

INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

**ProQuest Information and Learning
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
800-521-0600**

UMI[®]

A/

**GROUNDWATER-RISK ANALYSIS OF NEW YORK
UTILIZING GIS TECHNOLOGY**

by

Charles J. Hillenbrand III

A dissertation submitted to the Graduate Faculty in
Earth and Environmental Sciences in partial fulfillment of the
requirements for the degree of Doctor of Philosophy,
The City University of New York

2002

UMI Number: 3047228

**Copyright 2002 by
Hillenbrand, Charles John, III**

All rights reserved.

UMI[®]

UMI Microform 3047228

**Copyright 2002 by ProQuest Information and Learning Company.
All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.**

**ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346**

**This Manuscript has been read and accepted for the Graduate Faculty in Earth and
Environmental Sciences in satisfaction of the dissertation requirement
for the degree of Doctor in Philosophy**

4/23/2002

Date

Gerald M. Friedman

Prof. Gerald M. Friedman

Chair of Examining Committee

4/23/2002

Date

Jeffrey P. Osleeb

Prof. Jeffrey P. Osleeb

Executive Officer

Prof. Sean Ahearn

Prof. Nehru Cherukupalli

Prof. Duke Ophori

Supervisory Committee

THE CITY UNIVERSITY OF NEW YORK

ABSTRACT

GROUNDWATER-RISK ANALYSIS OF NEW YORK

UTILIZING GIS TECHNOLOGY

by

Charles J. Hillenbrand III

Advisor: Prof. Gerald Friedman

Using Geographic Information System (GIS) technology, data layers can be processed and analyzed to produce a regional groundwater-risk grid of New York State (NYS). GIS can be used to assess the potential to introduce contaminants at the ground surface, and assess the potential for the contaminants to migrate through the vadose zone and be introduced to an aquifer at the water-table.

The potential to introduce contaminants to the ground surface was assessed utilizing existing database information in combination with the United States Geological Survey (USGS) Multi-Resolution Land Classification (MRLC) land use grid. The databases allowed an analysis of contaminant association with Standard Industrial Classification (SIC) codes, risk evaluation of the contaminants using groundwater intake values protective of human health, the development of SIC code-risk values, the construction of a SIC code-risked facility point coverage, and the construction of a land use-risk grid; this grid assesses the potential to introduce contaminants to the ground

surface.

Aquifer susceptibility was determined by analyzing vadose zone residence time assuming saturated conditions. Vadose zone residence time is a measure of the vadose zone's ability to attenuate and retard the migration of contaminants. Existing data layers were processed to produce a depth to water-table (vadose zone thickness) grid. Existing GIS data layers of soil, surficial geology and bedrock geology, along with review of literature and pump/slug test data, enabled the creation of thickness, porosity and vertical hydraulic conductivity grids for the three considered components of the vadose zone. The average linear velocity was then calculated for each vadose zone component by dividing their hydraulic conductivity grid by their respective porosity grid. The thickness grid of each vadose zone component was then divided by their respective average linear velocity grid to produce vadose zone residence time grids. The sum of the three residence time grids produced a grid which is a measure of aquifer susceptibility.

A groundwater-risk grid of NYS was produced by dividing the land use-risk grid by the aquifer susceptibility grid. Areas of significant groundwater-risk were identified.

The confidence of the groundwater-risk grid was evaluated by correlating existing Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) National Priority List (NPL) groundwater contamination sites in NYS with identified areas of significant groundwater-risk. Maximum grid values of significant groundwater-risk within CERCLA NPL groundwater contamination areas show a correlation of 76%.

ACKNOWLEDGMENTS

The author dedicates this work to the memory of Professor John E. Sanders, who was instrumental in introducing me to the enjoyment of geology and environmental science. I am proud to have started my undergraduate studies under the tutelage of Professor Sanders and to be completing a Doctorate degree under the direction of his close colleague, Professor Gerald M. Friedman.

This writer expresses a special thanks to my parents Charles J. Hillenbrand, Jr. and Muriel Hillenbrand for their constant support and encouragement, especially during the last two years of this work when other events distracted me from this effort. A special thanks must also go to my children, C.J., Steven and Molly for the times I was too busy to spend quality time with them during the weekends, especially during the first few years of this endeavor when course work was intense. The writer would also like to thank Professor Gerald Friedman for his vigilant assistance, infectious enthusiasm, and concern for his students; working under Professor Friedman was strenuous, interesting, rewarding and fun.

The writer also appreciates the efforts of Dr. Duke Ophori. Dr. Ophori provided valuable insight regarding hydrogeology and computer modeling of groundwater systems. Dr. Shawn Ahern's directions and suggestions regarding Geographical Information System (GIS) processing is appreciated. Professor Jeffery P. Osleeb's comments and enthusiasm regarding this work were greatly appreciated. The writer also expresses thanks to the input of Dr. Nehru E. Cherukupalli.

The author would also like to thank Jack Monti, Jr., hydrologist, and Andrew J.

Cohen, hydrologist technician, of the United States Geological Survey for their assistance in obtaining Ground Water Site Inventory well data and water level measurements for GIS processing.

A special thanks goes to my colleagues at the U.S. Environmental Protection Agency who assisted me with several phases of this research. William Hansen and Robert Eckman provided GIS and database support in all phases of this work. Robert Simpson aided in ArcView processing of the land use-risk analysis. Robert Ferri provided assistance with electronic data quality checks against original hard copies; he also commented on my ideas as I developed my work plan for this effort and commented on several written drafts of this work.

TABLE OF CONTENTS

	Page
List of Tables	xi
List of Figures	xii
List of Plates	xiv
Introduction	1
Chapter 1: Background	5
A. Historical Setting	5
B. Groundwater-Risk Assessment Methods	8
C. Evaluation of Groundwater-Risk Schemes	12
D. Chapter 1 Summary	15
Chapter 2: Geographic Information System (GIS)	16
A. Development of GIS	16
B. Value of GIS in Groundwater-Risk Analysis	19
C. Chapter 2 Summary	19
Chapter 3: Groundwater Contamination System	20
A. Sources of Contamination.	20
B. Unconfined Aquifer Recharge Through the Vadose zone	21
C. Contaminant Attenuation and Retardation in the Vadose zone	25
D. Chapter 3 Summary	28
Chapter 4: Methodology	29
A. Available Data	29
a. GIS Data Layers	30
b. Databases	33
B. GIS Formula for Groundwater-Risk Analysis	49
C. Cartographic Modeling	52
a. Statement of Objectives	52
b. Statement of Conditions and Assumptions	52
c. Statement of Evaluation Methodology	54
D. Chapter 4 Summary	55
Chapter 5: Land-Use Risk Analysis	56
A. SIC Code-Risk Analysis	56
B. Land Use-Risk Calculation	58
C. Chapter 5 Summary	62
Chapter 6: Aquifer Susceptibility Risk Analysis	64
A. Vadose zone Thickness Analysis	64
a. Interpolation of Water-Table Elevation	64
b. Vadose zone Thickness (Depth to Water-Table) Grid Construction	80
c. Thickness of Soil, Surficial Geology and Bedrock Geology Components of the Vadose zone	80

B. Establishment of Vadose zone Porosity and Hydraulic Conductivity Values	93
a. Soil Porosity and Hydraulic Conductivity	93
b. Surficial Geology Porosity and Hydraulic Conductivity Assignments	94
1. Quaternary Geology of NYS, Pleistocene Epoch	97
1a. Till and Ablation Moraine	99
1b. Inwash, Alluvial Inwash, Kame (Eskers)	101
1c. Till Moraine	103
1d. Kame Moraine	104
1e. Outwash Sand and Gravel	105
1f. Fluvial Gravel, Pleistocene Alluvium and Fluvial-Deltaic Sand	106
1g. Undifferentiated Stratified Drift and Undifferentiated Drift Complex	107
1h. Lacustrine Delta	108
1i. Subaqueous Fan	109
1j. Lacustrine Silt and Clay	111
1k. Dunes	112
2. Quaternary Geology of NYS, Holocene Epoch	113
2a. Colluvial Diamicton, Colluvium Colluvial Fan	113
2b. Alluvial Fan, Recent Alluvium, Alluvial Terrace	113
2c. Swamp	115
2d. Lacustrine Beach, Lacustrine Sand, Undifferentiated Sand	115
2e. Marine Delta, Beach, Barrier Island	116
2f. Undifferentiated Silt and Clay	117
2g. Artificial Fill	117
c. Surficial Geology Vertical Hydraulic Conductivity Assignments	118
d. Bedrock Geology Porosity and Hydraulic Conductivity Assignments	118
1. Bedrock Geology of New York	123
1a. Middle Proterozoic Era	123
1b. Late Proterozoic Era	125
1c. Paleozoic Era, Cambrian Period, Continental Shelf	126
1d. Paleozoic Era, Cambrian Period, Continental Slope/Rise/Ocean Basin	128
1e. Paleozoic Era, Early Ordovician Period, Continental Shelf	129

1f. Paleozoic Era, Early Ordovician Period, Continental Slope/Rise/Ocean Basin	130
1g. Paleozoic Era, Middle Ordovician Period Continental Shelf/Foreland Basin Flysch	130
1h. Paleozoic Era, Later Ordovician Period Foreland Basin Molasse	132
1i. Paleozoic Era, Early Silurian Period	133
1j. Paleozoic Era, Late Silurian Period	134
1k. Paleozoic Era, Early Devonian Period	136
1l. Paleozoic Era, Middle Devonian Period	137
1m. Paleozoic Era, Late Devonian Period	139
1n. Paleozoic Era, Early Mississippian Period	141
1o. Paleozoic Era, Early Pennsylvanian Period	141
1p. Paleozoic Era, Alleghanian Orogeny (Pennsylvanian - Early Permian Periods)	142
1q. Mesozoic Era, Late Triassic - Early Jurassic Periods	142
1r. Mesozoic Era, Late Cretaceous Period	142
2. Bedrock Geology Porosity and Hydraulic Conductivity Assignments	143
e. Bedrock Geology Vertical Hydraulic Conductivity Assignment	148
C. Calculation of Average Linear Velocities	151
D. Calculation of Aquifer Susceptibility	152
E. Chapter 6 Summary	156
Chapter 7: Groundwater-Risk Analysis	163
A. Identified Areas of Significant Groundwater-Risk	163
B. Correlation of CERCLA NPL Groundwater Contamination Sites with Groundwater-Risk Grid	164
C. Chapter 7 Summary	168
Chapter 8: Discussion	170
A. Targeting Environmental Work	170
B. Future Water Use	171
C. Refinement of Groundwater-Risk Analysis	172
D. Chapter 8 Summary	175
Chapter 9: Conclusions	176
Appendices	182
A: Background, Groundwater Risk Methods	183
A. DRASTIC Modeling System	184
B. EPA Region 2 Long Island Groundwater Risk Analysis	191
C. LeGrande System	193
D. EPA Hazardous Waste Site Ranking System	203
E. Michigan Site Assessment System	212
F. EPA Superfund Human Health Evaluation Process	230

B: EPA Region 3, Hazardous Substance List	243
C: Human Health Intake-Risk SIC Code List	257
D: Appendix D: GIS Interpolation - Kriging, A Discussion	297
E: NYS CERCLA Files Pump/Slug Test Data	305
F: Sequence Stratigraphy: A Presentation of Terms	312
G: NYS Stratigraphic Column with Hydrogeologic Parameters	318
H: List of CERCLA NPL Groundwater Contamination Sites	329
References	334

LIST OF TABLES

	Page
Table 1 Comparison of Groundwater-Risk Methodologies	13
Table 2 NYS Museum Surficial Geology Coverage, Attributes	35
Table 3 NYS Museum Bedrock Geology Coverage, Attributes	39
Table 4 USGS GWSI Attributes Used in Study	46
Table 5 MRLC Land Use Classifications and Corresponding Calculated Risk	61
Table 6 Lithology Packages and Assigned Porosity and Hydraulic Conductivities	145
Table 7 Groundwater-Risk Ranges and Ordinal Scale	166
Table 5 Percent Correlation of CERCLA NPL Sites (Polygons) with Maximum Groundwater-Risk Ordinal Scale Values	167
Table 6 Percent Correlation of CERCLA NPL Sites (Polygons) with Median Groundwater-Risk Ordinal Scale Values	167
Table A1 DRASTIC Weights, Ranges and Ratings	188
Table A2 LeGrande System Values for Classification Components	197
Table A3 EPA Hazardous Ranking System; Factors, Characteristics and Values	206
Table A4 MDNR SAS Values for Categories and Subcategories Applicable to Groundwater	220
Table A5 Data Required for Groundwater Fate Models	242
Table B1 EPA Region 3, Hazardous Substance List	244
Table C1 Human Health Intake-Risk SIC Code List	258
Table E1 CERCLA Pumping/Slug Test Data	306
Table G1 NYS Stratigraphic Column with Hydrogeologic Parameters	319
Table H1 CERCLA NPL Groundwater Contamination Sites	330

LIST OF FIGURES

		Page
Figure 1	Cartographic Model, Land Use-Risk Flow Chart	58
Figure 2	Point Coverage of Dunn & Bradstreet Facilities in NYS	59
Figure 3	MRLC Land Use Grid	60
Figure 4	Land Use-Risk Grid	63
Figure 5	Cartographic Model, Derivation of Water-Table Elevation Points from Surface Hydrology (Arcs Coverage)	66
Figure 6	NYS Surface Hydrology (Arcs Coverage)	67
Figure 7	NYS Digital Elevation Model (DEM)	68
Figure 8	NYS Water-Table Elevation Points, Surface Hydrology (Arcs Coverage) Derived	69
Figure 9	Cartographic Model, Derivation of Water-Table Elevation Points from Surface Hydrology (Polygon Coverage)	70
Figure 10	NYS Surface Hydrology (Polygon Coverage)	71
Figure 11	NYS Water-Table Elevation Points, Surface Hydrology (Polygon Coverage) Derived	72
Figure 12	USGS GWSI Wells in NYS	73
Figure 13	Cartographic Model, Derivation of Water-Table Elevation Points from USGS GWSI Wells	74
Figure 14	USGS GWSI Wells with Unconfined Aquifer Water-Level Measurements	76
Figure 15	NYS Water-Table Elevation Points, USGS GWSI Well Derived	77
Figure 16	NYS Water-Table Elevation Points, Surface Hydrology and USGS GWSI Well Derived	78
Figure 17	Cartographic Model, Creation of Water-Table Elevation Surface	79
Figure 18	NYS Water-Table Elevation Grid	81
Figure 19	NYS Water-Table Elevation Variance Lattice	82
Figure 20	Cartographic Model, Creation of Depth to Water-Table Grid	83
Figure 21	NYS Depth to Water-Table Grid	84
Figure 22	Cartographic Model, Creation of Vadose zone Thickness Grids	85
Figure 23	NYS Soil Thickness Grid	86
Figure 24	NYS Museum Surficial Geology Coverage	87
Figure 25	NYS Surficial Geology Thickness Grid	88
Figure 26	NYS Soil Vadose zone Thickness Grid	90

	Page
Figure 27 NYS Surficial Geology Vadose zone Thickness Grid	91
Figure 28 NYS Bedrock Geology Vadose zone Thickness Grid	92
Figure 29 NYS Soil Porosity Grid	95
Figure 30 NYS Soil Hydraulic Conductivity Grid	96
Figure 31 NYS Surficial Geology Porosity Grid	119
Figure 32 NYS Surficial Geology Vertical Hydraulic Conductivity Grid	120
Figure 33 NYS Museum Bedrock Geology Coverage	121
Figure 34 NYS Physiological Provinces	122
Figure 35 NYS Bedrock Geology Porosity Grid	149
Figure 36 NYS Bedrock Geology Vertical Hydraulic Conductivity Grid	150
Figure 37 Cartographic Model, Creation of Average Linear Velocity Grids	151
Figure 38 NYS Soil Average Linear Velocity Grid	153
Figure 39 NYS Surficial Geology Average Linear Velocity Grid	154
Figure 40 NYS Bedrock Geology Average Linear Velocity Grid	155
Figure 41 Cartographic Model, Creation of Vadose zone Residence Time Grids	156
Figure 42 NYS Soil Vadose zone Residence Time Grid	157
Figure 43 NYS Surficial Geology Vadose zone Residence Time Grid	158
Figure 44 NYS Bedrock Geology Vadose zone Residence Time Grid	159
Figure 45 Cartographic Model, Creation of Aquifer Susceptibility Grid	160
Figure 46 Aquifer Susceptibility Grid	161
Figure 47 Cartographic Model, Creation of Groundwater-Risk Grid	164
Figure 48 Groundwater-Risk Grid	165
Figure 49 CERCLA "Superfund" NPL Groundwater Contamination Sites (Polygon) Coverage	169
Figure D1 Example of the Commonly Used Gaussian Variogram	304

LIST OF PLATES
(Found in Back Folder)

- Plate 1 NYS Land Use-Risk Grid**
- Plate 2 NYS Depth to Water-Table Grid**
- Plate 3 NYS Aquifer Susceptibility Grid**
- Plate 4 NYS Groundwater-Risk Grid**

INTRODUCTION

Enhancing protection of groundwater quality and delineation of areas of potential groundwater contamination, where closer investigation and data collection may be necessary, is best performed using Geographic Information System (GIS) technology. Using GIS technology, data layers can be processed and analyzed to produce a regional groundwater-risk grid of a large area, e.g. New York State (NYS).

Approximately one third of the population of NYS is dependent upon groundwater as a source of drinking water; approximately three million people are dependent upon groundwater on Long Island (NYSDEC, 1986); and approximately three million people rely on groundwater in Upstate New York (NYSDEC, 1987). Many of these drinking-water source areas are underlain by highly permeable aquifer systems that are vulnerable to contamination. Since the end of World War II, expanded industrialization, rural development and production of synthetic organic chemicals have in many instances introduced toxic contaminants to NYS's underground sources of drinking water. Groundwater contamination and associated health problems at the now infamous Love Canal, New York, were partly responsible for passage of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) or "Superfund" waste-cleanup program (Coffel, 1989). Since the discovery of the Love Canal contamination site in 1978, 75 significantly contaminated groundwater sites have been placed on the CERCLA National Priority List (NPL) in NYS.

This research uses existing GIS data layers and processes them to assess the potential to introduce contaminants to the groundwater system and assess the

susceptibility of unconfined aquifers to the introduction of contaminants; the division of land use-risk by aquifer susceptibility yields a risk of groundwater to contamination.

Groundwater-risk analysis was accomplished by using GIS, an organized collection of computer hardware, software and geographic data designed to capture, store, update, manipulate, analyze, and display most forms of geographically referenced information (DeMers, 1997). Existing GIS data layers were utilized to build new coverages and grids. These derived data layers were in turn used to produce land use-risk, aquifer susceptibility, and groundwater-risk grids.

Construction of the groundwater-risk grid incorporated existing GIS data layers of land-use, surface hydrology, topography (digital elevation model), soils data, surficial geology and bedrock geology. Existing database information was also used to create GIS coverages and grids incorporated in the groundwater-risk analysis; contaminant health risk, contaminants associated with Standardized Industrial Classification (SIC) codes, SIC codes associated with facilities, facilities with addresses and SIC codes, and groundwater well sites data were used. The GIS facilitated production of the following grids:

- Land Use-Risk**
- Water-Table Elevation**
- Depth to Water-Table**
- Soil Vadose zone Thickness**
- Surficial Geology Vadose zone Thickness**
- Bedrock Geology Vadose zone Thickness**
- Soil Vadose zone Porosity**
- Surficial Geology Vadose zone Porosity**
- Bedrock Geology Vadose zone Porosity**
- Soil Vadose zone Vertical Hydraulic Conductivity**
- Surficial Geology Vadose zone Vertical Hydraulic Conductivity**

Bedrock Geology Vadose zone Vertical Hydraulic Conductivity
 Soil Vadose zone Average Linear Velocity
 Surficial Geology Average Linear Velocity
 Bedrock Geology Average Linear Velocity
 Soil Vadose zone Residence Time
 Surficial Geology Vadose zone Residence Time
 Bedrock Geology Vadose zone Residence Time
 Aquifer Susceptibility
 Groundwater-Risk

Areas of high groundwater-risk were identified. Most areas of significant groundwater-risk possess substantial aquifer susceptibility and land use-risk; these areas were identified in the localities of Plattsburgh, Rome, Utica, Corning, Elmira, Horseheads, Cortlandt, Binghamton, Glen Falls, Schenectady, Albany and Long Island (especially south of the Harbor Hill Moraine). Areas of high groundwater-risk were also identified as a result of very high aquifer susceptibility and moderate land use-risk; these areas were noted in the northern St. Lawrence Lowlands and several glacial valleys within the Adirondack Mountains, especially in the Saranac Lake area.

The confidence of the groundwater-risk grid was evaluated by correlating existing CERCLA NPL groundwater contamination sites, often referred to as "Superfund" NPL groundwater contamination sites, in NYS with identified areas of significant groundwater-risk. Maximum grid values of significant groundwater-risk within a CERCLA NPL groundwater contamination area show a correlation of 76%. Median grid values of significant groundwater-risk within a CERCLA NPL groundwater contamination area display a 47% correlation. The strong correlation of significant groundwater-risk values with CERCLA NPL groundwater contamination sites lends a

strong degree of confidence to the groundwater-risk grid's ability to assess the potential of groundwater contamination in NYS.

This research attempts to lay the foundation for future GIS groundwater-risk analyses on a statewide-scale. Within the next few decades, as GIS analyses abilities advance and three-dimensional hydrogeologic data become digitally available, a more powerful method of regional groundwater-risk modeling will be accomplished. GIS modeling may be able to model potential contaminant transport through the groundwater migration pathway using D'Arcy's and advection-dispersion equations.

CHAPTER 1: BACKGROUND

Prior to the development of a GIS groundwater-risk formula, it is important to examine existing groundwater-risk methodologies. Environmentalism of the 1970's brought about political change to address environmental degradation. Environmental regulatory authorities, both Federal and State, developed groundwater-risk methods and outlined criteria needed to utilize these methods.

A. Historical Setting

Through the 1960's, as man strived to reach the moon, it became evident that his home planet's environment was under stress. The rapid advancement of technology and industrialization which preceded World War II had polluted lakes, rivers, groundwater, estuaries and oceans. In 1969 these problems were accentuated when the Cuyahoga River of Cleveland, Ohio caught fire and an offshore oil-well leak off Santa Barbara, California contaminated coastal areas and killed wildlife. These incidents were extensively covered by the media and heightened public concern.

Government responded to the environmental concerns of voters throughout the 1970's. Earth Day, a day of national reflection upon the earth's environmental condition, was established on April 22, 1970; this marked the beginning of the modern environmental movement and its politicization. At a time when the United States was in great political upheaval, largely a result of the Vietnam War, environmentalism crossed political boundaries; environmental legislation was easily pushed through congress. The EPA was created under the Nixon Administration on October 2, 1970 and took over

ecological bureaus distributed among several government departments. One of EPA's first major actions was to actively regulate industries and municipalities illegally discharging pollutants into lakes, rivers, estuaries and oceans with the authority granted it under the 1972 Clean Water Act. In 1974, an EPA study of water treatment plants indicated that many community drinking-water systems contained high concentrations of carcinogenic chemicals; in that year the Safe Drinking Water Act was ratified and regulations were created to protect underground sources of drinking-water from contamination. The Resource Conservation and Recovery Act (RCRA) was passed in 1976 with the intent of providing regulations to ensure that the disposal of hazardous wastes was done in a manner protective of human health and the environment.

The adverse effects pollution took upon human health were evidenced by several incidences in the late 1970's. In the Niagara Falls, New York community of Love Canal (Highland, 1981) toxic chemicals had leached from an abandoned industrial dump into basements of single family homes. Abnormally high degrees of miscarriages, birth defects, urinary tract disease, liver disease, and cancer were noted in this community. NYS health officials advised residents that the area was unsafe for pregnant women and young children; later, President Jimmy Carter declared a federal emergency which enabled families to relocate. Another incident occurred in the town of Toone, Tennessee. Many residents of Toone suffered from liver and urinary problems, dizziness, rashes and nausea. These families had been drinking from water wells contaminated with the pesticides endrin, dieldrin, aldrin and heptachlor (Highland, 1981). A nearby landfill, which had received approximately 300,000 drums of pesticide production residues, was

found to be the source of contamination. The contamination occurrences discovered at Love Canal and Toone were partly responsible for passage of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) (Coffel, 1989). CERCLA or "Superfund" was designed to provide EPA the mechanism and funding to identify, prioritize and implement clean-up of inactive or abandoned contaminated sites. Love Canal and Toone, as well as many other contaminated sites, have been addressed by Superfund.

With the passage of Federal and State environmental laws in the past three decades, many methods of assessing man-made deteriorative effects upon the environment and potential risk to human health have been devised. These methods assess different components of the migration pathways which connect potential sources of pollution to potential human intakes. Among these methods are the Michigan Department of Natural Resources (MDNR) Site Assessment System (SAS) (MDNR, 1983), the LeGrande System (LeGrande, 1983), the EPA Hazard Ranking System (HRS) (EPA, 1984), the EPA Superfund Human Health Evaluation (HHE) Process - Revised (EPA, 1988a; EPA, 1989), the EPA DRASTIC Model (Aller, 1987), and the EPA Region 2 Long Island UIC Inspection Targeting Method (Hillenbrand, Hansen and Ferri, 1995). These methods are used on different scales of data, from regional qualitative data to local quantitative data, and their uses vary from regional analysis of groundwater contamination risk potential to local site-specific remedial investigation. A brief description of the aforementioned methods, addressed in the order from regional to site-specific analysis, concentrating on their specifics to groundwater contamination, follows.

B. Groundwater-Risk Assessment Methods

As discussed above, several methods have been devised to assess the potential of groundwater-risk to contamination. The EPA DRASTIC Model (Aller, 1987), and the EPA Region 2 Long Island UIC Inspection Targeting Method (Hillenbrand, Hansen and Ferri, 1995) are best used on a small scale, regional analysis, such as at a county or state level. The LeGrande (LeGrande, 1983), HRS (EPA, 1984) and SAS (MDNR, 1983) methods are used on a large scale, site-specific level; these methods are used to compare sites for relative groundwater-risk potential. The HHE (EPA, 1988a; EPA, 1989) method is used on a large scale and addresses quantitative components of the contaminant migration pathway, from source to intake, at a specific site; this method is used prior to the construction and implementation of a remediation program.

The EPA developed a mapping method to display the geographic distribution of groundwater susceptibility to contamination called DRASTIC (Aller, 1987). This method incorporates a weighting and rating system addressing various hydrogeologic components (Appendix A:A). These components are depth to water-table (D), aquifer recharge (R), aquifer matrix media (A), soil media (S), topography (T), the impact of the vadose zone (I), and hydraulic conductivity (C); hence the acronym DRASTIC. Each component is assigned a weighting value and is given a rating value based on its assignment within designated ranges. The weight and rating values for each individual component are multiplied; the products of the various components are then added to produce a DRASTIC index value. Mapped DRASTIC index values display the relative susceptibility of unconfined aquifers if a contamination source was present.

EPA Region 2 (Hillenbrand, Hansen and Ferri, 1995) devised a groundwater-risk analysis method based on a Health Risk Index (HRI) formula (Carney, 1991). The HRI is a product of exposure and hazard. HRI exposure is the ratio of population exposed to total population, multiplied by an exposure factor (i.e., percent of time exposed). The EPA Region 2 method ranked population density to produce an exposure factor. Hazard value in the HRI formula is the product of a degree of impact (contaminant toxicity or carcinogenicity) and a degree of vulnerability (determined by the age and lifestyle of the population). The EPA Region 2 groundwater-risk analysis assigned a land-use rank, the potential to introduce contaminants to the groundwater system, as a degree of impact component, and ranked aquifer susceptibility for a degree of vulnerability component. The aquifer susceptibility rank was calculated utilizing depth to the water-table, vadose zone hydraulic conductivity (soil permeability), and recharge area data. The Region 2 total groundwater-risk values were calculated by multiplying population density rank, land-use rank, aquifer susceptibility rank and recharge (local adjustment factor) rank. Total groundwater-risk values were mapped on Long Island, New York to display the relative potential for aquifer contamination to impact the human population. These mapped values were used to target areas for Underground Injection Control (UIC) program inspections. For a more detailed description of this method please refer to Appendix A:B.

The LeGrande System (LeGrande, 1983) was developed to compare the potential of proposed waste disposal sites to contaminate unconfined aquifer systems and drinking water supplies. This system produces a cumbersome numeric-lettered term to describe a

proposed site's groundwater-risk; the numeric values in the term are added in order to facilitate site comparisons. Numeric values are assigned to rank the distance between a proposed waste disposal site (a contamination source) and nearest contact point (water-supply well, spring, stream etc.), depth to the water-table, speed and direction of groundwater flow with respect to contact points, and the ability of the vadose zone and unconfined aquifer to attenuate contaminants. The letter terms of the LeGrande System are used to describe site-specific characteristics such as the degree of confidence in the data used to assign the numeric values, type of contact point (such as a water-supply well), special hydrogeologic conditions (such as karst settings or cones of depression), and "degree of seriousness", which is based on aquifer sensitivity and contaminant severity. For a detailed description of the LeGrande System please refer to Appendix A:C.

The EPA HRS (EPA, 1984) uses site-specific qualitative data to devise a relative risk value addressing an existing contaminated site's potential to have deleterious effects upon human health and the environment. The HRS enables comparison of existing contaminated sites, which in turn facilitates an appropriate consideration for remedial action funding. One of the components of the HRS considers a groundwater migration hazard. The groundwater migration hazard score is determined by selecting numeric values for various factors, then placing the selected values into a set formula (Appendix A:D). The groundwater migration hazard factors considered are physical state of the contaminant (solid, liquid or gas), quantity of the contaminant, type of contaminant containment structures, toxicity/persistence properties of the contaminant, net

precipitation, permeability of the vadose zone, depth to the water-table, groundwater use, and distance to the nearest contact point.

The MDNR developed the SAS (MDNR, 1983) designed to compare the relative risks of existing contaminated sites to human health and the environment; in effect, the MDNR revised the HRS to include a more detailed evaluation of the chemical hazard posed at a site and considers the importance of existing human exposure to contaminants. A SAS site score is the product of a chemical hazard score and a site exposure score. The chemical hazard score is determined by considering quantity, toxicity, carcinogenicity, flammability, and reactivity of both identified chemical contaminants and unidentified wastes present at a site. The site exposure component addresses quantity and physical state of contaminants, containment structures and release potential, permeability of the vadose zone, depth to the water-table, contact points, and the magnitude of population exposed to contaminants in water found at concentrations above regulated maximum levels. Details of the SAS process may be referenced in Appendix A:E.

After a contaminated site has been selected for remediation by the EPA, a HHE (EPA, 1988a; EPA, 1989) is performed. This process establishes a baseline risk to human health; the risk posed to humans if remediation is not applied. The HHE uses existing quantitative data and collects new quantitative data to assess the concentrations of contaminants through the groundwater migration pathway, from source to contact point, with respect to time. Hydrogeologic data such as hydraulic conductivity, porosity, bulk density, fraction of organic carbon, and clay content are collected and used to construct a conceptual model of contaminant fate and transport through the groundwater

system. Contaminant intake quantities are derived based on the contaminant concentrations at contact points and the characteristics of the exposed human population. Carcinogenic and noncarcinogenic human health risks are evaluated over the exposure periods with the use of health-risk derived exposure levels. A carcinogenic risk is calculated for individual chemicals by multiplying the average lifetime exposure level by the carcinogen's slope factor; this yields a probability of developing cancer in a lifetime. A noncarcinogenic contaminant's health risk is derived by dividing the exposure level for a specified period of time by the contaminant's reference dose, a dosage that assures no ill health effects, for a similar exposure period (acute, sub-chronic, or chronic); this result is called the hazard quotient. Cancer probabilities of the individual carcinogenic contaminants are summed and hazard quotients of the noncarcinogenic contaminants are summed to assess a site's baseline human health risk. For a more detailed description of the HHE process please refer to Appendix A:F.

C. Evaluation of Groundwater-Risk Schemes

The methods of determining groundwater-risk to contamination discussed above vary in scope and magnitude. Table 1 identifies various components of the groundwater-risk schemes in terms of contaminant, migration pathway and contact point/intake characteristics.

The DRASTIC and EPA Region 2 methods are designed for qualitative regional analysis and mapping, such as on a county or state scale. The DRASTIC method concentrates on ranking characteristics associated with the migration pathway of the groundwater system. The DRASTIC method addresses aquifer susceptibility, but does

Table 1. Groundwater Contamination Evaluation Methods

	DRASTIC	EPA R2	LeGrande	HRS	SAS	HHE
CONTAMINANT CHARACTERISTICS						
General Contaminant Sources		Yes	Yes	Yes	Yes	Yes
Physical State of Contaminants				Yes	Yes	Yes
Toxicity of Contaminants			Yes	Yes	Yes	Yes
Persistence of Contaminant			Yes	Yes	Yes	Yes
Hazardous Waste Quantity			Yes	Yes	Yes	Yes
Surface Impoundment				Yes	Yes	Yes
Containers				Yes	Yes	Yes
Piles				Yes	Yes	Yes
Landfill				Yes	Yes	Yes
Quantitative Sampling of Contaminant Source				Yes	Yes	Yes
MIGRATION PATHWAY CHARACTERISTICS						
Net Precipitation	Yes			Yes		Yes
Net Recharge	Yes	Yes				Yes
Topography	Yes					Yes
Depth to Water-Table	Yes	Yes	Yes	Yes	Yes	Yes
Soil Media	Yes	Yes				Yes
Permeability of Vadose zone	Yes	Yes		Yes	Yes	Yes
Impact of Vadose zone	Yes					Yes
Aquifer Media	Yes			Yes	Yes	Yes
Aquifer Hydraulic Conductivity					Yes	Yes
Aquifer Thickness	Yes				Yes	Yes
Gradient of Water-Table, Direction of Flow			Yes			Yes
Sorption Properties			Yes			Yes
Special Descriptions (cone of depression, etc.)			Yes			Yes
Quantitative Sampling and Analysis of Migration Pathway			Yes			Yes
Prediction of Contaminant Concentrations through Time (Modeling)						Yes
CONTACT POINTS/INTAKE CHARACTERISTICS						
Groundwater Use (Unusable, Industrial, Drinking)				Yes		Yes
Distance to Nearest Well			Yes	Yes	Yes	Yes
Population Served		Yes		Yes	Yes	Yes
Present Groundwater Contamination					Yes	Yes
Existing Exposure to Population					Yes	Yes
Contact Points, Quantitative Sampling Analysis						Yes
Human Contaminant Intake Calculations						Yes

not consider the potential to introduce contaminants to the groundwater system, nor does it consider the potential for human intakes. The EPA Region 2 method of groundwater-risk analysis considers less factors contributing to aquifer susceptibility than the DRASTIC method. However, the EPA Region 2 method considers, to some degree, the potential to introduce contaminants to the groundwater system and potential human exposure.

The LeGrande, HRS and SAS methods are qualitative methods designed to make relative risk comparisons of numerous sites with minimal expense. These methods are designed to enable selection of sites for additional detailed investigation and are not used for regional mapping. The LeGrande system is used to compare potential hazardous waste sites whereas the HRS and SAS systems are used to compare existing contaminated sites. These methods are designed for analysis within confined areas; each method considers data within a certain radial distance from a site. Each method considers similar items of the groundwater-risk system, as displayed in Table 1. However each system considers unique items; the LeGrande Method considers vadose zone and aquifer sorption properties, speed and direction of groundwater flow with respect to contact points, and special hydrogeologic properties such as karst settings, cones of depressions, and mounding of the water-table; the HRS considers net precipitation and groundwater use; and the SAS addresses existing groundwater contamination and existing exposed population, aquifer thickness, and aquifer hydraulic conductivity.

The HHE is the large scale, quantitative, site-specific detailed analysis of contaminant sources, fate and transport through media pathways, concentration at contact

points with respect to time, human intake quantities averaged over time, and comparison of human intake with health-risked dosages.

D. Chapter 1 Summary

Pollution incidents, environmental contamination and related ill-effects upon humans, media coverage and heightened public concern lead to the establishment of environmental regulations and regulatory authorities. The regulatory authorities devised methods to assess environmental degradation. Several methods were developed to assess the potential of groundwater risk to contamination. The EPA DRASTIC and EPA Region 2 methods are designed for regional, county- to state-wide groundwater-risk assessments. The LeGrande, HRS and SAS methods are qualitative methods designed to assess groundwater-risk within a confined area surrounding a specific site. The HHE is the large scale, quantitative, site-specific detailed analysis of groundwater contamination, human intake, and adverse human health effects. Each method uses criteria to assess the contaminant, groundwater migration pathway, and contact point/intake characteristics of the groundwater contamination system. These criteria may be used by GIS, a tool designed to handle and process extensive quantities of geographically-referenced data, to assess the potential of groundwater contamination on a regional scale.

CHAPTER 2: GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic groundwater-risk analysis is a form of exploration mapping. Like petroleum- exploration mapping which uses criteria such as source rock, reservoir rock, sealing rock, and trapping mechanisms to determine where to advantageously drill a well to discover hydrocarbons (Levorsen, 1954; LeRoy and LeRoy, 1977), the geographic analysis of groundwater-risk uses criteria to calculate areas of potential groundwater contamination; areas designated as high risk may yield contaminated sites upon closer investigation and the need to perform remedial activities. The methods discussed in Chapter 1 present different criteria (Table 1) used in groundwater-risk analysis; these criteria include contaminant characteristics, migration pathway characteristics and contact points/intake characteristics. Contaminant introduction, contaminant toxicity, contaminant migration through the groundwater pathway, contaminant concentration at human contact points, and human contaminant intake amounts and duration data are used, to some degree, by these methods to assess groundwater-risk. These data can be converted into digital format and referenced geospatially. As the analysis methods change from regional to site-specific, the attribute data required for analysis shifts from small-scale qualitative to large-scale quantitative; the geospatial information must also increase in terms of spatial accuracy. GIS is a formidable tool to store, process, manipulate, analyze and display these geospatially-referenced criteria.

A. Development of GIS

Throughout history spatial data has been collected by political leaders, military leaders, wealthy land owners, navigators, geographers and surveyors to be recorded in

coded pictorial form by map-makers. One of the earliest known maps was created about 4,500 years ago in a clay tablet; the map depicts the estate of a wealthy Babylonian land owner (Van Riper, 1971). The diversity, quantity and quality of spatial data have greatly increased over the past few centuries. Today, fields of study such as sociology, economics, natural sciences, and medicine have gathered spatial data to be presented in map form. Spatially oriented aerial photographs and satellite imageries have added to spatial data and map analyses. Beginning in the 1960's, the availability of digital computers enabled the once paper-confined spatial data to be recorded in digital format. Spatial information was encoded in the form of entities and attributes (DeMers, 1967; Burrough and McDonnell, 1998). Entities such as points, lines and areas are used to describe objects of the real world. Attribute information describes the entities. Attributes are saved in relational database format and are also related digitally to the entity database. Howard T. Fisher developed the program SYMAP, which included a set of modules to produce choropleth or isoline interpolations (Burrough and McDonnell, 1998). Choropleth maps divide areas with similar attributes, while isoline data, such as contours, plot lines of equal attribute values. In 1963, Fisher used computers to produce simple maps of data plotted in a grid. Grid, or raster, mapping records digital data and references the values of the data to a geospatially referenced grid; a grid consists of columns and rows of cells, or pixels, with each cell containing a value. In the 1970s Fisher became the director of the Harvard Graduate School of Design's Laboratory for Computer Graphics which developed and improved upon several grid mapping programs. Through the 1980s Fisher and his team had a great influence upon the development of the

georepresentational and spatial analysis methodology known as GIS. Through the 1990s, GIS functionality, the ability of geospatial data to be analyzed, processed, related and mathematically manipulated, was advanced, refined and standardized.

GIS is an organized collection of computer hardware, software and geographic data designed to capture, efficiently store, update, analyze, and display all forms of geographically referenced information (DeMers, 1997). GIS is a computer system capable of holding and using data describing places on the earth's surface. The data can be used by GIS to produce a vector or raster model (Burrough and McDonnell, 1998). The vector model geographically displays entities such as points, lines and polygons which represent objects in the real world. These objects possess attributes in the GIS, which are data describing the entities. For example, points may be used to represent well locations and the attribute information for the wells may include kelly-bushing elevation, surface elevation, and depth measurements of different geologic formations. Raster models display objects as a geographically-referenced grid with values of real-world objects tied to the grid cells. Varying values of a continuous surface, such as topographic elevation, is best represented by the raster model. The raster and vector models can be manipulated and transformed by the GIS to analyze geospatial data relationships; raster models can be transformed to vector models and vice versa. GIS acts as an electronic mapping system with a geospatial calculator component. GIS can be used to model geospatial phenomena, such as groundwater flow speed and direction; model accuracy is determined by the accuracy of input data, both in terms of geospatial reference and attribute information.

B. Value of GIS in Groundwater-Risk Analysis

Groundwater-risk can be analyzed using a GIS process called cartographic modeling. Cartographic modeling (DeMers, 1997) is a GIS process which uses combinations of commands to answer questions about spatial phenomena; in the case of this study, the question is where may groundwater be contaminated. A cartographic model is a set of interacting, ordered geospatial operations that act on raw data, as well as derived and intermediate data, to simulate a spatial decision-making process (DeMers, 1997). Modeling is a logical or mathematical formulation that attempts to simulate some aspect of the real world. The cartographic model used in this research is discussed in Chapter 4; understanding the groundwater-contamination system is critical for the creation of an adequate groundwater-risk cartographic model.

C. Chapter 2 Summary

GIS is a computer system designed to capture, efficiently store, update and analyze all forms of geographically-referenced digital data. The GIS process called cartographic modeling can be used to simulate some aspect of the real world, such as the groundwater contamination system. Criteria used by groundwater-risk methods, such as those presented in Chapter 1, can be digitized and utilized in a GIS groundwater-risk analysis. Prior to establishing a cartographic model to assess groundwater contamination risk, it is important to be familiar with some aspects of the physical and chemical components of the groundwater contamination system.

CHAPTER 3: GROUNDWATER-CONTAMINATION SYSTEM

The aspect of the real world that this research attempts to model, using GIS technology, is to assess the potential to introduce contaminants at the earth's surface in NYS, and have them travel through the vadose zone and be introduced to an unconfined aquifer system at the water-table. In other words, this research attempts to explore for areas where groundwater may be contaminated using several of the criteria for groundwater-risk analysis discussed in the Chapter 1. The groundwater-risk methodology presented uses criteria for chemical characteristics and characteristics of the upper portion of the groundwater migration pathway. Several aspects of the contaminant introduction and groundwater migration pathway system must be understood before selection of criteria and mathematical formulation of a cartographic model can be derived.

A. Sources of Contamination

Sources of contamination must be evaluated in order to assess the groundwater-risk of contamination. Contaminants can be provided from a specific location, or point source, or from sources spread over large areas, known as non-point sources. Sewage-treatment plants, septic systems, injection wells, surface impoundments, stockpiles, leaking storage tanks, landfills, and leaking containers (barrels or drums) are examples of point sources of contamination (Rail, 1989). Non-point sources of potential contamination include agricultural activity, such as fertilizer and pesticide spreading, and animal feedlots; as well as spills, road drainage and other forms of surface spreading

(Rail, 1989). Contaminants are defined as any solute that enters the hydrologic cycle through human activity (Freeze and Cherry, 1979). Contaminants can be chemical, biological or radiological substance introduced to the groundwater. Appendix B, EPA Region 3 Hazardous Substances List (EPA, 2001), contains a list of chemical contaminants and the lower value ($\mu\text{g/l}$) of a given substance's noncarcinogenic or carcinogenic lifetime daily drinking-water intake concentration protective of human health.

B. Unconfined Aquifer Recharge Through the Vadose zone

Unconfined aquifer systems are the product of geological processes and the hydrologic cycle at the near surface of the earth; these aquifer systems receive water generally by recharge through the vadose zone, also termed the unsaturated zone. Rock materials exposed at the earth's surface, both consolidated and unconsolidated, contain pore spaces that allow the infiltration of water. Water at the ground surface is often supplied by precipitation, flooding, or by irrigation. Infiltration is equal to natural and man-made sources of water influx, minus the amounts of evapotranspiration and surface runoff (EPA, 1988b).

$$J = HL + Pr - ET - Qr$$

J = Specific discharge or flux

HL = Hydraulic loading from man-made sources

Pr = Precipitation

ET = Evapotranspiration

Qr = Surface runoff

The vadose zone, also known as the unsaturated zone, through which infiltrating

water migrates, is the geologic section between the ground surface and the saturated aquifer. Pores within this section are filled with water and air. The air pressure is equal to atmospheric pressure, while the fluid pressure is negative with respect to atmospheric pressure. The attraction of the fluid to rock surfaces, produced by the principals of capillarity and wettability, creates a negative tension in the fluid above the water-table; this includes an area of water saturated porosity above the water-table called the capillary fringe (Fetter, 1980). The degree of moisture within the vadose zone and geologic matrix permeability controls the rate of infiltration for a given geologic material. Dry sediment displays a high initial rate of infiltration as gravity and soil particle surface tension act upon water. Smaller sediment particles possess increased surface area, which increases rock matrix-surface-water contact tension; this decreases permeability. Permeability is proportional to the square of the mean diameter of particle size (Freeze and Cherry, 1979). Fractured rock permeability is a function of the mean width of the fractures and the number of fractures per cross-sectional area (Freeze and Cherry, 1979). For a given rock or sediment type, infiltration rates decrease as moisture content increases until the soil is fully saturated and a constant infiltration rate is reached. This constant rate of infiltration through the saturated soil is equivalent to the rock or sediment's saturated hydraulic conductivity. Hydraulic conductivity is a function of rock matrix intrinsic permeability and the properties of the migrating fluid with respect to gravity, specifically density and dynamic viscosity (Freeze and Cherry, 1979). In the case of this study, water is the considered migrating fluid. When soil-moisture content reaches a point, at which the forces of gravity are greater than the forces of surface tension, gravity drainage

initiates and water moves downward toward the saturated aquifer. At a point where soil-moisture content forces of gravity equal the forces of surface tension, gravity drainage ceases; this point is known as the field-capacity of soil. Soil-moisture varies with seasonal changes of precipitation and evapotranspiration; when soil-moisture field-capacity is exceeded, aquifer recharge can occur. After heavy periods of precipitation when field-capacity moisture content is substantially exceeded, resultant water slugs will move downward through the vadose zone to the water-table. Water flows downward by gravity in the vadose zone through interconnected pores that are filled, or partially filled, with water. As more pores become filled with water, the downward movement of water increases.

The main components which determine the characteristics of infiltration are porosity and hydraulic conductivity (a function of a rock or sediment's intrinsic permeability), which are determined by the nature of the subsurface materials, and the degree of moisture content present within the pore spaces. Darcy's Law is valid for flow in the unsaturated zone (Fetter, 1980), although the unsaturated hydraulic conductivity is not constant. Hydraulic conductivity is a function of geologic matrix type and degree of fracturing, and the properties of the fluid passing through the rock. For a given rock type, as the moisture content increases the hydraulic conductivity increases. The ability of recharge water to flow through the unsaturated pores increases as a rock's pore space becomes filled with water, as the porosity percent of water saturation increases, the forces of gravity acting upon the water increases with the respect to the forces of surface tension applied by the geologic matrix. Hence, the hydraulic conductivity increases with

increased moisture content; maximum hydraulic conductivity of the vadose zone is equal to saturated hydraulic conductivity. Specific discharge within the vadose zone can be expressed as follows (Nielsen, Biggar, and Erh, 1973):

$$J = K(\theta) \times \nabla H$$

J = Specific discharge or flux

$K(\theta)$ = Hydraulic conductivity, expressed as a function of moisture content

∇H = The hydraulic gradient, expressed in vector form

The average linear velocity of infiltration can also be estimated by dividing the specific discharge, or unsaturated hydraulic conductivity by the average moisture content of the vadose zone (Freeze and Cherry, 1979):

$$v = J / \phi_w = (K(\theta) \times \nabla H) / \phi_w$$

v = Average linear velocity

J = Specific discharge or flux

$K(\theta)$ = Hydraulic conductivity, expressed as a function of moisture content

∇H = The hydraulic gradient, expressed in vector form (unity)

ϕ_w = Water filled porosity percent (Moisture Content)

With a vertical flow direction in the vadose zone, the change in height of the water per unit of vertical travel distance is one ($dH/dZ = 1$); therefore, hydraulic gradient for vertical flow may be simplified as unity (Bouwer, 1978). If the vadose zone is saturated, the linear velocity is equal to the hydraulic conductivity divided by the matrix porosity.

$$v = K / \phi$$

v = Average linear velocity

K = Hydraulic conductivity

ϕ = Porosity

Hydraulic conductivity and porosity are a function of a geologic matrix.

If the thickness of the vadose zone is considered along with its average linear velocity, residence time of water percolating through the vadose zone can be calculated.

$$RT = VT / v$$

RT = Residence time of water in vadose zone

VT = Vadose zone thickness

v = average linear velocity of vadose zone

C. Contaminant Attenuation and Retardation in the Vadose zone

When a contaminant is introduced to the groundwater migration pathway at the top of the vadose zone, it may undergo several processes along its route toward the water-table. If the contaminant is a solid, its introduction to the system is a function of water percolation rates and solid contaminant solubility. Liquid contaminants can migrate through the vadose zone to the water-table by the force of gravity; vadose zone water percolation rates and liquid contaminant solubility will determine the concentration of a contaminant in a dilute plume. A contaminant may be soluble or insoluble in water.

As a dilute contaminant plume moves through the vadose zone it may undergo attenuation and retardation. Attenuation processes remove contaminants from a migrating dilute plume; contaminants may be removed by chemical transformation into less toxic derivatives or they may be removed from the system by media transfer.

Retardation is a reversible process which slows the velocity of contaminant migration with respect to groundwater linear velocity.

The two most important attenuation processes in the vadose zone are volatilization and biodegradation. Volatilization transfers a contaminant from the dilute water system to the atmosphere. Volatilization is most effective with compounds that are resistant to degradation, and possess low solubilities and high vapor pressures.

Volatilization decreases with increased vadose zone moisture content and normally is most efficient in the upper portions of the vadose zone. The upper portion of the vadose zone is also subject to greater fluctuations in temperature and pressure, and in general, more air exists in the pore space to accommodate media transfer and migration of contaminants upward out of the vadose zone to the atmosphere. Biodegradation results from the enzyme-catalyzed transformation of organic compounds by microbes, principally bacteria, fungi, actinomycetes, algae, and yeasts (Aller, 1987); microbes breakdown organic compounds and decrease their toxic properties. Biodegradation can occur in both aerobic and anaerobic environments. Soluble organic contaminants are usually biodegradable.

The most important retardation factor in the vadose zone is sorption. Sorption is a combination of two processes, adsorption and absorption. Adsorption occurs when molecules or ions are attached to the surface of charged particles by weak Van der Waals force or covalent bonds. Absorption involves the incorporation of the absorbed substance into the matrix particle. Colloidal clay minerals and organic content provide sorptive sites in the geologic matrix. Sorption of hydrophobic organic contaminants is a function

of the contaminant's octanol-water partition coefficient (K_{ow}) and the percent organic carbon in the geologic matrix. The greater a contaminant's K_{ow} , the more likely it will be sorbed to organic carbon in the geologic matrix.

The efficiency of the vadose zone to attenuate or retard contaminants is determined by the amount of time a contaminated plume has to interact with the matrix particles and air-filled porosity of the vadose zone. Long periods of groundwater residence time within the vadose zone allow volatilization, biodegradation and sorption to act more efficiently upon a contaminated plume than a short period of groundwater residence time. Groundwater residence time within the vadose zone is a measure of an aquifer's susceptibility to contamination; short periods of vadose zone residence time render an aquifer more susceptible to contamination.

Once contaminants reach the water-table, they may enter the aquifer system as an insoluble concentrated plume, or as a solute plume. Insoluble contaminants may float upon, sink below or flow within the groundwater of the aquifer system; the relative density of the concentrated plume to water determines its buoyant fate. Concentrated plumes that float upon or migrate within the aquifer proceed in the direction of groundwater flow. Concentrated plumes that sink through the aquifer system will flow in the dip direction of an aquifer's impermeable base. Contaminant migration within the saturated aquifer can be modeled using advection-dispersion equations (Freeze and Cherry, 1979); this process was considered too complex for this regional groundwater-risk study. This study attempts to define groundwater-risk as the ability of contaminants to be introduced at the upper portion of the vadose zone and the potential to be introduced

to the saturated aquifer at the water-table. Contaminant transport from the water table to human contact points may be addressed in the future.

D. Chapter 3 Summary

Contaminants are introduced to the upper portion of the vadose zone by point and non-point sources; they are incorporated into groundwater by the processes of infiltration and aquifer recharge. Aquifer recharge occurs by water infiltration through the vadose zone which consists of a three-component system of geologic matrix, air, and water. Infiltration rate is a function of rock or sediment porosity, hydraulic conductivity (in turn a function of a geologic matrix's intrinsic permeability), and moisture content. A simplified view of the rate of vertical migration of water through the vadose zone may be expressed as average linear velocity under maximum load conditions (saturated conditions). Average linear velocity may be calculated by dividing hydraulic conductivity by matrix porosity. Vadose zone residence time, under maximum load, may be expressed by dividing the thickness of the vadose zone, or depth to the water-table, by the average linear velocity. Contaminant attenuation and retardation efficiency within the vadose zone is a function of vadose zone residence time. Long periods of groundwater residence time within the vadose zone allow volatilization, biodegradation and sorption to act more efficiently upon a contaminated plume than a short period residence time. The presented formulas can be used to construct a GIS cartographic model for groundwater-risk analysis. The availability and extent of existing GIS data layers and digitized data pertaining to hydrogeologic parameters needed for the above discussed formulas will determine the means and design of a groundwater-risk cartographic model.

CHAPTER 4: METHODOLOGY

Groundwater-risk analyses assess the potential for an aquifer to become contaminated by the movement of a contaminant from a source, through the vadose zone, to the water-table, into the aquifer system as a concentrated or dilute plume, and delivery to a human contact point. For a perfect analysis of regional groundwater-risk, all the data required to perform the contaminant migration portion of the HHE (EPA, 1988a; EPA, 1989), groundwater fate modeling from source to intake points, would be available throughout a region; the sources of contaminants and loading rates, the three-dimensional contaminant-geologic matrix interaction components and hydrogeologic parameters of the vadose zone and unconfined aquifer would be fully identified and understood. Contaminant attenuation and retardation processes would be fully understood throughout the system. Today, this data is only available on site-specific basis where intense sampling and analyses have been established; little of this data has been digitized and made available to the public. In order to perform a regional groundwater-risk analysis, best performed utilizing GIS, regionally available digital data must be gathered and processed. The available data will allow the formulation of a groundwater-risk cartographic model.

A. Available Data

Prior to creating a formula for a regional groundwater-risk assessment utilizing GIS, existing GIS data layers and useful environmental databases must be identified. The following existing GIS data layers and digital databases cover NYS and were used in this

study:

a. GIS Data Layers

United States Geological Survey (USGS) Digital Line Graph (DLG-100)

Surface Hydrology - The USGS DLG files are a digital vector representation of cartographic information. The surface hydrology data was digitized or scanned from 1:100,000 scale series USGS topographic maps. The topographic map data were originally compiled from aerial photographs. The author modified the coverage to remove aqueduct lines (arcs) and to correct any obvious digital data errors by cross checking the coverage with printed paper copies of USGS 1:100,000 topographic maps. This study utilized the digitized surface expressions of streams, rivers, lakes, swamps, bays, estuaries and oceans.

USGS Digital Elevation Models (DEMs) - DEMs are digital records of terrain elevations for ground positions at regularly spaced horizontal intervals (grid) which are derived from USGS quadrangle maps. The source maps used in this study were 1-degree (1:250,000-scale) quadrangle maps; the DEM data were produced by the Defense Mapping Agency in 1-degree by 1-degree units which correspond to the east half or west half of USGS 1- by 2- degree topographic quadrangle maps series, for all the United States and its territories. 1-degree DEM data consist of a regular array of elevations referenced horizontally using the geographic (latitude/longitude) coordinate system of the World Geodetic System 1972 Datum. A few units are also available using the World Geodetic System 1984 Datum. Spacing of the elevations along and between each profile is

three arc seconds with 1,201 elevations per profile. The grid cell size of the NYS DEM utilized is 94.5634 meters.

Natural Resources Conservation Service (NRCS) State Soils Geographic

(STATSGO) Soil Data - Natural Resource Conservation Service (NRCS, formerly Soil Conservation Service) State Soils Data (USDA, 1993) was gathered from a 1:250,000 basemap scale. The data was compiled from large scale county level data to an approximate scale of 1:250,000. The basic interpreted area is the Map Unit Delineation, encompassing a minimum area of 625 hectares (1544 acres). The physical and chemical parameters for the map unit are contained in a series of related files including: a map unit table, a number of component tables, an interpretation table, a lookup table and a layer table. Layer attributes include thickness, bulk density, weight percent organic matter, and weight percent moisture.

NYS Museum (NYS Geological Survey) Surficial Geology - The New York Surficial Geology data layer contains information on the surface geology of New York, especially pertaining to the unconsolidated components. Bedrock outcrops are noted. The attributes of the surficial geology coverage address the type of material at the surface by classification of depositional environment. A range of thicknesses of each type of deposit is also included (Table 2). The source maps are referenced as NYS Museum Map and Chart Series Number 40. They were produced between 1986 and 1991 (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991).

NYS Museum (Geological Survey) Bedrock Geology - The bedrock geology data contains information on the consolidated rocks which outcrop at the surface or lie below unconsolidated sediments in NYS. The data was digitized from five map sheets which cover the state. They are the Finger Lakes, Hudson-Mohawk, Niagara, Lower Hudson and Adirondack Sheets. These 1:250,000-scale maps were used as the source maps for all coverages. Attributes for the coverages include formation, formation code, and lithologic description (Table 3). The maps used for digitizing were published on paper in 1970, and are referenced as NYS Museum Map and Chart Series Number 15 (Fisher, Isachsen and Rickard, 1970a; Fisher, Isachsen and Rickard, 1970b; Isachsen and Fisher, 1970; Rickard and Fisher, 1970a; Rickard and Fisher, 1970b).

Multi-Resolution Land Characteristics (MRLC) Land Use - The MRLC is a seamless, consistent land cover grid based on composite Landsat Thematic Mapper (TM) data from several years and seasonal conditions. The data was collected between 1991 and 1993. Each grid cell, 30 meters by 30 meters, is coded with one of sixteen values corresponding to a selected land classification scheme. This classification scheme was developed by the USGS EROS Data Center, Sioux Falls, South Dakota.

Wessex Roads - This coverage represents address matched road data including Interstate, highway and local streets based on the 1995 Topologically Integrated Geographic Encoding and Referencing system (TIGER) Line files from the U.S. Bureau of the Census. This data is an enhanced version of the U.S. Bureau of the

Census 1995 TIGER data made by Wessex Corporation.

Census Tracts - The coverage contains census-block boundaries. These boundaries were derived from the U.S. Bureau of the Census 1990 TIGER/Line data. Census blocks are small areas that do not cross the boundaries of counties, county subdivisions, places, census tract or block numbering areas, American Indian areas, congressional districts, voting districts, urban or rural areas, or urbanized areas. Census blocks can be associated with the 1990 census data and other census products that are tabulated by the block. GIS applications can use the Census Tract data layer for base mapping of block boundaries and for geo-demographic analysis.

ZIP Code Areas - Zip Code boundaries data layer coverage was constructed by Geographic Data Technology (GDT). The zip codes are administrative units established by the US Postal Service (USPS) for the distribution of mail. It contains representations for all 5-Digit ZIP.

b. Databases

USGS National Water Information System (NWIS)/Ground Water Site

Inventory (GWSI) - Groundwater well sites, were collected from the USGS NWIS/GWSI database and used to construct a point coverage of wells in NYS. Useful groundwater attributes were selected from the USGS NWIS database user manual (USGS, 1989); they are listed in Table 4. The point coverage was processed to produce a well coverage which contained measured water levels from wells completed in unconfined aquifers.

EPA Toxic Release Inventory (TRI) - The Toxic Release Inventory (TRI) is an EPA database tabulating the releases of toxic chemicals into the environment. Developed as part of the Emergency Planning and Community Right to Know Act of 1986, TRI stores information that is self-reported annually from industries that conduct manufacturing operations within certain specified SIC codes (SIC Codes 20-39 until the 1998 reports). A SIC code is a code representing a category within the Standard Industrial Classification System administered by the Statistical Policy Division of the U.S. Office of Management and Budget. The system was established to classify all industries in the U.S. economy. A two-digit code designates each major industry group, which is coupled with a second two-digit code representing subcategories. In addition to industrial classification, facilities are required to report if they manufacture or process more than 25,000 pounds of a listed chemical during a year, or otherwise used more than 10,000 pounds, and have the equivalent of more than 10 full-time employees. They must report the on-site releases of toxic chemicals into the air, water, and land; and quantities treated, combusted for energy recovery, and recycled on-site. They also report on transfers of wastes that are disposed, treated, combusted for energy recovery, or recycled at a separate facility.

EPA Permit Compliance System (PCS) - The Permit Compliance System (PCS) is a database of information on water discharge permits, designed to support the National Pollutant Discharge Elimination System (NPDES).

