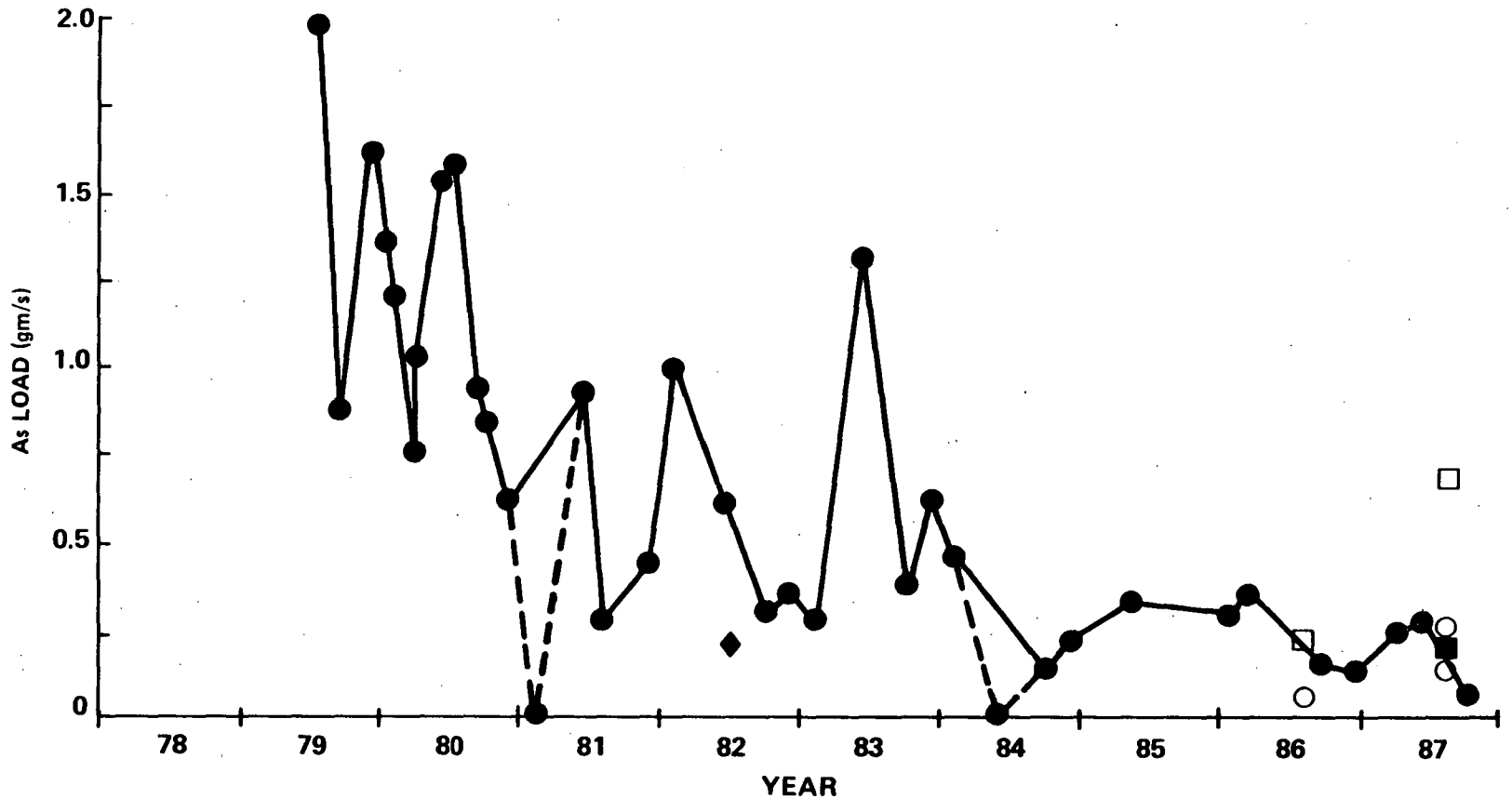
a) From USGS Water Resources Data-New Jersey Water Years 1979 - 1986; Volume 2.

b) This is the annual rate at the instaneous load.

c) USGS Data For Water Year 1987 - Preliminary Results from Fred Schaeffer, USGS-Trenton, personal communication.

d) This is the mean of dissolved arsenic load by year.

VIN 002 0706



● USGS STATION AT NORMA, N.J. DISSOLVED ARSENIC LOADING

○ EBASCO SITES ON BLACKWATER BRANCH

□ EBASCO MEASUREMENT AT NORMA WITH MEASURED FLOW

■ EBASCO MEASUREMENT AT NORMA FOR 7/15/87 WITH FLOW FROM 7/30/87

◆ LENNON & JOHNSON GROUNDWATER FLUX

NOTE: THE TWO VERY LOW VALUES MAY BE QUESTIONABLE DUE TO THEIR SIGNIFICANT DEVIATION FROM THE DATA TREND.

U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 5-5

USGS STATION AT NORMA, N.J. (ER-7)
DISSOLVED ARSENIC LOADING

EBASCO SERVICES INCORPORATED

VIN 002 0707

1 year in length) and the overall trend shows a large maximum occurring around 1978 of greater than 63 metric tons/yr (2 gm/s). Since that time the release from the site has steadily decreased and was probably less than 10 metric tons/yr in 1987 (0.3 gm/s).

5.2.2 Arsenic Transport in the Maurice River Watershed

In this section, the transport of arsenic in the Maurice River basin will be examined based on aqueous arsenic concentrations and water flow measurements from Ebasco, the USGS and Lennon and Johnson (1982). Both total and dissolved arsenic loadings will be calculated. A mass balance for Union Lake will be calculated as well. Each section of the river (upper, lower and Union Lake) will be examined to see if it acts as a sink or a conduit for arsenic entering the Maurice River Basin from the site.

The fate of arsenic in the surface water further downstream from the ViChem plant was estimated using USGS data, and data obtained by Ebasco during Phase II. In addition, Lennon and Johnson estimated the fate of arsenic in the surface water in a 1982 study prepared for ViChem.

In Ebasco's Phase II investigation, the water flow and arsenic concentrations at a number of stations in the Maurice River drainage basin were determined.

The Ebasco data for the upper Maurice River basin are plotted in Figure 5-3. The sample data at ER-4 and ER-7 are also plotted in Figure 5-5 for comparison with the USGS data. These data show good general agreement with the USGS data. The high flux at Norma (ER-7) is probably the result of a short-term flow variation, which raised the instantaneous arsenic flux. If the flow rate measured at Norma later that month is used, the agreement is nearly exact.

In Figure 5-3, the load calculations based on the limited number of measurements for the Upper Maurice River suggest that the dissolved load remains relatively constant downstream of the site. The dissolved load at ER-10 agrees well with those at ER-4&5. The variations seen in the dissolved loading probably result from short-term hydrologic flow variations over the sampling period (about 1 month). The total arsenic load shows significantly greater variation, most likely because of the general dependence of the suspended matter load on water flow. Both suspended matter and dissolved forms of arsenic are important in the arsenic load in the Blackwater Branch and upper Maurice River. Table 5-4 lists the total, dissolved and total suspended arsenic concentrations from Ebasco and USGS measurements. From this table, it is evident that the suspended

VIN 002 0708

TABLE 5-4

TOTAL, DISSOLVED AND SUSPENDED ARSENIC CONCENTRATIONS IN THE CONTAMINATED REGION OF THE MAURICE RIVER

Date	Location	Total Arsenic (ug/l)	Dissolved Arsenic (ug/l)	Total Arsenic on Suspended Matter (ug/l)	% Dissolved Arsenic
USGS Measurements					
Nov '80	Norma (ER-7)	240	220	20	92
Jan '81	Norma (ER-7)	11	8	3	73
May '81	Norma (ER-7)	320	320	0	100
Jul '81	Norma (ER-7)	170	130	40	76
Nov '81	Norma (ER-7)	180	160	(20)[b]	89
Jan '82	Norma (ER-7)	290	280	(10)	97
May '82	Norma (ER-7)	200	200	(0)	100
Sep '82	Norma (ER-7)	220	190	(30)	86
Ebasco 1986					
Blackwater Branch					
Jul 9	ER-4	(247)[b]	208	39	84
Upper Maurice River					
Jul 10	ER-7	(139)	126	13	91
Jul 8	ER-10	(70)	55	15.4	79
Lower Maurice River					
Jun 30	ER-13	(64)	58	5.5	91
Jun 30	ER-14	(52)	43	8.6	83
Ebasco 1987					
Blackwater Branch					
Jul 13	ER-4	153	202		
Jun 26	ER-5	570	460	(110)	81
Upper Maurice River					
Jul 9	ER-9A	123	65	(58)	53
Jul 9	ER-9C	150	56	(94)	37
Jul 10	ER-9E	146	48	(98)	33
Jul 9	ER-9F	105	36	(69)	34
Jul 9	ER-10	125	32	(93)	26
Jul 9	ER-10A	102	28	(74)	27

8213b

VIN 002 0709

TABLE 5-4 (Cont'd)

TOTAL, DISSOLVED AND SUSPENDED ARSENIC CONCENTRATIONS IN THE CONTAMINATED REGION OF THE MAURICE RIVER

Date	Location	Total Arsenic (ug/l)	Dissolved Arsenic (ug/l)	Total Arsenic on Suspended Matter (ug/l)	% Dissolved Arsenic
Ebasco 1987 (Cont'd)					
Lower Maurice River					
Aug 4	ER-20	79.7	39	(40)	49
Aug 4	ER-21	91	37	(54)	40
Aug 4	ER-22	89	32	(57)	36
Aug 4	ER-26	73	27	(46)	37
Aug 4	ER-27	82	26	(56)	32
Aug 4	ER-29	50	17	(33)	34
Aug 4	ER-32	48	16	(32)	33
Aug 4	ER-37	18	7.2J	(10.8)	40
Aug 4	ER-38	12	5.8J	(6.2)	48
Aug 5	ER-39	25	7.1J	(17.9)	28
Aug 5	ER-40	18	10	(8)	55
Aug 5	ER-43	13	10	(3)	77
Aug 5	ER-44	12	54		
Aug 6	ER-45	8J	8.4J	0	100
Aug 5	ER-50	2.8J	5.3J	0	100

a) This number is reported as total arsenic on the suspended matter per liter of sample.

b) Values in parentheses are calculated from the other measured arsenic concentrations (i.e. Total Suspended As = Total As - Dissolved As; Total As = Total Suspended As + Dissolved As).

VIN 002 0710

matter arsenic concentration can be very significant, accounting for 0 to 75% of the total arsenic transport per unit volume. The variations are most likely due to water flow velocity variations, as supported by the July 1986 vs July 1987 dissolved arsenic fractions at ER-10. The mean monthly flows were 69.6 and 136 cfs and the percent dissolved arsenic concentrations were 79% and 26%, respectively. This flow difference is most likely the cause of the higher suspended arsenic load for all of the July 1987 measurements relative to July 1986. Table 5-2a lists the total and dissolved arsenic loads for the Ebasco stations downstream of the Blackwater Branch. These loads were calculated using Ebasco measurements of arsenic concentration and water flow. For the two Ebasco investigations (summer 1986 and summer 1987), the median fluxes between ER-4 and ER-10 were 6.3 and 8.4 metric tons/year (200 and 266 mg/s) for dissolved and total arsenic loads, respectively.

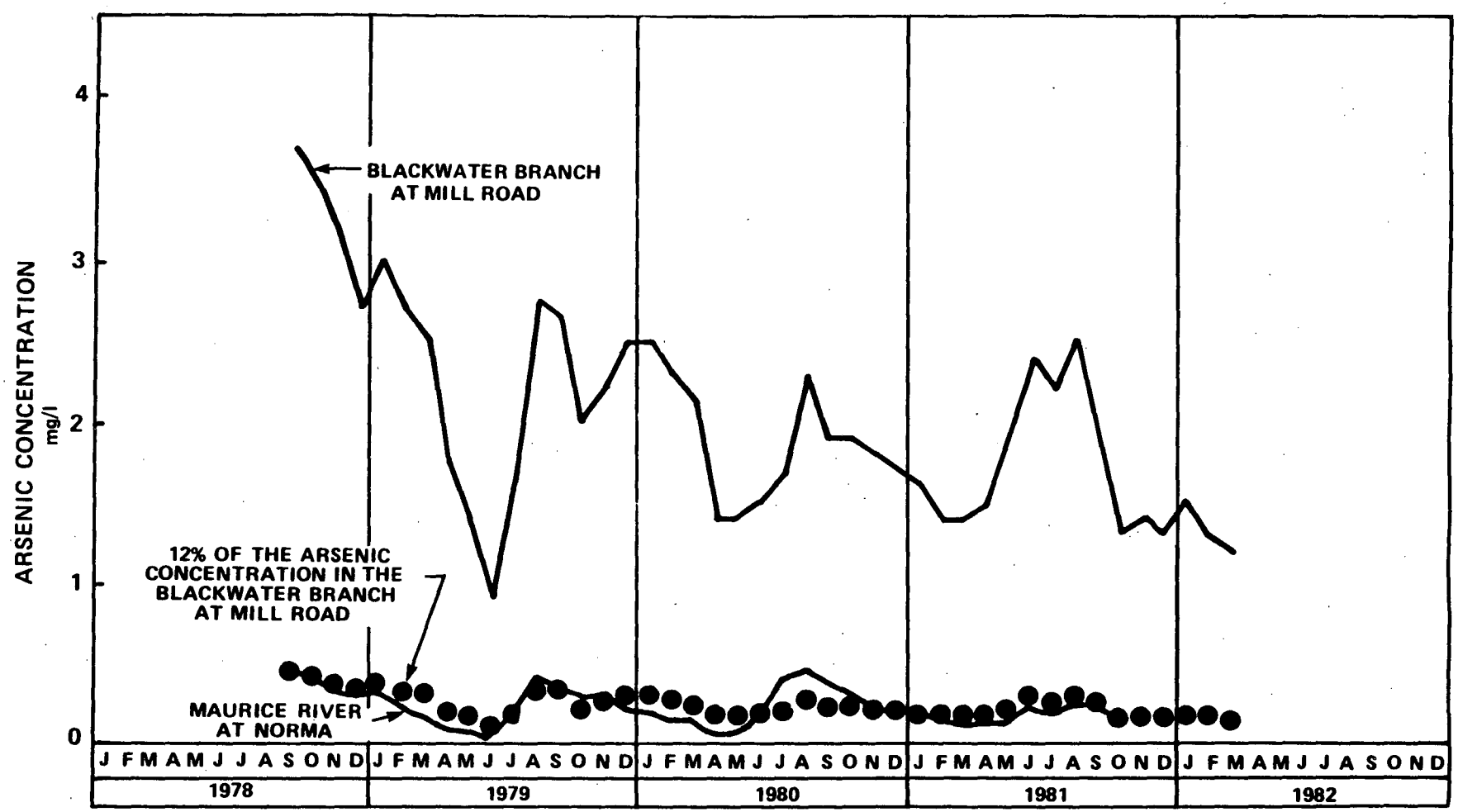
The good agreement between the Ebasco loading measurements down the river and between the USGS and ViChem data discussed in the previous section strongly suggest that the Blackwater Branch and Upper Maurice River act as a conduit for arsenic transport from the ViChem Site to Union Lake. In addition, the parallel downward trends of the total and dissolved arsenic concentrations in Figure 5-3 would also support this, since these trends are probably due to gradual dilution of the arsenic concentration by small tributaries. Also, the parallel trends suggest that there are no reactions taking place, since presumedly a reaction would affect either the dissolved arsenic or the suspended matter arsenic and change the ratio between the two.

Lennon and Johnson (1982) also concluded that the river was a simple conduit for the arsenic, based on data collected by ViChem. Their data, taken at Mill Road (ER-4) and at Norma (ER-7) indicate that the river was a simple conduit at least to ER-7. Figure 5-6 shows their data. Based on the ratio of the drainage area at Mill Road to that at Norma (14/112), the arsenic concentration at Norma ought to be 14/112 or 12% of that at Mill Road, given two assumptions: that flow is directly proportional to drainage area and that arsenic is conservatively transported by the river. Figure 5-6 shows that this is the case for the data reported by Lennon and Johnson.

The final support for the simple conduit argument comes from the arsenic sediment inventory between Mill Road and Union Lake. This will be discussed in greater detail later in this section. But it can be said that the present river sediment inventory is less than 1.5% of the total arsenic transported past Mill Road, approximately 500 metric tons as discussed in Subsection 5.2.1.

Having established that the Blackwater Branch and upper Maurice River presently act as conduits for the arsenic, the next main body of water downstream, Union Lake, needs to be examined. The purpose of the following discussion is to establish whether Union Lake is a sink or a conduit for the arsenic from the site.

VIN 002 0711



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 5-6
OBSERVED ARSENIC CONCENTRATIONS IN THE BLACKWATER BRANCH AT MILL ROAD AND THE MAURICE RIVER AT NORMA (mg/l)

EBASCO SERVICES INCORPORATED

VIN 002 0712

Ebasco collected an extensive set of samples for arsenic analysis from Union Lake and the lower Maurice River. However, flow measurements were not made in these areas. PRC Engineers, the engineers redesigning the Union Lake Dam spillway, estimate that the flow of water out of the dam is roughly twice the flow recorded at the USGS station at Norma (Roth, 1988). Knowing the flow at Norma, it's possible to roughly estimate the lake outflow and the flow in the lower Maurice River close to the outflow.

Based on USGS data, the dissolved arsenic load at the Norma gaging station in August 1986 was 0.14 g/s. Assuming the flow out of the lake was twice that recorded at Norma in August, and using the lake's mean dissolved arsenic concentration from Phase I (summer 1986), approximately 60 ug/l, the arsenic load out of the lake was estimated to be 0.18 g/s, or 5.6 metric tons per year. These load estimates compare very well given the uncertainties in the factors.

Similarly, in winter 1987, the dissolved arsenic load at Norma was 0.3 g/s or 9.5 metric tons per year. In the lake, the mean dissolved arsenic concentration was 17.6 ug/l which, when multiplied by an estimated flow twice that at Norma, yielded an estimated dissolved arsenic load of 0.23 g/s, or 7.2 metric tons per year.

Finally, in July 1986, Ebasco collected water samples at both ER-7 (the location of the Norma gage) and ER-13 at the base of the Union Lake Dam. Using the USGS flow at Norma, the calculated dissolved arsenic load upstream from the lake was 0.23 g/s or 7.2 metric tons per year, while the outflow was 0.20 g/s or 6.3 metric tons per year.

Given the uncertainties in the factors in the above estimates, it appears that the arsenic load into the lake is very similar to the load coming out of the lake. However, it is not clear whether the lake acts as a simple conduit for the arsenic in the water. There is some evidence that there may be significant cycling of arsenic between the lake water and sediments based on the K_d's of the lake sediments. This will be discussed later in this chapter. While the arsenic load in and out of the lake appears similar in 1986 and 1987, this could not have been the case in the past, since the lake sediments are significantly contaminated with arsenic. Based on the NJDEP measurements of lake sediment arsenic concentrations, the lake sediments contain approximately 30% of the arsenic transported past Mill Road. The nature of arsenic in these sediments will be discussed later in this section.

The implication of the arsenic fluxes in and out of the lake are important. It is not clear that the level of arsenic in the lake water will drop if the upstream source is cut off. Arsenic release from the sediments may be significant enough to raise lake water arsenic concentrations to levels of concern. This would be particularly important in the summer, when warmer

VIN 002 0713

temperatures, increased biological activity and low oxygen levels will enhance arsenic release from the sediments. In addition, this is also the time of maximum recreational use of the lake, potentially exposing a larger number of people. The lake sediment fluxes will be further discussed later in this section.

In the Maurice River below Union Lake, it is more difficult to determine the fate and transport of arsenic. This section of the river is an estuary and is, therefore, tidal and partly brackish; so it is impossible to accurately determine the fresh water and salt water flow in and out. The total drainage area at the mouth of the Maurice River is 384 square miles (near ER-45). Using the drainage area ratio arguments previously discussed, this would suggest that the total freshwater flow is about 3.4 times the flow at Norma. However, the tidal exchange at the mouth is not trivial, since saline water is found more than 10 miles upstream. Both flows will be important in arsenic transport within the lower Maurice River and to the Delaware Bay.

The fate of arsenic in the estuary is complicated by a number of factors. These are largely related to salt intrusion. With the salt intrusion comes a range of ions, which can form insoluble salts with arsenic, removing it from solution. In addition, biological activity is usually very intense in an estuarine system and can be expected to remove arsenic from the water column. At the same time, biological activity can remobilize arsenic bound to sediments and suspended matter. Lastly, measurements of concentrations do not extrapolate directly to loads since tidal exchange with the Delaware Bay is probably much greater than the net freshwater flow at the lower end of the estuary.

Lacking any better alternatives, the following simple estimate was made. It should be viewed very cautiously in light of the above concerns.

The dissolved arsenic concentration at station ER-5 on the Blackwater Branch was 460 ug/l in the Phase II investigation. At station ER-45 on the lower Maurice River, it was 8 ug/l. The ratio between these two is approximately 0.017. The ratio of the drainage basin areas between the two is estimated to be 15 mi^2 (ER-5) versus 384 mi^2 (ER-45), or 0.039. The drainage area of ER-5 was determined by using the drainage area of ER-4 and adding a small amount to account for increased downstream distance, while the area of ER-45 was taken as being the total area above the mouth of the Maurice River.

The drainage basin ratio (0.039) is approximately twice the dissolved arsenic ratio (0.017). Despite the crudeness of the estimates, they suggest that approximately one half of the arsenic in the watershed is transported out to the Delaware Bay. From the relatively constant loads in the watershed above and out of Union Lake, it is possible that one half of the arsenic load drops out of the water column in the estuarine

VIN 002 0714

portion of the Maurice River, although it is more likely that the actual fraction is less since dilution and tidal exchange have been ignored.

The data collected just above and just below the salt front support this as well. Both total and dissolved arsenic concentrations drop by more than 70% across the salt front; from 82 to 18 ug/l and from 26 to 7.2 ug/l for the total and dissolved arsenic concentrations, respectively. Again, the effect of dilution has been ignored here.

The sediments throughout the lower Maurice River show elevated arsenic levels. The geometric mean concentration is 30 mg/kg with a range of 9.2 to 234 mg/kg. The maximum values occurred between ER-22 and ER-37, the region of the salt front during the Phase II investigation.

These data all suggest that the sediments of the lower Maurice River are a significant sink for about 50% of the arsenic released from Union Lake. However, the flux from Union Lake over the history of arsenic releases from the ViChem site is not known. In view of the large amount of arsenic bound to the lake sediments (approximately 30% of that released) it is unlikely that the estuary sediments contain more than 30% of the release, or 150 metric tons. This point will be reviewed later.

To summarize the preceding discussions, the arsenic transport for the Maurice River basin is fairly well known. Based on sediment inventory and Ebasco river water measurements, it is apparent that the Blackwater Branch and the upper Maurice River presently act as simple, nonreactive conduits transporting arsenic in dissolved and suspended form from the site to Union Lake. The arsenic budget for Union Lake would suggest that during 1986 and 1987, the lake was also a simple conduit. However, the very large inventory of arsenic in the lake sediments indicates that this has not been the case in the past.

Finally, the lower Maurice River receives the arsenic flux from Union Lake. The best estimates are that 50 to 70% of this arsenic is incorporated in the estuarine sediments. The remainder is transported to Delaware Bay. However, a quantitative estimate of the amount of arsenic in these sediments is not possible, since the history of the arsenic flux over the dam at Union Lake is not known.

5.2.3 Arsenic Chemistry in the Maurice River Watershed

In this section, the factors governing arsenic solubility, speciation and concentration in the Maurice River Basin will be discussed. In particular, the change in arsenic speciation downstream from the site and its dependence on redox conditions will be examined. The correlation of sediment arsenic concentration with iron, total organic carbon and particle size distribution will be discussed. Also the dependence of the desorption coefficient (K_d) on redox conditions and sediment

VIN 002 0715

organic carbon content will be discussed. Finally, the relationship between the lake water arsenic concentration, K_d, and the lake sediment arsenic concentration will be explored.

The two most important factors governing arsenic concentrations in the sediments and waters are the redox conditions and the desorption coefficient (K_d). These two factors are somewhat related, since As^{+3} is more mobile than As^{+5} and will thus have a lower K_d. Thus redox conditions and K_d are linked but not by a one-to-one correlation. Another very important factor influencing K_d is the percent of organic matter in the solid phase.

The oxidation-reduction stability diagram for arsenic compounds in the presence of sulfur is shown in Figure 5-7. Superimposed on the theoretical plot are the conditions for the upper Maurice River, including the Blackwater Branch and for the lower Maurice River. The pe values within the box in Figure 5-7 represent oxidizing conditions that were determined by an analysis of the Eh of water samples. The pe is related to Eh as follows:

$$pe = \frac{F}{2.303\ RT}\ Eh$$

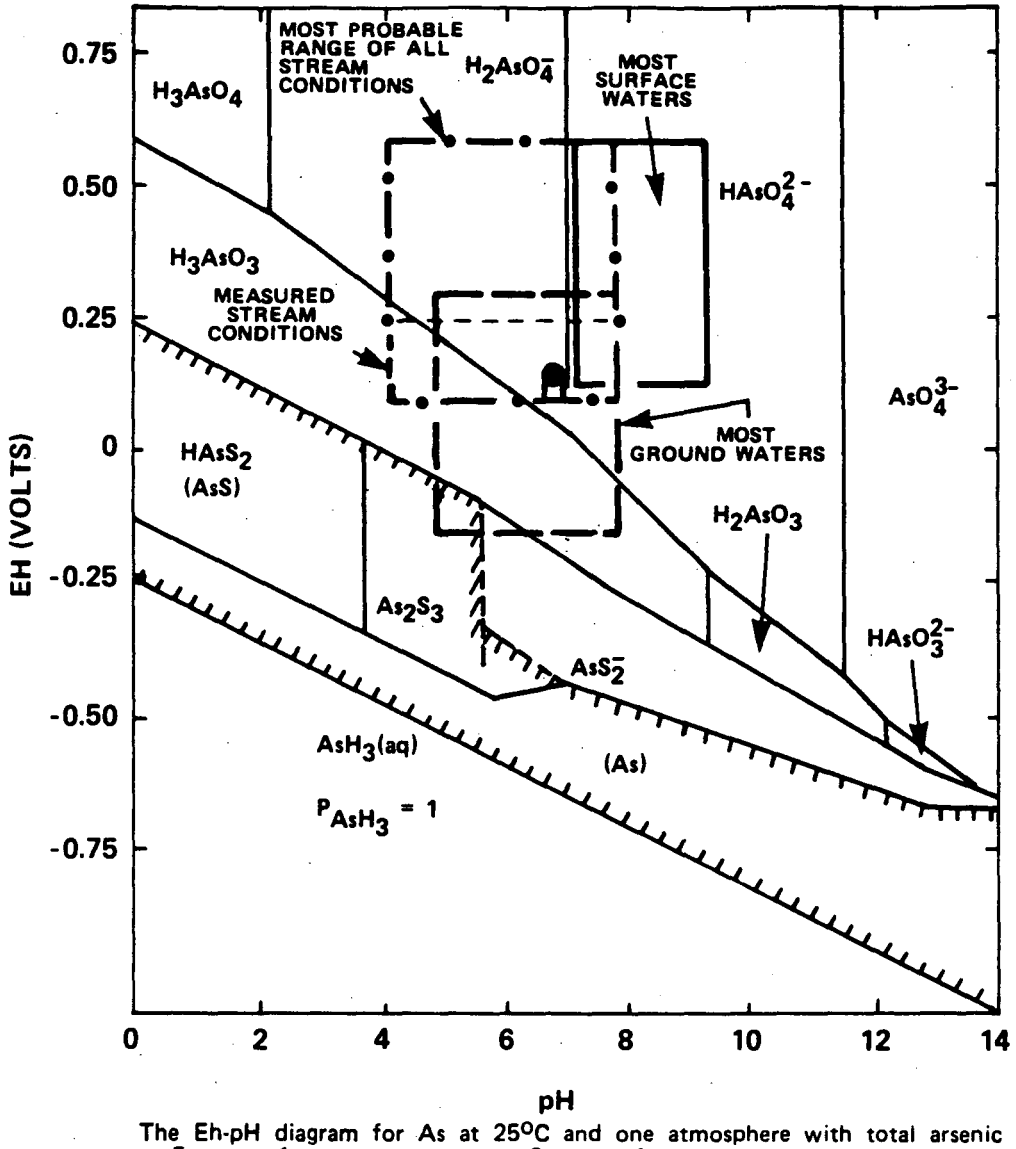
where: F = Faraday's constant (23.06 kcal/v-gm equivalent)
R = the gas constant (1.987×10^{-3} kcal/mole°K)
T = the absolute temperature (°K)

The measurement of Eh is difficult in most natural waters where a range of redox pairs may exist. In addition, there is also the possibility of matrix effects on the probe, preventing an accurate reading. The Eh measurements made in Phase I of this investigation were considered suspect and were not used. The Phase II measurements ranged from approximately 60 to 240 mv, more typical of a surface water system.

Figure 5-7 shows the mean Eh-pH conditions for the upper and lower Maurice River. The most likely Eh-pH range for the system is shown by the larger box in Figure 5-7. This box is based on the lake conditions measured by Ebasco and by Winka (1985). The indication from this diagram is that As^{+5} is the thermodynamically stable form of arsenic for most of the conditions found.

Winka (1985) examined the desorption coefficients (K_d) for arsenic in the sediments of Union Lake under a variety of conditions (see Table 5-5). The measurements show the importance of the presence of organic matter in the sediments in determining K_d. Winka incubated two samples of lake sediments, one sandy (2% organics), one organic rich (25% organic) and obtained a very significant difference in K_d under aerobic conditions (84 vs. 7690, respectively). He also obtained a large difference for anaerobic conditions (128 vs.

VIN 002 0716



The Eh-pH diagram for As at 25°C and one atmosphere with total arsenic 10^{-5} mol L^{-1} and total sulfur 10^{-3} mol L^{-1}. Solid species are enclosed in parentheses in cross-hatched area, which indicates solubility less than $10^{-5.3}$ mol L^{-1}.

From FERGUSON & GAVIS, 1972

● MEAN CONDITIONS FOR UPPER MAURICE RIVER, PHASE II, 1987

□ MEAN CONDITIONS FOR LOWER MAURICE RIVER, PHASE II, 1987

U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 5-7

Eh-pH DIAGRAM FOR ARSENIC

EBASCO SERVICES INCORPORATED

VIN 002 0717

TABLE 5-5

K_d OF LAKE SEDIMENTS UNDER AEROBIC LABORATORY CONDITIONS[a]

Reservoir	Avg. Arsenic Conc. in Water (ug/l)	Avg. Arsenic Conc. in Sed. (ug/g-dry)	Desorption Coefficient K_d [b]
Organic - Rich Sediments			
at 20°C.	219	1090	4980
at 30°C.	112	1161	10400
Average	166	1126	7690
Sandy Sediments			
at 20°C.	330	22.1	67.0
at 30°C	224	22.4	101
Average	227	22.3	84.0

K_d OF LAKE SEDIMENTS UNDER ANAEROBIC LABORATORY CONDITIONS[a]

Reservoir	Avg. Arsenic Conc. in Water (ug/l)	Avg. Arsenic Conc. in Sed. (ug/g-dry)	Desorption Coefficient K_d [b]
Organic - Rich Sediments			
at 20°C.	861	815	947
at 30°C.	1082	998	922
Average	972	907	935
Sandy Sediments			
at 20°C.	146	19.6	134
at 30°C	234	28.2	121
Average	190	23.9	128

a. Winka, 1985

b. $K_d = \frac{\text{Arsenic in sediment (ug/kg)}}{\text{Arsenic in Water (ug/l)}}$

VIN 002 0718

935, respectively). It is apparent that in the lake at least, the fraction of organic matter is the major factor in determining the K_d for arsenic and also the concentration of arsenic in the sediment. In fact Winka (1985) and NJDEP (1982) both found total arsenic concentration in the sediments to correlate very strongly with organic matter. Winka obtained a Spearman rho correlation coefficient of 0.87 (on a scale of -1 to +1). The K_d for arsenic in sandy soils does not appear to be a strong function of redox conditions. Both anaerobic and aerobic tests on sandy sediments produced similar K_d's of 126 to 81 respectively. Conversely, the K_d for organic rich sediments decreased by almost an order of magnitude between aerobic and anaerobic conditions (7690 to 935, respectively). This correlates well with the change in speciation from As^{+5} to As^{+3} to be discussed later in this section.