Table 2. Attributes describing NYS Museum Surficial Geology Coverage

Depositional Environment Code	Description	Range in Thickness (m)
al	recent sediments, generally confined to flood plains within a valley, oxidized, non-calcareous, fine sand to gravel, in larger valleys may be overlain by silt, subject to frequent flooding.	1 to 10
alf	alluvial fan, fan shaped accumulation, poorly stratified silt, sand and boulders, at the foot of steep slopes, generally permeable	1 to 10
ali	alluvial inwash, deposited between active or remnant glacier ice and draped on adjacent valley wall, lacks kettles, permeability varies	2 to 10
alt	alluvial terrace, fluvial sand and gravel, occasional laterally continuous lenses of silt, remnants of earlier higher floodplains, generally permeable	1 to 10
b	beach sand and gravel deposits at marine shoreline	-
bi	barrier island, sand and gravel deposits as barrier island	-
co	colluvium, mixture of sediments, deposited by mass wasting	1 to 5
cof	colluvial fan, fan shaped accumulation, mixture of sediment, at mouths of gullies	1 to 5
pm	swamp deposits, peat-muck, organic silt and sand in poorly drained areas, unoxidized, may be overlying marl and lake silts, potential land instability	2 to 20

Table 2 (continued). Attributes describing NYS Museum Surficial Geology Coverage

Depositional Environment Code	Description	Range in Thickness (m)
d	dunes, fine to medium sands, well-sorted, stratified, non-calcareous, unconsolidated, generally wind reworked lake sediments, permeable, well drained	1 to 10
lb	lacustrine beach, generally well-sorted sand and gravel, stratified, permeable and well drained, deposited at a lake shoreline, generally non-calcareous, may have wave-winnowed lag gravel	1 to 5
ld	lacustrine delta, coarse to fine gravel and sand, stratified, generally well-sorted, deposited at a lake shoreline	3 to 5
lsc	lacustrine silt and clay, generally laminated silt and clay deposited in proglacial lakes, generally calcareous, potential land instability	up to 100
ls	lacustrine sand, sand deposits associated with large bodies of water, generally a near-shore deposit or near a sand source, well-sorted, stratified, generally quartz sand	2 to 20
og	outwash sand and gravel, coarse to fine gravel with sand, proglacial fluvial deposition, well rounded and stratified, generally finer texture away from ice border	2 to 20
fg	fluvial gravel, same as outwash sand and gravel, except deposition is farther from the glacier	2 to 20
fds	fluvial deltaic sand, generally fine sands, proglacial topset fluvial deposition	2 to 10

Table 2 (continued). Attributes describing NYS Museum Surficial Geology Coverage

Depositional Environment Code	Description	Range in Thickness (m)
k	kame deposits, includes kame eskers, kame terraces, kame deltas, coarse to fine gravel and/or sand, deposition adjacent to ice, lateral variability in sorting, coarseness and thickness, locally firmly cemented with calcareous cement	10 to 30
ki	inwash, coarse to fine gravel and/or sand, interpreted as alluvium deposited adjacent to active or remnant ice by streams of nonglacial origin	2 to 20
km	kame moraine, variable texture (size and sorting) from boulders to sand deposition at an ice margin during deglaciation, locally during deglaciation, locally cemented with calcareous cement	10 to 30
tm	till moraine, more variably sorted than till, generally more permeable than till, deposition adjacent to ice, more variably drained, may include ablation till	10 to 30
mb	marine beach, generally well-sorted sand and gravel, elevation at or below highest marine level, permeable and well drained, may be fossiliferous, deposited in brackish to salt water	1 to 5
md	marine delta, coarse to fine gravel and sand, elevation at or below highest marine level, stratified, generally well-sorted, deposited in brackish or salt water, permeable	3 to 5

Table 2 (continued). Attributes describing NYS Museum Surficial Geology Coverage

Depositional Environment Code	Description	Range in Thickness (m)
s	undifferentiated marine and lacustrine sand, well-sorted, stratified, fine to medium sand, generally a near-shore deposit, at or below highest marine level, may include fossil shells, may be a brackish to salt water deposit, permeable	2 to 20
sc	undifferentiated marine and lacustrine silt and clay, elevation within highest marine level, generally laminated to massive silt and clay, may include fossil shells, deposited in brackish to salt water, low permeability, potential land instability	up to 50
sf	subaqueous fan, coarse to fine gravel and/or sand, variable texture and sorting, deposited adjacent to glacier with englacial or subglacial conduit debouching in deep water	5 to 30
t	till, variable texture (e.g., clay, silt-clay, boulder clay), usually poorly sorted diamict, deposition beneath glacier ice, relatively impermeable (loamy matrix), variable clast content	1 to 50
ta	ablation moraine, till, deposited by downwasting, with minor amounts of sand and silt deposition during final melting of glacier	1 to 10
udc	undifferentiated drift complex	-

Table 3. Attributes describing NYS Museum Bedrock Geology formation lithology

Formation	Fm Code	Lithology Package
Monmouth Group, Matawan Group, Magothy Fm	Km	clay, silt, sand and gravel
Raritan Fm	Kr	clay, silt, sand and gravel
Dikes	KJk	igneous, basic
	KJd	igneous, basic
Laccolith	KJtp	igneous, basic
Hammer Creek Fm	Trhc	conglomerate
Brunswick Fm	Trb	sandstone, conglomerate, siltstone, mudstone, arkose
	Trbg	sandstone, conglomerate
	Trba	mudstone, sandstone, arkose
Stockton Fm	Trs	sandstone, conglomerate, mudstone
Ladentown Basalt	Tri	igneous, basic
Palisades Diabase	Trp	igneous, basic
Olean Conglomerate, Connoquenessing Fm	Pp	sandstone, shale, conglomerate
Cuyahoga Fm, Corry Sandstone, Knapp Fm	Mp	shale, sandstone, conglomerate
Peekskill Pluton	Dpgr	igneous, acidic
	Dpgd	igneous, basic
	Dbg	igneous, acidic
Oswayo Fm, Venango Fm, Cattarugus Fm	Dco	shale, siltstone, sandstone, conglomerate
Ellicott Fm, Dexterville Fm, Germania Fm, Whitesville Fm, Hinsdale Sandstone, Wellsville Fm, Cuba Sandstone	Dct	shale, sandstone
Northeast Shale, Shumla Siltstone	Dcys	shale, siltstone
Westfield Shale, Lapna Siltstone	Dcyl	shale, siltstone
Gownada Shale, South Wales Shale, Dunkirk Shale	Dcyd	shale
Machias Fm, Rushford Sandstone, Caneadea Shale, Canisteo Shale, Hume Shale, Canseraga Sandstone	Dcy	shale, sandstone, siltstone
Hanover Shale, Wiscoy Fm, Pipe Creek Shale	D	shale, sandstone
Angola Shale, Rhinestreet Shale	Dwf	shale

Table 3 (continued). Attributes describing NYS Museum Bedrock Geology formation lithology

Formation	Fm Code	Lithology Package
Nunda Fm	Dwn	sandstone, shale
West Hill Fm, Corning Shale	Dwc	shale, sandstone, siltstone
Honesdale Fm	Dwh	sandstone, shale
New Milford Fm	Dwmn	sandstone, shale
West Hill Fm, Gardeau Fm, Roricks Glen Shale, Beers Hill Shale, Grimes Siltstone	Dwg	shale, siltstone
Gardeau Fm	Dwrg	shale, siltstone
Slide Mountain Fm	Dws	sandstone, shale, conglomerate
Dunn Hill Shale, Millport Shale, Moreland Shale	Dwr	shale
Beers Hill Shale, Grimes Siltstone	Dwm	shale, siltstone
Walton Fm	Dww	shale, sandstone, conglomerate
Cashaqua Shale, Middlesex Shale, Rue Point Shale, Rock Stream Siltstone, Pultney Shale, Sawmill Creek Shale, Johns Creek Shale, Montour Shale, Enfield Siltstone, Kattel Fm	Ds	shale, siltstone
Walton Fm	Dsw	shale, sandstone, conglomerate
West River Shale, Genundewa Limestone, Penn Yan Shale, Geneseo Shale, North Evans Limestone, Ithica Fm	Dg	shale, limestone, siltstone
Oneonta Fm	Dgo	shale, sandstone, conglomerate
Unadilla Fm, Laurens Fm, New Lisbon Fm, Gilboa Fm	Dgu	shale, siltstone, sandstone
Tully Limestone	Dt	limestone
Moscow Fm	Dhmo	shale, limestone, sandstone
Ludlowville Fm	Dhld	shale, limestone
Skaneateles Fm	Dhsk	shale, limestone
Panther Mountain Fm	Dhpm	shale, siltstone, sandstone
Plattekill Fm, Ashokan Fm	Dhpl	shale, sandstone
Marcellus Fm	Dhmr	shale, limestone, sandstone
Undifferentiated Hamilton	Dhm	shale, sandstone
Skunnemunk Fm, Bellvale Fm	Dh	shale, siltstone, sandstone, conglomerate
Onondaga Limestone	Dob	limestone

Table 3 (continued). Attributes describing NYS Museum Bedrock Geology formation lithology

Formation	Fm Code	Lithology Package
Onondaga Limestone, Schoharie Fm, Esopus Shale, Carlisle Center Siltstone	Dou	limestone, shale, siltstone
Oriskany Sandstone	Do	sandstone, limestone
Glenerie Fm, Port Jervis Fm	Dgl	limestone, shale
Port Ewen Limestone, Alsen Limestone, Becraft Limestone, New Scotland Limestone, Kalkberg Limestone, Coeymans Limestone, Manlius Limestone, Roundout Dolostone	Dhg	limestone, dolostone
Binnewater Sandstone, High Falls Shale, Kanouse Sandstone, Woodbury Creek Fm, Connely Conglomerate, Central Valley Sandstone, New Scotland Limestone, Decker Limestone, Poxono Island Fm, Longwood Shale, Green Pond Conglomerate	DS	limestone, dolostone, shale, sandstone, conglomerate
Akron Dolostone, Bertie Fm	Sab	dolostone, shale
Cobleskill Limestone, Bertie Fm, Camillus Fm, Syracuse Fm, Brayman Shale	Scs	limestone, shale, dolostone
Camillus Fm, Syracuse Fm, Vernon Fm	Scv	shale, dolostone, evaporites
Camillus Fm, Syracuse Fm	Scy	shale, dolostone, evaporites
Cobleskill Limestone, Bertie Fm, Camillus Fm	Scs	limestone, dolostone, shale
Syracuse Fm	Ssy	dolostone, shale, evaporites
Vernon Fm	Sv	shale, dolostone
Guelph Dolostone, Oak Orchard Dolostone, Eramosa Dolostone, Goat Island Dolostone,	Sl	dolostone, limestone

Table 3 (continued). Attributes describing NYS Museum Bedrock Geology formation lithology

Formation	Fm Code	Lithology Package
Gasport Limestone, Penfield Dolostone, Sconondoa Fm, Ilion Shale	Sl	dolostone, limestone
Roundout Fm, Binnewater Sandstone, High Falls Shale, Warwarsing Limestone, Decker Limestone, Bossardville Limestone, Poxono Island Fm	Srp	limestone, dolostone, shale, sandstone
Bloomsbrug Fm, Guymard Quartzite, Otisville Shale, Shawangunk Conglomerate	Sbs	shale, sandstone, conglomerate
Decew Dolostone, Rochester Shale, Irondequoit Limestone, Merriton Limestone, Herkimer Sandstone, Kirkland Hematite, Willowvale Shale, Westmoreland Hematite, Sauquoit Fm, Oneida Conglomerate	Scl	dolostone, limestone, shale, sandstone, conglomerate
Decew Dolostone, Rochester Shale	Sr	shale, dolostone
Thorold Sandstone, Grimsby Fm, Power Glen Shale, Cabot Head Shale, Whirlpool Fm	Sm	sandstone, shale
Undifferentiated Medina Group, Grimsby Fm, Queenston Fm	SmOq	sandstone, shale, siltstone
Mafic Complexes	Oban	igneous, basic
	Od	igneous, basic
	Ohn	igneous, basic
	Oh	igneous, basic
	Oopx	igneous, basic
	Opx	igneous, basic
	Ogb	igneous, basic
Queenston Fm	Oq	shale, siltstone
Quassaic Quartzite	Oqu	sandstone, conglomerate
Oswego Sandstone	Oo	sandstone
Pulaski Fm, Whetstone Fm	Opw	siltstone, shale
Frankford Fm	Of	shale, siltstone

Table 3 (continued). Attributes describing NYS Museum Bedrock Geology formation lithology

Formation	Fm Code	Lithology Package
Schenectady Fm	Osc	graywacke, sandstone, siltstone, shale
Austin Glen Fm	Oag	graywacke, shale
Utica Shale	Ou	shale
Canajoharie Shale	Oc	shale
Iberville Shale	Oi	shale
Stony Point Shale	Osp	shale
Cumberland Head Argillite	Ocum	shale
Normanskill Fm	On	shale, siltstone
Walloomsac Fm	Owl	mudstone, shale
Cobourg Fm, Glens Falls Fm	Ot	limestone
Balmville Limestone	Oba	limestone
Undivided Trenton - Black River	Otbr	limestone
Chaumont Limestone, Lowville Limestone, Pamelia Dolostone, Amsterdam Limestone, Isle La Motte Limestone	Obr	limestone, dolostone
Taconic Melange	Otm	shale, mudstone
Valcouth Limestone, Crown Point Limestone, Ste Therese Siltstone, Middlebury Limestone, St. Martin Limestone, Rockcliffe Limestone	Och	limestone, siltstone
Chuctanunda Creek Dolostone, Tribes Hill Fm, Gailor Dolostone, Providence Island Dolostone, Fort Cassin Fm, Fort Ann Fm, Cutting Fm, Ogdensburg Dolostone	Obk	dolostone, limestone
Serpentine	Os	igneous, basic
Copake Fm, Rochdale Fm, Halcyon Lake Dolostone	Ow	limestone, dolostone
Manhattan Fm	Om	schist
	Omb	schist
	Omc	schist
	Omd	schist
	Oma	schist
Bedford Gneiss	Ob	gneiss

Table 3 (continued). Attributes describing NYS Museum Bedrock Geology formation lithology

Formation	Fm Code	Lithology Package
Gneiss, Ravenswood Gneiss	Ohr	gneiss; Igneous, basic
Hartland Fm	Oht	schist, amphibolite
Mount Marino Fm, Indian River Fm	Omi	shale
Pillow Lava	Opl	igneous, basic
Poultney Fm	Op	shale, siltstone
Stuyvesant Falls Fm	Osf	shale, siltstone
Horses along normal faults	OCh	dolostone, limestone
Slivers	OCs	dolostone, limestone
Theresa Fm	OCth	dolostone, sandstone
Stockbridge Fm	OCst	marble
Inwood Marble	OCi	marble
Little Falls Dolostone, Hout Fm, Whitehall Fm, Ticonderoga Dolostone	Cbk	dolostone, limestone
Briarcliff Dolostone, Pine Plains Fm	Cw	dolostone, shale
Theresa (Galway) Fm	Cth	dolostone, sandstone, shale
Stissing Fm	Cs	dolostone, shale
Potsdam Sandstone	Cp	sandstone
Poughquaq Quartzite	Cpg	quartzite
Cheshire Quartzite	Cc	quartzite
Cheshire Quartzite, Dalton Fm	Ccd	quartzite
Elizville Fm	OCe	shale
Undifferentiated M Ord - L Camb	OCu	shale
Poultney Fm, Hatch Hill Fm, West Castleton Fm	Cpw	shale, limestone, dolostone, conglomerate
Germantown Fm	Cg	shale, conglomerate, limestone
Mettawee Slate	Cm	slate, quartzite
Nassau Fm	Cn	slate
Austerlitz Phyllite	Ca	phyllite
Greenstones tuffs and basalts	Cgt	greenstones; igneous, basic
Rensselaer Graywacke	Cr	graywacke
Everett Schist	Cev	schist
Fordham Gneiss	f	gneiss
Fordham Gneiss	fa	gneiss
Fordham Gneiss	fb	gneiss
Fordham Gneiss	fc	gneiss
Fordham Gneiss	fd	gneiss
Fordham Gneiss	fe	gneiss
Yonkers Gneiss	y	gneiss

Table 3 (continued). Attributes describing NYS Museum Bedrock Geology formation lithology

Formation	Fm Code	Lithology Package
Poundridge Gneiss	pg	gneiss
Intrusive Pegmatite Dikes	p	igneous, acidic
Metagabbro	gb	metagabbro
Metanorthosite	a	metanorthosite
Gneiss	bqp	gneiss
	bqpq	gneiss
Gneiss	garb	gneiss
Marble	mb	marble
Quartzite and Schist	qt	quartzite and schist
Gneiss	bqpc	gneiss
Marble	mb	marble
Gneiss	qtcs	gneiss
Gneiss and Quartzite	qtlg	gneiss and quartzite
Gneiss	rg	gneiss
	sc	gneiss
	amg	gneiss
	mug	gneiss
	ach	gneiss
Metanorthosite	ack	metanorthosite
Anorthositic Metamorphic	amu	metanorthosite
Gneiss	ffg	gneiss
	hqs	gneiss
	hs	gneiss
	phgs	gneiss
	phqs	gneiss
Gneiss	ps	gneiss
	bg	gneiss
	bhg	gneiss
	hg	gneiss
	qpg	gneiss
Amphibolite	am	amphibolite
Gneiss	hbg	gneiss
	lg	gneiss
	phg	gneiss

Table 4. USGS GWSI, List of attributes collected

GWSI Code	Description
C1	Site ID
C2	Site Type
C4	Agency Code
C6	District
C7	State
C8	County Code
C9	Latitude
C10	Longitude
C11	Lat-Long Accuracy
C16	Altitude
C24	Use of Site
C27	Hole Depth
C28	Well Depth
C31	Date of Water Level Measurement
C37	Water Level
C83	Depth to Top of Opening
C84	Depth to Bottom of Opening
C85	Type of Opening
C161	Name of Owner
C713	Aquifer Type
C714	Primary Aquifer

The Clean Water Act requires that all discharges from any point source into waters of the United States must obtain an NPDES permit. By point sources, EPA means discrete conveyances such as pipes or man-made ditches. Facilities that discharge directly to surface waters must obtain a permit. The Clean Water Act requires wastewater dischargers to obtain a permit establishing pollution limits and specifying monitoring and reporting requirements. The NPDES permit program regulates direct discharges from municipal and industrial wastewater treatment facilities. It also regulates industrial point source and concentrated animal feeding operations that discharge into other wastewater collection systems or that discharge directly into receiving waters. PCS tracks permit issuance, permit limits, monitoring data, and other data on the regulated facilities.

EPA Facility Registry System (FRS) - The Facility Registry System (FRS) is a centrally managed database that identifies facilities, sites or places subject to environmental regulations or of environmental interest. FRS creates high-quality, accurate, and authoritative facility identification records through rigorous verification and management procedures that incorporate information from program national systems, state master facility records, data collected from EPA's Central Data Exchange registrations and data management personnel. The FRS provides Internet access to a single integrated source of comprehensive (air, water, and waste) environmental information about facilities, sites or places.

EPA Aerometric Information Retrieval System (AIRS)/AIRS Facility

Subsystem (AFS) - AIRS/AFS contains compliance data and permit data for

stationary sources regulated by the U.S. EPA and state and local air pollution agencies. This information is used by the environmental regulation community to track the compliance status of point sources with various regulatory programs regulated under the Clean Air Act.

EPA Comprehensive Emergency Response Compensation and Liability

Information System (CERCLIS) - CERCLIS is a database of potential and confirmed hazardous waste sites at which the EPA CERCLA "Superfund" Program has some involvement. It contains sites that are either proposed to be on or are on the CERCLA National Priorities List (NPL) as well as sites that are in the screening and assessment phase for possible inclusion on the NPL. The database contains information regarding contamination assessments and remedial activities. The database also specifies type of contaminated media, such as groundwater.

EPA Resource Conservation and Recovery Information System (RCRIS) -

The 1976 Resource Conservation and Recovery Act (RCRA), as amended by the 1984 Hazardous and Solid Waste Amendments (HSWA), federal law directs the EPA to establish and administer the national program for safe cradle-to-grave management of solid and hazardous waste. Specifically, RCRA's Subtitle C establishes the regulatory framework for managing the generation, transportation, treatment, storage and disposal of hazardous waste. RCRIS is the EPA's RCRA Subtitle C information management tracking system. It tracks historical management information for all hazardous waste handlers regulated by the

Federal RCRA Subtitle C statutes and regulations. RCRIS holds identification and location information for all RCRA regulated facilities, and RCRA site remediation (i.e., cleanups) activities. The 1984 HWSA amendment to the 1976 RCRA Act authorized EPA a Corrective Action Program to address the cleanup of hazardous waste releases at RCRA-regulated sites. Facilities provide State and EPA with information on their corrective action progress. This file contains information concerning the area of the facility undergoing or to be undergoing remediation; specific activities detailing its progress; and legal authority used to implement the corrective action process.

Dunn & Bradstreet Business - The database contains business information including facility names, addresses and Standard Industrial Classification (SIC) codes which describe the business type.

B. GIS Formula for Groundwater-Risk Analysis

From the available data listed above, a regional analysis of groundwater-risk may be established. The analysis assesses the potential to introduce contaminants at the ground surface in NYS, and assesses the potential for the contaminants to migrate through the vadose zone and be introduced to an aquifer at the water-table. The analysis devised used the existing data layers and databases to produce several intermediate GIS coverages and grids, which in turn were used to produce the final groundwater-risk grid. The groundwater-risk grid is based on the following formula:

$$\text{GWR} = \text{LUR} / \text{AS}$$

$$\text{GWR} = \text{Groundwater-risk (l/}\mu\text{g/m}^2\text{/day)}$$

LUR = Land use-risk ($l/\mu g/m^2$)

AS = Aquifer susceptibility (days)

The assessment of the potential to introduce contaminants to the ground surface of NYS was produced utilizing the AIRS/AFS, Dunn & Bradstreet, FRS, PCS, RCRIS and TRI databases in combination with the MRLC Land Use grid. The databases allowed an analysis of contaminant association with SIC codes. The contaminants associated with a given SIC code were risked using the groundwater intake values protective of human health presented in the EPA Region 3 Hazardous Substances List (EPA, 2001) (Appendix B). The association of risked contaminants with a SIC code allowed the establishment of a SIC code-risk value. SIC code-risk values (Appendix C) were joined to Dunn & Bradstreet facilities possessing SIC code information. The Dunn & Bradstreet facilities which possessed a SIC code-risk were posted in a point coverage via the GIS function called address matching; address matching used facility addresses in combination with the Wessex Roads, Census Tract and Zip Code Area coverages. The Dunn & Bradstreet facilities were located with respect to the MRLC land use grid classifications; land use classifications were then assessed with respect to contaminant risks by the GIS function of point-in-grid analysis. The following formula was used to establish a land use-risk grid:

$$LUR = \sum SRK / \sum LUC$$

LUR = Land use-risk ($l/\mu g/m^2$)

SRK = SIC code-risk, by facility ($l/\mu g$)

LUC = Land use classification area (m^2)

Aquifer susceptibility was determined by analyzing vadose zone residence time.

As noted above, the time of movement of infiltrating water from the land surface to the water-table is a measure of the vadose zone's ability to attenuate and retard the migration of contaminants. Vadose zone residence time is a function of the thickness of the vadose zone, vertical hydraulic conductivity and porosity (as well as moisture content). For vertical saturated flow in the vadose zone, the time of movement from surface to water-table, saturated vadose zone residence time, can be estimated by dividing the vertical distance the water has to travel to reach the water-table (the depth to the water-table) by the estimated saturated average linear velocity (vertical hydraulic conductivity divided by porosity). This calculated time is an indication of aquifer susceptibility; short residence time indicates that contaminants may be input to the aquifer more readily than if a long residence time exists. Attenuation of contaminants is minimized with high linear velocity and short travel distance; the solute will have a short period of vadose zone residence time and therefore will not have substantial time to react with the geologic matrix and existing air components of porosity. Aquifer susceptibility was established using the following formula:

$$AS = (DWT / (HC / \emptyset))$$

AS = Aquifer Susceptibility (days)

DWT = Depth to Water-Table (m)

HC = Hydraulic Conductivity (m/day)

$\emptyset$ = Porosity (porosity percent)

C. Cartographic Modeling

Cartographic modeling (DeMers, 1997) is a GIS process using combinations of commands to answer questions about spatial phenomena, in the case of this study, the question is where may groundwater be most susceptible to contamination. Modeling is a logical or mathematical formulation that attempts to simulate some aspect of the real world. A cartographic model is a set of interacting, ordered map operations that act on raw data, as well as derived and intermediate map data, to simulate a spatial decision-making process (DeMers, 1997).

The following cartographic model was used to produce a regional NYS groundwater-risk grid. The GIS software utilized by this research were Earth Systems Research Institute (ESRI) ArcInfo (ESRI, 1991) and ArcView (ESRI, 1995). All grids in the study utilized a grid-cell size of 94.5634 meters, the same grid precision as the USGS DEM; MRLC Land Use grid size is 30 meters. Figures 1, 5, 9, 13, 17, 20, 22, 37, 41, 45 and 47 present flow charts outlining specifics of the groundwater-risk cartographic model; they display the mathematical manipulations, conversions and reclassifications of existing and intermediate GIS data layers needed to create a groundwater-risk grid.

a. Statement of Objectives

The objective of this study is to use existing GIS layers to geospatially derive new grids and coverages which in turn lead to further analyses resulting in the construction of a NYS groundwater-risk grid.

b. Statement of Conditions and Assumptions

The following conditions and assumptions were made to produce the

cartographic model.

Surface hydrology such as lakes, rivers, streams and swamps are expressions of the water-table exposed at the surface. This premise assumes that there are no perched water-table systems and that gaining and losing rivers and streams possess water elevations which are expressions of the flanking water-table.

USGS GWSI well data have been located accurately. The averaging of the well data over a grid of 94.563 meters will lessen the importance of precise well-location accuracy.

The most recent USGS GWSI water-level measurements were used (the GWSI data were collected in 1998) for individual wells in the database. Well water-level measurement dates range from 1890 to 1997. It is assumed that water-level measurements averaged over a grid of 94.563 meters are adequate for a regional groundwater-risk study.

Hydraulic conductivity and porosity values do not vary within a designated surficial geology or bedrock geology rock-type (lithologic package) classification; this is the best estimate that can be made on a regional scale until regional three-dimensional hydrogeologic data are collected and digitized. Estimates for unconsolidated rock and bedrock porosity were based on rock-types within formations and literature review. Estimates of surficial geology and bedrock geology hydraulic conductivities were based on rock-type, literature review and consideration of EPA CERCLA file pump and slug test data (Appendix E).

The thicknesses of the surficial geology rock-types were estimated using the corresponding maximum thickness within the range of a given rock-type established by the New York Surficial Geology coverage's attribute table (Table 2), except in the case of till, which was given a value of 10 meters (DEC, 1987). The New York Surficial Geology coverage attribute table (Table 2) did not contain thickness ranges for marine beach and barrier island classifications; a thickness of 10 meters was used for these deposits (Bernard and LaBlanc, 1965; Rampino and Sanders, 1980). These thicknesses are assumed to be sufficient for a regional, State-wide study.

The EPA databases, TRI, PCS, FRS, AIRS/AFS and RCRIS are sufficient for the analysis of contaminants associated with four-digit SIC codes. The SIC code-risk analysis incorporated health risk values associated with contaminants (Appendix B). The risk analysis evaluated contaminant associations with SIC codes; magnitudes of contaminants generated and released at individual facilities were not considered. This study assumes that enough SIC codes were incorporated to produce reliable SIC code-risk values (Appendix C).

Address matching of SIC code-risked Dunn & Bradstreet facilities, with the use of the Wessex Streets, Census Tracts and ZIP Code Area coverages, is sufficient to locate SIC code-risked facilities within the proper land use classification cells of the MRLC land use grid.

c. Statement of Evaluation Methodology

This groundwater-risk analysis is the quotient of two risk processes; one

process establishes a risk associated with the potential to introduce contaminants to the groundwater system at the top of the vadose zone, the other risk is attributed to an unconfined aquifer's susceptibility to the introduction of contaminants at the water-table. The final evaluation of the groundwater-risk analysis is provided by correlating known CERCLA NPL groundwater contamination sites with the GIS-derived areas of significant groundwater-risk.

D. Chapter 4 Summary

To perform a detailed NYS-wide analysis of groundwater-risk using GIS, the data required by the HHE process would have to be regionally available in digital format; it isn't; the availability of digital data determines the extent to which GIS cartographic formulation can represent real world processes. The GIS data layers and databases available for a NYS-wide groundwater-risk study are listed above. These data allow the formulation of a model to assesses the risk of the introduction of contaminants at the earth's surface in NYS, and the risk of the contaminants to percolate through the vadose zone and be introduced to the aquifer at the water-table. A cartographic model can be established to assess land-use risk and aquifer susceptibility; comparative geospatial groundwater-risk can be demonstrated by dividing land use-risk by aquifer susceptibility.

CHAPTER 5: LAND USE-RISK ANALYSIS

A land use-risk analysis was performed to assess the potential of introducing contaminants harmful to human health to the groundwater migration pathway; this is the first step in a groundwater-risk study. Databases containing facility locations, SIC codes, chemicals and chemical-risk values were used in combination with the MRLC land use grid to produce a land use-risk grid (Figure 1).

A. SIC Code-Risk Analysis

SIC code-risk analysis used AIRS/AFS, FRS, PCS, RCRIS and TRI databases. The facility, SIC code and contaminant fields of the individual databases were merged into one database for processing. The AIRS/AFS, FRS, PCS, and TRI databases incorporated nationwide data. RCRIS data was collected from facilities located in EPA, Region 2 (New Jersey, New York, Puerto Rico and the Virgin Islands). This composite database contains 1,262,278 records of facility identification, SIC codes and associated chemicals. Chemicals (contaminants) associated with the SIC codes of each facility record were used to establish a risk number for individual SIC codes. First, individual SIC codes were statistically analyzed to establish counts of individual SIC codes and the count of unique chemicals associated with a particular SIC code. Secondly, chemicals were assigned risk values; these values were based on the inverse of drinking water intake equivalents of chronic RfDs or slope-factors (based on 1:1,000,000 risk of cancer development), whichever was less. Appendix B (EPA, 2001) was used to assign a drinking water intake associated risk value, micrograms per liter ($\mu\text{g/l}$), to a chemical. Of the 1,262,278 records of facilities, associated chemicals and SIC codes, 537,766 records

enabled a chemical risk match-up; these records were used in the SIC code-risk analysis. SIC code-risk analysis incorporated the inverse of the $\mu\text{g/l}$ drinking water intake risk so that when summing of risk values was performed, high risk numbers would be large; by taking the inverse, high-risk chemicals would not be masked when individual chemical risks were summed. Thirdly, chemical risk values associated with individual SIC codes were weighted by multiplying the risk values of associated chemicals by the ratio of the chemical count to total count of the specific SIC code; the inverse of a chemical drinking water health risk intake value would be multiplied by 0.5 if the chemical was associated with half of the facility records possessing the given SIC code. Fourthly, SIC code-risk values were calculated by summing the weighted chemical risk values of all the chemicals associated with individual SIC codes. The SIC code-risk formula is:

$$\text{SRK} = \sum (\text{CC} / \text{TF}) \times (1 / \text{IR})$$

SRK = SIC code-risk ($1/\mu\text{g}$)

CC = Particular chemical count for a particular SIC code

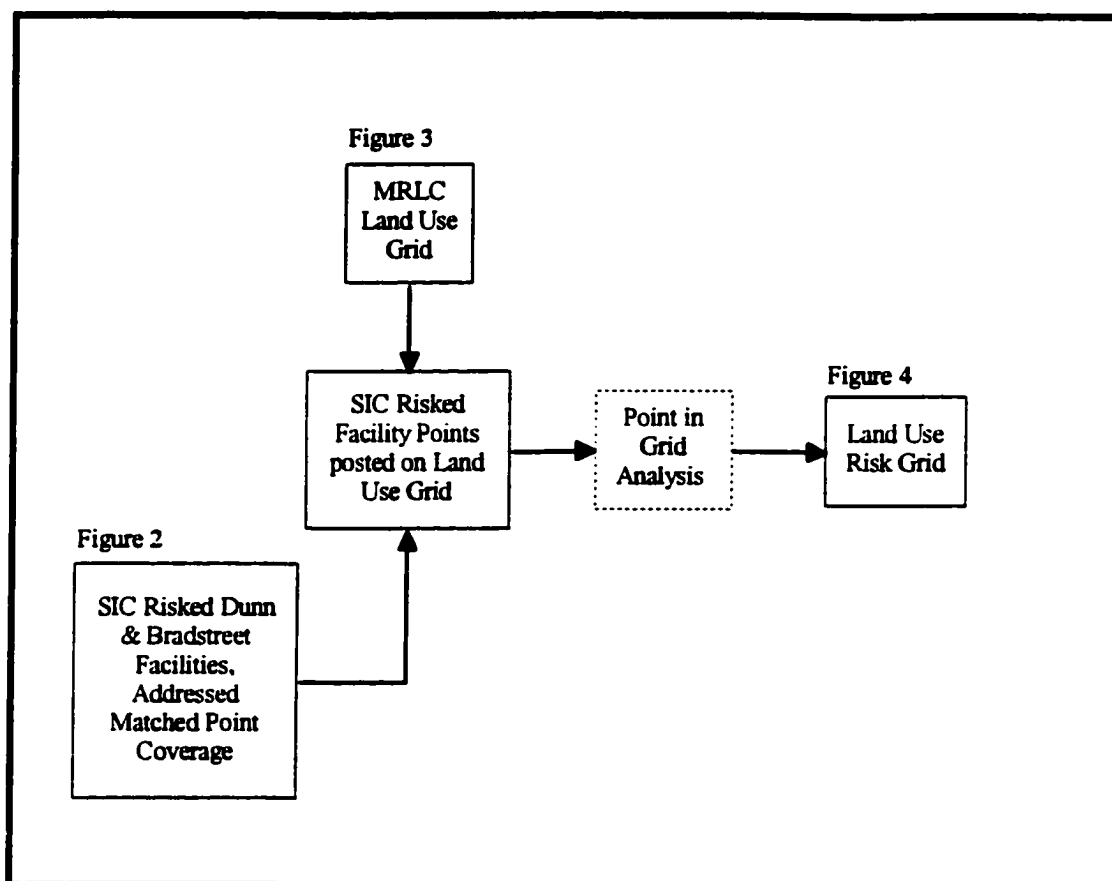
TF = Total count of facilities possessing a particular SIC code

IR = Drinking water intake risk of a particular chemical ($\mu\text{g/l}$)

Appendix C lists SIC code numbers, SIC code descriptions and their calculated SIC code-risk values.

Facilities of the Dunn & Bradstreet database, which contain SIC codes, were used to create a point coverage of facilities in NYS. The facilities in the database were located using the GIS function called address matching. The facilities were posted by addressing matching with the Wessex Roads, Census Tracts and ZIP Code Area coverages. Figure 2 displays the SIC code-risked Dunn & Bradstreet facilities located in NYS; the coverage

Figure 1. Land Use-Risk analysis cartographic model flow chart.



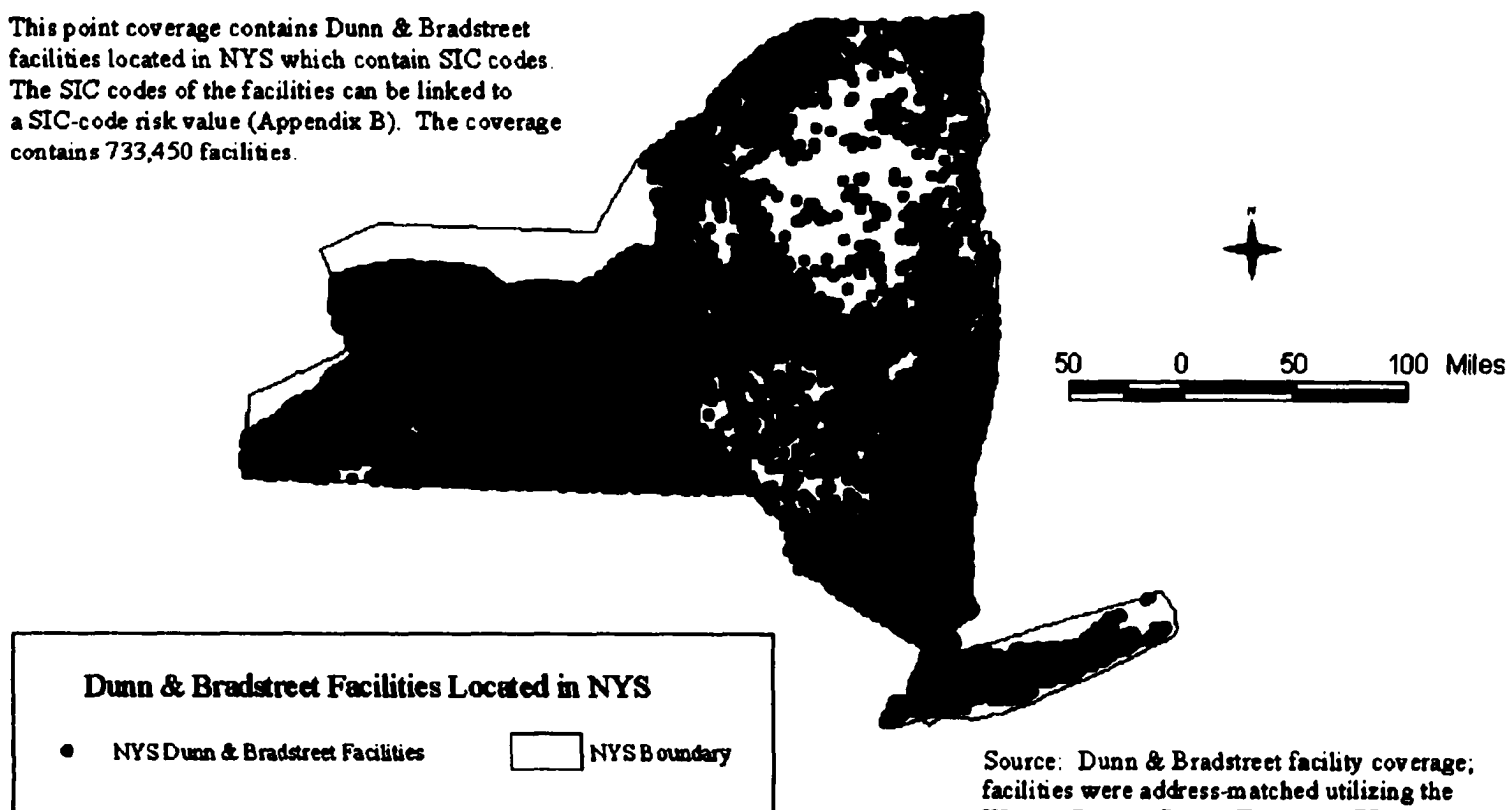
contains 733,450 facilities.

B. Land Use-Risk Calculation

A GIS function termed point-in-grid analysis was performed to derive a land use-risk classification; which in turn was used to produce a land use-risk grid. First, SIC code-risked Dunn & Bradstreet facilities were posted on the MRLC Land Use grid (Figure 3). This grid contains sixteen classifications of land use. Secondly, a point-in-grid analysis was performed. This analysis developed a land use-risk value with units of liters per microgram per square-meter ($l/\mu g/m^2$) for each land use classification. Table 5

Figure 2. Dunn & Bradstreet Facilities Located in New York State

This point coverage contains Dunn & Bradstreet facilities located in NYS which contain SIC codes. The SIC codes of the facilities can be linked to a SIC-code risk value (Appendix B). The coverage contains 733,450 facilities.



Source: Dunn & Bradstreet facility coverage; facilities were address-matched utilizing the Wessex Roads, Census Tract, and ZIP Code Areas coverages.

Figure 3. USGS Multi-Resolution Land Classification (MRLC) Land Use Grid

This grid contains sixteen classifications of land use which are displayed in Table 3. This figure has been reclassified so land use classifications may be displayed utilizing a gray scale.

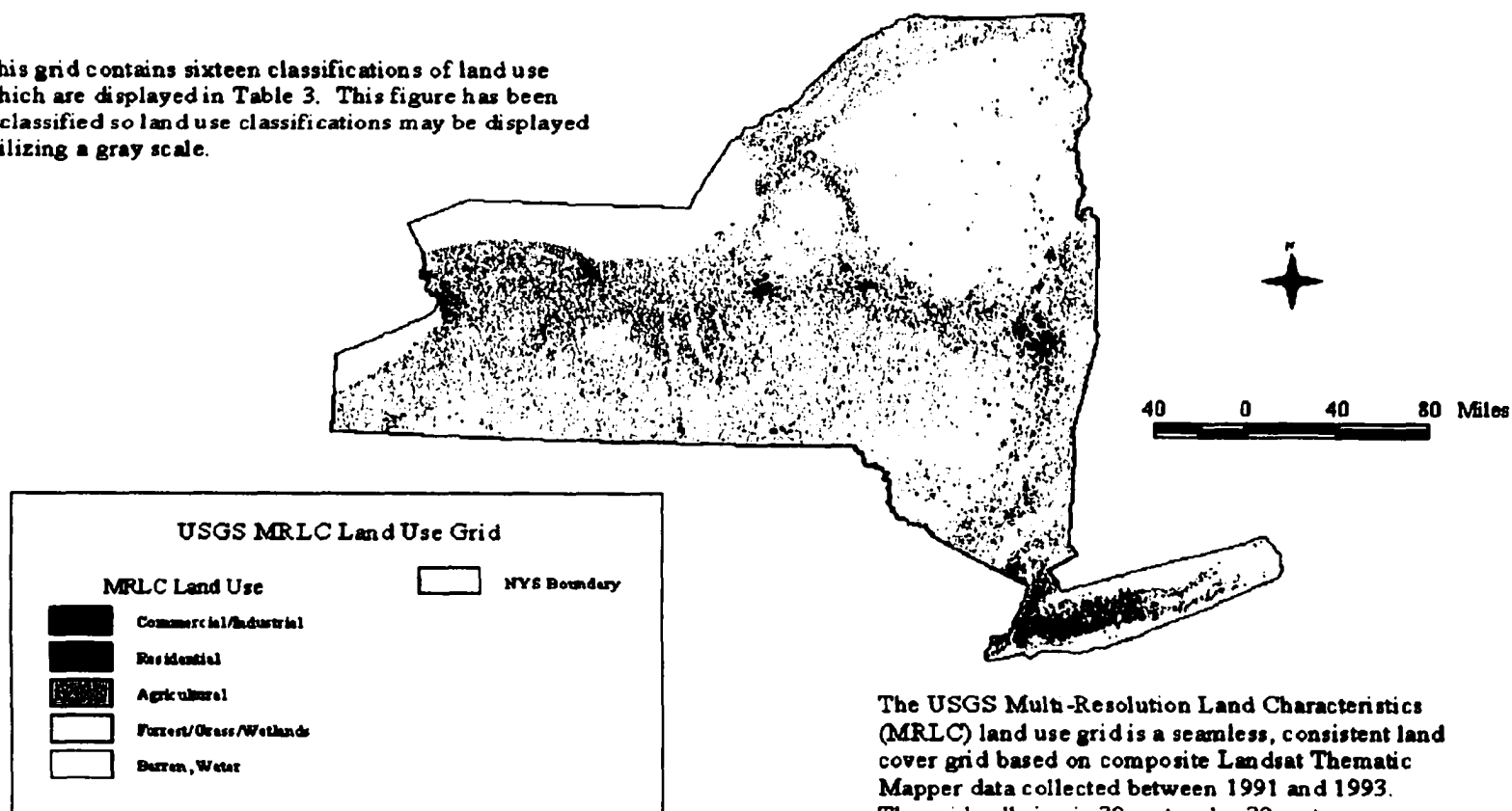


Table 5. MRLC Land Use classifications and corresponding calculated land use-risk.

MRLC Land Use Description	Risk (l/μg/m²)
Water	0.0000462473
Low Intensity Residential	0.0268021120
High Intensity Residential	0.1385353425
High Intensity Commercial / Industrial	0.0581683194
Pasture / Hay	0.0011688650
Row Crops	0.0015772192
Other Grasses	0.0119795942
Evergreen Forest	0.0003256491
Mixed Forest	0.0011278696
Deciduous Forest	0.0006069356
Woody Wetlands	0.0001313978
Emergent Wetlands	0.0003133457
Barren; Quarries	0.0168685610
Barren; Bare Rock and Sand	0.0000690376
Barren; Transitional (including clear-cut areas)	0.0006434367

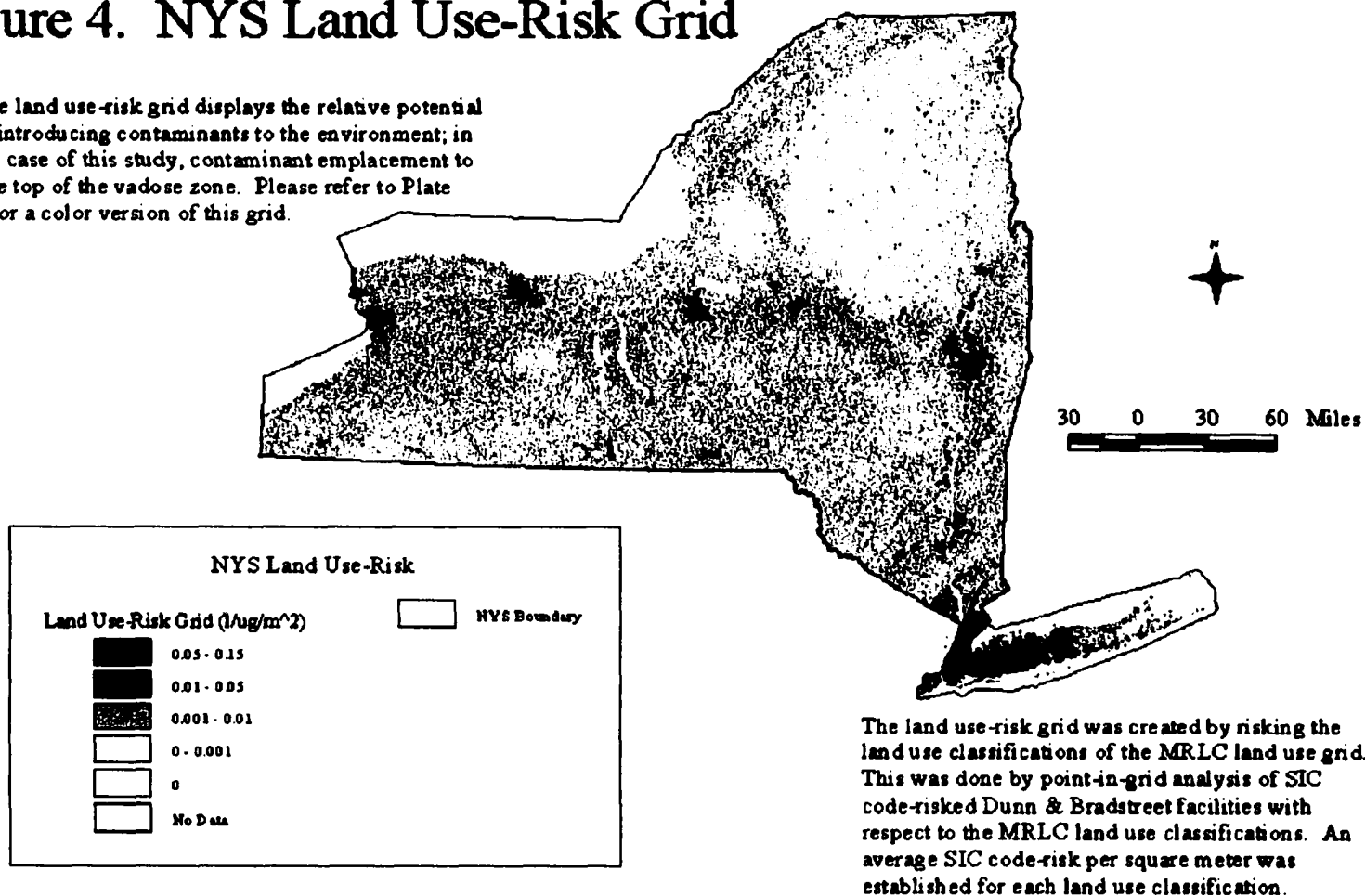
displays the relative risk values of the various land use classifications. The MRLC land use grid was converted to a land use-risk grid utilizing Table 5 (Figure 4, Plate 1). The land use-risk grid displays the relative potential to introduce contaminants to the upper portion of the groundwater system - the vadose zone.

C. Chapter 5 Summary

The MRLC Land Use grid was investigated for its potential to introduce contaminants to the environment; a land use-risk grid was constructed. First, existing EPA databases were analyzed to assess the relative risks to human health posed by businesses sorted by their various SIC code classifications. Secondly, derived SIC code-risks were associated with SIC code identified Dunn & Bradstreet facilities. The SIC code-risked Dunn & Bradstreet facilities were used to create a point coverage. Thirdly, a point-in-grid analysis was performed with the SIC code-risked Dunn & Bradstreet facilities and the MRLC Land Use grid; this enabled the creation of a land use classification risk and the development of a land use-risk grid. The land use-risk grid displays the relative risk of introducing contaminants to the environment, in the case of this study, introduction to the top of the vadose zone. As can be noted on the land use-risk grid, the potential to introduce contaminants to the environment is a function of human population; high land use-risk is noted in heavily populated areas.

Figure 4. NYS Land Use-Risk Grid

The land use-risk grid displays the relative potential of introducing contaminants to the environment; in the case of this study, contaminant emplacement to the top of the vadose zone. Please refer to Plate 1 for a color version of this grid.



CHAPTER 6: AQUIFER SUSCEPTIBILITY ANALYSIS

The second step in the groundwater-risk evaluation of NYS considers aquifer susceptibility. Aquifer susceptibility was established by calculating vadose zone residence time, a measure of the vadose zone's ability to attenuate and retard contaminants; the system was considered under a maximum load. This was performed by first calculating the depth to the water-table (thickness of the vadose zone) and the thicknesses of soil, surficial geology and bedrock geology components within the vadose zone. Secondly, vertical hydraulic conductivity and porosity grids were created for the soil, surficial geology and bedrock geology components of the vadose zone. Thirdly, the vadose zone average linear velocities of the three geologic components were calculated by dividing their respective vertical hydraulic conductivity by porosity. Fourthly, the vadose zone thicknesses of the respective geologic components were divided by their average linear velocities to yield groundwater residence times for the soil, surficial geology and bedrock geology components of the vadose zone. The sum of these groundwater residence times is a measure of aquifer susceptibility.

A. Vadose Zone Thickness Analysis

The first task of vadose zone thickness analysis is to use existing GIS data layers to construct a water-table elevation grid.

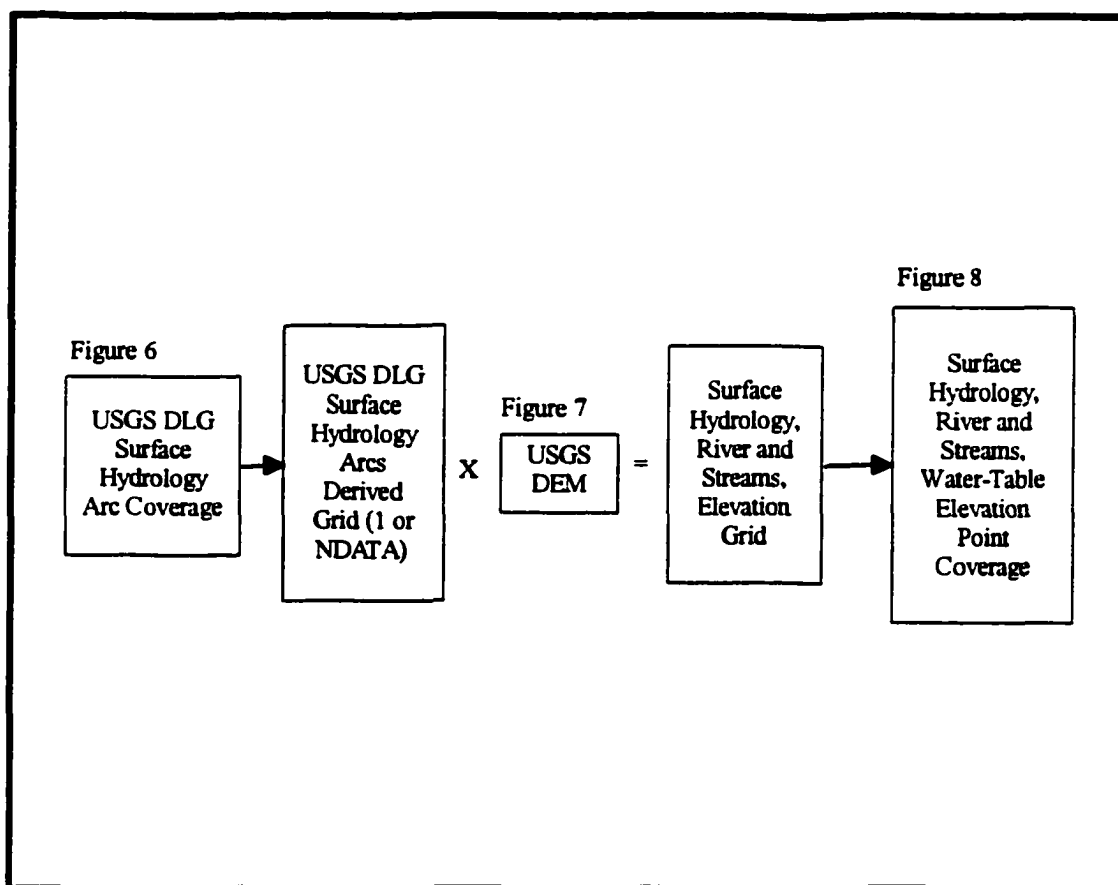
a. Interpolation of Water-Table Elevation Surface

Vadose zone thickness calculation requires the creation of a water-table elevation surface which can be subtracted from the surface elevation DEM. The first step in

creating a water-table elevation surface is to create a point coverage containing water-table elevations above sea-level. Water-table elevation points were established using the USGS DLG-100 Surface Hydrology coverage in combination with the USGS DEM grid, and USGS GWSI well data. Surface hydrology, as stated previously, was assumed to be the surface expression of the water-table. The surface hydrology coverage was cross checked against hard copies of USGS topographic maps, 1:100,000-scale series, to assure accuracy. Any lines or polygons that were not attributable to streams, rivers, lakes, swamps, bays or the ocean were removed (i.e., aqueducts, improperly digitized rivers, streams, lakes etc.). The attributes of the coverage were also checked against topographic map hard copies to assure accuracy. Any entity attributes of the GIS coverage that did not match the entity attributes of hard copy topographic maps were changed to match the hard copies. The surface hydrology coverage was then separated into line and polygon coverages to enable processing with the available hardware.

The surface hydrology line coverage was processed to construct a water-table elevation points coverage (Figure 5). The surface hydrology line coverage of streams and rivers (Figure 6) was converted to a grid with the same grid size as the USGS DEM grid utilized in the study, 94.5634 meters. This grid was assigned a cell value of one (1) wherever a line (stream or river) crossed a cell within the grid and no value (NODATA) if a line did not cross a cell. This line-derived grid was then multiplied by the topographic values of the USGS DEM grid (Figure 7) to produce a grid of stream and river derived elevations above sea-level. This grid was then converted to a point coverage (Figure 8); this coverage contains 1,777,426 water-table elevation points

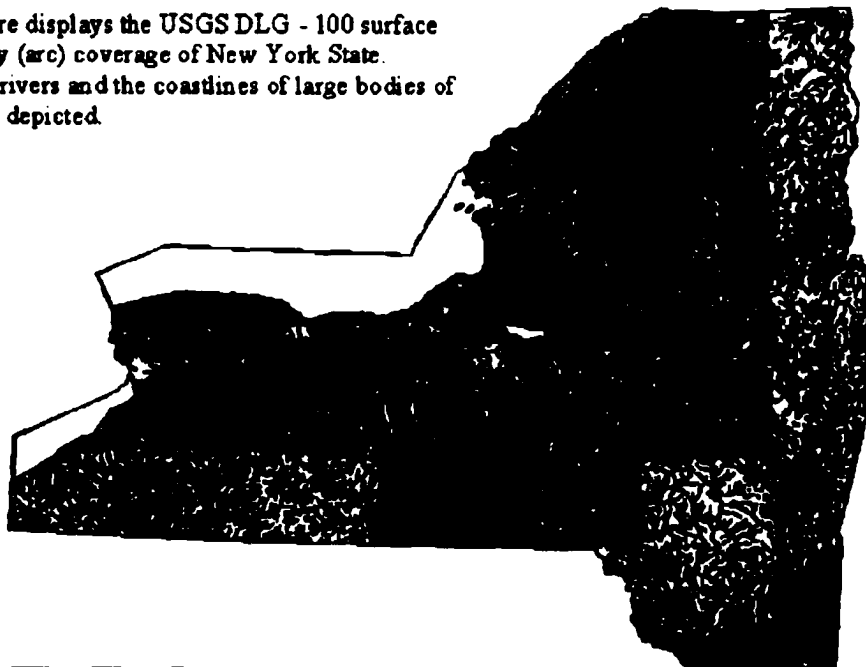
Figure 5. Cartographic model flow chart, development of elevation of water-table points derived from the USGS DLG Arc (Rivers, Streams etc.) source.



A similar process was performed on the surface hydrology polygon (swamp, lake, wide rivers, bays and ocean) coverage (Figure 9). The polygon coverage (Figure 10) was converted to a grid; cell values were assigned such that a cell value of one (1) was established in the geographic areas of swamps, lakes, wide rivers, bay and ocean, and no value (NODATA) was assigned if a surface hydrology polygon did not exist in a cell. This grid was also multiplied by the USGS DEM grid (Figure 7) to produce a grid of wide-water body elevations with respect to sea-level. This grid was then converted to a

Figure 6. USGS DLG-100 Surface Hydrology (Arcs) Coverage

This figure displays the USGS DLG - 100 surface hydrology (arc) coverage of New York State. Streams, rivers and the coastlines of large bodies of water are depicted.



30 0 30 60 Miles



The source of this coverage is the USGS Digital Line Graph (DLG) - 100 coverage. The surface hydrology was digitized from 1:100,000 scale series USGS topographic maps.

Figure 7. USGS Digital Elevation Model (DEM)

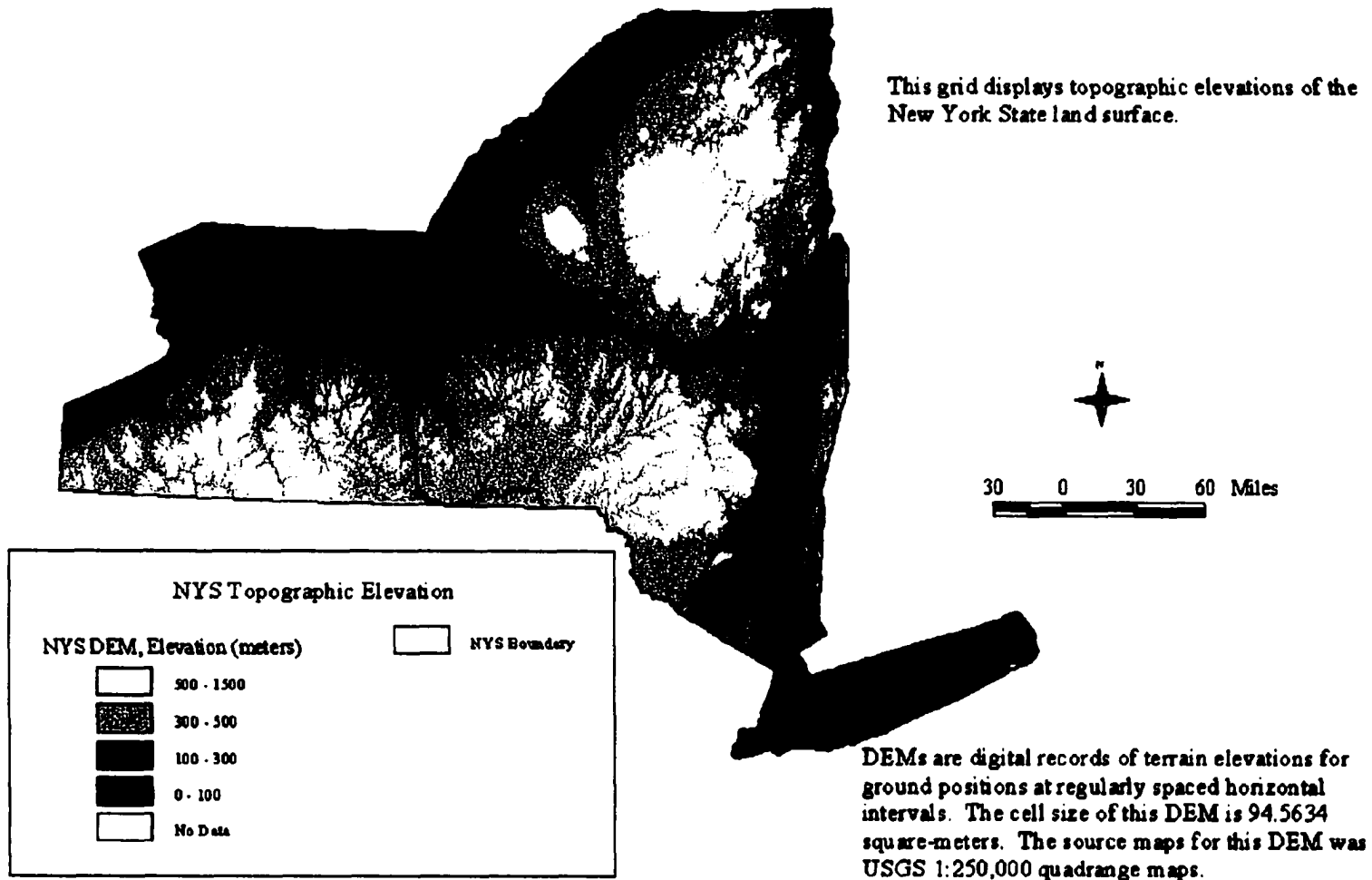
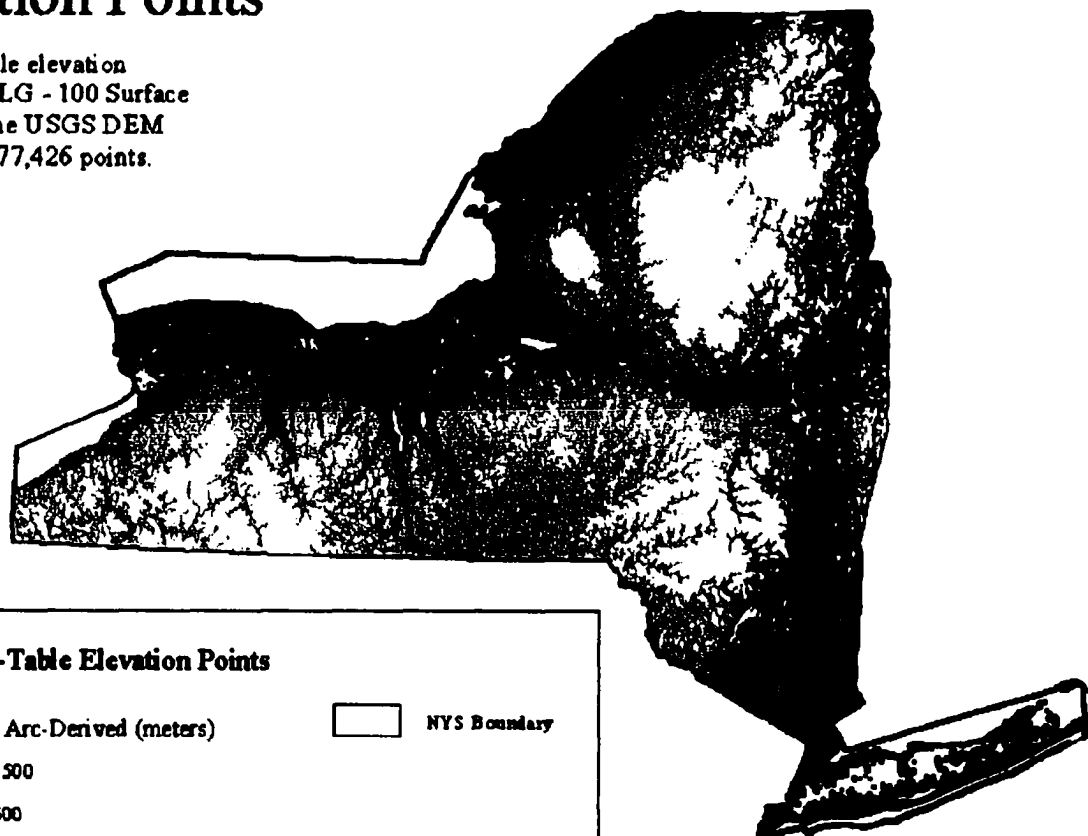
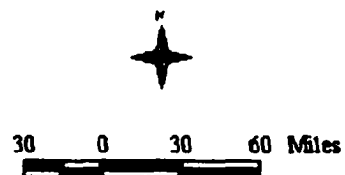


Figure 8. River and Stream Derived Water-Table Elevation Points

This coverage contains water-table elevation points derived from the USGS DLG - 100 Surface Hydrology (arcs) coverage and the USGS DEM grid. This coverage contains 1,777,426 points.



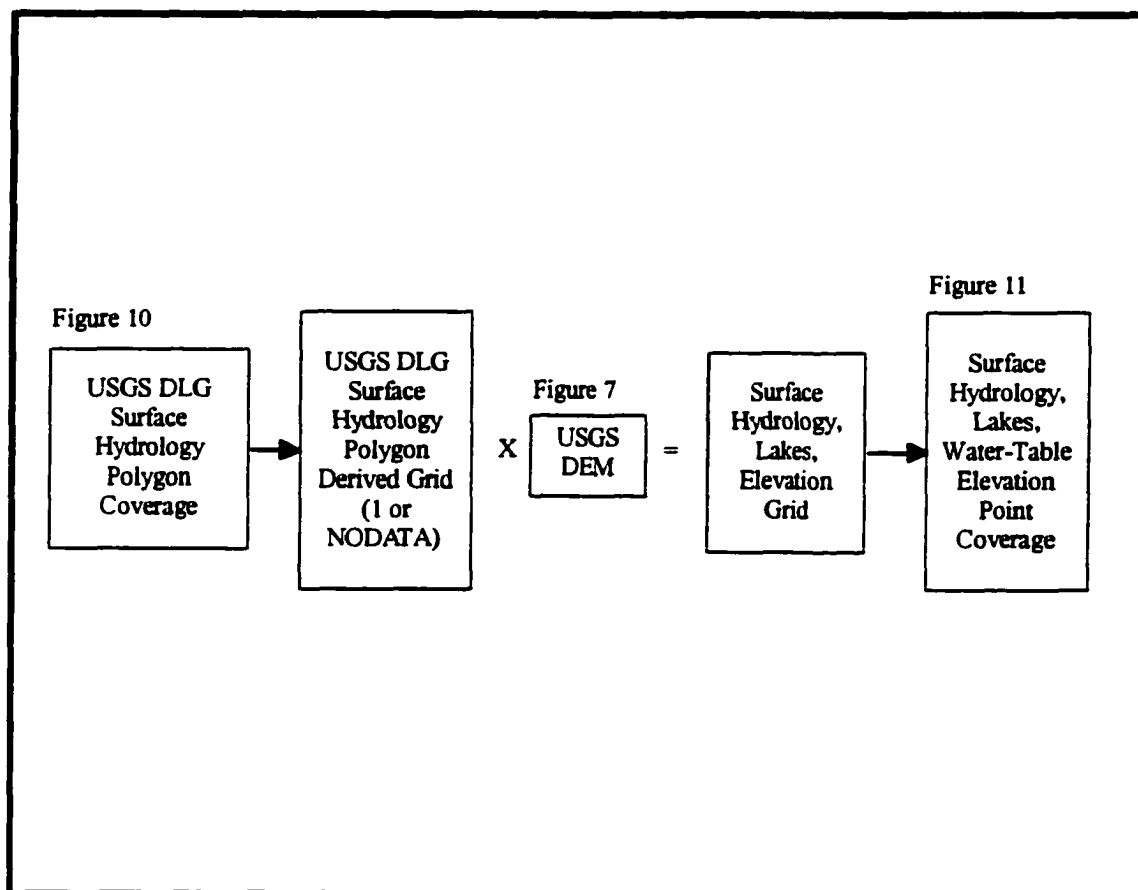
Water-Table Elevation Points

NYS Water-Table Elevation Points, Arc-Derived (meters)

- 500 - 1500
- ◆ 300 - 500
- 100 - 300
- 0 - 100

 NYS Boundary

Figure 9. Cartographic modeling flow chart displaying elevation of water-table points derivation from USGS DLG Polygon (Lakes, Reservoirs, Swamps etc.)

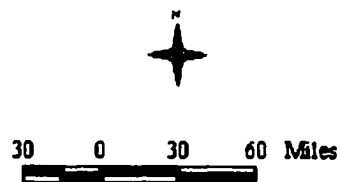


point coverage (Figure 11) which contains 2,240,301 water-table elevation points. The two surface hydrology derived water-table elevation grids were converted to point source coverages so the elevation data could be merged with a point coverage created from water-table elevations established from USGS GWSI well data files.

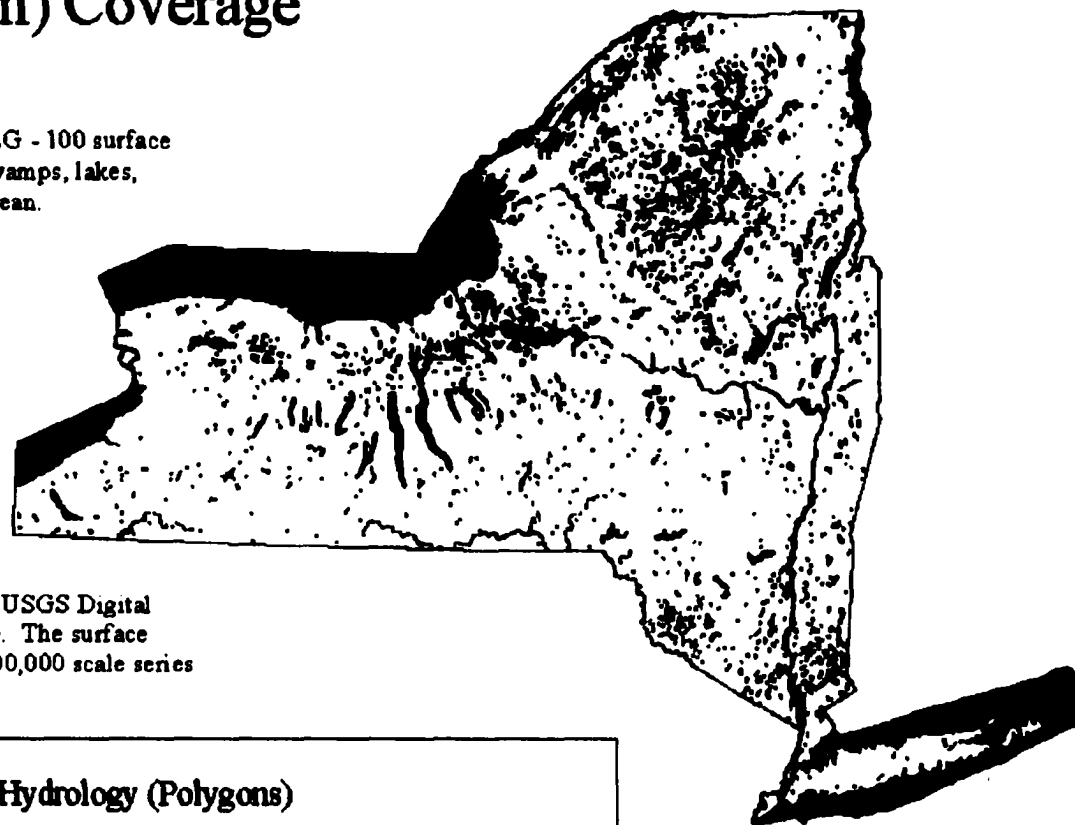
A USGS GWSI well point coverage was produced from the USGS GWSI data files. Well longitude and latitude data was used to create the point coverage (Figure 12). This USGS GWSI well coverage was analyzed and manipulated to re-select wells with

Figure 10. USGS DLG - 100 Surface Hydrology (Polygon) Coverage

This figure displays the USGS DLG - 100 surface hydrology polygon coverage of swamps, lakes, wide rivers, bays, estuaries and ocean.



The source of this coverage is the USGS Digital Line Graph (DLG) - 100 coverage. The surface hydrology was digitized from 1:100,000 scale series USGS topographic maps.



Surface Hydrology (Polygons)



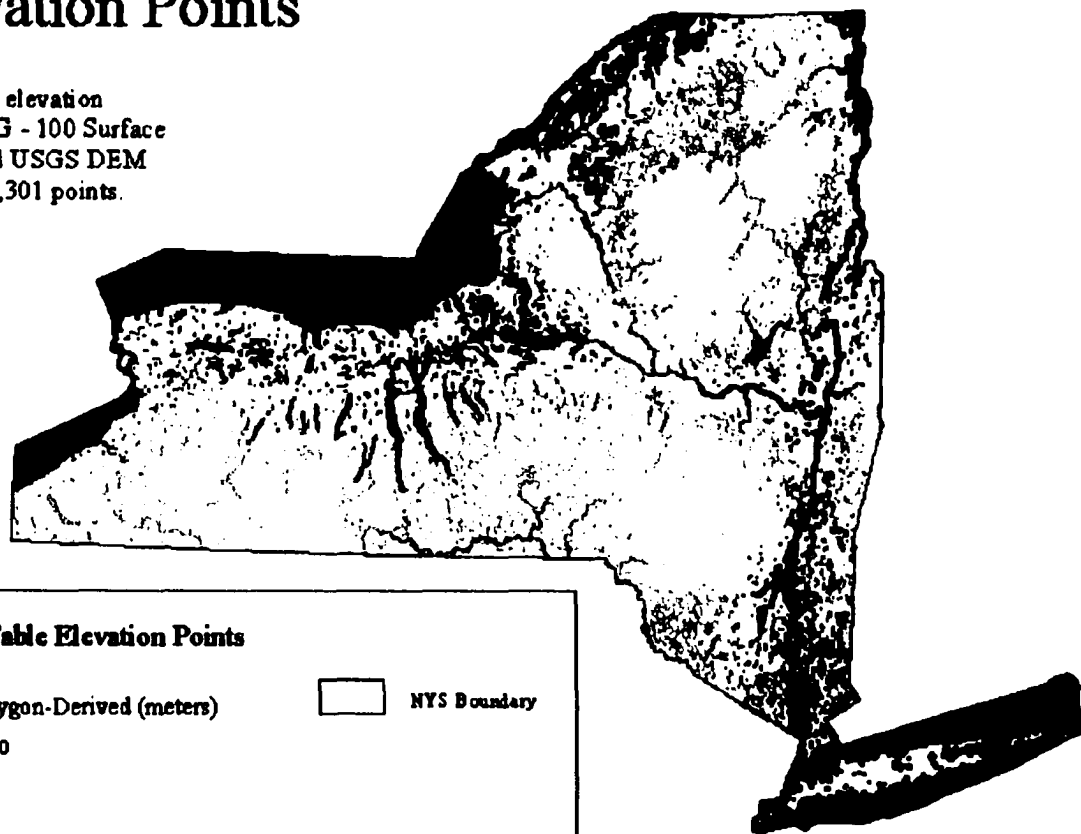
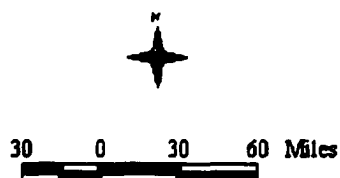
Lakes, Wide River, Swamp, Reservoir, Bay or Ocean



NYS Boundary

Figure 11. Wide Water Body Derived Water-Table Elevation Points

This coverage contains water-table elevation points derived from the USGS DLG - 100 Surface Hydrology (Polygon) coverage and USGS DEM grid. The coverage contains 2,240,301 points.



Water-Table Elevation Points

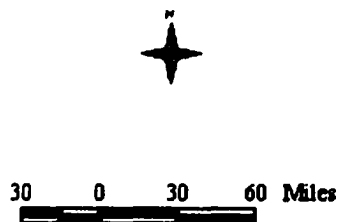
NYS Water-Table Elevation Points, Polygon-Derived (meters)

- 500 - 1500
- 300 - 500
- 100 - 300
- 0 - 100

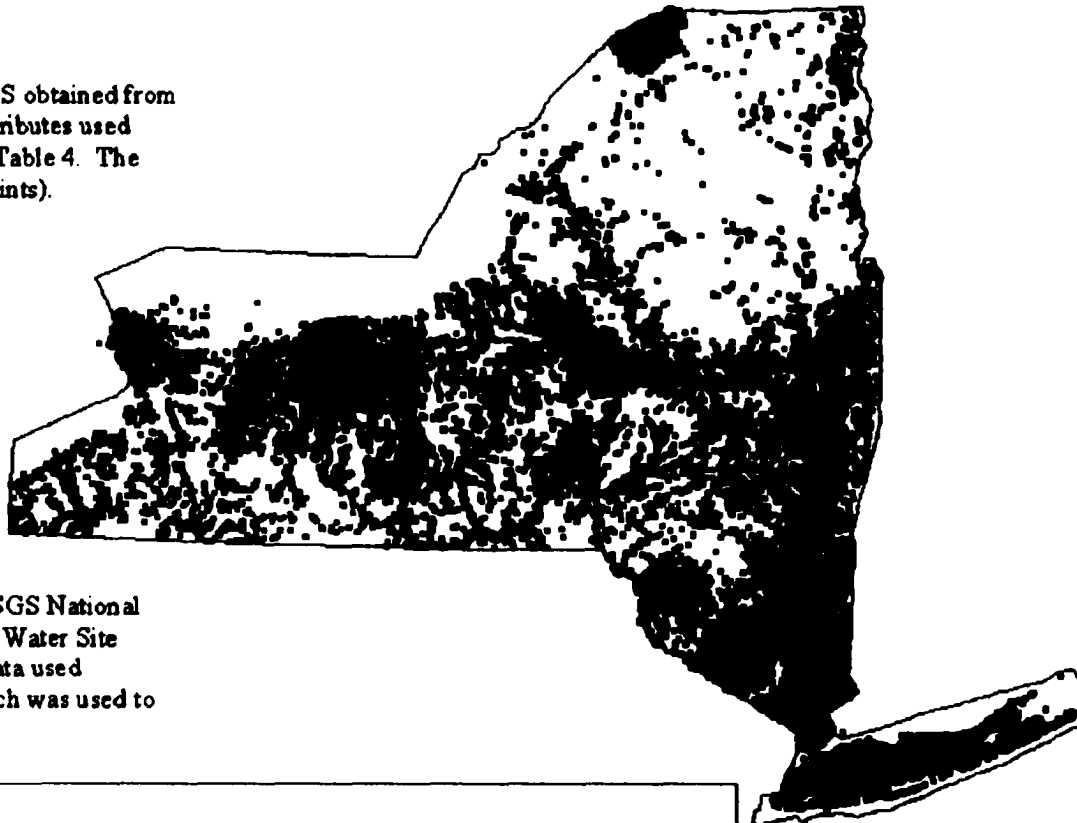
 NYS Boundary

Figure 12. USGS GWSI Wells Located in NYS

This coverage displays wells in NYS obtained from the USGS GWSI database. The attributes used to create the coverage are listed in Table 4. The coverage contains 45,494 wells (points).



Well data was obtained from the USGS National Water Information System/ Ground Water Site Inventory (GWSI) database. The data used included longitude and latitude which was used to create a point coverage.



GWSI Well Locations

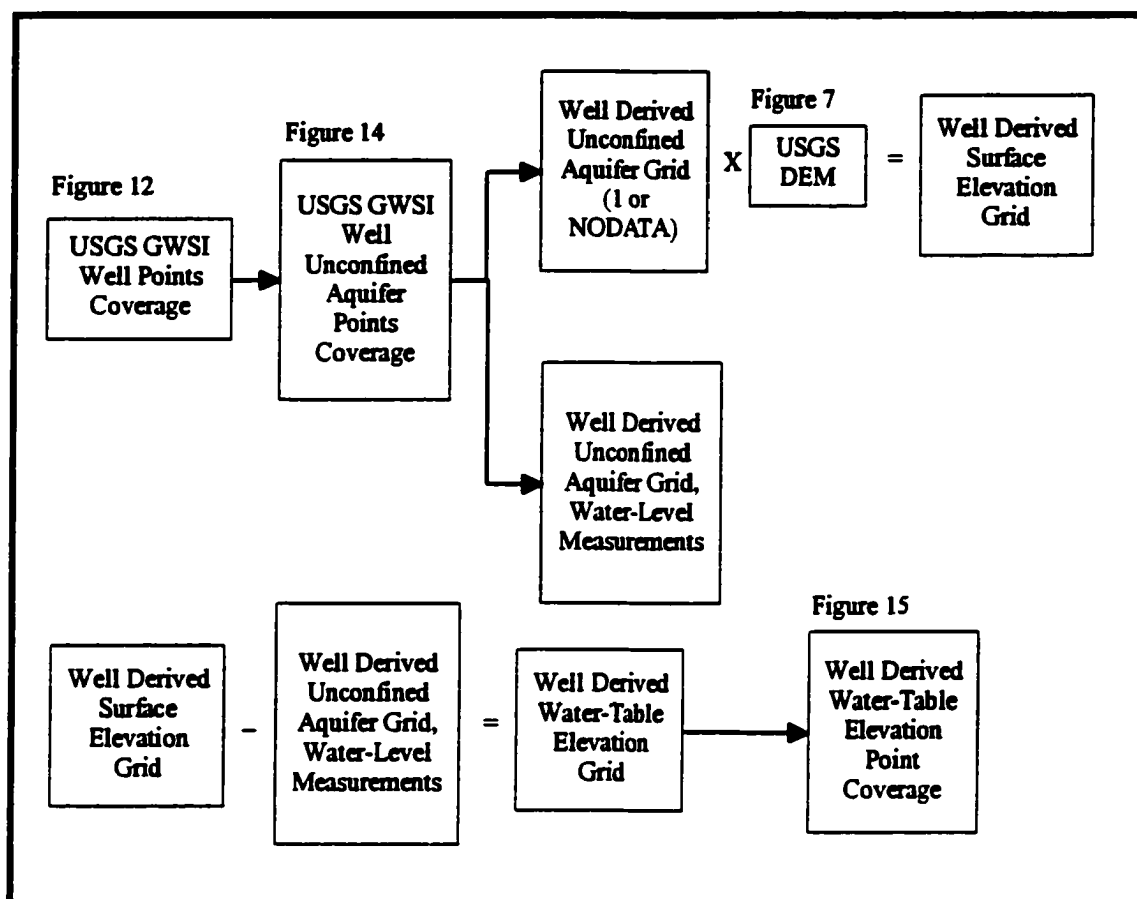


USGS GWSI Point Coverage, All Wells



NYS Boundary

Figure 13. Cartographic modeling flow chart, elevation of water-table points derivation from USGS GWSI source.

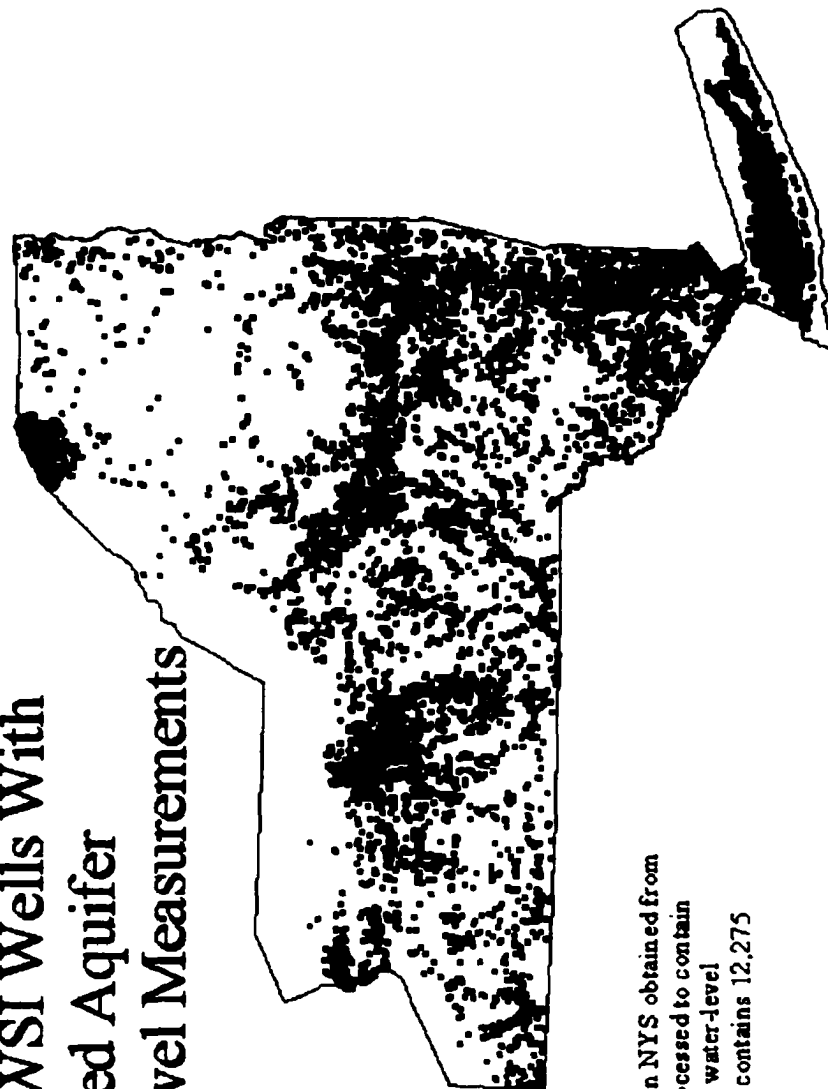


water-level measurements in unconfined aquifers (Figure 13). The original USGS GWSI well database contained 45,494 wells in NYS. The attributes examined in the database were well location, screened interval, measured water-level, and aquifer classification (confined or unconfined). Most wells do not possess a value for the aquifer classification attribute; this attribute is most often blank. The original coverage was processed by removing wells which contained screened intervals in designated confined aquifers. All wells which possessed a screened interval below 30.48 meters (100 feet) of depth were

removed; fractured aquifers shallower than this depth tend to be unconfined (Lewis-Brown and Jacobsen, 1995). This well coverage was then processed to remove all wells located in areas where the NYS Museum (Geological Survey) Surficial Geology coverage displayed clay at the surface; this was done to remove wells completed in shallow confined aquifers. Lastly, the well point coverage was modified to remove all wells which did not possess water-level measurement records. The final well points coverage (Figure 14) represents wells possessing measurements of water-table depth in unconfined aquifer systems (12,275 points). This well coverage was converted into two grids. The first grid was produced to give a value of one if a cell contained a well and a value of NODATA if the cell did not contain a well; this grid was then multiplied by the USGS DEM grid (Figure 7) to produce a grid representing surface elevation within grids that possess well water-level measurements. The second grid averaged water-level measurements of wells within the same cell. The well water-level measurement grid was then subtracted from well surface elevation grid to produce a well-derived water-table elevation above sea-level grid. This grid was converted to a point coverage (Figure 15) and contains 10,840 points.

The two surface hydrology-derived water-table elevation point coverages were merged together with the well-derived water-table elevation point coverage to produce a large point coverage of the elevation of the water-table (Figure 16); this coverage contains 4,028,603 points. This water-table elevation points coverage was used to create an interpolated surface by the GIS function called kriging (Figure 17). The interpolated surface is a grid representing water-table elevation with respect to sea-level.

**Figure 14. USGS GWSI Wells With
Unconfined Aquifer
Water-Level Measurements**

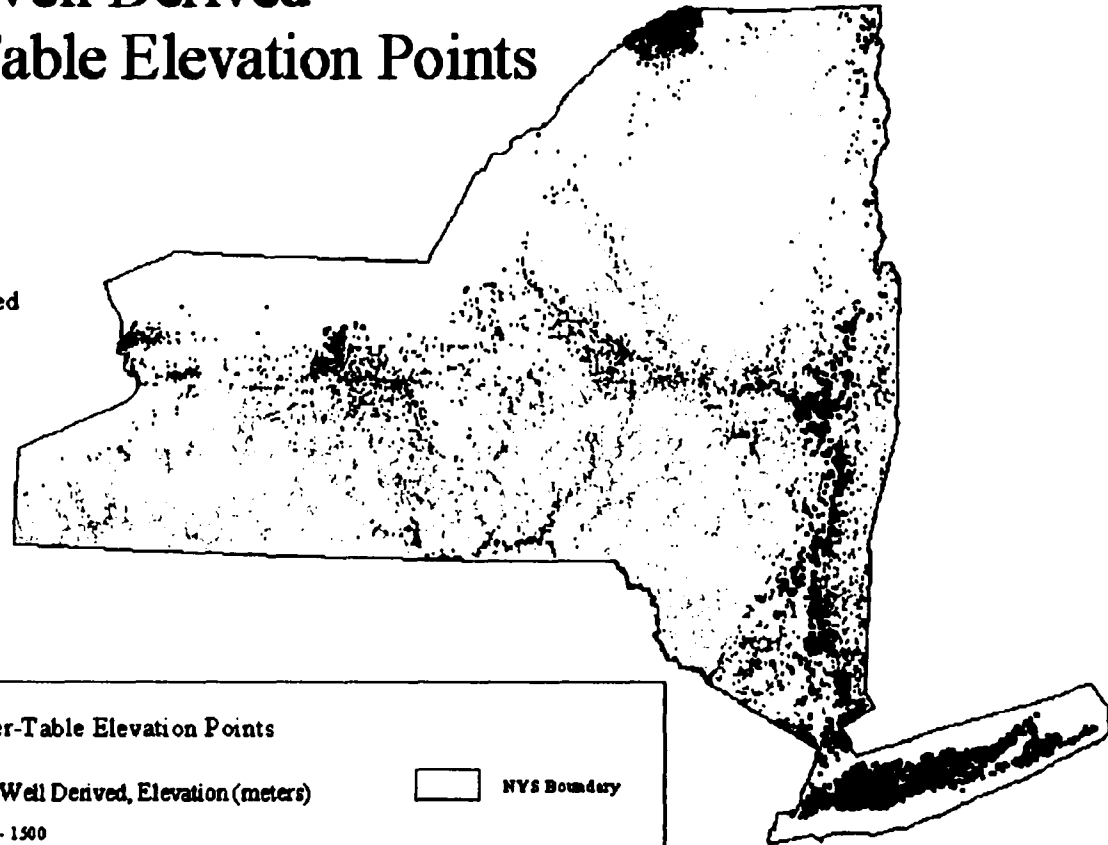


This coverage displays wells in NYS obtained from the USGS GWSI database processed to contain wells with unconfined aquifer water-level measurements. The coverage contains 12,275 wells (points).

GWSI Wells, Unconfined Water-Level Measurements

- USGS GWSI Point Coverage, Sorted for Wells with Measured Unconfined Aquifer Water-Level
- NYS Boundary

Water-level measurements for the wells displayed in Figure 14 were averaged over a grid size of 94.5634 meters. These depths were then subtracted from their corresponding DEM elevations. The grid was converted to a point coverage to produce the displayed water-table elevation points. This coverage contains 10,840 points.



Water-Table Elevation Points

NYS Water-Table Elevation Points, GWSI Well Derived, Elevation (meters)

- 0 - 100
- 100 - 300
- 300 - 500
- 500 - 1,500

Figure 16. NYS Water-Table Elevation Points

This coverage consists of the water-table elevation points derived from surface hydrology and USGS GWSI analyses. This point coverage contains 4,028,603 points.

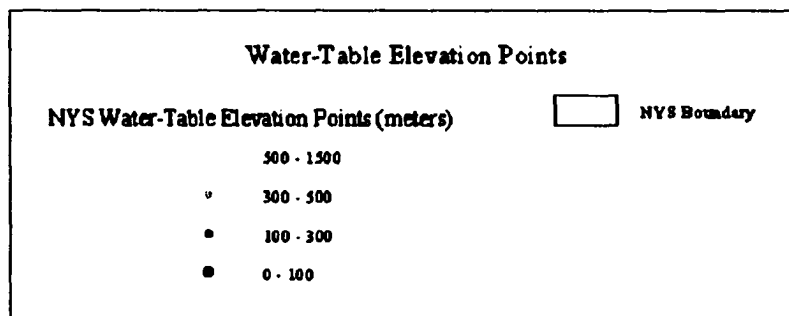
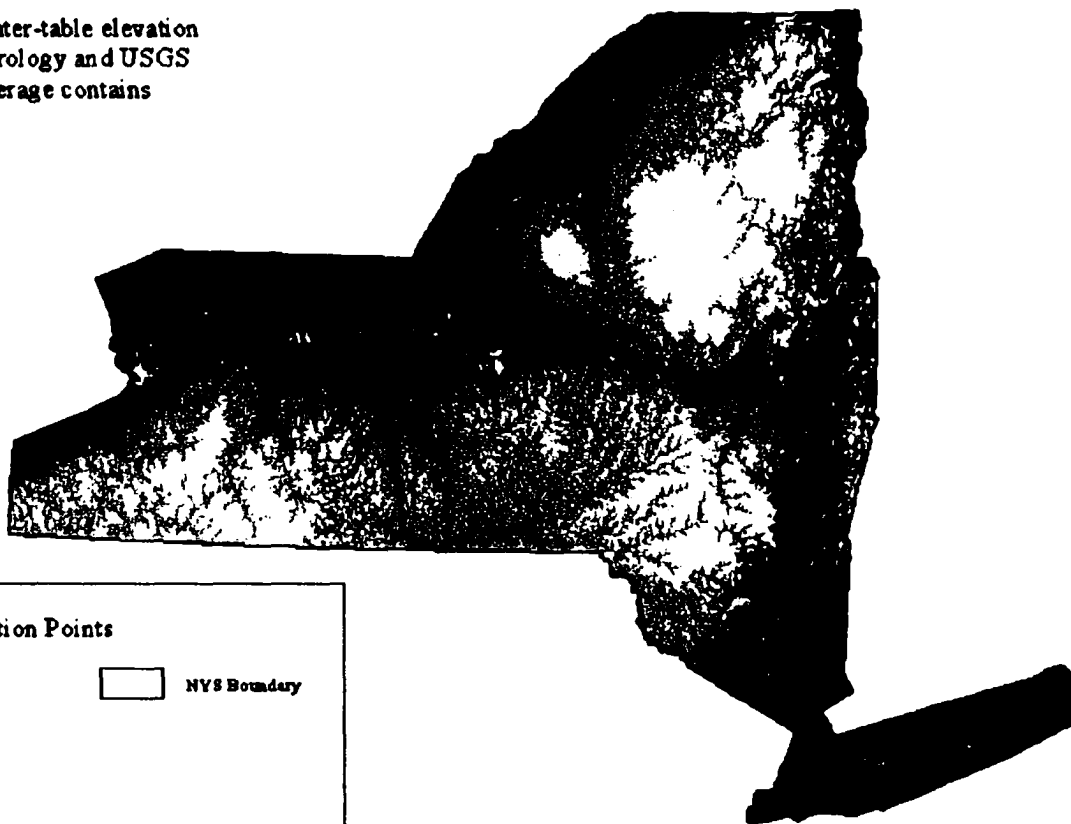
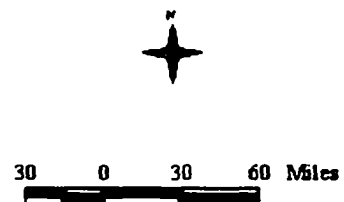
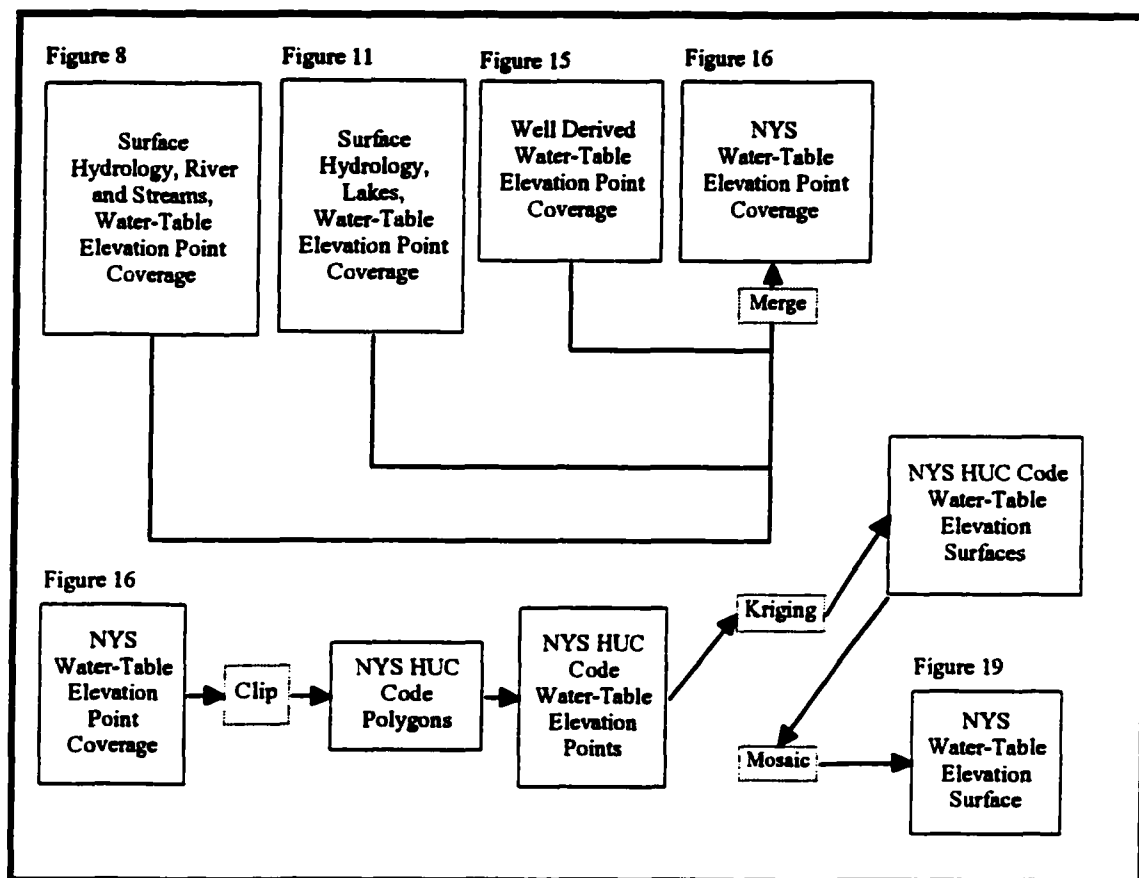


Figure 17. Cartographic modeling flow chart, interpolation of elevation of water-table points to produce water-table elevation surface.



The geostatistical method of interpolation, known as kriging (Burrough and McDonnell, 1998), was used to create the water-table elevation surface. For details regarding kriging refer to Appendix D. In order to preform kriging, the elevation of the water-table point coverage had to be broken down, or clipped, into separate coverages based on USGS Hydrologic Code (HUC) code boundaries. The size of the State-wide elevation of the water-table points coverage was too large to allow kriging with the computer hardware available to the author. HUC codes are coded areas of hydrologic drainage basins; they are areas within watershed boundaries. The gaussian model for

ordinary kriging was employed. The search radii employed were 7,000 or 6,000 meters. The search points selected was 12. After kriging was performed on each HUC code, the HUC code water-table elevation surfaces were joined by mosaic into one NYS-sized grid (Figure 18). The water-table elevation grid was produced as well as a water-table elevation-variance lattice (Figure 19); the variance lattice lends a determination of relative accuracy.

b. Vadose zone Thickness (Depth to Water-Table) Grid Construction

A vadose zone thickness (depth to water-table) grid was produced (Figure 20); the water-table elevation grid (Figure 18) was subtracted from the USGS DEM grid (Figure 7) to produce a vadose zone thickness (depth to water-table) grid (Figure 21, Plate 2). Any area which produced a negative depth to water-table value, the elevation of the water-table was higher than the land surface, was given a depth to water-table value of one meter; this occurred largely in areas of rough terrain and steeply cut valleys where water-table point resolution was poor. The areas that contained negative depth to water-table values are areas where the water-table is shallow; therefore, a depth to water-table value of one meter is a fair approximation.

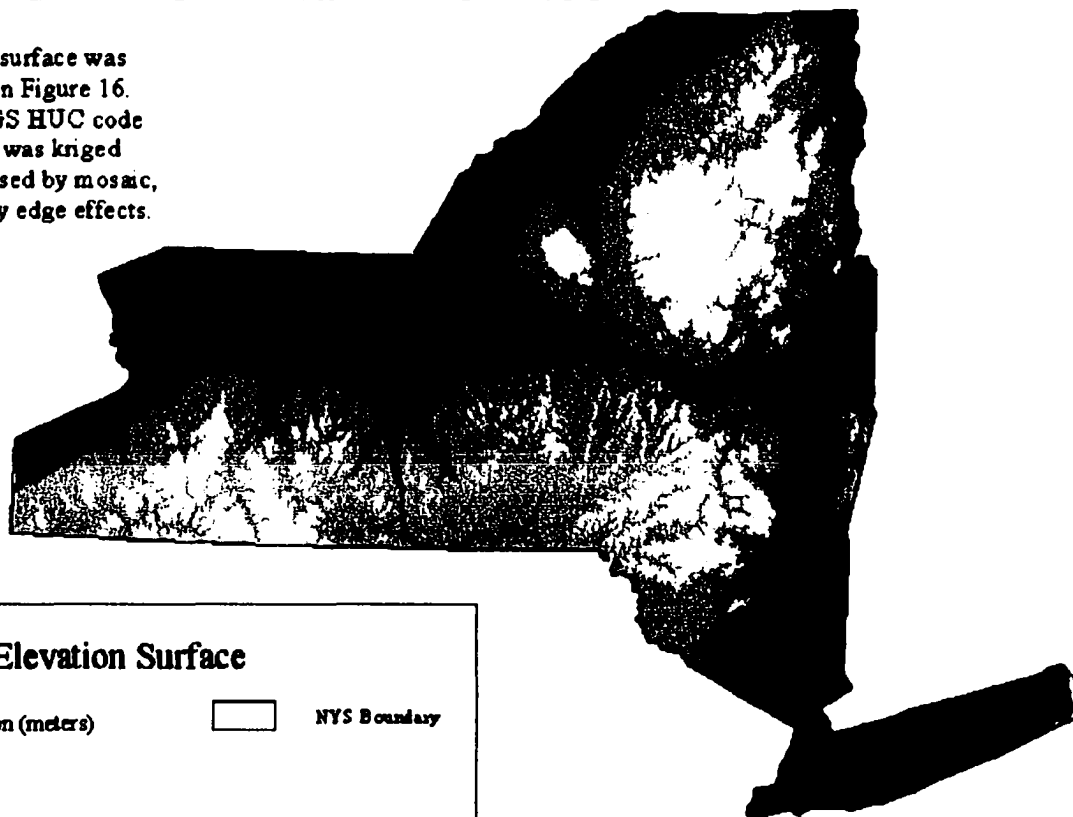
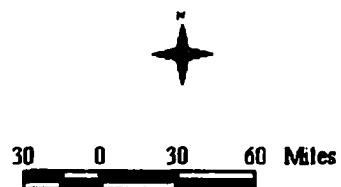
c. Thickness of Soil, Surficial Geology and Bedrock Geology Components of the Vadose zone

Prior to assigning values of vadose zone porosity and hydraulic conductivity, the thickness of each vadose zone component, soil, surficial geology and bedrock geology, was estimated (Figure 22).

The first step in assigning vadose zone thickness values for each geologic

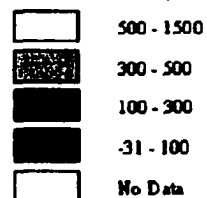
Figure 18. Water-Table Elevation Surface

The displayed water-table elevation surface was created by kriging points displayed in Figure 16. The points were clipped within USGS HUC code boundaries and each point coverage was kriged separately. This surface was composed by mosaic, with careful attention to alleviate any edge effects.



Water-Table Elevation Surface

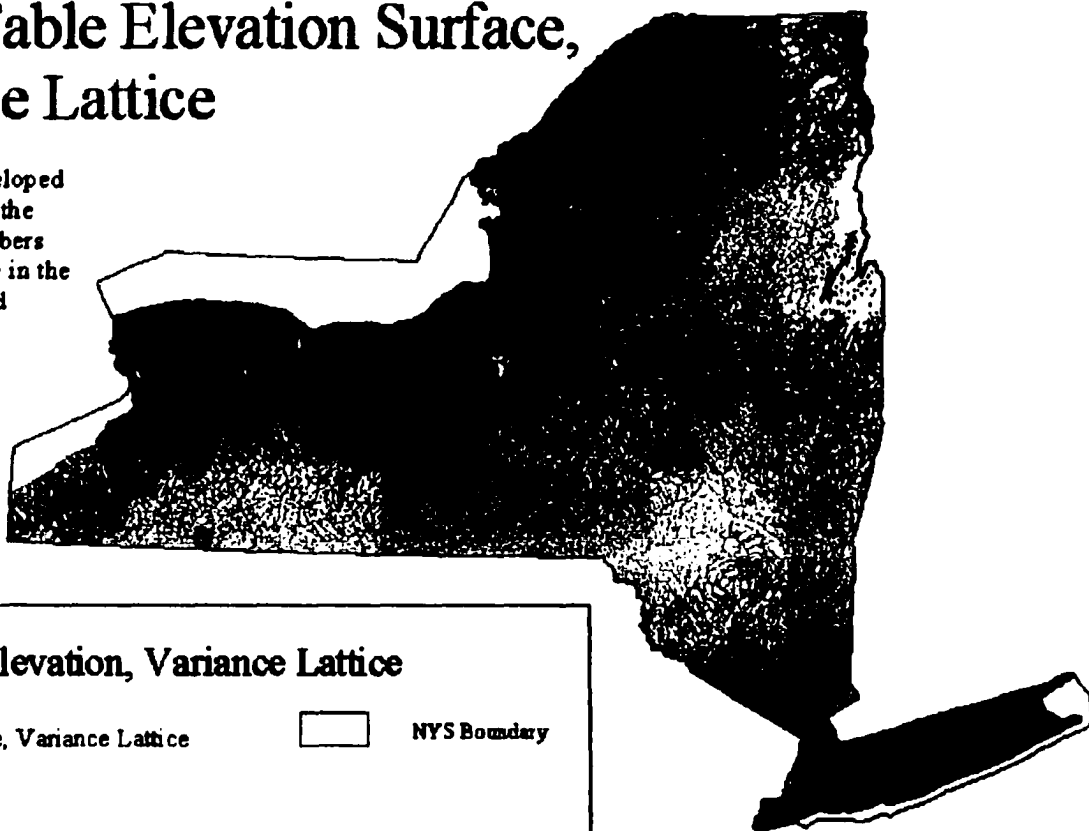
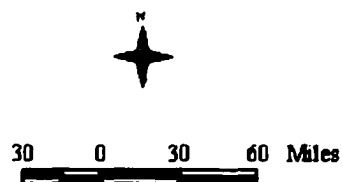
NYS Water-Table Elevation Grid, Elevation (meters)



 NYS Boundary

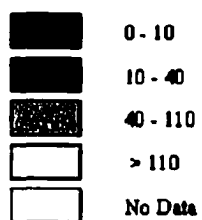
Figure 19. Water-Table Elevation Surface, Variance Lattice

This grid displays the variance lattice developed from the kriging operations used to create the water-table elevation surface. Lower numbers in the lattice indicate increased confidence in the interpolated surface; refer to Burrough and McDonnell, 1998.



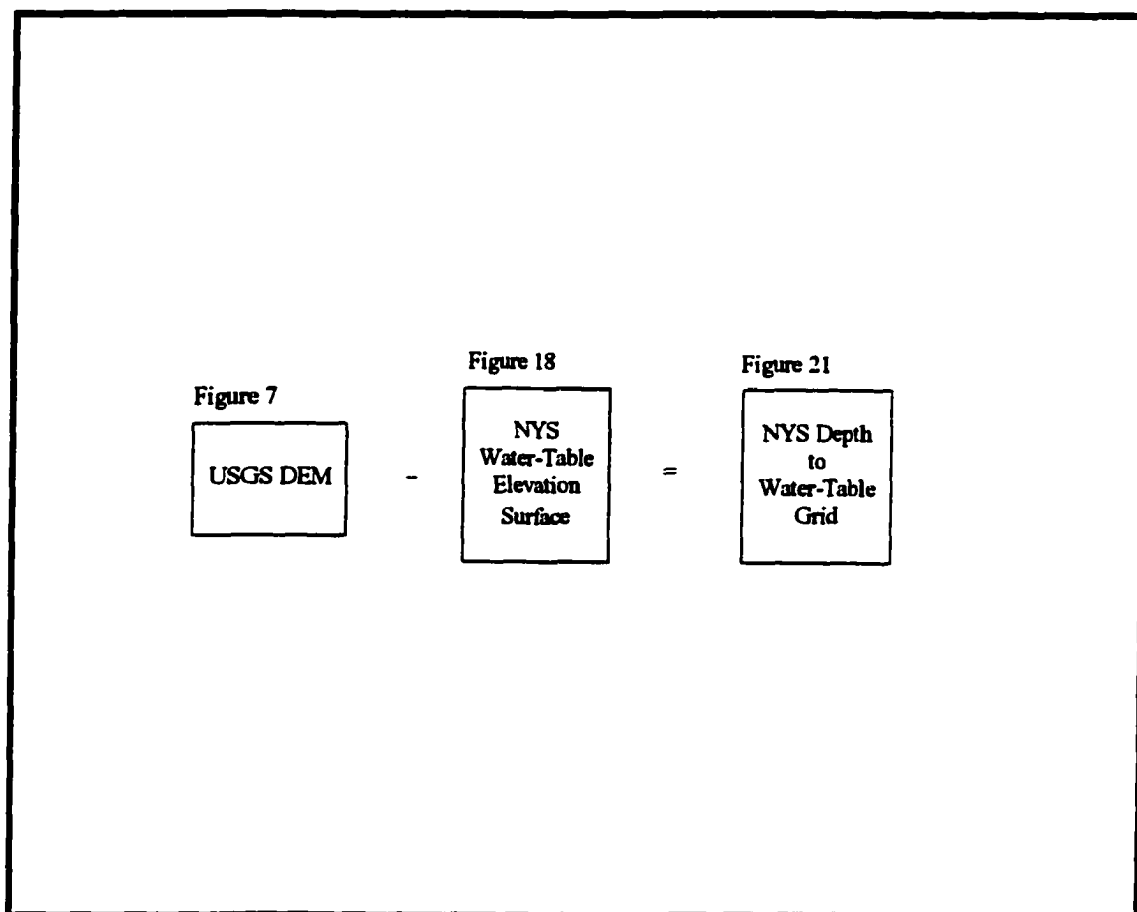
Water-Table Elevation, Variance Lattice

NYS Water-Table Elevation Surface, Variance Lattice



NYS Boundary

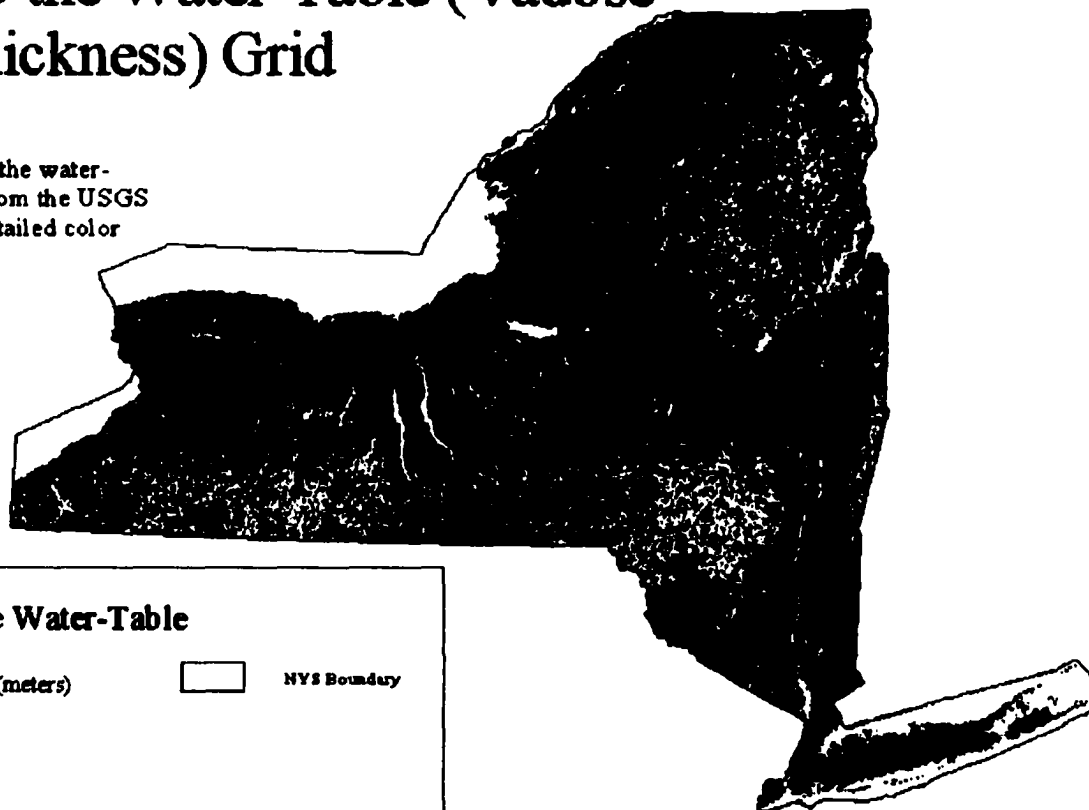
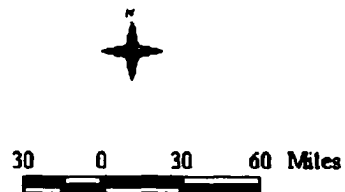
Figure 20. Cartographic modeling flow chart displaying depth to water-table grid construction.



component is to estimate the thicknesses of the soil and unconsolidated surficial geology deposits. The STATSGO Soil coverage (USDA, 1993) provided attribute data for the construction of a soil thickness grid (Figure 23). The NYS Museum Surficial Geology coverage displays unconsolidated sediments present at the surface; these sediments are classified by depositional environment (Figure 24). The attribute table of this coverage provides a range of thickness for the various depositional environments (Table 2); an

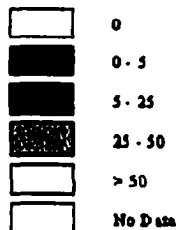
Figure 21. Depth to the Water-Table (Vadose Zone Thickness) Grid

This grid was created by subtracting the water-table elevation surface (Figure 18) from the USGS DEM grid (Figure 7). For a more detailed color version of this grid, refer to Plate 2.



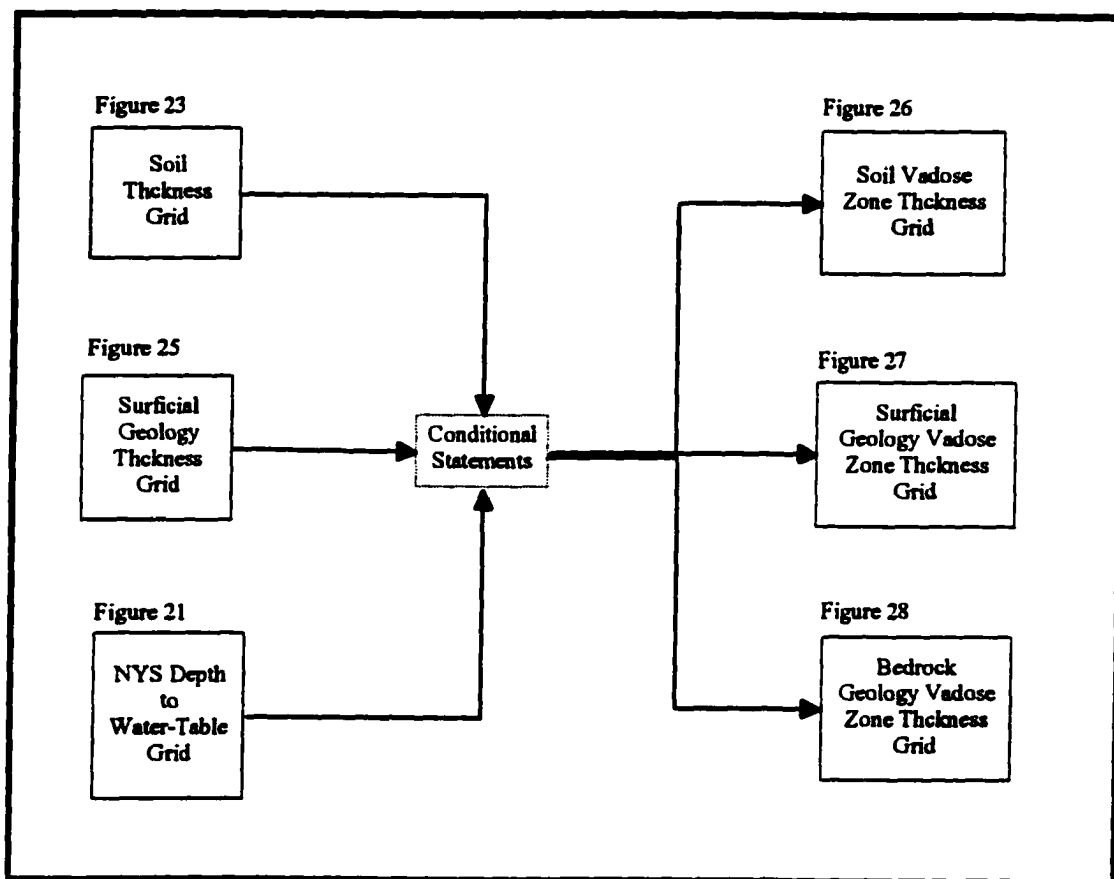
Depth to the Water-Table

NYS Depth to Water-Table Grid, Depth (meters)



NYS Boundary

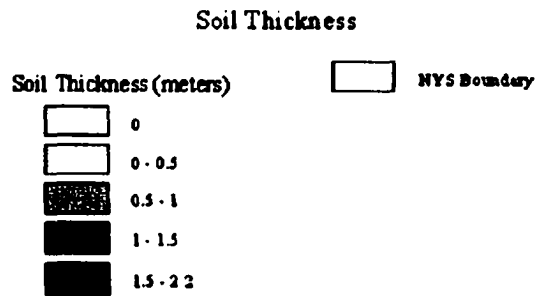
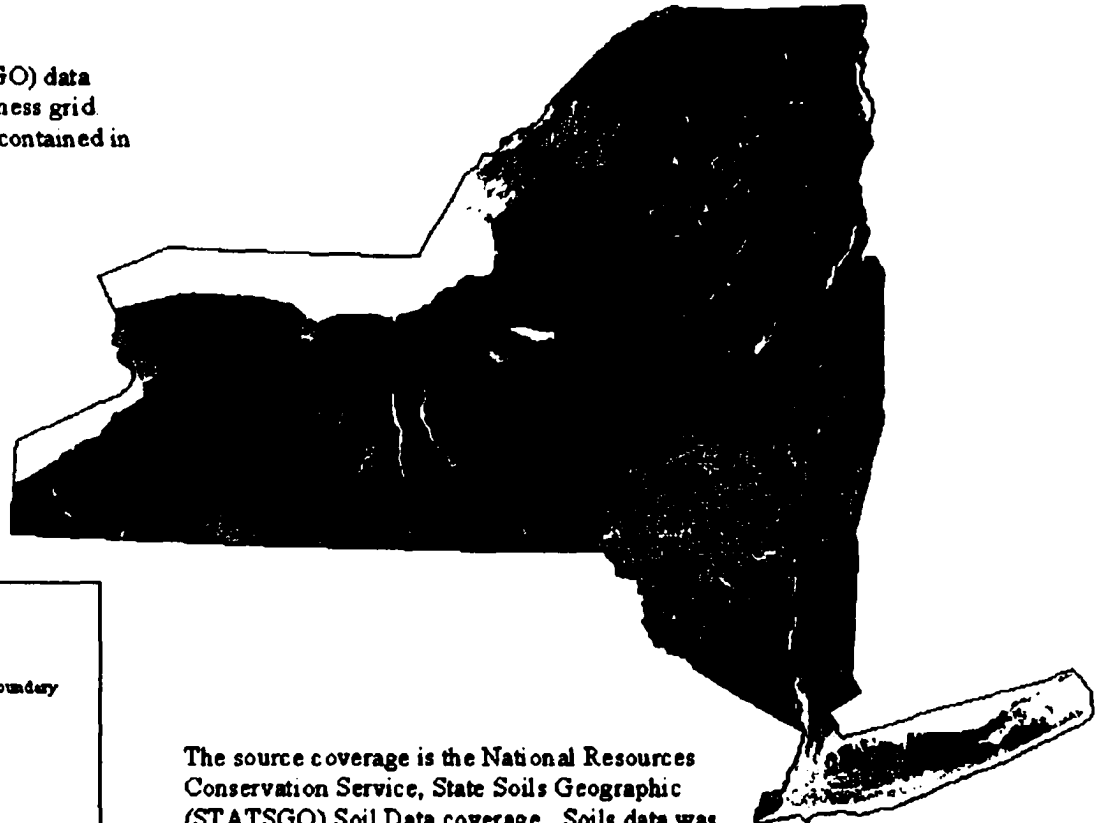
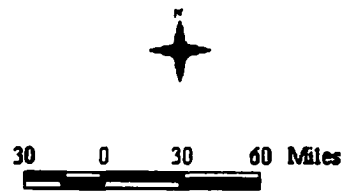
Figure 22. Cartographic model, vadose zone thickness calculation of soil, surficial geology and bedrock geology components.



attribute for surficial geology thickness was added to the coverage based on the thickest possible extent of a given depositional environment, except for till, which was given a value of 10 meters; a reasonable value for the elevated topographic areas on NYS (DEC, 1987) where till presence predominates. The New York Surficial Geology data layer did not contain a thickness range for marine beach and barrier island classifications; a thickness of 10 meters was used for these deposits (Bernard and LaBlanc, 1965; Rampino and Sanders, 1980). The establishment of depositional environment thicknesses enabled the construction of a surficial geology thickness grid (Figure 25). Although surficial

Figure 23. STATSGO Soil Thickness Grid

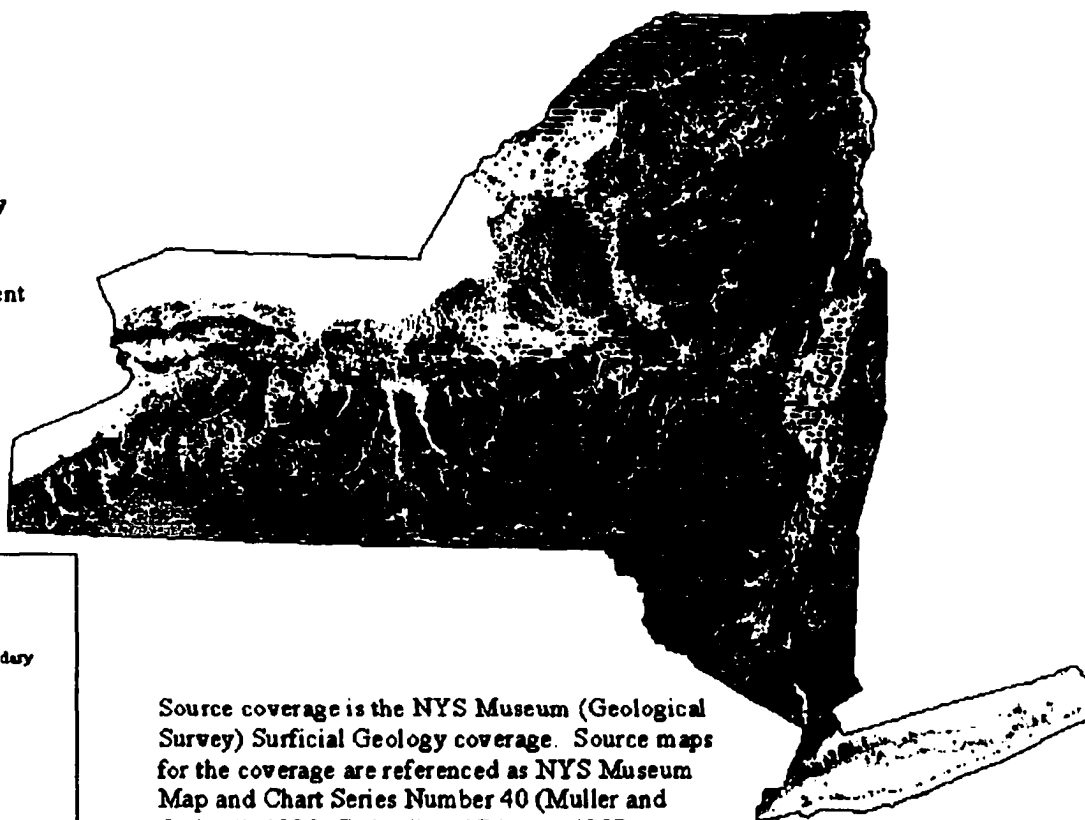
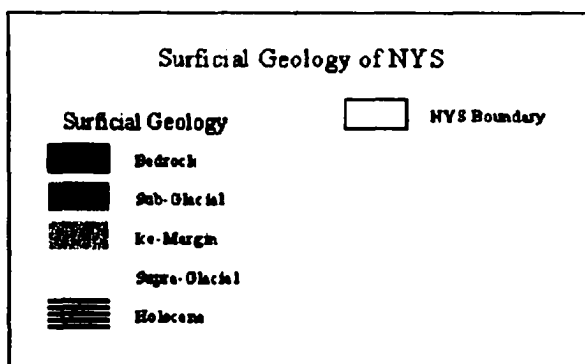
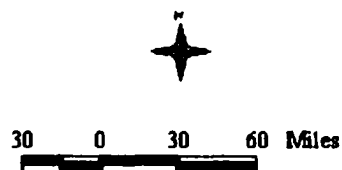
The State Soils Geographic (STATSGO) data layers were used to create a soil thickness grid. Soil thickness is one of the attributes contained in STATSGO.



The source coverage is the National Resources Conservation Service, State Soils Geographic (STATSGO) Soil Data coverage. Soils data was gathered from a 1:250,000 basemap scale; the map unit delineation encompasses a minimum area of 1544 acres.

Figure 24. NYS Museum Surficial Geology Coverage

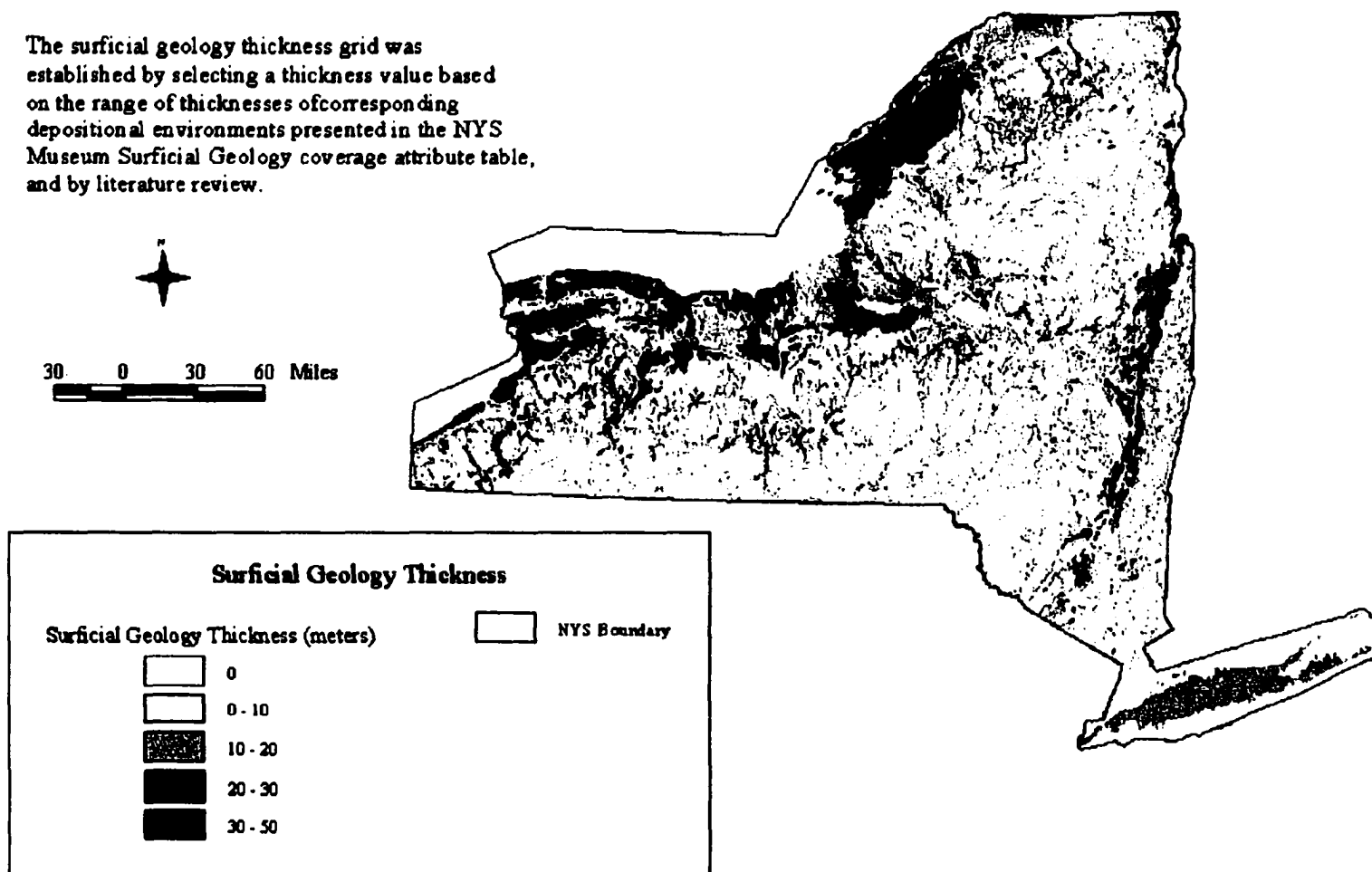
The displayed NYS Museum Surficial Geology Coverage is reclassified in order to display depositional environment settings using a gray scale. Surficial geology thickness, hydraulic conductivity, and porosity were established according to depositional environment settings.



Source coverage is the NYS Museum (Geological Survey) Surficial Geology coverage. Source maps for the coverage are referenced as NYS Museum Map and Chart Series Number 40 (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell and Pair, 1991).

Figure 25. Surficial Geology Thickness Grid

The surficial geology thickness grid was established by selecting a thickness value based on the range of thicknesses of corresponding depositional environments presented in the NYS Museum Surficial Geology coverage attribute table, and by literature review.



geology depositional environments present at the surface may not persist to the depth of the water-table, layers of several depositional environments may be stacked, this research assumes that the characteristic depositional environment will persist to the assigned thickness, under which bedrock will be present. As far as the vertical section of unconsolidated sediments go, this assumption is far fetched for glacial valleys with respect to the depth of bedrock (Kappel, Sherwood and Johnston, 1996; Waller and Finch, 1982; and Cosner, 1984). However, since the water-table tends to be shallow in glacial valleys, the assumption that the unconsolidated sediment depositional environment present at the surface will persist to the water-table depth is reasonable. Likewise, since the unconsolidated sediment depositional environments tend to be less vertically stacked in upland areas than in the valley areas, it is reasonable to assume that these depositional environments will persist to the depth of the bedrock in upland areas. The depth of the water-table may be within or below the section of unconsolidated matrix in upland areas.

The depth to the water-table grid was adjusted so the depth of the water-table was not greater than 100 meters. The deepest water-level measurement in the USGS GWSI database utilized for the unconfined aquifers analysis was 30.48 meters; unless the attribute table contained an aquifer attribute of unconfined at a depth deeper than 30.48 meters. A depth of 100 meters is similar to the deepest water source depths referenced by Arnou, 1949; Berdan, 1954; Perlmutter, 1959; Mack and Digman, 1963; Kammer and Hobba, 1967; and Frimpter, 1970. Drilling to depths greater than 100 meters in fractured rock is often not warranted as the number and size of openings below that depth rapidly

Figure 26. Soil Component of the Vadose Zone, Thickness Grid

The soil vadose zone thickness grid was calculated by determining the thickness of the soil section above the water-table.

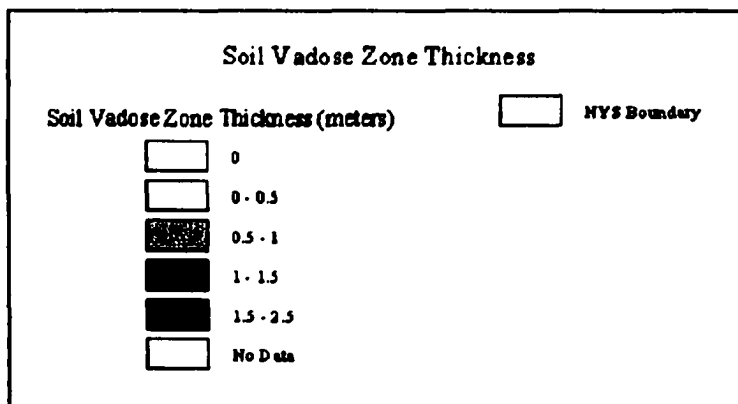
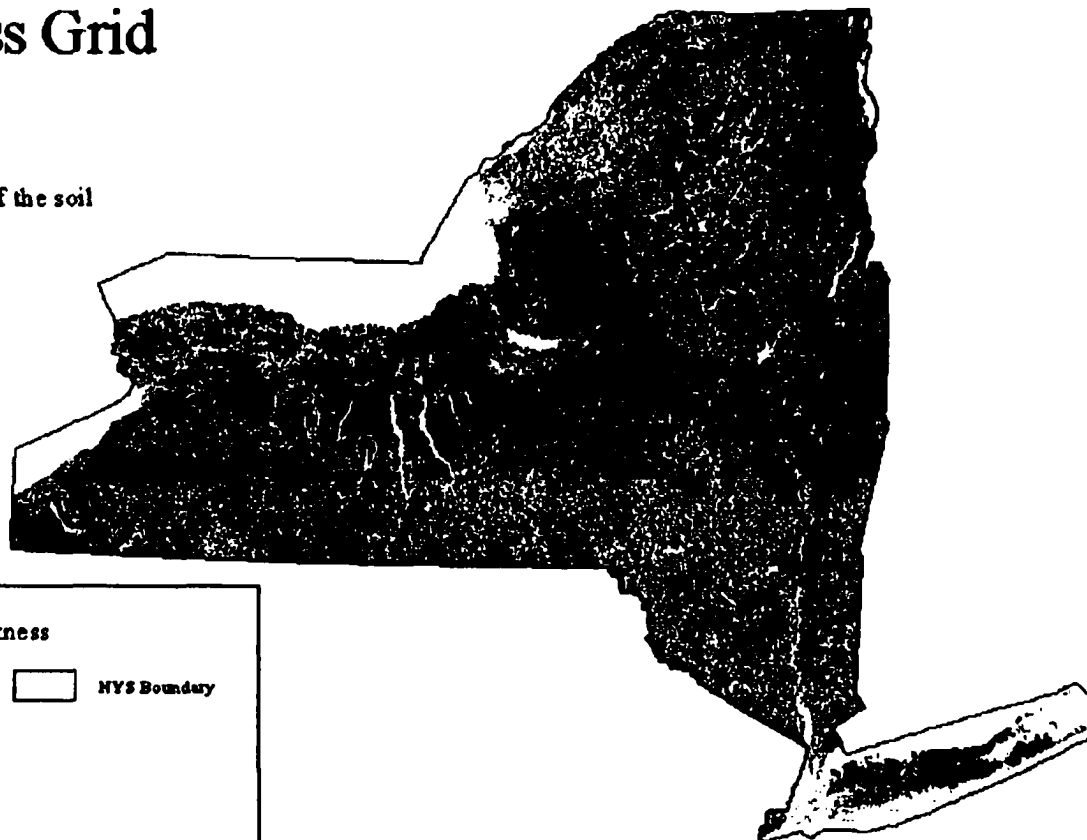
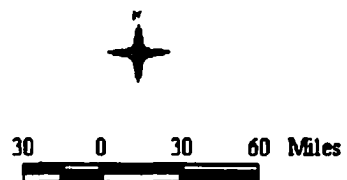


Figure 27. Surficial Geology Component of the Vadose Zone Thickness Grid

The surficial geology vadose zone thickness grid was calculated by determining the thickness of the surficial geology section above the water-table.

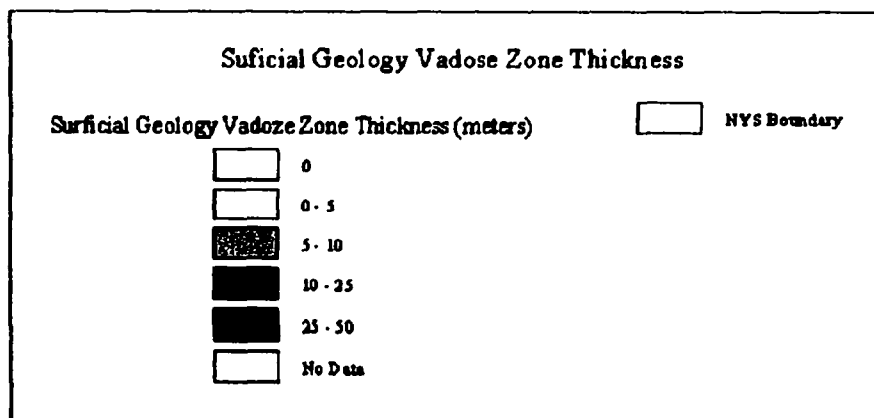
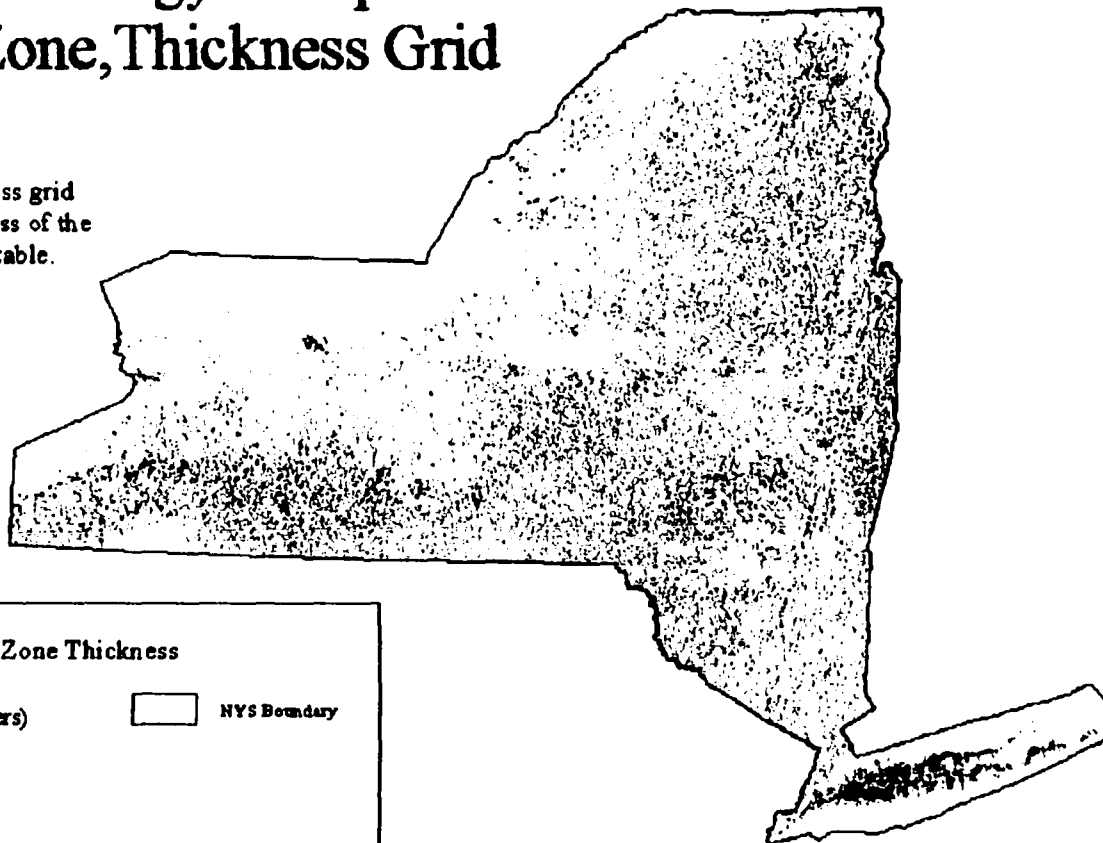
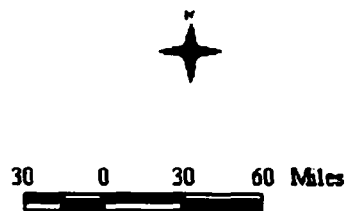
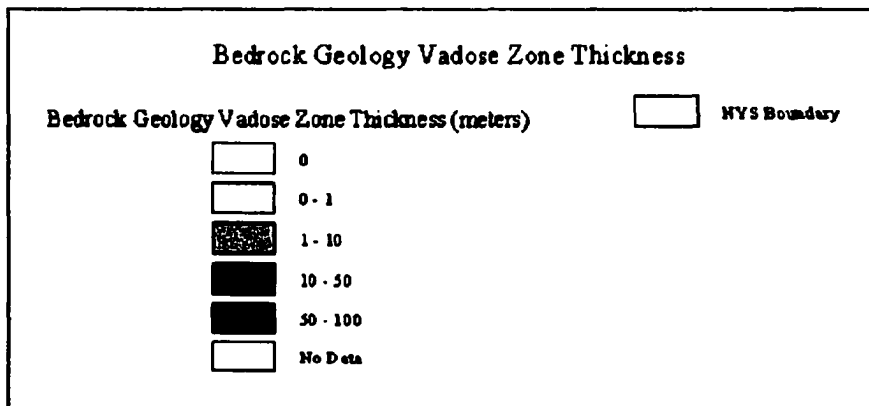
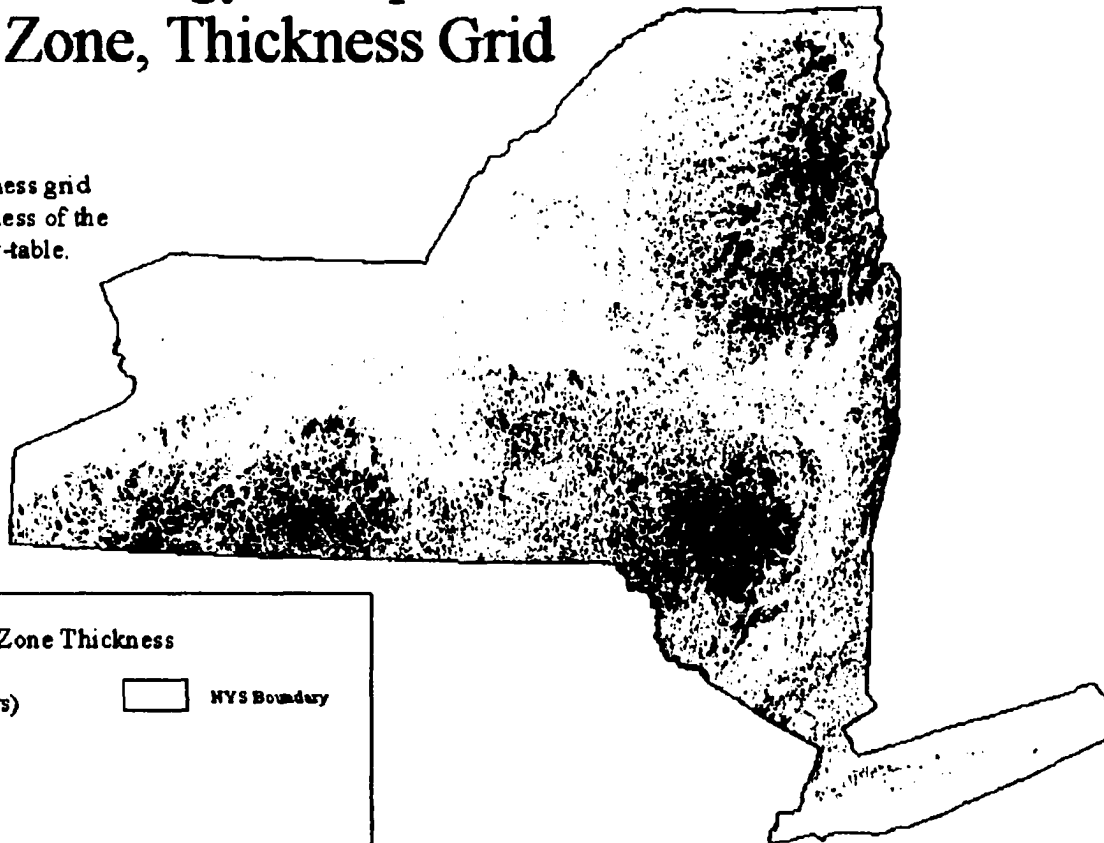
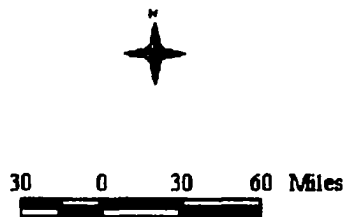


Figure 28. Bedrock Geology Component of the Vadose Zone, Thickness Grid

The bedrock geology vadose zone thickness grid was calculated by determining the thickness of the bedrock geology section above the water-table.



diminishes (Fetter, 1980). Thickness of the soil component of the vadose zone grid (Figure 26), thickness of the surficial geology component of the vadose zone grid (Figure 27) and the thickness of the bedrock geology component of the vadose zone grid (Figure 28) were created by GIS conditional grid statements. If the soil thickness was less than the depth of the water-table, the soil component of the vadose zone was assigned soil thickness; otherwise, the soil component was determined to be equal to the depth of the water-table. If the depth of the water-table was greater than the combined thickness of the soil and surficial geology thicknesses, then the thickness of the surficial geology component of the vadose zone was assigned the thickness of the surficial geology; otherwise, the value was determined by subtracting the soil thickness from the depth to the water-table. If the combined thickness of the soil and surficial geology thicknesses was less than the depth to the water-table, the bedrock geology component of the vadose zone was calculated by subtracting the combined thickness from the depth to the water-table; otherwise, a bedrock component of the vadose zone did not exist and a value of zero was assigned.