The effective K_d for the upper Maurice River and Union Lake is probably between 100 and 1,000, depending upon the distribution of organic material in the sediment. The higher K_d's correlate to higher organic content in the sediments. This correlation between K_d and organics in soil compares well with conditions in the aquifer at the ViChem site. The saturated soils there had low K_d's (6.6 to 10) and very low organic content.

As a part of this RI, Ebasco collected sediment samples for arsenic along with three sediment parameters; total iron, total organic carbon (TOC) and particle size distribution. Appendix J contains the statistical analysis of the Ebasco data.

In the Blackwater Branch, arsenic is well correlated with TOC, similar to the lake sediments. Additional parameters measured by Ebasco, total iron, % clay and % silt, also showed a positive correlation with arsenic. This correlation was expected in view of typical arsenic chemistry (see Subsection 5.1). Arsenic, particularly As^{+5}, is readily incorporated in ferric hydroxide matrices coating the sediment particles. The association of arsenic with the clay and silt fraction is probably due to the high surface area of these fractions, which provides sites for TOC and iron. These in turn absorb arsenic. The sand fraction showed a negative correlation with arsenic, TOC and iron, probably resulting from the low surface area of this fraction. It should be pointed out that in Union Lake, no correlation was observed between arsenic and the percent sand grain size data collected by the NJDEP, however the accuracy of the sizing data was suspect according to the NJDEP.

In the contaminated section of the upper Maurice River (between its confluence with the Blackwater Branch and Union Lake) arsenic exhibited the same general correlations as described above. However, the correlation with TOC deteriorated somewhat. This difference between the two river sections is

VIN 002 0719

probably related to the different conditions that existed in each one. A beaver dam on the Blackwater Branch created a swamp in this area. This dam was removed during the RI. The swamp provided an area of increased biological activity and water residence time relative to conditions downstream in the upper Maurice River. These two factors probably combined to provide more organic carbon, a biological absorpton pathway and a long contact time, enhancing arsenic absorption by TOC. Below the dam, these factors are less important and the correlation with TOC weakens somewhat. The dilution of sediment TOC from the Blackwater Branch with uncontaminated TOC from the upper Maurice River via sediment transport will also weaken this relationship.

Arsenic is strongly correlated with iron in both the Blackwater Branch and the upper Maurice River. This is probably a result of iron availability and oxidizing Eh conditions.

The sediment data for the lower Maurice River lack the correlations typical of arsenic in natural systems. Arsenic is uncorrelated with TOC and iron, and is positively correlated with the sediment fraction greater than sand. In the saline water sediment arsenic is negatively correlated with the clay fraction. These patterns are probably the result of a number of factors, including the heterogeneity of the sediments in this river section, the effect of ionic strength and available cations from the saline water, and alteration of the arsenic speciation and absorption matrix. Arsenic speciation will be discussed in the next several paragraphs. The complete description of the correlations between arsenic and the other sediment parameters is given in Appendix J.

The speciation of arsenic in the sediments and in the water column was studied by Winka (1985). Winka found that the speciation was related to the sediment types, again as defined by organic matter content (see Table 5-6a). His work also showed that the speciation found in both sediment types lies between the speciations seen under incubated aerobic and anaerobic conditions (see Table 5-6 b and c).

Winka (1985) also determined the speciation in the water of the Blackwater Branch at Mill Road (see Table 5-7). The dominant species found was As^{+5}. This is consistent with the redox conditions expected in a flowing stream (i.e., high Eh). Based on this speciation, the most probable paths of arsenic transfer to the sediments of the lake are either by absorption of As^{+5} on the surface of suspended matter particles or by biological fixation.

Although the cause is not clear, the difference in speciation between the water column and the sediment is significant. In particular, it is not possible to determine whether the conversion of As^{+5} in the water to As^{+3} in the sediments takes place as part of the adsorption process or whether the ion

VIN 002 0720

TABLE 5-6

ARSENIC SPECIATION IN UNION LAKE SEDIMENTS[c]

A. Speciation in the acid extractable fraction of Union Lake sediments

Species	Organic Rich Sediment	Sandy Sediment
	----------%[a]----------	
As(III)	73.4	31.5
MMAA	1.5	4.3
As(V)	25.1	64.2
DMAA	0.0	0.0

B. Speciation in the incubated sediments under aerobic conditions.

Species	Organic-Rich Sediments at 20°C Week 10	Sandy Sediments at 30°C Week 5
	----------%[b]----------	
As(III)	5.6	4.2
MMAA	0.0	0.0
As(V)	94.4	95.8
DMAA	0.0	0.0

VIN 002 0721

TABLE 5-6 (Cont'd)

ARSENIC SPECIATION IN UNION LAKE SEDIMENTS

C. Speciation in the incubated sediments under anaerobic conditions.

Species	Organic-Rich Sediments at 20° C Week 4	Organic-Rich Sediments at 30° C Week 5	Organic-Rich Sediments at 30° C Week 10	Sandy Sediments at 30° C Week 6
	%[b]			
As(III)	72.8	67.8	97.9	21.0
MMAA	1.5	1.6	0.0	5.7
As(V)	25.7	30.6	2.1	73.3
DMAA	0.0	0.0	0.0	0.0

a. Calculated as % of total arsenic extracted by 1N HCl solution.
b. Calculated as % of total arsenic in each sample.
c. From Winka (1985).

VIN 002 0722

TABLE 5-7

SPECIATION OF WATER SAMPLES FROM THE BLACKWATER BRANCH AT MILL ROAD[a]

Species	Date		
	Sept 82	Mar 83	Sept 83
	--------% of Total Arsenic------		
As(III)	23.5	12.0	3.5
MMAA	4.9	3.2	3.9
As(V)	69.8	84.8	92.6
DMAA	1.8	0.0	0.0

a. From Winka (1985).

VIN 002 0723

TABLE 5-8

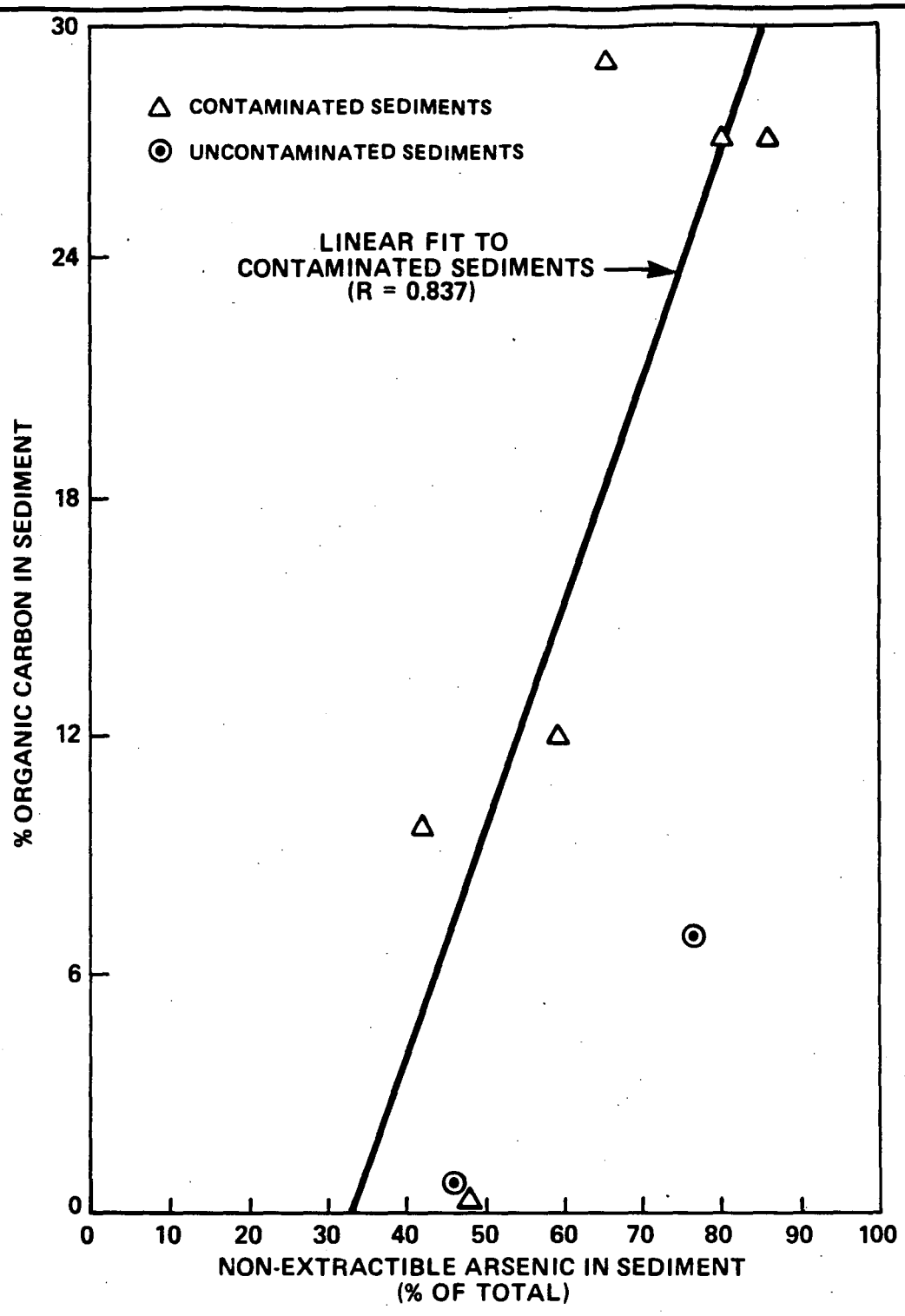
TOTAL NONEXTRACTABLE ARSENIC IN THE MAURICE RIVER WATERSHED[b]

Water Body	Location	River Mile Downstream of Site (ER-3A)	Non-Extractable Arsenic[a] (ug/g-dry) 9/16/82	12/2/82	3/4/83	6/16/83	9/9/83	Average	Total[a] Nonextractable Arsenic %	Mean % Organic
Blackwater Branch	Garden Rd.	control	14.9	11.9	3.74	19.8	48.2	19.7	77.9	7.2
	Weymouth Rd.	control	1.43	—	—	0.775	0.849	1.02	46.4	0.8
	Mill Rd.	0.4	28.5	551	—	479	168	307	59.6	12
Maurice River	Almond Rd. (beach)	2.6	8.60	—	14.7	17.6	6.72	11.9	48.1	0.2
Union Lake	North Side of Submerged Dam	8.6	73.1	77.9	1170	3450	8205	2385	66.2	29
	South Side of Submerged Dam	8.7	21.5	457	234	576	2070	4398	86.6	27
	Western Side of Lake Where Mill Creek Enters	10.0	211	51.3	125	22.2	59.5	93.8	43.0	9.7
	Deepest Portion of Lake Behind Dam Spillway	10.8	157	357	860	1215	8740	2270	81.3	27

a. % of Total Arsenic - dry weight basis.

b. From Winka (1985).

VIN 002 0724



a) FROM WINKA, 1985

U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 5-8

RELATIONSHIP BETWEEN NON-EXTRACTABLE ARSENIC AND ORGANIC CARBON CONTENT OF MAURICE RIVER BASIN SEDIMENTS[a]

EBASCO SERVICES INCORPORATED

VIN 002 0725

is converted within the sediments. Winka (1985) found evidence to suggest strongly that the arsenic adsorption onto sediment is not completely reversible. In Table 5-8 and Figure 5-8 his results for total nonextractable arsenic in a number of lake and river sediment samples are presented. The extraction consisted of a distilled water wash and a 1 N HCl wash. In general, the higher the arsenic concentration in the sample, the less was extractable. In addition, there was a distinct positive correlation between mean percent nonextractable arsenic and percent organic matter in the contaminated sediments. The uncontaminated sediments should not be considered here, since the nature of the arsenic compounds at the background levels is probably very different from that of the contaminated sediments.

Ultimately, one would like to be able to predict a leach rate from the sediments to the Maurice River watershed. This is needed to determine their impact on the water column inventory, once the arsenic releases from the ViChem site are stopped. However, this flux rate is dependent on the resuspension of sediments and on the pore water exchange rate. The pore water exchange rate is dependent upon pore water diffusivity, biological activities and groundwater seepage. Given these unknown factors, it is impossible to predict quantitatively the arsenic flux rate from the sediments.

In spite of this, it should be noted that the mean sediment concentration of 74.2 ug/g and an organic rich sediment Kd of 1000 yield a dissolved water column concentration of 74.2 ug/l, which compares well with the water column concentration range of 50 to 75 ug/l for June and July 1986 in Union Lake. During this time of the year the sediment would probably be under fairly anaerobic conditions, producing a lower Kd. During the more aerobic conditions of winter, a higher Kd would be expected. If the Kd for aerobic organic sediments is used (7,700) along with the mean sediment concentration (74.2 ug/g), a water concentration of 9.6 ug/l is predicted. This agrees well with the range of dissolved arsenic in measured lake water for January 1987 of 10 to 24 ug/l.

It would appear from the above discussion that the lake sediments control the lake arsenic concentrations. However, it must be recalled that the arsenic loading entering, within, and coming out of Union Lake have been approximately the same for periods where data are available. This suggests that the lake is presently a conduit, transferring arsenic through it. This transfer is controlled by the upstream arsenic flux. The fact that the mean sediment arsenic concentration and Kd produce the same estimated arsenic concentration in the lake water as the incoming and outgoing waters makes it impossible to determine which factor controls the lake's arsenic concentration, the incoming water or desorption off the sediments.

VIN 002 0726

It is not known whether the sediment flux required to maintain the lake arsenic levels is reasonable, since nothing is known about sediment-water exchange. If the K_d typical of sandy soils (100 l/kg) is used then the lake water is out of equilibrium. The level of arsenic in the water would be approximately 740 ppb based on the sediment concentration. This would also imply a much greater potential for arsenic release, so that a major arsenic flux from the sediments cannot be ruled out in either case. This is in direct conflict with the calculations of the previous section, which suggest that the lake water column inventory is controlled by an inflow/outflow balance. It is not possible to discern the controlling mechanism with the present data base. It is highly possible that both processes may be important.

To summarize, arsenic chemistry is strongly affected by redox conditions and the availability of TOC and iron. Arsenic strongly correlates with TOC and iron in the sediments in much of the Maurice River Basin. In general, arsenic is associated with the smaller size fractions of the sediments. The speciation of arsenic changes significantly from the water of the Blackwater Branch to the Union Lake sediments. Indications are that as a part of the arsenic transport and deposition in this system, a significant portion of the arsenic is permanently bound to the sediments. Related to this process is the organic carbon content of the sediment such that higher organic carbon content means more nonextractable arsenic. Also related to the above, the desorption coefficient, K_d, is inversely related to the organic carbon content. The changes and variations in speciation, organic carbon content, K_d and nonextractable arsenic fraction are most likely interrelated, based on literature, laboratory and in situ studies. Finally the flux of arsenic from the sediments of Union Lake cannot be determined with the present data base. However, the arsenic in the lake water and in the lake sediments appears to be in equilibrium if the K_d values for organic rich sediments are used in the calculation. Unfortunately, from a predictive standpoint, the estimated water equilibrium concentration is close to the arsenic concentration in the incoming and outgoing surface water. Therefore the driving mechanism for the lake's water arsenic concentration cannot be definitively determined.

5.2.4 Arsenic Inventory in the Maurice River Watershed Sediments

In this section, an inventory of arsenic in the upper Maurice River and in Union Lake will be calculated. These numbers are important in determining the fate of approximately 500 metric tons of arsenic estimated to have been transported past Mill Road (ER-4). This information is also needed to discuss areas of concern in the future, since these sediments may be sources of arsenic to human populations.

VIN 002 0727

There are three main areas to consider in examining the sediment-bound arsenic inventories in the Maurice River watershed:

1. The Blackwater Branch and upper Maurice River

2. Union Lake

3. The lower Maurice River

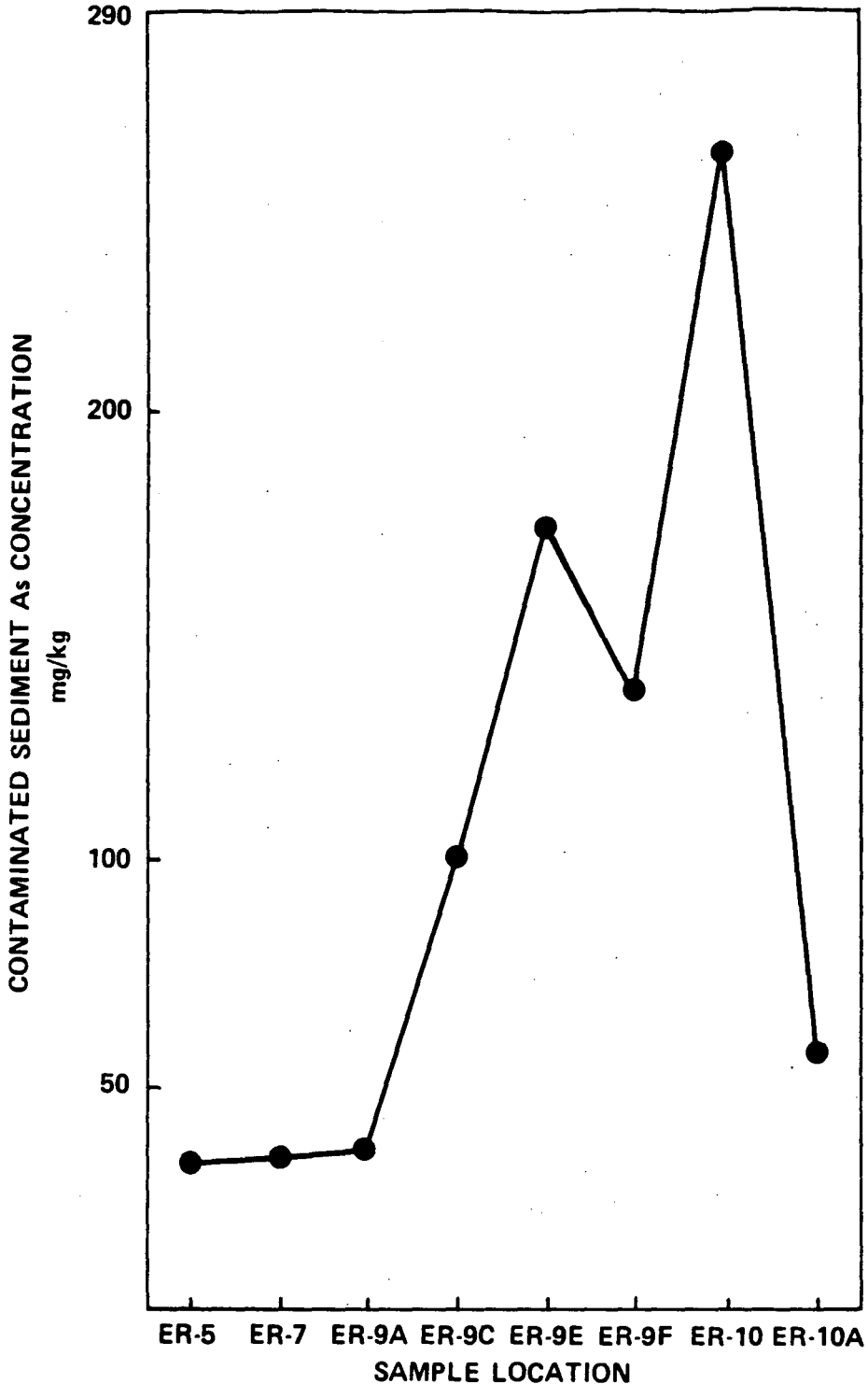
It is possible to make semiquantitative estimates for the arsenic inventory in the first two regions, since these areas have been extensively sampled and cross sectioned. The lower Maurice River has not undergone as extensive a study and will not yield a quantitative estimate.

The sediments of the upper Maurice River were extensively sampled by Ebasco during June through August 1987. This sampling included cross sections and sediment cores to three feet in depth. These data were used to estimate the volume of contaminated sediment in the upper Maurice River watershed for the FS.

The volume of sediment between stations ER-3A and ER-10A with concentrations of arsenic greater than 20 mg/kg is 89,000 yd^3 or 68,000 m^3. Of this total, 67,000 m^3 is between Union Lake and the confluence of the Blackwater Branch and the upper Maurice River. A conservative estimate of the mass of arsenic within this sediment was calculated as follows: the arithmetic mean sediment concentration for each cross section was calculated, then a median for all the cross section means was obtained and applied to the appropriate river section. For the Blackwater Branch, the median of ER-4 and ER-5 was used to calculate the arsenic inventory for the sediments between them (690 kg of arsenic). For the upper Maurice River between ER-5 and ER 10A, the median of all cross sections between these two stations was used to calculate the sediment arsenic inventory (5600 kg). The total arsenic inventory between ER-4 and ER10A is approximately 6,300 kg. The section between ER-3A and ER-4 was also inventoried. A range of total sediment arsenic obtained for this section is 560 to 4,700 kg, depending whether the median for locations ER-3, -3A and -4 or just -3A and -4 is used, respectively. This section of the Blackwater Branch was calculated separately, since it is upstream from Mill Road and cannot be directly compared with the flux past that point.

The mean arsenic concentration of the contaminated sediments in each cross section increases downstream from ER-5 to ER-10 (see Figure 5-9). This is partially explained by the mean percentage of organic matter in these sediments (see Figure 5-10). As just discussed in Subsection 5.2.3, arsenic is also strongly correlated with iron in this river section. This suggests that the arsenic in these sediments is largely associated with the organic matter or ferric hydroxide coatings on the sediment

VIN 002 0728



U.S. ENVIRONMENTAL PROTECTION AGENCY

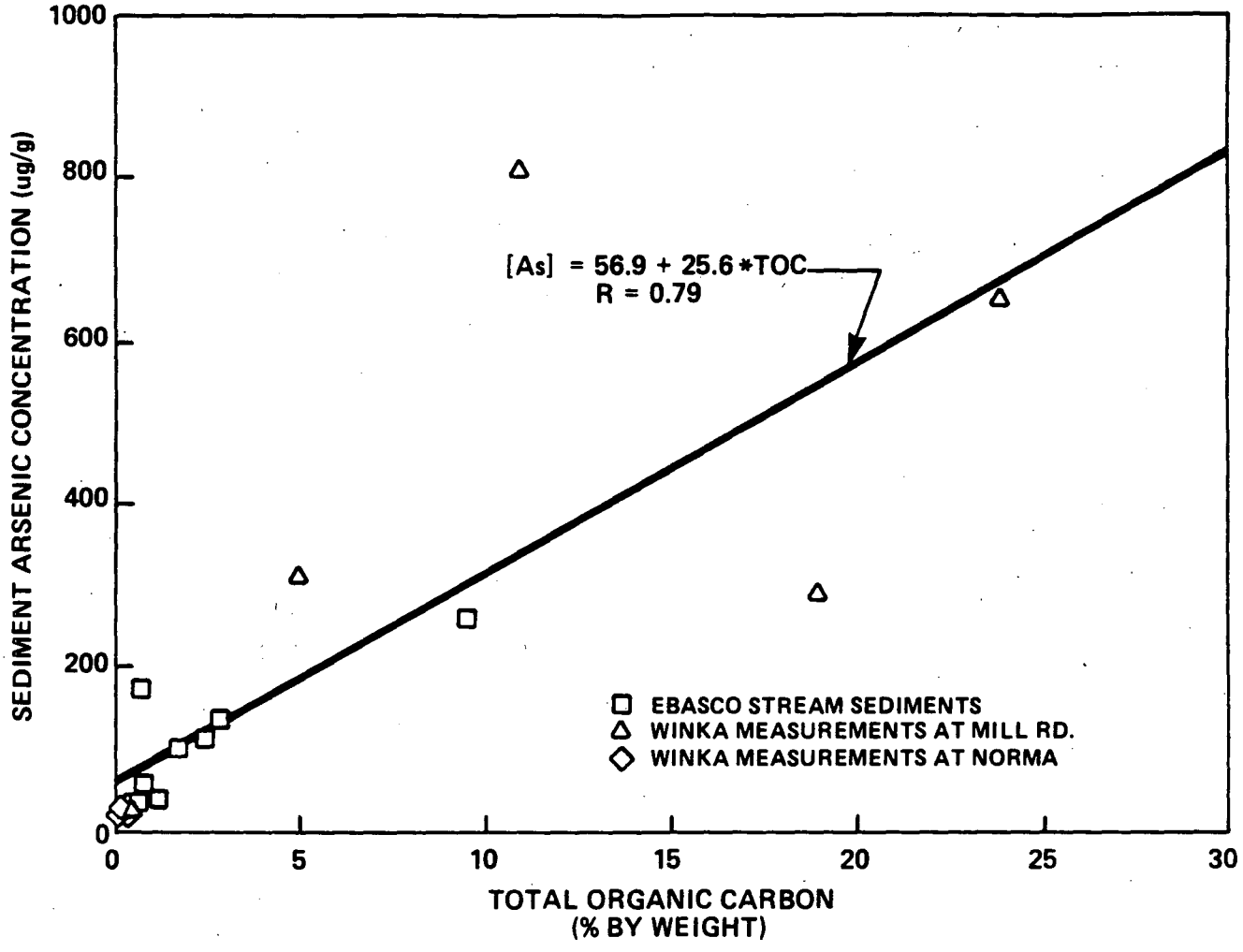
VINELAND CHEMICAL COMPANY SITE

FIGURE 5–9

CONTAMINATED SEDIMENT ARSENIC CONCENTRATION vs SAMPLE LOCATION

EBASCO SERVICES INCORPORATED

VIN 002 0729



U.S. ENVIRONMENTAL PROTECTION AGENCY

VINELAND CHEMICAL COMPANY SITE

FIGURE 5-10

ARSENIC CONCENTRATION IN STREAM SEDIMENTS vs SEDIMENT TOTAL ORGANIC CARBON CONTENT

EBASCO SERVICES INCORPORATED

VIN 002 0730

particles, which is similar to the results found by Winka (1985). However, the downstream increase may also be a function of the history of arsenic release. The large input of arsenic in the 1970s may have contaminated sediments in the Blackwater Branch to a much higher level than presently measured. These sediments may have been transported downstream and redeposited over cleaner sediments, yielding the pattern seen in Figure 5-9. This would suggest that the eventual sink for these sediments is downstream from the upper Maurice River, probably Union Lake. The resuspension of these sediments with storms and floods will maintain an arsenic flux to the lake even after the arsenic release from the ViChem plant site is stopped. It is not possible to predict this flux but, given the small size of the arsenic inventory in this river section, it will probably be much smaller than the present load.

The sediments of Union Lake were extensively studied by three investigators, Ebasco, NJDEP and Winka (1985). NJDEP conducted the most extensive sediment surveys during August 1986, examining the arsenic concentrations in the sediments under 10 feet of water or less. In general the contamination was confined to the top one foot of sediment, although concentrations above background were found at depths greater than one foot. The mean concentrations for the cores is given in Table 5-9. A windsorized mean of 74.2 ug/g for the Union Lake sediments below less than 10 feet of water was calculated as part of the RI for Union Lake, using cored and dredged samples (Ebasco, 1989e). This result agrees well with the data in Table 5-9 since the dredged samples combine surface and deeper sediments. Using the mean arsenic concentration and assuming a depth of one foot for the contaminated sediments at a porosity of 46% (based on NJDEP measurements), it is possible to calculate the arsenic inventory for all lake sediments less than 10 feet below the water surface. This represents an area of 2.0 km^2. The density of the solid sediments is assumed to be 2.65 gm/cc which, at a porosity of 46%, gives an overall density of 1.786 gm/cc. The inventory of arsenic is then 81,250 kg or 80 metric tons. The fraction of organic matter in the sediments has been ignored in this calculation since it is not well known. If it is significant, the sediment density and the estimated arsenic inventory will both be lower.

The sediment area deeper than 10 feet below the lake surface represents an additional 1.5 km^2. This area was not well characterized by any of the programs (see Table 5-10). Assuming that the conditions in this portion of the lake are approximately the same as in the shallower portion (mean arsenic concentration = 74.2 mg/kg; depth of contamination approximately one foot), then the arsenic inventory in this portion of the lake is approximately 60 metric tons. Combined with the 80 metric tons estimated in the shallow areas, this gives a total arsenic inventory of 140 metric tons for the sediments of Union Lake.

VIN 002 0731

TABLE 5-9

MEAN ARSENIC CONCENTRATIONS
IN THE SEDIMENT CORES FROM UNION LAKE[a]

Depth	Arsenic Concentration (ug/g)	No. of Samples
Surface	158	21
7 to 12 inches	39	17
13 to 24 inches	4.6	13

[a]from NJDEP, 1987

VIN 002 0732

TABLE 5-10

As CONCENTRATIONS IN LAKE SEDIMENTS
GREATER THAN 10 FEET BELOW THE SURFACE OF
UNION LAKE

Investigator	Collection Date	As Concentration (ug/g)	Median (ug/g)
Winka (1985)	1982	1215	
	1983	540	
		1440	
		1660	
		9080	
NJDEP (1982)	1979	478	
Median of Winka & NJDEP			1215
Ebasco	1987	68	
		75	
		38	
		14	
Median of Ebasco only			53

VIN 002 0733

The total inventory of arsenic from Mill Road to the Union Lake dam is estimated at 150 metric tons (see Table 5-11). This is approximately 30% of the estimated 500 metric tons released from the site past Mill Road through time. This contradicts somewhat the measured inflow/outflow balance calculated earlier in this section, since if arsenic inflow and outflow from the lake had always been equal there would be no contaminated sediment inventory in the lake. On the other hand, given the crudeness of the numbers used to estimate the inflow/outflow balance, the data suggest that most of the input into the lake has come out of the lake (70%). Whether the arsenic enters the lake, adsorbs onto the sediments, then desorbs back into the water column, or whether the arsenic in the water column simply passes through the lake with only a small percentage adsorbing onto the sediments, is still unknown.