B. Establishment of Vadose zone Porosity and Vertical Hydraulic Conductivity

Values

a. Soil Porosity and Hydraulic Conductivity

The STATSGO Soil coverage contains attributes for soil permeability (USDA, 1993). This coverage also contains attributes for bulk density, weight percent organic matter, and weight percent moisture; these attributes were used with an assumed mineral density of 2.65

g/cc, water density of 1.00 g/cc, and organic matter density of 0.22 g/cc, the density of peat near the surface (Orson, Osgood, Zajac and Tait, 2000), to estimate soil porosity.

Soil porosity was estimated by the following formula:

$$\phi = (1 - (((\rho_b - (\rho_b \times WP_{om}) + (\rho_b \times WP_{mat})) / \rho_{mat}) + ((\rho_b \times WP_{om}) / \rho_{om}))) / 1$$

ϕ = Porosity (porosity percent)

ρ_b = Bulk density

WP_{om} = Weight percent organic matter

ρ_{om} = Density of organic matter

WP_{mat} = Weight percent moisture

ρ_{mat} = Density moisture

ρ_{mat} = Density matrix

Soil porosity estimates allowed the creation of a soil porosity grid (Figure 29). The soil permeability attribute enabled the creation of a soil hydraulic conductivity grid (Figure 30).

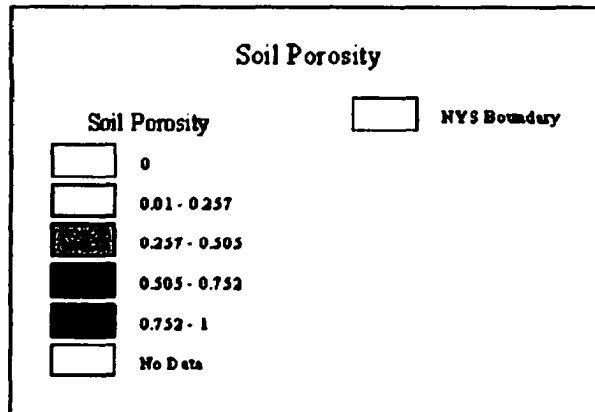
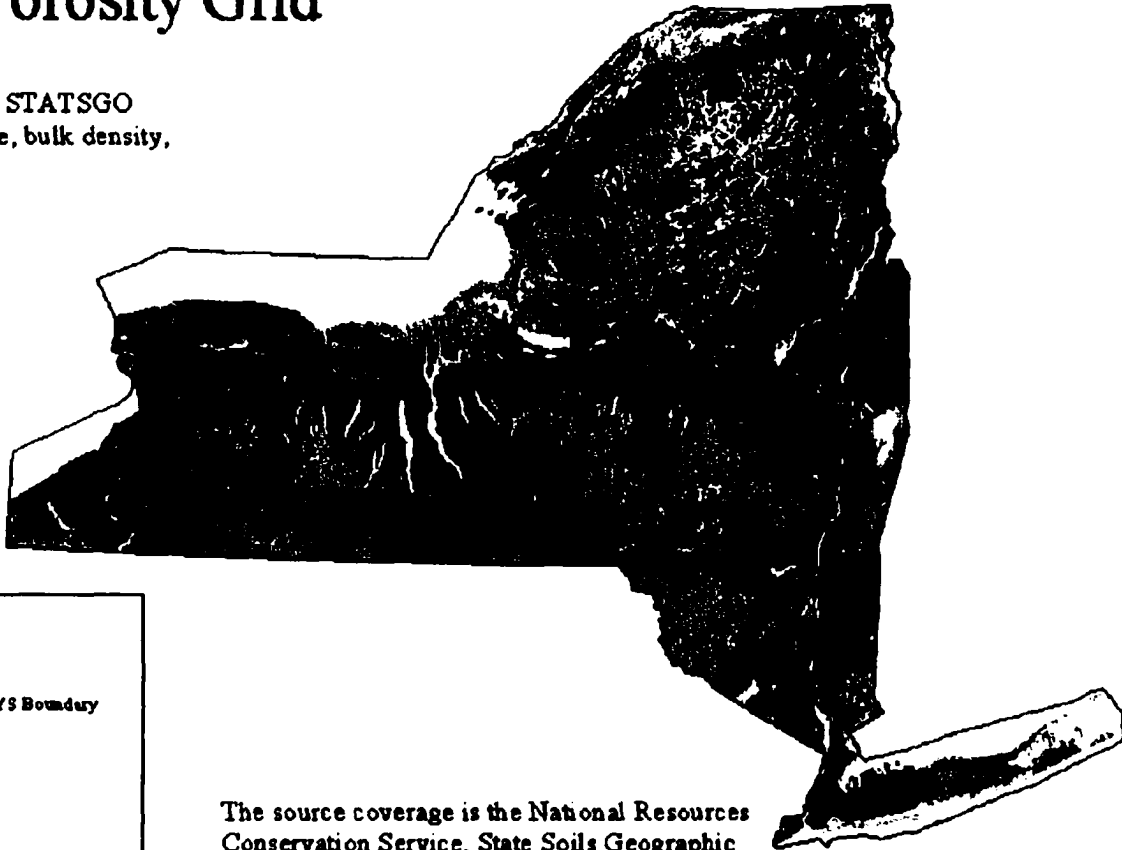
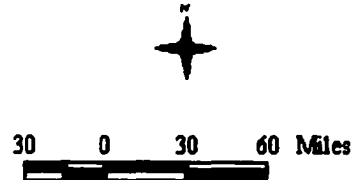
b. Surficial Geology Porosity and Hydraulic Conductivity Assignments

The NYS Museum Surficial Geology coverage displays depositional environment classifications of unconsolidated sediments present at the surface (Figure 24). Porosity and hydraulic conductivity attributes were added to the NYS Museum Surficial Geology attribute table according to the gravel, sand, silt or clay characteristics and literature review. Hydraulic conductivity values assigned also considered pump or slug test data obtained from EPA CERCLA files (Appendix E).

An understanding of depositional environment classifications of the Quaternary Geology of NYS must be established prior to the assignments of porosity and vertical hydraulic conductivity values to the NYS Museum Surficial Geology coverage. The

Figure 29. Soil Porosity Grid

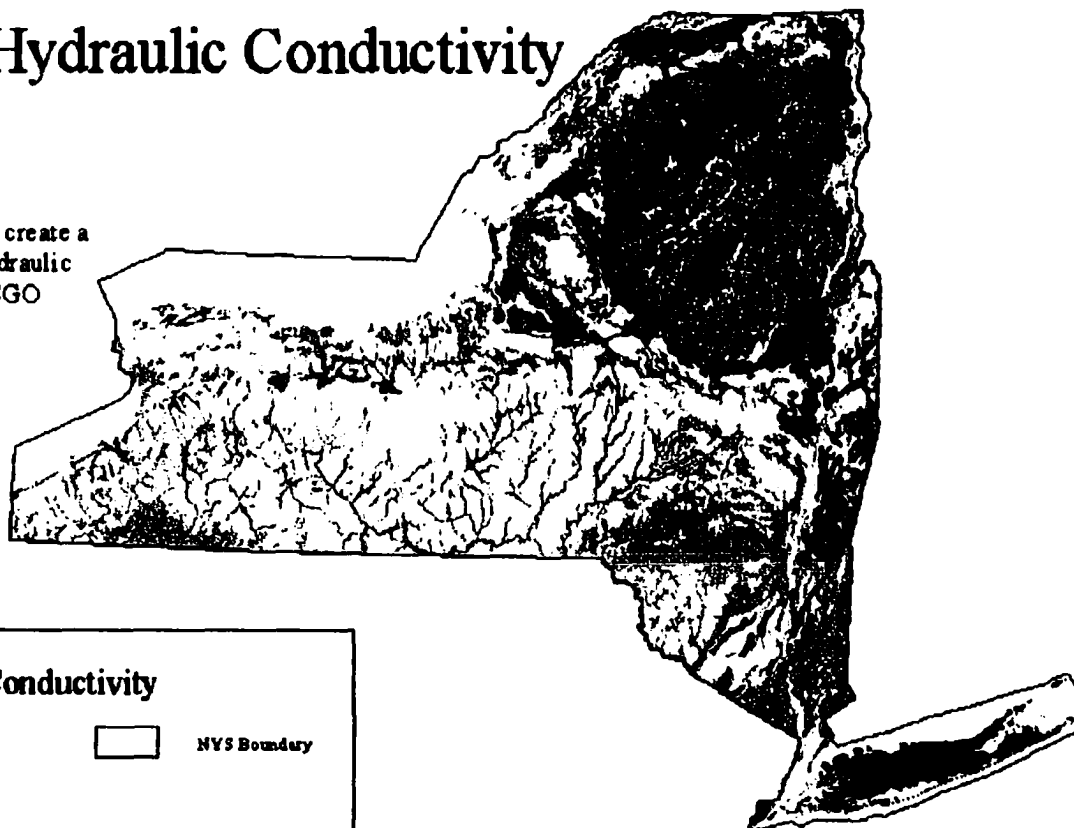
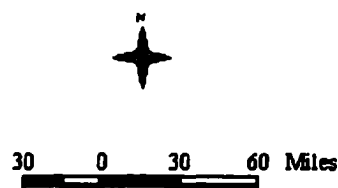
Soil porosity was estimated using STATSGO attribute data such as soil moisture, bulk density, and organic matter content.



The source coverage is the National Resources Conservation Service, State Soils Geographic (STATSGO) Soil Data coverage. Soils data was gathered from a 1:250,000 basemap scale; the map unit delineation encompasses a minimum area of 1544 acres.

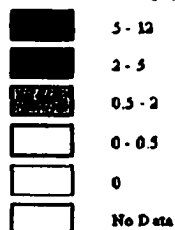
Figure 30. Soil Hydraulic Conductivity Grid

The STATSGO data layers were used to create a soil hydraulic conductivity grid. Soil hydraulic conductivity was obtained in the STATSGO attribute table (soil permeability).



Soil Hydraulic Conductivity

Soil Hydraulic Conductivity (meters/day)



NYS Boundary

The source coverage is the National Resources Conservation Service, State Soils Geographic (STATSGO) Soil Data coverage. Soils data was gathered from a 1:250,000 basemap scale; the map unit delineation encompasses a minimum area of 1544 acres.

following discussion and referral to the NYS Museum Surficial Geology coverage (Figure 24) will assist in the understanding of the assignment of surficial geology porosity and hydraulic conductivity values based on depositional environments. In the proceeding discussion, horizontal hydraulic conductivity will be referred to as hydraulic conductivity.

1. Quaternary Geology of NYS, Pleistocene Epoch

The Pleistocene Epoch is a glacial - interglacial epoch; huge ice sheets advanced and retreated across North America several times leaving distinct deposits of unconsolidated sediment. NYS has undergone at least three periods of glaciation during the Pleistocene Epoch. Recession of the last glacier during the Late Wisconsin period between 21,000 years ago, when the glacier reached its maximum southerly extent, and 11,000 years ago, when the glacier receded north of NYS, has left the glacial deposits and glacial topographic expressions which comprise the NYS landscape. A southwestern portion of NYS is the only part of the State which was not subject to Late Wisconsin glaciation; this area is called the Salamanca Re-Entrant (Van Diver, 1988). Glacial depositional environments are the result of sediment transport by ice-substrate shear, englacial ice flow, subglacial water flow, glacial melt-water discharge at the ice-margin, and discharge of glacially sourced meltwater to fluvial plains and valleys or basins beyond the ice-margin. The Late Wisconsin continental glacier was a large mass of ice which accumulated during an atmospherically cold period; the freezing temperatures allowed snow accumulation, compaction and recrystallization to produce a growing ice sheet. The ice sheet, or glacier, reached a thickness of 2 kilometers. The weight of the

thick glacial ice produced ice creep downslope or outward in all directions (Friedman, Sanders and Kopaska-Merkel, 1992). When glacial creep rate was greater than glacial melting rate, the glacier would advance. If glacial ice formation and resultant creep rate equaled glacial melting rate, the glacial margin would maintain a stable position.

Likewise, when glacial melting outpaced glacial creep rates, the glacier would recede.

Recession of the glacier northward through NYS has left a cornucopia of glacial facies.

Glacial depositional environments can be classified as subglacial, ice-margin/proximal, and supraglacial (slight revision of Ashley and Stanford, 1993). These environments are very complex and do not possess distinct boundaries; they undergo a gradual transition.

The following discussion of glacial depositional environments is largely based on a field trip notebook titled Hydrogeology of the Glacial Deposits of New Jersey: An Applied Field Course, 1993, by Gail M. Ashley, Rutgers University, Department of Geological Sciences and Scott D. Stanford, New Jersey Geological Survey.

Glaciers erode underlying unconsolidated sediments by incorporation into an underlying shear zone and erosion of consolidated bedrock through abrasion and plucking. The predominant mechanism of ice sheet movement over the substrate occurs when conditions at the ice-substrate interface are close to the pressure melting point and the ice flows over the substrate producing a thin shear zone (Eyles and Eyles, 1992). The thin shear zone lies within the lower layer of ice and upper portion of the substrate and is usually a few meters thick. Intense abrasion occurs within this zone between particles in the base of this layer and particles of underlying locked substrate. Particles at the basal shear zone can become lodged in the underlying fixed substrate and become polished and

faceted.

1a. Till and Ablation Moraine

Lodgement till is a diamicton, (Flint, Sanders and Rodgers, 1960) which is deposited at the base of a glacier and smeared onto the substrate (Ashley and Sanford, 1993). Lodgement till usually produces a roughly uniform thickness of regional cover. In Upstate New York the average cover on hills is less than 10 meters (DEC, 1987). However, till thickens in the scoured valleys within weak basement rock and also thickens on the hill slopes which faced advancing ice (Ashley and Stanford, 1993). Lodgement till rarely attains a thickness greater than 50 meters (Eyles and Eyles, 1992). Till is locally derived; resistant competent quartzitic bedrock sources produce sandy boulder tills, whereas weak bedrock precursors produce shaly, silty tills with few boulders.

Fixed substrate of competent frozen till can move along shear planes and stack, producing over thickened lenticular till units (Eyles and Eyles, 1992). These lenticular units occur locally within the sheet-like lodgement till. The units possess cross cutting and overlapping relationships and may be produced by changes in ice creep velocities. The individual stacked till units may possess different lithologic make-up.

Drumlins are hills of till that have been molded into streamline forms by overriding ice and are elongated in the direction of ice movement. NYS possesses extensive drumlin fields between Lake Ontario and the Allegheny Plateau/Adirondack Mountains areas. The drumlins overlie shale of the Upper Ordovician period in the Tug Hill Plateau, and shale, dolomite and evaporites of the Silurian period in the Ontario

Lowlands (Broughton, Fisher, Isachsen and Richard, 1976). The formation of drumlins is not understood and various hypotheses exist.

Ablation till is a diamicton which is produced when englacial debris is dumped on the land surface as glaciers melt away. In contrast to lodgement till, ablation till is not subject to shearing stress and thick ice column pressure; it is loosely consolidated and possesses a random fabric (Easterbrook, 1982). Ablation till found in NYS achieves thicknesses between one and 10 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991).

Till is a poorly sorted mixture of clay, sand, gravel and boulders. Average till porosity in Cattaraugus County, New York was noted to be 32% (Prudic, 1986). The average horizontal hydraulic conductivity of till present in the moraines of Long Island, New York is 4.6×10^{-4} m/s (Busciolano, Monti, and Chu, 1998; Feldman, Smolensky and Masterson, 1992); hydraulic conductivity values for silty and sandy till throughout New Jersey range between 1×10^{-8} and 1×10^{-5} m/s (Ashley and Sanford, 1993); till hydraulic conductivity observed in Cattaraugus County, New York averages approximately 2.0×10^{-10} m/s (Prudic, 1986); and EPA CERCLA file pump tests performed in till and reviewed by the author yield a hydraulic conductivity range between 6.5×10^{-3} and 5.9×10^{-4} (Appendix E). According to Freeze and Cherry, 1979, hydraulic conductivity of till ranges between 1.0×10^{-12} and 1.0×10^{-6} . The foregoing values enable the regional assignment of a till porosity of 32 percent, and a hydraulic conductivity of 5.0×10^{-7} m/s for the NYS Museum Surficial Geology coverage. Ablation moraine classification of the coverage was assigned a similar hydraulic conductivity, but due to the fact that ablation

till is less compacted, a slightly higher porosity of 34 percent was assigned.

1b. Inwash, Alluvial Inwash, Kame (Eskers)

Glaciers possess a complex plumbing network through which water will flow. Water may flow atop glaciers or enter glaciers through vertical conduits called moulins and network toward the ice-margin. Tunnel networks which work their ways toward the ice-margin are also located at the base of glaciers. Water flow atop glaciers may incorporate debris from within the glacier or carry a bedload from protruding sediment sources. Water flow through subglacial tunnel systems can act upon till and redeposit the sediments with varying degrees of sorting.

Subglacial channels can develop within the drainage system under a glacier and act as tributaries, supplying water and load to larger esker-forming subglacial tunnels. The channels are cut into lodgement till and trend subparallel to ice transport direction. These channels are often gravel filled and are marked by a planar upper surface which is in turn overlain by till (Eyles and Eyles, 1992). Subglacial tunnel systems transport sediment toward the ice-margin. Till under and adjacent to tunnels is incorporated into the tunnel's moving water system as load (Ashley and Stanford, 1993). The tunnel sediments tend to consist of cross-bedded sand and gravel deposited by restricted paleocurrents (Eyles and Eyles, 1992). The subglacial tunnel systems fill with well-sorted, coarse-grained sand, cobbles and boulders. When glaciers recede, removal of ice leaves a long, narrow deposit of stratified sand and gravel; these bodies display slightly meandering, undulating ridge form and are called eskers. Esker deposits are included under the classification of kame deposits in the NYS Museum Surficial Geology

coverage.

Kame deposits are deposits of sand and gravel which have been sorted by the action of moving water. Kame deposition takes place adjacent to ice sheets, usually along a valley wall. Kame deposits can include terrace or delta systems. Inwash and alluvial inwash are interpreted as alluvium deposited adjacent to active or remnant ice by streams of nonglacial origin; these streams are sourced from highlands that make their way to the ice margin, often along the flanks of valley walls. These deposits consist largely of gravel and coarse sand. According to Freeze and Cherry, 1979, sand and gravel porosity ranges between 25 and 40 percent; therefore, a regional porosity value of 30 percent was assigned to the alluvial inwash, inwash and kame deposits of the NYS Museum Surficial Geology coverage. Freeze and Cherry, 1979, also show a range in hydraulic conductivity of coarse sand to gravel deposits between 1.0×10^{-3} and 1.0 m/s ; a regional hydraulic conductivity of 5.0×10^{-2} was assigned to the alluvial inwash, inwash and kame deposits.

The ice-margin of a continental glacier is an area where glacial flow and glacial melt processes produce an ice-terminus; this terminus is marked by creeping ice and stagnant ice. Stagnant ice does not flow and as such is genetically detached from the continental glacier. As continental glacier flow abuts against stagnant ice, ice shear planes are developed which carry debris from the subglacial environment to the glacier front and surface. As debris is moved to the top and front of a glacier, gravity, water-current, wind and wave energy act upon the debris to form a wide variety of deposits. Melting of ice is seasonally controlled and water flow is normally very great over a short

period of time; in the northern hemisphere water flow is greatest during the summer.

Depositional facies at the ice-margin and beyond are normally a result of short, strong pulses of discharge. The glacial ice-margin/proximal environment can be either subaerial or subaqueous.

Subaerial ice-margin/proximal glacial environments are marked by gravity flow and fluvial processes which transport sediment from the glacial ice downslope around and over pre-existing sediment piles and stagnant ice clumps. As the stagnant ice melts, the surrounding sediment packages can become inverted (Eyles and Eyles, 1992) and the resulting low areas become new sediment sinks (kettle basins). Stagnant ice melting also produces internal deformation of the surrounding sediments; sediment deformation may include collapse features such as tilting and folding (Easterbrook, 1982). Subaerial ice-margin/proximal depositional processes often leave a hummocky topography. These areas of pronounced topography which signify a glacier terminus are called moraines. Moraine sediments consist of meltout till, debris flows, fan, fluvial and deltaic deposits. Moraine deposits in NYS range in thickness from 10 to 30 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991).

1c. Till Moraine

Meltout till is essentially lodgement till which has been incorporated into the ice at the ice-margin by shearing and is deposited as the ice melts. Meltout till is composed of interbedded sorted and unsorted sediment which reflects running water deposition or deposition directly from ice. Debris flows at the ice-margin occur when water-saturated

till becomes unstable and flows downhill in response to gravity. Debris flow diamictons are also called flow till (Easterbrook, 1992). Debris flow diamictons often display clast imbrication; the long axes of clasts are often oriented parallel to flow direction. Debris flow diamictons also exhibit clasts that project from the tops of beds, rafts of sediment slump blocks, lenticular channel cross section, and a downward thickening geometry (Eyles and Eyles, 1992). Debris flows fill topographic lows and often display an upper bed surface of low relief. Porosity and hydraulic conductivity assigned to the NYS Museum Surficial Geology coverage classification of a till moraine were equal to that assigned to till, 32% porosity and 5.0×10^{-7} m/s.

1d. Kame Moraine

Glacial meltwater from the glacial surface or subsurface tunnel systems discharges at the ice-margin and may rework existing sediment into well-sorted, stratified, fluvial deposits. Glacial debris is winnowed and transported by high bedload, low suspended load fluvial systems. Bedload usually consists of boulders, cobbles, pebbles and sand and the finer grains increased with distance away from the glacial front. At the ice-margin, clasts tend to be elongated and sands are angular in texture. With increased distance from the glacial front, clasts become rounded and sand particles become subangular. Pebble and cobble clasts are often imbricated within fluvial channels and dip in an up current direction; long axes of clasts are usually oriented transverse to main current flow. Large fluctuations in discharge produce abrupt particle-size changes and changes in bedform (Easterbrook, 1992). Prolific flood events may accomplish most of the sediment transport and produce most of the sedimentary structures preserved in the

sediment record of a channel (Eyles and Eyles, 1992). Braided to low-sinuosity meandering fluvial systems develop at the ice-margin. These environments display varying degrees of basal lag, trough cross-bedding, planar cross-bedding, planar parallel-bedding and ripple laminae in fining-upwards parasequences (Friedman and Sanders, 2000). Reactivation surfaces are also present. Porosity and hydraulic conductivity assigned to the NYS Museum Surficial Geology coverage classification of a kame moraine were equal to that assigned to kame deposits, 30% porosity and 5.0×10^{-2} m/s.

1e. Outwash Sand and Gravel

Fans can accumulate at steep ice-margins that receive significant debris. Coalesced fans and river-channel systems at the ice-margin are called outwash plains or sandar. Outwash plains receive abundant debris as a glacier advances (Ashley and Stanford, 1993) and often mark the terminus of farthest glacial advance; deposits distinguishing the farthest advance of a glacier make up a terminal moraine. The geomorphology of Long Island is marked by the resultant hills of the Ronkonkoma and Harbor Hill moraines and gently sloping plains associated with glacial outwash deposits. Braided river-channel systems at ice-margins of receding glaciers, which usually receive less debris than advancing glaciers, often migrate down low areas of the ice-margin slope. Outwash plain sediments, composed of gravel and sand, possess variable thicknesses between two and 20 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). Average porosity of the Long Island glacial outwash deposits have been estimated at 30% (Feldman, Smolensky, and Masterson, 1992). Average horizontal hydraulic conductivity of glacial outwash on Long

Island, New York approximates 9.52×10^{-4} m/s (Busciolano, Monti, and Chu, 1998; Feldman, Smolensky and Masterson, 1992) and 7.08×10^{-4} m/s (Getzen, 1977). EPA CERCLA file pump tests performed in glacial sand and gravel, reviewed by the author, yielded a hydraulic conductivity range between 2.5×10^{-4} and 9.8×10^{-3} m/s (Appendix E). A regional porosity of 30% was assigned to the NYS Museum Surficial Geology coverage deposits classified as outwash sand and gravel; the coverage was also given a regional hydraulic conductivity of 5.0×10^{-4} m/s for these deposits.

1f. Fluvial Gravel, Pleistocene Alluvium and Fluvial-Deltaic Sand

Glacial meltwater is often impounded against the ice-margin front as meltwater collects in basins produced by terrain which slopes toward the glacial front or damming of valleys at some distance in front of the glacier (Ashley and Stanford, 1993). Fluvial systems, which consisted of high bedload, sand and gravel, braided stream systems, debouched into glacial lakes and formed Gilbert-type or shoal-water deltas. Gilbert-type deltas tend to form in higher energy, coarse-grained systems and in lake basins with "deep" margins; whereas shoal water deltas (fan-style) tend to form in lower energy, fine-grained systems in "shallow lakes" (Ashley and Stanford, 1993). Subaerial delta plains of the ice-margin/proximal area are composed of bedload fluvial systems as described above. These systems produce thin topset deposits as vertical aggradation of sediment is limited to channel depth during flood periods and the base level of the lake. Thickness of the fluvial topset deposits range between two and 20 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). As noted above, a porosity of 30% can be assigned to sand and gravel deposits (Freeze and

Cherry, 1979); this value was assigned to the fluvial gravel, Pleistocene alluvium and fluvial deltaic sand deposits classified in the NYS Museum Surficial Geology coverage. Fluvial glacial sand and gravel hydraulic conductivity had been noted to range between 2.2×10^{-2} and 9.1×10^{-4} m/s in New Jersey (Ashley and Sanford, 1993) and 7.0×10^{-4} and 1.0×10^{-3} m/s on Long Island, New York (Smolensky, Buxton and Shernoff, 1989). A regional hydraulic conductivity of 5.0×10^{-3} m/s was assigned to the NYS Museum Surficial Geology coverage's classification of fluvial gravel, Pleistocene alluvium and fluvial deltaic sand.

1g. Undifferentiated Stratified Drift and Undifferentiated Drift Complex

Drift is a collective designation for any sediment related to a glacier (Friedman, Sanders and Kopaska-Merkel, 1992). A drift complex can represent a wide range of glacial depositional environments. Meltwater can act upon the drift and sort sediments to form stratified drift deposits. Since undifferentiated drift deposits can range in all sediment size and sorting classifications, porosity and hydraulic conductivity values were assigned to be within the range of silt and sand deposits. Silt and sand porosity values range between 25 and 50 percent (Freeze and Cherry, 1979); a porosity of 34 percent was assigned to the undifferentiated stratified drift and undifferentiated drift complex classifications of the NYS Museum Surficial Geology coverage. Silty sand hydraulic conductivity values range between 1.0×10^{-7} and 1.0×10^{-3} m/s (Freeze and Cherry, 1979); a value of 1.0×10^{-5} m/s was assigned to the undifferentiated stratified drift and undifferentiated drift complex classifications of the NYS Museum Surficial Geology coverage.

1h. Lacustrine Delta

Deltaic discharge of glacially derived sediments in a lake basin produces subaqueous delta front and prodelta depositional settings. Sediment load is deposited in a lake basin as dictated by contrasting densities of distributary water and water of the receiving basin. Fluvial discharge of glacially derived water with a suspended load can be either equal to or slightly greater than the density of lake water; interflows and underflows will carry suspended load to its place of deposition at the delta front and prodelta areas (foreset or bottomset beds). Bedload will move down the delta front by gravity flow and density flow (foreset beds). Ice-margin deltas are also likely to display interbeds of debris flow diamictons, sediment inversion character and collapse structures as a result of melting of incorporated ice within deltaic sediments.

Gilbert-type deltas are dominated by gravel and coarse-grained sand bedload which travel down the delta front by gravity flow or density flow. The delta front of the Gilbert-type delta commonly displays well-sorted coarse sediments; parallel bedding, steeply dipping foresets (which approach a dip of 33°), normal and inverse graded beds of sand and gravel, and clasts which lie parallel to bedding planes. Finer sands and silt are transported by underflow to the distal portion of the delta front (Friedman, Sanders and Kopaska-Merkel, 1992).

Shoal-water delta bedload contains finer sediments than the Gilbert-type delta and transports a large amount of sand. Shoal-water deltas transport sediment to the delta front largely via underflows. Shoal-water delta deposits display well-sorted medium- to fine-grained sand. The upper portion of the delta front often shows signs of rapid deposition,

such as convoluted bedding, slumps, ball and pillow structures, roll-up structures and pipes and dish structures. The middle to distal delta front displays lobed shaped sediment bodies composed of climbing ripple sequences of sand and silt. Foreset beds generally dip less than 20° . Shoal-water bottomset beds are composed of horizontally bedded sets of silt and clay which display drape laminae (Friedman, Sanders and Kopaska-Merkel, 1992).

Lacustrine deltas generally consist of well-sorted, stratified coarse sand and gravel. In NYS these deposits range in thickness between three and 5 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). According to Freeze and Cherry, 1979, sand and gravel porosity ranges between 25 and 40 percent; therefore, a regional porosity value of 30 percent was assigned to lacustrine delta deposits of the NYS Museum Surficial Geology coverage. Freeze and Cherry, 1979, also show a range in hydraulic conductivity of coarse sand to gravel deposits between 1.0×10^{-3} and 1.0 m/s ; a regional hydraulic conductivity of 5.0×10^{-2} was assigned.

1i. Subaqueous Fan

Subaqueous ice-margin fans are supplied by sediment discharged via subglacial tunnel systems which discharge subaqueously into a lake. Glacial meltwater from tunnel systems flows via hydraulic head into lacustrine waters. The exit point of the tunnel serves as a point of discharge that radially spreads a load of gravel and sand. The long axes of the larger clasts in subaqueous fan deposits are commonly oriented parallel to flow. The fan deposits also display chaotic and convoluted bedding as a result of rapid

deposition and dewatering. Large clasts are often dispersed in massive sands in the proximal fan. Mid-fan areas usually contain gravity flow deposits which display ball-and-pillow structures, dune and ripple cross-beds, and flame structures. Distal fan deposits contain climbing ripple sequences and drape laminae. Subaqueous fan deposits range in thickness between five and 30 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). These deposits consist largely of gravel and coarse sand. A regional gravel and sand porosity value of 30 percent (Freeze and Cherry, 1979) was assigned to subaqueous fan deposits of the NYS Museum Surficial Geology coverage. Freeze and Cherry, 1979, also show a range in hydraulic conductivity of gravel and coarse sand deposits between 1.0×10^{-3} and 1.0 m/s ; a regional hydraulic conductivity of 5.0×10^{-2} was assigned to the subaqueous fan deposits.

Supraglacial environments receive glacial meltwater and debris, but are distally removed from the ice-margin of both creeping and stagnant ice. The supraglacial environments consist of bedload channel and delta systems such as those described above; however, unlike lacustrine ice-margin deposits, there is a general lack of diamictons and sediment deformation such as inversion and collapse. Clasts are also smaller and more rounded down a depositional slope away from the ice-margin.

Supraglacial subaerial environments consist of fluvial, delta plain and eolian deposits.

Supraglacial subaqueous environments contain delta front, prodelta and basinal lacustrine environments. Since the subglacial fluvial and delta environments are much the same as deposited in the ice-margin/proximal area, the following section will focus on basinal

lacustrine and eolian depositional environments.

1j. Lacustrine Silt and Clay

The basinal lacustrine environment is often the largest of the glacially associated depositional environments in aerial extent (Ashley and Stanford, 1993). Glacial meltwater that carries large amounts of ground rock flour discharge into glacial lakes (Easterbrook, 1992). The silt-clay suspended sediments are deposited as parallel laminae forming rhythmites. These laminae are characteristic of glacially associated lacustrine deposits; if the rhythmites are deposited on an annual basis, they are called varves. Varve couplets are produced as silt and occasional sand layers are deposited in the summer months as glacial meltwater influx to the lacustrine environment introduces suspended load. The silt layers usually possess a light color. Clay layers are deposited in the quiet water underlying ice cover during the winter months. The clay layers commonly display a dark color. Another common sedimentary feature of lacustrine deposits is graded bedding; the silt and sand deposits are a result of turbidite deposition, which usually occurs during the warm summer months (Eyles and Eyles, 1982). Turbidity currents flow along low areas of the lacustrine bottom and hence their deposits fill lake bottom lows. Burrowing and trace fossils are commonly present in the summer layer, but not in the winter layer. Ice-rafted material such as dropstone is also evidenced in the basinal lacustrine layers. Lacustrine deposits of NYS can attain thicknesses up to 50 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). According to Freeze and Cherry, 1979, the porosity range of silt and clay deposits can vary widely between 35 and 70 percent, the compaction of these

sediments with depth control porosity percent (Athy, 1930). A porosity of 45 percent was assigned to lacustrine silt and clay deposits of the NYS Museum Surficial Geology coverage. Hydraulic conductivity values for glacial lacustrine silt and clay deposits have been noted to range between 1.4×10^{-7} and 1.0×10^{-10} m/s (Ashley and Stanford, 1993). A value of 5.0×10^{-9} m/s was assigned for the hydraulic conductivity of glacial lacustrine silt and clay deposits of the NYS Museum Surficial Geology coverage.

1k. Dunes

In the absence of vegetation cover, drained lakes and outwash plains provide a ready source of sediments for reworking by wind currents. Glacial deposits may be covered by loess deposits, small sand seas or eolian sheet sands. Eolian deposits may accumulate along former major depositional systems with the thickest accumulations occurring near the source material within topographic lows (Ashley and Stanford, 1993). Eolian deposits may consist of dune deposits consisting of fine- to medium-grained well-sorted sand. In NYS, dune deposits range in thickness between one and 10 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). A sand porosity value of 30 percent (Freeze and Cherry, 1979) was assigned to the dune deposits of the NYS Museum Surficial Geology coverage. According to Freeze and Cherry, 1979, eolian sand hydraulic conductivity ranges between 1.0×10^{-6} and 1.0×10^{-4} m/s, clean sand hydraulic conductivity ranges between 1.0×10^{-6} and 1.0×10^{-2} m/s. A hydraulic conductivity of 5.0×10^{-4} m/s was assigned to the dune deposits of the NYS Surficial Geology coverage.

2. Quaternary Geology of NYS, Holocene Epoch

The Holocene Epoch began about 11,000 years ago as the Laurentide continental glacier retreated northward of NYS (Isachsen, Landing, Lauber, Rickard and Rogers, 1991). These unconsolidated sediments are products of the following depositional environments ranging from colluvium to marginal marine environments.

2a. Colluvial Diamicton, Colluvium, Colluvial Fan

Colluvium is deposited by debris flow at the base of bedrock cliffs. Colluvium is often found at valley heads, mouths of gullies or steep valley flanks. Colluvium consists of a mixture of sediments deposited by mass wasting and possesses thicknesses that range between one and 5 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). Since colluvium is a mixture of sediments, and often a diamicton resembling till, porosity and hydraulic conductivity values were assigned to the NYS Museum Surficial Geology coverage's classifications of colluvial diamicton, colluvium and colluvial fan, with similar values to that assigned to ablation till; a porosity of 34 percent and a hydraulic conductivity value of 1.0×10^{-7} m/s were assigned.

2b. Alluvial Fan, Recent Alluvium and Alluvial Terrace

Alluvial fan deposits possess surfaces that are segments of cones and that radiate downslope from points where, along a fault scarp of precipitous slope, streams emerge from rocky highlands (Friedman, Sanders and Kopaska-Merkel, 1992). These deposits result from debris flow, stream flow and mudflow. They consist of poorly stratified silt, sand and boulders that attain thickness between one and 10 meters (Muller and Cadwell,

1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). Porosity values for silty sand and gravel range from 25 to 50 percent (Freeze and Cherry, 1979); a value of 34 percent was assigned to the alluvial fan classification of the NYS Museum Surficial Geology coverage. Hydraulic conductivity values of silty sand to gravel range from 1.0×10^{-7} to 1.0 m/s ; a value of $1.0 \times 10^{-4} \text{ m/s}$ was assigned to the alluvial fan deposits.

Alluvial plain deposits, recent alluvium and alluvial terrace deposits, possess more fluvial sand and gravel than the alluvial fans. The fluvial environments range from braided streams in the upper alluvial plain to meandering streams in the lower alluvial plain. Flood-plain deposits, which increase in significance in the lower alluvial plain, consist of silt and fine sand. Recent alluvial sediments attain thicknesses between one and 10 meters in NYS, and consist of fine sand to gravel (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). Alluvial terraces are remnants of earlier higher floodplains and consist largely of fine sand to gravel deposits one to 10 meters thick. Porosities of sand to gravel deposits range between 25 and 40 percent (Freeze and Cherry, 1979); a value of 30 percent was assigned to the recent alluvial sediments and alluvial terrace classifications of the NYS Museum Surficial Geology coverage. Hydraulic conductivity values for sand and gravel range between 1.0×10^{-6} and 1.0 m/s (Freeze and Cherry, 1979). A hydraulic conductivity of $5.0 \times 10^{-3} \text{ m/s}$, similar to that of deltaic sand and glacial fluvial sands and gravels, was assigned to the classifications of recent alluvial sediments and alluvial terraces.

2c. Swamps

Swamps consist of low-lying, water-saturated deposits of peat-muck, organic silt and sand. Swamp-deposit thicknesses range between two to 20 meters in NYS (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). Silt and sand porosity values can range between 25 and 50 percent (Freeze and Cherry, 1979); a porosity of 34 percent was assigned to the swamp deposit classification of the NYS Museum Surficial Geology coverage. Silty sand hydraulic conductivity values range between 1.0×10^{-7} and 1.0×10^{-3} m/s (Freeze and Cherry, 1979); a value of 1.0×10^{-5} m/s was assigned to the swamp deposits classification of the coverage.

2d. Lacustrine Beach, Lacustrine Sand and Undifferentiated Sand

Lacustrine beach deposits of NYS are made up of well-sorted sand and gravel; they range in thickness between one and 5 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). Porosity of sand to gravel deposits range between 25 and 40 percent (Freeze and Cherry, 1979); a value of 30 percent was assigned to the lacustrine beach classification of the NYS Museum Surficial Geology coverage. Hydraulic conductivity values for sand and gravel range between 1.0×10^{-6} and 1.0 m/s (Freeze and Cherry, 1979). A hydraulic conductivity of 5.0×10^{-3} m/s was assigned to the NYS Museum Surficial Geology classification of lacustrine beach.

Lacustrine sand deposits associated with large bodies of water and a local source of abundant sand can attain thicknesses up to 20 meters in NYS. Lacustrine sand

deposits range in thickness between two and 20 meters (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). These deposits are generally well-sorted, stratified deposits of fine to coarse sand. A sand porosity value of 30 percent (Freeze and Cherry, 1979) was assigned to the lacustrine sand deposits of the NYS Museum Surficial Geology coverage. According to Freeze and Cherry, 1979, clean sand hydraulic conductivity ranges between 1.0×10^{-6} and 1.0×10^{-2} m/s. A hydraulic conductivity of 5.0×10^{-4} m/s was assigned to the lacustrine sand deposits of the NYS Surficial Geology coverage. Undifferentiated sand deposits are similar to lacustrine sand deposits and were given the same thickness, porosity and hydraulic conductivity values as the lacustrine sand. Undifferentiated sand classifications have been made by the NYS Museum/Geological Survey because fossil evidence does not always enable a lacustrine or marine classification.

2e. Marine Delta, Beach and Barrier Island

Marine delta deposits range in thickness between three and 5 meters and consist of well-sorted coarse to fine gravel and sand (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). Marine beach deposits consist of well-sorted sand and gravel deposits; barrier island deposits consist of medium- to coarse-grained sand. The thickness of modern beach and barrier island deposits approximate 10 meters (Bernard and LaBlanc, 1965; Rampino and Sanders, 1980). Porosities of sand to gravel deposits range between 25 and 40 percent (Freeze and Cherry, 1979); a value of 30 percent was assigned to the marine delta, beach and barrier island classifications of the NYS Museum Surficial Geology coverage. Hydraulic

conductivity values for sand and gravel range between 1.0×10^{-6} and 1.0 m/s (Freeze and Cherry, 1979). A hydraulic conductivity of $5.0 \times 10^{-3} \text{ m/s}$ was assigned to the marine delta, beach and barrier island facies of the NYS Museum Surficial Geology coverage.

2f. Undifferentiated Silt and Clay

Undifferentiated silt and clay can be of either marine or lacustrine origin. These deposits may reach thickness as great as 50 meters in NYS (Muller and Cadwell, 1986; Cadwell and Dineen, 1987; Cadwell, 1988; Cadwell, 1989; Cadwell and Pair, 1991). According to Freeze and Cherry, 1979, the porosity range of silt and clay deposits can vary widely between 35 and 70 percent. A porosity of 45 percent was assigned to undifferentiated silt and clay deposits of the NYS Museum Surficial Geology coverage. Hydraulic conductivity values for lagoonal marine clay have been noted to average about $3.5 \times 10^{-8} \text{ m/s}$ (Smolensky, Buxton and Shernoff, 1989). According to Freeze and Cherry, 1979, unweathered marine clay hydraulic conductivity ranges between 1.0×10^{-12} and 10^{-9} m/s . A value of $5.0 \times 10^{-9} \text{ m/s}$ was assigned for the hydraulic conductivity of undifferentiated silt and clay deposits of the NYS Museum Surficial Geology coverage.

2g. Artificial Fill

Man has also created artificial fill deposits. Artificial fill is classified as a deposit on the NYS Museum Surficial Geology coverage. Artificial fill can vary in thickness. A value of 3 meters thickness was assigned to this classification. Sediment size can vary widely in an artificial fill and these materials are often very poorly sorted. Porosity and hydraulic conductivity values similar to a diamicton were assigned to artificial fill; a porosity value of 34% and a hydraulic conductivity value of $1.0 \times 10^{-7} \text{ m/s}$ were assigned

to the NYS Museum Surficial Geology coverage's classification of artificial fill.

c. Surficial Geology Vertical Hydraulic Conductivity Assignment

A vertical hydraulic conductivity attribute (vertical hydraulic conductivity was assumed to be an order of magnitude less than horizontal hydraulic conductivity) was assigned to the attribute tables of the NYS Museum Surficial Geology coverage. Vertical hydraulic conductivity was estimated to be equal to one tenth of the horizontal hydraulic conductivity. Literature review displays that vertical hydraulic conductivity approximates an order of magnitude less than the horizontal hydraulic conductivity (Getzen, 1977; Prudic, 1986; Lewis-Brown and Jacobsen, 1995; Busciolano, Monti and Chu, 1998).

The assignment of porosity and vertical hydraulic conductivity values to the depositional environment classifications of the NYS Museum Surficial Geology coverage allowed for the creation of a surficial geology porosity grid (Figure 31) and a surficial geology vertical hydraulic conductivity grid (Figure 32).

d. Bedrock Geology Porosity and Hydraulic Conductivity Assignments

The NYS Museum Bedrock Geology coverage (Figure 33) displays consolidated and semi-consolidated (Mesozoic) rock types present at the surface or below the unconsolidated sediments of the NYS Museum Surficial Geology coverage (Figure 24). Porosity and hydraulic conductivity attributes were added to the NYS Museum Bedrock Geology attribute table according to the rock-type characteristics, lithology packages and literature review. Hydraulic conductivity values assigned also considered pump or slug test data obtained from EPA CERCLA files (Appendix E).

An understanding of NYS geologic history should be established prior to the

Figure 31. Surficial Geology Porosity Grid

The surficial geology porosity grid was established by selecting values for the various depositional environment classifications based on literature review. Depositional environments were provided by the NYS Museum Surficial Geology coverage (Figure 24)

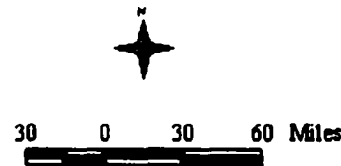
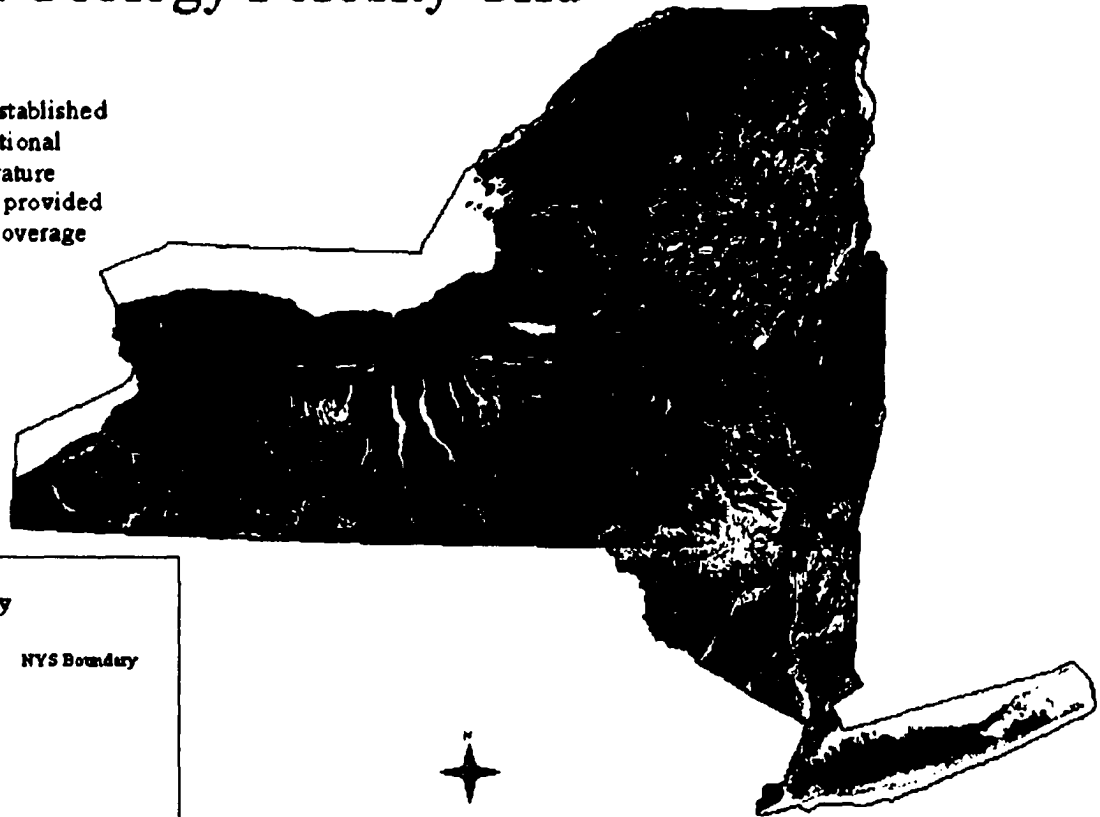
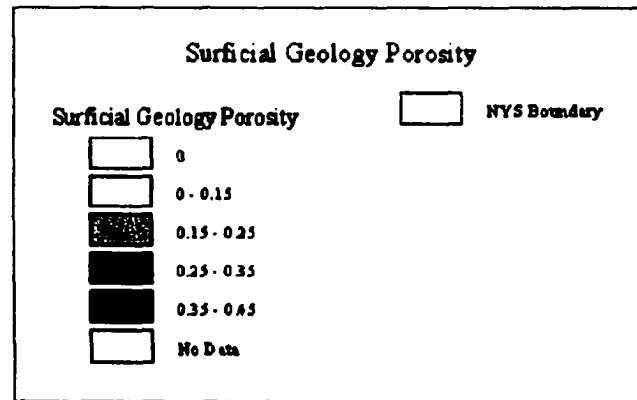
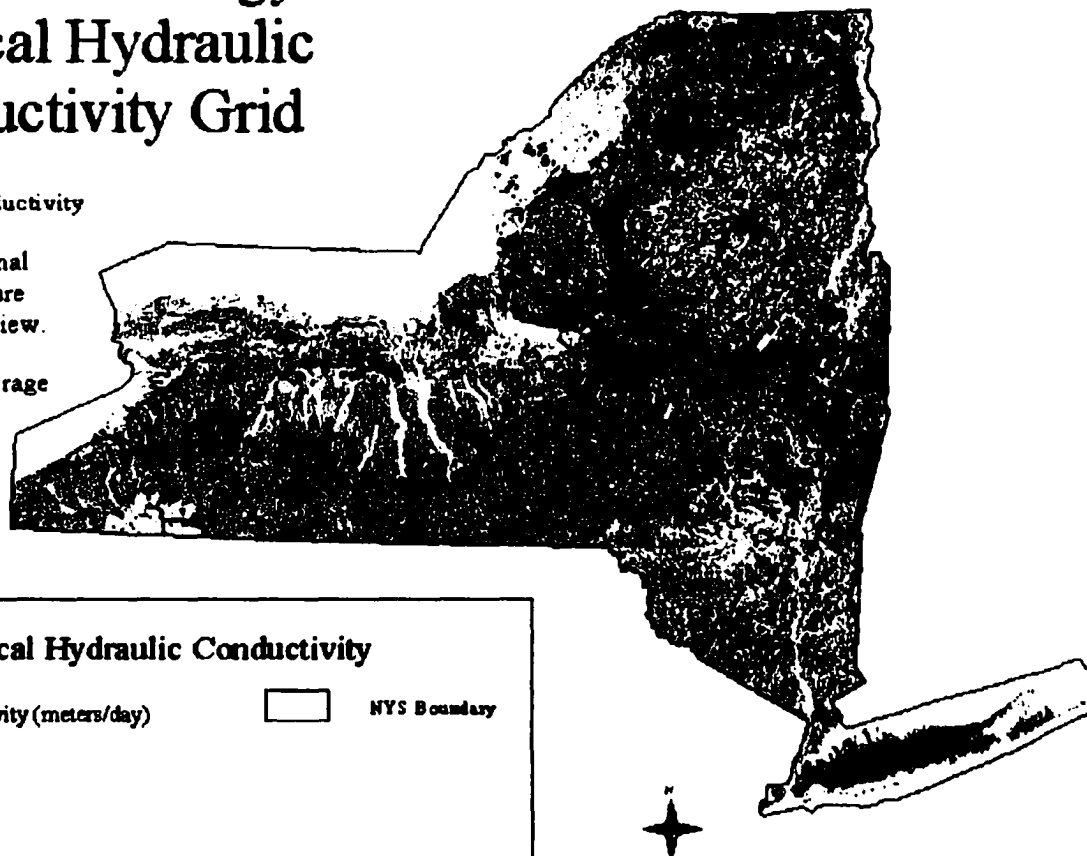


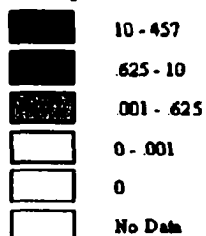
Figure 32. Surficial Geology Vertical Hydraulic Conductivity Grid

The surficial geology vertical hydraulic conductivity grid was established by selecting hydraulic conductivity values for the various depositional environment classifications, based on literature review and CERCLA pump and slug test review. Depositional environments were provided by the NYS Museum Surficial Geology coverage (Figure 24)



Surficial Geology Vertical Hydraulic Conductivity

Surficial Geology Vertical Hydraulic Conductivity (meters/day)

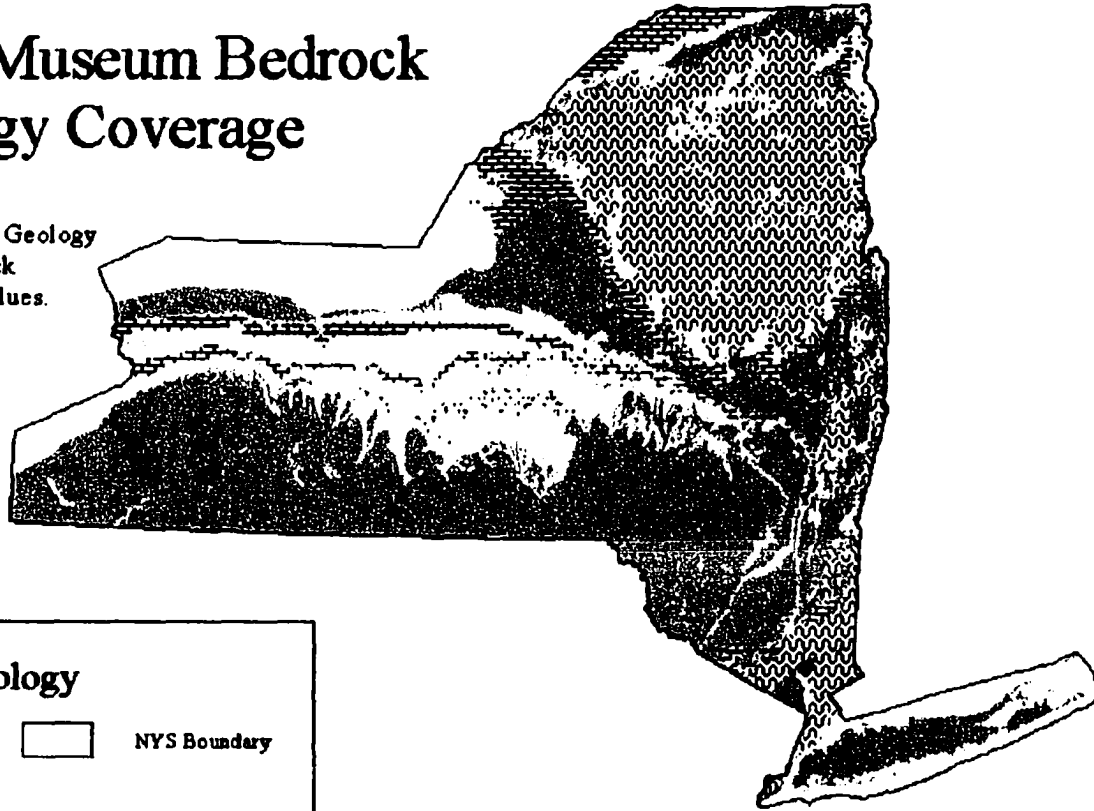
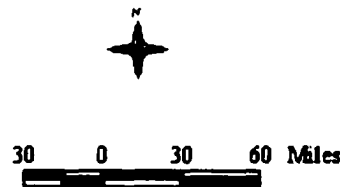


NYS Boundary

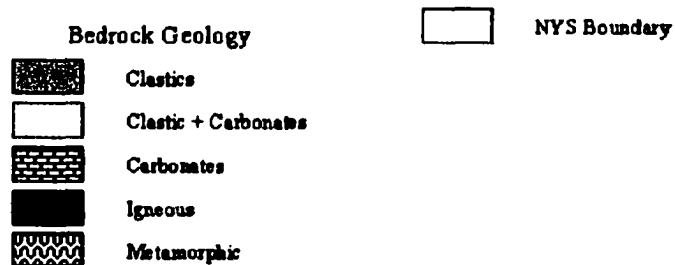


Figure 33. NYS Museum Bedrock Geology Coverage

The displayed NYS Museum Bedrock Geology Coverage was used to establish bedrock hydraulic conductivity and porosity values.

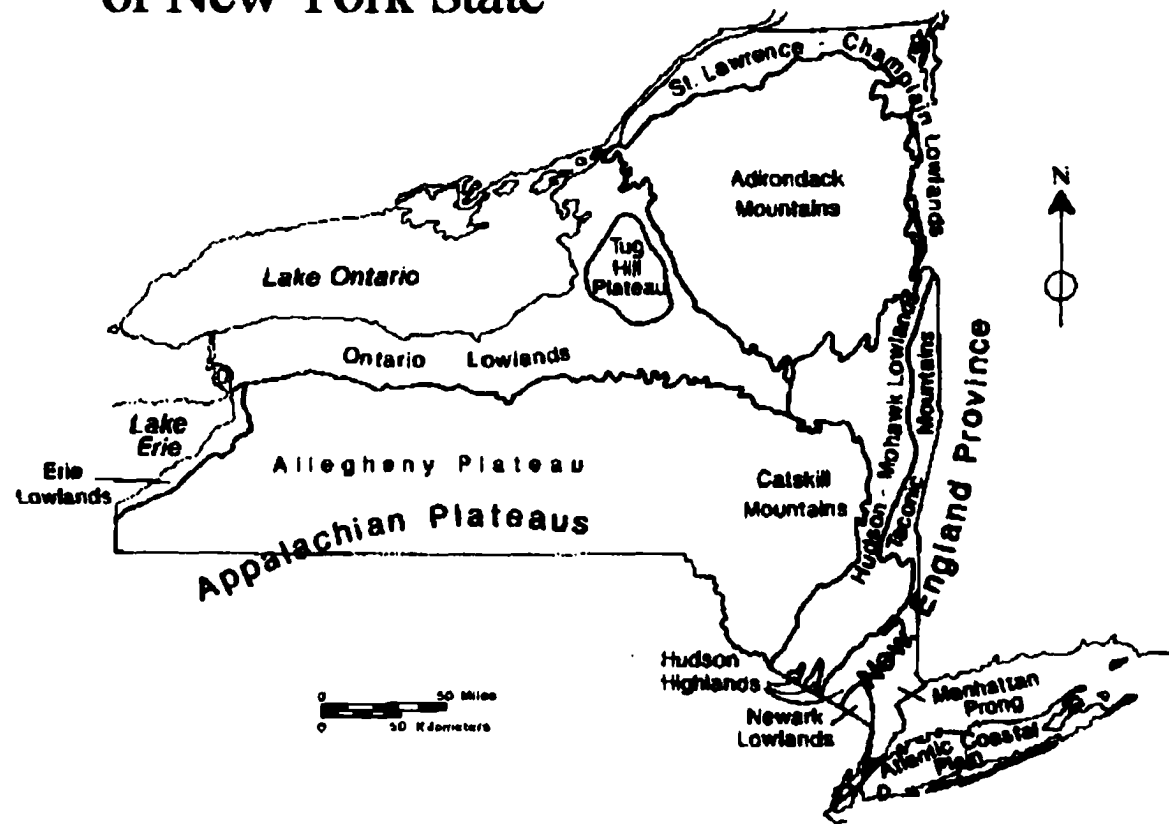


Bedrock Geology



Source coverage is the NYS Museum (Geological Survey) Bedrock Geology coverage. Source maps for the coverage are referenced as NYS Museum Map and Chart Series Number 15 (Fisher, Isachsen and Rickard, 1970; Isachsen and Fisher, 1970a; Isachsen and Fisher, 1970b; Rickard and Fisher, 1970a; Rickard and Fisher, 1970b).

**Figure 34. Physical Geography Provinces
of New York State**



The source of the map is Isachsen, Landing,
Lauber, Rickard and Rogers, 1991.

assignments of porosity and vertical hydraulic conductivity values to the NYS Museum Bedrock Geology coverage. The following discussion and referral to the NYS Museum Bedrock Geology coverage (Figure 33) will assist in the understanding of the assignment of bedrock geology porosity and horizontal hydraulic conductivity values, referred to below as hydraulic conductivity, based on rock-type and lithologic packages. A discussion of NYS bedrock geology with respect to geologic history follows; this discussion is based largely on a book titled Geology of New York, A Simplified Account, 1991, edited by Y. W. Isachsen, Y. W., E. Landing, J. M. Lauber, L. V. Rickard and W. B. Rodgers and the stratigraphic chart and geologic descriptions published in 1970, and are referenced as NYS Museum Map and Chart Series Number 15 (Fisher, Isachsen and Rickard, 1970a; Fisher, Isachsen and Rickard, 1970b; Isachsen and Fisher, 1970; Rickard and Fisher, 1970a; Rickard and Fisher, 1970b).

1. Bedrock Geology of New York

1a. Middle Proterozoic Era

The oldest rocks underlying NYS are metamorphic rocks of the Greenville Province (1.1 billion years ago). These rocks are exposed at the surface in the Adirondack Mountains and Hudson Highlands (Figure 34) and were buried as deep as 30 km (Isachsen, Landing, Lauber, Rickard and Rogers, 1991). The Adirondack Mountains are composed of metasedimentary, metavolcanic and metaplutonic rocks which underwent amphibolite and granulite-ranked metamorphism. Metasedimentary rocks lie in the northwestern portion of the Adirondack Mountains and consist of metasedimentary quartzite, schists and marbles. The metavolcanic and metaplutonic rocks consist of felsic

and mafic precursors. The metasedimentary rocks of the northwestern Adirondack Mountains are separated from metavolcanic and metaplutonic rocks by the Carthage-Colton Mylonite Zone. Mylonites are zones of intense deformation caused by ductile shearing (Dietrick and Skinner, 1979). The metamorphic rocks of the Adirondack Mountains have undergone both ductile and brittle deformation. The ductile deformation has produced complex foliations that were created in response to the great stresses and temperatures applied to the rocks near the core of the Greenville Mountain Range. Following the Greenville Orogeny, approximately 25 km of rock was eroded from the NYS area over a 400 million-year period (Isachsen, Landing, Lauber, Rickard and Rogers, 1991). Erosion, unloading, and isostatic rebound cooled the rocks. As a result, the rocks became more brittle and were subject to fracturing and faulting. Fracturing and faulting were a response to varying tensile and compressive stress fields related to unloading, orogenies and rifting which took place during the Late Proterozoic, Paleozoic, Mesozoic and Tertiary Eras. The present Adirondack Dome structure was produced during the Tertiary Era; the uplift of the dome may have been in response to a hot spot positioned at the base of the crust beneath the Adirondack area (King, 1977). This Tertiary uplift stripped the Paleozoic sedimentary rock cover from the Adirondack region.

The Hudson Highlands are made up of metasedimentary and metavolcanic rocks of the Greenville Province. The precursor rocks were originally deposited in a shallow sea about 1.3 billion years ago. The subsequent Greenville Orogeny, which peaked at 1.1 billion years ago, buried these precursor rocks to depths up to 30 km below the surface. The Middle Proterozoic rocks of the Hudson Highlands underwent rifting during the

Mesozoic era, and today there are three main highland areas separated by grabens, the western graben contains Paleozoic-aged rock, whereas the eastern grabens possess Paleozoic- and Mesozoic-aged rock.

1b. Late Proterozoic Era

The Fordham Gneiss and younger Yonkers Gneiss and Poundridge Gneiss were sedimentary and volcanic rocks which underwent peak metamorphisms a little later than the Greenville rocks of the Adirondacks and Hudson Highlands. These rocks are exposed in the Manhattan Prong area (Figure 34). Subsequent to the Greenville Orogeny a long period of erosion occurred. Doming and rifting of the area occurred about 550 million years ago. Rifting eventually developed a trailing margin along the eastern flank of North America; continued spreading developed a mid-oceanic ridge and the Iapetus Ocean basin (Dickenson, 1974) during the Cambrian and Early Ordovician Periods.

The sedimentary platform flanking the North American craton is a result of deposition of clastic, biochemical and chemical precipitate rocks. The presence of continental rock above sea-level presents a source of sediments and dissolved minerals. The abundance of rapidly flowing gaseous and liquid molecules, especially water, redistributing solar energy in the atmosphere and hydrosphere, physically and chemically react with rock minerals. Rocks weather as minerals are dissolved and the rocks are physically broken down into sediments. Sediments are transported by gravity slippage, bedload traction or by suspension currents. Dissolved minerals are transported in solution. Deposition takes place when a sediment can no longer be moved by gravity slippage, bedload traction or by a suspension current. Deposition also occurs when

chemical or biochemical precipitation of minerals, which had been in solution, produces particles that cannot be moved by physical mechanisms. The layers of rock, known as strata, surrounding the craton are products of their depositional environment and facies. Facies is defined as the lithologic and paleontologic characteristics of a sedimentary deposit imparted by the depositional environment (Friedman, Sanders and Kopaska-Merkel, 1992). The strata which make up the North American platform consist of clastic sedimentary rocks: conglomerates, sandstones, siltstones and shales; biochemically and chemically precipitated sedimentary rocks: limestones, dolostones and evaporites; and to some lesser degree bio-organic sedimentary rocks, such as coal (not present in NYS).

The following discussion regarding the NYS portion of the North American Platform will use terms of sequence stratigraphy (Friedman and Sanders, 2000) which can be referenced in Appendix F.

1c. Paleozoic Era, Cambrian Period, Continental Shelf

Progression of rifting, which started in the Early Cambrian Period, lead to the creation of the Iapetus Ocean Basin and development of a trailing margin on the eastern flank of North America (King, 1977). Uplift and erosion thinned the continental crust prior to rifting. As rifting progressed and the Iapetus Ocean Basin was created; subsequent cooling of the thinned continental rock, as it moved away from a developing mid-ocean ridge, caused it to subside. The ocean encroached upon the subsiding continental margin and deposited sandstone and carbonate in retrogradational parasequence sets upon an unconformable surface developed atop Greenville rocks. Retrogradational progression migrated from east to west (Friedman, Sanders and Guo,

1993) and deposited the paralic sands of the Dalton formation, Cheshire Quartzite, Poughquag Quartzite and Potsdam Sandstone. The source of these sandstones must have been Proterozoic precursor sandstones and quartzites or the depositional energy was such that all fine grained materials were transported and deposited eastward on the outer shelf, continental slope and rise; little shale is associated with these strata. Carbonate platform sediments were deposited eastward of these sands and today are present atop these sandstones and quartzites due to the retrogradation of parasequences. The carbonates were deposited in an epeiric sea and form the Cambrian portions of the Wappinger Group to the east and Beekmantown Group to the west (Guo, Sanders and Friedman, 1990). These carbonates were deposited in shallow, tropical waters. The dolostones give evidence of sabka and quiet shallow water environments where cyanobacteria thrived in algal mats and created stromatolites. Periods of excessive evaporation are also evidenced by the presence of halite, chert and quartz crystals in several formations. Oolitic carbonates are also present which show that shallow shoaling waters and current action existed. The platform carbonates display features that reflect repeated shoaling, and intermittent subaerial exposure. Features include mud cracks, birdseye textures, undulating stromatolitic structures, mottles, lumpy structures, scour-and-fill structures, flat pebbles, cross-beds, and, as a lithology, syngenetic dolostone (Friedman, Sanders and Martini, 1982). The Cambrian portion of the Wappinger/Stockbridge Group consists of the Stissing formation (dolostone and shale), Pine Plains formation (dolostone, oolitic dolostone and shale) and Briarcliff Dolostone. The Cambrian portion of the Beekmantown Group is made up of the Theresa/Galway formation (dolostone and

sandstone), Ticondaroga Dolostone (cherty in part), Hoyt formation (oolitic and stromatolitic limestone and dolostone), Little Falls Dolostone, and the Whitehail Formation (limestone and dolostone, contains Cryptozoan reefs).