The adsorption of arsenic on the lake sediments appears to be a product of adsorption by resuspended lake sediments and direct transfer from the water column to the lake sediments. The suspended matter load for the lake is on the order of 2,000 to 4,000 tons/yr based on the sediment loading at Norma. Distributing this over 3.5 km^2 of lake bottom yields a sedimentation rate of 0.03 to 0.06 cm/yr given a sediment density of 1.78 gm/cc. Thus in 20 years this represents 0.6 to 1.2 cm of fresh sediments. It would appear then that the contamination below this depth in the lake sediments is the result of more than simple deposition of the annual sediment load. Resuspension of sediments, biological stirring and direct adsorption via pore water exchange must also be involved. This has important implications for future arsenic levels. Since the contaminated sediments in Union Lake will not be buried for quite some time in the future (hundreds of years), the resuspension of sediments will probably continue to supply contaminated sediments to the lower Maurice River even after the input of arsenic from upstream sources is eliminated. In addition, these processes will also release extractable arsenic to the lake water column. Since the processes for arsenic release are difficult to estimate and sediment burial is so slow, it is impossible to estimate the rate or duration of arsenic flux from the sediments to the lake or to the lower Maurice River with the present data set.

The sediments of the Maurice River below the Union Lake dam show arsenic levels above background all the way to the Delaware Bay. The levels found were significantly lower than those found above the dam. The geometric mean for these sediments was 30 mg/kg compared with 74.2 mg/kg in Union Lake. The range of arsenic levels in the sediments of the lower Maurice River was 9.2 to 234 mg/kg. Since no good estimate exists for the surface area of these sediments and no estimate exists for the depth of contaminated sediments in this area, it is not possible to calculate an arsenic inventory. However, since the arsenic flux balance on Union Lake indicates that at present there was a

VIN 002 0734

TABLE 5-11

ARSENIC INVENTORIES IN THE
MAURICE RIVER WATERSHED

	Arsenic (metric tons)
Blackwater Branch	
Between Station ER-3 and Mill Road (ER-4)	0.56 to 4.7[a]
Between Mill Rd. (ER-4) and the Maurice River (ER-5)	0.69
Upper Maurice River	
Between Blackwater Branch (ER-5) and Union Lake (ER-10A)	6.3
Union Lake	
Sediments shallower than 10 ft.	80
Sediments deeper than 10 ft.	60 (980)[b]
Total of all sediment downstream of Mill Road (ER-4)	150
Calculated arsenic flux at Mill Road	500

a) Not included in total

b) High value is not included in total. This value was calculated using the median of Winka (1985) and NJDEP (1979) data.

VIN 002 0735

significant flux to the lower river, it is likely that 15 to 30% of the arsenic transported past Mill Road may be buried in these sediments.

This estimate is based on the conditions discussed in Subsection 5.2.2. This would make this region the second most important sink for arsenic. The exact fraction stored in these sediments depends upon a large number of factors, all of which are poorly known at best. As discussed in Subsection 5.2.2, these factors include biological activity, salt precipitation, sediment resuspension and tidal exchange, among others.

To summarize, the sediment inventories fairly decisively show that the upper Maurice River and the Blackwater Branch below Mill Road are presently behaving as conduits for arsenic, transferring arsenic released off the site into Union Lake. Union Lake's sediments contain an estimated 30% of the arsenic released off the site through time. The remaining arsenic released from the site may transfer through the lower Maurice River into the Delaware Bay, or may be bound to the lower Maurice River sediments. A crude estimate is that approximately one half of the approximately 350 metric tons of arsenic that have passed through the lake (approximately 175 metric tons) is bound to the lower Maurice River sediments.

It is not clear what controls the water column arsenic concentration in Union Lake. Adsorption of arsenic onto the sediments had to have occurred in the past to account for the large arsenic inventory. However, an estimated 70% of the arsenic that has been released from the site is no longer present above the Union Lake dam. This suggests that the lake passes the majority of the arsenic that comes into it back out. However, whether this is a function of adsorption/desorption or simple flow-through is not clear.

The slow sedimentation rate calculated for the lake indicates that the contaminated sediments will not be buried in the near future. Elevated arsenic concentrations seen at depth in the sediment cores must be the result of transport processes within the sediment or sediment resuspension. The lack of significant sediment burial may present a long-term problem if surface sediment arsenic concentrations are determined to be a problem by a risk assessment.

Finally, it must be recalled that the fate and transport discussion is based on a very crude data set. Detailed long-term data on lake inflow and outflow can be obtained in the future from the USGS gaging station at Norma and from the dam spillover out of Union Lake, respectively. Knowing with some detail the long-term arsenic concentration and flow coming in and going out of the lake will aid greatly in determining the desorption of arsenic from the lake sediments.

VIN 002 0736

5.2.5 Future Arsenic Transport

In this section, the implications of the previous sections will be discussed in terms of future arsenic levels in the Maurice River basin. The main points from each of the previous four subsections will be summarized and their importance for future arsenic release discussed. An assessment of whether the Federal drinking water MCL can be achieved will be made for each river section. Finally, additional data needs for the basin will be discussed.

The main conclusions from the previous discussions are as follows:

1. Arsenic Input to the Basin - An estimated 500 metric tons of arsenic were transported past Mill Road into the Blackwater Branch and upper Maurice River. Instantaneous flux measurements agree with the historic trend at Mill Road and indicate that the flux from the site was 4 to 8 metric tons/yr in 1987. These fluxes were confirmed by cross checking Ebasco, USGS and ViChem data.

2. Arsenic Transport in the Basin - Both dissolved and suspended matter arsenic are important forms for transport in the Maurice River Basin. Based on mass balance arguments, the Blackwater Branch and upper Maurice River are simple conduits for arsenic transport from Mill Road to Union Lake. No apparent chemical change occurs during this transport, since the ratio of dissolved to total arsenic in the river water remains fairly constant. In addition, the relationship between arsenic and the sediment parameters (iron and TOC) remained constant throughout this region, also suggesting that no important chemical changes occur in the upper Maurice River and Blackwater Branch. Union Lake appeared to be acting as a simple conduit based on arsenic mass balance calculations. The lower Maurice River appears to be a sink for 50 to 70% of the arsenic transported from the lake, based on mass balance and water column inventory arguments.

3. Arsenic Chemistry in the Basin - Redox conditions, organic carbon content, total iron content, sediment particle size distribution and Kd are important factors governing arsenic concentration and speciation. Union Lake Kd's for arsenic vary from about 100 l/kg for sandy sediments under any redox conditions to 1,000 to 7,700 l/kg for organic rich lake sediments under anaerobic and aerobic conditions, respectively. The arsenic concentrations of lake sediments and lake water appear to be in equilibrium during July 1986 and January 1987 if the organic-rich sediment Kd's are used. If the sandy sediment Kd's are used, the lake water is out of equilibrium with the sediment and the potential for arsenic release is much greater. Either set of conditions suggests that the lake sediments may release significant amounts of arsenic. The absorption of arsenic by the lake sediments is not completely reversible; approximately 50% or more of the arsenic in the sediments is not extractable by simple chemical means.

VIN 002 0737

4. Arsenic Inventory in the Basin Sediments - Union Lake sediments contain approximately 140 metric tons of arsenic. The sediments of the upper Maurice River and Blackwater Branch contain about 6 metric tons of arsenic. Based on these data and the water mass balance calculation, these sediments probably contain the smallest arsenic inventory. The sediments of the lower Maurice River cannot be inventoried at the present time, but probably represent an arsenic inventory between the other two areas. Any arsenic not removed to the sediments of the lower Maurice River is transported to Delaware Bay, generally at low concentrations. Sedimentation rates for Union Lake are estimated to be too slow to effectively bury the contaminated sediments. Thus the contaminated lake sediments may represent a significant arsenic source for many more years.

It is important to examine future levels of arsenic in the waters of the basin in view of these conclusions. The following discussion is based on the assumption that all future releases from the ViChem site are stopped. Under these conditions, the arsenic levels in the upper Maurice River and Blackwater Branch can be expected to drop fairly rapidly. Since the inventory of arsenic in the sediments from the region is low it should not take long (i.e. more than several years) for the leachable arsenic to be removed. Thus this section of the river should be able to attain arsenic levels less than the federal MCL of 50 ug/l. This is especially true in view of the fact that the total arsenic levels are only two to three times the MCL in the upper Maurice River throughout most of the year, according to USGS and Ebasco data for 1987. It should be noted that occasional resuspension of contaminated sediments would probably serve to raise the water concentration above the MCL during resuspension events.

Below Union Lake the total arsenic levels were twice the MCL or less, and the median value was well below the MCL in 1987. If the flux from the site is cut off, the arsenic levels for the entire estuary would most likely drop below the MCL.

The future arsenic levels in Union Lake are much more difficult to predict. The conclusions from each of the three sources of information for the lake, the arsenic mass balance, the K_d for the lake sediments, and the inventory of arsenic in the lake sediment, appear to partially or completely contradict each other. However, there is little question that the lake has been the major sink of arsenic in the past.

Considering the above, there are too many uncertainties to make any semiquantitative prediction of future lake water arsenic levels meaningful. Given the errors in the inflow/outflow calculations, it is likely that the inflow/outflow balance maintains at least half of the present lake inventory. By removing the flux from upriver, it is likely that the lake inventory would drop by half or more, putting water levels below the MCL. This argument has a sufficient number of assumptions to make it a very weak statement, at best.

VIN 002 0738

The following discussion may be useful to understanding the arsenic cycle in the lake. Presumably, most of the arsenic in the lake sediments was transported and absorbed during the 1970s and early 1980s when the flux of the site was the highest (see Figure 5-4). Thus the arsenic bound to the sediments was adsorbed when lake water arsenic concentrations were much higher than they were in 1986 and 1987.

In all likelihood the arsenic adsorbed was in the +5 state. At the present time (1986, 1987) the arsenic concentration in the lake water may be significantly lower than several years ago. Thus, were the adsorption process completely reversible, it would be expected that all of the arsenic adsorbed could then be leached by the cleaner lake water, limited only by the sediment-water exchange rate. This rate is enhanced by the effect of storms, biological stirring, human activity and wind on the broad shallow reach of the lake to the extent that all of these processes would help to resuspend sediments and improve exchange. However, the arsenic is not adsorbed reversibly and 50% or more is bound in a nonextractable form. Thus, not all of the sediment-bound arsenic is available for maintaining elevated lake levels. Although this argument is qualitative, in view of the calculated arsenic flux in and out of the lake by net flow and the relatively small difference between the MCL and the highest lake arsenic concentration measured in 1986-87 (50 and 75 ug/l, respectively), it is likely that the lake levels will fall below the MCL if the releases from the ViChem site are stopped. This estimate is only qualitative and cannot be substantiated in a numerical form with the present data base.

Additional data needed to clarify the arsenic mass balance in the watershed are outlined below:

- Flow measurements and concurrent water samples for arsenic analysis should be obtained over a period of time at several points. The USGS gaging station at Norma can be utilized, since this station presently obtains this information. Water samples could be obtained at the outflow from Union Lake, where flow could easily be gaged by measuring the depth of water flowing over the spillway. A station could also be established on the Blackwater Branch below the ViChem plant. Data from these three stations would determine the arsenic load in the basin at three points, and could also be obtained at a relatively low cost.

- Data on the rate of arsenic description off the sediments would also be useful. The direct measurement of arsenic flux off the sediments would help describe the lake flux conditions after the upstream sources have been eliminated.

VIN 002 0739

VIN 002 0740

6.0 BASELINE RISK ASSESSMENT

6.1 PUBLIC HEALTH EVALUATION - BLACKWATER BRANCH AND MAURICE RIVER NORTH OF UNION LAKE

The public health evaluation of the Blackwater Branch and the upper Maurice River area had two objectives. The first was to assess the nature and extent of potential public health risks associated with the Blackwater Branch and the upper Maurice River in its present condition. This allows a decision as to whether or not the rivers require remedial action. The second was to help determine cleanup levels if it were decided the area required remediation. Data collected from Ebasco's Phase I and Phase II sampling efforts were reviewed. Since more samples were taken and more parameters were evaluated in the Phase II study and the data were more recent, data from the Phase II study were used in the development of this risk assessment.

6.1.1 Risk Assessment Methodology

The public health evaluation methodology utilized in this study involved several steps. The first was to identify the chemical contaminants of concern at the site to be carried through for quantitative assessment (indicator chemicals). Indicator chemicals were selected on the basis of toxicity, measured concentrations, physical-chemical properties and expected mobility in the environment. The next step was to define the potential exposure pathways and receptors at risk. The pathways were evaluated for applicability, and site-specific scenarios were developed to define the exposures. Site-specific intake rates for indicator chemicals from each exposure pathway were then estimated. For carcinogens, potential health impacts were then estimated by multiplying the intake rate by the cancer potency slope. For noncarcinogens, the pathway and age-specific intake rates were compared to EPA Reference Doses (RfDs) or other critical toxicity values to determine if potential health risks existed. For an initial worst case risk analysis, maximum site concentrations of contaminants in sediment and water as well as upper estimates of exposure conditions were used to screen out pathways that did not pose potentially severe health risks. Contaminant concentrations and exposure conditions more representative of the site were then used in pathway modeling to calculate more realistic or "most probable" estimates of site-related risks. Finally, the remedial objectives necessary to eliminate the potential health risks associated with the river area were determined. These remedial objectives are discussed in Subsection 8.2.3.

6.1.1.1 Chemical Contaminants of Concern

A number of chemical constituents detected in Maurice River matrices were selected for evaluation in the risk assessment.

VIN 002 0741

They were selected based on their elevated concentrations relative to naturally occurring background levels, as well as their toxicological, physical and chemical characteristics. In addition, these chemicals were compared to those used or manufactured at ViChem as listed in Table 1-2.

6.1.1.1.1 Inorganics

Three metals were selected as indicators of inorganic contamination; arsenic, mercury, and lead. Arsenic was chosen because it was known to be related to past activities at the ViChem site and it was detected in almost all surface sediment samples (0-1 ft.) in the Maurice River, with concentration ranging from 1.0 to 3760 mg/kg (Tables 6-1 and 6-2). Since the background concentration of arsenic in U.S. soil ranges from 0.1 to 30 mg/kg (Table 6-3), the maximum detected arsenic concentration in sediment was at least 2 orders of magnitude above the normal background level. The concentration of arsenic in surface waters downgradient from the Vichem site ranged from 61 to 6200 ug/l (Tables 6-1 and 6-2). The Safe Drinking Water Act MCL for arsenic (i.e. the enforceable standard for arsenic in a public drinking water supply system) is only 50 ug/l. The maximum concentration of arsenic in surface water exceeded this value by approximately 2 orders of magnitude. Since organic arsenical herbicides and fungicides were the major compounds manufactured at the ViChem Plant (Table 1-2) , and arsenic is a human carcinogen, the potential health impacts from these elevated concentrations of arsenic in sediment and water were evaluated in this risk assessment.

No data were available from the RI sampling efforts as to the chemical or ionic speciation of arsenic in surface water or sediment. Therefore, total arsenic analyses were used in this assessment, and the assumption was made that the arsenic present was inorganic arsenic and that it possessed the same carcinogenic potency as the arsenic to which the population was exposed in the epidemiologic studies from which its carcinogenic potency factor was derived (Tseng et al., 1968). The possible effects of this assumption on the uncertainty in the risk assessment are discussed at the conclusion of this analysis.

In addition to arsenic, mercury was also chosen as an indicator chemical. It was detected in one upgradient sediment sample in the Blackwater Branch at 0.16 mg/kg (Table 6-1), and 3 out of 4 downgradient sediment samples in upper Maurice River (Table 6-2), with concentrations of 0.55 mg/kg, 1.1 mg/kg, and 0.32 mg/kg, respectively. While the background level of mercury in US soils ranges from 0.01 to 0.54 mg/kg (Table 6-3), freshwater sediment from nonpolluted rivers and lakes in the United States typically contain less than 0.1 mg/kg mercury (USEPA, 1980). The concentrations of mercury detected in sediments of the upper Maurice River exceeded this value. Moreover, mercury was also found in the surface water, with concentrations ranging from undetected to 0.8 ug/l (Table 6-1) in the Blackwater Branch, and from

VIN 002 0742

TABLE 6-1

SUMMARY OF OCCURRENCE OF CONTAMINANTS IN THE BLACKWATER BRANCH

Chemical	Sediment[1]				Surface Water[1]			
	Range in Upgradient Control Samples[2] (mg/kg) (Median)	Frequency of Occurrence in Control Samples	Range in Downgradient Samples[2] (mg/kg) (Median)	Frequency of Occurrence in Downgradient Samples	Range in Upgradient Control Samples (ug/l)	Frequency of Occurrence in Control Samples	Range in Downgradient Samples (ug/l) (Median)	Frequency of Occurrence i Downgradient Samples
Arsenic	U-11.0(6.9)	6/11	7.7-3760(229)	5/5	U-2.5	2/5	61-6200(361.5)	4/4
Mercury	U-0.16	1/6	U	0/1	U-0.6	2/6	U-0.8(0.7)	2/4
Lead	6.1-337.0(223.0)	5/5	23.3	1/1	29.4	1/1	U-7.5	1/2
Cadmium	1.2-3.9(2.0)	6/6	U	0/1	4.6	1/6	U	0/4
Chromium	8.71-31.9	2/5	N.D.	0/0	U	0/6	U-9.7	1/4
Toluene	U-0.255	2/5	0.13	1/1	U	0/6	U	0/2
Gamma-BHC	U-0.23	1/5	U	0/1	U	0/4	U	0/2

U = Undected

1 - Based on Ebasco Phase II Samples

2 - Based on 0-1 ft samples.

VIN 002 0743

TABLE 6-2

SUMMARY OF OCCURRENCE OF CONTAMINANTS IN THE UPPER MAURICE RIVER

Chemical	Sediment[1]				Surface Water[1]			
	Range in Upgradient Control Samples[2] (mg/kg) (Median)	Frequency of Occurrence in Control Samples	Range in Downgradient Samples[2] (mg/kg) (Median)	Frequency of Occurrence in Downgradient Samples	Range in Upgradient Control Samples (ug/l)	Frequency of Occurrence in Control Samples	Range in Downgradient Samples (ug/l) (Median)	Frequency o Occurrence Downgradien Samples
Arsenic	U-15.1	1/8	1.0-922 (70.8)	35/38	U-4.5	1/5	102-150 (124)	6/6
Mercury	U	0/5	U-1.1 (0.55)	3/4	U	0/5	U-0.5(0.3)	5/8
Lead	10.4-33.8 (19.1)	4/4	1.95-33 (22)	4/4	U-3.74	1/2	2.3-4.0 (3.75)	6/6
Chromium	4.2-3.9 (11.4)	4/4	5.2-17 (9.0)	3/3	U-14.0	1/5	U-13.0 (9.3)	3/8
Trichloroethylene	U	0/5	U	0/2	U	0/5	2.0-11.0 (3.0)	3/7
Toluene	U-0.100	1/2	0.003-0.015	2/2	U	0/5	U	0/8
DDT	U-0.032	1/5	U	0/3	U	0/4	U	0/4
Endosulfan sulfate	U	0/5	U-0.023	1/4	U	0/4	U	0/3

U = Undected

1 - Based on Ebasco Phase II Samples

2 - Based on 0-1 ft samples.

VIN 002 0744

TABLE 6-3

BACKGROUND CONCENTRATIONS IN SOIL AND SURFACE WATER FOR METALS FOUND IN THE MAURICE RIVER

METAL	TYPICAL RANGE IN SANDY SOIL IN THE U.S[a] (mg/kg)	TYPICAL RANGE IN SURFACE WATER (ug/l)
Al	0.45 - 10%[b]	
As	0.1 - 30	<10[d]
Ba	20 - 1500	
Cr	3 - 200	1-30[e]
Cd	0.01 - 3.5[c]	<1 [d]
Hg	0.01 - 0.54	
Mn	7 - 2000	
Ni	5 - 70	
Pb	<10-70	5-30[d]
Sb	0.05 - 4.0[b]	
Zn	<15 - 164	

a. From Kabata-Pendias, A., and H. Pendias, 1984. Trace Elements in Soils and Plants. CRC Press, Inc., Boca Raton, Florida.

b. Values are from a range of soil types, not just sandy soils. From Kabota-Pendias and Pendias 1984.

c. From NJDEP Files. Toth, S. Unpublished New Jersey Soils Data. Cook College, Rutgers University 1970's.

d. From ATSDR Toxicological Profiles 1987.

e. From Health Assessment Document for Chromium EPA, 1984.

VIN 002 0745

undetected to 0.5 ug/l in the upper Maurice River (Table 6-2). Although these measured concentrations were below the MCL for mercury of 2 ug/l, they were above Clean Water Act Ambient Water Quality Criteria (AWQC) for ingestion of aquatic organisms and drinking water of 0.144 ug/l (Table 6-4). Since mercury can bioaccumulate and was used by ViChem in manufacturing herbicides, it was selected in both sediment and surface water matrices as an indicator chemical.

Lead was another metal chosen as an indicator chemical. The background value for lead in U.S. soil ranges from <10 - 70 mg/kg (Kabota-Pendias and Pendias, 1984). Lead concentrations of 4 sediment samples from the Blackwater Branch exceeded this range (Table 6-1). Their values were 314 mg/kg, 223 mg/kg, 337 mg/kg and 153 mg/kg. Although these sediment samples were collected from stations upgradient from the ViChem site, and lead was not known to be used at the plant, lead was assessed as a contaminant of concern for sediment in the Blackwater Branch because of its high toxicity (see Appendix H).

The concentration of lead in all surface water samples ranged from undetected to 29.4 ug/l. Both the MCL and the AWQC for lead are 50 ug/l. In addition, the background level of lead of surface waters in the US ranges from 5-30 ug/l (USEPA, 1986a). Thus, the concentration of lead in the Maurice River was within background levels. Therefore, lead was not selected as an indicator chemical in water.

Other inorganic compounds such as chromium and cadmium were also detected in the Maurice River. They were not considered contaminants of concern because 1) they were not found in elevated concentrations relative to natural background levels, 2) they were below the Clean Water Act AWQC Criteria and the Safe Drinking Water Act MCLs. Although cadmium was used at the ViChem Plant and was detected in matrices onsite, it was not found in sediment and water samples downgradient from the plant.

6.1.1.1.2 Organics

Organic analyses of the sediment and surface water samples included volatile organics, semi-volatiles, pesticides and PCBs. In surface water, the only organics detected were trichloroethylene and trans-1,2-dichloroethene, with maximum concentrations of 11 ug/l and 9 ug/l, respectively (both at station ER-8 in upper Maurice River). Trichloroethylene (TCE) is a probable human carcinogen, and it was used by ViChem. Thus, it was selected as an indicator chemical in water. Trans-1,2-dichloroethene is a degradation product of trichloroethylene (Vogel & McCarthy, 1985) and has no toxicity data. Therefore, it was not evaluated.

VIN 002 0746

TABLE 6-4

WATER QUALITY REGULATORY CRITERIA FOR CONTAMINANTS IN BLACKWATER BRANCH AND UPPER MAURICE RIVER

Chemical	Safe Drinking Water Act MCLs (ug/l)	Clean Water Act Criteria for Human Health: Aquatic Organisms and Drinking Water (ug/l)	Clean Water Act Criteria for Human Health: Adjusted for Drinking Water Only (ug/l)	New Jersey Water Standard Surface Water Quality for FW2 Water (ug/l)	Black Water Branch[2]: Sediment Range[4] (mg/kg) (Median)	Black Water Branch[2]: Surface Water Range[3] (ug/l)(Median)	Upper Maurice River[2]: Sediment Range[4] (mg/kg) (Median)	Upper Maurice River[2]: Surface Water Range[3] (ug/l)(Median
Arsenic	50	0(2.2 ng/l)	(25 ng/l)	50	7.7-3760(229)	61-6200(361.5)	1.0-922(70.8)	102-150(124)
Mercury	2	144 ng/l	10	2	U	U-0.8 (0.7)	U-1.1(0.55)	U-0.5(0.3)
Lead	50	50	50	50	23.3	U-7.5	1.95-33(22)	2.3-4.0(3.75
Chromium	50	50(Cr V)	50(Cr V)	50	N.D.	U-9.7	5.2-17(9.0)	U-13.0 (9.3)
Trichloroethylene	5	0(2.7)	0(2.8)		U	U	U	2.0-11.0(3.0

U = Undected
ND - No Data

1. The criterion value, which is zero for all potential carcinogens, is listed for all chemicals in the Table. The concentration value given in parenthesis for potential carcinogens corresponds to a risk of 10^{-6}.
2. Based on Ebasco Phase II samples
3. Excludes control samples.
4. Based on 0-1 ft samples

VIN 002 0747

In sediment samples, the only volatile organic compound detected at significant levels was toluene, with a maximum concentration of 260 ug/kg. However, the chronic acceptable oral intake for toluene is 0.3 mg/kg/day (USEPA, 1986b). For a child with a body weight of 17 kg, 5.1 mg of toluene may be ingested per day. With sediment concentrations of toluene at 260 ug/kg, over 19 kg of toluene-contaminated sediment would have to be ingested per day to reach this level. As a result of this preliminary calculation, toluene was not considered further as an indicator chemical.

Among the semi-volatiles, polynuclear aromatic hydrocarbons (PAHs) including chrysene, acenaphthene, fluorene, anthracene, pyrene and fluoranthrene were detected in 3 control and 1 downgradient sample at low levels. These PAH compounds are common constituents of coal tar and asphalt. Their presence in sediment at station ER-10A (the only downgradient station where PAHs were detected) was not surprising since a new bridge was being constructed at that location during Phase II sampling efforts. Moreover, the background level of PAHs in soil has been reported to be between 4 and 13 mg/kg from relatively rural areas of the eastern United States (Blumer et al. 1977). None of these sediment samples had total PAH levels exceeding this range. Since none of these detected compounds were used at the ViChem site, they were probably not site-related contaminants and were not selected as indicator chemicals.

Lastly, four pesticides were detected in one or more sediment samples. These included gamma-BHC (Lindane) in 1 upgradient sample in the Blackwater Branch, DDD, DDT in a control sample, and Endosulfan sulfate in one downgradient sample in the upper Maurice River (Table 6-2). Although the presence of these compounds are probably related to localized agricultural use, unrelated to site operation, DDT, gamma BHC and Endosulfan sulfate were evaluated in the sediment ingestion pathway because of their persistence and high toxicity. DDD is a degradation product of DDT with no health criteria and was therefore not evaluated.

In summary, the chemical contaminants of concern which were addressed in the risk assessment for the Blackwater Branch and the upper Maurice River were as follows:

- Blackwater Branch

Sediment	Surface Water
Arsenic	Arsenic
Mercury	Mercury
Lead	
Gamma-BHC	

VIN 002 0748

- Upper Maurice River

Sediment	Surface Water	Biota
Arsenic	Arsenic	Arsenic
Mercury	Mercury	
Endosulfan Sulfate	TCE	
DDT		

6.1.1.2 Exposure Assessment

Based on the environmental features of the Maurice River area, along with the possible activities of receptor populations, the following exposure pathways were initially considered potentially significant.

- Ingestion of soil/stream sediment
- Ingestion of stream water
- Direct contact with soil/stream sediment
- Direct contact with stream water
- Ingestion of fish
- Ingestion of blueberries
- Ingestion of vegetables and/or forage crops
- Inhalation of soil/former stream sediment

These pathways were screened and all but three of them (direct contact with soil/stream sediment, ingestion of blueberries, and ingestion of vegetable/forage crops) were retained for quantitative evaluation. The rationale for selecting the evaluated pathways follows.

6.1.1.2.1 Ingestion of Soil/Stream Sediment

The Maurice River above Union Lake is frequented by local residents for activities such as swimming, fishing and wading. A public beach (Almond Road Beach) is located at Station ER-7 in the upper Maurice River. Other exposure points also exist as there are residences along the river. During the sampling period, children were observed swimming and playing by the water's edge. While intentional ingestion of stream sediment is unlikely, people, especially children, may contact contaminated soil/stream sediment and subsequently ingest a portion of the soil/stream sediment while eating, playing, or swimming. In contrast, the Blackwater Branch does not appear to be used extensively for recreation since the water level is not deep (ranging from 1 to less than 4 feet) and it is generally not as accessible as the Maurice River. Nevertheless, local children can still wade and play in the stream. During play, the bottom sediment can be easily contacted directly or stirred up, deposited on the body and subsequently ingested. In addition, chemical analysis of the former flood area in Blackwater Branch indicated that this area is probably covered with arsenic-contaminated former stream sediment. This area has been

VIN 002 0749

drained since the removal of the beaver dam which caused the flooding. Local residents, especially children, can come in contact with these contaminated sediments while playing in the area. Therefore, the ingestion of soil/stream sediment was evaluated as an exposure pathway for both the Blackwater Branch and the upper Maurice River.

6.1.1.2.2 Ingestion of Stream Water

The stream water in the upper Maurice River and the Blackwater Branch is not used for the drinking water supply. However, the inadvertent ingestion of stream water during swimming and playing activities cannot be ignored. Since arsenic and other indicator chemicals have been detected in the water in the Blackwater Branch and the Maurice River, the accidental ingestion of stream water was considered a potentially significant exposure route.

6.1.1.2.3 Direct Contact with Soil/Stream Sediment

Due to the low water levels in the Blackwater Branch and the upper Maurice River, people can come into direct contact with bottom sediments while swimming, wading, fishing and playing in the stream. In addition, the sediment can be resuspended in water and deposited on the body surface. This direct contact exposure pathway was not evaluated in the risk assessment for several reasons. First, it is not likely that the circumstances of exposure would lend themselves to efficient uptake of pollutants through the skin. Overall deposition rates are likely to be low and deposited sediments are likely to be washed off the skin by re-immersion. Also, arsenic and the other metals are not likely to be adsorbed to an appreciable extent through the skin. Dermal adsorption of pollutants, on the whole, are not likely to be significant compared to the ingestion of sediments, which is retained for quantitative analysis.

6.1.1.2.4 Direct Contact with Stream Water

As stated previously, the upper Maurice River is used for swimming, wading, and fishing activities. Thus, the potential exists for people to come into direct contact with the stream water during these recreational activities. Since contaminants in the water can be absorbed through the skin, this pathway was evaluated in the risk assessment.

6.1.1.2.5 Ingestion of Fish

Local residents commonly fish in the upper Maurice River. Since arsenic was detected in fish tissue from the upper Maurice River, the ingestion of fish was considered an important pathway and was evaluated in the risk assessment.

VIN 002 0750

6.1.1.2.6 Ingestion of Blueberries

Blueberries are widespread in the Maurice River area. While the soil in the river area is not believed to be contaminated, it is possible for those plants growing by the river to transfer arsenic from contaminated sediments to the fruits through their roots.

However, it is not believed that this pathway represents a major route of exposure, for several reasons. First, only a relatively small proportion of the blueberries growing in the area at any one time would be expected to be growing in soil derived from contaminated sediment. Thus only a small proportion of any individual's total intake of blueberries would be expected to come from contaminated areas. Second, arsenic uptake in plants tends to be relatively inefficient, and what little is taken up tends to accumulate in the roots. Baes, et. al. (1984) estimated an arsenic uptake factor of 6×10^{-3} for non-vegetative growth in plants. Therefore, this exposure pathway was not quantitatively carried through the risk assessment.

6.1.1.2.7 Ingestion of Vegetables and/or Forage Crops

There is no known use of the stream water in the Blackwater Branch and the upper Maurice River for irrigation purposes. The soil in the river area is not believed to be contaminated and was not analyzed. Therefore, exposure from the ingestion of vegetables and/or forage crops was not assessed.

6.1.1.2.8 Inhalation of Soil/Former Stream Sediment

As mentioned earlier, the former flood region in the Blackwater Branch is probably covered by arsenic-contaminated sediment. At present, this area is wet and covered with dead vegetation. Wind erosion of contaminated soil/former sediment is not likely to occur. However, during drought periods, these surficial soils may be dried, become entrained in the air, and inhaled by people. Since inhalation exposure to dust containing inorganic arsenic has been associated with an increased risk of lung cancer (USEPA, 1984), the inhalation of soil/former stream sediment was evaluated as a possible exposure pathway.

6.1.1.3 Toxicity Assessment

Toxicological evaluations of the indicator chemicals are summarized in Appendix H. For the purposes of a risk assessment at a CERCLA site, toxic effects of chemicals can be divided into two general classes. The first class of effects is non-carcinogenic, that is, any adverse health effect not associated with increased risks of cancer in an exposed population. Non-carcinogenic impacts can affect a wide variety of organ systems, through a large number of chemical mechanisms, but they have the general property that there is a range of doses above zero and below a "threshold" level, in which adverse effects are unlikely to occur in the exposed population. This

VIN 002 0751

threshold dose level, which can be defined only approximately for a given chemical substance, population, and duration of exposure, provides the basis for defining "acceptable" dose levels (see below) and exposures for non-carcinogic effects.

The other class of toxic effects, carcinogenic effects, involve the development of an increased risk of cancer among a population exposed to a particular agent. On mechanistic grounds (supported to some extent by mathematical modeling and low-dose studies), it is generally assumed that the magnitude of the carcinogenic effect (the increased risk of cancer in an exposed population) is a linear function of the dose of carcinogenic exposures received by the population. There is thus assumed to be no "threshold", or acceptable dose of carcinogens. Instead, the carcinogenic activity of a substance is generally characterized in terms of a slope parameter (a carcinogenic potency factor or CPF, see below) which defines the relationships between dose and incremental risks for the exposed population.

Acceptable Intakes

Acceptable intake values for non-carcinogenic effects are derived based on the amount of a substance that is not expected to produce adverse non-carcinogenic health effects to the general population (including sensitive subgroups). Acceptable intake values may be defined for acute exposures, for subchronic exposures, and for long-term chronic exposures. Generally, exposure levels and durations at hazardous waste sites are such that the acceptable intakes for chronic exposure (AIC) or subchronic exposure (AIS) are the most relevant measures of toxicity. Most AIS values are based on subchronic (10-90 day) animal studies, although some are derived from human exposure data. The highest subchronic exposure level not causing adverse effects, or No-Observed-Adverse-Effect-Level (NOAEL), is determined from all valid animal studies in the literature. The NOAEL is then divided by an appropriate uncertainty factor (usually 100) to give the AIS. Similarly, AIC values are based on long-term animal, or, occasionally, human epidemiologic studies. The highest chronic exposure level not causing an adverse effect (NOAEL) is also determined from all appropriate studies in the literature. The NOAEL is then divided by an uncertainty factor to give the AIC.

For assessing the health impact of non-carcinogens, AICs are compared to route-specific intake rates of the chemical in question. If the ratio of the average daily dose to the AIC or AIS exceeds 1.0 for the time period of exposure, this provides an indication that the exposed population may experience adverse health impacts. If the ratio is less than 1.0, then it is assumed that no adverse health effects will occur. For exposures where the ratio of pollutant dose to the acceptable intake is in the range of 1.0, risk results should be interpreted with caution, owing to the uncertainties associated with the procedures used to define acceptable intakes, and associated with the assessment of exposure and dose. Because of

VIN 002 0752

the uncertainty factors incorporated in definitions of acceptable intakes, it is generally believed that they are protective of human health for most populations and exposure circumstances, and that a dose to acceptable intake ratio of approximately 1.0 should be considered more nearly an estimate of the maximum "safe" dose than an indication that adverse effects will definitely occur in the exposed populations.

Values for acceptable intakes (AIC, AIS, long-term RfD) of non-carcinogenic pollutants used in this risk assessment have been developed by EPA for all of the non-carconigenic indicator chemicals selected for quantitative assessment. These values are summarized in Table 6-5.

In assessing non-carcinogenic risks from exposure to more than one chemical, this assessment follows EPA Guidance for the Assessment of Health Effects Due to Chemical Mixtures (cited in OSWER Directive 9285.4-1). The approach employed is to sum the ratios of the daily intakes for the chemicals in question to their respective acceptable intakes. The sum of these ratios is called a Hazard Index, and it is generally interpreted similiarly to the individual dose/acceptable intake ratios. That is, a value exceeding 1.0 is considered an indication that adverse health impacts may be experienced by the population exposed to the mixture of chemicals being assessed. This approach assumes (in the absence of information to the contrary) the additivity of the effects of the individual chemicals. In instances where interactions between the toxic effects of specific chemicals are known to occur this assumption breaks down. EPA guidance also suggests that, if a Hazard Index of greater than 1.0 is encountered, the relative contributions of the individual chemicals to the hazard index be examined. If the ratio of dose to acceptable intake exceeds 1.0 for individual chemicals in the mixture, it should be assumed that exposures to these chemicals are of concern, just as they would be if no other exposures were occurring. If no individual chemical has a dose/acceptable intake ratio greater than 1.0, but the hazard index for all the chemicals together is above 1.0, then EPA guidelines suggest that the chemicals be grouped according to the target organs affected, and that the Hazard Index be recalculated separately for chemicals affecting each specific organ or organ system.

Carcinogenic Potency Factors

Carcinogenic risks are estimates of the increase in lifetime cancer risks that would be experienced in a population if it is given a specific exposure to one or more carcinogenic chemicals. The Carcinogenic Potency Factor (CPF) for a compound is the upper 95-percent confidence limit on the slope of the dose-response curve of the compound. Carcinogenic potency factors are used to estimate potential cancer risks by multiplying the chronic daily intake of a compound (CDI) by the CPF. CPFs are expressed as the lifetime cancer risk per mg of

VIN 002 0753

TABLE 6-5

CRITICAL TOXICITY VALUES FOR CONTAMINANTS IN BLACKWATER BRANCH AND UPPER MAURICE RIVER[1]

Chemical	Acceptable Intake Subchronic (AIS) (mg/kg/day)	Acceptable Intake Chronic (AIC) (mg/kg/day)	Source	Cancer Potency Factor $(mg/kg/day)^{-1}$	Source	EPA Weight of Evidence[3]
A. Oral Route						
Arsenic	-	-		1.80E + 00[2]	CAG	A
Lead	-	1.40E-03	HEA			
Mercury (Inorganic)	1.4E-03	1.4E-03	RfD			
Mercury (methyl)	2.80E-04	3.00E-04	RfD			
Endosulfan	-	5.00×10^{-5}	IRIS			
Trichloroethylene	-	-		1.10E-02	HEA	B2
DDT	-	5.00E-04	RfD	3.4-01	IRIS	B2
Gamma-BHC (Lindane)	-	3.00E-04	RfD			
B. Inhalation Route						
Arsenic	-	-		1.50E+01	CAG	A
Lead	-	4.30E-04	HEA			
Mercury (Inorganic)	5.10E-04	5.10E-05	HEA			
Mercury (methyl)	1.00E-04	1.00E-04	HEA			
Trichloroethylene	-	-		4.60E-03	HEA	B2

1. Taken from USEPA, OSWER Dir 9285. 4-1, update Nov 16, 1987.

2. CPF for arsenic, oral route, is based on applying a multistage model to the cancer initiation rather than using the more conservative absolute risk linear model.

3. Alphanumerics represent EPA weight of evidence classifications, defined as follows:

   Group A - Human Carcinogen. Sufficient evidence from epidemiologic studies to support a casual association between exposure and cancer.

   Group B - Probable Human Carcinogen. Limited evidence of carcinogenicity in humans from epidemiologic studies.

   Group C - Probable Human Carcinogen. Sufficient evidence of carcinogenicity in animals, inadequate evidence of carcinogenicity in humans.

RfD = Agency-wide reference dose value, developed by an inter-office work group chaired by the Office of Research and Development, USEPA, Washington, D.C., 1986.
HEA = Health Effects Assessment Document, prepared by the Environmental Criteria and Assessment Office, USEPA, Cincinnati, Ohio, 1985. (Updated in May 1986).

IRIS = USEPA Integrated Risk Information Systems
CAG = Carcinogen Assessment Group, EPA.

7999b

VIN 002 0754

the compound per kg body weight per day. The carcinogenic potency factors for the indicator chemicals, which are derived by EPA's Carcinogen Assessment Group, are summarized in Table 6-5.

6.1.1.3.1 Dose-Response Parameters for Indicator Chemicals

Arsenic

Arsenic, the major contaminant in Maurice River, is carcinogenic to humans by both oral and inhalation routes. Chronic oral exposure to inorganic arsenic is associated with an increased risk of skin cancer. Arsenic-induced skin cancers differ from those of ultraviolet light etiology by occurring on areas generally not exposed to sunlight, e.g. palms and soles, and occurring as multiple lesions (Pershagen and Vahter, 1979). These cancers appear to be of two histopathological types: squamous carcinomas in the keratotic areas and basal cell carcinomas (Neubarier, 1947).

The data that was used to derive the CPF for arsenic via the oral route was collected by Tseng et al., (1968). In this study, the authors surveyed the occurrence of skin cancer among a stable population of 40,421 individuals in a rural area in Taiwan where arsenic levels in deep wells used for drinking water ranged from 0.001 to 1.82 mg/l, with average levels of approximately 0.4 to 0.6 mg/l. Recent analyses of water samples from 2 wells in the Yenshei Province of Taiwan (Irgolic, 1982) showed that the water contained inorganic arsenic (arsenite (+3), 0.024 mg/l; arsenate (+5) 0.9 mg/l) and no organic arsenicals. Therefore, the people could have been exposed to both trivalent and pentavalent arsenic compounds. The data from Tseng's study has been reinterpreted recently, using a multistage carcinogenesis model (USEPA, 1987). The CPF for arsenic via the oral route estimated by this model is 1.8 $(mg/kg/day)^{-1}$ (Table 6-5).

Inhaled arsenic also increases the risk of lung cancer. This has been observed mostly in humans exposed to high levels of airborne arsenic in or around smelters, but excess respiratory cancers have also been observed in areas near pesticide plants (Matanoski et al. 1981). The CPF for arsenic via the inhalation route was derived from 5 respiratory cancer epidemiological studies on smelter workers and was estimated to be 15 $(mg/kg/day)^{-1}$ (USEPA, 1984). In this analysis, the oral CPF will be used to assess risks for all routes except inhalation of sediment.

Chronic and subchronic exposures to arsenic has also resulted in a variety of non-cancer health effects in individuals of all age groups. These effects are discussed in full detail in Subsection 6.1.1.4.1.

VIN 002 0755

Gamma-BHC (Lindane)

Gamma-BHC is a persistent chlorinated pesticide which has been found in sediment in the Blackwater Branch. It is a neurotoxin, causing central nervous system stimulation whose symptoms may include vomiting, tremor, fainting, muscle spasms, convulsions, coma, respiratory failure and death after acute exposure to humans. The estimated human LD_{50} is 50-500 mg/kg. EPA has defined a reference dose (RfD) of 3.0×10^{-4} mg/kg/day to be protective against the chronic non-carcinogenic effects of exposure.

Lead

Elevated levels of lead (relative to regional background values) were also found in sediments in the Blackwater Branch. Inorganic lead compounds may enter the body either through the gastrointestinal tract after ingesting lead-containing sediment or particulates suspended in air. Absorption efficiencies for lead in sediment or in food are quite variable, ranging from an average of about 8% in adults to 50% in children. Depending upon the size of the particles involved, between 30-50% of inhaled particulate lead is absorbed into the body.

High exposures to lead, usually in the occupational environment, can result in severe central nervous system depression, lead-related encephalopathy and death. Chronic, low level exposure to lead results in a wide variety of clinical effects, including effects on hematopoiesis, anemia, altered energy metabolism, calcium homeostasis, and neurobehavioral and developmental disorders. Of major concern are the neurobehavioral and developmental effects in children (slowed physical and intellectual development), which appear to be induced at exposures lower than those required to produce effects in adults. EPA has defined an acceptable chronic dose level of 1.40×10^{-3} mg/kg/day for oral intake and 4.3×10^{-4} mg/kg/day for inhalation exposures. The MCL for lead is 50 ug/l.

Mercury

Mercury is a heavy metal pollutant found at levels exceeding background in both sediment and surface water in the Blackwater Branch and upper Maurice River. Mercury commonly exists in the environment in several forms. Inorganic mercury salts vary in their solubility, with mercuric (+2) salts being much more soluble than mercurous (+1) salts. Inorganic mercury may also form soluble organic complexes in the environment, and inorganic mercury is easily metabolized to methylmercury compounds by soil and sediment bacteria. Both the organic and inorganic forms of mercury are highly toxic, with the primary target organ being the central nervous system and the kidney. Generally, organic mercury compounds are more neurotoxic than inorganic compounds, perhaps due in part to their more rapid passage across the

VIN 002 0756

blood-brain barrier. Inorganic mercury, especially the (+2) salts, are more toxic to the kidney than organic mercury salts, and EPA's RfD for inorganic mercury (1.4×10^{-3} mg/kg/day) is based on the results of an animal study of kidney toxicity. The RfD for methylmercury is 3.0×10^{-4} mg/kg/day, based on a human study of the central nervous system effects (ataxia, paresthesia). EPA has defined chronic acceptable intake values via the inhalation route for inorganic and organic mercury of 5.1×10^{-5} mg/kg/day and 1.0×10^{-4} mg/kg/day, respectively. Both the organic and inorganic forms of mercury have also been demonstrated to be teratogenic in animal systems.

Trichloroethylene

Trichloroethylene, TCE is a volatile chlorinated organic solvent, which has been found in several samples from the upper Maurice River. TCE is quite volatile and consequently has a short half-life in surface water. It degrades readily in the atmosphere, and may be metabolized by soil organisms to form vinyl chloride and other metabolites.

Chronic exposure to high levels of TCE has been found to produce adverse effects on the liver, kidney and central nervous system of exposed animals. TCE has been found to induce liver tumors in mice and the EPA has categorized TCE as a B2 (probable human) carcinogen. CPFs of 1.1×10^{-2} and 4.6×10^{-3} $(mg/kg/day)^{-1}$ have been defined for oral and inhalation exposures, respectively.

Endosulfan Sulfate

Endosulfan sulfate is one of a series of closely related pesticide compounds that was found in one sediment sample from the upper Maurice River. The major target organ for the toxic activity of endosulfan is the central nervous system. EPA's Integrated Risk Information System (IRIS) data base reports an acceptable intake value of 5.00×10^{-5} mg/kg/day by the ingestion route.

6.1.1.4 Exposure Model and Risk Assessment Results

The next step in the public health risk assessment procedure was to determine the amount of human exposure to the selected contaminants via the various pathways described in Section 6.1.1.2. This step was necessary since applicable or relevant and appropriate requirements (ARAR's) do not exist for most of the exposure pathways. In addition, calculating the total exposure via several pathways requires the site-specific evaluation of each medium or matrix.

VIN 002 0757

Quantitative exposure models which reflect the transport of contaminants from the source to the receptors were developed. Such models are especially useful to estimate chronic human exposure expressed in terms of intake. The pathways are expressed as a series of equations describing a site-specific intake and route-specific intake for a particular concentration of an indicator chemical. Two sets of pathway models were derived: one to estimate the maximum or worst case exposure of receptors to a contaminant, and one to estimate a more realistic or most probable exposure. By comparing the results of the two sets of models, the range of risks that exposed populations may experience can be determined. The method is general and is described in detail in Subsection 6.1.1.4.1 for the exposure of a person to sediment via the sediment ingestion pathway. Summaries of the methods used for the other pathways are given in subsequent sections. Table 6-6 presents the equations used to calculate the exposure via the various pathways, while Table 6-7 presents the exposure parameters for the Blackwater Branch and upper Maurice River.

6.1.1.4.1 Ingestion of Soil/Stream Sediment

Because recreational use of the upper Maurice River and the Blackwater Branch is known to occur, the incidental ingestion of river sediment is a potential exposure pathway. The following scenario of recreational use was used to determine site-specific intake rates for sediment ingestion. The major receptor via these pathways are the local children, who spend their recreational time at the river swimming, wading, fishing and playing. In the worst case assumptions, these activities are assumed to occur for 5 months per year (April-September), 4 days a week, for a total of 80 days per year. Exposures may occur frequently during peak months of the summer, but less frequently early and late in the swimming season. This number of days of exposure, although conservative, is realistic considering there are residences by the river. Adults and infants are assumed to spend less time in the river, 2 days a week, for a total of 40 days per year. In the most probable case assumption, adults and infants are assumed to spend a total of 7 days per year in the river, applying the frequency of water use for swimming recommended in EPA's Superfund Exposure Assessment Manual (USEPA, 1986). Children are assumed to spend more time in the river, for a total of 40 days per year. These parameters are summarized in Table 6-7.

The site-specific contaminant intake rate from soil/sediment ingestion is calculated from sediment contaminant concentrations, soil ingestion rate, the fraction of year a person is exposed to the river, the fraction of the ingested compound that is absorbed from the gut, as well as the body weight of the exposed individual. The equation is shown in Table 6-6. It is assumed that the receptors have a specific incidental soil ingestion rate that is related to their age and behavior.

VIN 002 0758

TABLE 6-6

SUMMARY OF EQUATIONS USED TO
CALCULATE CHRONIC DAILY INTAKES FOR RIVER AREAS[a]

Equation	Expression	
7-1	Sediment Ingestion	
	CDI =	$\frac{(SC)(IRS)\ (\%ABS)\ (EVT)\ (EXP)}{(BW)\ (365\ days)(70\ years)\ (1000)}$
7-2	Lake Water Ingestion	
	CDI =	$\frac{(WC)\ (WI)(\%ABS)\ (EVT)\ (EXP)}{(BW)(365\ days)(70\ years)}$
7-3	Fish Ingestion	
	CDI =	$\frac{(FC)(FI)(\%ABS)(EXP)}{(BW)(70\ years)}$
7-4	Fish Ingestion (Bioconcentration)	
	CDI=	$\frac{(WC)(BCF)\ (FI)\ (\%\ ABS)}{(BW)}$
7-5	Lake Water Dermal Absorption	
	CDI =	$\frac{(WC)(Flux)(TD)(\%ABS)(EVT)(EXP)(SA)}{(BW)(365\ days)(70\ years)}$
7-6	Sediment Inhalation	
	CDI =	$\frac{(SC)(SAA)(\%ABS)(BR)(EXP)(FC)(10^{-6})}{(BW)(70\ years)}$

a To calculate CDIs for carcinogens, CDI is calculated for each age group, and the lifetime weighted-average CDI is used to assess cancer risks. For noncarcinogens, the CDI_t for the most heavily exposed age group is compared to the acceptable daily intake for the pollutant of concern.

Definitions

1. CDI = Chronic Daily Intake (mg/kg/day)
2. SC = Soil Concentration (mg/kg)
3. IRS = Soil Ingestion Rate (g/day for age group)
4. % ABS = Percent Take up by Body (for age group)
5. EVT = # of Events per year (for age group)
6. EXP = Years of Exposure (for age group)

7999b

VIN 002 0759

SUMMARY OF EQUATIONS USED TO
CALCULATE CHRONIC DAILY INTAKES FOR RIVER AREAS(a)

7. BW = Body Weight (kg for age group)
8. WC = Water Concentration (mg/l)
9. WI = Water Ingested (l/day)
10. FC = Fish Concentration (mg/kg)
11. FI = Fish Ingestion Rate (kg/day)
12. BCF = Bioconcentration Factor for Contaminent (l/kg)
13. Flux = Flux Rate of Water Across Skin ($mg/cm^2/hr$)
14. D = Time of Exposure (hours)
15. SA = Body Surface Area (cm^2)
16. SAA = Suspended Sediment Concentration (mg/m^3)
17. BR = Breathing Rate (m^3/day)
18. FC = Fraction of Inhaled Particulate that came from Blackwater Branch

VIN 002 0760

TABLE 6-7

PARAMETERS FOR RECREATIONAL EXPOSURES TO BLACKWATER BRANCH AND MAURICE RIVER WATER AND SEDIMENT

Physical Parameters

Population	Age	Body Weight kg	Surface Area cm^2
Infant	0-2	8.95	2.00E+03
Young Child	2-6	17	6.80E+03
Child	6-10	28.4	1.02E+04
Child	11-14	45.3	1.15E+04
Child	15-18	59.7	1.75E+04
Adults	18-70	70	2.0E+04

Site Exposure Parameters

Population	Days at River/Yr		Hours/day at River		Years Exposure	Soil Ingestion Rate g/day	
	Worst Case	Most Probable Case	Worst Case	Most Probable Case		Worst Cast	Most Probable Case
Infant (0-2)	40	7	4	2.6	2	1.00E-01	5.00E-02
Young Child (2-6)	80	40	4	2.6	5	2.00E-01	8.00E-02
Child (6-10)	80	40	4	2.6	5	1.00E-01	5.00E-02
Child (11-14)	80	40	4	2.6	3	5.00E-02	1.00E-02
Child (15-18)	80	40	4	2.6	3	5.00E-02	1.00E-02
Adults (18-70)	40	7	4	2.6	52	5.00E-02	1.00E-02

Water Ingested = 100 ml (2 mouthfuls/day) Worst case; 50 ml (1 mouthful/day) most probable case

Water flux through skin = 0.5 $mg/cm^2/hr$

%ABS for arsenic (ingestion) = 100%
(inhalation) = 30% (most probable case), 80% (worst case)
(dermal contact from water) = 6.0% adults, 12% child (up to 10 yers)

% ABS for mercury (inorganic) = 15%
(methyl) = 100 %

% ABS for lead = 50% for children
15% for adult

% ABS for DDT = 100%

% ABS for gamma BHT = 35%

% ABS for Endosulfan sulfate = 100%

% ABS for TCE = 100%

BCF for mercury (inorganic) = 5500 l/kg

Average fish ingestion for US = 6.5 g/day above age 6 (most probable case)
= 37 g/day above age 6 and 6.5 g/day below age 6 (worst case).

SAA = 0.17 mg/m^3 (air dust cone)

BR = 37.7 m^3/day (worst case); 12.8 m^3/day (most probable case) (breathing rate)

FC = 10% (fraction of suspended particulate coming from Blackwater Branch)

Note: Inhalation evaluated for a 5 year draught, therefore exp. = 5 years

7999b

VIN 002 0761

According to USEPA (1986), a young child (1.5 to 4 years old) typically ingests 0.1 to 0.2g of soil per day. Older children and adults ingest less. The soil ingestion rates for the various age groups are presented in Table 6-7. In this mathematical model, the absorption of ingested arsenic from the gastrointestinal tract is assumed to be 100%. This assumption is based on reports using human subjects that soluble inorganic arsenic is almost totally absorbed from the gastrointestinal tract (USEPA, 1984). The bioavailability of arsenic adsorbed to ingested sediment may be less. However, the stomach is acidic (pH of 1.5 to 2.5). Much of the arsenic should be freed from the sediment. Therefore, the absorption of ingested arsenic bound to sediment is assumed to be 100%, although this is probably conservative.

Assumed absorption from the gastrointestinal (GI) tract for other indicator chemicals were as follows: mercury, 15%, (the mercury bound to sediment is probably in inorganic form, and the absorption of inorganic mercury from GI tract is about 15%) USEPA, (1980); lead, 15% for adults (Chamberlain et al., 1978) and 50% for children (Hammond, 1982); endosulfan sulfate, 100%; DDT, 100% (USEPA, 1980b); and gamma BHC, 35% (Koransky et al., 1963).

To assess risks for carcinogenic indicator chemicals, the lifetime CDI, calculated as a weighted average over all the age group categories identified in Table 6-7, was multiplied by the CPFs for the chemicals to give a lifetime incremental cancer risk. This is the "integrated lifetime model" (see Appendix E). For non-carcinogens, worst case CDIs were calculated for each age group and the highest value (for sediment ingestion, 2-6 years-old) was compared to the RfD or AIC for specific contaminants. In addition, the CDI, averaged over the summer swimming season, was compared to the subchronic acceptable intakes (AIS) where these values were available for specific indicator chemicals.

The actual calculations of CDI and associated carcinogenic risks for the worst case sediment ingestion pathways in the Blackwater Branch and upper Maurice River are shown in Table E-1 and E-2 of Appendix E. Arsenic concentrations in the surface sediment (0-1 ft) were used in the calculations, since surficial sediments are most likely to be ingested.

For a maximum arsenic concentration of 3760 mg/kg in the Blackwater Branch and worst case exposure assumptions, the site-specific CDI of arsenic was calculated to be 1.32×10^{-3} mg/kg/day, and the associated cancer risk was 2×10^{-3}. For the maximum arsenic concentration of 922 mg/kg in the upper Maurice River, the site-specific CDI was calculated to be 3.23×10^{-4} mg/kg/day, and the associated cancer risk was 5×10^{-4}.

Since the cancer risk for both areas exceeded 1×10^{-6}, the calculations were repeated with more representative (most probable case) arsenic concentrations and exposure conditions.

VIN 002 0762

For the Blackwater Branch, the median arsenic concentration (excluding controls) of 229 mg/kg was used. For the upper Maurice River, the mean arsenic concentration of all surface (0-1 ft) samples at each downgradient station was determined, and the median of these mean concentrations (70.8 mg/kg) was used to calculate a most probable case CDI.

Utilizing the median arsenic concentrations and most probable exposure assumptions, the CDI of arsenic in the Blackwater Branch was 1.32×10^{-5}, with an associated cancer risk of 2×10^{-5}; the CDI of arsenic for the upper Maurice River is 4.07×10^{-6} mg/kg/day, with an associated cancer risk of 6×10^{-6}.

Under the worst-case assumptions, the CDI for the pesticide gamma-BHC associated with sediment ingestion was 2.82×10^{-8} mg/kg/day, which corresponds to a cancer risk of 4×10^{-8} respectively; whereas the CDI for DDT was 1.12×10^{-8} mg/kg/day, which corresponds to a cancer risk of and 4×10^{-9}, respectively.

For the non-carcinogenic contaminant, mercury, detected in the upper Maurice River at a maximum concentration of 1.1 mg/kg, the CDI for the most heavily exposed group (age 2-6) was 4.3×10^{-7} mg/kg/day using worst case exposure assumptions. In the Blackwater Branch, the CDI for the same group for mercury was 6.1×10^{-8} mg/kg/day. These values are about 4 orders of magnitude lower than the chronic acceptable daily intake of 1.4×10^{-3} mg/kg/day. Subchronic doses of mercury, calculated for the summer exposure period, were also at least three orders of magnitude below the acceptable subchronic intakes. For lead, the worst case CDI in the Blackwater Branch is 4.3×10^{-4} mg/kg/day, which is lower than the acceptable daily intake of 1.4×10^{-3} mg/kg/day. For endosulfan, the CDI is 5.9×10^{-8} mg/kg/day, is about 3 orders of magnitude lower than the acceptable intake of 5.0×10^{-5} mg/kg/day.

In addition to carcinogenic effects, the potential acute or subchronic toxic effect of ingesting arsenic-contaminated sediment was also evaluated. Oral intake as low as 20 to 60 ug/kg/day of inorganic arsenic may produce some of the characteristic signs of arsenic poisoning, including gastrointestinal irritation, anemia, neuropathy, vascular lesions, skin lesions, hepatic or renal injury (Tay and Seah, 1975). Lethality may occur at doses of around 600 ug/kg/day or higher (Armstrong et al. 1984). Applying this dose response relationship, a child of 17 kg may have toxic symptoms at arsenic doses of 0.340 to 1 mg/day. Death may occur at about 10.2 mg/day. At the maximum arsenic sediment concentration in Blackwater Branch of 3760 mg/kg, ingesting 90.4 mg of sediment a day could produce adverse health effects. If 2.7 g of such sediment is ingested, more severe effects might occur. As discussed previously, in Subsection 6.1.1.4.1, the estimated soil ingestion rate of young children is about 0.1 to 0.2 g per day. Thus, it is possible

VIN 002 0763

for children to experience adverse acute and subacute health effects if large amounts of very highly contaminated sediments are ingested.

6.1.1.4.2 Ingestion of Stream Water

The site-specific intakes of arsenic from the incidental ingestion of surface water in the Blackwater Branch and the upper Maurice River were also estimated. The mathematical model for stream water ingestion is described in Table 6-6, with the exposure assumptions summarized in Table 6-7. A value of 100 ml (approximately two mouthfuls of water) was selected as representative of the amount of water one might ingest for worst case assumption during a day of swimming, playing and splashing in the river; whereas 50 ml (1 mouthful) was used as the amount of water ingested for the most probable case assumption. The total arsenic concentration in the water was used in the risk assessment, since the total amount of arsenic ingested should include soluble arsenic species in the water, those adsorbed by sediment and organic matter in the water, as well as the insoluble species in suspension.

The actual calculations of arsenic intake via this pathway are shown in Table E-5 to Table E-8 in Appendix E. Using the worst case and most probable case assumptions for the Blackwater Branch results in CDIs of 2.08×10^{-3} and 2.13×10^{-5} mg/kg/day, which correspond to cancer risks of 3×10^{-3} and 3×10^{-5}, respectively. Worst case and most probable exposure assumptions in the upper Maurice River result in CDIs of 5.0×10^{-5} and 7.3×10^{-6} mg/kg/day, which correspond to cancer risks of 8×10^{-5} and 1×10^{-5}, respectively.

For trichloroethylene (TCE), using the maximum concentration of 11 ug/l in upper Maurice River resulted in a worst case CDI of 3.7×10^{-6} mg/kg/day, which corresponds to a cancer risk of 4×10^{-8}.

The total cancer risk from ingestion of water in the upper Maurice River would be the sum of cancer risks from arsenic and TCE via this pathway, assuming the risks are additive. Since the risk due to TCE ingestion is 3 orders of magnitude lower than that of arsenic, the total cancer risk from ingestion of water in the upper Maurice River is essentialy all due to arsenic with a most probable case estimate of 1×10^{-5}, which exceeds the target level of 1×10^{-6}.

In calculating a CDI of mercury from ingestion of stream water, the gastrointestinal (G.I.) absorption factor for methylmercury was used since methylmercury species may be present in the water (see Appendix H). The G.I. absorption factor for methylmercury is 1.0 and is much higher than the value of 0.15 used for inorganic mercury. Using the worst case exposure assumptions and maximum mercury concentrations in the Blackwater Branch and

VIN 002 0764

the upper Maurice River results in CDIs of 1.0×10^{-6} mg/kg/day and 6.4×10^{-7} mg/kg/day, which are far below the acceptable intakes of 1.4×10^{-3} mg/kg/day for inorganic mercury and 3.00×10^{-4} mg/kg/day for methyl mercury.

6.1.1.4.3 Ingestion of Fish

Fishing is a popular recreational activity in the upper Maurice River. The site-specific intake of arsenic from the ingestion of fish was calculated by the equation shown in Table 6-6, using the assumptions shown in Table 6-7. Since children under six ingest very little fish in general, their fish ingestion rate is assumed to be zero under the most probable case scenario. For populations in other age groups, a fish ingestion rate of 6.5 g/day is used. This is an estimate made for an average person in the U.S. (USEPA, 1980c). For the worst case scenario, children under six are assumed to ingest 6.5 g of fish per day, and populations in other age groups are assumed to ingest 37 g of fish per day. This fish ingestion rate is based on studies of sports fishing in contaminated lakes in the Western U.S. From the arsenic concentration measured in fish tissue (0.91 mg/kg), (arsenic was detected in only 1 out of 3 fish) the CDI is calculated to be 8.75×10^{-5} mg/kg/day for the most probable case, and the associated cancer risk is 1×10^{-4} (as shown in Appendix E; Table E-9). For the worst-case scenario, CDI is calculated to be 5.42×10^{-4} mg/kg/day, and the associated cancer risk is 8×10^{-4}.