1d. Paleozoic Era, Cambrian Period, Continental Slope / Rise / Ocean Basin

The Cambrian sediments deposited east of the shelf edge on the continental slope, rise and ocean basin are composed predominantly of graywacke, shale and sandstone, with minor amounts of carbonate rock (Friedman, 1979). A relatively steep slope existed down which clastic and carbonate sediment moved by mass wasting, slides, slumping, debris flow, liquified cohesionless particle flows and turbidity currents (Keith and Friedman, 1977). The Everett Schist was originally composed of graywacke. Overlying the Everest Schist are the Renseselaer Graywacke, greenstones (tuffs and basalts), Austerlitz Phyllite (precursor rock was shale) and the overlying Nassau and Mettawee formations, made up of shale, quartzite and slate. The greenstones give evidence of volcanic activity which was occurring on the eastern flank of the Iapetus Ocean basin and signified the beginning of ocean basin closure as an island arc approached North America. The slope-rise-basin sediments which began to receive igneous input are termed eugeosynclinal deposits. Above the Mettawee Slate (precursor rock was shale) the Germantown formation (shale, limestone and conglomerate), West Casltleton Formation (shale, limestone, and conglomerate), Hatch Hill Formation (shale, dolostone, and brecciolas), and Poultney Formation "A" Member (shale and limestone), were deposited in environments which received shelf and upper slope derived debris flows. The input of conglomerate and limestone blocks originating from the shelf may signify

the approach of an island arc as seismically activated tsunamis produced mass wasting at the shelf edge; another interpretation is that a meteor impact may have created a tsunami which produced the mass wasting (Friedman, 1995).

1e. Paleozoic Era, Early Ordovician Period, Continental Shelf

Continued carbonate deposition in an epeiric sea produced aggradational parasequences upon the continental shelf during the Early Ordovician Period. A high stand facies tract continued to be deposited. The Lower Ordovician portion of the Wappinger/Stockbridge Group contains the Halcydon Lake Dolostone (locally cherty), Rockdale Formation (limestone and dolostone), and Copake formation (limestone and dolostone). The Lower Ordovician section of the Beekmantown Group consists of the Cutting Formation (siltstone, dolostone which is locally cherty, and limestone), Gailor Dolostone, Tribes Hill Formation (limestone and dolostone), Fort Ann Formation (limestone and dolostone), Chuctanunda Creek Dolostone, Fort Cassin Formation (limestone and dolostone), and Providence Island Dolostone. The Tribes Hill Formation shows evidence of tidal channel deposition and may have been deposited near the shelf-edge where tidal currents were strong. Feldspar noted in the Lower Ordovician carbonates may partly be a result of deposition of tephra (Buyce and Friedman, 1975), which came from volcanic island arc activity which was approaching North America (Friedman, Sanders and Martini, 1982).

The top of the Lower Ordovician platform carbonates is marked by a major unconformity. This unconformity, called the Knox Unconformity in the Appalachian basin, is noted around the world and signifies a worldwide drop in sea-level. The Knox

Unconformity marks the top of the Sauk Sequence (Sloss, 1963) and most likely was produced by a decrease in sea-floor spreading rates and an increase in ocean basin volume.

1f. Paleozoic Era, Early Ordovician Period, Continental Slope / Rise / Ocean Basin

The eugeosynclinal deposits of the Early Ordovician Period consist of similar rocks as those associated with the Cambrian Period. From the lower to upper part of the section, the formations making up the eugeosynclinal deposits are the Elisville Formation (shale, argillite and quartzite), Poultney Formation "B" and "C" Members (shale, slate and siltstone) - eastward correlative Stuyvesant Falls Formation (slate and siltstone), Mount Merino/Indian River Formations (shale, argillite and chert) and the Austin Glen Formation (graywacke and shale). Serpentinite, which makes up the backbone of Staten Island, is evidence that oceanic crust was incorporated into eugeosynclinal deposits as part of the accretionary wedge of the subduction zone. Hartland Formation (amphibolite overlain by pelitic schist), Harrison Gneiss, Bedford/Harrison Gneiss and the Manhattan Formation are all indications of Cambrian to Early Ordovician eugeosynclinal sediments which have undergone later metamorphism as a result of subsequent orogenies and deep burial.

1g. Paleozoic Era, Middle Ordovician Period, Continental Shelf / Foreland Basin Flysch

The Middle Ordovician through Late Ordovician strata are marked by the Taconic Orogeny which took place as an island arc located on the eastern margin of the closing Iapetus Ocean collided with the passive trailing margin of the North American continent. The island arc was eventually sutured to North America.

Sea level rose during Middle Ordovician time as deposition of the Tippacano Sequence (Sloss, 1963) was initiated. The Middle Ordovician Chazy Group was deposited upon the Knox Unconformity. The Ste. Theresa Siltstone Formation of the Chazy Group onlapped upon the unconformity and was succeeded by carbonates deposited in the clear shallow water of the platform. Sea level fell following the deposition of the Chazy Group and produced an unconformity which left patchy remnants of the Chazy Group upon the Knox Unconformity. Most of the Chazy Group is missing in NYS as it was stripped away by erosion. Atop the Chazy Group and exposed Beekmantown Group, the platform carbonates of the Black River Group were deposited. The Black River Group onlapped upon the continental shelf retrogradationally and then formed aggradational parasequence sets. The Black River Group consists of the Amsterdam, Isle La Motte, Lowville and cherty Chaumont Limestones and Parnelia Dolostone. The Trenton Group and Balmville Limestone were deposited upon the Black River Group in slightly deeper shelf environments. The Trenton Group consists of several members, the Hillier, Steuben, Rust, Denley, Glen Falls, Sugar River, Kings Falls and Rockland Limestones. The Black River and Trenton Groups contain bentonite layers which were a result of volcanic ash deposition and signify the presence of an island arc which lied to the east. As the shallow water platform carbonates of the Trenton Group and Balmville Limestone were being deposited, eastward the continental platform began to downwarp in front of the approaching trench-island arc system. Shale and siltstone were deposited on the continental slope (Manhattan Formation) and subsequently upon the subsiding continental edge as the Walloomsac Formation (shale). The rising

accretionary wedge - island arc system provided clastic sediments. As the accretionary wedge of the subduction zone approached the continental shelf and eventually overrode it, rocks from the underlying plate were incorporated into a sheared pelitic matrix, this formation is known as the Taconic Melange (sheets of the accretionary wedge). West of the advancing arc a foreland basin was created as the continental shelf was downwarped and block faulted. The foreland basin received flysch from the sediment source rising on its eastern flank as the accretionary wedge and island arc rose above sea-level. Black shales were deposited in the anoxic basin above the downwarped carbonates of the platform. Fine clastic deposits of the Normanskill Formation (shale, argillite and siltstone), Cumberland Head Argillite, Stoney Point Shale, Canajoharie Shale, Utica Shale, Austin Glenn Formation (graywacke, shale), Schenectady Formation (graywacke, sandstone, siltstone and shale), and Frankford Formation (shale and siltstone) marked the end of carbonate deposition in the foreland basin during this period.

1h. Paleozoic Era, Late Ordovician Period, Foreland Basin Molasse

In-fill of the Taconic foreland basin continued into the Late Ordovician Period as coarser-grained clastic sediment sequences prograded across the basin. The island arc and its accretionary wedge were sutured onto North America; the suture line is referred to as the Emmon's Line (Rodgers, 1970); as the accretionary wedge, plates of the Taconic Sequence, were thrust upon the underlying rocks of the continental shelf - rise and those of the foreland basin (Hollocher, 1995). Evidence of island arc-continental plate collision intrusive igneous activity is evidenced by the Cortlandt and smaller mafic complexes. The erosion of the uplifted Taconic Mountains provided the molasse sediments of the

Quassic Quartzite (quartzite, sandstone, conglomerate), Pulaski - Whetstone Gulf Formations (siltstone and shale), and Oswego Sandstone . These systems were sourced from the east of the foreland basin by the Taconic Mountains and make up tectonic deltaic and fan-delta complexes (Friedman and Sanders, 1978). The final fan-delta complex that in-filled the foreland basin during the Late Ordovician Period has left the Queenston Formation (shale and siltstone).

1i. Paleozoic Era, Early Silurian Period

The Medina Group unconformably overlies the Queenston Formation. The Medina Group consists of the Thorold Sandstone, Grimsby Formation (sandstone and shale), Power Glen/Cabot Head Shales, Manitoulin Dolostone (argillaceous dolostone) and Whirlpool Sandstone. The lowermost Whirlpool Sandstone was deposited in the western portion of the state and gives evidence of eolian deposition succeeded vertically by transgressive marine retrogradational parasequences. Above the Whirlpool Sandstone, marine carbonate, prodelta, delta front, delta plain and lower alluvial plain sediments of the rest of the Medina Group were deposited (Friedman, Sanders and Martini, 1982). The Medina Group clastic deposits, with the exception of the Whirlpool Sandstone, were sourced by the Taconic Mountains.

The Clinton Group was deposited unconformably atop the Medina Group. The lower Clinton Group consists of the Kodak Sandstone to the west and Oneida Conglomerate to the east; the clastic source of the Clinton Group was the Taconic Mountains. The Kodak Sandstone and Oneida Conglomerate are overlain by the Neahga and Maplewood Shales which interbed eastward with the Sauquoit Formation (sandstone

and shale), and eventually grade into beds of the Otsquago Sandstone. Thin shales, limestones, hematitic limestone and dolostones make up the middle section of the Clinton Group; these formations are the Hickory Corners Limestone, Furnaceville Hematite, Wallington Limestone, Westmoreland Hematite, Wallington Limestone, Willowvale Shale, Bear Creek Shale, Sodus Shale, Wolcott Limestone, Wolcott Furnace Hematite, Kirkland Hematite, Rockaway Dolostone, Merriton Limestone, Williamson Shale and Irondequoit Formation (which contains algal bryozoan reefs). Above this section, the upper Clinton Group consists of the Rochester Shale which is overlain by the Decew Dolostone.

On the eastern flank of the foreland basin alluvial fan and alluvial plain deposits were emplaced off the flanks of the Taconic Mountains. These facies are the eastern chronostratigraphic equivalents of the Medina and Clinton Group deposits. The alluvial fan and plain deposits are represented by the Bloomsburg and High Falls Formation. The Bloomsburg and High Falls Formations are made up of shale and sandstone and is closely associated with the Guymard Quartzite, Otisville Shale and Shawangunk Conglomerate (sandstone and conglomerate). As the Taconic Mountains were eroded down toward base-level, clastic sediment size decreased and the depositional environments shifted eastward. This process is marked by retrogradational parasequence sets.

1j. Paleozoic Era, Late Silurian Period

By the late Silurian Period, the clastic sediment source area, the Taconic Mountains, waned as the Mountains were worn down by erosion. On the eastern flank of the Appalachian Basin the Poxono Island Formation (shale and dolostone) and

Binnewater Sandstone were deposited; these clastic sediments are the last clastic vestiges of the Taconic Mountains. In the central and western portion of the basin the Lockport Group was deposited. The Lockport Group represents carbonate deposition in a shallow, clear water platform setting where reefs were created from the colonization of honeycomb, chain, tube and horn corals. The Lockport Group consists of the Gasport Limestone, Goat Island Dolostone, Eramosa Dolostone, Oak Orchard / Guelph / Penfield Dolostone, Sconondoa Formation (limestone and dolostone) and toward the central portion of the subsiding basin the Ilion Shale. Following the deposition of the Lockport Group high evaporation rates produced conditions of hypersalinity within the Appalachian basin. Evaporites (halite and anhydrite), shale and dolostone were deposited in this hypersaline sea and make up the Salina Group. The Salina Group consists of the Vernon Formation (shale and dolostone), Brayman Shale, Syracuse Formation (dolostone, shale, anhydrite and halite), Camillus Formation (shale and dolostone) and Bertie Formation (shale and dolostone). The latest Silurian deposits marked the return of normal marine waters as shallow water carbonates were once again deposited with the return of abundant sea life. The Akron Dolostone and Cobbleskill Limestone were deposited at the close of the Silurian Period. On the eastern flank of the basin the Boussardville Limestone, Decker Limestone and Warwashing Limestone were deposited atop the Poxono Island Formation and Binnewater Sandstone. Deposition of carbonates on the eastern flank of the Appalachian Basin attests to the absence of the Taconic Mountains.

1k. Paleozoic Era, Early Devonian Period

The marine marginal and shallow water carbonates of the Roundout Dolostone and Heldeberg Group were deposited upon an unconformity. The Heldeberg Group consists of the Manlius, Coeyman, Kalkberg, New Scotland, Becraft, Alsen and Port Ewen Limestones. These limestones display parasequences (Friedman, 1990); each parasequence represents a shoaling upward sequence deposited atop a flooding surface. The parasequences make up retrogradational and aggradational parasequence sets. The thickest Heldeberg Group exists in the center of the Appalachian basin as subsequent erosion produced a major unconformity atop the Heldeberg Group and removed greater portions of the section on the flanks of the basin. This unconformity marks the top of the Tippacano Sequence (Sloss, 1963) and is called the Wallbridge Unconformity. The Tristates Group marks the beginning of the Kaskaskia Sequence and deposition atop the Wallbridge Unconformity. The Tristates Group consists of the Oriskany Sandstone - Glenerie Formation, Port Jervis Formation, Esopous Shale, Calisle Center Siltstone and Schoharie Formation. The Oriskany Sandstone retrogradationally onlapped upon the Wallbridge Unconformity. The Oriskany Sandstone was deposited in shallow-marine shoreface to nearshore environments (Ver Straeten and Brett, 1995) and laterally grades into the Glenerie Formation (sandstone, limestone and chert) to the east. The Port Jervis Formation (shales, limestone and chert) conformably overlies the Glenerie Formation. Sea-level rose as the Esopous Shale overlies the Oriskany Sandstone, Glenerie and Port Jervis Formations. The Esopous Shale marks deposition in a deep, partially anoxic basin as represented by black organic shales. The Esopous Shale was deposited in the basin as

a maximum flooding surface was reached. The Esopous Shale was deposited in the basin reaches of aggradational and progradational parasequence sets (Ver Straeten and Brett, 1995). The Esopous Shale signifies the initial clastic influx from Acadian clastic sources to the east. Atop the Esopous Shale the Schoharie Formation (shale and limestone) was deposited in a basin environment and laterally grades into the Bois Blanc Formation (dolostone, limestone and Springvale Sandstone Member) to the west. The limestone of the Schoharie Formation signifies tectonic quiescence as carbonate intrabasinal deposition predominated; on the western flank of the basin, reworking of the Oriskany Sandstone produced the deposits of the Springvale Sandstone.

11. Paleozoic Era, Middle Devonian Period

The Onondaga Limestone was deposited in a shallow sea unconformably atop the Oriskany Sandstone and Helderberg Group around the central portion and western flanks of the basin and conformably atop the Schoharie Formation to the east (Ver Straeten and Brett, 1995). The Onondaga Limestone members are the Edgecliff (cherty limestone with local bioherms), Nedrow, Morehouse (cherty limestone) and Seneca. Southward the Onondaga Limestone laterally becomes the deeper water carbonates of the Buttermilk Falls Limestone. The Edgecliff Member displays retrogradational parasequence succession formed during a transgressive facies tract system. The Nedrow and Moorehouse Members display progradational and aggradational characteristics of a highstand facies tract. Fining-upward parasequence sets of the Seneca Member display characteristics of a transgressive facies tract; the Seneca Member may signify basin downwarping associated with the ensuing Acadian Orogeny. Tioga Bentonite beds

present in the Onondaga Limestone signify the approach of a subduction zone and related volcanism located to the east.

The Hamilton Group signifies the existence of a prominent Acadian clastic source to the east of the Appalachian basin. The Hamilton Group represents the first phase of Acadian flysch and molasse deposits that prograde into the basin throughout the rest of the Devonian Period. The Acadian Orogeny occurred as the microcontinent of Avalon collided with North America. The subsidence of the foreland basin was reinvigorated and the Acadian Mountains rose east of the basin. The Hamilton Group is made up of the Union Springs Formation, Oatka Creek Formation - Mount Marion Formation, Skaneateles Formation, Ludlowville Formation and Moscow Formation. The continental alluvial - deltaic deposits of the Ashokan Formation and Plattekill Formation were deposited on the eastern portions of the basin.

Several times during the Middle Devonian Period, uplift of the Acadian Mountains and associated downwarp of the foreland basin produced anoxic conditions in the foreland basin. The Union Springs Formation (Marcellus subgroup) organic shales were deposited atop the Onondaga Limestone. Pyroclastic deposition, which formed the Tioga Bentonites, is also evident in the lower Union Springs Formation. The upper parts of the Union Springs Formation received more carbonate deposition than the lower section as the waters were again oxygenated. The Mount Marion Formation displays an overall clastic basin in-filling sequence with argillaceous carbonates in its lower section progressively being replaced by black organic shale, shale and siltstone and then shale and sandstone in its upper portion. The Mount Marion Formation represents progradation

of Acadian Mountain derived clastics into the basin. Progradation of non-marine delta plain and alluvial plain sediments, molasse deposition, occurred in the eastern portion of the basin as continental shales, siltstones and sandstones of the Ashokan and Plattekill Formations were deposited. The increase of limestone in the marine deposits of the Skaneateles Formation (shale and limestone), Ludlowville Formation (shale and limestone) and Moscow Formation (shale and limestone) signifies less input of clastic material than the lower formations of the Hamilton Group; this was a result of erosional stripping of the less-prominent Acadian Highlands.

The Tully Limestone was deposited in the basin atop the Hamilton Group as the clastic source from the Acadian Highlands wore down and relative sea level rose. The delta fronts were moved eastward and the main basin allowed for abundant calcium carbonate forming marine growth in clear water. To the east, in front of the Acadian Orogen, deltas and delta plain and lower alluvial plain deposits, such as meandering stream deposits, were being laid down (Friedman, 1995). The Devonian marine deltas of the Catskill region were of the shoal-water variety (Friedman, Sanders and Martini, 1982).

1m. Paleozoic Era, Late Devonian

The late Devonian Period was highlighted by the resurgence of Acadian Uplift and the building of the "Catskill Delta" (Isachsen, Landing, Lauber, Rickard and Rogers, 1991) across the foreland basin. Most of these deposits are continental molasse deposits. These delta-fan deposits have been divided into six groups: the Genesee, Sonyea, West Falls, Canadaway, Conneaut and Conewango Groups. The progressive facies change

within these progradational parasequences grade from east to west from conglomerate, sandstone and siltstone of alluvial fans and upper alluvial plain facies; to sandstone, red, green and gray shale, mudstone and siltstone of the lower alluvial plain, delta plain and delta front facies; to gray shale, mudstone, siltstone and sandstone of the delta front and prodelta facies; to thin black shales of the anoxic basinal and distal prodelta environments. Periodic transgressions are marked by thin eastward projections of black shales; these shales represent a rapid relative sea level rise and the creation of an extensive onlapping flooding surface upon a coast line of low relief. The Genesee Group consists of the Oneonta Formation (shale and sandstone) in the east and progressively grades westward to the Unidilla, Laurens, and New Lisbon Formations (shale, siltstone and sandstone), Pen Yan and Genesee Shales, Genundewa Limestone, West River Shale, and the westernmost North Evans Limestone. The Sonyea Group includes the Lower Walton Formation (shale, sandstone and conglomerate), Enfield and Kattel Formations (shale, siltstone and sandstone); Sawmill Creek, Johns Creek and Montour Shales; Rock Stream Siltstone, Rye Point Shale, and the Cashaqua and Middlesex Shales to the west. The West Falls Group is made of westward progradational parasequence sets that make up from east to west the Upper Walton Formation (shale, sandstone and conglomerate), Slide Mountain Formation (sandstone, shale and conglomerate), Honesdale Formation (sandstone and shale); Beers Hill, Dunn Hill, Millport and Moreland Shales; New Milford Formation (sandstone and shale), Gardeau Formation (shale and siltstone), West Hill Formation (shale and siltstone), Nunda Formation (sandstone and shale), Roricks Glen Shale, and the westernmost Angola and Rinestreet Shales. The Java Group consists

of the Wiscoy Formation (sandstone and shale) and western Hanover and Pipe Creek Shales. The Canadaway Group is made up of the Machias Formation (shale and siltstone), Rushford Sandstone; Caneadea, Canisteo and Hume Shales; Canaseraga Sandstone; South Wales and Dunkirk Shales; Lagona Siltstone, Westfield Shale, Shumla Siltstone and Northeast Shale. The Conneaut Group is made up of the Cuba Sandstone, Wellsville Formation (shale and sandstone), Hinesdale Sandstone, Whitesville Formation (shale and sandstone), Germania Formation (shale and sandstone), Ellicott Formation (shale and siltstone) and Dexterville Formation (shale and siltstone). The Conewango Group consists of the Cattaraugus Formation (shale, sandstone, conglomerate) and the Oswayo and Vernango Formations (shale and siltstone).

1n. Paleozoic Era, Early Mississippian

The only Early Mississippian rocks found in NYS are located in the southwesternmost part of the state on the Alleghany Plateau. Sedimentary environments of these rocks are similar to the underlying Late Devonian Conewango Group. The Early Mississippian Pocono Group consists of the Cuyahoga Formation (shale and sandstone), Corry Sandstone and Knapp Formation (shale and conglomerate).

1o. Paleozoic Era, Early Pennsylvanian

Early Pennsylvanian rocks were deposited unconformably atop the Early Mississippian formations. The Early Pennsylvanian Pottsville Group consists of the Connoquenessing Formation (sandstone and shale), Sharon Formation (shale, sandstone and conglomerate) and the Olean Conglomerate.

1p. Paleozoic Era, Alleghanian Orogeny (Pennsylvanian through Early Permian)

The Alleghanian Orogeny marked the close of the Iapetus Ocean and the collision of Europe and Africa with North America. The final suture of the continental collisions produced the super-continent of Pangea. The Alleghanian Orogeny produced thrust faulting and fold structures throughout the Appalachian Basin. The faulting and folding of the Valley and Ridge Province as well as the “blind faults and folds” of the Allegheny Plateau are a result of the great compressive forces of this orogeny.

1q. Mesozoic Era, Late Triassic - Early Jurassic Periods

The initial break up of the continent of Pangea was initiated during the Triassic Period. Crustal doming and erosion were followed by rifting (Sleep, 1971; Bott, 1973). Continued rifting, tensile tectonics and continental subsidence eventually lead to the creation of the Atlantic Ocean and the passive trailing margin of North America. The rift basins were filled with clastic alluvial fan through lacustrine deposits as well as extrusive and intrusive basic igneous rocks. The Newark Group filled the rift basins and was deposited upon an unconformity. This group consists of the Stockton Formation (arkose, conglomerate and mudstone), Brunswick Formation (sandstone, conglomerate, siltstone, mudstone, and arkose), and Hammer Creek Formation (conglomerate). The Ladentown Basalt was extruded upon the Newark Group during the Late Triassic and Early Jurassic Periods, while the igneous rocks of the Palisade Diabase were intruded into the Newark Group during the Early Jurassic Period.

1r. Mesozoic Era, Late Cretaceous Period

The Raritan Formation (clay, silty clay, sand and gravel) overlapped Proterozoic

and Paleozoic Era rocks atop the Fall Zone Peneplain. The Raritan Formation possesses two members; the lower Lloyd Sand Member was deposited in high energy fluvial to deltaic environments and the upper Raritan Formation clay member was deposited in low energy fluvial to deltaic environments. The undifferentiated Monmouth Group, Matawan Group and Magothy Formation consist of silty clay, glauconitic sandy clay, sand, and gravel. These sediments unconformably overlie the Raritan Formation. The Matawan/Magothy sediments were a result of fluvial to deltaic deposition. The Monmouth Group consists of marine deposits.

2. Bedrock Geology Porosity and Hydraulic Conductivity, Assignments by Lithologic Packages

Porosity and hydraulic conductivity values were assigned to the NYS Museum Bedrock Geology coverage based on the geologic description of the formations (Fisher, Isachsen and Rickard, 1970a; Fisher, Isachsen and Rickard, 1970b; Isachsen and Fisher, 1970; Rickard and Fisher, 1970a; Rickard and Fisher, 1970b) contained in the attribute table, termed lithologic packages (Table 3) in this work, and representative values based on literature review and pump/slug test record reviews. The Proterozoic and Paleozoic bedrock of the NYS Bedrock Geology coverage (Figure 33) were given estimated porosity values of fractured rock (2 percent); except in the case of sandstone, limestone, dolostone and evaporites where a matrix porosity percent was added. Matrix porosity values were assigned to lithology packages (Table 3) based on the low-end values found in Freeze and Cherry, 1979. Fracturing increases porosity by about two to 5 percent (Fetter, 1980); a value of 2 percent was used for fracture porosity. Matrix porosities were

assigned in accordance with low-end values found in Freeze and Cherry, 1979. A lithology package consisting totally of sandstone received a matrix porosity value of 5 percent; if sandstone was part of the make-up of a lithology package, for example sandstone, siltstone and shale, a porosity value of 3 percent attributable to the sandstone matrix component was assigned to the lithology package. If a lithology package was made up entirely of carbonates (limestone or dolostone) a matrix porosity of 2 percent was given to the lithology package; if carbonates made up a portion of the lithology package, a matrix porosity of 1 percent attributable to carbonate matrix porosity was assigned. If evaporites made up a portion of the lithology package, 1 percent of matrix porosity was added to the lithology package porosity as attributable to the evaporite component. Addition of porosity to carbonate and evaporite containing lithology packages was done in order to account for dissolution of carbonate and evaporite minerals in a fractured vadose zone. Lithology packages which did not consist of sandstone, limestone, dolostone or evaporite components were not given any enhanced porosity values, these formations were only assigned a fracture porosity component of 2 percent. Lithology packages and their assigned porosity values are listed in Table 6 below.

Hydraulic conductivity values of lithology packages were assigned based on Freeze and Cherry (1979), literature review and review of EPA CERCLA files pump test/slug test values (Appendix E). According to Freeze and Cherry (1979) hydraulic conductivity values of fractured igneous and metamorphic rocks range between 1.0×10^{-9} and 1.0×10^{-4} m/s. Fractured diabase values averaged 1.1×10^{-6} m/s in the Triassic Rift

Table 6. Porosity and hydraulic conductivity values assigned to the lithology packages of the NYS Museum Bedrock Geology coverage.

<u>Rock Classification</u>	<u>Lithology Package</u>	<u>Porosity Porosity Percent</u>	<u>Horizontal Hydraulic Conductivity m/s</u>
Igneous	Igneous, acidic	2	1.0×10^{-6}
	Igneous, basic	2	1.0×10^{-6}
Metamorphic	Gneiss	2	1.0×10^{-6}
	Metagabbro	2	1.0×10^{-6}
	Metanorthosite	2	1.0×10^{-6}
	Amphibolite	2	1.0×10^{-6}
	Schist	2	1.0×10^{-6}
	Greenstones	2	1.0×10^{-6}
	Phyllite	2	1.0×10^{-6}
	Slate	2	1.0×10^{-6}
	Quartzite	2	1.0×10^{-6}
	Marble	2	1.0×10^{-6}
Sedimentary	Clay, Silt and Sand	35	1.0×10^{-7}
	Conglomerate	2	5.0×10^{-6}
	Sandstone, conglomerate	5	5.0×10^{-6}
	Sandstone	7	5.0×10^{-6}
	Sandstone, conglomerate, siltstone, mudstone	5	5.0×10^{-6}
	Sandstone, conglomerate, mudstone	5	5.0×10^{-6}
	Sandstone, shale, conglomerate	5	5.0×10^{-6}
	Sandstone, shale, siltstone	5	1.0×10^{-6}
	Sandstone, shale	5	1.0×10^{-6}
	Sandstone, limestone	6	5.0×10^{-6}
	Graywacke, sandstone, siltstone, shale	5	1.0×10^{-6}
	Graywacke	2	1.0×10^{-6}
	Graywacke, shale	2	1.0×10^{-6}
	Mudstone, sandstone	5	1.0×10^{-6}
	Mudstone, shale	2	1.0×10^{-6}
	Siltstone, shale	2	1.0×10^{-6}
	Shale, sandstone, conglomerate	5	1.0×10^{-6}
	Shale, sandstone	5	1.0×10^{-6}
	Shale, sandstone, siltstone	5	1.0×10^{-6}

Table 6 (continued). Porosity and hydraulic conductivity values assigned to the lithology packages of the NYS Museum Bedrock Geology coverage.

<u>Rock Classification</u>	<u>Lithology Package</u>	<u>Porosity Porosity Percent</u>	<u>Horizontal Hydraulic Conductivity m/s</u>
Sedimentary	Shale, siltstone, sandstone, conglomerate	5	1.0×10^{-6}
	Shale, siltstone, sandstone	5	1.0×10^{-6}
	Shale, mudstone	2	1.0×10^{-6}
	Shale, siltstone	2	1.0×10^{-6}
	Shale	2	1.0×10^{-6}
	Shale, dolostone	3	1.0×10^{-6}
	Shale, dolostone, evaporites	4	1.0×10^{-6}
	Shale, limestone, conglomerate	3	1.0×10^{-6}
	Shale, limestone, sandstone	6	1.0×10^{-6}
	Shale, limestone	3	1.0×10^{-6}
	Shale, limestone, dolostone	3	1.0×10^{-6}
	Dolostone, sandstone	6	5.0×10^{-6}
	Dolostone, sandstone, shale	6	5.0×10^{-6}
	Dolostone, limestone, shale, sandstone, conglomerate	6	5.0×10^{-6}
	Dolostone, shale, evaporites	4	5.0×10^{-6}
	Dolostone, shale	3	5.0×10^{-6}
	Dolostone, limestone, siltstone	4	5.0×10^{-6}
	Dolostone, limestone	4	5.0×10^{-4}
	Limestone, dolostone	4	5.0×10^{-4}
	Limestone, dolostone, shale	3	5.0×10^{-6}
	Limestone, dolostone, shale, sandstone	6	5.0×10^{-6}
	Limestone, shale, dolostone	3	5.0×10^{-6}
	Limestone, shale, siltstone	3	5.0×10^{-6}
	Limestone, siltstone	3	5.0×10^{-6}
	Limestone, shale	3	5.0×10^{-6}
	Limestone	4	5.0×10^{-4}

basins of western New Jersey (Lewis-Brown and Jacobsen, 1995). A hydraulic conductivity of 1.0×10^{-6} m/s was assigned to all igneous and metamorphic rocks of the NYS Museum Bedrock Geology coverage. The hydraulic conductivity for fine-grained clastic lithology packages such as shale and siltstone were also assigned a hydraulic conductivity value of 1.0×10^{-6} m/s; the shallow fractured units of the Canadaway Group displayed hydraulic conductivity approximating this value (Prudic, 1986). All lithology packages of the NYS Museum Bedrock Geology coverage containing substantial components of shale, siltstone, mudstone and graywacke were given a hydraulic conductivity value of 1.0×10^{-6} m/s. Fractured sandstone and conglomerate display hydraulic conductivities ranging between 1.7×10^{-7} and 1.3×10^{-4} m/s (EPA CERCLA pump/slug tests, Appendix E) and 5.7×10^{-6} to 5.7×10^{-4} m/s (Lewis-Brown and Jacobsen, 1995). Lithology units of the NYS Museum Bedrock Geology coverage consisting of coarse-grained clastics were assigned a hydraulic conductivity of 5.0×10^{-6} m/s. EPA CERCLA pump/slug tests performed in fractured carbonates of the Onondaga Limestone, Akron Dolomite and Black River Formation display hydraulic conductivities ranging between 1.5×10^{-6} and 2.3×10^{-2} m/s; a hydraulic conductivity of 5.0×10^{-4} m/s was assigned to the NYS Museum Bedrock Geology coverage's lithology packages made up entirely of carbonates. NYS Museum Bedrock Geology coverage's lithology packages made up predominantly of carbonates with clastic components were given a hydraulic conductivity value of 5.0×10^{-6} m/s. The semi-consolidated Mesozoic sediments of the Cretaceous NYS Museum Bedrock Geology coverage, which range from clay to sand, were given a porosity value of 35 percent; this value falls within the ranges

of Freeze and Cherry (1979). The range of clay to silty sand hydraulic conductivities listed by Freeze and Cherry (1979) is between 1.0×10^{-12} and 1.0×10^{-3} ; Smolensky, Buxton and Shernoff (1989) noted that Cretaceous low energy fluvial-deltaic clay and silty clay approximate a hydraulic conductivity of 3.5×10^{-8} m/s. A hydraulic conductivity of 1.0×10^{-7} m/s was assigned to the Cretaceous clay, silt and sand deposits of the NYS Museum Bedrock Geology coverage.

e. Bedrock Geology Vertical Hydraulic Conductivity Assignment

From the NYS geology discussion, formations of the NYS Museum Bedrock Geology coverage can be sorted into rock-type classifications, or lithologic packages (Table 3) and assigned porosity and hydraulic conductivity values as displayed in Table 6, below. A vertical hydraulic conductivity attribute (vertical hydraulic conductivity was assumed to be an order of magnitude less than horizontal hydraulic conductivity) was also assigned to the attribute tables of the NYS Museum Bedrock Geology coverage. Like the NYS Museum Surficial Geology coverage, the vertical hydraulic conductivity was estimated to be equal to one tenth of the horizontal hydraulic conductivity; literature review displays that vertical hydraulic conductivity approximates an order of magnitude less than the horizontal hydraulic conductivity (Getzen, 1977; Prudic, 1986; Lewis-Brown and Jacobsen, 1995; Busciolano, Monti and Chu, 1998). The foregoing discussion and assignment of porosity and vertical hydraulic conductivity values to the NYS Museum Bedrock Geology coverage allowed for the creation of a bedrock geology porosity grid (Figure 35) and a bedrock geology vertical hydraulic conductivity grid (Figure 36).

Figure 35. Bedrock Geology Porosity Grid

The bedrock geology porosity grid was established by selecting porosity values for the various rock types (lithologic packages) based on literature review. Lithologic packages of geologic formations were provided by the NYS Museum Bedrock Geology coverage (Figure 33).

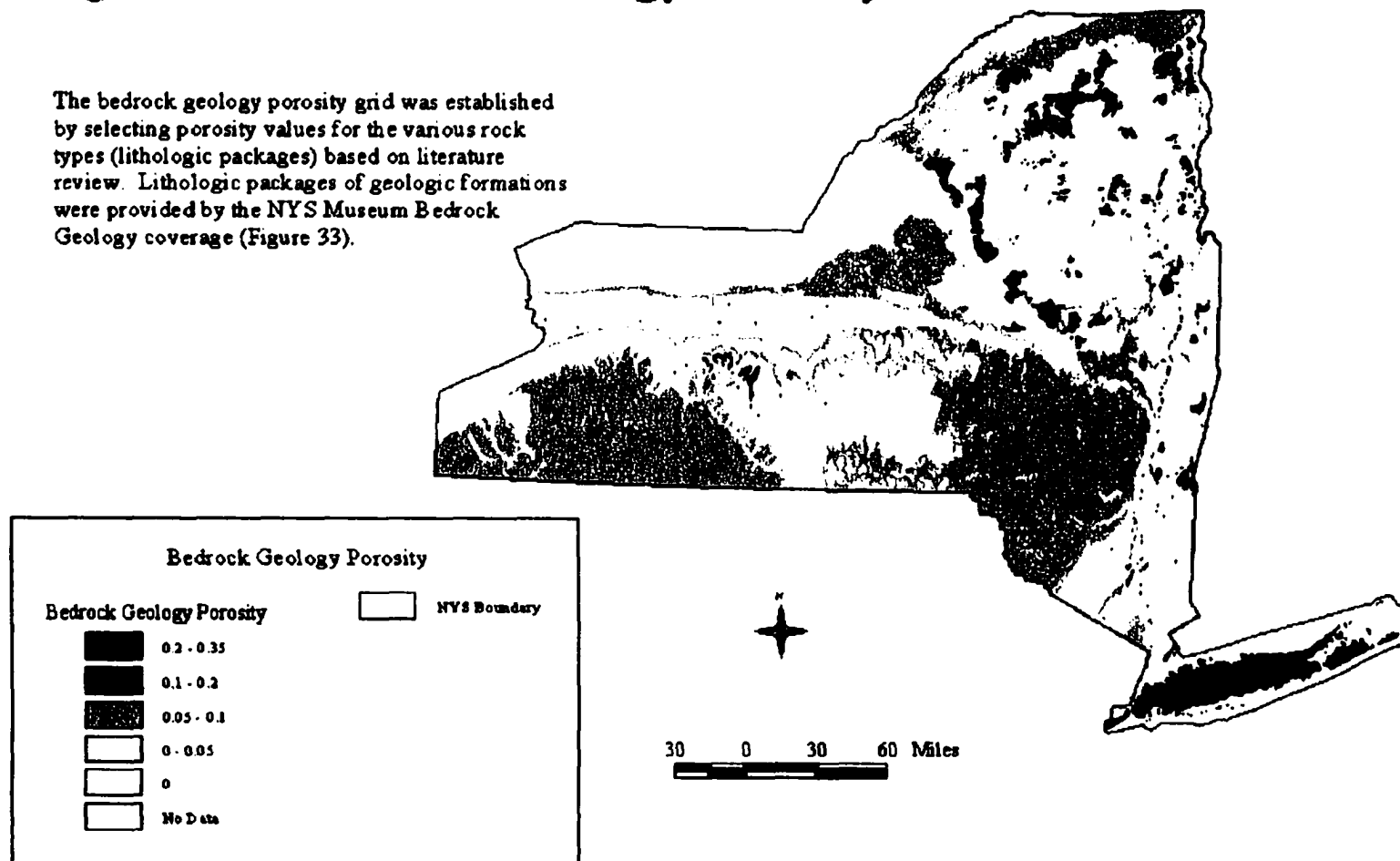


Figure 36. Bedrock Geology Vertical Hydraulic Conductivity Grid

The bedrock geology vertical hydraulic conductivity grid was established by selecting hydraulic conductivity values for the various rock types (lithologic packages) based on literature review and review of CERCLA files pump and slug test data. Lithologic packages of geologic formations were provided by the NYS Museum Bedrock Geology coverage (Figure 33)

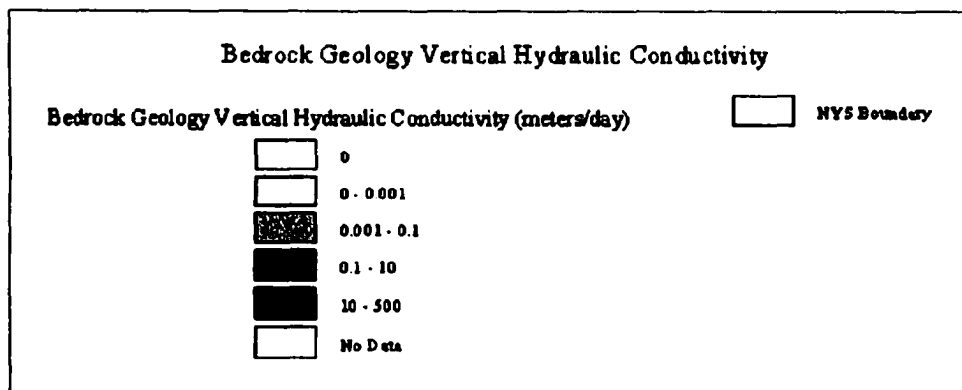
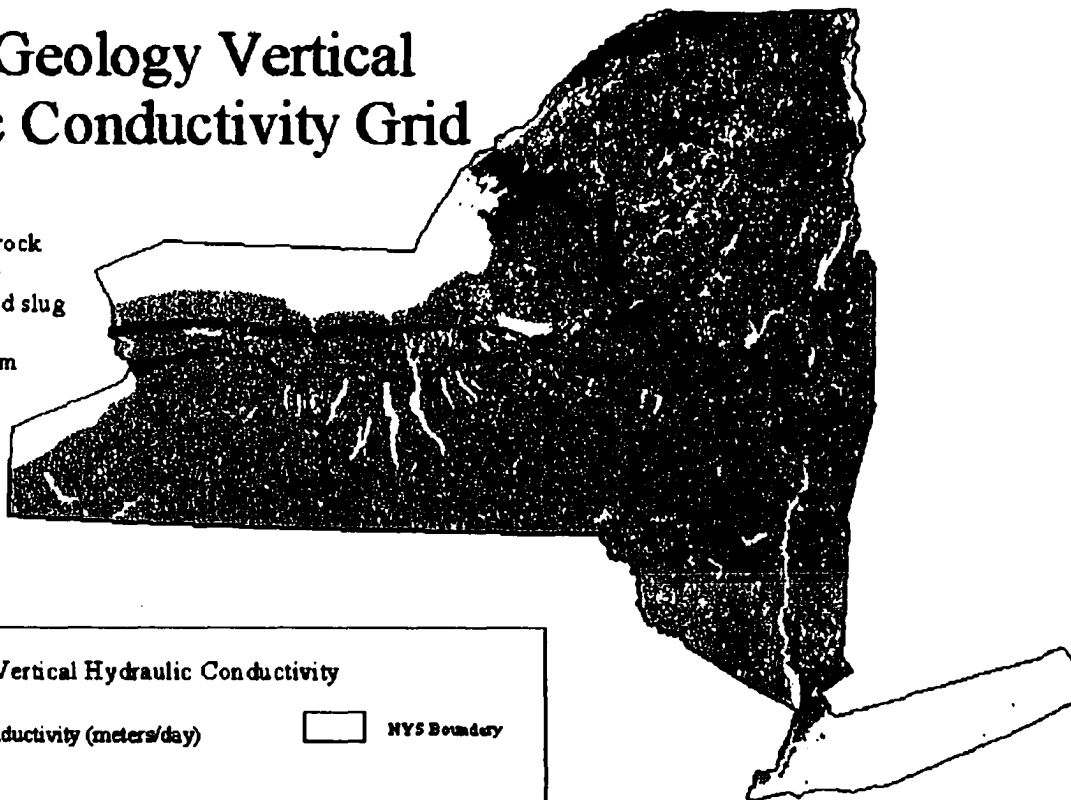
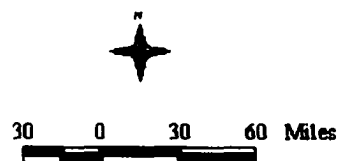
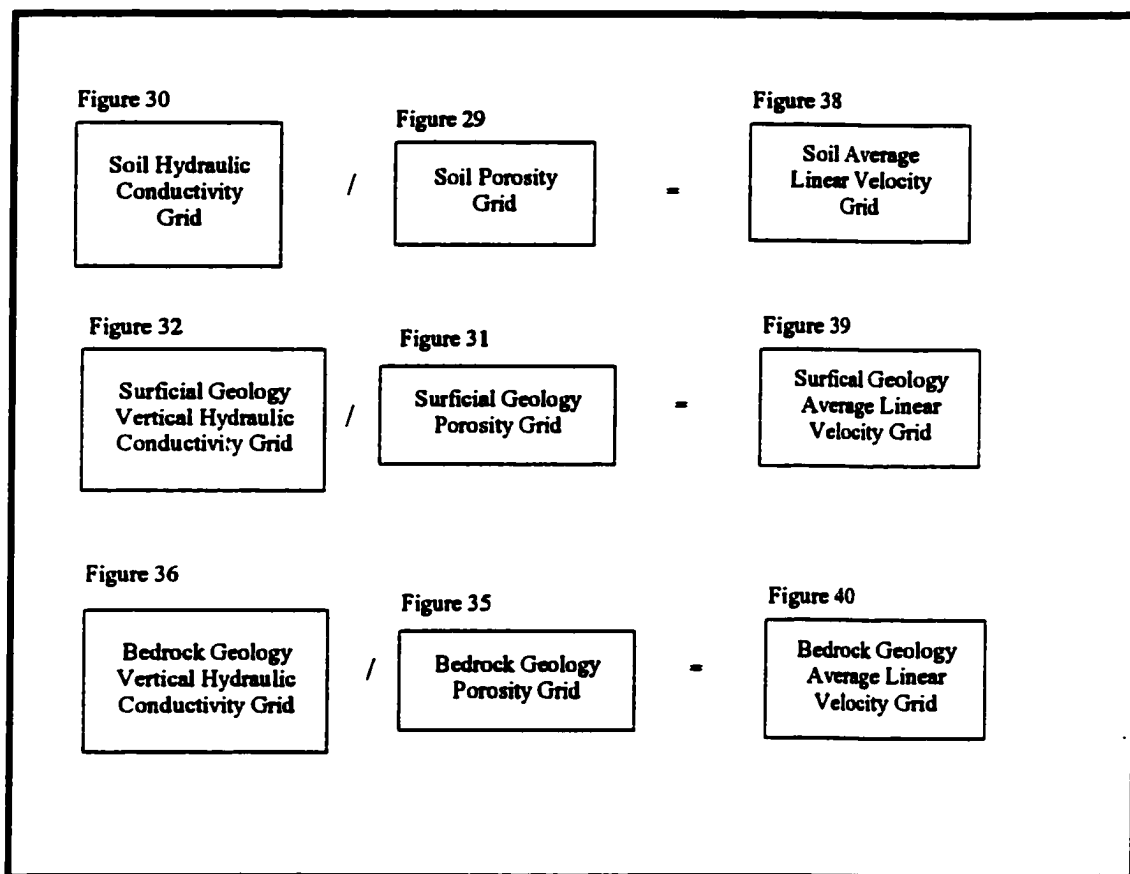


Figure 37. Cartographic model flow chart for the calculation of average linear velocities.



C. Calculations of Average Linear Velocities

Soil, surficial geology and bedrock geology components of the vadose zone were analyzed with respect to average linear velocity (Figure 37). As noted previously, the average linear velocity of the vadose zone was considered to be under a maximum load; in other words, the vadose zone is considered under saturated conditions. Vadose zone average linear velocity is equal to vadose zone vertical hydraulic conductivity divided by vadose zone porosity. The soil hydraulic conductivity grid (Figure 30) was divided by

the soil porosity grid (Figure 29) to yield a soil average linear velocity grid (Figure 38). The surficial geology vertical hydraulic conductivity grid (Figure 32) was divided by the surficial geology porosity grid (Figure 31) to produce a surficial geology average linear velocity grid (Figure 39). Likewise, the bedrock geology vertical hydraulic conductivity grid (Figure 36) was divided by the bedrock geology porosity grid (Figure 35) to make a bedrock geology average linear velocity grid (Figure 40).

D. Calculation of Aquifer Susceptibility

Aquifer susceptibility to contamination may be expressed in terms of vadose zone residence time; the time groundwater would take to travel through the vadose zone from surface to water-table; in the case of this study, the vadose zone is considered to be under a maximum load. Contaminant attenuation decreases with decreasing residence time, so short vadose zone residence times would yield areas of high unconfined aquifer risk to contamination. The residence times of the three components of the vadose zone considered in this study, soil, surficial geology and bedrock geology, can be calculated (Figure 41) by dividing the thicknesses of each vadose zone component (Figures 26, 27 and 28) by their respective average linear velocities (Figures 38, 39 and 40). The results are a soil component of the vadose zone residence time (Figure 42), a surficial geology component of the vadose zone residence time (Figure 43), and a bedrock geology component of the vadose zone residence time (Figure 44). The sum of the soil, surficial geology and bedrock geology residence times (Figure 45) yields vadose zone residence time; the vadose zone residence time grid, referred to as the aquifer susceptibility.

Figure 38. Soil Average Linear Velocity Grid

The soil average linear velocity grid was calculated by dividing the soil hydraulic conductivity grid (Figure 30) by the soil porosity grid (Figure 29).

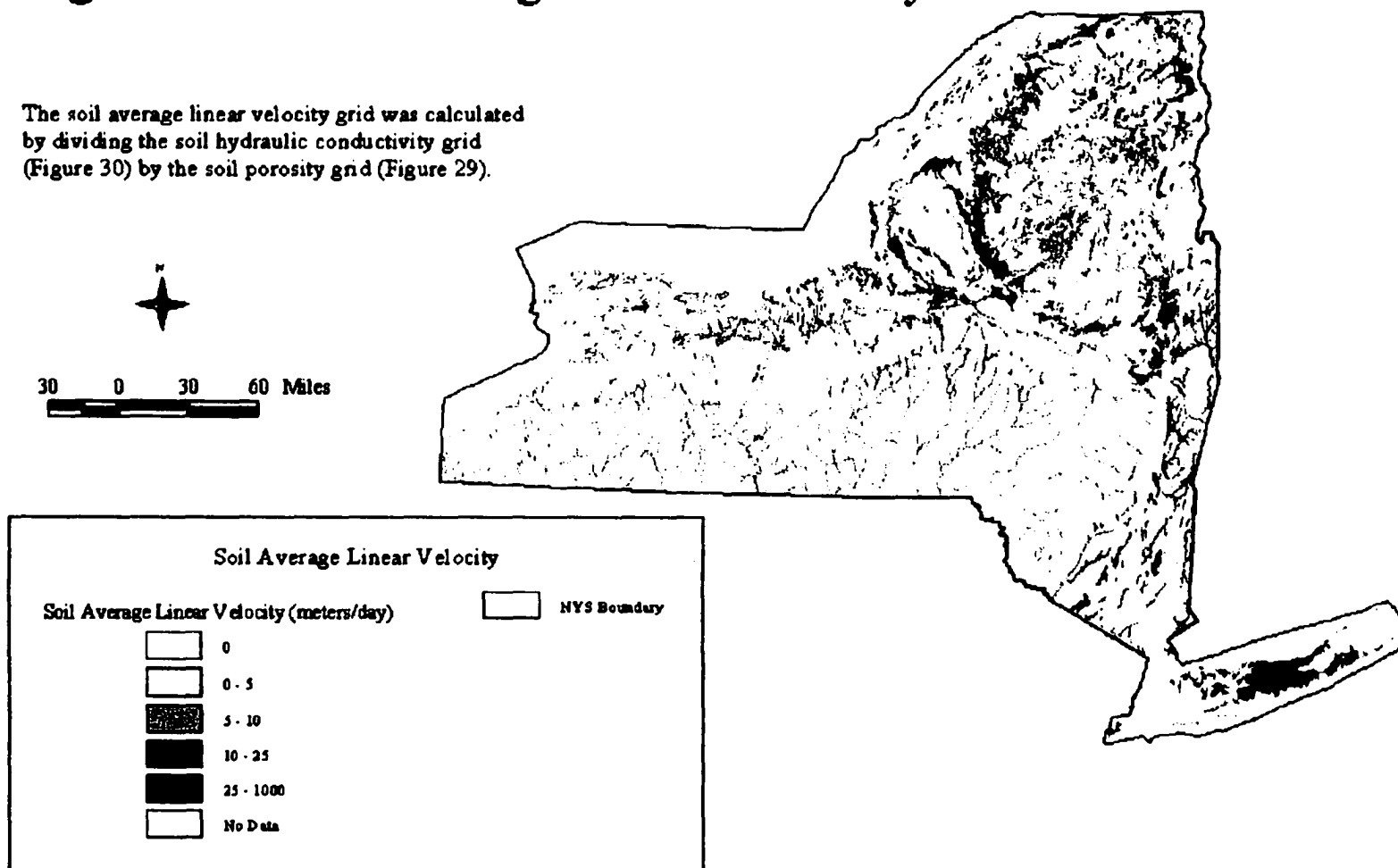


Figure 39. Surficial Geology Average Linear Velocity Grid

The surficial geology average linear velocity grid was calculated by dividing the surficial geology vertical hydraulic conductivity grid (Figure 32) by the surficial geology porosity grid (Figure 31).

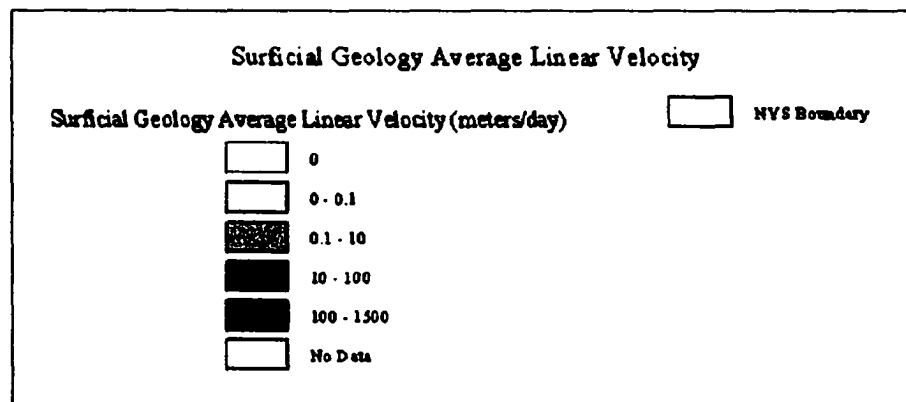
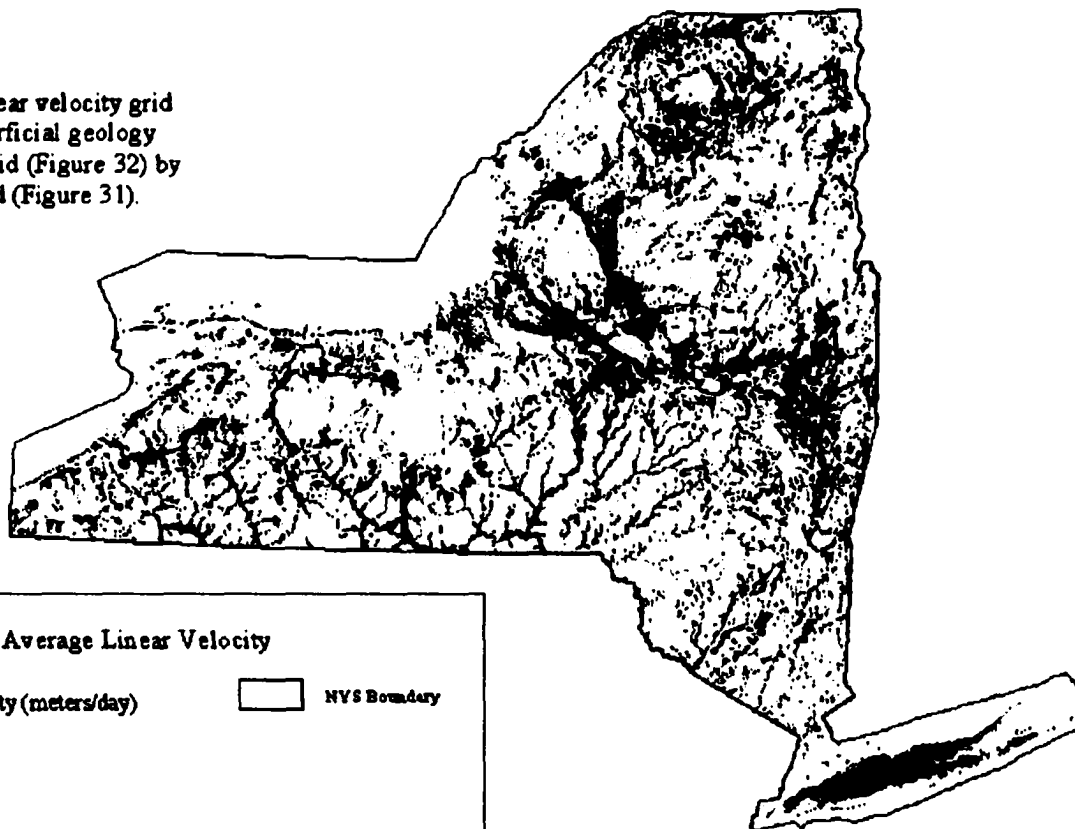
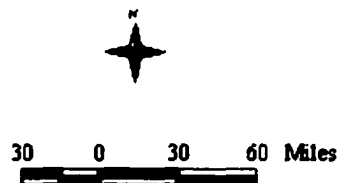


Figure 40. Bedrock Geology Average Linear Velocity Grid

The bedrock geology average linear velocity grid was calculated by dividing the bedrock geology vertical hydraulic conductivity grid (Figure 36) by the bedrock geology porosity grid (Figure 35).

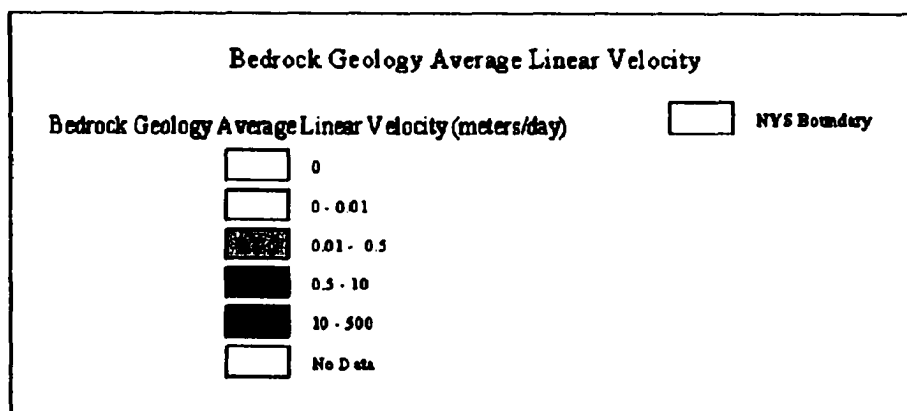
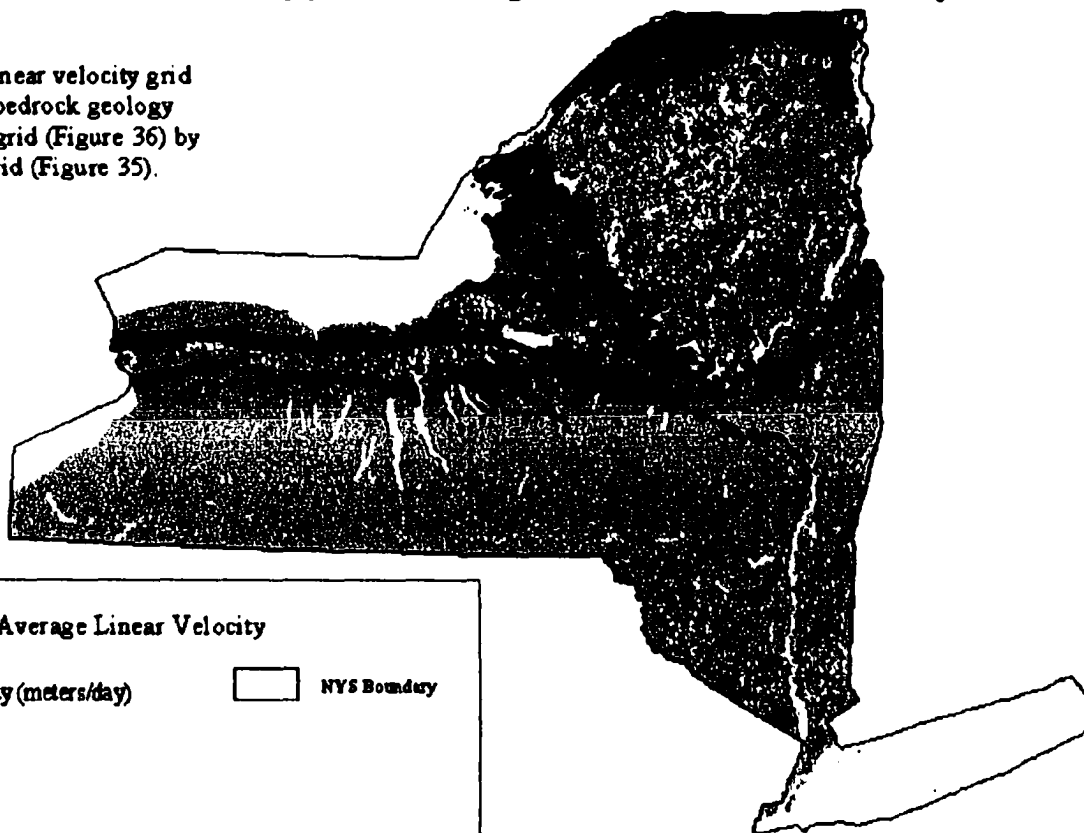
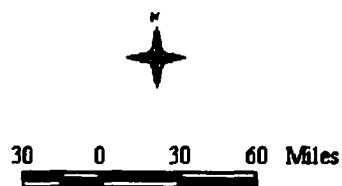
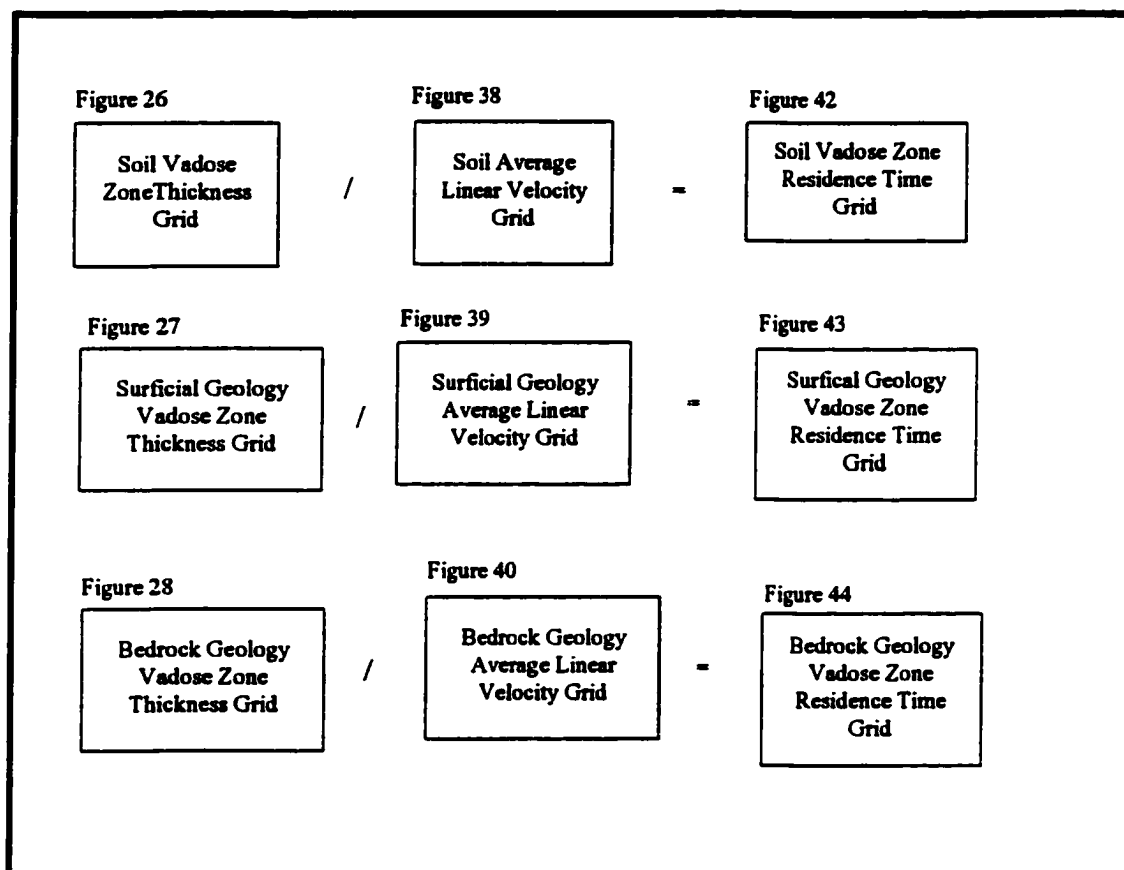


Figure 41. Cartographic model, vadose zone residence time calculations for soil, surficial geology and bedrock geology sections.



E. Chapter 6 Summary

Aquifer susceptibility was established by calculating vadose zone residence time, a measure of the vadose zone's ability to attenuate and retard contaminants; the system was considered under a maximum load.

The first step of the aquifer susceptibility analysis was to construct a water-table elevation surface. This was accomplished by using USGS surface hydrology, DEM, and

Figure 42. Soil Component of the Vadose Zone, Vadose Zone Residence Time Grid

Soil vadose zone residence time is calculated by dividing soil vadose zone thickness (Figure 26) by soil average linear velocity (Figure 38).

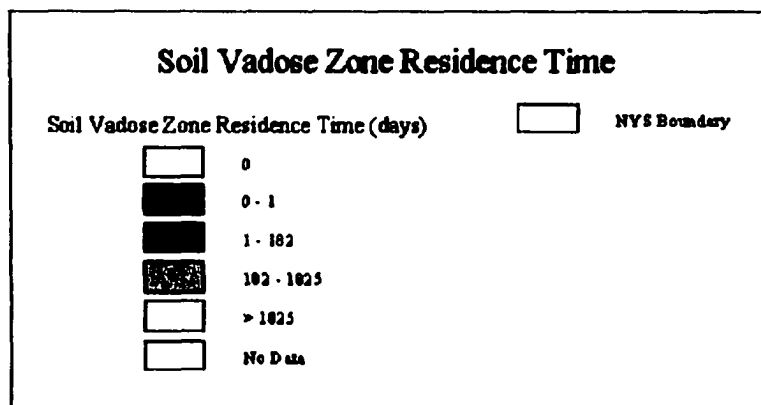
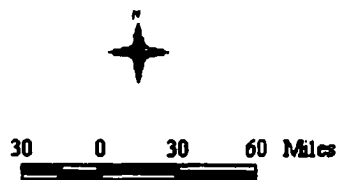
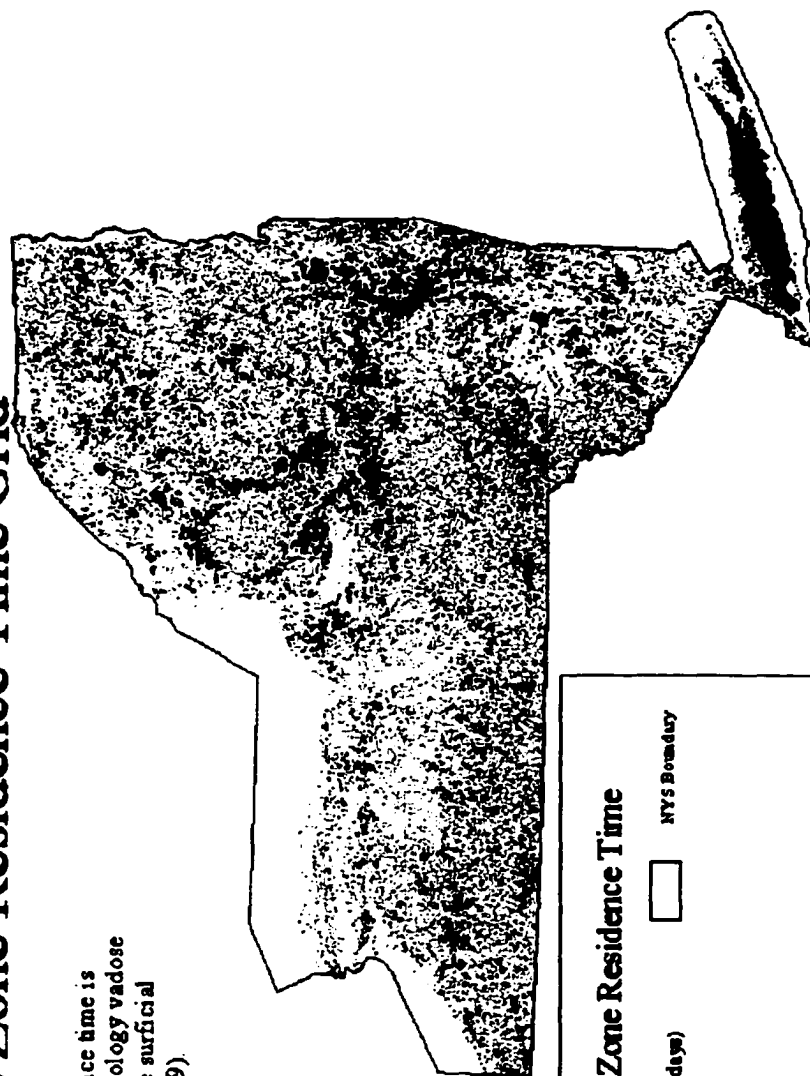


Figure 43. Surficial Geology Component of the Vadose Zone Vadose Zone Residence Time Grid

Surficial geology vadose zone residence time is calculated by dividing the surficial geology vadose zone thickness grid (Figure 27) by the surficial geology linear velocity grid (Figure 39).



Surficial Geology Vadose Zone Residence Time

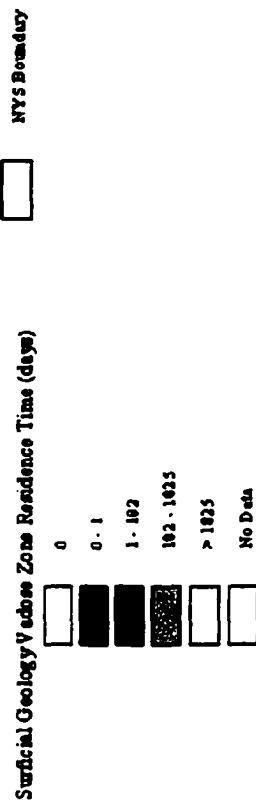


Figure 44. Bedrock Geology Component of the Vadose Zone, Vadose Zone Residence Time Grid

Bedrock geology vadose zone residence time is calculated by dividing bedrock geology vadose zone thickness (Figure 28) by bedrock geology average linear velocity (Figure 40).