For comparison purposes, the CDI of arsenic from fish ingestion was also calculated from its bioconcentration factor (44 l/kg) USEPA, 1986b), and concentration in water using the model described in Table 6-6. The value obtained is 5.25×10^{-4} mg/kg/day for the most probable case, which corresponds to a cancer risk of 8×10^{-4}. Thus, the risk obtained is in the same order of magnitude as that obtained by the model shown in Table 6-7.

Since mercury, another indicator chemical in the Maurice River, is known to bioaccumulate in fish, but its concentration in fish tissue was not measured, a site-specific intake of mercury from fish ingestion also can be estimated by the equation presented in Table 6-6. The mathematical model for this pathway utilizes the bioconcentration factor, the contaminant concentration in water, as well as the fish ingestion rate. The bioconcentration factor for inorganic mercury is 5500 l/kg (USEPA, 1986b). Since mercury in fish tissue should be predominantly in the form of methylmercury (Appendix H), the oral absorption factor for methylmercury is used in the human dose calculations. From the maximum mercury concentration in the upper Maurice River of 0.5 ug/l, the worst-case CDI for age 6-10 group is calculated to be 3.6×10^{-3} mg/kg/day, which is 12 times the acceptable intake of 3.00×10^{-4} mg/kg/day for methylmercury compounds. For adults, the worst-case CDI is calculated to be 1.5×10^{-3} mg/kg/day, which is 4.8 times the acceptable intake.

VIN 002 0765

Site-specific intake of TCE in fish ingestion was also estimated using the model in Table 6-6. Using the maximum concentration of 11 ug/l in water, its bioconcentration factor of 10.6 l/kg, and an oral absorption factor of 1.0, the CDI was calculated to be 6.9×10^{-5} mg/kg/day for the worst case assumption, with an associated cancer risk of 8×10^{-7}. This is again about three orders of magnitude below the cancer risk associated with arsenic exposure.

From the calculations performed for this exposure pathway, it can be concluded that risk from ingestion of fish in the upper Maurice River is primarily due to arsenic, and is estimated by most probable case assumptions to be between 1×10^{-4} and 8×10^{-4}, depending upon the exposure models used. However, the form of arsenic in the fish was not analyzed; only the total arsenic was measured. Studies of arsenic speciation in fish indicate that more than 85% of the total arsenic may be in the form of a water-soluble organic arsenic compound, arsenobetaine, (Shinagawa et al, 1983). This substance is easily excreted by humans after ingestion and thus is much less toxic than inorganic arsenic. Studies have shown that oral doses of arsenobetaine as high as 10,000 mg/kg produced no toxic symptoms in mice (Kaise et al, 1985). In the risk assessment calculations presented, it was assumed that all the arsenic in the fish is in the more toxic inorganic form. Thus, the cancer risk calculated for arsenic in the fish is very conservative, and the actual risks may be much lower.

When comparing the arsenic level in fish along the Maurice River with background levels of arsenic in food (see Table 6-8), the detected arsenic concentration of 0.91 mg/kg is in the range of mean values commonly observed in fin fish and shellfish.

6.1.1.4.4 Direct Contact With Stream Water

Direct contact with water in the Maurice River can occur during swimming, wading and other water recreational activities. The contaminants in the stream water can be absorbed through the skin into the bloodstream. The exposure model used to estimate the CDI of contaminants via this pathway was based on the approach recommended in the USEPA Superfund Exposure Assessment Manual (USEPA, 1986b). The equation is presented in Table 6-6, with assumptions listed in Table 6-7. The contaminant intake is estimated based on the flux rate of water through the skin, the duration of exposure, the surface area of exposure, and the dermal absorption factor of the contaminant. The flux rate of water through the skin is assumed to be 0.5 mg/cm^2/hr, as recommended by EPA (USEPA, 1986c). The duration of exposure is assumed to be 2.6 hours per day for the most probable case, applying the recommendation in EPA's Superfund Exposure Assessment Manual (USEPA, 1986). For the worst case scenario, the duration of exposure is assumed to be 4 hours per day. It is assumed that the whole body is immersed in water, although this

VIN 002 0766

TABLE 6-8

ARSENIC LEVELS IN FOODS[a]

Food Group	Arsenic concentrations (mg/kg)[b]	
	Range of mean values	Maximum
Meats, eggs, and milk	0.01-0.03	0.5 (chicken)
Vegetables and fruits	0.01-0.03	0.3 (potato products)
Cereal, nuts, and sugar products	0.01-0.04	0.4 (rice)
Fin fish and shellfish	0.07-1.47	19.1 (fin fish)

a From ATSDR Toxicological Profile for Arsenic, 1987.

b Arsenic levels are reported as concentrations of As_2O_3, but this does not imply that arsenic exists in this form in the food samples.

VIN 002 0767

is probably an overestimate for exposure in the Blackwater Branch. A dermal absorption factor of about 1.8% was derived from studies on arsenic absorption by rat skin (Dutkiewicz, 1977). However, for conservatism, the dermal absorption rate derived (Hawley 1985) for contaminants in general (6% for adult, 12% for children) were used in the risk assessment. This factor was multiplied in the model by the flux of water across the skin to account for a smaller fraction of arsenic passing from the water through the skin and into the bloodstream. A cancer potency factor of 1.8 $(mg/kg/day)^{-1}$, the cancer risks for direct contact with water are 6×10^{-5} and 8×10^{-7} for the worst case and most probable case in the Blackwater Branch; and are 1×10^{-6} and 3×10^{-7} for the worst case and most probable case in the upper Maurice River (Appendix E, Table E-13 through Table E-16).

For TCE, the cancer risk from dermal absorption is 1×10^{-8}, using the worst case mathematical model and assuming all TCE passes through the skin with water. Thus, as was the case with sediment ingestion, over 99% of the total risk from direct contact is due to arsenic exposure. While the worst case cancer risk from direct contact with stream water exceeds the acceptable level of 1×10^{-6} for the Blackwater Branch, risks for the most probable case are below this level for both the Blackwater Branch and the upper Maurice River.

6.1.1.4.5 Inhalation of Soil/Former Stream Sediment

As discussed in Subsection 6.1.1.2.8, chemical analysis of the sediment in the flood region in Blackwater Branch (at station ER-3A) indicates that this area is probably contaminated with arsenic. This area was under water previously but is now exposed since the beaver dam was removed. At present, the area is wet and covered with vegetation. However, during drought periods, these surficial soils may be dried and entrained in air and inhaled by people. In this risk assessment, it is assumed that drought occurs for 5 years out of an individual's life-time. Thus, a simple adult model can be used to calculate the site-specific intake of arsenic via inhalation (see Table 6-6).

For the most probable case, a respiratory volume of 12.8 m^3/ day was used. This corresponds to 16 hours/day exposure (assumed 8 hours per day in a "clean" indoor environment or commuting to unpolluted areas); 90% at "rest" and 10% at moderate activity as defined by EPA's Exposure Assessment Manual. The worst case scenario assumes 24 hours/day exposure; 60% at "rest, 35% at moderate activity and 5% at heavy activity. This corresponds to a heavily exposed individual who lives and works near the expose sediment and has an outdoor job requiring moderate activity.

In the absence of direct measurements of airborne particulate levels, for both worst case and most probable case exposure conditions, it is assumed that the total airborne particulate

VIN 002 0768

level near the river would be 0.017 mg/m^3, corresponding to a representative rural ambient airborne particulate concentration. It is also assumed that about 10% of the dust in the air is from the arsenic contaminated sediment. In addition, the percent absorption of inhaled arsenic is assumed to be 30% (USEPA, 1984) for the most probable case, and 80% for the worst case (Holland et al. 1959).

The cancer risk calculated, using a maximum arsenic concentration of 3760 mg/kg, worst case exposure conditions, and a CPF of 50 $(mg/kg/day)^{-1}$ for inhalation, is 1×10^{-5}. The risk is 8×10^{-8} when the median arsenic concentration and the most probable exposure conditions are used.

6.1.1.5 Summary of Risk Estimates

This section summarizes the potential public health effects from chronic exposure to contaminants found in the Blackwater Branch and the upper Maurice River. Cancer risks obtained from the various exposure pathways are presented in Tables 6-9 through 6-11. In addition, hazard indices for non-carcinogens are presented in Tables 6-12 and 6-13.

For all of the pathways, arsenic exposure accounts for over 99% of the total cancer risks. Thus, the total risk numbers in the tables are given only for arsenic exposures. If it is assumed that the same population receives exposure by all of the routes analyzed, the total environmental lifetime cancer risk for the worst case exposure scenario in the Blackwater Branch is 5×10^{-3}. Using the most-probable exposure scenario, the total cancer risk calculated for the Blackwater Branch is 5×10^{-5}. In both scenarios, ingestion exposures account for over 97% of the total risk, with the ingestion of water accounting for somewhat more (60%) of the total risks than sediment (38%). Risks from fish consumption are not calculated for the Blackwater Branch because it is believed that this waterway is too shallow to support significant sport fishing.

Cancer risks calculated for exposures in the upper Maurice River are given in Table 6-10. Again, assuming the same population is exposed via all routes of exposure, the worst-case cancer risk (calculated using the highest measured water and sediment concentrations of arsenic) is 1×10^{-3}. Again, the ingestion pathways dominate. Ingestion of sediment accounts for 35.4% of the total risk, water 5.5% and fish 59.3%. Fish ingestion alone is associated with a cancer risk of 8×10^{-4}, and if fish ingestion is discounted, the remaining pathways are associated with a total cancer risk of 6×10^{-4}.

Using the most probable exposure assumptions and median sediment and surface water concentrations in the upper Maurice River, the total cancer risk, including the contribution of fish ingestion,

VIN 002 0769

TABLE 6-9

SUMMARY OF CANCER RISKS FROM EXPOSURE PATHWAYS IN BLACKWATER BRANCH

	INGESTION[1]			DIRECT CONTACT[1]	INHALATION[2]	
	Bottom Sediment	Stream Water	Total Ingestion	Stream Water	Exposed Sediment	TOTAL CANCER RISK FROM ALL EXPOSURE PATHWAYS
Worst Case						
Cancer risk	2×10^{-3}	3×10^{-3}	5×10^{-3}	6×10^{-5}	1×10^{-5}	5×10^{-3}
Percent of Total Exposure[3]	38.1%	60%	98.1%	1.15%	0.19%	100%
Most Probable Case[5]						
Cancer risk	2×10^{-5}	3×10^{-5}	5×10^{-5}	8×10^{-7}	8×10^{-8}	5×10^{-5}
Percent of Total Exposure[3]	37.4%	60.2%	97.5%	1.5%	0.14%	100%

[1] These risks reflect a 70-year chronic exposure to Blackwater Branch.

[2] This risk is calculated assuming drought conditions for 5 years.

[3] The percentage of total exposure are calculated before cancer risks are rounded to 1 significant figure.

[4] Sediment As conc. - 3760 mg/kg; water As conc. - 6200 ug/l

[5] Sediment As conc. - 229 mg/kg; water As conc. - 361 ug/l

VIN 002 0770

TABLE 6-10

SUMMARY OF CANCER RISKS FROM EXPOSURE PATHWAYS IN UPPER MAURICE RIVER

	INGESTION[1]			DIRECT CONTACT[1]		
	Bottom Sediment	Stream Water	Fish[2]	Total Ingestion	Stream Water	TOTAL CANCER RISK FROM ALL EXPOSURE PATHWAYS
Worst Case[4]						
Cancer Risk	5×10^{-4}	8×10^{-5}	8×10^{-4}	1×10^{-3}	1×10^{-6}	1×10^{-3}
Percent of Total Exposure[3]	35.4%	5.5%	59.3%	100%	0.11%	100%
Most Probable Case[5]						
Cancer Risk	6×10^{-6}	1×10^{-5}	1×10^{-4}	1×10^{-4}	3×10^{-7}	1×10^{-4}
Percent of Total Exposure[3]	4.1%	7.4%	88.5%	100%	0.18%	100%

1 These risks reflect a 70-year chronic exposure to Upper Maurice River.

2 This risk is calculated from arsenic concentration in fish tissue.

3 The percentage of total exposure are calculated before cancer risks are rounded to 1 significant figure.

4 Sediment As conc. - 922 mg/kg; water As conc. - 150 ug/l

5 Sediment As conc. - 70.8 mg/kg; water As conc. - 124 ug/l

VIN 002 0771

TABLE 6-11

SUMMARY OF CANCER RISKS FROM MAJOR EXPOSURE PATHWAYS AT ALMOND ROAD BEACH

	INGESTION[1]		DIRECT CONTACT[1]	TOTAL CANCER RISK FROM
	SEDIMENT BOTTOM SEDIMENT	STREAM WATER	STREAM WATER	ALL EXPOSURE PATHWAYS
Worst Case				
Cancer Risk	2×10^{-5}	5×10^{-5}	9×10^{-7}	7×10^{-5}
Percent of Total Exposure[2]	25.9%	72.5%	1.4%	100%
Most Probable Case				
Cancer Risk	1×10^{-6}	8×10^{-6}	2×10^{-7}	9×10^{-6}
Percent of Total Exposure[2]	14.2%	83.5%	2.1%	100%

1. These risks reflect a 70 year chronic exposure to Upper Maurice River.

2. The percentage of total exposure are calculated before cancer risks are rounded to 1 significant figure.

VIN 002 0772

TABLE 6-12

SUMMARY OF WORST CASE CHRONIC HAZARD INDICES FROM EXPOSURE TO NON-CARCINOGENS IN BLACKWATER BRANCH

	INGESTION		DIRECT CONTACT	CUMULATIVE INTAKE FROM MULTIPLE EXPOSURES
	Sediment	Stream Water	Stream Water	
Mercury CDI[1]	6.1×10^{-8}	1.0×10^{-6}	1.7×10^{-8}	1.1×10^{-6}
AI	$(1.4 \times 10^{-3})^2$	$(3.0 \times 10^{-4})^4$	$(3.0 \times 10^{-4})^4$	
CDI/AI (Hazard Index)	4.4×10^{-5}	3.3×10^{-3}	5.7×10^{-5}	3.3×10^{-3}
Lead CDI	4.3×10^{-4}	NA	NA	4.3×10^{-4}
AI[3]	1.4×10^{-3}	NA	NA	
CDI/AI (Hazard Index)	0.3	NA	NA	0.3

1. CDI[1] Site-specific chronic intake rate (mg/kg/day) for the exposure pathway listed based on the maximum concentration found in the particular matrix listed.

2. AI Acceptable chronic intake rate (mg/kg/day) for inorganic mercury and compounds.

3. This acceptable chronic intake rate is for inorganic lead and compounds.

4. AI Acceptable chronic intake (mg/kg/day) for alkyl mercury and compounds.

7999b

VIN 002 0773

TABLE 6-13

SUMMARY OF WORST CASE CHRONIC HAZARD INDICES FROM EXPOSURE TO NON-CARCINOGENS IN UPPER MAURICE RIVER

	INGESTION			DIRECT CONTACT	CUMULATIVE INTAKE FROM MULTIPLE EXPOSURES
	Sediment	Stream Water	Fish	Stream Water	
Mercury CDI[1]	4.3×10^{-7}	6.4×10^{-7}	3.6×10^{-3}	1.1×10^{-8}	3.6×10^{-3}
AI	$(1.4 \times 10^{-3})^2$	$(3.0 \times 10^{-4})^3$	$(3.0 \times 10^{-4})^3$	$(1.4 \times 10^{-3})^2$	
CDI/AI (Hazard Index)	3.1×10^{-4}	2.1×10^{-3}	12	7.9×10^{-6}	12
Endosulfan CDI sulfate[4]	5.9×10^{-8}	NA	NA	NA	5.9×10^{-8}
AI	5.0×10^{-5}	NA	NA	NA	
CDI/AI (Hazard Index)	1.2×10^{-3}	NA	NA	NA	1.2×10^{-3}

1. CDI - Site-specific chronic intake rate (mg/kg/day) for the exposure pathway listed based on the maximum concentration found in the particular matrix listed.

2. AI - Acceptable chronic intake (mg/kg/day) for inorganic mercury and compounds.

3. AI - Acceptable chronic intake (mg/kg/day) for alkyl mercury and compounds.

4. AI - Acceptable chronic intake (mg/kg/day) for Endosulfan is used since there is no acceptable intake established for endosulfan sulfate.

NA - Not applicable. The chemical parameter was not detected within the stream water.

VIN 002 0774

is 1 x 10^{-4}. In this case, fish ingestion accounts for 88.5% of the total cancer risk. If fish ingestion is omitted, the total cancer risk for this scenario is 2 x 10^{-5}.

Total cancer risks calculated for most probable exposures at Almond Beach, in a park on the upper Maurice River, are 9 x 10^{-6} (see Table 6-11), with the stream water ingestion pathway accounting for 83.5% of the total cancer risks.

The non-cancer risks for exposure to water and sediment in the Blackwater Branch are given in Table 6-12. None of the exposure routes for any of the pollutants are associated with CDI:AIC ratios greater then 1.0, even when exposures are calculated using the highest measured arsenic levels and worst case exposure assumptions. This indicates that there is little basis for concern for non-cancer effects associated with exposure to most of the pollutants.

For exposures in the upper Maurice River, (Table 6-13) CDI:AIC levels are less than or close to 10^{-3} for all pollutants and all routes of exposure, except for mercury ingestion arising from ingesting fish. The worst case CDI:AIC ratio for mercury ingestion is 12 (for 6-10 year-olds), a level that may be associated with adverse health effects. Under the assumptions made in this analysis, risks for older children and adults would be lower, due to their higher body weight. The CDI:AIC ratio for a 70-kg adult is 4.8, a level that may also be associated with adverse health impacts. It must be recalled, however, that the mercury risk calculations are not based on measurements of mercury in fish tissue, but instead on estimated concentrations based on the bioconcentration factor for mercury in fish.

6.1.1.6 Uncertainty in Risk Estimates

The procedures used to develop the estimates of risk for exposure to sediment, surface water, and biota involve many analytical assumptions, models and procedures which introduce uncertainty into those estimates. In this section, three principle sources of uncertainty in these estimates; sampling and analytical error, exposure and dose estimation models, and toxicologic models, will be discussed. The possible effects on the risk estimates will be addressed.

6.1.1.6.1 Sampling and Analytical Error

All of the estimates of exposure, doses and risks developed in this assessment ultimately depend upon the chemical sampling and analytical results obtained during the RI. They therefore reflect the limitations and inherent uncertainties of these data. The first source of uncertainity in the results are the errors associated with the procedures employed to select and gather samples for chemical analyses. Two major concerns in any assessment are whether there are enough samples to adequately

VIN 002 0775

characterize concentrations in the media of concern, and whether the samples collected are collected in a manner, and at locations, which are representative of the areas being characterized. In this regard, it must be recognized that the area being characterized in this analysis is quite large (over 10 miles of water course altogether) and that, except for arsenic in sediment and water, the number of analyses is quite limited. It is thus very difficult to develop a statistically reliable characterization of the levels and variability of the pollutants other than arsenic in the Maurice River and Blackwater Branch. The limited number of samples for the other pollutants means that the uncertainty associated with estimates of both the median and maximum pollutant levels other than arsenic is quite large. There is, however, no reason to suspect that the sampling locations or methods are such as to introduce any systematic bias into the estimates of total pollutant levels.

The chemical analyses performed and used in the risk assessment were done under the Contract Laboratory Program (CLP). This program ensures that samples undergo a complete series of quality control measures in a certified laboratory. After laboratory analysis was completed, data were fully validated using rigorous quality control measures to ensure the reliability of the results. These measures provide additional confidence in the data.

In regards to arsenic and mercury, the lack of data concerning ionic and chemical speciation also needs to be addressed in any discussion of uncertainty. For both of these metals, only total concentration data were available. As will be discussed further below, both of the pollutants can exist in more than one chemical species in the environment, and these species differ in both their environmental fate and their toxicologic properties. Using the total arsenic and mercury analyses, therefore, involves making assumptions about speciation which introduces uncertainty into the assessment.

6.1.1.6.2 Uncertainty in Exposure and Dose Assessment Model

In this analysis, estimates of pollutant exposures and doses were made using models and assumptions which describe the environmental fate and distribution of contaminants, the behavior of potential contaminant receptors, and the biological interactions between contaminated media and receptors resulting in contaminant uptake. For the sediment and surface water pathways, exposure point concentrations were estimated directly from the analytical data, and therefore depend heavily upon the quality and representativeness of that data and the methods used to summarize them for the exposure assessment. The quality of these data have been discussed above, and the methods used to summarize the data (maximum and median values) are appropriate to the development of worst case and representative pollutant

VIN 002 0776

levels where the distribution of the data is not well-characterized, but expected to be positively skewed from a Gaussian distribution.

For the fish ingestion pathway, exposure point concentrations were estimated using two methods; directly from a small number of biota sampling results, and from surface water analyses using bioconcentration factors (BCFs). Both of these approaches involve uncertainty; the former associated with analytical error, the latter associated with the modeling process and with the selection of the specific parameter values chosen. The former method is uncertain to the extent that the measured values of pollutants in the sampled species are not representative of the levels actually present in species actually consumed in areas where they are most often caught. The extent of this uncertainty cannot be accurately assessed but, again, the sample size is quite small. The use of the BCFs introduces another level of uncertainty into the exposure estimates. For arsenic, the one pollutant for which both biota and water concentration data are available, the two methods agree to within approximately one order of magnitude. This difference may be taken as an approximate indication of the expected level of agreement between measured and estimated pollutant levels in fish tissue. However, there is no guarantee that this relationship would hold for pollutants other than arsenic. It does suggest however, that the exposure estimates for the other pollutants in fish, which were also estimated using BCFs, cannot be expected to be more reliable than within a factor of 10. This is of special significance for the interpretation of the CDI:ADI ratio for mercury by fish ingestion by adults (4.8), which cannot, with a high degree of certainty, be said to either exceed or be less than 1.0.

Other factors which introduce uncertainty into the exposure estimates include behavioral assumptions (days spent swimming, hours/day exposed, fish consumed, etc.), exposure-related factors (skin deposition of pollutants, soil ingestion, etc.) and intake factors (matrix-specific bioavailability, dermal and gastrointestinal absorption factors). In many cases, it is difficult to judge the direction or magnitude of the bias that may be introduced into dose estimates by specific models using a parameter value selected. On the whole, however, it is probable that the overall effect of the analytical assumptions made is moderately to very "conservative", that is, values are chosen which are likely to somewhat overstate rather than understate risks. The rationale for this approach is to allow a relatively high degree of certainty that the "worst case" exposure scenario actually represents a plausible upper-bound on exposures and risks.

VIN 002 0777

6.1.1.6.3 Uncertainty in Toxicological Models and Parameters

The final source of potential uncertainty in the risk estimate is the models used to characterize the toxicologic properties of the indicator chemicals. Throughout this analysis, EPA-approved models and toxicologic parameters (RfDs and CPFs) have been used for both carcinogenic and non-carcinogenic effects. In both cases there are uncertainties built into the analyses by virtue of the assumptions used to define the models and derive the parameters.

The carcinogenic risk model used assumes a linear non-threshold model of cancer induction, which takes as its slope parameter the CPF derived as the upper 95% confidence limit of the dose-response slope derived using data from specific animal or epidemiologic studies of cancer induction. As such, the value also tends to be "conservative", giving an upper estimate of the true slope parameter. In the case of arsenic, the data used to develop the CPF is derived from an epidemiologic study of a population in Taiwan exposed to primarily pentavalent arsenic in drinking water. Since no speciation data is available for arsenic in any of the media sampled in this investigation, it is not clear how closely the speciation is similar to that for which the CPF was derived, although for comparatively well-oxygenated surface water, it may be assumed that a large proportion of the arsenic was also in the pentavalent state. The largest uncertainty introduced into the cancer risk assessment for arsenic is in the fish consumption pathway, because there is a substantial body of data that suggests that a large proportion of arsenic present in fish tissue is present as an organoarsenic compound, arsenobetaine (see Subsection 6.1.1.4.3) which is rapidly excreted by humans and is thought to be much less toxic than inorganic arsenic compounds. It is thus quite likely that the risks calculated for the fish ingestion pathway for arsenic are considerably higher than those which would be calculated if concentration and toxicity data were available for the precise chemical species present. The magnitude of this potential bias cannot be estimated.

The basis for the assessment of non-cancer risks which is used in this analysis is the comparison of daily average doses (CDIs) to acceptable chronic intake values (AICs), with CDI:AIC values exceeding 1.0 being indicative of potential health effects. All the AIC values used in this analysis are RfDs (reference doses) derived by EPA using uncertainty factors applied to the results of animal or human studies which demonstrate No Adverse Effects Levels (NOAELS) or Lowest Adverse Effect Levels (LOAELS). The net effect of the use of uncertainty factors tends towards conservatism; the RfDs represent values below which average daily doses are very unlikely to have an adverse affect on even the most sensitive population; they do not necessarily represent doses above which adverse effects will definitely be seen.

VIN 002 0778

For both carcinogenic and non-carcinogenic effects, the assumption of multiple pathways and multiple pollutant additivity of effects is made in this analysis. The multipathway assumption has a firm basis in theory; the risk associated with exposure to a specific pollutant should depend upon the total dose reaching the bloodstream, independent of the route of administration, unless there is some special consideration regarding absorption, disposition, or metabolism, that determines otherwise. Where such factors exist they can be taken into account (as is done in this analysis for ingested vs. inhaled arsenic).

The assumption of additivity for multiple pollutant exposures is less firmly supported by theory for both carcinogenic and non-carcinogenic effects. However, this assumption is not likely to have a significant impact since for essentially all of the routes of exposure, the total risks are dominated by one pollutant (arsenic).

6.1.1.6.4 Summary of Uncertainty

The quantitative estimates of risk are likely to be quite uncertain, since their derivation involves the interpretation of inherently uncertain analytical data, and the use of imprecise models to assess pollutant exposures, doses, and health risks. It does not appear that the use of the analytical data introduces any systematic bias into the analysis (except possibly owing to the lack of speciation data). However, it is likely that both the exposure and toxicologic models provide somewhat conservative estimates of risk. The extent of this conservatism and of the total uncertainty inherent in the risk estimates cannot be assessed quantitatively, but it would appear that to claim any greater accuracy for these estimates than plus-or-minus one order of magnitude would not be justified, based on the available information.

6.2 PUBLIC HEALTH EVALUATION - MAURICE RIVER SOUTH OF UNION LAKE

In this section, a qualitative public health risk assessment for the lower Maurice River was performed. The objective of the assessment was to determine if an actual or potential public health threat existed due to site contamination or off-site migration. Data collected from surface sediment, water, and aquatic biota during Ebasco's Phase II sampling efforts were used.

6.2.1 Risk Assessment Methodology

The methodology for the qualitative assessment involved the following steps. First, the contaminants of concern in the lower Maurice River were identified by comparing measured contaminant concentrations with background levels and existing health criteria. Second, the potential exposure pathways and the receptors at risk were defined. Assuming that the exposure

VIN 002 0779

scenarios are similar for upper and lower Maurice River, the measured contaminant concentration for a specific matrix in the lower Maurice River can be compared to the concentrations derived for a specific pathway in the upper Maurice River (Table 6-14) which are associated with specific risk levels. Thus, decisions can be made as to any adverse health effects posed to the receptor population in the rivers study area.

6.2.1.1 Chemical Contaminants of Concern

Chemical analyses of matrices collected from the lower Maurice River include total arsenic and iron content in surface sediments, HSL inorganics and dissolved arsenic in water samples, as well as total arsenic in biota samples. Results of these analyses indicate that arsenic is the only contaminant of concern. Arsenic was found in all sediment samples above the background level of less than 2 mg/kg (Table 6-15), with a maximum concentration of 234 mg/kg at station ER-22. Arsenic was also present in all water samples. The maximum arsenic concentrations detected was 91 ug/l (at Station ER-21), and a background level (less than 10 ug/l) was approached at station ER-44. Another contaminant, chromium, was found in 7 out of 17 samples, with a range of undetected to 56 ug/l. Although the maximum chromium concentration was above the usual range of 1 to 30 ug/l in U.S. river waters (USEPA, 1984b), it does not exceed the MCLG of 0.12 mg/l for total chromium (VI) and chromium (III) in drinking water (Chromium was measured as total chromium in Ebasco's Phase II sampling effort). In addition, even if the worst case assumption is made that all the chromium detected was chromium (VI), the acceptable intake rate of chromium (VI) would be quite high (0.005 mg/kg/day), (Table 6-16). An adult of 70 kg would have to ingest more than two liters of water a day in Lower Maurice River to reach this limit. Thus, chromium should not be a health concern. Other chemicals found include lead which was detected within background levels; and antimony, which was detected in 3 out of 16 samples, but the maximum concentration was below the ambient Water Quality Criteria of 146 ug/l. Mercury, which was present in the upper Maurice River, was not found in the lower Maurice River.

6.2.1.2 Toxicity Assessment

The toxicity evaluation of arsenic was summarized in Appendix H. In addition, critical toxicity values associated with contaminants along the lower Maurice River is presented in Table 6-16.

6.2.1.3 Exposure Assessment

Based on the environmental characteristics of the lower Maurice River and information relating to possible activities of receptor populations, the following exposure pathways were initially considered to be of potential significance.

VIN 002 0780

TABLE 6-14

ACCEPTABLE ARSENIC CONCENTRATIONS IN SEDIMENTS FOR SEDIMENT EXPOSURE PATHWAYS IN BLACKWATER BRANCH AND UPPER MAURICE RIVER

SEDIMENT EXPOSURE PATHWAYS	ACCEPTABLE ARSENIC CONCENTRATION IN SEDIMENT[1] (mg/kg)	N.J.SOIL CLEANUP OBJECTIVE (mg/kg)
Ingestion of bottom sediment (worst case)	2	20
Ingestion of bottom sediment (most probable case)	12	20

[1] Acceptable sediment concentrations are based on risk of 1.0×10^{-6}

VIN 002 0781

TABLE 6-15

WATER QUALITY REGULATORY CRITERIA FOR CONTAMINANTS IN LOWER MAURICE RIVER

Chemical	Safe Drinking Water Act MCLs (ug/l)	Clean Water Act Criteria for Human Health: Aquatic Organisms and Drinking Water (ug/l)	Clean Water Act Criteria for Human Health: Adjusted for Drinking Water Only (ug/l)	New Jersey Water Standard Surface Water Quality for FW2 Water (ug/l)	Lower Maurice River[2]: Sediment Range (mg/kg) (Median)	Lower Maurice River[2]: Frequency of Occurrence in Sediment Samples	Lower Maurice River[2]: Surface Water Range (ug/l)(Median)	Lower Maurice River[2]: Frequency of Occurrence in Water Samples
Arsenic	50	0(2.2 ng/l)	(25 ng/l)	50	9.2-234(26)	16/16	2.7-91(21.5)	16/16
Chromium	50	50 (Cr VI)	50 (Cr VI)	50	N.A.	N.A.	U-56(48)	7/17
Lead	50	50	50	50	N.A.	N.A.	U-10(6.3)	7/17
Antimony		146	146		N.A.	N.A	U-38(26)	3/17

U = Undected
N.A. - Not applicable. These parameters were not measured.

1. The criterion value, which is zero for all potential carcinogens, is listed for all chemicals in the table. The concentration value given in parenthesis for potential carcinogens corresponds to a risk of 10^{-6}.

2. Based on Ebasco Phase II samples

VIN 002 0782

TABLE 6-16

CRITICAL TOXICITY VALUES FOR CONTAMINANTS IN LOWER MAURICE RIVER[1]

CHEMICAL ORAL ROUTE	Acceptable Intake Subchronic (AIS) mg/kg/day	Acceptable Intake Chronic (AIC) mg/kg/day	Source	Cancer Potency Factor $(mg/kg/day)^{-1}$	Source	EPA Weight of Evidence[4]
Arsenic	—	—		1.8E+0[2]	CAG	A
Chromium[3]	2.50E-02	5.00E-03	HEA			
Inhalation Route						
Arsenic	—	—		5.00E+01	HEA	A

[1]Taken from USEPA, OSWER Dir 9285, 4-1, update Nov 16, 1987.

[2]CPF for arsenic, oral route, is based on applying a multistage model to the cancer initiation rather than using the more conservative absolute risk linear model.

[3]Intake is for Chromium VI and compounds.

[4]Alphanumerics represent EPA Weight of Evidence classifications, defined as follows:
Group A - Human carcinogen. Sufficient evidence from epidemeologic studies to support a casual association between exposure and cancer

HEA = Health Effects Assessment Document prepared by the Environmental Criteria and Assessment Office, USEPA, Cincinnati, Ohio, 1985 (Updated in May, 1986).

CAG = Carcinogen Assessment Group, EPA

VIN 002 0783

- o Ingestion of soil/river sediment
- o Ingestion of river water
- o Direct contact with river water
- o Direct contact with soil/river sediments
- o Ingestion of fish/shellfish
- o Ingestion of gamebirds/waterfowl

These pathways were evaluated with site-specific data to determine if chronic intake of arsenic via these routes could cause adverse public health effects.

6.2.1.3.1 Ingestion of Soil/River Sediment

The lower Maurice River is used by local residents for recreational activities such as boating, swimming and fishing. Since the lower Maurice River is much deeper and wider than upstream locations, the river bottom sediment cannot as easily be contacted directly during these activities.

From Table 6-14, the sediment concentration corresponding to a most probable case risk of $1x10^{-6}$ for ingestion of sediment in the upper Maurice River is 12 mg/kg. However, risks estimated by the same mathematical model used in the upper Maurice River would probably be over-estimated because the incidental sediment ingestion rate for all populations should be at least 10 times lower, as the water level is much deeper in the lower Maurice River. Thus, the sediment concentration associated with a risk of $1x10^{-5}$ (120 mg/kg) may be a more appropriate criterion. Since only two out of the 16 detected arsenic concentrations in the sediment exceeded this value (234 mg/kg and 136 mg/kg, respectively), ingestion of river sediment in the lower Maurice River should have no significant health impacts.

6.2.1.3.2 Ingestion of River Water

The water in the lower Maurice River is not used as a drinking water supply. However, inadvertent ingestion of river water during recreational activities has to be considered since this pathway was found to be significant in the upper Maurice River. When the measured water concentrations of arsenic were compared to the MCL of 50 ug/l, 6 out of 16 water samples exceeded this value. The maximum arsenic concentration was 91 ug/l (at ER-21) and the median concentration was 21 ug/l, which is below the MCL. Using the mathematical model from the upper Maurice River, the maximum arsenic concentration corresponds to a worst case cancer risk of 5×10^{-5}, whereas the median concentration corresponds to a most probable risk of 2×10^{-6}. As a reference, the MCL of 50 ug/l has an associated most probable cancer risk of 4×10^{-6} by this pathway.

Downstream from station ER-29, the arsenic concentrations in water were all below the MCL. Thus, while accidental ingestion of river water from upstream of station ER-29 in the lower

VIN 002 0784

Maurice River may have a slightly increased cancer risk, ingestion of water downstream from this station should have no adverse health impact from arsenic. It must be recalled, however, that the very lowest portions of the Maurice River are subject to saline intrusions from the tides.

6.2.1.3.3 Direct Contact with River Water

Direct contact with river water can occur during swimming and other water sports in the lower Maurice River. The contaminants in the water can be absorbed through the skin and exert their systemic effect in the body. However, arsenic intake via this exposure pathway has been determined to pose no health risk in the upper Maurice River, which has a maximum arsenic concentration of 150 ug/l in water. Since the maximum arsenic concentration in the lower Maurice River is only 91 ug/l, exposure to arsenic via this route should have no significant health impact.

6.2.1.3.4 Direct Contact with River Sediment

Resuspended sediment in water can be deposited on the body surface after recreational activities in the river. Some of the contaminants in the sediment can be adsorbed through the skin. However, arsenic intake via this pathway was not quantitatively evaluated in the upper Maurice River due to lack of adequate models. Arsenic intake via this route in this study area also cannot be evaluated.

6.2.1.3.5 Ingestion of Fish/Shellfish

Fishing and crabbing are widespread in the lower Maurice River vicinity. The Heislerville Fish and Wildlife Management Area, which is dedicated to fishing, hunting and wildlife preservation, is located in this study area. In addition, the lower Maurice River is a major oyster setting bed in New Jersey. The oyster, Crassostrea virginica supports a major industry in the area. Thus, a receptor population can be exposed to arsenic via the ingestion of fish and shellfish collected in this area. Arsenic, measured as total arsenic, was not detected in the 2 fish samples collected, but was found in the 4 crab and oyster samples, with concentrations ranging from 1.2 to 1.6 mg/kg. However, crustaceans often contain naturally high concentrations of organic arsenic (USEPA, 1984a). The concentration range of arsenic measured is actually close to the range of mean values of arsenic in fin fish and shellfish (0.07-1.47 mg/kg) (see Table 6-8). Moreover, as discussed in Subsection 6.1.1.4.3, greater than 85% of arsenic in fish and shellfish is in the form of a water-soluble organic compound, arsenobetaine, which has very low toxicity. Based on all this information, ingestion of fish and shellfish in the lower Maurice River should be of no significant health concern.

VIN 002 0785

6.2.1.3.6 Ingestion of Vegetables and/or Forage Crops

The water in the lower Maurice River is not known to be used for irrigation. Also, arsenic concentrations in soil in the lower Maurice River area was not measured. Therefore, this exposure pathway was not evaluated.

6.2.1.3.7 Ingestion of Waterfowl and Gamebirds

The lower Maurice River, with its extensive wetland and estuary, should be a favorable habitat for waterfowl and gamebirds. Local residents can be exposed to arsenic via ingestion of waterfowl and gamebirds taken in this area. However, birds can biomethylate arsenic which can be subsequently excreted (NAS, 1977; Braman & Foreback, 1973). Thus, bioaccumulation of arsenic in birds should not be high. In addition, arsenic concentrations were not measured in tissue of waterfowl. Therefore, ingestion of waterfowl and gamebirds was not quantitatively evaluated.

6.2.2 Risk Characterization

Of the four exposure pathways evaluated for the Maurice River south of Union Lake, only the ingestion of river water pathway may be of some health concern.

6.3 ENVIRONMENTAL ASSESSMENT

In this section, the environmental impact of the contamination in Maurice River was evaluated via a literature search. Attention was directed at whether the aquatic life or terrestrial wildlife were receiving doses of contaminants which might adversely affect these populations, or which might constitute a secondary risk to humans consuming fish or waterfowl taken in or around the area.

The USEPA's Environmental Response Team (ERT) performed a field investigation in the Maurice River basin. Their investigation assessed the relative health of the river system through field sampling. Their report is presented in Appendix L of this RI, and is summarized in Subsection 6.3.1.4.

6.3.1 Blackwater Branch and Maurice River North of Union Lake

In these two study areas, the major contaminants are arsenic and mercury. The maximum and median arsenic concentrations of water in the Blackwater Branch were 6200 ug/l and 361 ug/l, respectively. These concentrations are highly elevated when compared to the background level of 10 ug/l for U.S. surface water (ATSDR, 1987, see Table 6-3) and the very low to undetected levels of arsenic seen upstream of the ViChem plant. Toxicological data revealed that adverse effects of arsenic on aquatic organisms could occur at concentrations as low as 19 to 48 ug/l in water (Eisler, 1988). The most sensitive aquatic species

VIN 002 0786

tested were developing embryos of the narrow-mouth toad (Gastrophryne carolenensis), of which 50% were dead or malformed in 7 days at 40 ug As+3; and a freshwater alga (Scenedesmus obliquus), in which growth was inhibited 50% in 14 days at 48 ug As^{+5}/l (USEPA, 1985). For other species, such as the amphipod, Gammarus pseudolimnaeus, mortality was 10 to 32% at 85 to 88 ug/l of As^{+3} in 28 days (Spehar et al. 1980); and the snail, Helisoma campanulata, mortality was 10% at 0.98 mg/l of As^{+3} in 28 days (Spehar et al. 1980). At 2300 ug/l, trivalent inorganic arsenic was fatal to 100% of 3 species of freshwater algae in 2 weeks, and 95% of submerged plants (Potamogeton, sp), in a month (Cowell, 1965). The levels of arsenic seen in the Blackwater Branch swamp caused by the beaver dam, 6200 ug/l, would therefore pose a significant threat to aquatic plants and invertebrates. On the other hand, freshwater fish are generally more tolerant to trivalent inorganic arsenic. The LC_{50} of arsenic in fish is high, ranging from 13,340 ug/l in rainbow trout to 41,760 ug/l in juvenile bluegill (Cardwell et al. 1976). According to the Ambient Water Quality Criteria for freshwater aquatic life recommended by USEPA, the concentration of total recoverable trivalent inorganic arsenic should not exceed 440 ug/l at any time (EPA, 1980). The concentration of arsenic in the upper Maurice River is below this level. Therefore, fish could probably survive arsenic exposure in the Blackwater Branch, in the absence of other environmental stresses. Such stress could occur if aquatic vegetation and prey organisms were adversely affected by arsenic. In the upper Maurice River, the concentration of arsenic in water was much lower, and more evenly distributed than in the Blackwater Branch. The maximum and median concentrations were 150 ug/l and 124 ug/l, respectively. These concentrations of arsenic may have some adverse effects to sensitive species, but should have no significant impact to the aquatic environment.

Since most aquatic life can tolerate the arsenic concentration in the upper Maurice River, the potential of arsenic for bioaccumulation has to be addressed. It is well documented that arsenic is accumulated from the water by a variety of organisms, especially phytoplankton. Both freshwater and marine algae can accumulate high concentrations of inorganic arsenic. In addition, marine phytoplankton can transform inorganic arsenic to methylated compounds that are later transferred in the food chain. (Irgolic et al. 1977). However, there is no evidence of biomagnification along the aquatic food chain. It has been demonstrated in a microcosm experiment (Isensee et al. 1973) that algae concentrated arsenic the most, with bioconcentration factors (BCF) ranging from 736 to 2175; snails accumulated arsenic to a lesser extent, with BCFs ranging from 110 to 446; and fish exhibited the least accumulation, with a bioconcentration factor of 21 for cacodylic acid. Based on Ebasco's Phase

VIN 002 0787

II data, the arsenic concentration in fish tissue (0.91 mg/kg), and in water of the upper Maurice River (0.124 mg/l), can be related by the equation:

$$BCF = \frac{\text{arsenic concentration in tissue (mg/kg)}}{\text{arsenic concentration in water (mg/l)}}$$

The BCF of arsenic in fish is 7.3 l/kg. Thus, bioaccumulation of arsenic in fish is relatively low.

Finally, the amount of arsenic accumulated by aquatic plants has to be considered. In a study of arsenic levels in an arsenic-rich river in New Zealand, the bioaccumulation of arsenic by aquatic plants was related to the total amount transported by the river (Reay, 1973). By estimating total ecological production and the amount of arsenic transported by the river, it was estimated that only 3-4% of the annual arsenic input to the river was bioaccumulated, with much of the balance being discharged to the sea and the remainder settling out with sediment.

In addition to arsenic, total mercury concentrations were measured in the Blackwater Branch and Upper Maurice River at maximum levels of 0.8 and 0.5 ug/l, respectively. According to a survey of the concentration of mercury in U.S. waters in 1970 (Jenne, 1972), half of the samples from the Mississippi River contained less than 0.1 ug/l of mercury and the mercury content of groundwater samples was generally below the 0.1 ug/l detection level. Thus, the total mercury level in the upper Maurice River area was slightly above these background levels.

According to the USEPA, toxic concentrations of mercury salts ranged from 0.02 ug/l to more than 2000 ug/l for representative species of freshwater organisms (USEPA, 1980a). The lower concentrations (<2.00 ug/l) recorded were usually associated with early developmental stages, long exposures and flowthrough tests. Reduced growth of sensitive species of aquatic organisms was most commonly observed at water concentrations of 0.04 to 1.0 ug/l. For the most sensitive species tested, the rainbow trout, growth reduction was observed after 64 days in 0.04 ug/l of methylmercury (EPA, 1980a). The hazardous levels of mercury for freshwater aquatic plants range from 80 to 2,600 ug/l for inorganic species. Thus, based on the available data, the concentration level of mercury in the upper Maurice River may have some adverse effect to sensitive species, but has no significant impact to the total aquatic environment. In the Blackwater Branch, the impact from arsenic contamination probably far outweighs that from mercury. As a further comparison, the Ambient Water Quality Criteria for mercury proposed by EPA for protection of freshwater aquatic life is 1.1 ug/l for acute toxicity and 0.2 ug/l for chronic toxicity (US EPA, 1984c). The mercury concentrations in the Blackwater Branch and the upper Maurice River are above the proposed chronic toxicity value, but not the acutely toxic value.

VIN 002 0788

6.3.1.1 Mammals

Animals such as the red fox, beaver, mink, and white-tailed deer inhabit the Maurice River area. These mammals and domestic animals such as dogs can be exposed to arsenic by ingesting stream water. However, animals are generally less sensitive to the toxic effects of arsenic than humans (ATSDR, 1987). Arsenic poisoning in most animals is usually manifested by acute or subacute symptoms, including appetite loss, reduced growth, loss of hearing, dermatatis, blindness, degenerative changes in liver and kidney, birth defects, and death. Chronic arsenic poisoning from continuous ingestion of small doses is rare, because in mammals, inorganic arsenic is oxidized in vivo, biomethylated, and usually excreted rapidly in the urine (Woolson, 1975). Death or malformations in the fetus have been documented at a single oral dose of 2.5 to 33 mg As/kg body weight to pregnant animals, and at chronic doses of 1 to 10 mg As/kg body weight (Eisler, 1988). However, even at the maximum arsenic concentration found in the water of the Blackwater Branch, a lethal dose could not be reached by drinking stream water. Less serious sublethal effects may occur, but no dose-response relationship has been documented for these effects in terrestrial mammals.

Mercury, the other contaminant present in the Maurice River, has a concentration range of 0.2 to 0.8 ug/l in surface water. Among sensitive species of mammals, e.g., the mink, death occurred at daily organomercury concentrations of 0.1 to 0.25 mg/kg body weight, or 1.0 to 5.0 mg/kg in the diet (Sheffy and St. Amant, 1982). Larger animals, such as mule, deer and harp seals, are more resistant to mercury than smaller mammals such as mink, cats, and dogs. In dogs, a high incidence of stillbirths occured when 0.1 to 0.5 mg/kg bodyweight of organomercury was administered orally during entire pregnancies (Khera, 1979). However, mercury intake by animals via ingestion of water in the Maurice River is too low to result in these adverse effects. Therefore, mercury contamination in the river area should have no significant impact on mammals.

6.3.1.2 Birds

Signs of inorganic trivalent arsenite poisoning in birds include muscular incoordination, debility, slowness, jerkiness, falling hyperactivity, fluffed feathers, drooped eyelids, huddled position, loss of sighting reflex, immobility and seizures (Hudson et al., 1984). However, toxic doses of arsenic to birds are usually high. For example, for the mallard, Anas platychynchos, the acute oral LD_{50} of sodium arsenite is 323 mg/kg body weight (Hudson et al. 1984; NAS, 1977). For the ring-necked pheasant, the single-dose oral LD_{50} for sodium arsenite is 386 mg/kg bodyweight (Hudson et al., 1984). Chicken, Gallus sp, can be dosed orally with cacodylic acid at 100 mg/kg bodyweight for 10 days without effect (Hood, 1985). This is probably because

VIN 002 0789

birds can rapidly excrete arsenic, e.g., in chickens, only 2% of dietary sodium arsenite remained after 60 hours (NAS, 1977). However, developmental and teratogenic effects can occur. Up to 8% of chicken embryos dosed with 0.01 to 1 ug of As^{+5}, died. The threshold for malformation in chickens is 0.3 to 3 ug of inorganic pentavalent arsenite per embryo (NRCC, 1978). Therefore, birds in the Maurice River area (e.g., herons) should not be affected with acute toxic effects of arsenic. However, some developmental effects may occur.

Mercury, the other contaminant in the Maurice River, has an acute toxicity value of 2.2 to 31.0 mg/kg of bodyweight for most species tested (Hudson et al., 1984). In addition, some deaths occur when 15 ug/egg of methyl mercury is injected into yolk sacs of chickens, and when 9.0 ug/egg is applied to an egg surface of the mallard. Since the intake of mercury by birds in the Maurice River will not reach these dose levels, mercury contamination in this area should have no effect on birds.

6.3.1.3 Terrestrial Plants and Crops

Arsenic is known to be phytotoxic (Woolson et al. 1971). For example, seedlings of Scotspine, Pinus sylvestus die when soil (sandy) concentrations of inorganic As^{+5} exceed 250 mg/kg dry weight (Sheppard et al., 1985). For most crops, depressed yields occur at 25 to 85 mg/kg total soil As concentration (NRCC, 1988). In the Maurice River area, the arsenic concentration in soil was not measured, so it is difficult to evaluate the effect of arsenic on terrestrial plants. Areas of potential vegetative stress were identified along the Blackwater Branch near the ViChem facility in aerial photographs taken by EPA (1988). Another area of vegetative stress is the former flood region in Blackwater Branch, where the soil is covered with contaminated former sediment. However, the flood area is a swamp, and is not used for agricultural purposes.

Mercury is also toxic to plants. Plant growth was reduced in soils containing 50 mg/kg mercury (Weaver et al. 1984). However, the level of mercury contamination in the Maurice River area is probably too low to cause phytotoxic effects.

6.3.1.4 Environmental Response Branch Biological Assessment

The USEPA's Environmental Response Branch conducted a biological assessment in the Blackwater Branch and the upper Maurice River. The purpose was to determine if impacts to the Blackwater Branch and Maurice River systems had occurred as a result of the ViChem plant. Their report is presented in Appendix L of this report.

Pertinent findings of their report may be summarized as folows:

- o There is an adverse impact to the benthic communities in the Blackwater Branch downstream from the ViChem

VIN 002 0790

plant site, which takes the form of lower species diversity and a toxic response in bioassay tests done with the sediments; and

- The impact lessens downstream in the Maurice River, probably resulting from dilution. The Maurice River has a much higher flow rate than the Blackwater Branch.

6.3.2 Maurice River South of Union Lake

6.3.2.1 Aquatic Life

The maximum arsenic concentration in waters of the lower Maurice River is 91 ug/l. Since this value is much lower than the Ambient Water Quality Criteria of 440 ug/l arsenic recommended by EPA for the protection of freshwater aquatic life, arsenic contamination in this study area should have no significant impact to aquatic life.

As for bioaccumulation of arsenic by aquatic life, bioconcentration factors for crustaceans can be calculated from Ebasco's biota data. Arsenic was not detected in the two fish samples (catfish and yellow perch) in this area, but was measured in the American oyster sample and crab backfin and hepatopancreas samples, with a concentration range of 1.3 to 1.6 mg/kg. Using the median arsenic concentration in water of 21 ug/l, bioconcentration factors of arsenic in these crustaceans range from 61.9 l/kg to 76.2 l/kg. These values are much higher than that obtained for the black bullhead sample in the upper Maurice River of 7.3 l/kg. It is well documented, however, that crustaceans and bivalves can accumulate more arsenic from water and food sources than fish (USEPA, 1980d). However, there was no consistent relationship between oyster body burdens of arsenic and water concentrations. Previous reports indicate that the uptake of sediment and biota by oysters contribute more to their arsenic uptake than did the arsenic concentration in water (Zaroogian and Hoffman, 1982). This is well illustrated by the observation that the American oyster sample from the Delaware Bay, which has normal background arsenic levels in water, had almost the same arsenic concentration in tissue as the oyster sample collected in the lower Maurice River (1.2 mg/kg Vs 1.3 mg/kg). Therefore, it does not appear that bioconcentration of arsenic in the food chain is having major impacts on the ecosystem in the lower Maurice River.

6.3.2.2 Mammals

It has been determined that arsenic has no significant effect o animals in the upper Maurice River. Since the arsenic concentration in the lower Maurice River is lower, arsenic contaminatior should also have no significant impact on animals in this area.

VIN 002 0791

6.3.2.3 Birds

Based on available toxicological data (Subsection 6.3.1.3) as well as arsenic concentrations in the lower Maurice River, waterfowl and other birds in this area should not be significantly affected. Also, since birds accumulate little ingested arsenic (Subsection 6.3.1.3), and the arsenic concentration in the lower Maurice River area is only moderately elevated, there should be no significant health risk to humans via ingestion of birds and waterfowl.

VIN 002 0792

VIN 002 0793

7.0 BENCH-SCALE TREATABILITY TESTS

The bench scale treatability studies for the arsenic-contaminated sediments from the river areas were conducted to produce adequate data for the evaluation of the technical feasibility and cost-effectiveness of the treatment processes tested. Based on the general feasible technologies for arsenic treatment in sediments, the following bench scale tests were proposed to be conducted:

- o Chemical fixation and solidification test.
- o Chemical extraction of arsenic from sediments test.

The fixation test was conducted by Lopat Enterprises, Inc. and the extraction test was performed by Hittman Ebasco Associates Incorporated (HEAI) during the summer and fall of 1987.

Each of these two bench scale tests is discussed separately in the following subsections. For each test, the discussion covers the testing objectives, description of the test, the results and the conclusion. The laboratory testing materials (e.g. sediments), apparatus, procedures, and results of the bench scale tests performed by Lopat and Hittman are presented, respectively, in Appendix F and G of this report.

7.1 SEDIMENT FIXATION TEST

Sediments contain total arsenic concentrations in the range of not detected to 6,600 mg/kg. Four arsenic species contained in the sediments are As (V), As (III), monomethyl arsenic acid (MMAA) and dimethyl arsenic acid (DMMA). The inorganic arsenate is approximately 75 percent of the total arsenical species. The sediment sample for the chemical fixation tests was a composite. One-half was collected from the on-site unlined lagoon which receives treated wastewater and non-contact cooling water discharge, and the other half was collected from the Blackwater Branch. The composite sample was obtained on August 14, 1987. The sample tested was a composite sample with equal volumes of sample collected from both areas.

7.1.1 Objectives

The purpose of conducting the fixation test was to confirm whether arsenic in the sediments could be chemically stabilized or physically bound to the sediment such that leachable arsenic was reduced after performing the RCRA Extraction Procedure Toxicity Test (EP Tox) to a level below 5 mg/l of total arsenic. At the time of the test, it was believed that if the treated material passed this criterion, it would be considered nonhazardous and could be disposed of in a nonhazardous waste landfill. Subsequent guidance has been received on the requirements to consider the treated materials nonhazardous. These requirements are discussed in detail in the River Areas FS (Ebasco, 1989d).

VIN 002 0794

7.1.2 Description of Test

The fixation test consisted of four (4) sequential tasks:

- o Sediment characterization;
- o Chemical fixation and solidification with different formulations;
- o Unconfined strength (UCS) test and RCRA Extraction Procedure (EP) Toxicity Test; and
- o USEPA Multiple Extraction Procedure (MEP) test.

Sediment Characterization

The sediment sample was analyzed for total arsenic content and total organic carbon content to determine whether the sample was representative and suitable for testing. The sample was found to contain total arsenic of 320 mg/kg which was representative of the arsenic concentration of the sediments in the river areas.

Fixation and Solidification

Three (3) samples were treated using three formulations in an attempt to economically transform the sediment into materials which would meet the performance criteria (e.g., leachable concentration below 5 mg/l of total arsenic and 1,500 lb/ft^2 of UCS).

A commercial silicated blend known as K-20/LSC Lead-in-Soil Control System developed and manufactured by Lopat Enterprises, Inc. of Wanamassa, New Jersey was selected because of its ability to be custom-blended as needed for a particular application. In addition, the K-20/LSC System has been demonstrated and proven effective for essentially all of the toxic metals (e.g., Pb, Ba, Cd, Cr, As, Hg etc.). Although to a lesser degree, K-20/LSC has also been proven effective for certain organic compounds such as PCBs.

As shown in Table 7-1, the three samples were chemically fixed and solidified using three different mixtures of chemicals (such as Darco Gro-Safe Activated Carbon), additives (Type 1 Portland cement, lime, and Type F fly ash) and properietary reagents (K-20/LSC). The treated samples were allowed 48 hours curing and drying.

UCS Test and EP Toxicity Test

The treated samples were tested for Unconfined Strength (UCS) during the 48-hour curing and for the EP Toxicity Test (40 CFR 261.24) after curing for 48 hours.

VIN 002 0795

TABLE 7-1

SUMMARY OF TREATABILITY TESTS FOR THE CHEMICAL FIXATION AND SOLIDIFICATION OF ARSENIC IN SEDIMENT

SAMPLE NUMBER	SAMPLE TREATMENT	USC (lb/ft^2)	VOLUME CHANGE (%)	TOTAL ARSENIC CONCENTRATION: EP TOX TEST (mg/l)	Multiple Extraction Procedure (MEP Tests (mg/l) 1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1. 1106-84-02	400 grams of Sediment + 0.5%* K-20 LSC **+ 2% Darco Gro-Safe Activated Carbon + 36% Type I Portland Cement + 12% Type F Fly Ash.	9,000	-34	1.5	0.02	0.14	0.12	0.07	0.07	0.08	0.05	0.07	0.09	0.12
	Results of Confirmatory Analyses	-	-	0.80	0.32	0.20	0.08	0.05	0.05	0.06	0.05	0.05	0.06	0.06
2. 1106-85-01	400 grams of Sediment + 0.5% K-20 LSC + 2% Darco Gro-Safe Activated Carbon + 40% Lime + 20% Type I Portland Cement + 20% Type F Fly Ash.	8,000	- 2	1.2										
3. 1106-85-02	400 grams of Sediment + 0.5% K-20 LSC + 2% Darco Gro-Safe Activated Carbon + 60% Lime + 60% Type F Fly Ash.	600	+70	1.0										

* Percentage of Sample weight.

** K-20 is a silicate based fixation reagent and a proprietary reagent of Lopat Enterprises, Inc. LSC (K-20 Lead-in-soil Control System)

VIN 002 0796

MEP Test

The tested sample which best complied with the established performance criteria was further tested by the USEPA Multiple Extraction Procedure (MEP) to estimate the long-term stability of the treated material under conditions simulating 1,000 years of exposure to acid rain (47 CFR 52686-87, November 22, 1982). If the solidified sample complied with the leachable concentration of 5 mg/l for all ten sequential extractions, a duplicate treated sample would be prepared to demonstrate the reproducibility of the treatment.

7.1.3 Results

As shown in Table 7-1, all three treated samples meet the performance criteria of fixation and solidification except Sample 1106-85-02 which failed to meet the UCS requirement (i.e., 1,500 lb/ft^2). The leachable arsenic concentrations resulting from the EP Tox tests were in the range of 1.0 to 1.5 mg/l.

Sample 1106-84-02 consisted of sediment, K-20/LSC, activated carbon, Portland cement and fly ash. Since the fixation required water, no dewatering was required for the sediments other than decanting of the supernatant. After 48 hours of curing, the mixture passed the RCRA EP toxicity test and its unconfined compressive strength reached 9,000 pounds per square foot (lbs/ft^2) as measured by the ASTM unconfined strength test. This strength is higher than the 1500 lbs/ft^2 generally required for landfilling and is sufficient to support truck traffic and other earth moving equipment. The sediment-mixture volume was only 34 percent of the original sediment volume due to the drying and solidification of the sediments. Cost for a full scale fixation operation was estimated to be $150 to $200 per cubic yard of sediment.

Sample 1106-85-01 reacted similarly to Sample 1106-84-82 although lime was also added to the mixture. The mixture passed the EP Tox test and had an unconfined compressive strength of 9,000 lbs/ft^2. There was substantially no change in the mixture volume after drying and solidification. The cost for a full-scale operation was estimated to be $175 to $225 per cubic yard of sediment.

Sample 1106-85-02 reacted similarly to Sample 1106-85-01 but Portland cement was not used in the mixture. The mixture passed the EP Tox test and resulted in 600 lbs/ft^2 of unconfined strength, below the performance criteria of 1,500 lbs/ft^2 The mixture volume increased 70 percent over the sedimen volume. Costs for a full-scale operation were estimated to be $200 to $250 per cubic yard of sediment.

VIN 002 0797

Sample 1106-84-02 was found to be the most promising of the three test formulations and was therefore selected to undergo MEP testing. The selection was made based on the consideration of cost-effectiveness and the potential for volume reduction. As shown in Table 7-1, the leachable arsenic concentrations from the MEP test were in the range of 0.02 to 0.15 mg/l which is far below the toxicity criterion of 5 mg/l. All ten sequential extractions performed as part of the MEP test passed the toxicity criterion. A duplicate treated sample was then prepared for MEP testing. This duplicate sample also passed the MEP test and demonstrated the reproducibility of the treatment.

The K-20/LSC System is an inorganic silicate-based material that is non-toxic, non-hazardous, and easy and safe to apply. The major functions of the K-20/LSC System which contribute to the successful fixation and solidification of arsenic compounds are:

- Precipitation of heavy metals contaminants;
- Encapsulation of heavy metals contaminants; and
- Protection and stabilization of encapsulated metal contaminants from acid (rain).

7.1.4 Conclusion

Based on these laboratory results, it is concluded that the arsenic compounds in the river area sediments could be chemically stabilized to well below the target criterion of 5 mg/l leachable arsenic.

7.2 ARSENIC EXTRACTION FROM SEDIMENT TEST

The sediment sample for the arsenic extraction tests was a composite, with one-half collected from the on-site unlined lagoon which receives treated wastewater and non-contact cooling water discharge, and the other half collected from the Blackwater Branch on July 17, 1987. The sample tested was a composite sample with equal volumes of sample collected from both areas.

7.2.1 Objectives

The primary purpose of the chemical extraction tests was to obtain performance data on the extraction of arsenic oxides and methylated arsenic oxides from the sediments. The performance criterion required that the treated sediment contain a total arsenic concentration below 20 mg/kg (the arsenic cleanup level in the New Jersey Environmental Cleanup Responsibility Act Standards (ECRA, NJAC 7:26B-1.1 et seq.)). This target level was established at the beginning of the investigation. Subsequent guidance has been received concerning the criteria for nonhazardous disposal of the extracted sediments. The new requirements are discussed in detail in the River Areas FS report (Ebasco, 1989d).

VIN 002 0798

In addition, the results of this test provided the data to determine the amount of and costs for chemicals required for successful extraction. This information was needed for determining the economic feasibility of extracting arsenic from sediments.