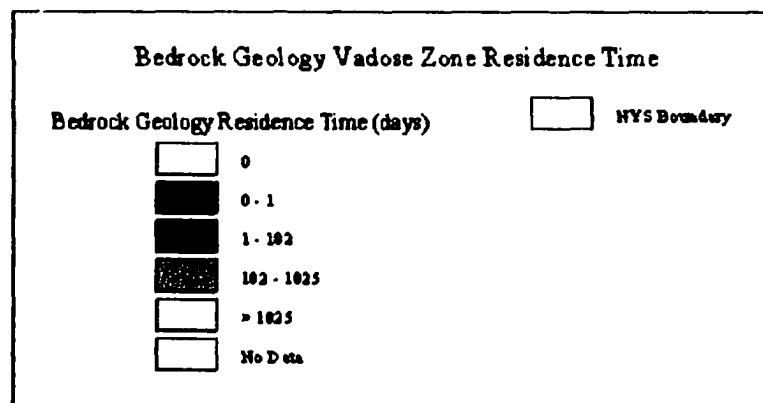
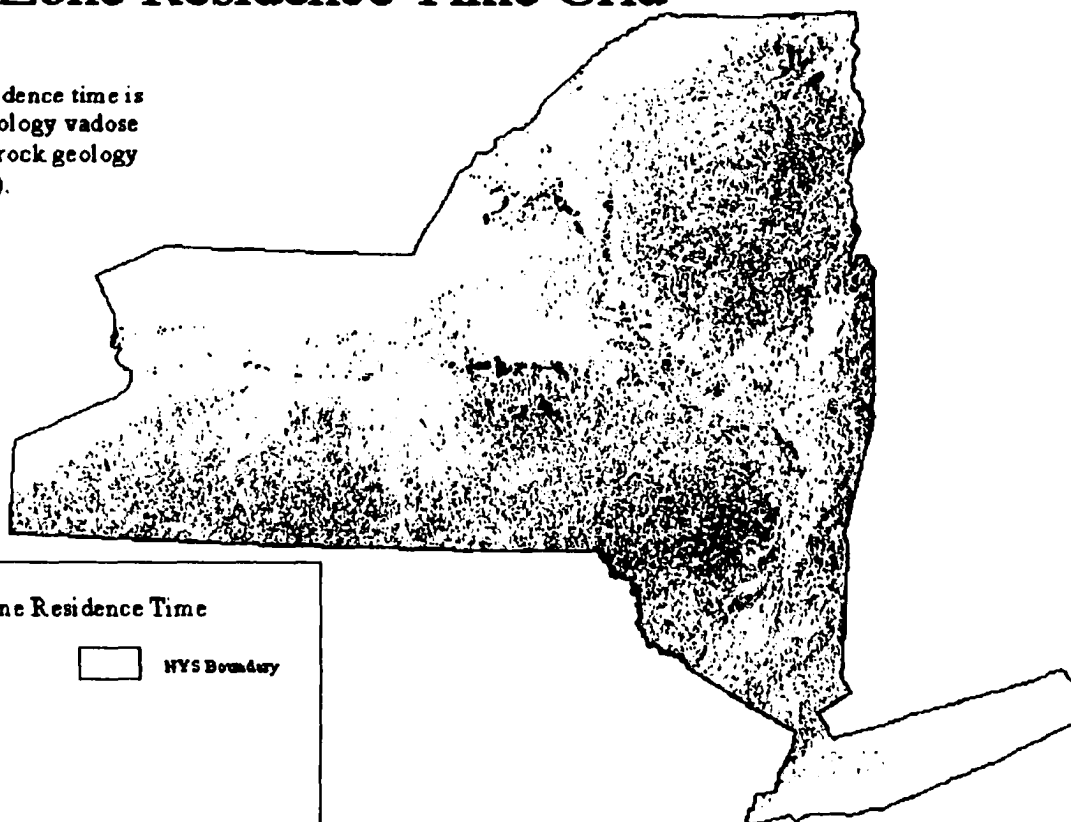
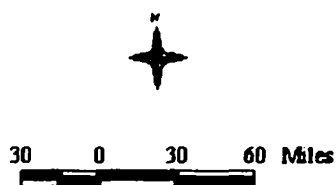
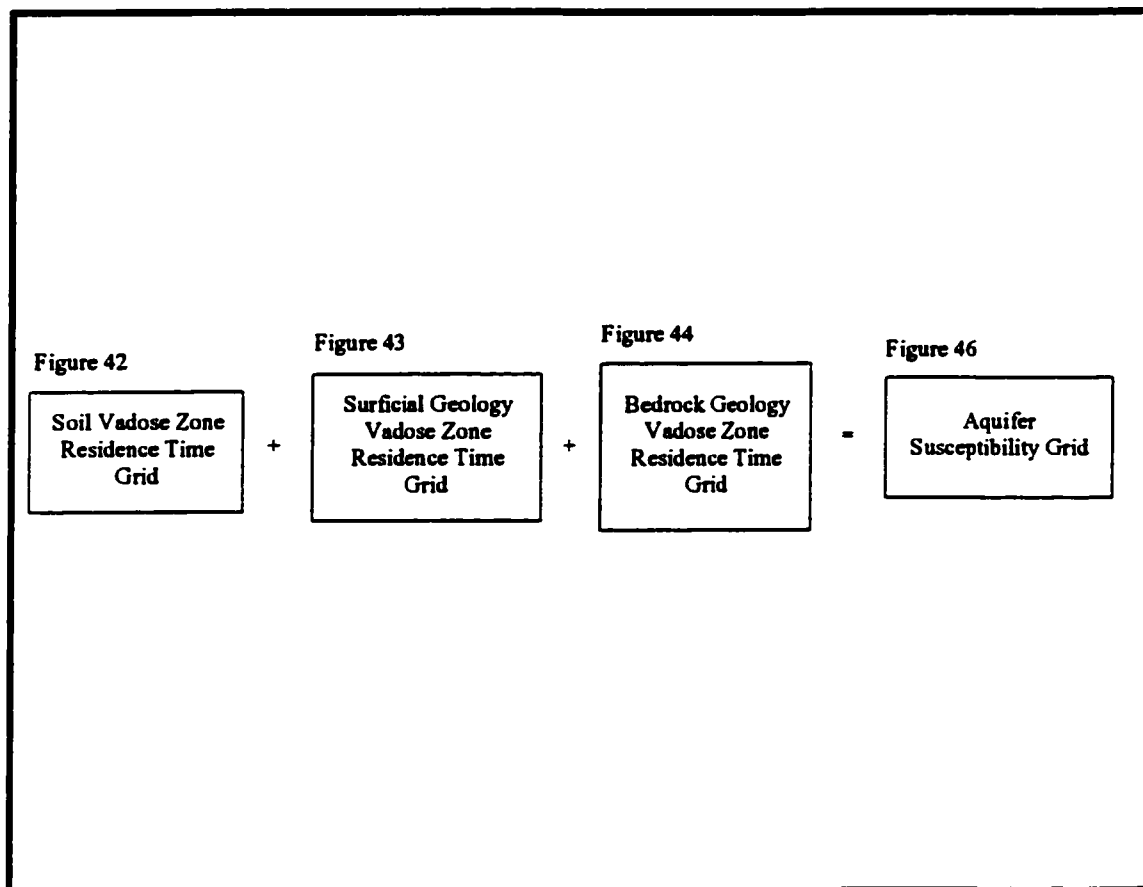


Figure 45. Cartographic model flow chart displaying the calculation of aquifer susceptibility.

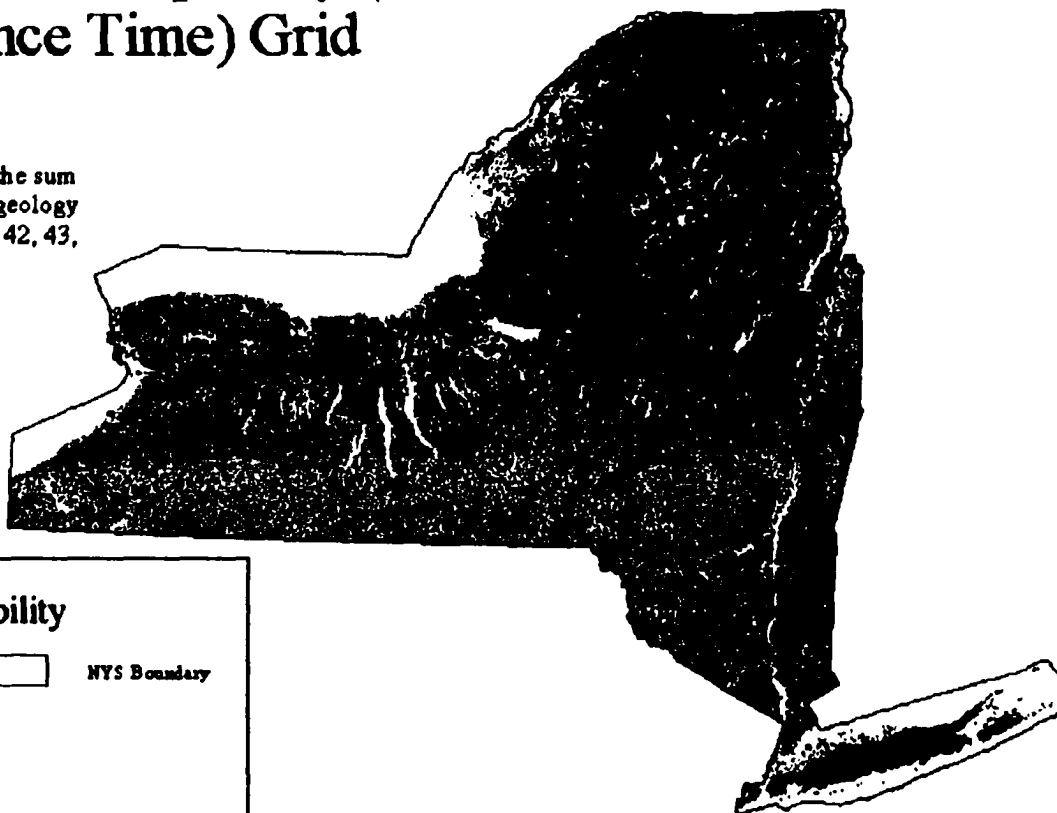
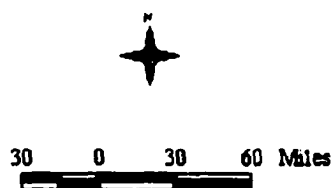


water well data layers. A water-table elevation point coverage for NYS was created; a NYS water-table elevation surface was interpolated from this coverage through the GIS function termed kriging.

Thickness of the vadose zone, depth to the water-table, was then calculated by subtracting the water-table elevation grid from the USGS DEM. The various geologic components of the vadose zone; soil, surface geology, and bedrock geology; were then investigated. Thickness grids were established for the soil and surface geology data

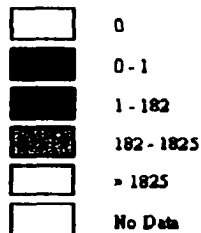
Figure 46. Aquifer Susceptibility (Vadose Zone Residence Time) Grid

The aquifer susceptibility grid is equal to the sum of the soil, surficial geology and bedrock geology vadose zone residence time grids (Figures 42, 43, and 44).



Aquifer Susceptibility

Aquifer Susceptibility (days)



 NYS Boundary

layers. GIS conditional statements were then used to create grids of the soil, surficial geology and bedrock geology thicknesses above the water-table.

Porosity and vertical hydraulic conductivity grids were established for the soil, surficial geology and bedrock geology components of the vadose zone. Data layer attribute table investigation, literature review, and consideration of CERCLA file pump test and slug test data were performed to establish porosity and hydraulic conductivity values. Special attention was placed on the geologic make-up of the surficial geology and bedrock geology data layers. Until three-dimensional hydrogeologic data is gathered, digitized, and interpolated, this study made a reasonable first step in establishing regional porosity and hydraulic conductivity estimates from the available geologic data.

The porosity and hydraulic conductivity grids of each component of the vadose zone, soil, surficial geology and bedrock geology, were used to create average linear velocity grids for each component. Average linear velocity was calculated by dividing the vertical hydraulic conductivity of each component by their respective porosity values.

A residence time grid for each component of the vadose zone was calculated. This was accomplished by dividing the vadose zone thickness grid of each component by their respective average linear velocity grid. Vadose zone residence time grids were created for the soil, surficial geology and bedrock geology components of the vadose zone. The sum of these groundwater residence times is a measure of aquifer susceptibility; an aquifer susceptibility grid of NYS was created.

CHAPTER 7: Groundwater-Risk Analysis

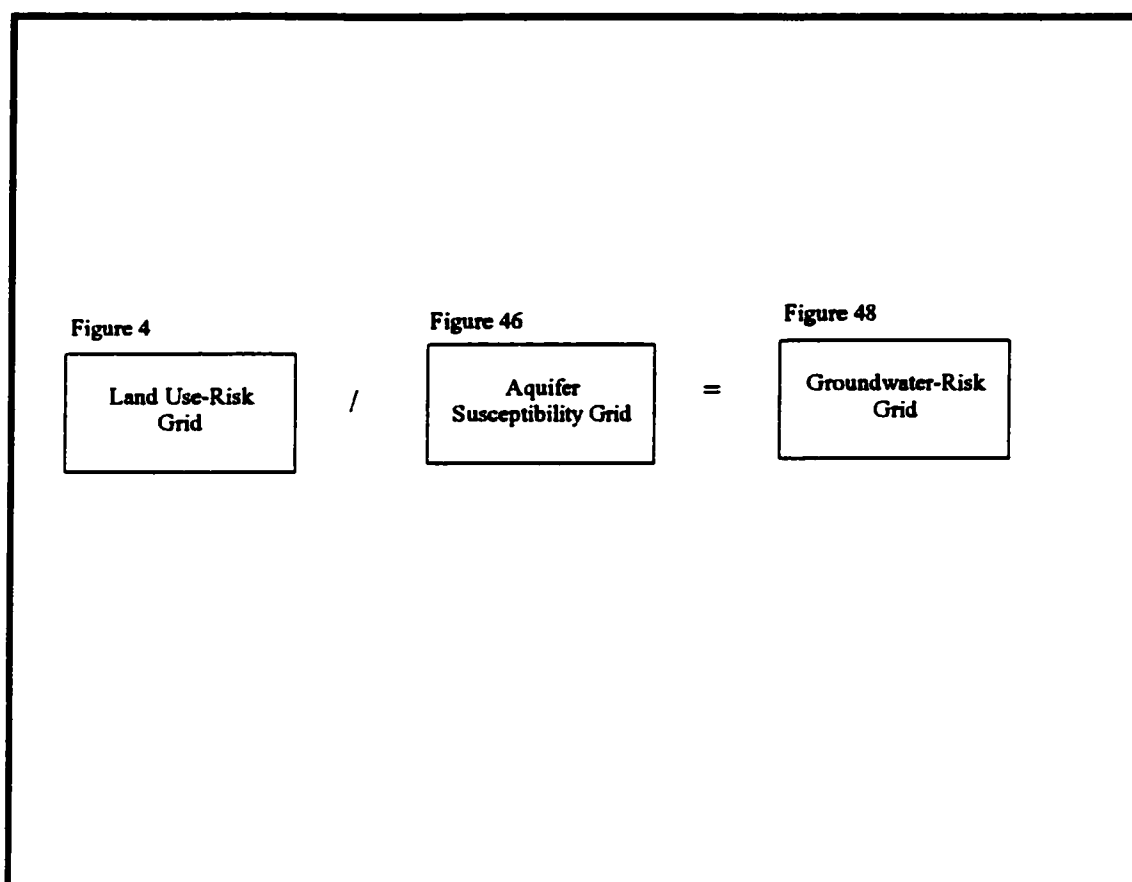
The land use-risk analysis assessed the potential to introduce contaminants at the ground surface of NYS. The aquifer susceptibility analysis assessed the vulnerability of an unconfined aquifer if a contaminant source was present. Groundwater-risk was calculated by dividing the potential to introduce contaminants, land use-risk, by the potential to attenuate and retard contaminants, aquifer susceptibility.

As displayed in Figure 47, the groundwater-risk grid was produced by dividing the land use-risk grid (Figure 4, Plate 1) by the aquifer susceptibility grid (Figure 46, Plate 3). The regional groundwater-risk grid (Figure 48 and Plate 4) was then analyzed to produce an ordinal scaled groundwater-risk grid with values from a low risk of one to a high risk of seven. Table 7 displays the ordinal values, one to seven, and the corresponding ranges of groundwater-risk.

A. Identified Areas of Significant Groundwater-Risk

The groundwater-risk grid (Figure 48, Plate 4) displays several areas of significant groundwater-risk. Most of these areas are areas determined to possess a combination of significant land use-risk and aquifer susceptibility. The most notable of these areas are Coming-Big Flats-Horseheads-Elmira Area (Steuben and Chemung Counties), Endicott-Endwell-Figure 42. Soil component of vadose zone residence time grid. Binghamton-Port Dickerson Area (Broome County), Glen Falls Area (Saratoga County), Jamestown Area (Chautauqua County), Long Island (Nassau and Suffolk Counties), Olean Area (Cattaraugus County), Plattsburg Area (Clinton County), Schenectady Area (Schenectady County), Utica Area (Oneida County), and Watertown Area (Jefferson County). Several

Figure 47. Cartographic model, calculation of groundwater-risk.



areas show a significant groundwater-risk as a result of very high aquifer susceptibility and moderate land use-risk. Of these areas the most notable is in the St. Lawrence Lowlands between Messina and Malone (Franklin and St. Lawrence Counties); this area displays a very shallow water-table in combination with highly permeable deposits of sand and gravel.

B. Correlation of NPL Groundwater Contamination Sites with Groundwater-Risk Areas

The confidence of the groundwater-risk grid (Figure 48, Plate 4) was evaluated by

Figure 48. Groundwater-Risk Grid

The groundwater-risk grid is calculated by dividing the land use-risk grid (Figure 4) by the aquifer susceptibility grid (Figure 46).

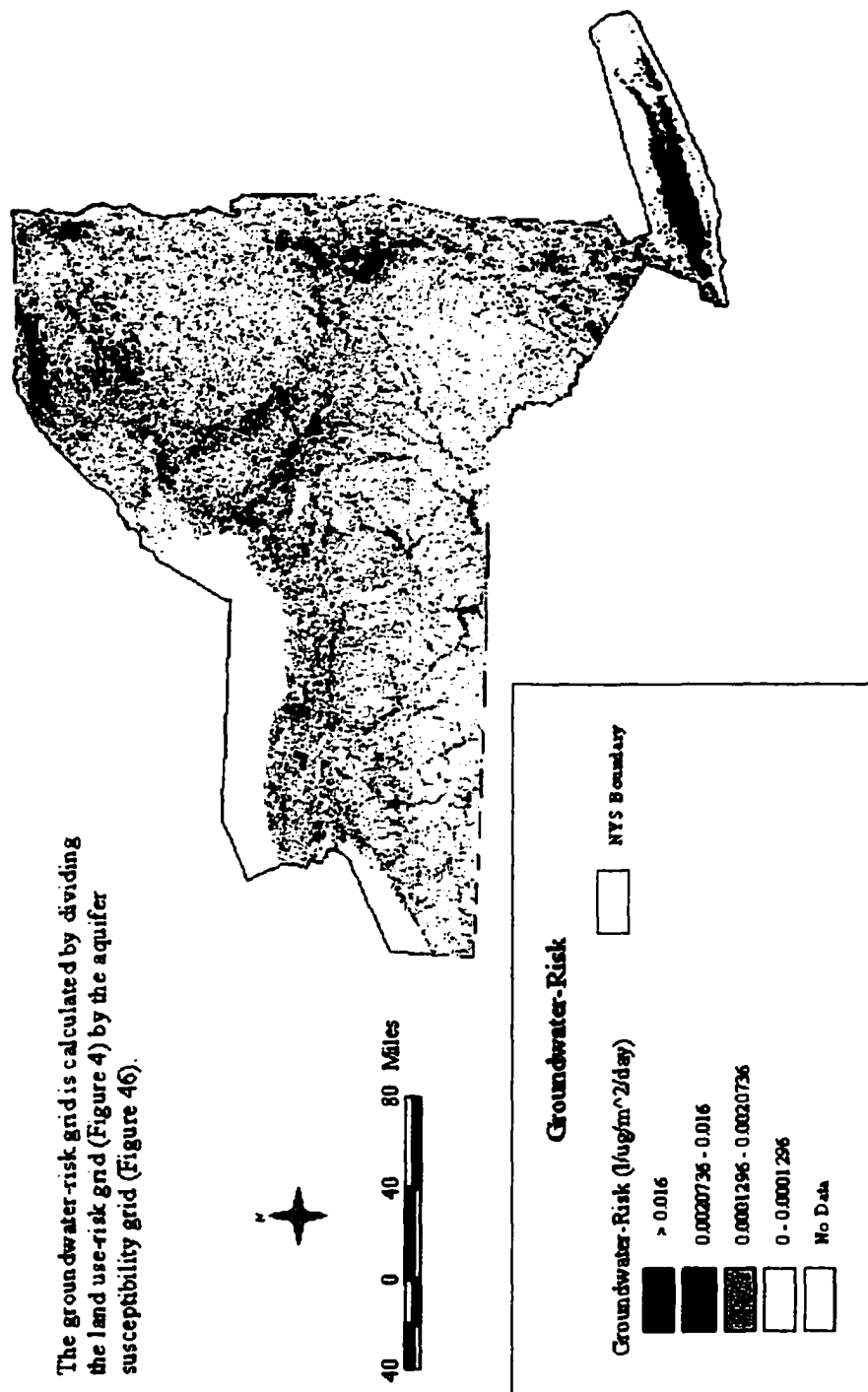


Table 7. Ordinal groundwater-risk scale and corresponding groundwater-risk values (l/μg/m²/day).

Ordinal Scale	Groundwater-Risk Value (l/μg/m²/day)
7.00	> 0.081
6.00	0.016 - 0.081
5.00	0.002 - 0.016
4.00	0.00065 - 0.002
3.00	0.00012 - 0.00065
2.00	0.0000081 - 0.00012
1.00	< 0.0000081

correlating existing CERCLA NPL groundwater contamination sites in NYS (EPA, 1990)(Appendix H), a total of 68 with accurately located spatial polygon data, with the ordinally scaled groundwater-risk grid. The EPA CERCLIS database was processed to develop a polygon coverage displaying NPL groundwater contamination sites in NYS (Figure 49). Groundwater contamination sites were posted on the ordinally scaled groundwater- risk grid and a grid-in-polygon analysis was performed. Table 8 displays the groundwater-risk scale, the corresponding number of NPL groundwater contamination sites (polygons) containing the maximum cell value of the given groundwater-risk scale, the total number of polygons investigated, and the percent correlation of total facilities possessing the given maximum ordinally ranked groundwater-risk value. Table 9 displays a similar correlation of NPL groundwater

Table 8. The maximum groundwater-risk grid ordinal value and corresponding count of facilities containing the value, total number of facilities investigated and percent correlation with the given maximum groundwater-risk value.

Maximum Groundwater-risk value	Number of CERCLA NPL Facilities Count	Total Number of CERCLA NPL Facilities Investigated	Percent Correlation
1.	5.	68.	0.0735
2.	4.	68.	0.0588
3.	2.	68.	0.0294
4.	5.	68.	0.0735
5.	9.	68.	0.1324
6.	14.	68.	0.2059
7.	29.	68.	0.4265

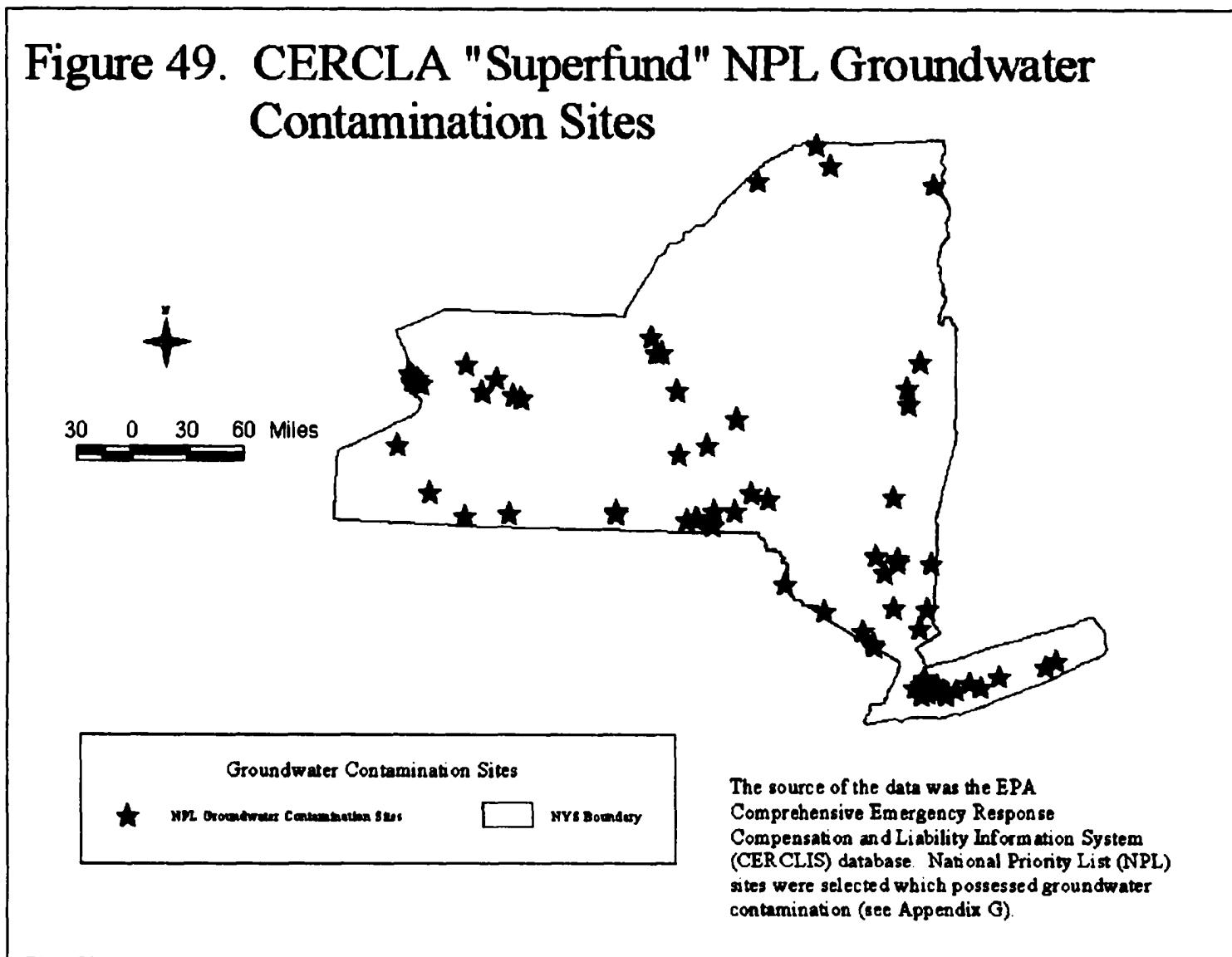
Table 9. The median groundwater-risk grid ordinal value and corresponding count of facilities containing the value, total number of facilities investigated and percent correlation with the given median groundwater-risk value.

Median Groundwater-risk value	Number of CERCLA NPL Facilities Count	Total Number of CERCLA NPL Facilities Investigated	Percent Correlation
1.	11.	68.	0.1618
2.	7.	68.	0.1029
3.	4.	68.	0.0588
4.	14.	68.	0.2059
5.	14.	68.	0.2059
6.	12.	68.	0.1765
7.	6.	68.	0.0882

contamination sites, however, instead of the maximum groundwater-risk value, the median groundwater-risk value was investigated. CERCLA NPL groundwater contamination sites show a 76% correlation of sites containing maximum groundwater-risk values of 5, 6, and 7 (Table 8). CERCLA NPL groundwater contamination sites also display a 47% correlation with sites containing median groundwater-risk values of 5, 6, and 7 (Table 9). The strong correlation of significant groundwater-risk values (values of 5, 6 and 7) with CERCLA NPL groundwater contamination sites lends a strong degree of confidence to the groundwater-risk grid's ability to assess the potential of groundwater contamination.

C. Chapter 7 Summary

A NYS groundwater-risk grid was created by dividing a NYS land use-risk grid by a NYS aquifer susceptibility grid. Areas of significant groundwater-risk within NYS are displayed on the NYS groundwater-risk grid. Evaluation of the groundwater-risk grid was made by correlation maximum and mean grid values within areas of known groundwater contamination, CERCLA NPL groundwater contamination sites in NYS. A 76% correlation of maximum grid values of significant groundwater-risk was made with the CERCLA NPL groundwater contamination site areas. A 45% correlation of mean grid values of significant groundwater-risk was made with the CERCLA NPL groundwater contamination site areas. The strong correlation of significant groundwater-risk values with CERCLA NPL groundwater contamination sites lends a strong degree of confidence to the groundwater-risk grid's ability to assess the potential of groundwater contamination.



CHAPTER 8: DISCUSSION

The development of a NYS groundwater-risk grid may provide a useful tool for groundwater protection strategies. Businesses may determine their potential for environmental liability and need to perform environmental audits based on their location with respect to high groundwater-risk areas. Environmental regulatory authorities may also use the groundwater-risk grid for inspection targeting and drinking-water protection strategies. The aquifer susceptibility grid may also be used for aquifer protection strategies, such as hazardous waste routing to avoid areas of high aquifer susceptibility.

A. Targeting Environmental Work

As environmental regulators embrace advanced technology, it is a matter of time before businesses operating under a noncompliance are detected. The groundwater-risk grid (Figure 48) and coverage may be used by businesses to high-grade properties for Phase I, II and III Environmental Site Assessment (ESA) (ASTM, 1994). Phase I ESAs can benefit property owners by highlighting environmental conditions which may cause economic liability. Businesses may voluntarily contact regulators for compliance assistance and reap the benefit of reduced or non-penalty compliance orders with extended periods to achieve compliance. The developing policies of environmental regulators are to reward voluntary compliance procedures and aggressively penalize and enforce environmental laws against businesses which disregard environmental regulations or make no effort to determine their compliance status. Aggressive regulation of these operators also takes away the economic advantage that operating under a noncompliance has provided them over environmentally accountable businesses; most penalty policies

calculate the economic benefit of non-compliance.

The groundwater-risk grid (Figure 48) may be used to assist in the protection of drinking- water wells, both regulated and unregulated. Public water-supply wells can be displayed on the groundwater-risk coverage to determine if areas of high groundwater-risk lie within their drawdown zone. These areas can be targeted for environmental compliance inspections to enhance the protection of public groundwater supply. Privately owned drinking water wells in residential communities are not regulated by federal, state or local governments. Therefore, they are not required to perform monitoring of water quality. Analysis of the groundwater-risk grid in combination with analysis performed with the water-table, hydraulic conductivity and porosity grids may assist in the protection of citizens dependent upon private water wells. The water-table grid, which provides hydraulic gradients, and hydraulic conductivity and porosity grids may be used to estimate direction and speed of groundwater flow. If groundwater is determined to be rapidly flowing from a high groundwater-risk area toward a residential area that is dependent upon private wells, these residential areas may be notified that water analysis of their drinking water wells may be warranted. Areas of high groundwater-risk which may be a source of private water-well contamination may be targeted for environmental compliance inspections.

B. Future Water Use

The aquifer susceptibility grid (Figure 46, Plate 3) may be used to target areas for aquifer protection strategies. Areas where unconfined aquifers are susceptible to contamination may be protected by refining local zoning laws so that land-use would

minimize the potential to introduce contaminants in these areas. Refined zoning laws with respect to unconfined aquifer susceptibility would aid in the protection of currently used and future sources of underground drinking water.

Routing of hazardous materials should also attempt to avoid areas of highly susceptible unconfined aquifers; if transportation routes cannot avoid these areas, then special hazardous material transportation precautions can be devised within areas of high risk. Avoiding hazardous material spills in areas of high aquifer susceptibility will also assist in the protection of currently used and future sources of underground drinking water.

Local fire departments may use the aquifer susceptibility grid to determine the safest way to put out a fire. The use of foam or water to put out a fire and protect underground sources of drinking water and community drinking water supplies may be influenced by the aquifer susceptibility grid.

C. Refinement of Groundwater-Risk Analysis

As real world data is digitized and refined with respect to three-dimensional spatial accuracies, groundwater-risk analysis models will become more accurate.

The refinement of land-use coverages with respect to land-use categories and potential contaminant associations will add to refinement and accuracy of a GIS groundwater-risk analysis. As local governments utilize GIS for zoning and street-address refinement, the location of businesses will become refined. The continued use of the Global Positioning System (GPS) for locating geographically referenced items will also add to the accuracy of spatial data. Contaminant association with SIC codes and

individual facilities will be refined as the databases containing contaminant, SIC code, and facility information advance.

As local governments create coverages displaying the distribution of public and private water wells and the population dependent upon these sources and the source locations, the groundwater-risk analysis may be refined by adding a potential population exposure component. New census tract data should be refined to include, public water well dependency, private water well dependency and the number of private wells. Census-tract data should also include a disability/terminal disease component. In the future, environmental data may be geospatially linked to disease data and yield environmental science-health analyses.

The aquifer susceptibility component of the groundwater-risk analysis can be refined as a three-dimensional hydrogeologic database is assembled. A database should be created with the parameters such as depth to water-table, average moisture content of vadose zone, hydraulic conductivity, effective porosity, dispersivity, hydraulic gradient, bulk density, partitioning coefficient for organic carbon, fraction of organic carbon, and contaminant attenuation properties. Spatial collections of such parameters should be made with respect to lateral and vertical variations in geology. Interpolation of the three-dimensional hydrogeologic parameters will someday be established for the state. The digital surface and bedrock geology coverages are the first steps in this effort. The second step should be digital compilation of a thickness of unconsolidated material. This should be followed by the vertical specification of depositional environments, based on surficial geology attribute classifications, for the thickness of unconsolidated deposits.

The vertical assignment of attributes will have to be based on sampled data. This data should then be geospatially interpolated to produce three-dimensional layers of geologic parameters for the unconsolidated rock thickness. All permeability tests collected from any source should be collected with respect to the screened geologic specifics and statistically analyzed. Porosity and other hydrogeologic parameter data should be analyzed in a similar fashion. The addition of three-dimensional hydrogeologic data will enable a refinement of vadose zone residence time, as the data will allow the calculation of vertical travel time through several rock types. The total travel time through the vadose zone will be the sum of travel time through the individual layers. Attenuation of contaminants can also be evaluated with the input of proper parameters, such as those mentioned above. The creation of three-dimensional GIS hydrogeologic data layers below the water-table can be used to evaluate the speed, direction and attenuation of contaminants.

The ultimate goal of groundwater-risk analysis is to protect drinking water sources from contamination and determine areas where contamination exists and poses a risk to human health. In the future, regional analysis of groundwater systems and the potential to introduce contaminants may lead to the relative risks associated with all human-drinking water contact points, both private and public. These risks may be correlated with the geospatial distribution of disease. A strong correlation between contaminated water intake and disease will increase the incentive to protect public health and remediate or develop new sources of drinking water.

D. Chapter 8 Summary

The NYS groundwater-risk grid has several practical uses. Businesses may use the groundwater-risk grid to assess their potential to environmental liability.

Environmental regulators may use the groundwater-risk grid for inspection targeting and groundwater protection strategies. The aquifer susceptibility grid may also be used in developing aquifer protection strategies; especially those that address future drinking-water needs.

As real world data is digitized and refined with respect to three-dimensional spatial accuracies, groundwater-risk models will become more accurate. This study lays the foundation for future work. As technology advances and land use and hydrogeologic data become digitally available, more complex methods of groundwater-risk cartographic modeling will be devised.

CHAPTER 9: CONCLUSIONS

Enhancing protection of groundwater quality and delineation of areas of potential groundwater contamination, where closer investigation and data collection may be necessary, is best performed using GIS technology. This study used GIS technology and existing data layers and databases to produce a regional groundwater-risk grid of NYS. The analysis presented, assessed the potential to introduce contaminants at the ground surface in NYS, and assessed the potential for the contaminants to migrate through the vadose zone and be introduced to an aquifer at the water-table.

Pollution incidents, environmental contamination and related ill-effects upon humans, media coverage and heightened public concern throughout the 1960s and 1970s lead to the establishment of environmental regulations and regulatory authorities. The regulatory authorities devised methods to assess environmental degradation. Several methods were developed to assess the potential of groundwater risk to contamination. The EPA DRASTIC and EPA Region 2 methods are designed for regional, county- to state-wide groundwater-risk assessments. The LeGrande, HRS and SAS methods are qualitative methods designed to assess groundwater-risk within a confined area surrounding a specific site. The HHE is the large scale, quantitative, site-specific detailed analysis of groundwater contamination, human intake, and adverse human health effects. Each method uses criteria to assess the contaminant, groundwater migration pathway, and contact point/intake characteristics of the groundwater contamination system. These criteria may be used by GIS, a tool designed to handle and process

extensive quantities of geographically-referenced data, to assess the potential of groundwater contamination on a regional scale.

GIS is a computer system designed to capture, efficiently store, update and analyze all forms of geographically-referenced digital data. The GIS process called cartographic modeling can be used to simulate some aspect of the real world, such as the groundwater contamination system. Criteria used by groundwater-risk methods, such as those presented in Chapter 1, can be digitized and utilized in a GIS groundwater-risk analysis. Prior to establishing a cartographic model to assess groundwater contamination risk, it is important to be familiar with some aspects of the physical and chemical components of the groundwater contamination system.

Contaminants are introduced to the upper portion of the vadose zone by point and non-point sources; they are incorporated into groundwater by the processes of infiltration and aquifer recharge. Aquifer recharge occurs by water infiltration through the vadose zone which consists of a three-component system of geologic matrix, air, and water. Infiltration rate is a function of rock or sediment porosity, hydraulic conductivity (in turn a function of a geologic matrix's intrinsic permeability), and moisture content. A simplified view of the rate of vertical migration of water through the vadose zone may be expressed as average linear velocity under maximum load conditions (saturated conditions). Average linear velocity may be calculated by dividing hydraulic conductivity by matrix porosity. Vadose zone residence time, under maximum load, may be expressed by dividing the thickness of the vadose zone, or depth to the water-table, by the average linear velocity. Contaminant attenuation and retardation efficiency within the

vadose zone are a function of vadose zone residence time. Long periods of groundwater residence time within the vadose zone allow volatilization, biodegradation and sorption to act more efficiently upon a contaminated plume than a short period residence time. The formulas presented in Chapter 4 can be used to construct a GIS cartographic model for groundwater-risk analysis. The availability and extent of existing GIS data layers and digitized data pertaining to hydrogeologic parameters needed for the above discussed formulas determines the means and design of a groundwater-risk cartographic model.

To perform a detailed NYS-wide analysis of groundwater-risk using GIS, the data required by the HHE process would have to be regionally available in digital format; this data is not currently available. Availability of digital data determines the extent to which GIS cartographic formulation can represent real world processes. The GIS data layers and databases available for a NYS-wide groundwater-risk study are listed in Chapter 5. These data allow the formulation of a model to assess the risk of the introduction of contaminants at the earth's surface in NYS, and the risk of the contaminants to percolate through the vadose zone and be introduced to the aquifer at the water-table. A cartographic model can be established to assess land-use risk and aquifer susceptibility; comparative geospatial groundwater-risk can be demonstrated by dividing land use-risk by aquifer susceptibility.

The MRLC Land Use grid was investigated for its potential to introduce contaminants to the environment; a land use-risk grid was constructed. First, existing EPA databases were analyzed to assess the relative risks to human health posed by businesses sorted by their various SIC code classifications. Secondly, derived SIC code-

risks were associated with SIC code identified Dunn & Bradstreet facilities. The SIC code-risked Dunn & Bradstreet facilities were used to create a point coverage. Thirdly, a point-in-grid analysis was performed with the SIC code-risked Dunn & Bradstreet facilities and the MRLC Land Use grid; this enabled the creation of a land use classification risk and the development of a land use-risk grid. The land use-risk grid displays the relative risk of introducing contaminants to the environment, in the case of this study, introduction to the top of the vadose zone. As can be noted on the land use-risk grid, the potential to introduce contaminants to the environment is a function of human population; high land use-risk is noted in heavily populated areas.

Aquifer susceptibility was established by calculating vadose zone residence time, a measure of the vadose zone's ability to attenuate and retard contaminants; the system was considered under a maximum load.

The first step of the aquifer susceptibility analysis was to construct a water-table elevation surface. This was accomplished by using USGS surface hydrology, DEM, and water well data layers. A water-table elevation point coverage for NYS was created; a NYS water-table elevation surface was interpolated from this coverage through the GIS function termed kriging.

Thickness of the vadose zone, depth to the water-table, was then calculated by subtracting the water-table elevation grid from the USGS DEM. The various geologic components of the vadose zone; soil, surface geology, and bedrock geology; were then investigated. Thickness grids were established for the soil and surface geology data layers. GIS conditional statements were then used to create grids of the soil, surficial

geology and bedrock geology thicknesses above the water-table.

Porosity and vertical hydraulic conductivity grids were established for the soil, surficial geology and bedrock geology components of the vadose zone. Data layer attribute table investigation, literature review, and consideration of CERCLA file pump test and slug test data were performed to establish porosity and hydraulic conductivity values. Special attention was placed on the geologic make-up of the surficial geology and bedrock geology data layers. Until three-dimensional hydrogeologic data is gathered, digitized, and interpolated, this study made a reasonable first step in establishing regional porosity and hydraulic conductivity estimates from the available geologic data.

The porosity and hydraulic conductivity grids of each component of the vadose zone, soil, surficial geology and bedrock geology, were used to create average linear velocity grids for each component. Average linear velocity was calculated by dividing the vertical hydraulic conductivity of each component by their respective porosity values.

A residence time grid for each component of the vadose zone was calculated. This was accomplished by dividing the vadose zone thickness grid of each component by their respective average linear velocity grid. Vadose zone residence time grids were created for the soil, surficial geology and bedrock geology components of the vadose zone. The sum of these groundwater residence times is a measure of aquifer susceptibility; an aquifer susceptibility grid of NYS was created.

A NYS groundwater-risk grid was created by dividing a NYS land use-risk grid by a NYS aquifer susceptibility grid. Areas of significant groundwater-risk within NYS are displayed on the NYS groundwater-risk grid. Evaluation of the groundwater-risk grid

was made by correlation maximum and mean grid values within areas of known groundwater contamination, CERCLA NPL groundwater contamination sites in NYS. A 76% correlation of maximum grid values of significant groundwater-risk was made with the CERCLA NPL groundwater contamination site areas. A 45% correlation of mean grid values of significant groundwater-risk was made with the CERCLA NPL groundwater contamination site areas. The strong correlation of significant groundwater-risk values with CERCLA NPL groundwater contamination sites lends a strong degree of confidence to the groundwater-risk grid's ability to assess the potential of groundwater contamination.

The NYS groundwater-risk grid has several practical uses. Businesses may use the groundwater-risk grid to assess their potential to environmental liability. Environmental regulators may use the groundwater-risk grid for inspection targeting and groundwater protection strategies. The aquifer susceptibility grid may also be used in developing aquifer protection strategies; especially those that address future drinking-water needs.

As real world data is digitized and refined with respect to three-dimensional spatial accuracies, groundwater-risk models will become more accurate. This study lays the foundation for future work. As technology advances and land use and hydrogeologic data become digitally available, more complex methods of groundwater-risk cartographic modeling will be devised.

Appendices

,

Appendicesx A: Background, Groundwater Risk Methods

Appendix A: Background, Groundwater Risk Methods

A. DRASTIC Modeling System

A groundwater susceptibility to contamination modeling system called DRASTIC was developed by EPA in 1985 (Aller et al., 1987); this system was devised to regionally map, on a county or state level, areas of relative unconfined aquifer susceptibility to contamination. The DRASTIC method considers the hydrogeologic migration pathway of the groundwater system; it does not consider the potential sources of contaminant introduction nor the potential for human contact and intake. DRASTIC utilizes broad scale hydrogeologic criteria to risk geographic areas for aquifer susceptibility.

Aller et al. (1987) determined that the most important mappable hydrogeologic characteristics that control the groundwater susceptibility to pollution were depth to water-table (D), recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I), and conductivity (hydraulic) (C), hence the acronym DRASTIC. DRASTIC considerations focus on hydrogeologic data which can transport contaminants through the vadose zone and introduce them to the phreatic zone. Depth to the water-table determines the vertical distance that a contaminant must travel before it can be introduced to the aquifer; this is also an important zone of contaminant attenuation. Aquifer recharge areas are characterized by the downward components of groundwater migration; these areas are localities where water is added to aquifer systems. Recharge is estimated by the amount of annual precipitation minus annual evapotranspiration and surface runoff, which is a function of the topography of the drainage basin. Aquifer media refers to the saturated rock system within which groundwater flows; the main

characteristics which determine the speed and volume of groundwater flow are porosity and permeability. Soil media refers to the upper portion of the vadose zone characterized by significant biological activity. Silt, clay and organic matter content within soils can decrease permeability and restrict infiltration, recharge and contaminant migration. Organic matter is composed of decayed plant matter and animal tissues, charcoal and various humic compounds. Organic content decreases with depth. Silts, clays and organic matter give the soil sorption properties. Where the soil zone is thick the attenuation process of filtration, biodegradation, sorption and volatilization may be significant. The topography is classified to estimate the degree of hydraulic head as well as direction and speed of flow, the potentiometric surface is assumed to correspond to topographic slopes. The impact of the vadose zone determines the speed, volume of recharge, and rate of contaminant introduction to the groundwater system. Characteristics such as porosity, tortuosity of the pores, permeability, clay and organic matter, and degree of saturation, influence the rate of contaminant migration through the unsaturated zone. Hydraulic conductivity determines the rate of hydraulic flux, both within the vadose zone and within the aquifer itself. Hydraulic conductivity, aquifer media characteristics (such as porosity) and topography allow a general consideration of the volume, speed and direction of potential contaminant transport within an unconfined aquifer.

The DRASTIC model contains three significant parts: weights, ranges, and ratings. Weights assign each DRASTIC hydrogeologic characteristic a relative importance between 1 and 5, 5 being a characteristic of greater importance in the overall formula. Ranges are the division of each hydrogeologic characteristic into sets or

significant media types which in turn can be assigned a rating; DRASTIC ranges and rating values can be found in Table A1. The DRASTIC ratings vary between 1 and 10; a DRASTIC rating of 10 indicates that the particular range exerts a significant component to groundwater pollution potential.

The equation for determining the DRASTIC Index, a value of relative aquifer susceptibility to contamination, is:

$$DI = (Dr \times Dw) + (Rr \times Rw) + (Ar \times Aw) + (Sr \times Sw) + (Tr \times Tw) + (Ir \times Iw) + (Cr \times Cw)$$

DI = DRASTIC Index

Dr = Depth to Water-Table rating

Dw = Depth to Water-Table weight = 5

Rr = Net Recharge rating

Rw = Net Recharge weight = 4

Ar = Aquifer Media rating

Aw = Aquifer Media weight = 3

Sr = Soil Media rating

Sw = Soil Media weight = 2

Tr = Topography rating

Tw = Topography weight = 1

Ir = Impact of Vadose zone rating

Iw = Impact of Vadose zone weight = 5

Cr = Hydraulic Conductivity of Aquifer rating

Cw = Hydraulic Conductivity of Aquifer weight = 3

Maps of the DRASTIC Index display geographic distribution of the relative potential of unconfined aquifer susceptibility to contamination. The scale and quality of the data needed for input to DRASTIC strongly influence the results of the DRASTIC mapping technique. The EPA (EPA, 1992) analyzed the correlation of results of the National Survey of Pesticides in Drinking Water Well data with DRASTIC index maps produced by Aller et al. (1987) at a scale of 1:2,000,000 and found a very poor

correlation. It was obvious that the quality and scale of the input maps, which determined the hydrogeologic characteristics for DRASTIC evaluation, strongly influenced the quality of the DRASTIC index outputs. Kumar et al. (1999), using source maps of a 1:250,000 scale, displayed a 67% correlation coefficient of groundwater-quality data (nitrate contamination) sampled across the state of Indiana with high and very high DRASTIC index determinations.

Table A1. DRASTIC weights, ranges and ratings.

A) DRASTIC Weights for given features.

<u>Feature</u>	<u>Weight</u>	<u>Weight (Pesticides)</u>
Depth to Water-Table	5	5
Net Recharge	4	4
Aquifer Media	3	3
Soil Media	2	5
Topography	1	3
Impact of the Vadose Zone Media	5	4
Hydraulic Conductivity of the Aquifer	3	2

B) Ranges and ratings for depth to water-table.

<u>Range (meters)</u>	<u>Rating</u>
0 - 1.5	10
1.5 - 4.6	9
4.6 - 9.2	7
9.2 - 15.3	5
15.3 - 22.9	3
22.9 - 30.6	2
> 30.6	1

C) Ranges and ratings for net recharge.

<u>Range (cm)</u>	<u>Rating</u>
0 - 5	1
5 - 10.2	3
10.2 - 17.8	6
17.8 - 25.4	8
> 25.4	9

Table A1 (continued). DRASTIC weights, ranges and ratings.

D) Ranges and ratings for aquifer media.

<u>Range</u>	<u>Rating</u>	<u>Typical Rating</u>
Massive Shale	1 - 3	2
Metamorphic/Igneous	2 - 5	3
Weathered Metamorphic/Igneous	3 - 5	4
Glacial Till	4 - 6	5
Bedded Sandstone, Limestone and Shale Sequences	5 - 9	6
Massive Sandstone	4 - 9	6
Massive Limestone	4 - 9	6
Sand and Gravel	4 - 9	8
Basalt	2 - 10	9
Karst Limestone	9 - 10	10

E) Ranges and ratings for soil media.

<u>Range</u>	<u>Rating</u>
Thin or Absent	10
Gravel	10
Sand	9
Peat	8
Shrinking and/or Aggregated Clay	7
Sandy-Loam	6
Loam	5
Silty Loam	4
Clay Loam	3
Muck	2
Nonshrinking and Nonaggregated Clay	1

Table A1 (continued). DRASTIC weights, ranges and ratings

F) Ranges and ratings for topography

Range (percent slope) Rating

0 - 2	10
2 - 6	9
6 - 12	5
12 - 18	3
18+	1

G) Ranges and rating for impact of vadose zone media

<u>Range</u>	<u>Rating</u>	<u>Typical Rating</u>
Confining Layer	1	1
Silt / Clay	2 - 6	3
Shale	2 - 5	3
Limestone	2 - 7	6
Sandstone	4 - 8	6
Bedded Limestone, Sandstone, Shale	4 - 8	6
Sand and Gravel with significant Silt and Clay	4 - 8	6
Metamorphic / Igneous	2 - 8	4
Sand and Gravel	6 - 9	8
Basalt	2 - 10	9
Karst Limestone	8 - 10	10

H) Ranges and rating for hydraulic conductivity.

<u>Range (m/s)</u>	<u>Rating</u>
4.72×10^{-7} - 4.72×10^{-5}	1
4.72×10^{-5} - 1.42×10^{-4}	2
1.42×10^{-4} - 3.30×10^{-4}	4
3.30×10^{-4} - 4.72×10^{-4}	6
4.72×10^{-4} - 9.44×10^{-4}	8
$> 9.44 \times 10^{-4}$	10

B. EPA Region 2 Long Island Groundwater Risk Analysis

EPA Region 2 (Hillenbrand, Hansen and Ferri, 1995) devised a groundwater-risk analysis method utilizing GIS technology. Unlike the DRASTIC method which concentrates on risk analysis of the groundwater migration pathway components, this method, in addition to aquifer susceptibility assessment, considers potential sources of contamination as a function of land-use and potentially exposed populations as a function of census-tract data. The EPA Region 2 groundwater-risk scheme utilized existing and derived GIS coverages which were input to a modified Health Risk Index (HRI) formula (Carney, 1991). The HRI is the product of exposure and hazard. Exposure is the ratio of population exposed to total population, multiplied by an exposure factor (percent of time exposed). The hazard component of the HRI is a product of degree of impact and degree of vulnerability. The degree of impact is a chemical specific component in the HRI which assesses the degree of cancer and non-cancer potency, mutagenicity, environmental fate and pharmacokinetics. The degree of vulnerability component in the HRI is a measure of the vulnerability of the population to adverse reaction due to exposure; factors such as age, lifestyle and preexisting disease are quantified when selecting a degree of vulnerability. In the Long Island study, EPA Region 2 used a GIS population density coverage (census tracts) to obtain an ordinaly ranked exposure factor, a generalized GIS land-use rank coverage for the degree of impact, and a calculated GIS aquifer susceptibility coverage for the degree of vulnerability. The aquifer susceptibility was calculated by dividing a depth to water-table GIS grid by a soil permeability GIS grid; the calculated transport times were ranked ordinaly to show the relative

susceptibility of the unconfined aquifers. A local adjustment factor was used to prioritize areas of vertical groundwater flow (aquifer recharge areas) over areas of predominant horizontal transport. The following formula was used to calculate the total groundwater-risk (TGR):

$$\text{TGR} = \text{PDR} \times \text{LUR} \times \text{ASR} \times \text{LAF}$$

TGR = Total groundwater-risk

PDR = Population density risk rank (1 - 10)

LUR = Land-use risk rank (1 - 10)

ASR = Aquifer susceptibility risk rank (1 - 10)

LAF = Local adjustment factor (1 - 2)

The EPA Region 2 Underground Injection Control (UIC) Section used the resultant maps derived from the GIS analysis for inspection targeting on Long Island. The EPA Region 2 GIS study prioritized areas for inspection where aquifer systems may be most susceptible to contamination and impact the most people (Hillenbrand, Hansen and Ferri., 1995).

C. LeGrande System

The LeGrande System (LeGrande, 1983) of evaluating the potential risk of groundwater contamination was developed to compare geographic areas prior to siting a waste-disposal facility. The LaGrande System is a method which reviews the severity of potential contaminant sources, the hydrogeologic properties of the groundwater migration pathway, and points of potential human contact. Unlike the DRASTIC and EPA Region 2 methods, the LeGrande System requires site-specific data such as a more detailed description of contaminant sources, severities and quantities; locations of water-supply sites and the distance separating a potential contaminant source from the water-supply sites; and local hydrologic characteristics such as water-table doming or cones of depression. The system creates a cumbersome combined numeric-lettered description. The LeGrande evaluation system compares site specific values with values representative of an approximate “upper limit” to protect an aquifer system.

The LeGrande System focuses on the unconfined aquifers in the area of a potential waste disposal site; LeGrande stated that 99% of all groundwater contamination problems, excluding salt intrusion, occur in unconfined aquifers. Thus, the unsaturated zone, where water and leachable contamination have a predominant vertical movement downward from the land surface to the water-table, and the uppermost saturated zone, where water has a predominant horizontal movement, are the two zones that are of special importance in this rating system. Unlike the previously discussed qualitative methods, the LeGrande method refined the consideration of migration and attenuation of

contaminants within a hydrogeologic environment; a contaminant is weakened by attenuation in the natural system away from its source by a combination of dilution, sorption on earth materials and some sort of decay mechanism.

LeGrande's System uses a numeric-letter method of describing site hydrogeology, a function of four key factors. First, the distance between the contamination source and nearest contact point, such as a water-supply well, is given a value between 0 and 9 based on specific ranges. Secondly, based on the range of depth of the water-table, a value between 0 and 9 is assigned. Thirdly, a value between 0 and 5 is assigned based on the characteristics of groundwater flow speed and direction. Fourthly, a porosity-sorption number and letter are given as an indicator to characterize the ability of the unsaturated and saturated zones to attenuate contaminants; this value takes into consideration unconsolidated material and fractured bedrock. Following step 4, the numbers of the first four steps are added together and placed at the beginning of the descriptive term for comparison of potential waste disposal sites. A letter (A, B or C), A being a high degree of confidence and C being the lowest, is used in the formula following the hydrogeologic terms to assess the degree of confidence in the first four assigned hydrogeologic values. Another letter follows the degree of confidence letter and indicates whether the human contact point is a well, spring, perennial stream or property boundary. This letter is followed by another, or two letters, which describe special circumstances such as mounding of the water-table under a contamination source, closeness to a water-supply well cone of depression, or a water-table in fractured or karst settings. The final letters, after an addition symbol (+) are given to describe a degree of seriousness based on

aquifer sensitivity and contaminant severity. The degree of seriousness is determined by a chart; the axes of the “degree of seriousness” chart are aquifer sensitivity and contaminant severity. Aquifer sensitivity is determined mainly by its rock type and permeability - sorption characteristics. Aquifer sensitivity is rated as sensitive, moderately sensitive or insensitive. The contaminant severity is a composite term; it includes qualitative weighting of toxicity, concentration and volume, mobility in water and persistence. The contaminant severity is rated as low, moderate or high and is based on industry classifications. Refer to the reference LeGrande, 1983 and Table A2 for the specifics of the LeGrande System range and rating components.

An example of a LeGrande rating for a sanitary landfill follows:

21-3936ABWD+E

This example signifies that a comparative risk of 21 is calculated by adding the first four numbers in the example; 3, 9, 3 and 6. From the first number, 3, and the LeGrande reference table (found below), the distance between the contamination source and nearest contact point was determined to be between 300 and 999 meters. The second number, 9, signifies that the range of depth of the water-table is less than 3 meters. The third number, 3, was assigned that value to specify that hydraulic gradient between the potential sanitary landfill and water supply is less than 2 percent, and water flow is in the direction from landfill toward water supply. The fourth number and letter, 6A, signifies that the aquifer matrix consists of greater than 30 meters of sand with less than 15% of clay. The next letter, B, asserts the degree of confidence in the first four assigned hydrogeologic values; in this case, B, indicates that the precise measurements were not

available to obtain point values, but that the estimates appear to be reasonably accurate.

The letter W in the formula designates that the contact source is a water-supply well. The fourth letter, D, signifies that a cone of depression from the pumping water well exists near the potential sanitary landfill. The last letter, E, following the (+) designates that the overall degree of seriousness, based on interactions between contaminant severity, ranked as moderate, and aquifer sensitivity, ranked as moderately sensitive; E signifies a moderately high hazard potential

The LeGrande system enables the evaluation of a potential site's probability of contamination and degree of acceptance. A site is entered into the "hazard potential matrix" in a similar fashion as entered into the "degree of seriousness" chart, based on aquifer sensitivity and contaminant severity. The "hazard potential matrix" possesses a PAR value, which is a value representing a performance standard to which individual site descriptions are compared; the PAR value is the approximate upper limit value of a site for a given total value and permeability-sorption value that should not be exceeded to assure protection of an aquifer. The PAR total value and permeability-sorption value are subtracted from a site's calculated total number and permeability-sorption value; the results are added to produce a hazard potential value; negative values pose a minimal hazard to groundwater, whereas large positive values pose a significant threat of contamination.

Table A2. LeGrande system values for classification components.

A) Determine the distance on ground between contamination source and water supply

<u>Distance (meters)</u>	<u>Point Value</u>
2000+	0
1000 - 2000	1
300 - 999	2
150 - 299	3
75 - 149	4
50 - 74	5
35 - 49	6
20 - 34	7
10 - 19	8
0 - 9	9

B) Estimate the depth to the water-table below base of contamination source more than 5% of the year.

<u>Depth (meters)</u>	<u>Point Value</u>
60+	0
30 - 60	1
20 - 29	2
12 - 19	3
8 - 11	4
5 - 7	5
3 - 4	6
1.5 - 2.5	7
0.5 - 1	8
0	9

Table A2 (continued). LeGrande system values for classification components.

C) Estimate water-table gradient from contamination site.

<u>Water-Table Gradient and Flow Direction</u>	<u>Point Value</u>
Gradient away from all water supplies that are closer than 1000 meters	0
Gradient almost flat	1
Gradient less than 2 percent toward water supply, but not the anticipated direction of flow	2
Gradient less than 2 percent toward water supply and is the anticipated direction of flow	3
Gradient greater than 2 percent toward water supply, but not the anticipated direction of flow	4
Gradient greater than 2 percent toward water supply, and is the anticipated direction of flow	5

Table A2 (continued). LeGrande system values for classification components.

D) Permeability-Sorption Value, I = shale bedrock; II = non-shale, fractured bedrock

	<u>Clay</u>		<u>Clay, < 50% Sand</u>		<u>Sand, 15 - 30% Clay</u>		<u>Sand, < 15% Clay</u>		<u>Clean Fine Sand</u>		<u>Clean Gravel, Coarse Sand</u>	
	I	II	I	II	I	II	I	II	I	II	I	II
More than 30	0A		2A		4A		6A		8A		9A	
25 - 29	0B	1C	1D	2F	3E	4G	5F	6E	7F	8E	9G	9M
Thickness of Unconsolidated Materials Over Bedrock (meters)												
20 - 24	0C	2C	1E	3D	4D	5E	5G	6F	7G	8F	9H	9N
15 - 19	0D	3B	1F	4C	4E	6C	5H	7D	7H	8G	9I	9O
10 - 14	0E	4B	2D	5B	4F	6D	5I	7E	7I	9D	9J	9P
3 - 9	1B	6B	2E	7B	5C	7C	5J	8D	7J	9E	9K	9Q
Less than 3	2B	8B	3C	8C	5D	9B	5K	9C	7K	9F	9L	9R
Bedrock at land surface I = 5Z, II = 9Z												

Table A2 (continued). LeGrande system values for classification components.

E) Degree of confidence in accuracy of values (choose appropriate category)

<u>Degree of Confidence</u>	<u>Value</u>
Confidence in estimates of values for the parameters is high and estimated values are considered to be fairly accurate	A
Confidence in estimates of values for the parameters is fair	B
Confidence in estimates of values for the parameters is low and estimated values are not considered to be accurate	C

F) Third letter, designates type of target away from contaminant source

<u>Description</u>	<u>Value</u>
Well	W
Stream or perennial spring	S
Property boundary	B

Table A2 (continued). LeGrande system values for classification components.

G) Fourth (and Fifth) letter designates special circumstances

<u>Description</u>	<u>Value</u>
Special conditions require that a comment or explanation be added to the evaluation	C
Cone of pumping depression near a contamination source, which may cause contaminated ground water to be directed toward the pumped well	D
Distance recorded is that from a water supply to the estimated closest edge of an existing plume rather than to the original source of contamination	E
Indicates the contamination source is located on a groundwater discharge area such as a flood plain, and would likely cause minimal groundwater contamination	F
The site is located in karst topography or is underlain by cavernous limestone	K
Mounding of the water table beneath a contamination site - common beneath waste sites where there is a liquid input	M
Percolation may not be adequate - the permeability-sorption digit suggests the degree to which percolation may be a problem, a digit of 3 or less being a special warning of poor percolation	P
Designates a "recharge or transmission" part of an extensive aquifer that is sensitive to contamination - may be suggested by a high value on the permeability-sorption scale	Q

Table A2 (continued). LeGrande system values for classification components.

Radial or partial radial flow from a high water-table position (two or more site ratings may be needed)	R
Indicates that the water-table is fractured or cavernous rock	T
One or more confined (artesian) aquifers underlie the water-table aquifer	Y

D. EPA Hazardous Ranking System

CERCLA required that a contaminated site ranking system, known as the Hazardous Ranking System (HRS), be established. The HRS (EPA, 1984) uses site-specific qualitative data to risk-rank a site. The ranking system assesses relative risk, taking into account the hazardous potential of contaminants at the site, the potential for contamination migration, the potential of population exposure and intake, the potential to destroy sensitive ecosystems, and the potential for fire and explosion. HRS enables site comparisons, which in turn facilitates an appropriate consideration for remedial action funding. The high-risk facilities selected for remediation are placed on the National Priority List (NPL).

The HRS assigns three hazard mode scores to a contaminated facility; the three hazard modes are migration, fire or explosion, and direct contact. The migration score assesses a relative risk to humans or the environment caused by the migration of hazardous substances away from a source of contamination via groundwater, surface water, and air routes; this score is used to compare sites for NPL consideration. The fire or explosion score reflects the risk of harm from substances that can explode or cause fire. The direct contact score addresses the potential for harm from direct contact with hazardous substances at the facility; migration does not need to be involved. The fire or explosion score and the direct contact score are used to identify facilities requiring emergency action.

The score of each migration hazard mode component, groundwater, surface water and air, is obtained by considering a set of factors under the heading of specific categories. Factors associated with the specific categories are listed in Table A3. This study will consider the establishment of the groundwater component of the migration hazard mode. The groundwater component score is determined by selecting numeric values for the various factors (see tables below), then placing the selected numeric values into a set formula. The numeric values are weighted in the formula, then the weighted values which fall under the appropriate factor categories are added together. The sums of the individual factor categories are then multiplied. The product of the factor categories is then divided by the product of factor categories using maximum numeric values for the factors; for the groundwater component the maximum multiplied category scores is 57,330. In essence this calculated value is a percent of the maximum score value. This value is then multiplied by 100 so a number between 0 and 100 is derived. For the groundwater migration route score the following formula applies:

$$\text{Sgw} = \frac{[(\text{DA} \times 2) + (\text{NP} \times 1) + (\text{KV} \times 1) + (\text{PS} \times 1)] \times [\text{C} \times 1] \times [(\text{TP} \times 1) + (\text{Hw} \times 1)] \times [(\text{GU} \times 1) + (\text{DP} \times 1)]}{57,330} \times 100$$

Sgw = Groundwater Route Score

DA = Depth to Aquifer Factor (Weighting Factor = 2)

NP = Net Precipitation Factor (Weighting Factor = 1)

KV = Permeability of the Vadose zone Factor (Weighting Factor = 1)

PS = Physical State Factor (Weighting Factor = 1)

C = Containment Factor (Weighting Factor = 1)

TP = Toxicity/Persistence Factor (Weighting Factor = 1)

HW = Hazardous Waste Quantity Factor (Weighting Factor = 1)

GU = Groundwater Use Factor (Weighting Factor = 1)

DP = Distance to Nearest Well/Population Served Factor (Weighting Factor = 1)

For the migration hazard mode a composite score is obtained from the three possible migration routes; groundwater, surface water and air, according to the following formula:

$$S_m = 1/1.73 (S_{gw}^2 + S_{sw}^2 + S_a^2)^{1/2}$$

S_m = Migration Mode Score

S_{gw} = Groundwater Route Score

S_{sw} = Surface Water Route Score

S_a = Air Route Score

The resultant migration mode score ranges between 0 and 100 and is used for comparing sites for NPL consideration. The HRS does not quantify the probability of risk from a facility, but rather approximates the element of risk.

Table A3. EPA Hazardous Ranking System; Factors, Characteristics and Values.

HRS groundwater migration factors and values

<u>Factor (Weighting Factor)</u>	<u>Characteristics</u>	<u>Value</u>
<u>Route Characteristics Category</u>		
Depth to the Aquifer of Concern Factor (2)		
	> 150 feet	0
	76 to 150 feet	1
	21 to 75 feet	2
	0 to 20 feet	3
Net Precipitation Factor (1)		
	< -10 inches	0
	-10 to +5 inches	1
	+5 to +15 inches	2
	> +15 inches	3
Permeability of the		
Unsaturated (Vadose) Zone Factor (1)		
<u>Rock Types</u>	<u>Hydraulic Conductivity (cm/s)</u>	<u>Value</u>
Clay, compact till, shale; unfractured metamorphic and igneous rock	less than 10^{-7}	0
Silt, loess, silty clays, silty loams; less permeable limestones, dolostones and sandstones; moderately permeable till	10^{-5} to 10^{-7}	1
Fine sand and silty sand; sandy loams; loamy sands; moderately permeable limestones, dolostones, and sandstones (no karst); moderately fractured igneous and metamorphic rocks, some coarse till	10^{-3} to 10^{-5}	2

Table A3 (continued). EPA Hazardous Ranking System.

Gravel, sand; highly fractured igneous and metamorphic rocks; permeable basalt and lavas; karst limestones and dolostones		greater than 10^{-3}	3
Physical State Factor (1)			
		Solid, consolidated or stabilized	0
		Solid, unconsolidated or unstabilized	1
		Powder or fine material	2
		Liquid, sludge or gas	3
<u>Containment Category</u>			
Containment Factor (1)			
Surface Impoundment	Sound run-on diversion structure, essentially Non permeable liner (natural or artificial) compatible with the waste, and adequate leachate collection system		0
	Essentially non permeable compatible liner with no leachate collection system; or inadequate freeboard		1
	Potentially unsound run-on diversion structure; or moderately permeable compatible liner		2
	Unsound run-on diversion structure; no liner or incompatible liner		3
Containers	Containers sealed and in sound condition, adequate liner, and adequate leachate collection system		0
	Containers sealed and in sound condition, no liner or moderately permeable liner		1
	Containers leaking, moderately permeable liner		2

Table A3 (continued). EPA Hazardous Ranking System

	Containers leaking and no liner or incompatible liner	3
Piles	Piles uncovered and waste stabilized; or piles covered, waste unstabilized, and essentially non permeable liner	0
	Piles uncovered, waste unstabilized, moderately permeable liner, and leachate collection system	1
	Piles uncovered, waste unstabilized, moderately permeable liner, and no leachate collection system	2
	Piles uncovered, waste unstabilized, and no liner	3
Landfill	Essentially non permeable liner, liner compatible with waste, and adequate leachate collection system	0
	Essentially non permeable compatible liner, no leachate collection system, and landfill surface precludes ponding	1
	Moderately permeable, compatible liner, and landfill surface precludes ponding	2
	Non liner or incompatible liner, moderately permeable compatible liner, landfill surface encourages ponding; no run-on control	3

Waste Characteristics Category**Toxicity/Persistence Factor (1)**

The toxicity/persistence value is a cross-referenced value based on the value of the individual components - toxicity and persistence.