7.2.2 Description of Test

The chemical extraction test consisted of three sequential tasks:

- o Sediment characterization;
- o Comparison of extraction reagents; and
- o Evaluation of pH and temperature effects on arsenic removal.

Sediment Characterization

The sediment sample was analyzed for total arsenic content and total organic carbon content to determine whether the sample was suitable for testing. The sample was found to contain total arsenic of 2,780 mg/kg. The sample represented arsenic concentrations at the high end of those found in the river sediments.

Comparison of Extraction Reagents

The sample was decanted for supernatant only and did not require any further dewatering. The sample was extracted with water, with and without added chelating compounds. Sodium citrate, sodium oxalate, and ethylenediaminetetra-acetate (EDTA), all commonly used extracting agents, were the three chelating reagents tested. A 200 gram sample was added with 200 ml of aqueous reagent to form a slurry. The slurry was stirred continuously for two hours at a speed of 40 rpm. The treated samples were allowed to settle and the settled samples were then analyzed for total arsenic and total organic carbon. The tests for the chelating reagents evaluation were conducted at room temperature and a pH of 7.0.

Evaluation of pH and Temperature Effects on Arsenic Removal

The samples were extracted with water at different pH levels to determine the optimal pH for arsenic extraction. Sodium hydroxide and hydrochloric acid were used to adjust the samples from near-neutral condition to acid and alkali conditions. The samples were extracted with water at pH's of 7.0, 12.0, and 3.0.

The chelating reagent which appeared most effective in removing arsenic compounds was used for extraction at different temperatures (24°C and 50°C) and different pH levels (5.0 and 7.0). Due to the very high organic content (70,000 mg/l) of the sediment, a very large amount of NaOH was required to maintain the extraction at a high pH level.

VIN 002 0799

7.2.3 Results

As shown in Table 7-2, extraction without a chelating reagent did not remove arsenic from the sediments below the performance criterion (i.e., 20 mg/kg of total arsenic) at room temperature or near-neutral pH. Chelated extraction with sodium citrate seemed to work best at removing arsenic under these conditions. After washing (to remove any residual reagent), the extracted sludge contained 21 mg/l of total arsenic which almost achieved the target arsenic concentration of 20 mg/l of total arsenic. It should be noted that the chemical extraction process generated a significant amount of suspended fine organic particles which almost equal 90 percent of the TOC contained in the original sediment sample. Most of the suspended organic particles could not be removed by gravity sedimentation.

With the exception of extreme alkali conditions (i.e., pH of 12.0) the pH effects on the removal of arsenic from sediments were insignificant. The experiment revealed that extremely large amounts of NaOH were required to maintain the pH at a constant value of 12. For example, 400 ml of 5N NaOH were not sufficient to keep the pH at 12 through the two-hour extraction of a 200 ml slurry. This phenomenon was probably due to the very high organic content of the sediment.

The experiment indicated that high temperature did not result in any improvement in arsenic extraction. In fact, the extraction at high temperature (50°C) removed less arsenic from the sediments than at room temperature (24°C). Therefore temperature is not an important factor in the chemial extraction treatment process.

Cost for a full-scale operation of arsenic extraction processes utilizing sodium citrate was estimated to be $100 to $150 per cubic yard.

7.2.4 Conclusion

Based on these laboratory results, it is concluded that the target arsenic concentration (below 20 mg/l of total arsenic) could be achieved for the sediments by chemical extraction with the citrate chelator at a pH range of 5 to 7 at room temperature (24°C).

VIN 002 0800

TABLE 7-2

SUMMARY OF TREATABILITY TESTS FOR THE EXTRACTION OF ARSENIC FROM SEDIMENT

Sediment Characterization

Sample Number	Untreated Sediments Total As (mg/kg)	TOC (mg/kg)
833-039-03	2,780	70,000

Selection of Chelating Reagents

Sample Number		Treated Sediments* Total As (mg/Kg)	TOC (mg/Kg)
836-003-03	No Chelator, pH = 7.0, 24°C	36	513
836-005-01	Sodium Citrate 3,170 mg/l, pH = 7.0, 24°C	21	635
836-005-02	Sodium Oxalate 3,490 mg/l, pH = 7.0, 24°C	45	953
836-005-03	EDTA (Tetrasodium Salt) 1,440 mg/l, pH - 7.0, 24°C	37	506

pH Effects

Sample Number		Treated Sediments* Total As (mg/Kg)	TOC (mg/Kg)
836-003-03	No Chelator, pH = 7.0, 24°C	36	513
836-003-04	No chelator, pH = 12.0, 24°C	14	488
836-003-05	No Chelator, pH = 3.0 24°C	36	833

* Performance criterion of treated sediments contain total As less than 20 mg/Kg.

VIN 002 0801

TABLE 7-2 (Cont'd)

SUMMARY OF TREATABILITY TESTS FOR THE EXTRACTION OF ARSENIC FROM SEDIMENT

pH And Temperature Effects

Sample Number		Treated Sediments Total As (mg/Kg)	TOC (mg/Kg)
836-007-01	Sodium Citrate 3,170 mg/l, pH = 5.0, 24°C	21	756
836-008-01	Sodium Citrate 3,170 mg/l, pH = 7.0, 50°C	44	2,650
836-008-02	Sodium Citrate 3,170 mg/l, pH = 5.0, 50°C	32	1,460

VIN 002 0802

VIN 002 0803

8.0 SUMMARY AND CONCLUSIONS

This section summarizes the major findings of the RI, and provides recommendations for future work. Potential remedial action objectives are also identified.

8.1 SUMMARY

8.1.1 Nature and Extent of Contamination

The main contaminant of concern in the river areas is arsenic. Arsenic was detected at elevated concentrations in the sediment and surface water in the Blackwater Branch downstream from the ViChem plant, the upper Maurice River below its confluence with the Blackwater Branch, Union Lake, and the Maurice River below Union Lake. Arsenic concentrations were very low to undetected upstream from the plant.

The highest surface water arsenic concentration was observed in the flooded swamp caused by a beaver dam on the Blackwater Branch (over 6000 ug/l). The swamp was directly adjacent to the ViChem plant and in the direction of the arsenic-contaminated groundwater plume emenating from the plant site. This swamp has been drained since the sampling took place through the removal of the beaver dam.

The arsenic concentration in the surface water decreased progressively downstream in the upper Maurice River, probably as a result of dilution. All of the tributaries to the Maurice River between the Blackwater Branch and Union Lake had undetected arsenic concentrations.

The arsenic concentration in the surface water in the lower Maurice River decreased gradually downstream from the lake until the tidal front was encountered, evidenced by elevated specific conductance levels. The arsenic concentration dropped fairly sharply at the tidal front, and stayed low further downstream to the Delaware Bay.

The total arsenic concentration in the Maurice River did not drop below 50 ug/l, the Federal Primary Drinking Water Standard for arsenic, until approximately 21 river miles downstream from the ViChem plant at station ER-37 in the lower Maurice River. In the 1979 sampling performed by the NJDEP, the total arsenic concentration in the surface water did not drop below 50 ug/l until approximately 26.5 river miles downstream from the site.

Unlike the surface waters, there was no clear pattern of arsenic distribution areally in the sediments. Some concentrations were higher further downstream than upstream. The sediment arsenic distribution is more likely controlled by arsenic's

VIN 002 0804

chemical partitioning to fine grain sized material and by the local deposition rate than by strict distance downstream from the site.

The arsenic concentration in the sediment cores was variable. In some cores the arsenic concentration was higher at the surface than at depth, while in some others the concentration was higher at depth. In some cross-sectional studies one core showed higher concentrations at the surface while another core showed the opposite. This was interpreted to indicate that the sediments were subject to mixing, resuspension and redeposition.

No pesticides/PCB's were found in the three fish samples taken from the upper Maurice River. However, arsenic was detected in one of the fish samples from the upper Maurice River, and the crab and oyster samples from the lower river. Arsenic was not detected in the two fish samples from the lower Maurice River. The detected concentrations were generally within the range of normal background levels in fish and shellfish.

Other compounds detected in the river areas included mercury, lead, cadmium, chromium, antimony, toluene, TCE, Gamma-BHC, DDT, and endosulfan sulfate. These compounds were generally detected at very low concentrations and posed no significant health or environmental risks, with the exception of mercury. As discussed in the text, an increased health risk from ingesting fish containing mercury was calculated. However, the calculation was based on the mercury concentration in the water and the bioconcentration factor for mercury in fish, not on actual measurements of mercury in fish tissue.

8.1.2 Contaminant Fate and Transport

The ViChem plant was shown to be the only significant source of arsenic to the Maurice River drainage basin. All river sections downstream from the site showed elevated levels of arsenic in both water and sediments. The levels of arsenic in all of the other tributaries studied was very low to undetected. Small sources below the Union Lake dam cannot be ruled out but no evidence exists for any inputs.

Based on samples collected by ViChem at Mill Road, an estimated 500 metric tons of arsenic were transported past Mill Road into the Blackwater Branch and upper Maurice River. Instantaneous flux measurements by a number of investigations agreed with the historic trend at Mill Road and indicated that the flux from the site was 4 to 8 metric tons/yr in 1987. These fluxes were confirmed by cross checking Ebasco, USGS and ViChem data. Arsenic was transported in the basin in both dissolved and suspended forms. Arsenic concentrations varied throughout the year, inversely correlating with water flow.

VIN 002 0805

Arsenic concentrations in the sediments of the Blackwater Branch and upper Maurice River positively correlated with total organic carbon content, iron content and percent clay. These data suggested that arsenic was bound to the sediments via organic carbon and ferric hydroxide matrices which coat the finer sediments fractions. Leach tests of Union Lake sediments by Winka (1985) showed that 50 to 70% of the sediment bound arsenic was not easily extractable. The fraction retained correlated positively with percent organic matter.

The three river sections were examined to determine their influence on the arsenic load. The Blackwater Branch and upper Maurice River appeared to be simple conduits for arsenic released from the site based on the arsenic mass balance for 1987 and the low inventory of arsenic in the sediments. The effect of Union Lake on the present arsenic balance was unclear. Mass balance calculations showed it to be a simple conduit. However, sediment-water equilibria show that the lake water and sediments were near equilibrium. Given these conflicting mechanisms, the present fate of arsenic in the lake was not predictable. The large inventory of arsenic in the lake sediments (140 metric tons) showed that the lake has been a sink for arsenic in the past. The lower Maurice River may capture on the order of 50 percent of the arsenic which escapes from Union Lake in its estuarine sediments. However, it was noted that an insufficient data base exists to reliably quantify the sediment arsenic inventory in the lower Maurice River. Any arsenic entering the lower river and not adsorbed onto the sediments was presumably transported to Delaware Bay.

Future arsenic levels are difficult to predict in certain parts of the basin even if the arsenic flux to the basin from the site is halted. The level of water-borne arsenic in the upper Maurice River and the Blackwater Branch should drop shortly after the source of arsenic is eliminated due to the low arsenic inventory in the sediments. Since it is not clear what is controlling the water column arsenic inventory in Union Lake at present, it is difficult to predict future levels. Almost certainly though, the lake arsenic levels will decrease. The water column arsenic levels in the lower Maurice River are dependent upon lake arsenic levels so that it is not possible to conclude that future arsenic levels will drop below 50 ug/l, but this would be the most likely scenario.

8.1.3 Risk Assessment

Two types of risk assessments were performed. In the Blackwater Branch and the upper Maurice River, a semi-quantitative risk assessment for populations potentially exposed to the river sediments, water, and fish was prepared. Quantitative exposure models were developed, and measured contaminant concentrations were used to calculate site-specific carcinogenic risks, and to

VIN 002 0806

estimate probable non-carcinogenic risks. Risks were estimated for both "worst case" and "most probable" exposure scenarios to determine the likely range of risks. In the lower Maurice River, a qualitative risk assessment was performed. Pathway models and contaminant concentrations were reviewed to estimate in a qualitative sense whether the lower Maurice River posed a potential health threat to exposed populations.

In the Blackwater Branch, the total worst case and most probable carcinogenic risks were $5x10^{-3}$ and $5x10^{-5}$, respectively. In the upper Maurice River, were $1x10^{-3}$ and $1x10^{-4}$, respectively. At the Almond Road beach, a popular local recreational area on the Maurice River, the total worst case and most probable risks were $7x10^{-5}$ and $9x10^{-6}$ respectively. Non-carcinogenic risks were generally minor. In all cases, ingestion, either of sediment, water or fish, composed essentially all of the risks. Dermal contact with the water and inhalation were insignificant.

In the lower Maurice River, it was estimated that none of the exposure pathways posed increased health risks from arsenic. This was based both on differences in exposure pathways between the upper and lower river, and on the generally lower arsenic concentrations in the lower river.

The ingestion of fish, crabs and oysters with the arsenic concentrations found in this study posed risks above the 1×10^{-6} target level. However, it was pointed out that the actual risks may be much lower than the calculated risks. The form of arsenic in fish and shellfish is generally non-toxic and is easily excreted by humans. Also, the levels of arsenic found in the biota samples were within the range of arsenic normally found in fish and shellfish.

An increased health risk from ingesting mercury in fish was calculated. However, it was noted that the risk was based on estimated mercury concentrations in the biota determined from the mercury concentration in the surface water and the bioconcentration factor. The biota samples were not analyzed for mercury, therefore their actual mercury concentration is unknown.

An environmental assessment was prepared by the USEPA. The study concluded that an impact to the benthic communities in the Blackwater Branch had occurred. The impact took the form of lower specie diversity, and increased toxicity in bioassay studies from arsenic laden sediments collected just downstream from the site.

VIN 002 0807

A data quality analysis and the limitations of the risk assessment were discussed. It was concluded that, while the analytical data used was of the highest quality, there is enough uncertainty in the exposure assumptions to attach confidence in the risk calculations only within one order of magnitude.

Finally, potential cleanup levels for remediating contaminated sediments were calculated using both the worst case and the best estimate exposure assumptions. This was done by setting a target risk level, and back-calculating the sediment arsenic concentration which would produce that risk level using the pathway models. This was done to help EPA determine potential cleanup strategies for the river areas if desired. The cleanup levels are discussed in Subsection 8.2.3, Recommended Remedial Action Objectives.

8.2 CONCLUSIONS

8.2.1 Data Limitations

The samples taken by Ebasco in Phase I and II for this RI, with the exception of treatability samples, were analyzed and validated by the CLP. These analyses were considered confirmational level, that is, the highest level of data quality. These analyses required full CLP analytical and validation procedures, and were designed to be legally defensible. These types of analyses are used for risk assessments, engineering design, and cost recovery documentation.

The quantity estimates, results and conclusions presented in this RI are based on this CLP validated analytical data. Data which were rejected in the validation process were not considered when drawing conclusions about the nature and extent of contamination at the site.

Extensive use was made of data previously obtained by others in this RI report. For example, the arsenic speciation work performed by Winka in the watershed, the USGS streamflow and arsenic data collected at Norma (ER-7), previous studies performed for NJDEP, and arsenic analyses in the City of Millville's and Vineland's water supply system were reviewed and incorporated in some fashion into the description of arsenic's mobility in the watershed. While the chemical analyses presented in many of these previous studies may not have been performed to the same QA/QC standards as the samples taken for this RI, the previous body of existing data could not be ignored in attempting to define the arsenic contamination in the watershed. While the previous investigations provided significant assistance, the location of contamination and its fate are fully supported by Ebasco's validated analytical data.

VIN 002 0808

Certain field tests were performed, such as pH, Eh, specific conductance and temperature measurements on surface water samples. These field tests provided useful background information, but were not the basis for documenting the contamination at the site.

Various quantity estimates presented in this RI used the CLP analytical data and physical measurements made in the field. For example, the load of arsenic in the Blackwater Branch was determined using the arsenic concentration from the CLP analytical data and stream flow measured in the field. Field measurements were made consistent with the methods presented in the Field Operations Plan for the ViChem Site (Ebasco, 1986).

The risk assessments presented in Section 6 were semi-quantitative in the Blackwater Branch and the upper Maurice and qualitative in the lower Maurice River. The first is considered semi-quantitative because some of the assumptions made, days per year at the river, for example, are estimates rather than actual measured values. As discussed in the text, because so many assumptions are made in the pathway models, the risk calculations should not be considered more accurate than one order of magnitude.

8.2.2 Recommendations for Future Work

The groundwater discharge off of the ViChem site clearly is the major source of arsenic to the Maurice River system. Assuming that the source of arsenic was eliminated, i.e., a remedial action at the site prevented groundwater discharge into the Blackwater Branch, the effect of this on the surface water quality downstream would be important to know. The data suggest that the Blackwater Branch and the upper Maurice River behave basically as conduits, transferring arsenic in the water column downstream into Union Lake. Reducing the arsenic flux off the site should reduce the arsenic load and concentration in these streams. However, as discussed in the text, the effect of this on Union Lake's water is unknown since it is not known whether the lake is presently behaving as a conduit or whether the lake water is at equilibrium with the sediments.

An additional data need would therefore be to obtain water quality and flow data at various points in the basin. One point could be located on the Blackwater Branch, another could be located at the existing USGS gaging station at Norma (ER-7), and a third could be located on the Union Lake spillway. Concurrent flow and water quality data obtained at these three points. This would definitively establish arsenic inflow and outflow from the basin.

Logistically, the sampling program would be fairly simple to put in place. The USGS gaging station at Norma is now operational, and the frequency of sampling could be increased to monthly or

VIN 002 0809

semi-monthly sampling for arsenic. Some type of flow measuring device could be installed on the dam at the outlet of Union Lake. Water samples could be obtained on the same frequency as samples from the Norma station. A gaging station could be established on the Blackwater Branch downstream from the ViChem site, recording the stream flow and serving as a water quality sampling point. A comparison of the results through time would provide valuable data to determine the arsenic behavior in the basin. If the program were started relatively quickly, a data base would be established prior to performing any remedial action at the site, and would help to determine its effectiveness. Also, this type of sampling would have a relatively low cost.

Additional studies to determine the adsorption/desorption rates of arsenic from the sediments should also be performed. These could aid in determining the fate and transport of arsenic within the sediments. Presently, it is known that arsenic can desorb off of the sediments, but the extent to which this desorption will influence the water quality of Union Lake and the lower Maurice River is unknown since the rate of desorption is not known. Detailed information on this process would help determine if source area remediation (at the ViChem plant site) would lower the arsenic concentraton of the lake and lower Maurice River. This work could be done in conjunction with the simple sampling program mentioned above for the lake and river.

The fish in the rivers contain some arsenic, which calculates to a possible health risk through ingestion. However, as discussed previously, the form of arsenic in the fish is not known. It is probable that the arsenic is present in a fairly non-toxic organic form. The form of arsenic in some fish samples in the river should be determined since fishing is a popular recreational activity in the river.

8.2.3 Recommended Remedial Action Objectives

The source of the arsenic contamination to the river system is the groundwater discharge off of the ViChem site. Before any remedial action was taken in the river area, this source should be eliminated.

The formerly flooded area near the Blackwater Branch contains very high arsenic concentrations. This area is now exposed since the beaver dam was breached, making public access to the former sediments more likely. There are other areas where sediment arsenic concentrations are elevated and are estimated to pose potential health risks. Table 8-1 presents sediment arsenic concentrations which produce various risk estimates based on the worst case and most probable pathway models. Public access to areas with arsenic concentrations greater than that deemed acceptable by the EPA, considering Table 8-1, should be eliminated. This can be accomplished by some type of remedial action such as removal, or through sign posting.

VIN 002 0810

TABLE 8-1

CALCULATED RISK FROM SEDIMENTS
AT
VARIOUS ARSENIC CONCENTRATIONS

CALCULATED RISK[1]	SEDIMENT ARSENIC CONCENTRATION (mg/kg)[2]
Worst Case:	
1×10^{-4}	200
1×10^{-5}	20
1×10^{-6}	2
1×10^{-7}	0.2
Most Probable Case:	
1×10^{-4}	1200
1×10^{-5}	120
1×10^{-6}	12
1×10^{-7}	1.2

[1] Calculated Risks Assume Sediment Exposure Pathways only.

[2] Contract Laboratory Program Required Detection Limit for arsenic in soil/sediment is approximately 2 mg/kg.

VIN 002 0811

The river water is contaminated with arsenic. However, the data indicates that once the arsenic source from the plant is eliminated, the river arsenic concentration should decrease. Because of this and because of the infeasibility of treating a flowing stream, no remedial action other than removing the source of arsenic (the groundwater discharge) is recommended. The monitoring program presented previously should be implemented to monitor/verify the effectiveness of any remedial action.

The fish in the river contain some arsenic, however there are no remedial alternatives for this problem. If EPA risk managers determine, either through additional sampling or a further review of the literature, that the fish arsenic concentration is unacceptably high, then the only practical remedial action to take would be posting signs banning fishing. Detailed consideration should be given before taking this action, however, due to the uncertainties of the risk estimates and the popularity of this activity to the local population.

In summary, the recommended remedial action objective for the river areas is as follows:

- Minimize public access, either through containment, treatment, or institutional controls, to areas with unacceptably high sediment arsenic concentrations, particularly the exposed former sediments in the Blackwater Branch floodplain.

VIN 002 0812

REFERENCES

Anderson, A.C. et al. 1975. The acute toxicity of MSMA to black bass (Micropterus dolomien), crayfish (Procambarus Sp.), and channel catfish (Icatalurus lacustris). Bull. Environ. Contam. Toxicol. 14:330.

Andreae, M.O. 1979. Arsenic speciation in seawater and interstitial water: the influence of biological - chemical interactions on the chemistry of a trace element. Limnol. Oceanogr. 24: 440-452.

Armstrong, C.W., Stronbi, R.B., Rubio, T., et al. 1984. Outbreak of fatal arenic poisoning caused by contaminated drinking water. Arch Environ Health 39: 276-279.

Arsenic, CAS RN 7440-38-2, 1984. OAMTADS Data Base (Oil and Hazardous Materials Technical Assistance Data Base). Chemical Information System, Inc., Baltimore, MD.

ATSOR. 1987. Draft Toxicological Profile for Arsenic.

Atkinson, R. 1985. Kinetics and mechanisms of the gas-phase reactions of hydroxyl radicals with organic compounds under atmospheric conditions. Chem Rev 85: 129.

Bakri, F. et al. 1973. Methylmercury poisoniong in Iraq. Science 181: 234.

Baes, C.F., III, R.D. Sharp, A.L. Sjoreen, and R.W. Shor, 1984. A review and analysis of parameters for assessing transport of environmentally released radionuclides through agriculture. Prepared for the USEPA by Oak Ridge National Laboratory, Oak Ridge, TN.

Baranski, B. and I. Szymczyk. 1973. Effects of mercury vapor upon reproductive functions of female white rat. Med. Pracy. 24: 248.

Bardodey, Z. and J. Vyskocil 1956. The problem of trichloroelene in occupational medicine: Trichloroethylene metabolism and its effects on the nervous system is a means of hygienic control. AMA arch. Ind. Health 13: 581.

Benson, A. and R. Summons, 1981. Arsenic accumulation in Great Barrier Reefs, Australian Invertebrates. Science 211: 47-52.

Berger, K. and A. Jernelov. 1979. Methyletion of mercury in neutral waters. Pages 201-210 in J.O. Nrigen (ed.). The biogeochemistry of mercury in the environment. Elsevier/North-Holland Biomedical Press. New York.

VIN 002 0813

Birge, W.J. 1979. Aquatic Toxicology of Trace Elements in Coal and Fly Ash. In: Energy and Environmental Stress in aquatic systems. Thomas Hunt Morgan School of Biological Sciences, Lexington, Kentucky, Sel. Water Res. Abs. 12: W79-09248.

Blumer, M., W. Blumer, and Reich, T. 1977. Poly cyclic aromatic hydrocarbons in soils of a mountain valley: correlation with highway traffic and cancer incidence. Environ. Sci. Tech. 11: 1082-1084.

Bolt, H.M. and J.G. Filser. 1977 Irreversible binding of chlorinated ethylene to macromolecules. Environ. Health Presp. 21: 107.

Boudon, A., and F. Ribeyre, 1983. Contamination of aquatic biocenoses by mercury compounds: an experimental toxicological approach. Pages 73-116 In: J.O. Niragu (ed.) aquatic toxicology. John Wiley, New York.

Braman, R.S., and C.C. Foreback 1973. Science 183: 1247-9.

Braman, R.S., and C.C. Foreback 1973. Methylated forms of arsenic in the environment. Science. 182: 1247.

Buchet, J.P., Lauwerys, R., and H. Roels. 1980. Comparison of several methods for the determination of arsenic compounds in water and in urine. Int. Arch. Occup. Environ. Health 46: 11-29.

Burgdoff, W., K. Kurvink and J. Cervenka 1977. Elevated sister chromatid exchange rate in lymphocytes of subjects treated with arsenic. Hum. Genet. 36: 69-72.

Burrows, W.D. and P.A. Krenkel. 1973. Studies on uptake and loss of methylmercury -203 by bluegills. Environ. Sci. Tech. 7: 1127.

Callahan, M.A., M.W. Slimak, N.W. Gabel, et al. 1979. Water-related environmental fate of 129 priority pollutants - Vol II. EPA-440/4-79-0298. Washington D.C.

Callahan, M. M. Slimek, N. Gabel, I. May, C. Fowler, R. Freed, P. Jennings, R. Durfee, F. Whitmore, B. Maestir, W. Mabey, B. Holt, and C.S. Gould. 1979. Water Related Fate of 129 Priority Pollutants, Vol.1 and 2. U.S. Environmental Protection Agency, Washington, D.C. Research Report EPA - 440/4-79-029.

Cannon, J.R., J.B. Saunders, and R.F. Toia. 1983. Isolation and preliminary toxicological evaluation of arsenobetaine - the water soluble arsenical constituent from the hepatopancreas of the western rock lobster. The Sci. of the Total Environmental 31: 181-185.

VIN 002 0814

Cardwell, R.D. et al. 1976. Acute toxicity of selected toxicants to six species of fish. Ecol. Res. Series EPA 600/3-76-008. US Environ. Prot. Agency.

Carr, R.A. and P.E. Wilkens. 1973. Mercury: Short term storage of neutral waters. Environ. Sci. Technol. 7: 62-63.

Chamberlain, A., C. Heard, M.J. Little, et al. 1978. Investigations into lead from motor vehicles. Harwell, United Kingdom: United Kingdom Atomic Energy Authority. Report No AERE-9188.

Clarkson, T.W. 1971. Epidemiological and experimental aspects of lead and mercury contamination of food. Food Cosmet. Toxicol. 9: 1.

Clarkson, T.W., and D.O. Marsh 1982. Mercury toxicity in man. Pages 549-568. In A.S. Prasad (ed.). Clinical, biochemical and nutritional aspects of trace elements. Vol 6. Alan R. Liss, Inc. New York.

Clayton, G.D. and F.E. Clayton, editors. 1981. Patty's Industrial Hygiene and Toxicology Vol 2B, Toxicology. 3rd Edition, John Wiley and Sons, New York.

Clement, W. and S. Faust. 1981. The release of arsenic from contaminated sediments and muds. J. Environ. Sci Health 16: 87-122.

Cole, W.J., R.G. Mitchell, R.F. Salsmonsen, 1975. Isolation, characterization and quantitation of chlorel hydrate as a transport metabolite of trichloroethylene in man using electron gas chromotography and mass fragementography. J. Rharm. Pharmacol 27: 167.

Cox, D.P. and M. Alexander. 1973. Production of trimethylarsine gas from various arsenic compounds by three sewage fungi. Bull. Environ. Contam. Toxicol. 9: 84-88.

Damluji, S., et al. 1976. Intoxication due to alkyl mercury treated seed, 1971-1972. Outbreak in Iraq: Clinical aspects. In: WHO conference in intoxication due to methylmercury 0 treated seed. Suppl. Bull. WHO 53, Baghdad.

Daniel, J.W. 1963. The metabolism of Cl-labeled trichloroethylene in the net. Biochem Parmacol 12: 795.

Das, S.K., A. Sherma, and G. Talukder. 1982. Effects of mercury on cellular systems in mammals - a review. Nucleus (Calcutt) 25: 193-230.

Dekant, W., M. Metzler, D. Hanschler 1984. Novel metabolites of trichloroethylene through dichlorination reactions in rats, mice, and humans, Brochem. Pharmacol. 33: 2021.

VIN 002 0815

Deuel, L.E. and A.R. Swoboda. 1972. Arsenic solubility in a reduced environment. Soil Sci. Soc. Americ. Proc. 36: 276-278.

Dilling, W.L., N.B. Tefertiller and G.J. Kallos. 1975. Evaporation rates and reactivities of methylene chloride, chloroform, 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene, and other chlorinated compound in diulte aqueous solutions. Environ. Sci. Techn. 9: 833.

Druckrey, H. et al. 1987. Carcinogenic action of metallic mercury after intraperitioned administration in rats. Z. Krebsyforsch 61: 511.

Dutkiervicy, T. 1977. Experimental Studies on Arsenic Absorption Routes in Rats. Environ. Health Persp. 19: 173-177.

Dykson, J.E. and A.F. Hess. 1982. Alternative for controlling organics in groundwater supplies. J. Am. Water Works Assoc. 74: 394.

Ebasco, 1989a. Vineland Chemical Company Site. Final Draft Remedial Investigation Report - Plant Site.

Ebasco, 1989b. Vineland Chemical Company Site. Final Draft Feasibility Study Report - Plant Site.

Ebasco, 1989d. Vineland Chemical Company Site. Final Draft Feasibility Study Report - River Areas.

Ebasco, 1989e. Vineland Chemical Company Site. Final Draft Remedial Investigation Report - Union Lake.

Ebasco, 1989f. Vineland Chemical Company Site. Final Draft Feasibility Study Report - Union Lake.

Ehrlich. H.L. 1981. Geomicrobiology. Marcel Dekker, New York.

Eisler, R. 1988. Arsenic Hazards to Fish, Wildlife and Invertebrates: A Synoptic Review. Biological Report 85 (1.12). U.S. Fish and Wildlife, Dept. of Interior.

Elkhatib, E.A., O.L. Bennet, and R. J. Wright 1984. Arsenite sorption and desorption in soils. Soil Sci. Soc. Amer. J. 48: 1025-1030.

Erickson, E. 1960. The yearly circulation of chloride and sulfur in nature. Tellus. 12:63-109.

Ferguson, J.F. and J. Gavis. 1972, A review of the arsenic cycle in natural waters. Water Research 6: 1259-1274.

VIN 002 0816

Frankehthal, R.P., 1963 Equilibrium. In: Handbook of Analytical Chemistry, 1st Edition (edited by L. Meites). pp 1-13 to 1-19 McGraw Hill, Toronto.

Fribery, L. et al. 1961. Resorption of mercuric choloride and methylmercury dicyandiamide in guinea pigs through normal skin and through skin pretreated with acetone, alkyl-arylsulphonate and soap. Actu Derm. Veneral. 41:40.

Fribey, L. and F. Nordbey. 1973. Inorganic mercury - a toxicological and epidemiological appraised. In: M.W. Miller and T.W. Clarkson (eds.) Mercury, mercurials and merceptans. Charles C. Thomas, Springfield, Illinois.

Gale, T. and V. Ferm 1971. Embryopathic effects of mercuric. salts. Life Sci 10: 1341.

Garbarini, D.R. & L.W. Lion 1986. Influence of the nature of soil organics on the sorption of toluene and trichloroethylene. Environ. Sci. Technol. 20:1263.