Table A3 (continued). EPA Hazardous Ranking System.

Toxicity/Persistence Factor (1), continued

Toxicity values are established by examining the most toxic substance found at the site accordingly:

No toxicity - no acute or chronic effects to humans	0
Slight toxicity - acute or chronic effects to humans which cause slight effects which are non-life threatening and reversible	1
Moderate toxicity - acute or chronic effects to humans which cause non-life threatening effects and may be reversible or irreversible	2
Severe toxicity - acute or chronic effects to humans which can cause death or serious physical impairment	3

Persistence of each hazardous substance is evaluated on its biodegradability as follows:

Easily biodegradable compounds	0
Straight chain hydrocarbons	1
Substituted and other ring compounds	2
Metals, polycyclic compounds and halogenated hydrocarbons	3

The cross-referenced value is obtained accordingly:

Value of Toxicity	Value of Persistence			
	0	1	2	3
0	0	0	0	0
1	3	6	9	12
2	6	9	12	15
3	9	12	15	18

Table A3 (continued). EPA Hazardous Ranking System.

Hazardous-Waste Quantity Factor (1)

<u>Tons/Cubic Yards</u>	<u>Number of Drums</u>	
0	0	0
1 to 10	1 to 40	1
11 to 62	41 to 250	2
63 to 125	251 to 500	3
126 to 250	501 to 1000	4
251 to 625	1001 to 2500	5
626 to 1250	2501 to 5000	6
1251 to 2500	5001 to 10000	7
> 2500	> 10000	8

Target Category**Groundwater Use Factor (3)**

Unusable (e.g., extremely saline aquifer, extremely low yield, etc.)	0
Commercial, industrial or irrigational and another source presently available not used, but usable	1
Drinking water with municipal water from alternate unthreatened sources presently available (i.e., minimal hookup requirements); or commercial, industrial or irrigation with no other water source presently available	2
Drinking water; no municipal water from alternate unthreatened sources presently available	3

Distance to Nearest Well/Population Served Factor (1)

The distance to nearest well/population served is a cross-reference value obtained as follows:

Table A3 (continued). EPA Hazardous Ranking System

Distance to Nearest Well	Value
> 3 miles	0
2 to 3 miles	1
1 to 2 miles	2
2001 feet to 1 mile	3
< 2000 feet	4
Population Served by Well	Value
0	0
1 to 100	1
101 to 1000	2
1001 to 3000	3
3001 to 10000	4
> 10000	5

Value of Population Served	Value of Distance to Nearest Well				
	0	1	2	3	4
0	0	0	0	0	0
1	0	4	6	8	10
2	0	8	12	16	20
3	0	12	18	24	30
4	0	16	24	32	35
5	0	20	30	35	40

E. Michigan Site Assessment System

The State of Michigan Department of Natural Resources (MDNR) developed a rating scheme, the Site Assessment System (SAS), designed to rank large numbers of contaminated sites within the State of Michigan for clean-up prioritization purposes; this system is similar in purpose to the federal HRS. The MDNR in effect revised the HRS to include a more detailed evaluation of chemical hazards and considers the importance of existing exposure of human population to chemical contaminants.

The SAS was designed to prioritize sites for clean up, using limited resources. Like the HRS, the SAS relies on site-specific qualitative data. The calculated risk is a function of hazard and exposure. The SAS site score is a product of a chemical hazard score and a site subscore:

$$\text{SAS} = \text{CHS} \times \text{SS}$$

SAS = SAS site score

CHS = Chemical hazard score

SS = Site subscore (exposure component)

The chemical hazard score assesses the hazard posed by a substance from toxicity and flammability/reactivity and is much more detailed than the Waste Characteristics Category of the HRS. The chemical hazard score considers chemical characteristics and quantity associated with sites to assess levels of concern. The scoring system uses known literature sources and professional agency data to evaluate known chemicals. The chemical hazard scoring system considers quantity; potential toxicity; and

flammability/reactivity of identified and unidentified constituents of the waste. The formula uses level of concern values determined from potential toxicity scores and flammability/reactivity scores.

$$CHS = (((ICQ/TWQ) \times LCI) + ((UCQ/TWQ) \times LCU) + (((ICQ/TWQ) \times LFI) + ((UCQ/TWQ) \times LFU)$$

CHS = Chemical hazard score

ICQ = Identified chemicals quantity, kg

TWQ = Total waste quantity, kg

LCI = Level of concern/potential toxicity, identified chemicals

LCU = Level of concern/potential toxicity, unidentified waste

LFI = Level of concern/flammability, identified chemicals

LFU = Level of concern/flammability, unidentified waste

From the types and numbers of containment structures on a site, the total on-site waste quantity (TWQ) must be calculated. The quantity of each identified chemical must be determined (the sum of these quantities is the ICQ) as well as the quantity of unidentified waste constituents (UCQ).

The potential toxicity of each identified chemical is evaluated based on scoring values acquired for the subcategories acute toxicity, genotoxicity, subchronic/chronic toxicity, ecological toxicity, bioaccumulation, and persistence. The acute toxicity subcategory value is based on LD₅₀ or LC₅₀ values generated in tests involving oral, dermal or inhalation dosages of the species most sensitive to the chemical of concern. Genotoxic effects rated by SAS include carcinogenicity, hereditary mutagenicity, and mutagenicity in single cell test systems. Chemicals demonstrated to be positive or potential carcinogens in humans or animals based on data reported by the International Agency for Research on Cancer, the National Cancer Institute, or the National Institute

for Occupational Safety and Health are valued as carcinogens. Hereditary mutagenicity has been defined as the ability of a chemical to produce a statistically significant dose related mutation in a complex multicellular organism with mutations heritable in subsequent generations of the test organism. Subchronic and chronic toxicity are evaluated on the basis of evidence documenting the occurrence or irreversible adverse health effects. Adverse health effects are effects which result in functional impairment and/or pathological lesions which may affect the performance of the whole organism, or which reduce an organism's ability to respond to an additional challenge. Ecological toxicity considers measurements of toxicity to fish, other aquatic organisms, birds and plants; the organism with the most sensitive effect to the given chemical is used for scoring. Bioaccumulation values are based on either fish bioaccumulation or on the octanol/water coefficient ($\log K_{ow}$). The persistence value is based on a contaminant's half-life measured in air, water or soil. Each factor is then multiplied by an uncertainty factor, based on the reliance and availability of data used to assign a score.

A potential toxicity score is derived by a complicated process. First, all potential toxicity subcategory values (acute toxicity, genotoxicity, subchronic/chronic toxicity, ecological toxicity, bioaccumulation and persistence) are summed for individually identified chemicals. The sum of the components is then multiplied by a "Data Uncertainty Multiplier", which is based on the lack of available data and the lack of placement of a value in one or more of the potential toxicity subcategories as follows:

<u>Potential Toxicity Subcategories with no Value</u>	<u>Data Uncertainty Multiplier</u>
0 - 1	1.2

2 - 3	1.5
4-5	1.8

The calculated value, potential toxicity, for the individually identified chemicals is then placed into one of four categories base on the values listed below:

Category I, potential toxicity values 1 to 20

Category II, potential toxicity values 21 to 40

Category III, potential toxicity values 41 to 60

Category IV, potential toxicity values greater than 60

The quantity of chemicals for each category is entered into a level of concern chart (see below) to determine a category level of concern; the category level of concerns are summed and entered in the formula above as LCI. The quantity of unidentified chemicals is entered into a level of concern chart to determine the level of concern for unidentified waste components (LCU).

Reactivity and flammability scores are assigned to each chemical based on the ranking system developed by the National Fire Protection Association. The sum of the individual quantities of the four different scores are summed and placed in a Flammability/Reactivity level of concern chart. The obtained sum (LFI) of the Flammability/Reactivity level of concern values for identified chemicals is place in the Chemical Hazard Score formula above. For unknown waste constituents a Flammability/Reactivity level of concern score is obtained by considering the source of the waste: domestic or commercial waste, light industry and assembly waste, heavy manufacturing waste, or chemical production waste; this value (LFU) obtained by a chart

is placed in the Chemical Hazard Score formula above.

The Site Subscore (the exposure component of the SAS site score) assumes there are five routes through which contaminants can be released to the environment or by which exposure can occur - groundwater, surface water, air, direct contact, and fire-and-explosion. Each route is investigated by evaluating four categories: release potential, environmental exposure, targets, and existing exposure. Scoring values for the category factors pertaining to groundwater can be found in Table A4.

For the groundwater component of the site subscore, the following formula applies:

$$SS = (GWR \times (GWE + GWT)) + GWX$$

SS = Site subscore (exposure component)

GWR = Groundwater release potential

GWE = Groundwater exposure

GWT = Groundwater targets

GWX = Groundwater existing exposure

The release potential evaluates the ability of the potential contaminant source to release substances to the migration pathway; adequacy of containment and physical state of the contaminants are evaluated. The groundwater component of the release potential is calculated by using the following formula:

$$GWR = \sum(QF/TQ) \times PS$$

GWR = Groundwater release potential

QF = Quantity in containment structure

QT = Total quantity of containment structure (volume size)

PS = Physical state factor

The formula uses physical state values and adequacy of containment determined by calculating the percent by containment volume of contaminant product within the containment structure.

The environmental exposure category assesses the ability of the contaminant to enter or move along a specific route; for groundwater, the permeability and thickness of the unsaturated zone are used to obtain a factor value.

Target evaluation considers human population, non-human life resources, and ecosystems that may be affected by a substance entering a specific route; the target category considers two sub-categories: population at risk and resource value. For the groundwater route the population at risk score is calculated by first determining a target area. The target area may be estimated by creating a semi-circle in the downgradient direction from a contaminated site with a radius of approximately $\frac{1}{2}$ mile. SAS considers that a plume of contaminants generally moves directionally from a site rather than radially; an assumption is made that drinking water wells downgradient from a contamination site will most likely intercept contaminants flowing in the groundwater away from the site. Secondly, the population within this area is determined by counting the number of homes, businesses, hospitals, schools etc. within the area. The number of homes dependent on public water-supply wells located within the target area must also be considered; actual population estimates of people dependent upon a public well may be obtained from municipal authorities. For each building, a multiple of 4 is used to determine population. If homes are seasonally occupied, the multiple is 2. From the population estimate, a score is determined by considering a chart (displayed below).

The resource value scores are based on the thickness of the saturated aquifer and its permeability. The target category subscore is determined using the following formula:

$$\text{GWT} = \text{GWP} + \text{GWV}$$

GWT = Groundwater targets

GWP = Groundwater population at risk

GWV = Groundwater resource value

The existing exposure category considers the magnitude of human population presently exposed to a substance that has entered a specific route. Documentation must exist demonstrating that a set population is being exposed to a chemical. The groundwater existing exposure subscore is determined by considering the concentration of individual chemicals above State and Federal Maximum Contamination Levels (MCL) and the population being exposed to the chemical. The population being exposed is determined as discussed above in the target category. Scores are determined by considering the tables listed below. The following formula is used to determine the groundwater existing exposure subscore:

$$\text{GWX} = \sum (\text{CES} \times \text{EEP})_{\text{chemical}}$$

GWX = Groundwater existing exposure

CES = Chemical exposure score

EEP = Existing exposure population

The maximum SAS numeric value of a site is 2,000, and is composed of a maximum of 1,400 from the release potential, environmental exposure, targets and existing exposure components of all the routes, the site subscore (exposure factor); and 600 from the chemical hazard score. For specifics of the scoring procedures for the total

SAS value, refer to the reference MDNR, 1983.

Table A4. MDNR SAS Values for Categories and Subcategories Applicable to Groundwater

<u>Factor</u>	<u>Characteristics</u>	<u>Value</u>
CHEMICAL HAZARD SCORE		
Potential Toxicity Score		
Acute Toxicity Subfactor		
<u>Oral LD₅₀</u>	<u>Dermal LD₅₀</u>	<u>Inhalation LC₅₀</u>
≤ 5 mg/kg	≤ 5 mg/kg	≤ 0.5 mg/l
5 - 500 mg/kg	5 - 500 mg/kg	0.5 - 20 mg/l
≥ 500 mg/kg	≥ 500 mg/kg	≥ 20 mg/l
		10
		5
		0
Genotoxicity Subfactor		
A) The chemical has been demonstrated to be a human positive, potential human, animal positive or potential animal carcinogen by any route of exposure based on data reported by the International Agency for Research on Cancer (IARC), or the National Cancer Institute (NCI), or the National Institute for Occupational Safety and Health (NIOSH), or the National Toxicity Program (NTP). AND The chemical has been demonstrated to be a hereditary mutagen in a multicellular organism. The chemical produces a statistically significant dose related mutation in a complex multicellular organism (i.e., plants, insects, rodents, etc.) with mutations inheritable in subsequent generations of the test organism.		20
B) The chemical has been demonstrated to be a human positive, potential human, animal positive or potential animal carcinogen by any route of exposure based on data reported by the International Agency for Research on Cancer (IARC), or the National Cancer Institute (NCI), or the National Institute for Occupational Safety and		10

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

Health (NIOSH), or the National Toxicity Program (NTP).

OR

The chemical has been demonstrated to be a hereditary mutagen in a multicellular organism. The chemical produces a statistically significant dose related mutation in a complex multicellular organism (i.e., plants, insects, rodents, etc.) with mutations inheritable in subsequent generations of the test organism.

C) The chemical has been demonstrated by accepted mutagenicity tests, cell transformation or promotion studies to be a suspect or strongly suspect carcinogen.	5
D) The chemical has been tested for human and/or animal carcinogenicity and for mutagenicity in single cell test systems according to acceptable testing protocols and has been shown not to be a positive, potential or suspect carcinogen in humans or animals.	0

Subchronic/Chronic Toxicity Subfactor

A) The chemical has been demonstrated to produce an irreversible adverse effect at a very low dose (i.e., <0.5 mg/kg, <0.05 mg/l) by oral, dermal or inhalation route of exposure.	20

AND

The chemical has been demonstrated to be teratogen in at least one well conducted mammalian study via the oral, dermal or inhalation route of exposure.

B) The chemical has been demonstrated to produce an irreversible adverse effect at a very low dose (i.e., <0.5 mg/kg, <0.05 mg/l) by oral, dermal or inhalation route of exposure.	10

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

OR

The chemical has been demonstrated to be teratogen in at least one well conducted mammalian study via the oral, dermal or inhalation route of exposure.

C)	The chemical has been demonstrated to produce an adverse effect at low doses via the oral, dermal or inhalation route of exposure.	5
D)	The chemical has been tested at low doses in animals or humans according to accepted testing protocols and has been shown not to cause an irreversible effect.	0

Ecological Toxicity Subfactor

A)	Fish 96 hour $LC_{50} \leq 1$ mg/l	10
	or	
	Aquatic Life Chronic $EC_{50} \leq 0.1$ mg/l	
	or	
	LD_{50} in Avian species ≤ 5 mg/l	
B)	Fish 96 hour LC_{50} 1 - 100 mg/l	5
	or	
	Aquatic Life Chronic EC_{50} 0.1 - 10 mg/l	
	or	
	LD_{50} in Avian species 5 - 500 mg/l	

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

	or	
	Mean Inhibitory Limit (ILM) in Terrestrial Plants ≤ 5 mg/l	
C)	Fish 96 hour $LC_{50} > 100$ mg/l	0
	or	
	Aquatic Life Chronic $EC_{50} > 10$ mg/l	
	or	
	LD_{50} in Avian species > 500 mg/l	
	or	
	Mean Inhibitory Limit (ILM) in Terrestrial Plants > 5 mg/l	
Bioaccumulation Subfactor		
A)	Fish Bioconcentration Factor $> 4,000$	10
	or	
	$\text{Log } K_{ow} > 6$	
B)	Fish Bioconcentration Factor = 700 - 4,000	5
	or	
	$\text{Log } K_{ow} = 4.5 - 6$	
C)	Fish Bioconcentration Factor < 700	0
	or	

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

$$\text{Log } K_{ow} < 4.5$$

Persistence Subfactor

Half-life in soil, air or water > 6 months	5
Half-life in soil, air or water < 6 months	0

Flammability and Reactivity of Identified Chemicals

<u>Flammability Criteria</u>	<u>Reactivity Criteria</u>	
A) Very flammable gasses or very volatile flammable liquids, and materials that in the form of dusts or mists readily form explosive mixtures when dispersed in air. or If no NFPA rating is available; the material has been identified as having a flash point <0°F.	Materials which in themselves are readily capable of detonation or of explosive decomposition or explosive reaction at normal temperatures and pressures. Includes materials which are sensitive to mechanical or localized shock.	4
B) Liquids which can be ignited under all normal temperature conditions. Any material that ignites spontaneously at normal temperatures in air. or If no NFPA rating is available; the material has been identified as having a flash point ≥0°F - ≤100°F	Materials which in themselves are capable of detonation or of explosive decomposition or of explosive reaction but which require a strong initiating source or which must be heated under confinement before initiation. Includes materials which are sensitive to thermal or mechanical shock at elevated temperatures and pressures or which react explosively with water without requiring heat or confinement.	3

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

C) Liquids which must be moderately heated before ignition will occur and solids that readily give off flammable vapors. or If no NFPA rating is available; the material has been identified as having a flash	Materials which in themselves are normally unstable and readily undergo violent chemical change but do not detonate. Includes materials which can undergo chemical change with rapid release of energy at normal temperatures and pressures. Also includes those materials which may react violently with water or which may form potentially explosive mixtures with water.	2
D) All other materials.	All other materials	0

SITE SUBSCORE (Exposure Component)

Release Potential Category

Physical State Factor

Physical State	Solid	1.0
	Semi-solid	1.5
	Liquids and Gases	2.0
Containment Structure	Demolition Waste	1.0
	General Waste	1.25
	Industrial Waste	1.5*
	Organic Chemical	
	Industrial Waste	1.5*
Waste Piles		1.0
Sludges		1.5
Salt Storage Piles		1.0
Surface Impoundment		2.0**
Gravel Pits		1.0/1,5/2.0***
Drilling Mud Pits		1.5
Holding Ponds		2.0
Containers		1.0/1,5/2.0***
Wells (dry, oil, injection)		2.0
Spray Irrigation		2.0
Fertilizer Application		1.0/2.0***
Road Brining		2.0

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

Spills 1.0/1,5/2.0***
Septic Tanks 2.0

landfill * - unless liquids are known to have been placed in
 documented ** - unless presence of other materials is
 *** - depending on file information

Environmental Exposure Category

The unsaturated zone (vadose zone) value is determined from the following rating matrix.

		Rating Factors					
<u>Earth Materials Category</u>		I	II	III	IV	V	VI
Unconsolidated Rock		Gravel, Medium to Coarse Sand	Fine to Very Fine Sand	Sand with < 15% clay, silt	Sand with > 15% but < = 50% clay	Clay with < 50% sand	Clay, > 15' Continuous
Consolidated Rock		Cavernous or Fractured Limestone Evaporites, Basalt Lava, Fault Zones	Fractured Igneous and Metamorphic (Except Lava), Sandstone (Poorly Cemented)	Sandstone (Moderately Cemented), Fractured Shale	Sandstone (Well Cemented)	Siltstone	Unfractured Shale, Igneous and Metamorphic Rocks
Representative Permeability (cm/s)		>10 ⁻³	10 ⁻⁴ - 10 ⁻³	10 ⁻⁵ - 10 ⁻⁴	<10 ⁻⁵	<10 ⁻⁶	<10 ⁻⁷
		Rating Matrix					
Thickness of the Vadose Zone (m)	>30	90	60	40	20	8	2
	9.1 - 30	92	70	50	30	20	4
	3.3 - 9.1	96	80	70	40	30	8
	1.2 - 3.3	98	90	80	60	40	20
	<1.2	100	92	90	80	70	60

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

Targets Category

<u>Population at Risk</u>	<u>Points</u>
Population dependent on drinking water wells located within ½ mile downgradient of contamination site	
<6	20
7 - 10	25
11 - 15	30
16 - 25	35
26 - 40	40
41 - 55	45
56 - 75	50
76 - 100	55
101 - 140	60
141 - 180	65
181 - 260	70
261 - 360	75
361 - 500	80
501 - 1400	85
1401 - 4000	90
4001 - 12000	95
> 12000	100

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

<u>Resource Value</u>		<u>Rating Factors</u>		
<u>Earth Materials Category</u>		I	II	III
Unconsolidated Rock		Gravel or Sand	Sand with $\leq 50\%$ Clay	Clay with $< 50\%$ Sand
Consolidated Rock		Cavernous or Fractured Rock Poorly Cemented Sandstone, Fault Zones, Basalt Lava	Moderately to Well Cemented Sandstone, Fractured Shale	Siltstone, Unfractured Shale and other Impervious Rock
Representative Permeability (cm/s)		$>10^{-4}$	$10^{-4} - 10^{-6}$	$<10^{-6}$
<u>Rating Matrix</u>				
Thickness of the Vadose Zone (m)	>30	60	40	20
	3 - 30	50	30	10
	<3	30	10	5

Existing Exposure

Chemical Exposure

Concentration Above MCL

Chemical Exposure Factor

< 10	2
10 - 50	4
51 - 500	6
501 - 1000	8
> 1000	10

Table A4 (continued). MDNR SAS Values for Categories and Subcategories Applicable to Groundwater.

Existing Exposure Population

Number of People Exposed

Population Factor

0	0
1 - 50	1
51 - 100	2
101 - 500	5
501 - 1000	10
1001 - 5000	15
5001 - 10000	20
> 10001	25

F. The EPA Superfund Human Health Evaluation Process

After a potential Superfund site is identified, the site is screened to identify the release situation and determine if remedial or containment action is warranted. The HRS risk analysis is performed to determine the sites relative risk compared to other sites. The HRS scoring process is the primary mechanism for determining if a site is included on the NPL thereby making it eligible for Superfund-financed remedial action. Once a site is selected, unlike the HRS, the Human Health Evaluation (HHE) Process is performed utilizing quantitative data.

CERCLA requires that actions selected to remedy hazardous waste sites be protective of human health and the environment. The HHE developed by EPA provides a method for developing health risk information at a contaminated site. The process enables the establishment of baseline risk, the risk posed by a site if remediation is not applied. The remedial investigation - feasibility study (RI/FS) is the methodology established by the Superfund program to characterize the nature and extent of risk posed by uncontrolled hazardous waste sites, and for developing and evaluating remedial options. The stages of the RI/FS are project scoping, site characterization, establishment of remedial action objectives, development and screening alternatives and detailed analysis of alternatives (EPA, 1988a).

The HHE is planned and performed in the project scoping and site characterization stages of the RI/FS; the remaining phases address remediation engineering, comparison of remediation alternatives and plans for evaluation of the

remediation process once it is initiated.

The project scoping stage initiates the collection of existing data and planning for the gathering of additional data needed to quantify a site's risk to human health. A preliminary conceptual model is developed in this phase that identifies potential sources of contamination; identifies types and concentrations of contaminants detected at the site; identifies potentially contaminated media such as soil, groundwater, surface water or air; identifies contaminant migration pathways which model the contaminant concentrations along the path from source to human contact points; determine all human contact points (such as drinking water wells or swimming pond); and determines potential human intake amounts. A comprehensive sampling and analysis plan is developed to substantiate the conceptual model.

The site characterization phase follows the project scoping phase; data collection and analysis are performed in this phase. Contaminants and their concentrations within media are identified. In addition to chemical contamination sampling and analysis, this phase requires sampling of the physical properties of the media of interest. For the groundwater media, the hydrogeologic properties of the site must be established; hydraulic conductivity, porosity, bulk density, and fraction of organic carbon are some of the physical properties that need to be determined for the unsaturated and saturated zones of the site. Fate, transport and persistence effects upon contaminants within the media are then determined with the assistance of physical data input and computer modeling (EPA, 1988b). The evaluation of the fate and transport of chemicals within media is essential to predict future exposures and to help link sources with currently contaminated media.

After a chemical is released to the environment it may be transported, physically transformed (e.g., volatilized or precipitated), chemically transformed (e.g., photolysis, hydrolysis, oxidation, reduction etc.), biologically transformed (e.g., biodegradation), or accumulated in one or more media (e.g., sorption). Important physical, chemical and environmental fate parameters used in groundwater fate modeling are listed in Table A5. Site characterization is designed to demonstrate the nature and extent of contamination of a media through sampling and analysis. This allows refinement of the conceptual model developed in the scoping phase and assessment of exposure of humans to contaminants.

The site characterization phase enables an assessment of the risk to human health posed by the contaminated site. Exposure pathways link the sources, locations, and types of environmental releases with population locations and activity patterns to determine the significant pathways of human exposure. An exposure pathway consists of a source and mechanism of chemical release, a retention and transport medium (or media in cases involving media transfer of chemicals), a point of potential human contact with the contaminated medium (referred to as the exposure point), and an exposure route - "intake" (e.g., ingestion) at the contact point. The HHE is performed to assess this risk and is the product of an exposure assessment, which quantifies population exposure to contaminants and a toxicity assessment, which quantifies the human health risk associated with contaminants.

The objective of an exposure assessment is to quantify human exposure by calculating human intake of toxic substances. Human intakes are expressed in terms of the mass of a substance in contact with the body per unit body weight per time (e.g.,

mg/kg - day). First, exposure pathways are assessed to quantify the concentration of toxic substances at contact points. Then, each toxic substance intake is evaluated using contact rate, exposure frequency and duration, body weight and averaging time.

$$I = C \times ((CR \times EF \times FD) / BW) \times (1 / AT)$$

I = Intake (e.g., mg/kg - day)

C = Concentration of toxic substance at contact point averaged over exposure period (e.g., mg/liter)

CR = Contact Rate, the amount of contaminated media per unit time or event (e.g., liters/day)

EF = Exposure Frequency, (e.g., days/year)

ED = Exposure Duration, (e.g., years)

BW = Body Weight, the average body weight over the exposure period (e.g., kg)

AT = Averaging Time, times selected based of the toxic effects - acute, subchronic, chronic etc.

The concentration of a contaminant at the contact point must be averaged over the period of exposure in order to calculate an intake. For groundwater ingestion, groundwater monitoring well and monitored drinking water well data may be used in combination with groundwater models to estimate the average concentration of a contaminant at a drinking water well contact point throughout the period of exposure. The results of monitoring well data through time should be used to calibrate the groundwater contamination model. For adult drinking water intakes: contact rate or ingestion rate is 2 liters per day; body weight of an adult is 70 kg; and for chronic effects, the exposure duration for a lifetime is 70 years.

Toxicity assessment of substances is accomplished by hazard identification and dose-response assessments. Hazard identification is the process of determining whether

exposure to a substance can cause an increase in the incidence of an adverse health effect; the nature and strength of the evidence of causation are also assessed. Dose-response evaluation is the process of quantitatively evaluating the toxicity of a substance by examining the relationship between administered dose and responses of adverse health effects. Data from human epidemiological and animal toxicology studies are used. From the quantitative dose-response relationship, toxicity values (e.g., reference doses and slope factors) are derived that can be used to estimate the incidence or potential for adverse effects as a function of human exposure to the contaminant. These toxicity values are used in the risk characterization step to estimate the likelihood of adverse effects occurring in humans at different exposure levels. Adverse effects include noncarcinogenic and carcinogenic effects.

A reference dose, or RfD, is the toxicity value used most often in evaluating noncarcinogenic effects resulting from exposures. Noncarcinogenic effects do not include cancer. Examples of noncarcinogenic effects include hematologic, adrenal, kidney and liver effects; these effects can cause irreversible changes in human organisms and may produce serious physical impairment or death. Various types of RfDs are available depending on the exposure route, the critical effect, and the length of exposure being evaluated. A chronic RfD is defined as an estimate, with uncertainty spanning perhaps an order of magnitude or greater, of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deteriorious effects during a lifetime. A chronic RfD is specifically developed to be protective for long-term exposure to a substance. A chronic RfD should be used to

evaluate the noncarcinogenic effects associated with an exposure period between 7 years and a lifetime (70 years). A subchronic RfD is used to evaluate the potential noncarcinogenic effect of a substance for an exposure period between two weeks and seven years. An acute RfD evaluates the potential noncarcinogenic effects of a substance for exposure periods less than two weeks. The chronic, subchronic and acute RfDs of substances, along with evidence of causation references can be obtained from the EPA Integrated Risk Information System (IRIS), (<http://www.epa.gov/iris>).

For many noncarcinogenic effects, protective biological mechanisms are believed to exist that must be overcome before an adverse effect is manifested in an organism. In developing a RfD, the approach is to identify the upper bound of the tolerance range (threshold level) in the dose-response relationship and modify it to account for the variability in the human population, such that sensitive individuals in the population are protected. In the development of oral RfDs, all available studies examining the toxicity of a chemical following exposure by the oral route are gathered and judged for scientific merit. Any differences between studies are reconciled and an overall evaluation is reached. If adequate human data are available, this information is used as the basis of the RfD. Otherwise, animal study data are used. If data from several animal studies are evaluated, the animal model that is most relevant to humans based on biological rationale is used. If there is not a clear-cut species preference, it is assumed that humans are as sensitive to the substance as the most sensitive animal species tested. After the critical study and toxic effect has been selected, the experimental exposure level representing the highest level tested at which no adverse effects were demonstrated is determined; this

exposure level is known as the No Observed Adverse Effect Level (NOAEL). A NOAEL observed in an animal study in which the exposure was intermittent is adjusted to reflect continuous exposure. The NOAEL is selected based on the assumption that if the critical toxic effect exposure level is prevented, then all toxic effects are prevented. The RfD is derived from the NOAEL by consistent application of uncertainty factors (UF) and a modifying factor (MF). The uncertainty factors generally consist of multiples of 10, with each factor representing a specific area of uncertainty inherent in the extrapolation from the available data. An UF of 10 is used to account for variations in the general population and is intended to protect sensitive subpopulations. An UF of 10 is used when extrapolating from animals to humans; this factor is intended to account for interspecies variability between humans and other mammals. An UF of 10 is used when a NOAEL derived from subchronic instead of a chronic study is used as the basis for a chronic RfD. An UF of 10 is also used when a Lowest Observed Adverse Effect Level (LOAEL) is used instead of a NOAEL; this factor is intended to account for the uncertainty associated with extrapolating from a LOAEL to a NOAEL. A MF from greater than 0, but less than 10 is included to reflect a quantitative professional assessment of additional uncertainties in the initial study and in the entire data base for the chemical not explicitly addressed by the preceding uncertainty factors. The default value for MF is 1. A RfD is calculated using the following formula:

$$\text{RfD} = \text{NOAEL (or LOAEL if a NOAEL cannot be obtained)} / (\text{UF}_1 \times \text{UF}_2 \times \dots \text{UF}_i \times \text{MF})$$

RfD = Reference dose

NOAEL = No observed adverse effect level

LOAEL = Lowest observed adverse effect level

UF₁, UF₂, UF_i = Uncertainty factors; first, second to ith
MF = Modifying factor

RfDs can be obtained from the EPA Integrated Risk Information System (IRIS). Oral RfDs are usually expressed in mg/kg-day.

A slope factor and the accompanying weight-of-evidence determination are the toxicity data most commonly used to evaluate potential human carcinogenic risks. Carcinogenesis, unlike noncarcinogenic health effects, is generally thought to be a phenomenon for which risk evaluation based on presumption of a threshold is inappropriate. For carcinogens, it is assumed that a small number of molecular events can evoke changes in a single cell that can lead to uncontrolled cellular proliferation and eventually to a clinical state of disease. This hypothesized mechanism for carcinogenesis is referred to as “nonthreshold” because there is believed to be no level of exposure to such a chemical that it does not pose a finite probability of generating a carcinogenic response; no dose is considered to be risk free. For carcinogenic effects, a weight-of-evidence classification and then a calculated slope factor is used to evaluate carcinogens.

The available data are evaluated to determine the likelihood that a substance is a human carcinogen. The evidence is characterized separately for human studies and animal studies. The classification system, weight-of-evidence system, places the substance into one of the groups listed in the table below.

Based on the weight-of-evidence that the chemical is a human carcinogen or probable human carcinogen (A, B1, B2 or C Group), a toxicity value that quantitatively defines the relationship between dose and response is calculated - the slope factor.

Generally, the slope factor is a plausible upper-bound estimate of the probability of a response, for example a probability of the one human developing cancer in a population of one million, per unit intake of a chemical over a lifetime. The slope factor is used in risk assessment to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen. In choosing appropriate data sets, human data of high quality are preferable to animal data. If animal data are used, the species that possesses biologic characteristics similar to humans is preferred. When a clear choice is not possible, the most sensitive species is given the greatest emphasis. Because risk at low exposure levels is difficult to measure directly either by animal experiments or by epidemiologic studies, the development of a slope factor generally entails applying a model to the available data set and using the model to extrapolate from the relatively high doses administered to animals to the lower exposure levels expected for human contact in the environment. In general, after the data have been fit to the appropriate model, usually the linearized multistage model (EPA, 1986), the upper 95th percent confidence limit of the slope of the resulting dose-response curve is calculated. Toxicity values for carcinogenic effects can be expressed in several ways. The slope factor is usually the upper 95th percent confidence limit of the slope of the dose-response curve and is expressed in mg/kg-day. Toxicity values for carcinogenic effects also can be expressed in terms of risk per unit concentration of the substance in the medium where human contact occurs. These measures, called unit risks, are calculated by dividing the slope factor by 70 kg and multiplying by the water consumption rate (2 liters/day), for risks associated with unit concentration in water:

$$\text{Water unit risk} = ((\text{slope factor} / 70 \text{ kg}) \times 2 \text{ liter/day})$$

The final step of the baseline health risk assessment process, risk characterization, summarizes the toxicity and exposure assessments and integrates them into a quantitative expression of risk. To characterize potential noncarcinogenic effects, comparisons are made between projected intakes of substances and toxicity values; to characterize potential carcinogenic effects, probabilities that an individual will develop cancer over a lifetime of exposure are estimated from projected intake and chemical-specific dose-response information.

For carcinogens, risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The slope factor converts estimated daily intakes averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer. If the slope factor is a constant, the risk will be directly related to the intake.

$$\text{Risk} = \text{CDI} \times \text{SF}$$

Risk = unitless probability of an individual developing cancer (e.g., 10^{-6} , or one in a million)
 CDI = chronic daily intake over 70 years (mg/kg-day)
 SF = slope factor, expressed in (mg/kg-day)⁻¹

The linear equation is valid only at low risk levels, below risks of 0.01. If risks are greater than 0.01, then a one-hit equation should be employed:

$$\text{Risk} = 1 - \exp(-\text{CDI} * \text{SF})$$

The risk potential for noncarcinogenic effects is evaluated by comparing an exposure level of a specified time period with a reference dose derived for a similar

exposure period. The ratio of exposure to toxicity is called the hazard quotient.

$$\text{NHQ} = E/\text{RfD}$$

NHQ = Noncancer hazard quotient

E = Exposure level (intake)

RfD = Reference dose

The greater the NHQ is above 1, the greater the risk of adverse health effects.

After the carcinogenic risks and noncarcinogenic hazard quotients are derived for the various individual substances, the carcinogenic risks are summed and the hazard quotients are summed. The final HHE analysis derives a total carcinogenic risk to human health and a total noncarcinogenic hazard quotient which indicates a baseline degree of human health risk associated with a site.

Carcinogenic Effects

$$\text{Risk T} = \sum \text{Risk, } i$$

Risk T = The total cancer risk, expressed in unitless probability

Risk, i = The risk estimate for the i-th substance

Noncarcinogenic Effects

$$\text{HI} = (E1/\text{RfD}1) + (E2/\text{RfD}2) + \dots + (Ei/\text{RfD}i)$$

HI = Hazard Index

Ei = Exposure level (or intake) for ith toxicant

RfDi = Reference dose for the ith toxicant

These equations for total carcinogenic and noncarcinogenic risk assume that

intakes of individual substances are small, and assume independence of action; that there are no synergistic or antagonistic interactions.

From the study of noncarcinogenic and carcinogenic effects, a lifetime dose, concentration, of a substance can be devised for drinking water that will be protective of human health. For noncarcinogenic substances a chronic RfD can be expressed in mg/l. For the carcinogenic effect of a substance, a probability of 1:1,000,000 can be used with the slope factor to calculate a lifetime concentration of a carcinogenic substance; this value can be expressed in mg/l. EPA Region 3 (EPA, 2001) has created a list of substances that displays these values; the list displays lower concentration value (mg/l) of a given substance's noncarcinogenic or carcinogenic lifetime effect. This list can be referenced in Appendix B.

Table A5. Example of data requirements for vadose zone and groundwater fate models.

Time Parameters

Time Step Increments

Contaminant Parameters

**Initial Concentration of Contaminant
Contaminant Physical and Chemical Properties
Contaminant Release Rates
Ion Exchange Capacity**

Contaminant - Geologic Matrix Interaction Parameters

**Dispersivity Coefficient
Partitioning Coefficient
Retardation Coefficient
Attenuation Decay Factor
Attenuation "half-life"
Partitioning Coefficient for Organic Carbon
Temperature Regime
Atmospheric Regime (Windspeed, Barometric Pressure)**

Hydrogeologic Parameters

**Vadose zone Thickness
Net Recharge Rates
Average Moisture Content
Average Unsaturated Hydraulic Conductivity
Vadose zone Average Porosity
Aquifer Thickness
Hydraulic Conductivity
Hydraulic Gradient
Porosity
Clay Content
Organic Carbon Content
Bulk Density**

Appendix B: EPA Region 3, Hazardous Substance List

Sources: I = IRIS H = HEAST A = HEAST Alternate							Basis:	
W = Withdrawn from IRIS or HEAST							C = Carcinogenic effects	
							N = Noncarcinogenic effects	
							I = RBC at HI of 0.1 < RBC-c	
E = EPA-NCEA provisional value O = other								
Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	Tap water ug/l	
ACETALDEHYDE	75070			2.57E-003	7.7E-003	y	1.6E+000	C
ACETOCHLOR	34256821	2E-002					7.3E+002	N
ACETONE	67641	1.00E-001				y	6.1E+002	N
ACETONITRILE	75058			1.7E-002		y	1.2E+002	N
ACETOPHENONE	98862	1.00E-001		5.70E-006		y	4.2E-002	N
ACROLEIN	107028	2.00E-002		5.70E-006		y	4.2E-002	N
ACRYLAMIDE	79061	2.00E-004	4.50E+000		4.50E+000		1.5E-002	C
ACRYLONITRILE	107131	1.00E-003	5.40E-001	5.70E-004	2.40E-001	y	3.7E-002	C
ALACHLOR	15972608	1.00E-002	8.00E-002				8.4E-001	C
ALAR	1596845	1.50E-001					5.5E+003	N
ALDICARB	116063	1.00E-003					3.7E+001	N
ALDICARB SULFONE	1646884	1.00E-003					3.7E+001	N
ALDRIN	309002	3.00E-005	1.70E+001		1.70E+001		3.9E-003	C
ALUMINUM	7429905	1.00E+000		1.00E-003			3.7E+004	N
AMINODINITROTOLUENES		6.00E-005					2.2E+000	N
4-AMINOPYRIDINE	504245	2.00E-005					7.3E-001	N
AMMONIA	7664417			2.86E-002		y	2.1E+002	N
ANILINE	62533	7.00E-003	5.70E-003	2.90E-004			1.2E+001	C
ANTIMONY	7440360	4.00E-004					1.5E+001	N
ANTIMONY PENTOXIDE	1314609	5.00E-004					1.8E+001	N
ANTIMONY TETROXIDE	1332816	4.00E-004					1.5E+001	N
ANTIMONY TRIOXIDE	1309644	4.00E-004		5.70E-005			1.5E+001	N
ARSENIC	7440382	3.00E-004	1.50E+000		1.51E+001		4.5E-002	C

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l
ARSINE	7784421			1.40E-005		y	1.0E-001
ASSURE	76578148	9.00E-003					3.3E+002
ATRAZINE	1912249	3.50E-002	2.20E-001				3.0E-001
AZOBENZENE	103333		1.10E-001		1.10E-001		6.1E-001
BARIUM	7440393	7.00E-002		1.40E-004			2.6E+003
BAYGON	114261	4.00E-003					1.5E+002
BAYTHROID	68359375	2.50E-002					9.1E+002
BENTAZON	25057890	3.00E-002					1.1E+003
BENZALDEHYDE	100527	1.00E-001					3.7E+003
BENZENE	71432	3.00E-003	5.5E-002	1.70E-003	2.90E-002	y	3.2E-001
BENZENETHIOL	108985	1.00E-005				y	6.1E-002
BENZIDINE	92875	3.00E-003	2.30E+002		2.30E+002		2.9E-004
BENZOIC ACID	65850	4.00E+000					1.5E+005
BENZYL ALCOHOL	100516	3.00E-001					1.1E+004
BENZYL CHLORIDE	100447		0.17			y	6.2E-002
BERYLLIUM	7440417	2.00E-003		5.7E-006	8.40E+000		7.3E+001
BIPHENYL	92524	5.00E-002				y	3.0E+002
BIS(2-CHLOROETHYL)ETHER	111444		1.10E+000		1.10E+000	y	9.6E-003
BIS(2-CHLOROISOPROPYL)ETHER	108601	4.00E-002	7.00E-002		3.50E-002	y	2.6E-001
BIS(CHLOROMETHYL)ETHER	542881		2.20E+002		2.20E+002	y	4.8E-005
BIS(2-ETHYLHEXYL)PHTHALATE	117817	2.00E-002	1.40E-002		1.40E-002		4.8E+000
BORON	7440428	9.00E-002		5.70E-003			3.3E+003
BROMODICHLOROMETHANE	75274	2.00E-002	6.20E-002			y	1.7E-001
BROMOETHENE	593602			8.6E-004	1.10E-001	y	1.1E-001
BROMOFORM	75252	2.00E-002	7.90E-003		3.90E-003		8.5E+000
BROMOMETHANE	74839	1.40E-003		1.40E-003		y	8.5E+000
BROMOPHOS	2104963	5.00E-003					1.8E+002
1,3-BUTADIENE	106990				1.80E+000	y	7.0E+003
1-BUTANOL	71363	1.00E-001					3.7E+003
BUTYLBENZYLPHTHALATE	85687	2.00E-001					7.3E+003
BUTYLATE	2008415	5.00E-002					1.8E+003
N-BUTYLBENZENE	104518	4.00E-002				y	2.4E+002
SEC-BUTYLBENZENE	135988	4.00E-002				y	2.4E+002
TERT-BUTYLBENZENE	98066	4.00E-002				y	2.4E+002
CADMIUM-WATER	7440439	5.00E-004			6.30E+000		1.8E+001
CADMIUM-FOOD	7440439	1.00E-003			6.30E+000		3.7E+001
CAPROLACTAM	105602	5.00E-001					1.8E+004

Chemical	CAS	RfDo mg/kg/d	CSFo l/mg/kg/d	RfDi mg/kg/d	CSFi l/mg/kg/d	VOC	water ug/l	
CARBARYL	63252	1.00E-001					3.7E+003	N
CARBON DISULFIDE	75150	1.00E-001		2.00E-001		y	1.0E+003	N
CARBON TETRACHLORIDE	56235	7.00E-004	1.30E-001	5.71E-004	5.30E-002	y	1.6E-001	C
CARBOSULFAN	55285148	1.00E-002					3.7E+002	N
CHLORAL HYDRATE	302170	1.00E-001					3.7E+003	N
CHLORANIL	118752		4.00E-001				1.7E-001	C
CHLORDANE	57749	5.00E-004	3.5E-001	2.00E-004	3.5E-001		1.9E-001	C
CHLORINE	7782505	1.00E-001		5.7E-005		y	4.2E-001	N
**CHLORINE DIOXIDE	10049044	3.00E-002		5.70E-005		y	4.2E-001	N
CHLOROACETIC ACID	79118	2.00E-003					7.3E+001	N
4-CHLOROANILINE	106478	4.00E-003					1.5E+002	N
CHLOROBENZENE	108907	2.00E-002		1.7E-002		y	1.1E+002	N
CHLOROBENZILATE	510156	2.00E-002	2.70E-001		2.70E-001		2.5E-001	C
P-CHLOROBENZOIC ACID	74113	2.00E-001					7.3E+003	N
2-CHLORO-1,3-BUTADIENE	126998	2.00E-002		2.00E-003		y	1.4E+001	N
1-CHLOROBUTANE	109693	4.00E-001				y	2.4E+003	N
1-CHLORO-1,1-DIFLUOROETHANE	75683			1.40E+001		y	1.0E+005	N
CHLORODIFLUOROMETHANE	75456			1.40E+001		y	1.0E+005	N
CHLOROETHANE	75003	4.00E-001	2.90E-003	2.90E+000		y	3.6E+000	C
CHLOROFORM	67663	1.00E-002	6.10E-003	8.6E-005	8.10E-002	y	1.5E-001	C
CHLOROMETHANE	74873		1.30E-002	8.6E-002	3.5E-003	y	2.1E+000	C
4-CHLORO-2-METHYLANILINE	95692		5.80E-001				1.2E-001	C
BETA-CHLORONAPHTHALENE	91587	8.00E-002				y	4.9E+002	N
O-CHLORONITROBENZENE	88733		2.50E-002			y	4.2E-001	C
P-CHLORONITROBENZENE	100005		1.80E-002			y	5.9E-001	C
2-CHLOROPHENOL	95578	5.00E-003				y	3.0E+001	N
2-CHLOROPROPANE	75296			2.90E-002		y	2.1E+002	N
O-CHLOROTOLUENE	95498	2.00E-002				y	1.2E+002	N
CHLORPYRIFOS	2921882	3.00E-003					1.1E+002	N
CHLORPYRIFOS-METHYL	5598130	1.00E-002					3.7E+002	N
CHROMIUM III	16065831	1.50E+000					5.5E+004	N
CHROMIUM VI	18540299	3.00E-003		3.00E-005	4.10E+001		1.1E+002	N
**COBALT	7440484	2.00E-002		5.00E-006			7.3E+002	N
COKE OVEN EMISSIONS (COAL TAR)	8007452				2.2			
COPPER	7440508	4.00E-002					1.5E+003	N
CROTONALDEHYDE	123739		1.90E+000			y	5.6E-003	C
CUMENE	98828	1.00E-001		1.10E-001		y	6.6E+002	N

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l	
CYANIDE (FREE)	57125	2.00E-002					7.3E+002	N
CALCIUM CYANIDE	592018	4E-002					1.5E+003	N
COPPER CYANIDE	544923	5.00E-003					1.8E+002	N
CYANAZINE	21725462	2.00E-003	8.40E-001				8.0E-002	C
CYANOGEN	460195	4.00E-002				y	2.4E+002	N
CYANOGEN BROMIDE	506683	9.00E-002					3.3E+003	N
CYANOGEN CHLORIDE	506774	5.00E-002					1.8E+003	N
HYDROGEN CYANIDE	74908	2.00E-002		8.60E-004		y	6.2E+000	N
POTASSIUM CYANIDE	151508	5.00E-002					1.8E+003	N
POTASSIUM SILVER CYANIDE	506616	2.00E-001					7.3E+003	N
SILVER CYANIDE	506649	1.00E-001					3.7E+003	N
SODIUM CYANIDE	143339	4.00E-002					1.5E+003	N
THIOCYANATE		5.00E-002					1.8E+003	N
ZINC CYANIDE	557211	5.00E-002					1.8E+003	N
CYCLOHEXANONE	108941	5.00E+000					1.8E+005	N
CYHALOTHRIN/KARATE	68085858	5.00E-003					1.8E+002	N
CYPERMETHRIN	52315078	1.00E-002					3.7E+002	N
DACTHAL	1861321	1.00E-002					3.7E+002	N
DALAPON	75990	3.00E-002					1.1E+003	N
DDD	72548		2.40E-001				2.8E-001	C
DDE	72559		3.40E-001				2.0E-001	C
DDT	50293	5.00E-004	3.40E-001		3.40E-001		2.0E-001	C
DIAZINON	333415	9.00E-004					3.3E+001	N
DIBENZOFURAN	132649	4.00E-003				y	2.4E+001	N
1,4-DIBROMOBENZENE	106376	1.00E-002					3.7E+002	N
DIBROMOCHLOROMETHANE	124481	2.00E-002	8.40E-002			y	1.3E-001	C
1,2-DIBROMO-3-CHLOROPROPANE	96128		1.40E+000	5.70E-005	2.40E-003	y	4.7E-002	C
1,2-DIBROMOETHANE	106934		8.50E+001	5.70E-005	7.60E-001	y	7.5E-004	C
DIBUTYLPHTHALATE	84742	1.00E-001					3.7E+003	N
DICAMBA	1918009	3.00E-002					1.1E+003	N
1,2-DICHLOROBENZENE	95501	9.00E-002				y	5.5E+002	N
**1,3-DICHLOROBENZENE	541731	3.00E-002				y	1.8E+002	N
1,4-DICHLOROBENZENE	106467	3.00E-002	2.40E-002	2.29E-001	2.2E-002	y	4.7E-001	C
3,3'-DICHLOROBENZIDINE	91941		4.50E-001				1.5E-001	C
1,4-DICHLORO-2-BUTENE	764410				9.30E+000	y	1.3E-003	C
DICHLORODIFLUOROMETHANE	75718	2.00E-001		5.00E-002		y	3.5E+002	N
1,1-DICHLOROETHANE	75343	1.00E-001		1.40E-001		y	8.0E+002	N

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l	
1,2-DICHLOROETHANE	107062	3.00E-002	9.10E-002	1.40E-003	9.10E-002	y	1.2E-001	C
1,1-DICHLOROETHENE	75354	9.00E-003	6.00E-001		1.75E-001	y	4.4E-002	C
CIS-1,2-DICHLOROETHENE	156592	1.00E-002				y	6.1E+001	N
TRANS-1,2-DICHLOROETHENE	156605	2.00E-002				y	1.2E+002	N
TOTAL 1,2-DICHLOROETHENE	540590	9.00E-003				y	5.5E+001	N
2,4-DICHLOROPHENOL	120832	3.00E-003					1.1E+002	N
2,4-D	94757	1.00E-002					3.7E+002	N
4-(2,4-DICHLOROPHENOXY)BUTYRIC ACID	94826	8E-003					2.9E+002	N
1,2-DICHLOROPROPANE	78875		6.80E-002	1.14E-003		y	1.6E-001	C
2,3-DICHLOROPROPANOL	616239	3.00E-003					1.1E+002	N
1,3-DICHLOROPROPENE	542756	3.00E-002	1.00E-001	5.71E-003	1.00E-002	y	4.4E-001	C
DICHLORVOS	62737	5E-004	0.29	1.43E-004			2.3E-001	C
DICOFOL	115322		4.4E-001				1.5E-001	C
DICYCLOPENTADIENE	77736	3E-002		6.00E-005		y	4.4E-001	N
DIELDRIN	60571	5.00E-005	1.60E+001		1.60E+001		4.2E-003	C
DIESEL EMISSIONS				1.40E-003				
DIETHYLPHthalATE	84662	8.00E-001					2.9E+004	N
DIETHYLENE GLYCOL, MONOBUTYL ETHER	112345			5.70E-003				
DIETHYLENE GLYCOL, MONOETHYL ETHER	111900	2.00E+000					7.3E+004	N
DI(2-ETHYLHEXYL)ADIPATE	103231	6.00E-001	1.20E-003				5.6E+001	C
DIETHYLSTILBESTROL	56531		4.70E+003				1.4E-005	C
DIFENZOQUAT (AVENGE)	43222486	8.00E-002					2.9E+003	N
1,1-DIFLUOROETHANE	75376			1.10E+001		y	8.0E+004	N
DIISOPROPYL METHYLPHOSPHONATE (DIMP)	1445756	8.00E-002					2.9E+003	N
3,3'-DIMETHOXYBENZIDINE	119904		1.40E-002				4.8E+000	C
DIMETHYLAMINE	124403			5.70E-006		y	4.2E-002	N
2,4-DIMETHYLANILINE HYDROCHLORIDE	21436964		5.80E-001				1.2E-001	C
2,4-DIMETHYLANILINE	95681		7.50E-001				8.9E-002	C
N,N-DIMETHYLANILINE	121697	2.00E-003					7.3E+001	N
3,3'-DIMETHYLBENZIDINE	119937		9.20E+000				7.3E-003	C
1,1-DIMETHYLHYDRAZINE	57147		2.60E+000		3.50E+000		2.6E-002	C
1,2-DIMETHYLHYDRAZINE	540738		3.70E+001		3.70E+001		1.8E-003	C
2,4-DIMETHYLPHENOL	105679	2.00E-002					7.3E+002	N
2,6-DIMETHYLPHENOL	576261	6.00E-004					2.2E+001	N
3,4-DIMETHYLPHENOL	95658	1.00E-003					3.7E+001	N
DIMETHYLPHthalATE	131113	1.00E+001					3.7E+005	N
1,2-DINITROBENZENE	528290	4.00E-004					1.5E+001	N

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l	
1,3-DINITROBENZENE	99650	1.00E-004					3.7E+000	N
1,4-DINITROBENZENE	100254	4.00E-004					1.5E+001	N
4,6-DINITRO-O-CYCLOHEXYL PHENOL	131895	2.00E-003					7.3E+001	N
4,6-DINITRO-2-METHYLPHENOL	534521	1.00E-004					3.7E+000	N
2,4-DINITROPHENOL	51285	2.00E-003					7.3E+001	N
DINITROTOLUENE MIX			6.80E-001				9.8E-002	C
2,4-DINITROTOLUENE	121142	2.00E-003					7.3E+001	N
2,6-DINITROTOLUENE	606202	1.00E-003					3.7E+001	N
DINOSEB	88857	1.00E-003					3.7E+001	N
DIOCTYLPHTHALATE	117840	2.00E-002					7.3E+002	N
1,4-DIOXANE	123911		1.10E-002				6.1E+000	C
DIPHENYLAMINE	122394	2.50E-002					9.1E+002	N
1,2-DIPHENYLHYDRAZINE	122667		8.00E-001		8.00E-001		8.4E-002	C
DIQUAT	85007	2.20E-003					8.0E+001	N
DISULFOTON	298044	4.00E-005					1.5E+000	N
1,4-DITHIANE	505293	1.00E-002					3.7E+002	N
DIURON	330541	2.00E-003					7.3E+001	N
ENDOSULFAN	115297	6.00E-003					2.2E+002	N
ENDRIN	72208	3.00E-004					1.1E+001	N
EPICHLOROHYDRIN	106898	2.00E-003	9.90E-003	2.86E-004	4.20E-003	y	2.0E+000	N
ETHION	563122	5.00E-004					1.8E+001	N
2-ETHOXYETHANOL	110805	4.00E-001		5.70E-002			1.5E+004	N
ETHYL ACETATE	141786	9.00E-001				y	5.5E+003	N
ETHYLBENZENE	100414	1.00E-001		2.90E-001		y	1.3E+003	N
ETHYLENE DIAMINE	107153	2.00E-002					7.3E+002	N
ETHYLENE GLYCOL	107211	2.00E+000					7.3E+004	N
ETHYLENE GLYCOL, MONOBUTYL ETHER	111762	5.00E-001		3.70E+000			1.8E+004	N
ETHYLENE OXIDE	75218		1.00E+000		3.50E-001	y	2.3E-002	C
ETHYLENE THIOUREA	96457	8.00E-005	1.1E-001				6.1E-001	C
ETHYL ETHER	60297	2.00E-001				y	1.2E+003	N
ETHYL METHACRYLATE	97632	9.00E-002				y	5.5E+002	N
FENAMIPHOS	22224926	2.50E-004					9.1E+000	N
FLUOMETURON	2164172	1.30E-002					4.7E+002	N
FLUORINE	7782414	6.00E-002					2.2E+003	N
FOMESAFEN	72178020		1.90E-001				3.5E-001	C
FONOFOS	944229	2.00E-003					7.3E+001	N
FORMALDEHYDE	50000	2.00E-001			4.50E-002		7.3E+003	N

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l	
FORMIC ACID	64186	2.00E+000					7.3E+004	N
FURAN	110009	1.00E-003				y	6.1E+000	N
FURAZOLIDONE	67458		3.80E+000				1.8E-002	C
FURFURAL	98011	3.00E-003		1.00E-002			1.1E+002	N
GLYCIDALDEHYDE	765344	4.00E-004		2.90E-004			1.5E+001	N
GLYPHOSATE	1071836	1.00E-001					3.7E+003	N
HEPTACHLOR	76448	5.00E-004	4.50E+000		4.50E+000		1.5E-002	C
HEPTACHLOR EPOXIDE	1024573	1.30E-005	9.10E+000		9.10E+000		7.4E-003	C
HEXABROMOBENZENE	87821	2.00E-003					7.3E+001	N
HEXACHLOROBENZENE	118741	8.00E-004	1.60E+000		1.60E+000		4.2E-002	C
HEXACHLOROBUTADIENE	87683	2.00E-004	7.80E-002		7.80E-002		8.6E-001	C
ALPHA-HCH	319846		6.30E+000		6.30E+000		1.1E-002	C
BETA-HCH	319857		1.80E+000		1.80E+000		3.7E-002	C
GAMMA-HCH (LINDANE)	58899	3.00E-004	1.30E+000				5.2E-002	C
TECHNICAL HCH	608731		1.80E+000		1.80E+000		3.7E-002	C
HEXACHLOROCYCLOPENTADIENE	77474	7.00E-003		2.00E-005			2.6E+002	N
HEXACHLORODIBENZODIOXIN MIX	19408743		6.20E+003		4.55E+003		1.1E-005	C
HEXACHLOROETHANE	67721	1.00E-003	1.40E-002		1.40E-002		4.8E+000	C
HEXACHLOROPHENE	70304	3.00E-004					1.1E+001	N
1,6-HEXAMETHYLENE DIISOCYANATE	822060			2.90E-006				
HEXANE	110543	6.00E-002		5.71E-002		y	3.5E+002	N
2-HEXANONE	591786	4.00E-002		1.4E-003			1.5E+003	N
HEXAZINONE	51235042	3.30E-002					1.2E+003	N
HMX	2691410	5.00E-002					1.8E+003	N
HYDRAZINE	302012		3.00E+000		1.70E+001		2.2E-002	C
HYDROGEN CHLORIDE	7647010			5.70E-003				
HYDROGEN SULFIDE	7783064	3.00E-003		2.85E-004			1.1E+002	N
HYDROQUINONE	123319	4.00E-002					1.5E+003	N
IRON	7439896	3.00E-001					1.1E+004	N
ISOBUTANOL	78831	3.00E-001				y	1.8E+003	N
ISOPHORONE	78591	2.00E-001	9.50E-004				7.0E+001	C
ISOPROPALIN	33820530	1.50E-002					5.5E+002	N
ISOPROPYL METHYL PHOSPHONIC ACID	1832548	1.00E-001					3.7E+003	N
TETRAETHYLLEAD	78002	1.00E-007					3.7E-003	N
LITHIUM	7439932	2.00E-002					7.3E+002	N
MALATHION	121755	2.00E-002					7.3E+002	N
MALEIC ANHYDRIDE	108316	1.00E-001					3.7E+003	N

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l
MANGANESE-NONFOOD	7439965	2.00E-002		1.43E-005			7.3E+002
MANGANESE-FOOD	7439965	1.40E-001		1.43E-005			5.1E+003
MEPHOSFOLAN	950107	9.00E-005					3.3E+000
MEPIQUAT CHLORIDE	24307264	3.00E-002					1.1E+003
MERCURIC CHLORIDE	7487947	3.00E-004					1.1E+001
MERCURY (INORGANIC)	7439976			8.60E-005			
METHYLMERCURY	22967926	1.00E-004					3.7E+000
METHACRYLONITRILE	126987	1.00E-004		2.00E-004		y	1.0E+000
METHANOL	67561	5.00E-001					1.8E+004
METHIDATHION	950378	1.00E-003					3.7E+001
METHOXYCHLOR	72435	5.00E-003					1.8E+002
METHYL ACETATE	79209	1.00E+000				y	6.1E+003
METHYL ACRYLATE	96333	3.00E-002				y	1.8E+002
2-METHYLANILINE	95534		2.40E-001				2.8E-001
4-(2-METHYL-4-CHLOROPHENOXY) BUTYRIC ACID	94815	1.00E-002					3.7E+002
2-METHYL-4-CHLOROPHENOXYACETIC ACID (MCPA)	94746	5.00E-004					1.8E+001
2-(2-METHYL-4-CHLOROPHENOXY)PROPIONIC ACID (MCPP)	93652	1.00E-003					3.7E+001
METHYLCYCLOHEXANE	108872			8.60E-001		y	6.3E+003
METHYLENE BROMIDE	74953	1.00E-002				y	6.1E+001
METHYLENE CHLORIDE	75092	6.00E-002	7.50E-003	8.60E-001	1.65E-003	y	4.1E+000
4,4'-METHYLENE BIS(2-CHLOROANILINE)	101144	7.00E-004	1.30E-001		1.30E-001		5.2E-001
4,4'-METHYLENE BIS(N,N'-DIMETHYL)ANILINE	101611		4.60E-002				1.5E+000
4,4'-METHYLENEDIPHENYL ISOCYANATE	101688			1.7E-004			
METHYL ETHYL KETONE (2-BUTANONE)	78933	6.00E-001		2.86E-001		y	1.9E+003
METHYL HYDRAZINE	60344		1.10E+000				6.1E-002
METHYL ISOBUTYL KETONE (4-METHYL-2- PENTANONE)	108101	8.00E-002		2.00E-002		y	1.4E+002
METHYL METHACRYLATE	80626	1.40E+000		2.00E-001		y	1.4E+003
2-METHYL-5-NITROANILINE	99558		3.30E-002				2.0E+000
METHYL PARATHION	298000	2.50E-004					9.1E+000

Chemical	CAS	RfDo mg/kg/d	CSFo l/mg/kg/d	RfDi mg/kg/d	CSFi l/mg/kg/d	VOC	water ug/l	
2-METHYLPHENOL	95487	5.00E-002					1.8E+003	N
3-METHYLPHENOL	108394	5.00E-002					1.8E+003	N
4-METHYLPHENOL	106445	5.00E-003					1.8E+002	N
METHYLSTYRENE MIX	25013154	6.00E-003		1.00E-002		y	5.5E+001	N
ALPHA-METHYLSTYRENE	98839	7.00E-002				y	4.3E+002	N
METHYL TERT-BUTYL ETHER	1634044			8.57E-001		y	6.3E+003	N
METOLACHLOR (DUAL)	51218452	1.50E-001					5.5E+003	N
MIREX	2385855	2.00E-004					7.3E+000	N
MOLYBDENUM	7439987	5E-003					1.8E+002	N
MONOCHLORAMINE	10599903	1E-001		1.00E-001			3.7E+003	N
NALED	300765	2E-003					7.3E+001	N
NICKEL REFINERY DUST					8.4E-001			
NICKEL	7440020	2.00E-002					7.3E+002	N
NITRATE	14797558	1.60E+000					5.8E+004	N
NITRIC OXIDE	10102439	1.00E-001				y	6.1E+002	N
NITRITE	14797650	1.00E-001					3.7E+003	N
2-NITROANILINE	88744			5.70E-005				
NITROBENZENE	98953	5.00E-004		6.00E-004		y	3.5E+000	N
NITROFURANTOIN	67209	7.00E-002					2.6E+003	N
NITROFURAZONE	59870		1.50E+000				4.5E-002	C
NITROGEN DIOXIDE	10102440	1.00E+000				y	6.1E+003	N
NITROGLYCERIN	55630		1.4E-002				4.8E+000	C
4-NITROPHENOL	100027	8.00E-003					2.9E+002	N
2-NITROPROPANE	79469			5.70E-003	9.40E+000	y	1.3E-003	C
N-NITROSO-DI-N-BUTYLAMINE	924163		5.40E+000		5.60E+000	y	1.9E-003	C
N-NITROSODIETHANOLAMINE	1116547		2.80E+000				2.4E-002	C
N-NITROSODIETHYLAMINE	55185		1.50E+002		1.50E+002		4.5E-004	C
N-NITROSODIMETHYLAMINE	62759		5.10E+001		5.10E+001		1.3E-003	C
N-NITROSODIPHENYLAMINE	86306		4.90E-003				1.4E+001	C
N-NITROSODIPROPYLAMINE	621647		7.00E+000				9.6E-003	C
N-NITROSO-N-ETHYLUREA	759739		1.40E+002				4.8E-004	C
N-NITROSO-N-METHYLETHYLAMINE	10595956		2.20E+001				3.0E-003	C
N-NITROSOPYRROLIDINE	930552		2.10E+000		2.10E+000		3.2E-002	C
M-NITROTOLUENE	99081	2.00E-002				y	1.2E+002	N
O-NITROTOLUENE	88722	1.00E-002				y	6.1E+001	N
P-NITROTOLUENE	99990	1.00E-002				y	6.1E+001	N
NUSTAR	85509199	7.00E-004					2.6E+001	N

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l	
ORYZALIN	19044883	5.00E-002					1.8E+003	N
OXADIAZON	19666309	5.00E-003					1.8E+002	N
OXAMYL	23135220	2.50E-002					9.1E+002	N
OXYFLUORFEN	42874033	3.00E-003					1.1E+002	N
PARAQUAT DICHLORIDE	1910425	4.50E-003					1.6E+002	N
PARATHION	56382	6.00E-003					2.2E+002	N
PENTACHLOROBENZENE	608935	8.00E-004					2.9E+001	N
PENTACHLORONITROBENZENE	82688	3.00E-003	2.60E-001				2.6E-001	C
PENTACHLOROPHENOL	87865	3.00E-002	1.20E-001				5.6E-001	C
PERMETHRIN	52645531	5.00E-002					1.8E+003	N
PHENOL	108952	6.00E-001					2.2E+004	N
M-PHENYLENEDIAMINE	108452	6.00E-003					2.2E+002	N
O-PHENYLENEDIAMINE	95545		4.70E-002				1.4E+000	C
P-PHENYLENEDIAMINE	106503	1.90E-001					6.9E+003	N
2-PHENYLPHENOL	90437		1.90E-003				3.5E+001	C
PHOSPHINE	7803512	3.00E-004		8.60E-005			1.1E+001	N
PHOSPHORIC ACID	7664382			2.90E-003				
PHOSPHORUS (WHITE)	7723140	2.00E-005					7.3E-001	N
P-PHTHALIC ACID	100210	1.00E+000					3.7E+004	N
PHTHALIC ANHYDRIDE	85449	2.00E+000		3.43E-002			7.3E+004	N
POLYBROMINATED BIPHENYLS		7.00E-006	8.90E+000				7.5E-003	C
POLYCHLORINATED BIPHENYLS	1336363		2.00E+000		2.00E+000		3.3E-002	C
AROCLOR-1016	12674112	7.00E-005	7.00E-002		7.00E-002		9.6E-001	C
AROCLOR-1221	11104282		2.00E+000		2.00E+000		3.3E-002	C
AROCLOR-1232	11141165		2.00E+000		2.00E+000		3.3E-002	C
AROCLOR-1242	53469219		2.00E+000		2.00E+000		3.3E-002	C
AROCLOR-1248	12672296		2.00E+000		2.00E+000		3.3E-002	C
AROCLOR-1254	11097691	2.00E-005	2.00E+000		2.00E+000		3.3E-002	C
AROCLOR-1260	11096825		2.00E+000		2.00E+000		3.3E-002	C
POLYCHLORINATED TERPHENYLS	61788338		4.50E+000				1.5E-002	C
POLYNUCLEAR AROMATIC HYDROCARBONS:								
ACENAPHTHENE	83329	6.00E-002				y	3.7E+002	N
ANTHRACENE	120127	3.00E-001				y	1.8E+003	N
BENZ[A]ANTHRACENE	56553		7.30E-001				9.2E-002	C
BENZO[B]FLUORANTHENE	205992		7.30E-001				9.2E-002	C
BENZO[K]FLUORANTHENE	207089		7.30E-002				9.2E-001	C
BENZO[A]PYRENE	50328		7.30E+000		3.10E+000		9.2E-003	C