Gilderhus, 1966. Taken from USAMBRDL PPLV Analysis for As. 1986.

Gleason, M.N., et al. 1957. In: Clinical Toxicology of Commercial Products. Williams and Wilkens Co., Baltimore, Maryland.

Gupta, S. and K.Y. Chen. 1978. Arsenic removal by adsorption. J. Water Poll. Control Fed. 50: 493-506.

Hammond, P.B. 1982. Metabolism of lead. In: Chisolm J.J., O'Hara, D.M, eds. Lead absorption in children: management, clinical and environmental aspects. Baltimore, M.D.

Harada, Y.C. 1968. Clinical Investigations on Minameta Disease. C. Congenital (or fetal) Minameta Disease. In: M. Kutsuna (Ed.), Minameta Disease, Study Group of Minameta Disease. Kumomoto University, Japan.

Hawley, N.K. 1985. Assessment of Health Risk From Exposure to Contaminated Soil. Risk Analysis 5:289-302.

Healy, T.E. for T.R. Poole, & A. Hooper. 1982. Rat fetal development and maternal exposure to trichloroethylene at 100 ppm. Br. J. Anaesth 54: 337.

Holland, R.H., M.S. McCall, and H.C. Lanz. 1959. A study of inhaled arsenic -74 in man. Cancer Res. 19: 1154-1156.

Hood, R.D. 1985. Cacodylic acid: agricultural uses, biological effects, and environmental fate. VA Monograph. Avail. from Sup. Documents, U.S. Govt. Printing Off., Washington D.C. 20402.

VIN 002 0817

Hudson, R.H., R.K. Tucker, and M.A. Haegele, 1984. Handbook of toxicity of pesticides to wildlife. U.S. Fish Wildl. Serv. Resour. Publi. 153.

Huff, J.E. 1971. New evidence on the old problems of trichloroethylene, Ind. Med. 40: 25.

Hursch, J.B. et al. 1976. Clearance of mercury (^{197}Hg, ^{203}Hg) vapor inhaled by human subjects. Arch. Environ. Health 4: 302.

Ikeda, M., Y. Miyake, M. Ogeta and S. Ohmori, 1980. Metabolism of trichloroethylene. Biochem Pharmacol. 29: 2983.

Irgolic, K.J, E.A. Woolson, R.A. Stockton, R.D. Newman, N.R. Bottino, R.A. Zingaro, P.C. Kearney, R.A. Pyles, S. Malda, W.J. McShane, and E.R. Cox. 1977. Characterization of arsenic compounds formed by Daphnia magna and tetraselmis chuii from inorganic arsenate. Environ. Helth Perspec. 19: 61-66.

Irgolic, K. 1982. Speciation of arsenic compounds in water supplies, U.S. Environmental Protection Agency, Health Effects Research Laboratory, Cincinnati, Ohio. EPA-600/S1-82-010.

Isensee, A.R., P.C. Kearney, E.A. Woolson, G.E. Jones and V.P. Williams. 1973. Distribution of alkyl arsenicals in model ecosystem. Environ. Sci. Technology 7: 841-845.

Jacobs, L., J.K. Syers, and D.R. Keeney. 1970. Arsenic adsorption by soils. Soils Sci. Amer. Proc. 34: 750-754.

Jalili, M.A. and A.H. Abbasi, 1961. Poisoning by ethyl mercury toluene sulphonanilide. Br. Jour. Ind. Med. 18: 303.

Jenne, E.A., 1972. Mercury in waters of the United States, 1970-1971. Open file rep. U.S. Dep. Interior. Geol. Surv. Menlo Park, California.

Jennelov, A. 1971. Mercury. A case study of Marine Pollution. In: D. Dyressen and D. Jagner (eds.). The Changing Chemistry of the Oceans. Proceed. 20th Nobel Symp., August, 1971. John Wiley and Sons, Inc. New York.

Johnson, D.L. and R.S. Bramen. 1974. Distribution of atmospheric mercury near ground. Environ. Sci. Technol. 8: 1003-1009.

Joran, G.E., D.C. Cameron, and G.W. Halpenny. 1955. Massive necrosis of the liver due to trichloroethylene. Can. Med. Assoc. J. 73: 890.

VIN 002 0818

Kabata - Pendias, A. and H. Pendias, 1984: Trace elements in soils and plants, CRC Press, Boca Raton, FL. Stolzenburg, et al 1986 Aug, 1982, Jernelov, 1981, Lee et al. 1985, Inoue and Muneemori, 1979, Semu et al, 1986, Kuco 1982, in Kabata Pendi as and Pendias).

Kabota-Pendios, A., and H. Pendios. 1984. Trace Elements in Soils and Plants. CRC Press, Inc., Boca Raton, Fl.

Kadowski, K. 1980. Studies in the arsenic contents in organ tissues of the normal Japanese. Osaka City Med. Journal 9: 2083).

Kaise, T. S. Watanabe, K. Itoh. 1985. The acute toxicity of arsenobetaine. Chemosphere 14: 1427-1332.

Karickhoff, S.W. et al. 1979. Sorption of hydrophobic pollutants on natural sediments. Water Res. 13: 241.

Karickhoff, S.W. 1981. Semi-empirical estimation of sorption of hydrophobic pollution on neutral sediments and soils. Chemospheric 10: 833.

Khera, K.S. 1979. Terategenic and genetic effects of mercury toxicity. Pages 501-518 In J.O. Nriagu (ed.) The biogeochemistry of mercury in the environment. Elsevier/North-Holland Biomedical Press, New York.

Kleopfer, R.D., D.M. Easley, B.B. Hass, T.G. Deihl, D.E. Jackson, and C.J. Warrey. 1985. Anaerobic degradation of trichloroethylene in soil. Eviron. Sci. Tech. 19: 277.

Koksay, M. and P.M.D. Bradshaw. 1969. Secondary dispersion of mercury from cinnebar and stibnite deposits, West Turkey. Colorado School Mines Quart. 64: 33-356.

Kopp, J.F. 1969. The occurrence of Trace Elements in Water. In: D.D. Hemphill, (ed.) Proc. 3rd Ann. Conf. Trace Substances in Environ. Health. University of Missouri, Columbia.

Koransky, W. et al. 1963. Absorption, distribution, and elimination of alpha- and beta-benzene hexachloride. Arch. Exp. Pathol. Pharmacol. 244: 564.

Kudo, A., A. Hiroketon, D.C. Mortimer, and D.R. Miller, 1977. Isotopic organic and inorganic mercury exchange in river water. Environ. Sci. Technol. 11: 907-908.

Lambert, S.M., P.E. Porter, R.H. Schieferstein, 1965. Weeds 13: 185.

VIN 002 0819

Lee, T.C., M. Oshimura, J.C. Barrett. 1985. Comparison of arsenic induced cell transformation cytotoxicity, mutation and cytogenetic effects in Syrian hamster embryo cells in culture. Carcinogenesis (Lond.) 6: 1421-1426.

Lennon, G. P. and R. L. Johnson, 1982. Investigation and Proposed Groundwater Decontamination Program for the Vineland Chemical Company Plant Site, W. Wheat Road Vineland, NJ.

Lovejoy, H.B. et al. 1974. Mercury exposure evaluations and their correlation with urine mercury excretion. Jour. Occup. Med. 15: 590.

Lunde, G. 1977. Occurrence and transformation of arsenic in the marine environment. Environ. Health Perspect. 19: 47-52.

Lyman, W.J., W.F. Reehl, & D.H. Rosenblatt. 1982. Handbook of Chemical Property Estimation Methods, McGraw Hill Book Co. New York.

Malton, C., G. Lefemine, & G. Cotti. 1986. Experimental Research on Trichloroethylene Carcinogenesis. Archi-Res. Industrial Carcinogenesis Series. Maltoni, C. Mehlman, M.A., ed., Vol. V., Princeton Scientific Publishing Co., Inc., Princeton, NJ p. 393.

Marafante, E. and M. Vahter. 1987. Solubility, retention and metabolism of intratracheally and orally adminstered inorganic arsenic compounds in the hamster. Environ. Res. 42: 72-82.

Matanoski, G., E. Landau, J. Tonascia, C. Lazar, E. Elliot, W. McEnroe, and K. King. 1981. Cancer mortality in an industrial area of Baltimore. Environ. Res. 25: 8-28.

MacNaughton, M.G. and R.O. James 1974. Adsorption of aqueous mercury (II) complexes at the oxide/water interface. J. Coolid Interface Sci. 47 (2): 431-440.

Medical Tribune. 1978. Methylmercury affects Japanese school children. September 13, 1978.

McBride, B.C. and R.S. Wolfe. 1971. Biosynthesis of dimethylarsine by methano-bacteria. Biochem 10: 4312-4317.

McKim, J.M. et al. 1976. Long-term effects of methyl-mercuric chloride on three generations of brook trout, Salvelinus fontinelis. Toxicity, accumulation, distribution and elimination 33: 2726.

Miettinen, J.K. 1973. Absorption and Elimination of Dietary (Hg#) and methylmercury in man. In: M.W. Miller and T.W. Clarkson (eds.), Mercury, Mercurials, and Merceptans, Charles C. Thomas, Springfield Illinois.

VIN 002 0820

Miller, R.E., & F.P. Geungerich. 1983. Metabolism of trichloroethylene in isolated hepetocytes, microsomes and reconstituted systems contining cytochrome P-450. Cancer Res. 43: 1145.

Milne, J. et al. 1970. Acute mercurial pneumonites. Br. Jour. Ind. Med. 27: 334.

Monster, A.C., J. Bolrsman, and W.C. Dubor. 1979a. Kinetics of trichloroethylene in repeated exposure of volunteers. Int. Arch. Occup. Environ. Health 42: 283.

Monster, A.C. et. al. 1976. Pharmacokinetics of trichloroethylene in volunteers, influence of workload and exposure concentration. Int. Arch. Occup. Environ. Health 38: 87.

Morrow, P.E., et al. 1964. Clearance of insoluble dust from the lower respiratory tracts. Health Phys. 10: 543.

Mudge, G.H. and J.M. Weiner. 1958. The mechanism of action of mercurial and xanthive diuretics. Ann. NY Acad. Sci. 71: 344.

NAS. 1977. Arsenic. Natl. Acad. Sci., Washington, D.C.

NCI (National Cancer Institute) 1976. Carcinogenesis Bioassay of Trichloroethylene Case No. 79-01-6, NCI-CG-TR-2, PHEW Publ. No. (NIH) 76-802.

NIOSH (National Institute of Occupational Safety and Health) 1984. KX4550000 Ehtylene, trichloro- Registry of Toxic Effects of Chemical Substances, 906-987.

N.J. Department of Environmental Protection. 1982. Assessment of the chemical and biological significance of arsenic compounds in the Blackwater Branch, Maurice River and Union Lake, N.J. - Finish Report. Trenton, N.J.

NRCC. 1978. Effects of arsenic in the Canadian environment. Natl. Rs. Coun. Canada Publ. No. NRCC. 15391.

NTP (National Toxicology Program) 1982. Bioassay of 2,3,7,8-tetrachlorodibenzo-p-dioxin for possible carcinogencity (gauge study). DHHS Publ. No. (NIH) 82-1765. Bethesda, MD: Carcinogenesis Testing Program, NCI, NIH; Research Triangle Park, NC: National Toxicology Program.

National Research Council. 1978. An assessment of mercury in the environment. National Academy of Science, Washington, D.C.

Neubiarier, O. 1947. Arsenical cancer: A review. Br. J. Cancer 1: 192-251.

VIN 002 0821

Nomigama, K., and H. Nomigama. 1971. Metabolism of trichloroethylene in humans. Sex difference in urinary excretion of trichloroacetic acid and trichloroethanol. Internation Arch. Arbeitemed. 28: 37.

Nomigama, K., H. Nomigama. 1977. Dose-response relationship for trichloroethylene in man. Int. Arch. Occup. Environ. Health. 39: 237.

Norseth, T. and T.W. Clarkson. 1971. Intestinal transport of 203 Hg labelled methylmercury chloride: role of biotransformation in rats. Arch. Environ. Health. 22: 258.

Oharajawa, H. 1968. Chromosomal abnormalities and terratogenesis induced by ethyl mercuric phosphate in pregnant mice. Nippon Sanka - Fujinka Gakk: Zasshi 20: 1479.

Olson, G.F. et al. 1975. Mercury residues in fathead minnows, Pimephales promelas Rafinesque, chronically exposed to methylmercury in water. Bull. Environ. Contam. Toxicol. 14: 129.

ORNL. 1984. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture.

Pershagen, G. and M. Vahter, 1979. Arsenic. A toxicological and epidemiological appraised. Libertryck, Stockholm, Sweden, SNV PM-1128.

Person, H. 1934. On trichloroethylene intoxication Acta Med. Scand. 59: 410.

Phillips, G.R. and D.R. Buhler. 1978. The relative contributions of methylmercury from food or water to rainbow trout (Salmo gaireneri) in a controlled laboratory environment. Trans. Am. Fish. Soc. 107: 853.

Rai, D. and J. M. Zachara. 1984. Chemical attenuation rates, coefficients and constants in leachate migration. Electric Power Research Institute, Palo Alto, Calif. Report EA-3356.

Ramamoorthy, S. and B.R. Rust 1976. Mercury sorption and desorption characteristics of some Ittawa River sediments. Can. J. Earth. Sci. 13: 530-536.

Ray - Bettley, F. and J.A. O'Shea. 1975. The absorption of arsenic and its relation to carcinoma. Br. J. Deermatol 92: 563.

Reay. P.R. 1973. The accumulation of arsenic form arsenic-rich neutral waters by aquatic plants. J. Appl. Ecology 9: 557-565.

VIN 002 0822

Reimers, R.S. and P.A. Krenkel. 1974. Kinetics of mercury adsorption and desorption in sediments. Jour. Water Poll. Control Fed 46 (2): 352-365.

Rentos, P. and E. Seligman. 1968. Relationship between environmental exposure to mercury and clinical observations. Arch. Environ. Health 16: 794.

Ridley, W.P., L. Dizikes, A. Chek, and J.M. Wood. 1977. Recent studies on biomethylation and demethylation of toxic elements. Environ. Health Perspect. 19: 43-46.

Rooney, James G., Groundwater Resources, Cumberland County, NJ, Special Report No. 34, USGS Trenton, NJ 1971.

Roth, S. 1988. Personal Communication.

Rothstein, A. and A.D. Hayes. 1964. The turnover of mercury in rats exposed repeatedly to inhalation of vapor. Health Phys. 10: 1099.

Salvini, M., S. Binaschi, & M. Riva. 1971. Evaluation of the psychophysiological functions in humans exposed to trichloroethylene. Br. J. Ind. Med. 28: 293.

Sanders V.M., A.N. Tucker, K.L. White, Jr. et al. 1982. Humoral and cell mediated immune status in mice exposed to trichloroethylene in drinking water. Toxicol. Appl. Pharmacol 62: 358.

Sato, A., T. Kakahima, Y. Fujiwana, M. Murayama. 1977. A pharmacokinetic model to study the excretion of trichloroethylene and its metabolites after an inhalation exposure. Br. J. Ind. Med. 34: 55.

Sato, A. and T. Nakajima, 1978. Differences following skin or inhalation exposure in the absorption and excretion kinetics of trichloroethylene and toluene. Brit. J. Ind. Med. 35: 43.

Schaeffer, F. 1988. Personal Communication: USGS Data for Water Year 1987. Preliminary Results, USGS.

Seip, H.M., J. Alstad, G.E. Carlberg, J. Martinsen, and R. Skaane. 1986. Measurement of mobility of organic compounds in soils. The Sci. of Total Environ. 50: 87.

Shahristani, H. and K. Shiheb. 1974. Variations of biological halftime of methylmecury in man. Arch. Environ. Health 18: 342.

Sheffy, T.B., and J.R. St. Amant. 1982. Mercury burdens in forebearers in Wisconsin. J. Wildl. Manage. 46:1117-1120.

VIN 002 0823

Sheppard, M.I., D.H. Thibault, and S.C. Sheppard. 1985. Concentrations and concentration ratios of U, As and Cs in Scoto Pine grown in a waste-site soil and an experimentally contaminated soil. Water Air Soil Pollut. 26: 85-94.

Shomagarva. A. et al. 1983. Nippon Swison Gapparishi 49: 75-78.

Singh, H.B., L.J. Salas, R.E. Stiles. 1982 Distribution of selected gaseous organic mutagens and suspect carcinogens in ambient air. Environ. Sci & Technol. 16: 872.

Skerfving, S., et al. 1974. Methylmercury - induced chromosomes damage in man. Environ. Res. 7: 83.

Skinner, W.F., R.F. Denoncourt and B.D. Snyder. 1982. Flow-Through Biomonitoring Applied to a Power-Plant Effluent, With Emphasis on Arsenic Bioaccumulation. Proc. of Penn. Academy of Sci. 56: 49-54.

Skinner, W.F. 1986. Trace Element Concentrations in Wastewater Treatment Basin - Reared Fishes: Results of a Pilot Study. Proc. of Penn. Acad. of Sci. 59: 155-161.

Sorenson, E.M.B. 1976. Thermal effects on the accumulation of arsenic in green sunfish, Lepomis cyanellus. Arch. Environ. Contam. Toxicol. 4: 8.

Sorenson, E.M.B. 1976. Toxicity and accumulation of arsenic in green sunfish, Lepomis cyanellus, exposed to arsenate in water. Bull. of Environ. Contam. Toxicol. 15: 756-761.

Sorjo, G. 1976. Trichloroethylene, carbon tetrachloride, and gasoline intoxication at itiological factors in the development of arterio and coronary sclerosis. Arch. Toxicol. 35: 295.

Soucke, B., & D. Vlachova. 1960. Excretion trichloroethylene metabolites in human urine. Br. J. Ind. Med. 17: 6064.

Spehar, R.L., J.T. Fiandt, R.L. Anderson, and D.L. DeFoe. 1980. Comparative toxicity of arsenic compounds and their accumulation in invertebrates and Fish. Arch. Environ. Contam. Toxicol. 9: 53-63.

Stott, W.T., J.F. Quast and P.G. Watanabe. 1982. Pharmacokinetics and macromolecular interactions of trichloroethylene in mice and rats. Toxicol. appl. Pharmacol. 62: 137.

Tag, C.H., & C.S. Seah. 1975. Arsenic poisoning from anit-asthmetic herbal preparations. Med. J. Aust. 2: 424-428.

Tam, G.K.H, S.M. Charbonneau, F. Bryce, and E. Sandi. 1982. Excretion of a single oral dose of fish-arsenic in man. Bull. Environ. Contam. Toxicol. 28: 669-673.

VIN 002 0824

Task Group on Metal Accumulation. 1973. Accumulation of toxic metals, excretion and biological halftimes. Environ. Phys. Biochem. 3: 65.

Tseng, W.P., H.M. Chu, S.W. How, J.M. Fonj, C.S. Lin, and S. Yeh. 1968. Prevalence of skin cancer in and endemic area of chronic arsenalicelism in Taiwan. J. Natl. Cancer Inst. 40: 453-463.

Tucker, A.N., V.M. Sanders, D.W. Barnes et al. 1982. Toxicology of trichlorethylene in the mouse. Toxicol. Appl. Pharmacol 62: 351.

Turner, M.D., et al. 1974. Methylmercury (MeHg) in Human Population Eating Large Quantities of Marine Fish in Northern Peru. In: Proc. 1st int. Cong. Mercury. Barcelona, May 5-10.

USDA, Soil Conservation Service, 1978, Soil Survey of Cumberland County, NJ, April, 1978.

US Dept. of Agriculture. 1982. Food Consumption Households in the Northeast, Spring 1977.

USEPA. 1975e. Occupational Exposure to Trichloroethylene. 40 FR 490.31.

USEPA. 1976. Arsenic. Subcommittee on Arsenic, Com. on Med and Biol. Effects of Environ. Pollut. NRC/NAS, EPA 600/1-76-036. U.S. Environ. Prot. Agency, Washington, D.C.

USEPA. 1978. In depth studies on health and environmental impacts of selected water pollutants. U.S. Environmental Prot. Agency, Contract No 68-01-4646.

U.S.EPA. Ambient Water Quality Criteria for arsenic. EPA 440/5-80-021 October 1980.

USEPA. 1980. Ambient Water Quality Criteria for Trichloroethylene. EPA 440/5-80-077.

USEPA. 1980a. Ambient Water Quality Criteria for Mercury. EPA 440/5-80-058.

USEPA. 1980b. Ambient Water Quality Criteria for DDT. EPA 440/5-80-038.

USEPA. 1980c. Ambient Water Quality Criteria Documents.

USEPA. 1980d. Ambient Water Quality Criteria for Arsenic. EPA 440/5-80-021.

USEPA. 1984 Water quality criteria; request for comments. Fed. Reg. 49: 4551-4553.

VIN 002 0825

USEPA. 1984a. Health Assessment Document for Inorganic Arsenic. Final Report. U.S. Environmental Protection Agency. Research Triangle Park, N.C. EPA-600/8-83-021F.

USEPA. 1984b. Health Assessment Document for Chromium. Research Triangle Park, NC: Environmental Assessment and Criteria Office. EPA/600/8-83-014F.

USEPA. 1985. Ambient Water Quality Criteria for Arsenic - 1984. US Environmental Protection Agency Rep. EPA 440/5-84-003.

USEPA 1985b. Health Assessment Document for trichloroethylene. Final Report. Washington, D.C.: EPA NTIS PB 249696.

USEPA. 1985c. Preliminary study of selected potential environmental contaminants optical brighteners, methyl chloroform, trichlorethylene, tetrachloroethylene, ion exchange resins. Enviromental Protection Agency (Office of Toxic Substances), Washinton, D.C. 286 p. EPA 560/2-75-002.

USEPA. 1986. Superfund Public Health Evaluation Manual. Publication No. 540/1-86/060. October, 1986.

USEPA 1986. U.S. Environmental Protection Agency. Office of Health and Environmental Assessment. Evaluation of the potential carcinogencity of arsenic (7940-38-2) in support of reportable quantity adjustments pursuant to CERCLA Section 102. Washington, D.C.: U.S. Environmental Protection Agency. OHEA C-073-5.

USEPA, 1986a. Air Quality Criteria for Lead. June, 1986 and Addendum, September, 1986. Research Triangle Park, NC: Office of Research and Development, Office of Health and Environmental Assessment, Environmental Criteria and Assesment Office, EPA. EpA 600/8-83-018F.

USEPA, 1986b. Superfund Public Health Evauation Manual. EPA 540/1-86/060.

USEPA, 1986c. Superfund Exposure Assessment Manual. Office of Emergency and Remedial Response.

USEPA, 1987. Special Report on Ingested Inorganic Arsenic: Skin Cancer; Nutritional Essentiallaty. EPA/625/3-87/013A.

USGS. Stream Gauging Station Number 02411500, Maurice River at Norma, NJ, Water Resources Division, Trenton, NJ 1981-1987.

Vahter, M. 1983. Metabolism of arsenic. In: Fowler, B.A. (ed.) Biological and Environmental Effects of Arsenic. New York: Elsiver P171-198.

VIN 002 0826

Valle, B.L., Ulmer, D.D., and W.E.C. Wacker, 1960. Arsenic toxicology and biochemistry. Arch. Ind. Health 21: 132-151.

Versar, Inc., 1979. Water Related Fate of 129 Priority Pollutants: IV. Halogenated Aliphatics. USEPA. Washington, D.C.

Vogel, T. and P. McCarthy. 1985. Biotransformation of tetrachloroethylene to trichloroethylene, dichloroethylene, vinyl chloride, and carbon dioxide under methanogenic conditions. Applied and Environ. Microbiology 49: 1080-1083.

Walker, T.J. Fate and Disposition of Trichloroethylene in surface soils. Doctoral Thesis. Purdue University 1984.

Wauchope, R.D. 1975. Fixation of arsenical herbicides, phosphate, and arsenate in alluvial soils. J. Environ. Quality 4: 355-358.

Wauchope, R.D., and L.L. McDowell. 1984. Adsorption of phospate, arsenate, methane-arsonate, and cacodylate by lake and stream sediments: Comparisons with soils. J. Environ. Qual. 13: 499-509.

Weaver, R.W., J.R. Melton, D.S. Wang & R.L. Duble. 1984. Uptake of Arsenic and Mercury from Soil by Bermudapass Cynodon dactylon Environmental Pollution (Series A) 33: 133-142.

Weast, R.C. (ed). 1977. Handbook of Chemistry & Physics, 57th Edition, CRC Press, Cleveland, OH.

Winka, A.J. 1985. An Assessment of the Arsenic Concentrations and Arsenic Species in the Lower Maurice River Drainage Basin (NJ). Ph.D. Dissertation, Rutgers University Graduate School - New Brunswick, December.

Woodward-Clyde Consultants. 1985. RCRA Part B Permit Application for Vineland Chemical Co., Inc. Vineland, N.J.

Woolson, E.A., J.H. Axley, and P.C. Keaney. 1971. The chemistry and phytotoxicity of arsenic in soils: I. Contaminated Field Soils. Soil Sci. Soc. Amer. Proc. 35: 938-943.

Woolson, E.A. and P.C. Kearny. 1972. Persistence and Reactions of 14C-Cacodylic Acid in Soil. Env. Sci. Tech. 6, 47-50.

Woolson, E.A. (ed.) 1975. Arsenical pesticides. Am. Chem. Soc. Sup. Ser. 7.

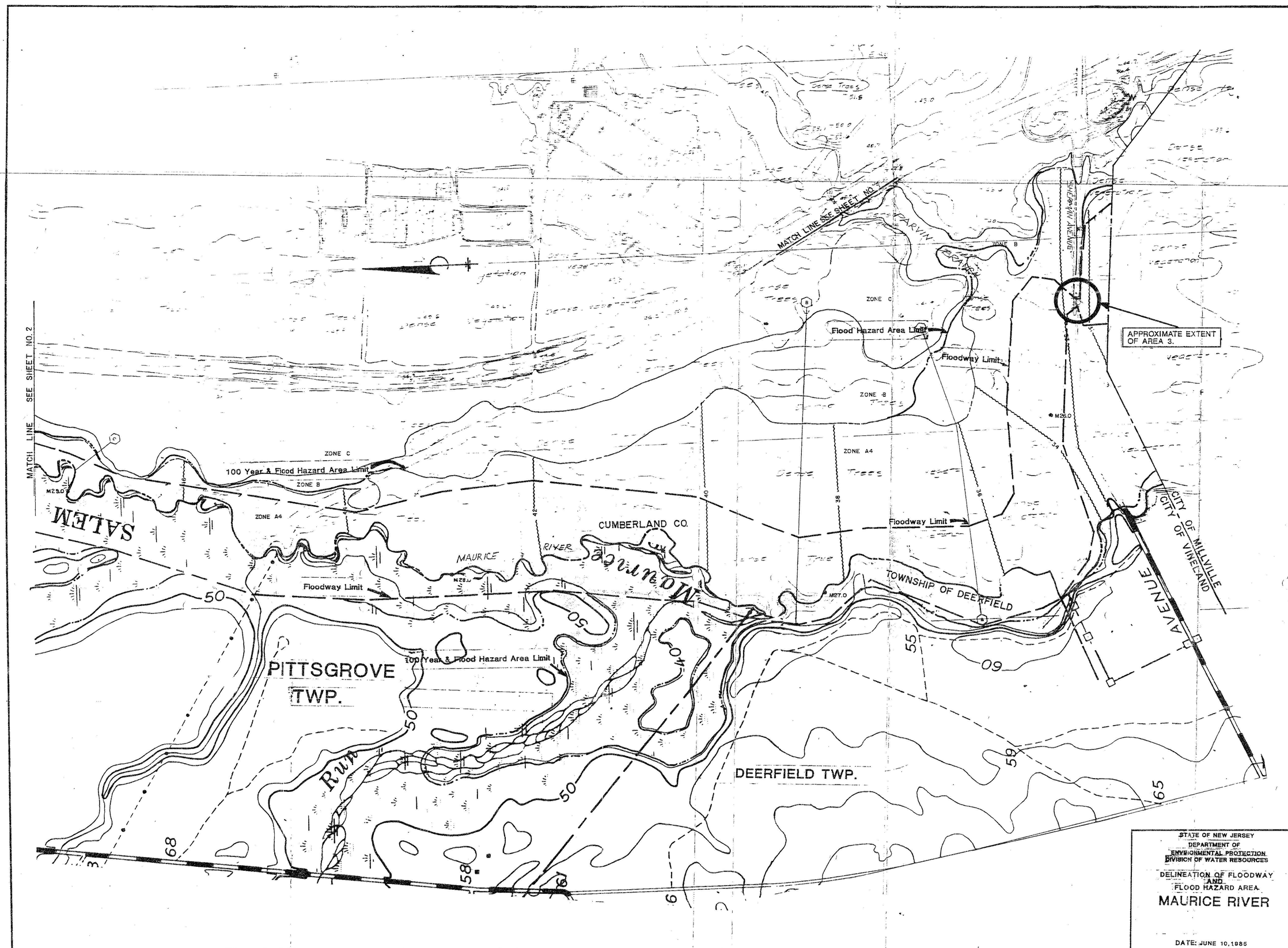
World Health Organization. 1976. Environmental health criteria. Mercury Geneva.

VIN 002 0827

Zaroogian, G.E. and G.L. Hoffman 1982. Arsenic uptake and loss in the American oyster, Crassotrea virginica. Environ. Monitor. Assess 1: 345-358.

Zepp, R.G., N.L. Wolfe, and J.A. Gordon. 1973. Photodecomposition of phenylmercury compounds in sunlight. Chemosphere. 3: 93-99.

VIN 002 0828



KEY TO MAP

500-Year Flood Boundary
100-Year Flood Boundary
FLOODWAY FRINGE — FLOODWAY
100-Year Flood Boundary
500-Year Flood Boundary
Approximate 100-Year Flood Boundary
Cross Section Line — (A)——(A)
Elevation Reference Mark — RM7 ×
River Mile — • M1.5

NOTES TO USER

Boundaries of the floodways were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the Federal Insurance Administration.

This map was prepared to facilitate floodplain management activities only; it may not show all special flood hazard areas in the community or all planimetric features outside of the floodplain. Refer to the latest official Flood Insurance Rate Map for any additional areas of special flood hazard.

For adjoining map panels, see separately printed Index To Map Panels.

This map is intended for use in defining floodway and flood boundaries. Zone and Base Flood Elevation (BFE) data may not be correct as shown. Refer to the separately printed Flood Insurance Rate Map for correct Zone and BFE data.

Refer to the Flood Insurance Rate Map for description of Elevation Reference Marks.

This map does not show all flood boundaries. Refer to the Flood Insurance Rate Map for additional flood boundaries.

NEW JERSEY
FLOOD HAZARD AREA
DESIGN FLOOD LIMIT
Floodway Limit

MAURICE RIVER

APPROXIMATE SCALE
400 0 400 FEET

STATE OF NEW JERSEY
DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF WATER RESOURCES

DELINEATION OF FLOODWAY AND FLOOD HAZARD AREA

MAURICE RIVER

DATE: JUNE 10, 1985

NATIONAL FLOOD INSURANCE PROGRAM

FLOODWAY

FLOOD BOUNDARY AND FLOODWAY MAP

CITY OF VINELAND, NEW JERSEY
CUMBERLAND COUNTY

PANEL 1 OF 6
(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
340176 0002 A

EFFECTIVE DATE:

federal emergency management agency
federal insurance administration

DRAWING
DRW-2

2.5
TASK 2E