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l	
CARBAZOLE	86748		2.00E-002				3.3E+000	C
CHRYSENE	218019		7.30E-003				9.2E+000	C
DIBENZ[A,H]ANTHRACENE	53703		7.30E+000				9.2E-003	C
DIBENZOFURAN	132649	4.00E-003				y	2.4E+001	N
FLUORANTHENE	206440	4.00E-002					1.5E+003	N
FLUORENE	86737	4.00E-002				y	2.4E+002	N
INDENO[1,2,3-C,D]PYRENE	193395		7.30E-001				9.2E-002	C
2-METHYLNAPHTHALENE	91576	2.00E-002				y	1.2E+002	N
NAPHTHALENE	91203	2.00E-002		9.00E-004		y	6.5E+000	N
PYRENE	129000	3.00E-002				y	1.8E+002	N
PROMETON	1610180	1.50E-002					5.5E+002	N
PROMETRYN	7287196	4.00E-003					1.5E+002	N
PROPACHLOR	1918167	1.30E-002					4.7E+002	N
PROPANIL	709988	5.00E-003					1.8E+002	N
PROPARGITE	2312358	2.00E-002					7.3E+002	N
N-PROPYLBENZENE	103651	4.00E-002				y	2.4E+002	N
PROPYLENE GLYCOL	57556	2.00E+001					7.3E+005	N
PROPYLENE GLYCOL, MONOETHYL ETHER	52125538	7.00E-001					2.6E+004	N
PROPYLENE GLYCOL, MONOMETHYL ETHER	107982	7.00E-001		5.70E-001			2.6E+004	N
PURSUIT	81335775	2.50E-001					9.1E+003	N
PYRIDINE	110861	1.00E-003					3.7E+001	N
QUINOLINE	91225		1.20E+001				5.6E-003	C
RDX	121824	3.00E-003	1.10E-001				6.1E-001	C
RESMETHRIN	10453868	3.00E-002					1.1E+003	N
RONNEL	299843	5.00E-002					1.8E+003	N
ROTENONE	83794	4.00E-003					1.5E+002	N
SELENIUS ACID	7783008	5.00E-003					1.8E+002	N
SELENIUM	7782492	5.00E-003					1.8E+002	N
SILVER	7440224	5.00E-003					1.8E+002	N
SIMAZINE	122349	5.00E-003	1.20E-001				5.6E-001	C
SODIUM AZIDE	26628228	4.00E-003					1.5E+002	N
SODIUM DIETHYLDITHIOCARBAMATE	148185	3.00E-002	2.70E-001				2.5E-001	C
STRONTIUM, STABLE	7440246	6.00E-001					2.2E+004	N
STRYCHNINE	57249	3.00E-004					1.1E+001	N
STYRENE	100425	2.00E-001		2.86E-001		y	1.6E+003	N
2,3,7,8-TETRACHLORODIBENZODIOXIN	1746016		1.50E+005		1.50E+005		4.5E-007	C
1,2,4,5-TETRACHLOROBENZENE	95943	3.00E-004					1.1E+001	N

Chemical	CAS	RfDo mg/kg/d	CSFo 1/mg/kg/d	RfDi mg/kg/d	CSFi 1/mg/kg/d	VOC	water ug/l
1,1,1,2-TETRACHLOROETHANE	630206	3.00E-002	2.60E-002		2.60E-002	y	4.1E-001
1,1,2,2-TETRACHLOROETHANE	79345	6.00E-002	2.00E-001		2.00E-001	y	5.3E-002
TETRACHLOROETHENE	127184	1.00E-002	5.20E-002	1.4E-001	2.00E-003	y	1.1E+000
2,3,4,6-TETRACHLOROPHENOL	58902	3.00E-002					1.1E+003
P.A.A.-TETRACHLOROTOLUENE	5216251		2.00E+001				3.3E-003
1,1,1,2-TETRAFLUOROETHANE	811972			2.29E+001		y	1.7E+005
TETRAHYDROFURAN	109999	2.00E-001	7.6E-003	8.6E-002	6.8E-003		8.8E+000
TETRYL	479458	1.00E-002					3.7E+002
THALLIC OXIDE	1314325	7.00E-005					2.6E+000
THALLIUM	7440280	7.00E-005					2.6E+000
THALLIUM ACETATE	563688	9.00E-005					3.3E+000
THALLIUM CARBONATE	6533739	8.00E-005					2.9E+000
THALLIUM CHLORIDE	7791120	8.00E-005					2.9E+000
THALLIUM NITRATE	10102451	9.00E-005					3.3E+000
THALLIUM SULFATE (2:1)	7446186	8.00E-005					2.9E+000
THIOBENCARB	28249776	1.00E-002					3.7E+002
TIN	7440315	6.00E-001					2.2E+004
TITANIUM	7440326	4.00E+000		8.60E-003			1.5E+005
TITANIUM DIOXIDE	13463677	4.00E+000		8.60E-003			1.5E+005
TOLUENE	108883	2.00E-001		1.14E-001		y	7.5E+002
TOLUENE-2,4-DIAMINE	95807		3.20E+000				2.1E-002
TOLUENE-2,5-DIAMINE	95705	6.00E-001					2.2E+004
TOLUENE-2,6-DIAMINE	823405	2.00E-001					7.3E+003
P-TOLUIDINE	106490		1.90E-001				3.5E-001
TOXAPHENE	8001352		1.10E+000		1.10E+000		6.1E-002
1,2,4-TRIBROMOBENZENE	615543	5.00E-003					1.8E+002
TRIBUTYL TIN OXIDE	56359	3.00E-004					1.1E+001
2,4,6-TRICHLOROANILINE	634935		3.40E-002				2.0E+000
1,2,4-TRICHLOROBENZENE	120821	1.00E-002		5.70E-002		y	1.9E+002
1,1,1-TRICHLOROETHANE	71556	2.80E-001		6.30E-001		y	3.2E+003
1,1,2-TRICHLOROETHANE	79005	4.00E-003	5.70E-002		5.60E-002	y	1.9E-001
TRICHLOROETHENE	79016	6.00E-003	1.10E-002		6.00E-003	y	1.6E+000
TRICHLOROFLUOROMETHANE	75694	3.00E-001		2.00E-001		y	1.3E+003
2,4,5-TRICHLOROPHENOL	95954	1.00E-001					3.7E+003
2,4,6-TRICHLOROPHENOL	88062		1.10E-002		1.00E-002		6.1E+000
2,4,5-T	93765	1.00E-002					3.7E+002
2-(2,4,5-TRICHLOROPHENOXY)PROPIONIC	93721	8.00E-003					2.9E+002

Chemical	CAS	RfDo mg/kg/d	CSFo l/mg/kg/d	RfDi mg/kg/d	CSFi l/mg/kg/d	VOC	water ug/l
ACID							
1,1,2-TRICHLOROPROPANE	598776	5.00E-003				y	3.0E+001 N
1,2,3-TRICHLOROPROPANE	96184	6.00E-003	2.00E+000	1.4E-003		y	5.3E-003 C
1,2,3-TRICHLOROPROPENE	96195	5.00E-003				y	3.0E+001 N
1,1,2-TRICHLORO-1,2,2-TRIFLUOROETHANE	76131	3.00E+001		8.60E+000		y	5.9E+004 N
1,2,4-TRIMETHYLBENZENE	95636	5.00E-002		1.70E-003		y	1.2E+001 N
1,3,5-TRIMETHYLBENZENE	108678	5.00E-002		1.70E-003		y	1.2E+001 N
TRIMETHYL PHOSPHATE	512561		3.70E-002				1.8E+000 C
1,3,5-TRINITROBENZENE	99354	3.00E-002					1.1E+003 N
2,4,6-TRINITROTOLUENE	118967	5.00E-004	3.00E-002				2.2E+000 C
URANIUM (SOLUBLE SALTS; from IRIS)	7440611	3.00E-003					1.1E+002 N
URANIUM (SOLUBLE SALTS; provisional)	7440611	2.00E-004					7.3E+000 N
VANADIUM	7440622	7.00E-003					2.6E+002 N
VANADIUM PENTOXIDE	1314621	9.00E-003					3.3E+002 N
VANADIUM SULFATE	16785812	2.00E-002					7.3E+002 N
VINCLOZOLIN	50471448	2.50E-002					9.1E+002 N
VINYL ACETATE	108054	1.00E+000		5.71E-002		y	4.1E+002 N
**VINYL CHLORIDE inc earlylife(see cover memos)	75014	3.00E-003	1.40E+000	2.8E-002	3.00E-002	y	1.5E-002 C
**VINYL CHLORIDE: adult (see cover memos)	75014	3.00E-003	7.20E-001	2.8E-002	1.5E-002	y	
WARFARIN	81812	3.00E-004					1.1E+001 N
M-XYLENE	108383	2.00E+000				y	1.2E+004 N
O-XYLENE	95476	2.00E+000				y	1.2E+004 N
P-XYLENE	106423					y	
XYLENES	1330207	2.00E+000				y	1.2E+004 N
ZINC	7440666	3.00E-001					1.1E+004 N
ZINC PHOSPHIDE	1314847	3E-004					1.1E+001 N
ZINEB	1212677	5E-002					1.8E+003 N

Appendix C: Human Health Intake-Risk SIC Code List

Appendix C: Human Health Intake-Risk SIC Code List

SIC Code	Risk (l/ug)	SIC Code Description
0011	1496.1697	DISCONTINUED, CHANGED, OR UNKNOWN
0013	2.4035	
0030	0.0005	
0034	0.0001	
0036	0.0421	
0038	12.2541	
0116	0.2433	AGRICULTURE - SOYBEANS
0119	0.7849	AGRICULTURE - CASH GRAINS, NEC
0131	0.0029	AGRICULTURE - COTTON
0133	2.1551	AGRICULTURE - SUGAR CANE AND SUGAR BEETS
0134	0.6849	AGRICULTURE - IRISH POTATOES
0139	13.5972	AGRICULTURE - FIELD CROPS, EXCEPT CASH GRAINS, NEC
0161	2.4035	AGRICULTURE - VEGETABLES AND MELONS
0171	0.1207	AGRICULTURE - BERRY CROPS
0172	0.0048	AGRICULTURE - GRAPES
0173	0.5038	AGRICULTURE - TREE NUTS
0174	0.0039	AGRICULTURE - CITRUS FRUITS
0175	0.0048	AGRICULTURE - DECIDUOUS TREE FRUITS
0181	0.3265	AGRICULTURE - ORNAMENTAL NURSERY PRODUCTS
0182	1.2577	AGRICULTURE - FOOD CROPS GROWN UNDER COVER
0211	0.7550	AGRICULTURE - BEEF CATTLE FEEDLOTS
0212	0.6849	AGRICULTURE - BEEF CATTLE, EXCEPT FEEDLOTS
0213	0.6420	AGRICULTURE - HOGS
0219	0.6873	AGRICULTURE - GENERAL LIVESTOCK, NEC
0241	0.6354	AGRICULTURE - DAIRY FARMS
0251	0.6746	AGRICULTURE - BROILER, FRYER, AND ROASTER CHICKENS
0252	0.4034	AGRICULTURE - CHICKEN EGGS
0253	0.4731	AGRICULTURE - TURKEYS AND TURKEY EGGS

SIC Code	Risk (I/ug)	SIC Code Description
0254	0.7222	AGRICULTURE - POULTRY HATCHERIES
0259	0.4202	AGRICULTURE - POULTRY AND EGGS, NEC
0273	0.3969	AGRICULTURE - ANIMAL AQUACULTURE
0279	0.3228	AGRICULTURE - ANIMAL SPECIALTIES, NEC
0291	2.4035	AGRICULTURE - GENERAL FARMS, PRIMARILY ANIMAL
0332	0.0002	
0367	0.3217	
0711	1.1887	AGRICULTURE - SOIL PREPARATION SERVICES
0721	0.0396	AGRICULTURE - CROP PLANTING AND PROTECTING
0722	1.4803	AGRICULTURE - CROP HARVESTING
0723	2.2508	AGRICULTURE - CROP PREPARATION SERVICES FOR MARKET
0724	0.3487	AGRICULTURE - COTTON GINNING
0741	0.8013	AGRICULTURE - VETERINARY SERVICES FOR LIVESTOCK
0742	0.4716	AGRICULTURE - VETERINARY SERVICES, SPECIALTIES
0751	0.0894	AGRICULTURE - LIVESTOCK SERVICES, EXCEPT VETERINARY
0752	1.9713	AGRICULTURE - ANIMAL SPECIALTY SERVICES
0762	2.5479	AGRICULTURE - FARM MANAGEMENT SERVICES
0782	0.5496	AGRICULTURE - LAWN AND GARDEN SERVICES
0783	6.4772	AGRICULTURE - ORNAMENTAL SHRUB AND TREE SERVICES
0811	1.4582	AGRICULTURE - TIMBER TRACTS
0831	0.0982	AGRICULTURE - FOREST PRODUCTS
0851	7.3841	AGRICULTURE - FORESTRY SERVICES
0865	3.5031	
0912	1.2018	AGRICULTURE - FINFISH
0913	2.4035	AGRICULTURE - SHELLFISH
0919	0.0006	AGRICULTURE - MISCELLANEOUS MARINE PRODUCTS
0921	0.4846	AGRICULTURE - FISH HATCHERIES AND PRESERVES
1010	0.0118	
1011	2.3887	MINING - IRON ORES
1021	2.0994	MINING - COPPER ORES

SIC Code	Risk (l/ug)	SIC Code Description
1031	0.7678	MINING - LEAD AND ZINC ORES
1041	2.2494	MINING - GOLD ORES
1044	3.1528	MINING - SILVER ORES
1051	0.0007	
1061	0.9646	MINING - FERROALLOY ORES, EXCEPT VANADIUM
1081	0.0044	MINING - METAL MINING SERVICES
1094	1.4063	MINING - URANIUM, RADIUM, VANADIUM ORES
1099	0.4081	MINING - METAL ORES, NEC
1111	8.1499	DISCONTINUED, CHANGED, OR UNKNOWN
1211	0.6314	DISCONTINUED, CHANGED, OR UNKNOWN
1213	0.4015	
1221	1.3449	MINING - BITUMINOUS COAL AND LIGNITE - SURFACE
1222	0.6318	MINING - BITUMINOUS COAL - UNDERGROUND
1240	0.0048	
1241	0.4344	MINING - COAL MINING SERVICES
1311	13.2528	MINING - CRUDE PETROLEUM AND NATURAL GAS
1321	3.5277	MINING - NATURAL GAS LIQUIDS
1359	0.0021	DISCONTINUED, CHANGED, OR UNKNOWN
1380	0.1665	DISCONTINUED, CHANGED, OR UNKNOWN
1381	0.0021	MINING - DRILLING OIL AND GAS WELLS
1382	2.6544	MINING - OIL AND GAS EXPLORATION SERVICES
1389	19.3567	MINING - OIL AND GAS FIELD SERVICES, NEC
1410	1.3699	
1411	29.9484	MINING - DIMENSION STONE
1422	110.9730	MINING - CRUSHED AND BROKEN LIMESTONE
1423	1.0303	MINING - CRUSHED AND BROKEN GRANITE
1429	1.0595	MINING - CRUSHED AND BROKEN STONE, NEC
1442	1.3764	MINING - CONSTRUCTION SAND AND GRAVEL
1446	1.1324	MINING - INDUSTRIAL SAND
1452	0.0001	

SIC Code	Risk (l/ug)	SIC Code Description
1454	0.0183	
1455	2.7717	MINING - KAOLIN AND BALL CLAY
1459	0.6149	MINING - CLAY AND RELATED MINERALS, NEC
1474	2.4839	MINING - POTASH, SODA AND BORATE MINERALS
1475	0.5368	MINING - PHOSPHATE ROCK
1476	0.2836	
1479	0.5337	MINING - CHEMICAL AND FERTILIZER MINING, NEC
1481	0.0054	MINING - NONMETALLIC MINERALS SERVICES
1496	0.0001	
1499	1.1149	MINING - MISCELLANEOUS NONMETALLIC MINERALS, NEC
1521	0.2416	CONSTRUCTION - SINGLE-FAMILY HOUSING CONSTRUCTION
1522	65.3401	CONSTRUCTION - RESIDENTIAL CONSTRUCTION, NEC
1531	2.4035	CONSTRUCTION - OPERATIVE BUILDERS
1541	1.2795	CONSTRUCTION - INDUSTRIAL BUILDINGS AND WAREHOUSES
1542	1.5443	CONSTRUCTION - NONRESIDENTIAL CONSTRUCTION, NEC
1548	490.3158	
1549	0.3035	
1611	1.9866	CONSTRUCTION - HIGHWAY AND STREET CONSTRUCTION
1622	1.2526	CONSTRUCTION - BRIDGE, TUNNEL, AND ELEVATED HIGHWAY
1623	2.4970	CONSTRUCTION - WATER, SEWER, AND UTILITY LINES
1629	4021.3404	CONSTRUCTION - HEAVY CONSTRUCTION, NEC
1711	0.3445	CONSTRUCTION - PLUMBING, HEATING, AIR CONDITIONING
1721	0.7166	CONSTRUCTION - PAINTING AND PAPER HANGING
1731	0.2205	CONSTRUCTION - ELECTRICAL WORK
1741	0.0312	CONSTRUCTION - MASONRY AND OTHER STONE WORK
1742	2.4038	CONSTRUCTION - PLASTERING, DRYWALL, AND INSULATION
1743	0.0009	CONSTRUCTION - TERRAZZO, TILE, MARBLE, MOSAIC WORK
1751	0.0231	CONSTRUCTION - CARPENTRY WORK
1752	0.1630	CONSTRUCTION - FLOOR LAYING AND FLOOR WORK, NEC
1761	0.0007	CONSTRUCTION - ROOFING, SIDING, AND SHEET METAL WORK

SIC Code	Risk (l/ug)	SIC Code Description
1771	0.0000	CONSTRUCTION - CONCRETE WORK
1791	0.0077	CONSTRUCTION - STRUCTURAL STEEL ERECTION
1794	1.6465	CONSTRUCTION - EXCAVATION WORK
1795	2.0189	CONSTRUCTION - WRECKING AND DEMOLITION WORK
1796	1119870.9981	CONSTRUCTION - INSTALLING BUILDING EQUIPMENT, NEC
1798	3.1373	
1799	0.7293	CONSTRUCTION - SPECIAL TRADE CONTRACTORS, NEC
1911	3.2936	
1925	0.0418	UNKNOWN (FLORIDA DATA)
1931	0.0048	
1941	0.0001	
2000	103.1630	
2010	0.1991	
2011	0.5792	MANUFACTURING - MEAT PACKING PLANTS
2013	0.3710	MANUFACTURING - SAUSAGES AND OTHER PREPARED MEATS
2015	0.7276	MANUFACTURING - POULTRY SLAUGHTERING AND PROCESSING
2016	1.7331	DISCONTINUED, CHANGED, OR UNKNOWN
2017	1.0109	
2020	0.0058	
2021	0.1990	MANUFACTURING - CREAMERY BUTTER
2022	0.3570	MANUFACTURING - CHEESE, NATURAL AND PROCESSED
2023	0.3723	MANUFACTURING - DRY, CONDENSED, EXAPORATED PRODUCTS
2024	16348.5890	MANUFACTURING - ICE CREAM AND FROZEN DESSERTS
2026	0.6948	MANUFACTURING - FLUID MILK
2030	0.6056	
2031	0.0018	
2032	0.6775	MANUFACTURING - CANNED SPECIALTIES
2033	7.7651	MANUFACTURING - CANNED FRUITS AND VEGETABLES

SIC Code	Risk (l/ug)	SIC Code Description
2034	5.0532	MANUFACTURING - DEHYDRATED FRUITS, VEGETABLES, SOUPS
2035	1.2725	MANUFACTURING - PICKLES, SAUCES, AND SALAD DRESSINGS
2037	2.7761	MANUFACTURING - FROZEN FRUITS AND VEGETABLES
2038	0.2128	MANUFACTURING - FROZEN SPECIALTIES, NEC
2040	1.0842	
2041	2.7550	MANUFACTURING - FLOUR AND OTHER GRAIN MILL PRODUCTS
2042	0.1318	
2043	0.8298	MANUFACTURING - CEREAL BREAKFAST FOODS
2044	1.1345	MANUFACTURING - RICE MILLING
2045	0.2535	MANUFACTURING - PREPARED FLOUR MIXES AND DOUGHS
2046	5.0476	MANUFACTURING - WET CORN MILLING
2047	0.9987	MANUFACTURING - DOG AND CAT FOOD
2048	1.7024	MANUFACTURING - PREPARED FEEDS, NEC
2050	0.0048	
2051	0.6157	MANUFACTURING - BREAD, CAKE, AND RELATED PRODUCTS
2052	0.2319	MANUFACTURING - COOKIES AND CRACKERS
2053	0.0035	MANUFACTURING - FROZEN BAKERY PRODUCTS, EXCEPT BREAD
2061	1.4642	MANUFACTURING - RAW CANE SUGAR
2062	12.0928	MANUFACTURING - CANE SUGAR REFINING
2063	1.4956	MANUFACTURING - BEET SUGAR
2064	0.5397	MANUFACTURING - CANDY AND OTHER CONFECTIONERY PRODUCTS
2065	0.5594	
2066	2.7548	MANUFACTURING - CHOCOLATE AND COCOA PRODUCTS
2067	1.6119	MANUFACTURING - CHEWING GUM
2068	0.8561	MANUFACTURING - SALTED AND ROASTED NUTS AND SEEDS
2070	0.0048	
2074	0.0461	MANUFACTURING - COTTONSEED OIL MILLS

SIC Code	Risk (I/ug)	SIC Code Description
2075	0.3929	MANUFACTURING - SOYBEAN OIL MILLS
2076	2.7599	MANUFACTURING - VEGETABLE OIL MILLS, NEC
2077	1.2717	MANUFACTURING - ANIMAL AND MARINE FATS AND OILS
2079	0.5495	MANUFACTURING - EDIBLE FATS AND OILS, NEC
2082	0.8101	MANUFACTURING - MALT BEVERAGES
2083	5.8304	MANUFACTURING - MALT
2084	1.0164	MANUFACTURING - WINES, BRANDY, AND BRANDY SPIRITS
2085	0.8096	MANUFACTURING - DISTILLED AND BLENDED LIQUORS
2086	1.3322	MANUFACTURING - BOTTLED AND CANNED SOFT DRINKS
2087	1.5215	MANUFACTURING - FLAVORING EXTRACTS AND SYRUPS, NEC
2090	0.8044	
2091	0.6249	MANUFACTURING - CANNED AND CURED FISH AND SEAFOOD
2092	0.6115	MANUFACTURING - FRESH OR FROZEN PREPARED FISH
2095	54.8672	MANUFACTURING - ROASTED COFFEE
2096	1.0404	
2097	0.0157	MANUFACTURING - MANUFACTURED ICE
2098	0.5264	MANUFACTURING - MACARONI AND SPAGHETTI
2099	2.1542	MANUFACTURING - FOOD PREPARATIONS, NEC
2111	0.6525	MANUFACTURING - CIGARETTES
2121	1.6182	MANUFACTURING - CIGARS
2124	0.0001	
2131	0.4825	MANUFACTURING - CHEWING AND SMOKING TOBACCO
2141	1.3074	MANUFACTURING - TOBACCO STEMMING AND REDRYING
2169	3.4754	
2171	0.9783	
2200	0.6868	DISCONTINUED, CHANGED, OR UNKNOWN
2211	0.6252	MANUFACTURING - BROADWOVEN FABRIC MILLS, COTTON
2221	0.4535	MANUFACTURING - BROADWOVEN FABRIC MILLS, MAN-MADE
2228	0.2147	
2231	1.3154	MANUFACTURING - BROADWOVEN FABRIC MILLS, WOOL

SIC Code	Risk (l/ug)	SIC Code Description
2241	3.2836	MANUFACTURING - NARROW FABRIC MILLS
2250	0.0070	
2251	1.2453	MANUFACTURING - WOMEN'S HOSIERY, EXCEPT SOCKS
2252	1.2696	MANUFACTURING - HOSIERY, NEC
2253	0.4288	MANUFACTURING - KNIT OUTERWEAR MILLS
2254	0.0404	MANUFACTURING - KNIT UNDERWEAR MILLS
2257	0.2560	MANUFACTURING - WEFT KNIT FABRIC MILLS
2258	0.1853	MANUFACTURING - LACE AND WARP KNIT FABRIC MILLS
2259	0.1171	MANUFACTURING - KNITTING MILLS, NEC
2260	0.4188	
2261	0.9238	MANUFACTURING - FINISHING PLANTS, COTTON
2262	0.3957	MANUFACTURING - FINISHING PLANTS, MAN-MADE
2269	0.8587	MANUFACTURING - FINISHING PLANTS, NEC
2270	0.0003	
2271	0.1280	
2272	10.0764	
2273	1.0529	MANUFACTURING - CARPETS AND RUGS
2279	35.9908	
2281	1.8225	MANUFACTURING - YARN SPINNING MILLS
2282	0.2129	MANUFACTURING - THROWING AND WINDING MILLS
2283	0.1911	
2284	0.7857	MANUFACTURING - THREAD MILLS
2290	0.0013	
2291	15.0854	
2292	0.0004	
2293	5.5482	
2295	4.9263	MANUFACTURING - COATED FABRICS
2296	0.2407	MANUFACTURING - TIRE CORD AND FABRICS
2297	2.4099	MANUFACTURING - NONWOVEN FABRICS
2298	0.0607	MANUFACTURING - CORDAGE AND TWINE

SIC Code	Risk (I/ug)	SIC Code Description
2299	1.3161	MANUFACTURING - TEXTILE GOODS, NEC
2311	0.4291	MANUFACTURING - MEN'S AND BOYS' SUITS AND COATS
2321	0.2953	MANUFACTURING - MEN'S AND BOYS' SHIRTS
2322	0.0091	MANUFACTURING - MEN'S AND BOYS' UNDERWEAR AND NIGHTWEAR
2325	0.0019	MANUFACTURING - MEN'S AND BOYS' TROUSERS AND SLACKS
2326	0.0021	MANUFACTURING - MEN'S AND BOYS' WORK CLOTHING
2328	0.0003	
2329	0.1194	MANUFACTURING - MEN'S AND BOYS' CLOTHING, NEC
2330	0.0003	
2331	1.2042	MANUFACTURING - WOMEN'S AND MISSES' BLOUSES AND SHIRTS
2335	0.0009	MANUFACTURING - WOMEN'S, JUNIORS' AND MISSES' DRESSES
2341	0.0023	MANUFACTURING - WOMEN'S AND CHILDREN'S UNDERWEAR
2351	0.0016	
2352	0.0016	
2353	0.0349	MANUFACTURING - HATS, CAPS, AND MILLINERY
2369	0.0022	MANUFACTURING - GIRLS' AND CHILDREN'S OUTERWEAR, NEC
2381	0.1841	MANUFACTURING - FABRIC DRESS AND WORK GLOVES
2384	0.2342	MANUFACTURING - ROBES AND DRESSING GOWNS
2386	0.2409	MANUFACTURING - LEATHER AND SHEEP LINED CLOTHING
2389	0.1447	MANUFACTURING - APPAREL AND ACCESSORIES, NEC
2390	0.0014	
2391	0.0467	MANUFACTURING - CURTAINS AND DRAPERIES
2392	55.1351	MANUFACTURING - HOUSE FURNISHINGS, NEC
2393	0.0013	MANUFACTURING - TEXTILE BAGS
2394	0.0006	MANUFACTURING - CANVAS AND RELATED PRODUCTS
2395	0.4472	MANUFACTURING - PLEATING AND STITCHING
2396	2.2421	MANUFACTURING - AUTOMOTIVE AND APPAREL TRIMMINGS
2399	1.9886	MANUFACTURING - FABRICATED TEXTILE PRODUCTS, NEC

SIC Code	Risk (l/ug)	SIC Code Description
2411	21905.6762	MANUFACTURING - LOGGING
2421	2229.2487	MANUFACTURING - SAWMILLS AND PLANING MILLS, GENERAL
2426	2.7060	MANUFACTURING - HARDWOOD DIMENSION AND FLOORING MILLS
2429	1.3175	MANUFACTURING - SPECIAL PRODUCT SAWMILLS, NEC
2430	0.0021	DISCONTINUED, CHANGED, OR UNKNOWN
2431	3303.7214	MANUFACTURING - MILLWORK
2432	0.0018	
2434	0.0429	MANUFACTURING - WOOD KITCHEN CABINETS
2435	0.8344	MANUFACTURING - HARDWOOD VENEER AND PLYWOOD
2436	21958.8315	MANUFACTURING - SOFTWOOD VENEER AND PLYWOOD
2439	2.8702	MANUFACTURING - STRUCTURAL WOOD MEMBERS, NEC
2441	0.0023	MANUFACTURING - NAILED WOOD BOXES AND SHOOK
2448	0.5223	MANUFACTURING - WOOD PALLETS AND SKIDS
2449	0.0002	MANUFACTURING - WOOD CONTAINERS, NEC
2450	0.0003	
2451	0.2105	MANUFACTURING - MOBILE HOMES
2452	0.0604	MANUFACTURING - PREFABRICATED WOOD BUILDINGS
2471	0.0014	
2490	0.0906	DISCONTINUED, CHANGED, OR UNKNOWN
2491	589.8359	MANUFACTURING - WOOD PRESERVING
2492	25356.4297	
2493	3309.0350	MANUFACTURING - RECONSTITUTED WOOD PRODUCTS
2499	3702.3251	MANUFACTURING - WOOD PRODUCTS, NEC
2500	0.0036	DISCONTINUED, CHANGED, OR UNKNOWN
2510	0.0670	
2511	0.1117	MANUFACTURING - WOOD HOUSEHOLD FURNITURE
2512	0.4325	MANUFACTURING - UPHOLSTERED HOUSEHOLD FURNITURE
2514	1.0447	MANUFACTURING - METAL HOUSEHOLD FURNITURE
2515	0.0812	MANUFACTURING - MATTRESSES AND BEDSPRINGS

SIC Code	Risk (l/ug)	SIC Code Description
2517	0.0415	MANUFACTURING - WOOD TV AND RADIO CABINETS
2519	0.5120	MANUFACTURING - HOUSEHOLD FURNITURE, NEC
2520	0.0004	
2521	0.0761	MANUFACTURING - WOOD OFFICE FURNITURE
2522	0.2845	MANUFACTURING - OFFICE FURNITURE, EXCEPT WOOD
2525	3.8140	
2530	1.2042	
2531	2.0537	MANUFACTURING - PUBLIC BUILDING AND RELATED FURNITURE
2541	0.0946	MANUFACTURING - WOOD PARTITIONS AND FIXTURES
2542	0.2007	MANUFACTURING - PARTITIONS AND FIXTURES, EXCEPT WOOD
2581	0.0448	
2585	0.0085	
2591	0.1152	MANUFACTURING - DRAPERY HARDWARE AND BLINDS AND SHADES
2593	0.0012	
2599	0.0515	MANUFACTURING - FURNITURE AND FIXTURES, NEC
2611	17740.9098	MANUFACTURING - PULP MILLS
2621	10688.5298	MANUFACTURING - PAPER MILLS
2631	5091.0421	MANUFACTURING - PAPERBOARD MILLS
2640	0.0007	
2641	4.0388	DISCONTINUED, CHANGED, OR UNKNOWN
2642	0.2092	
2643	0.3508	DISCONTINUED, CHANGED, OR UNKNOWN
2644	125.1203	
2645	0.9247	DISCONTINUED, CHANGED, OR UNKNOWN
2646	0.0006	
2647	439.5707	
2648	1.0191	DISCONTINUED, CHANGED, OR UNKNOWN
2649	0.2818	DISCONTINUED, CHANGED, OR UNKNOWN

SIC Code	Risk (l/ug)	SIC Code Description
2650	0.0009	
2651	0.3172	
2652	2.1119	MANUFACTURING - SET-UP PAPERBOARD BOXES
2653	0.3247	MANUFACTURING - CORRUGATED AND SOLID FIBER BOXES
2654	0.0011	DISCONTINUED, CHANGED, OR UNKNOWN
2655	0.2807	MANUFACTURING - FIBER CANS, DRUMS, AND SIMILAR PRODUCTS
2656	0.0806	MANUFACTURING - SANITARY FOOD CONTAINERS
2657	0.0487	MANUFACTURING - FOLDING PAPERBOARD BOXES
2661	10.8792	DISCONTINUED, CHANGED, OR UNKNOWN
2670	0.0001	
2671	0.8038	MANUFACTURING - PAPER COATED AND LAMINATED, PACKAGING
2672	0.8281	MANUFACTURING - PAPER COATED AND LAMINATED, NEC
2673	2.7418	MANUFACTURING - BAGS - PLASTICS, LAMINATED AND COATED
2674	0.1630	MANUFACTURING - BAGS - UNCOATED PAPER AND MULTIWALL
2675	0.2168	MANUFACTURING - DIE-CUT PAPER AND BOARD
2676	0.5567	MANUFACTURING - SANITARY PAPER PRODUCTS
2677	0.3606	MANUFACTURING - ENVELOPES
2678	0.0416	MANUFACTURING - STATIONARY PRODUCTS
2679	0.1602	MANUFACTURING - CONVERTED PAPER PRODUCTS, NEC
2700	0.0883	
2711	0.3763	MANUFACTURING - NEWSPAPERS
2721	2.0103	MANUFACTURING - PERIODICALS
2731	5.9919	MANUFACTURING - BOOK PUBLISHING
2732	0.1328	MANUFACTURING - BOOK PRINTING
2741	0.0156	MANUFACTURING - MISCELLANEOUS PUBLISHING
2749	0.0017	

SIC Code	Risk (l/ug)	SIC Code Description
2750	0.0017	
2751	0.6079	DISCONTINUED, CHANGED, OR UNKNOWN
2752	0.1249	MANUFACTURING - COMMERCIAL PRINTING, LITHOGRAPHIC
2753	0.0987	
2754	0.1607	MANUFACTURING - COMMERCIAL PRINTING, GRAVURE
2759	0.2018	MANUFACTURING - COMMERCIAL PRINTING, NEC
2761	2.0884	MANUFACTURING - MANIFOLD BUSINESS FORMS
2771	0.1275	MANUFACTURING - GREETING CARDS
2780	0.0000	
2782	0.0749	MANUFACTURING - BLANKBOOKS AND LOOSELEAF BINDERS
2786	0.0007	
2789	0.6786	MANUFACTURING - BOOKBINDING AND RELATED WORK
2793	0.4462	
2795	0.1650	
2796	0.3831	MANUFACTURING - PLATE MAKING SERVICES
2800	0.6273	DISCONTINUED, CHANGED, OR UNKNOWN
2802	132.4794	
2803	31.1939	
2810	33.5255	
2812	21.3744	MANUFACTURING - ALKALIES AND CHLORINE
2813	15.4600	MANUFACTURING - INDUSTRIAL GASES
2815	1.4921	
2816	4.3626	MANUFACTURING - INORGANIC PIGMENTS
2818	9.0066	DISCONTINUED, CHANGED, OR UNKNOWN
2819	374.6539	MANUFACTURING - INDUSTRIAL INORGANIC CHEMICALS, NEC
2820	0.1290	
2821	278.5101	MANUFACTURING - PLASTICS MATERIALS AND RESINS
2822	22.6494	MANUFACTURING - SYNTHETIC RUBBER
2823	3.7720	MANUFACTURING - CELLULOSIC MAN-MADE FIBERS
2824	4.2640	MANUFACTURING - ORGANIC FIBERS, NONCELLULOSIC

SIC Code	Risk (l/ug)	SIC Code Description
2830	1.7789	
2831	11.5780	DISCONTINUED, CHANGED, OR UNKNOWN
2833	57.6945	MANUFACTURING - MEDICINALS AND BOTANICALS
2834	6.2637	MANUFACTURING - PHARMACEUTICAL PREPARATIONS
2835	43.7865	MANUFACTURING - DIAGNOSTIC SUBSTANCES
2836	0.1645	MANUFACTURING - BIOLOGICAL PRODUCTS, EXCEPT DIAGNOSTIC
2840	0.3372	
2841	21.0863	MANUFACTURING - SOAP AND OTHER DETERGENTS
2842	1.1262	MANUFACTURING - POLISHES AND SANITATION GOODS
2843	4.8664	MANUFACTURING - SURFACE ACTIVE AGENTS
2844	8.5223	MANUFACTURING - TOILET PREPARATIONS
2850	0.3657	DISCONTINUED, CHANGED, OR UNKNOWN
2851	0.8674	MANUFACTURING - PAINTS AND ALLIED PRODUCTS
2860	14.7157	
2861	3.5810	MANUFACTURING - GUM AND WOOD CHEMICALS
2865	489.1183	MANUFACTURING - CYCLIC CRUDES AND INTERMEDIATES
2868	0.0394	
2869	159.6813	MANUFACTURING - INDUSTRIAL ORGANIC CHEMICALS, NEC
2870	0.4330	
2871	0.3358	
2873	4.3755	MANUFACTURING - NITROGENOUS FERTILIZERS
2874	0.6718	MANUFACTURING - PHOSPHATIC FERTILIZERS
2875	1.4215	MANUFACTURING - FERTILIZERS, MIXING ONLY
2878	3.7401	
2879	6.3740	MANUFACTURING - AGRICULTURAL CHEMICALS, NEC
2890	1.2368	
2891	2.5017	MANUFACTURING - ADHESIVES AND SEALANTS
2892	39.6491	MANUFACTURING - EXPLOSIVES
2893	1.7183	MANUFACTURING - PRINTING INK

SIC Code	Risk (l/ug)	SIC Code Description
2895	1.3232	MANUFACTURING - CARBON BLACK
2898	0.1026	
2899	26.8904	MANUFACTURING - CHEMICAL PREPARATIONS, NEC
2900	5.2361	DISCONTINUED, CHANGED, OR UNKNOWN
2911	602.5994	MANUFACTURING - PETROLEUM REFINING
2950	0.0541	
2951	49.2294	MANUFACTURING - ASPHALT PAVING MIXTURES AND BLOCKS
2952	0.2104	MANUFACTURING - ASPHALT FELTS AND COATINGS
2991	0.0167	
2992	3.0262	MANUFACTURING - LUBRICATING OILS AND GREASES
2999	3.7827	MANUFACTURING - PETROLEUM AND COAL PRODUCTS, NEC
3000	0.0962	
3010	0.0004	
3011	1.3551	MANUFACTURING - TIRES AND INNER TUBES
3020	0.0819	
3021	4.9178	MANUFACTURING - RUBBER AND PLASTICS FOOTWEAR
3031	0.0001	
3041	3.6779	DISCONTINUED, CHANGED, OR UNKNOWN
3049	0.0493	
3050	0.0002	
3052	6.8552	MANUFACTURING - RUBBER AND PLASTICS HOSE AND BELTING
3053	1.3118	MANUFACTURING - GASKETS, PACKING AND SEALING DEVICES
3060	4.0156	
3061	0.7917	MANUFACTURING - MECHANICAL RUBBER GOODS
3067	0.2438	
3069	1.0699	MANUFACTURING - FABRICATED RUBBER PRODUCTS, NEC
3070	0.1580	
3079	53.4210	DISCONTINUED, CHANGED, OR UNKNOWN
3080	0.0018	

SIC Code	Risk (l/ug)	SIC Code Description
3081	4.8785	MANUFACTURING - UNSUPPORTED PLASTICS, FILM AND SHEET
3082	0.5047	MANUFACTURING - UNSUPPORTED PLASTICS, PROFILE SHAPES
3083	1.3076	MANUFACTURING - LAMINATED PLASTICS, PLATE AND SHEET
3084	13.0924	MANUFACTURING - PLASTICS, PIPE
3085	0.1252	MANUFACTURING - PLASTICS, BOTTLES
3086	4.7336	MANUFACTURING - PLASTICS, FOAM PRODUCTS
3087	0.4999	MANUFACTURING - CUSTOM COMPOUND PURCHASED RESINS
3088	0.1191	MANUFACTURING - PLASTICS, PLUMBING FIXTURES
3089	1.3272	MANUFACTURING - PLASTICS PRODUCTS, NEC
3090	0.0001	
3110	0.0012	
3111	0.2230	MANUFACTURING - LEATHER TANNING AND FINISHING
3130	0.0012	
3131	0.0803	MANUFACTURING - FOOTWEAR, CUT STOCK
3140	0.0012	
3142	0.0653	MANUFACTURING - HOUSE SLIPPERS
3143	0.3301	MANUFACTURING - MEN'S FOOTWEAR, EXCEPT ATHLETIC
3144	0.0310	MANUFACTURING - WOMEN'S FOOTWEAR, EXCEPT ATHLETIC
3149	0.0262	MANUFACTURING - FOOTWEAR, EXCEPT RUBBER, NEC
3160	0.0028	
3161	14.8563	MANUFACTURING - LUGGAGE
3171	0.0221	MANUFACTURING - WOMEN'S HANDBAGS AND PURSES
3172	1.3719	MANUFACTURING - PERSONAL LEATHER GOODS, NEC
3174	0.0001	
3199	0.1081	MANUFACTURING - LEATHER GOODS, NEC
3200	0.0022	
3211	1.3137	MANUFACTURING - FLAT GLASS
3221	0.1234	MANUFACTURING - GLASS CONTAINERS
3224	0.0183	
3225	0.1225	

SIC Code	Risk (l/ug)	SIC Code Description
3229	1.5185	MANUFACTURING - PRESSED AND BLOWN GLASS, NEC
3230	0.0006	
3231	0.2301	MANUFACTURING - PRODUCTS OF PURCHASED GLASS
3241	805.8168	MANUFACTURING - CEMENT, HYDRAULIC
3251	0.6162	MANUFACTURING - BRICK AND STRUCTURAL CLAY TILE
3253	0.0240	MANUFACTURING - CEREMIC WALL AND FLOOR TILE
3255	0.1036	MANUFACTURING - CLAY REFRACTORIES
3259	0.3009	MANUFACTURING - STRUCTURAL CLAY PRODUCTS, NEC
3261	0.0956	MANUFACTURING - VITREOUS PLUMBING FIXTURES
3262	0.0640	MANUFACTURING - VITREOUS CHINA TABLE AND KITCHENWARE
3263	0.8744	MANUFACTURING - SEMIVITREOUS TABLE AND KITCHENWARE
3264	0.4400	MANUFACTURING - PORCELAIN ELECTRICAL SUPPLIES
3269	0.0454	MANUFACTURING - POTTERY PRODUCTS, NEC
3271	0.6133	MANUFACTURING - CONCRETE BLOCK AND BRICK
3272	1.7510	MANUFACTURING - CONCRETE PRODUCTS, NEC
3273	2.1986	MANUFACTURING - READY-MIXED CONCRETE
3274	13.8736	MANUFACTURING - LIME
3275	68.8789	MANUFACTURING - GYPSUM PRODUCTS
3281	0.0472	MANUFACTURING - CUT STONE AND STONE PRODUCTS
3291	0.2145	MANUFACTURING - ABRASIVE PRODUCTS
3292	0.0218	MANUFACTURING - ASBESTOS PRODUCTS
3293	0.0420	DISCONTINUED, CHANGED, OR UNKNOWN
3295	3.6761	MANUFACTURING - MINERALS, GROUND OR TREATED
3296	0.1115	MANUFACTURING - MINERAL WOOL
3297	0.3815	MANUFACTURING - NONCLAY REFRACTORIES
3299	0.4719	MANUFACTURING - NONMETALLIC MINERAL PRODUCTS, NEC
3310	0.2019	
3311	0.1151	
3312	2.3616	MANUFACTURING - BLAST FURNACES AND STEEL MILLS

SIC Code	Risk (l/ug)	SIC Code Description
3313	1.2530	MANUFACTURING - ELECTROMETALLURGICAL PRODUCTS
3315	0.4717	MANUFACTURING - STEEL WIRE AND RELATED PRODUCTS
3316	0.3836	MANUFACTURING - COLD FINISHING OF STEEL SHAPES
3317	0.3758	MANUFACTURING - STEEL PIPE AND TUBES
3320	0.0077	DISCONTINUED, CHANGED, OR UNKNOWN
3321	0.6062	MANUFACTURING - GRAY AND DUCTILE IRON FOUNDRIES
3322	0.8218	MANUFACTURING - MALLEABLE IRON FOUNDRIES
3323	0.0526	
3324	0.2307	MANUFACTURING - STEEL INVESTMENT FOUNDRIES
3325	0.2388	MANUFACTURING - STEEL FOUNDRIES, NEC
3330	8.6761	
3331	2.3032	MANUFACTURING - PRIMARY COPPER
3332	7.5614	DISCONTINUED, CHANGED, OR UNKNOWN
3333	3.3888	
3334	3.3044	MANUFACTURING - PRIMARY ALUMINUM
3335	0.0370	
3339	1.8391	MANUFACTURING - PRIMARY NONFERROUS METALS, NEC
3340	0.0688	
3341	1.1564	MANUFACTURING - SECONDARY NONFERROUS METALS
3347	0.0039	
3350	0.0033	DISCONTINUED, CHANGED, OR UNKNOWN
3351	0.4734	MANUFACTURING - COPPER ROLLING AND DRAWING
3352	0.4382	
3353	0.2696	MANUFACTURING - ALUMINUM SHEET, PLATE, AND FOIL
3354	0.2372	MANUFACTURING - ALUMINUM EXTRUDED PRODUCTS
3355	1.4664	MANUFACTURING - ALUMINUM ROLLING AND DRAWING, NEC
3356	5.9146	MANUFACTURING - NONFERROUS ROLLING AND DRAWING, NEC
3357	1.6323	MANUFACTURING - NONFERROUS WIRE DRAWING AND INSULATING

SIC Code	Risk (l/ug)	SIC Code Description
3359	509.5973	
3360	0.0050	
3361	0.3913	DISCONTINUED, CHANGED, OR UNKNOWN
3362	0.0269	DISCONTINUED, CHANGED, OR UNKNOWN
3363	0.3797	MANUFACTURING - ALUMINUM DIE-CASTINGS
3364	0.2148	MANUFACTURING - NONFERROUS DIE-CASTING, EXCEPT ALUMINUM
3365	0.2981	MANUFACTURING - ALUMINUM FOUNDRIES
3366	0.1875	MANUFACTURING - COPPER FOUNDRIES
3369	0.2410	MANUFACTURING - NONFERROUS FOUNDRIES, NEC
3398	0.2014	MANUFACTURING - METAL HEAT TREATING
3399	0.4711	MANUFACTURING - PRIMARY METAL PRODUCTS, NEC
3400	0.0709	DISCONTINUED, CHANGED, OR UNKNOWN
3410	0.4042	
3411	0.0514	MANUFACTURING - METAL CANS
3412	1927.2285	MANUFACTURING - METAL BARRELS, DRUMS, AND PAILS
3417	0.0013	
3421	1.9303	MANUFACTURING - CUTLERY
3423	0.2875	MANUFACTURING - HAND AND EDGE TOOLS, NEC
3425	0.1537	MANUFACTURING - SAW BLADES AND HANDSAWS
3429	0.2416	MANUFACTURING - HARDWARE, NEC
3430	0.0007	DISCONTINUED, CHANGED, OR UNKNOWN
3431	0.1850	MANUFACTURING - METAL SANITARY WARE
3432	0.3350	MANUFACTURING - PLUMBING FIXTURE FITTINGS AND TRIM
3433	0.3811	MANUFACTURING - HEATING EQUIPMENT, EXCEPT ELECTRIC
3440	0.0272	DISCONTINUED, CHANGED, OR UNKNOWN
3441	0.6578	MANUFACTURING - FABRICATED STRUCTURAL METAL
3442	2.6117	MANUFACTURING - METAL DOORS, SASH, AND TRIM
3443	0.3012	MANUFACTURING - FABRICATED PLATE WORK (BOILER SHOPS)
3444	0.3155	MANUFACTURING - SHEET METAL WORK

SIC Code	Risk (l/ug)	SIC Code Description
3446	0.4412	MANUFACTURING - ARCHITECTURAL METAL WORK
3448	0.4499	MANUFACTURING - PREFABRICATED METAL BUILDINGS
3449	0.5380	MANUFACTURING - MISCELLANEOUS METAL WORK
3450	0.1723	
3451	0.8119	MANUFACTURING - SCREW MACHINE PRODUCTS
3452	0.2970	MANUFACTURING - BOLTS, NUTS, RIVETS, AND WASHERS
3460	0.0699	DISCONTINUED, CHANGED, OR UNKNOWN
3461	0.1893	
3462	6.9629	MANUFACTURING - IRON AND STEEL FORGINGS
3463	0.0738	MANUFACTURING - NONFERROUS FORGINGS
3464	0.0633	
3465	0.7929	MANUFACTURING - AUTOMOTIVE STAMPINGS
3466	0.0680	MANUFACTURING - CROWNS AND CLOSURES
3468	0.0034	
3469	0.3627	MANUFACTURING - METAL STAMPINGS, NEC
3470	0.1423	UNKNOWN (FLORIDA DATA)
3471	7.3252	MANUFACTURING - PLATING AND POLISHING
3479	1.1362	MANUFACTURING - METAL COATING AND ALLIED SERVICES
3480	0.0003	
3481	0.0033	DISCONTINUED, CHANGED, OR UNKNOWN
3482	0.7728	MANUFACTURING - SMALL ARMS AMMUNITION
3483	5603.2130	MANUFACTURING - AMMUNITION, EXCEPT FOR SMALL ARMS, NEC
3484	0.0935	MANUFACTURING - SMALL ARMS
3489	0.9023	MANUFACTURING - ORDNANCE AND ACCESSORIES, NEC
3490	0.0197	
3491	0.2129	MANUFACTURING - INDUSTRIAL VALVES
3492	1.9213	MANUFACTURING - FLUID POWER VALVES AND HOSE FITTINGS
3493	1.5901	MANUFACTURING - STEEL SPRINGS, EXCEPT WIRE
3494	126.7357	MANUFACTURING - VALVES AND PIPE FITTINGS, NEC

SIC Code	Risk (l/ug)	SIC Code Description
3495	0.0413	MANUFACTURING - WIRE SPRINGS
3496	0.3898	MANUFACTURING - MISCELLANEOUS FABRICATED WIRE PRODUCTS
3497	0.0107	MANUFACTURING - METAL FOIL AND LEAF
3498	0.6317	MANUFACTURING - FABRICATED PIPE AND FITTINGS
3499	0.9422	MANUFACTURING - FABRICATED METAL PRODUCTS, NEC
3500	0.0007	
3510	0.3586	
3511	0.9088	MANUFACTURING - TURBINES AND TURBINE GENERATOR SETS
3519	0.5178	MANUFACTURING - INTERNAL COMBUSTION ENGINES, NEC
3520	0.0003	
3523	0.2172	MANUFACTURING - FARM MACHINERY AND EQUIPMENT
3524	0.0503	MANUFACTURING - LAWN AND GARDEN EQUIPMENT
3531	0.1882	MANUFACTURING - CONSTRUCTION MACHINERY
3532	0.2358	MANUFACTURING - MINING MACHINERY
3533	0.9059	MANUFACTURING - OIL AND GAS FIELD MACHINERY
3534	0.1094	MANUFACTURING - ELEVATORS AND MOVING STAIRWAYS
3535	0.1741	MANUFACTURING - CONVEYORS AND CONVEYING EQUIPMENT
3536	0.0553	MANUFACTURING - HOISTS, CRANES, AND MONORAILS
3537	0.0931	MANUFACTURING - INDUSTRIAL TRUCKS AND TRACTORS
3540	0.0011	
3541	1.4505	MANUFACTURING - MACHINE TOOLS, METAL CUTTING TYPES
3542	0.7492	MANUFACTURING - MACHINE TOOLS, METAL FORMING TYPES
3543	0.0007	MANUFACTURING - INDUSTRIAL PATTERNS
3544	0.7500	MANUFACTURING - SPECIAL DIES, TOOLS, JIGS, AND FIXTURE
3545	0.3385	MANUFACTURING - MACHINE TOOL ACCESSORIES
3546	0.5121	MANUFACTURING - POWER DRIVEN HAND TOOLS
3547	0.8767	MANUFACTURING - ROLLING MILL MACHINERY
3548	0.0674	MANUFACTURING - WELDING APPARATUS
3549	0.2668	MANUFACTURING - METAL WORKING MACHINERY, NEC

SIC Code	Risk (l/ug)	SIC Code Description
3550	0.2174	
3551	0.7454	DISCONTINUED, CHANGED, OR UNKNOWN
3552	2.1862	MANUFACTURING - TEXTILE MACHINERY
3553	0.6458	MANUFACTURING - WOODWORKING MACHINERY
3554	0.8940	MANUFACTURING - PAPER INDUSTRIES MACHINERY
3555	0.2098	MANUFACTURING - PRINTING TRADES MACHINERY
3556	0.2100	MANUFACTURING - FOOD PRODUCTS MACHINERY
3559	4.9672	MANUFACTURING - SPECIAL INDUSTRY MACHINERY, NEC
3560	0.0005	
3561	0.6829	MANUFACTURING - PUMPS AND PUMPING EQUIPMENT
3562	0.4015	MANUFACTURING - BALL AND ROLLER BEARINGS
3563	0.1524	MANUFACTURING - AIR AND GAS COMPRESSORS
3564	0.3370	MANUFACTURING - BLOWERS AND FANS
3565	0.2505	MANUFACTURING - PACKAGING MACHINERY
3566	139.6061	MANUFACTURING - SPEED CHANGERS, DRIVES, AND GEARS
3567	0.0540	MANUFACTURING - INDUSTRIAL FURNACES AND OVENS
3568	1.7042	MANUFACTURING - POWER TRANSMISSION EQUIPMENT, NEC
3569	0.5079	MANUFACTURING - GENERAL INDUSTRIAL MACHINERY, NEC
3571	142.7303	MANUFACTURING - ELECTRONIC COMPUTERS
3572	0.2602	MANUFACTURING - COMPUTER STORAGE DEVICES
3573	0.3293	DISCONTINUED, CHANGED, OR UNKNOWN
3574	0.8828	
3575	0.8693	MANUFACTURING - COMPUTER TERMINALS
3576	0.0001	DISCONTINUED, CHANGED, OR UNKNOWN
3577	0.0816	MANUFACTURING - COMPUTER PERIPHERAL EQUIPMENT, NEC
3579	1.5567	MANUFACTURING - OFFICE MACHINES, NEC
3580	0.1032	
3581	0.3266	MANUFACTURING - AUTOMATIC VENDING MACHINES
3582	0.5915	MANUFACTURING - COMMERCIAL LAUNDRY EQUIPMENT

SIC Code	Risk (l/ug)	SIC Code Description
3585	0.2810	MANUFACTURING - REFRIGERATION AND HEATING EQUIPMENT
3586	0.0718	MANUFACTURING - MEASURING AND DISPENSING PUMPS
3589	10771.3870	MANUFACTURING - SERVICE INDUSTRY MACHINERY, NEC
3592	1.5404	MANUFACTURING - CARBURETORS, PISTONS, RINGS, VALVES
3593	0.6288	MANUFACTURING - FLUID POWER CYLINDERS AND ACTUATORS
3594	0.1632	MANUFACTURING - FLUID POWER PUMPS AND MOTORS
3596	0.0820	MANUFACTURING - SCALES AND BALANCES, EXCEPT LABORATORY
3599	1.0286	MANUFACTURING - INDUSTRIAL MACHINERY, NEC
3600	0.0008	
3602	2.4035	
3611	0.0005	UNKNOWN (FLORIDA DATA)
3612	1.2075	MANUFACTURING - TRANSFORMERS, EXCEPT ELECTRONIC
3613	0.7986	MANUFACTURING - SWITCHGEAR AND SWITCHBOARD APPARATUS
3614	0.5570	
3620	0.0006	
3621	0.8103	MANUFACTURING - MOTORS AND GENERATORS
3622	0.6403	DISCONTINUED, CHANGED, OR UNKNOWN
3623	0.0022	DISCONTINUED, CHANGED, OR UNKNOWN
3624	0.2507	MANUFACTURING - CARBON AND GRAPHITE PRODUCTS
3625	0.3334	MANUFACTURING - RELAYS AND INDUSTRIAL CONTROLS
3629	0.4010	MANUFACTURING - ELECTRICAL INDUSTRIAL APPARATUS, NEC
3630	0.0634	
3631	1.2586	MANUFACTURING - HOUSEHOLD COOKING EQUIPMENT
3632	1.7515	MANUFACTURING - HOUSEHOLD REFRIGERATORS AND FREEZERS
3633	0.7132	MANUFACTURING - HOUSEHOLD LAUNDRY EQUIPMENT

SIC Code	Risk (l/ug)	SIC Code Description
3634	0.6884	MANUFACTURING - ELECTRIC HOUSEWARES AND FANS
3635	2.5850	MANUFACTURING - HOUSEHOLD VACUUM CLEANERS
3636	0.1086	
3639	1.0523	MANUFACTURING - HOUSEHOLD APPLIANCES, NEC
3641	8.8168	MANUFACTURING - ELECTRIC LAMPS
3643	0.2102	MANUFACTURING - CURRENT-CARRYING WIRING DEVICES
3644	0.5373	MANUFACTURING - NONCURRENT-CARRYING WIRING DEVICES
3645	0.2598	MANUFACTURING - RESIDENTIAL LIGHTING FIXTURES
3646	0.9289	MANUFACTURING - COMMERCIAL LIGHTING FIXTURES
3647	0.0871	MANUFACTURING - VEHICULAR LIGHTING EQUIPMENT
3648	0.0298	MANUFACTURING - LIGHTING EQUIPMENT, NEC
3651	0.2951	MANUFACTURING - HOUSEHOLD AUDIO AND VIDEO EQUIPMENT
3652	8.6880	MANUFACTURING - PRERECORDED RECORDS AND TAPES
3661	41.8453	MANUFACTURING - TELEPHONE AND TELEGRAPH APPARATUS
3662	1.4825	UNKNOWN (FLORIDA DATA)
3663	0.1473	MANUFACTURING - RADIO AND TV COMMUNICATION EQUIPMENT
3669	0.1195	MANUFACTURING - COMMUNICATIONS EQUIPMENT, NEC
3670	0.1137	DISCONTINUED, CHANGED, OR UNKNOWN
3671	0.3071	MANUFACTURING - ELECTRON TUBES
3672	0.2593	MANUFACTURING - PRINTED CIRCUIT BOARDS
3673	0.3956	
3674	0.2636	MANUFACTURING - SEMICONDUCTORS AND RELATED DEVICES
3675	0.6899	MANUFACTURING - ELECTRONIC CAPACITORS
3676	0.1211	MANUFACTURING - ELECTRONIC RESISTORS
3677	0.6573	MANUFACTURING - ELECTRONIC COILS AND TRANSFORMERS
3678	0.0736	MANUFACTURING - ELECTRONIC CONNECTORS
3679	2.9624	MANUFACTURING - ELECTRONIC COMPONENTS, NEC
3681	0.2536	

SIC Code	Risk (l/ug)	SIC Code Description
3690	0.0358	
3691	2.1973	MANUFACTURING - STORAGE BATTERIES
3692	0.4839	MANUFACTURING - PRIMARY BATTERIES, DRY AND WET
3693	0.1195	
3694	0.2051	MANUFACTURING - ENGINE ELECTRICAL EQUIPMENT
3695	0.2812	MANUFACTURING - MAGNETIC AND OPTICAL RECORDING MEDIA
3698	0.0136	
3699	0.1394	MANUFACTURING - ELECTRICAL EQUIPMENT AND SUPPLIES, NEC
3700	0.0006	UNKNOWN (FLORIDA DATA)
3710	0.2424	
3711	0.3653	MANUFACTURING - MOTOR VEHICLES AND CAR BODIES
3713	0.0731	MANUFACTURING - TRUCK AND BUS BODIES
3714	459.9718	MANUFACTURING - MOTOR VEHICLE PARTS AND ACCESSORIES
3715	0.2280	MANUFACTURING - TRUCK TRAILERS
3716	0.1475	MANUFACTURING - MOTOR HOMES
3720	0.0430	
3721	1.7435	MANUFACTURING - AIRCRAFT
3722	2.4582	
3724	1.0228	MANUFACTURING - AIRCRAFT ENGINES AND ENGINE PARTS
3728	3.2198	MANUFACTURING - AIRCRAFT PARTS AND EQUIPMENT, NEC
3730	0.0010	
3731	28.3043	MANUFACTURING - SHIP BUILDING AND REPAIRING
3732	0.0258	MANUFACTURING - BOAT BUILDING AND REPAIRING
3740	0.0002	
3741	1.0309	
3743	1.3789	MANUFACTURING - RAILROAD EQUIPMENT
3751	0.0600	MANUFACTURING - MOTORCYCLES, BICYCLES, AND PARTS
3761	3.0572	MANUFACTURING - GUIDED MISSILES AND SPACE VEHICLES

SIC Code	Risk (l/ug)	SIC Code Description
3764	7638.9899	MANUFACTURING - SPACE PROPULSION UNITS AND PARTS
3769	2.1115	MANUFACTURING - SPACE VEHICLE EQUIPMENT, NEC
3792	0.5008	MANUFACTURING - TRAVEL TRAILERS AND CAMPERS
3795	1.0136	MANUFACTURING - TANKS AND TANK COMPONENTS
3799	1.0168	MANUFACTURING - TRANSPORTATION EQUIPMENT, NEC
3811	0.8177	
3812	177.7325	MANUFACTURING - SEARCH AND NAVIGATION EQUIPMENT
3815	0.0021	
3821	0.6141	MANUFACTURING - LABORATORY APPARATUS AND FURNITURE
3822	0.8721	MANUFACTURING - ENVIRONMENTAL CONTROLS
3823	9849.9130	MANUFACTURING - PROCESS CONTROL INSTRUMENTS
3824	0.5067	MANUFACTURING - FLUID METERS AND COUNTING DEVICES
3825	0.7677	MANUFACTURING - INSTRUMENTS TO MEASURE ELECTRICITY
3826	0.5302	MANUFACTURING - ANALYTICAL INSTRUMENTS
3827	0.0639	MANUFACTURING - OPTICAL INSTRUMENTS AND LENSES
3829	0.5056	MANUFACTURING - MEASURING AND CONTROLLING DEVICES, NEC
3830	0.0000	
3832	1.3518	
3840	0.0005	
3841	7.4437	MANUFACTURING - SURGICAL AND MEDICAL INSTRUMENTS
3842	8.4808	MANUFACTURING - SURGICAL APPLIANCES AND SUPPLIES
3843	0.0838	MANUFACTURING - DENTAL EQUIPMENT AND SUPPLIES
3844	0.0411	MANUFACTURING - X-RAY APPARATUS AND TUBES
3845	8.0589	MANUFACTURING - ELECTROMEDICAL EQUIPMENT
3851	0.0829	MANUFACTURING - OPHTHALMIC GOODS
3860	0.0024	
3861	87.2198	MANUFACTURING - PHOTOGRAPHIC EQUIPMENT AND SUPPLIES

SIC Code	Risk (l/ug)	SIC Code Description
3873	0.4680	MANUFACTURING - WATCHES, CLOCKS, WATCHCASES, AND PARTS
3900	0.0010	
3910	0.0026	
3911	0.2724	MANUFACTURING - JEWELRY, PRECIOUS METAL
3914	0.1398	MANUFACTURING - SILVERWARE AND PLATED WARE
3915	0.0490	MANUFACTURING - JEWELERS' MATERIALS AND LAPIDARY WORK
3931	0.2192	MANUFACTURING - MUSICAL INSTRUMENTS
3940	0.2438	
3942	0.0229	MANUFACTURING - DOLLS AND STUFFED TOYS
3944	0.3125	MANUFACTURING - GAMES, TOYS, AND CHILDREN'S VEHICLES
3949	0.0992	MANUFACTURING - SPORTING AND ATHLETIC GOODS, NEC
3951	0.1843	MANUFACTURING - PENS AND MECHANICAL PENCILS
3952	1.2769	MANUFACTURING - LEAD PENCILS AND ART GOODS
3953	0.0896	MANUFACTURING - MARKING DEVICES
3955	6.1554	MANUFACTURING - CARBON PAPER AND INKED RIBBONS
3961	0.3822	MANUFACTURING - COSTUME JEWELRY
3963	0.2337	
3964	0.5007	
3965	0.1579	MANUFACTURING - FASTENERS, BUTTONS, NEEDLES, AND PINS
3990	0.0274	
3991	0.1075	MANUFACTURING - BROOMS AND BRUSHES
3993	0.2006	MANUFACTURING - SIGNS AND ADVERTISING SPECIALTIES
3995	0.1360	MANUFACTURING - BURIAL CASKETS
3996	0.6339	MANUFACTURING - HARD SURFACE FLOOR COVERINGS, NEC
3999	2065.7501	MANUFACTURING - MANUFACTURING INDUSTRIES, NEC
4010	15.0212	
4011	7.0996	TRANS. & UTILITIES - RAILROADS, LINE-HAUL OPERATING
4013	1.3817	TRANS. & UTILITIES - SWITCHING AND TERMINAL DEVICES

SIC Code	Risk (l/ug)	SIC Code Description
4089	0.0006	
4111	0.9409	TRANS. & UTILITIES - LOCAL AND SUBURBAN TRANSIT
4119	1.1260	TRANS. & UTILITIES - LOCAL PASSENGER TRANSPORTATION, NEC
4121	1.5543	TRANS. & UTILITIES - TAXICABS
4131	1.2065	TRANS. & UTILITIES - INTERCITY AND RURAL BUS TRANSPORTATION
4142	1.3323	TRANS. & UTILITIES - BUS CHARTER SERVICE, EXCEPT LOCAL
4151	1.0209	TRANS. & UTILITIES - SCHOOL BUSES
4173	2.3339	TRANS. & UTILITIES - BUS TERMINAL AND SERVICE FACILITIES
4200	5.8307	
4210	3.3223	DISCONTINUED, CHANGED, OR UNKNOWN
4212	234.9310	TRANS. & UTILITIES - LOCAL TRUCKING, WITHOUT STORAGE
4213	264.5095	TRANS. & UTILITIES - TRUCKING, EXCEPT LOCAL
4214	340.6761	TRANS. & UTILITIES - LOCAL TRUCKING WITH STORAGE
4215	0.9891	TRANS. & UTILITIES - COURIER SERVICES, EXCEPT BY AIR
4221	14.1128	TRANS. & UTILITIES - FARM PRODUCT WAREHOUSING AND STORAGE
4222	0.6420	TRANS. & UTILITIES - REFRIGERATED WAREHOUSING AND STORAGE
4225	5.0148	TRANS. & UTILITIES - GENERAL WAREHOUSING AND STORAGE
4226	8.7336	TRANS. & UTILITIES - SPECIAL WAREHOUSING AND STORAGE, NEC
4231	1.6803	TRANS. & UTILITIES - TRUCKING TERMINAL FACILITIES
4311	45.2464	TRANS. & UTILITIES - U.S. POSTAL SERVICE
4431	0.2406	
4449	0.8611	TRANS. & UTILITIES - WATER TRANSPORTATION OF FREIGHT, NEC
4462	0.2742	
4463	2.0857	DISCONTINUED, CHANGED, OR UNKNOWN

SIC Code	Risk (l/ug)	SIC Code Description
4469	3.2419	DISCONTINUED, CHANGED, OR UNKNOWN
4491	22.1103	TRANS. & UTILITIES - MARINE CARGO HANDLING
4492	5.2866	TRANS. & UTILITIES - TOWING AND TUGBOAT SERVICE
4493	1.8117	TRANS. & UTILITIES - MARINAS
4499	5.6256	TRANS. & UTILITIES - WATER TRANSPORTATION SERVICES, NEC
4511	0.3494	
4512	0.8979	TRANS. & UTILITIES - AIR TRANSPORTATION, SCHEDULED
4513	1.1550	TRANS. & UTILITIES - AIR COURIER SERVICES
4521	18.3366	
4522	1.5543	TRANS. & UTILITIES - AIR TRANSPORTATION, NONSCHEDULED
4532	12.8992	DISCONTINUED, CHANGED, OR UNKNOWN
4581	5260.2377	TRANS. & UTILITIES - AIRPORTS, FLYING FIELDS, AND SERVICES
4582	0.4999	DISCONTINUED, CHANGED, OR UNKNOWN
4612	0.3278	TRANS. & UTILITIES - CRUDE PETROLEUM PIPELINES
4613	7.8596	TRANS. & UTILITIES - REFINED PETROLEUM PIPELINES
4619	0.7516	TRANS. & UTILITIES - PIPELINES, NEC
4700	22.3973	
4724	3.2220	TRANS. & UTILITIES - TRAVEL AGENCIES
4731	1.2718	TRANS. & UTILITIES - FREIGHT TRANSPORTATION ARRANGEMENT
4741	1.2578	TRANS. & UTILITIES - RENTAL OF RAILROAD CARS
4748	502.2940	
4785	2.1130	TRANS. & UTILITIES - INSPECTION AND FIXED FACILITIES
4789	13.6709	TRANS. & UTILITIES - TRANSPORTATION SERVICES, NEC
4811	0.0048	
4812	1.0970	TRANS. & UTILITIES - RADIOTELEPHONE COMMUNICATIONS
4813	7.0981	TRANS. & UTILITIES - TELEPHONE COMMUNICATIONS, EXCEPT RADIO
4832	0.0001	TRANS. & UTILITIES - RADIO BROADCASTING STATIONS

SIC Code	Risk (l/ug)	SIC Code Description
4841	4.0285	TRANS. & UTILITIES - CABLE AND OTHER PAY TV SERVICES
4910	3.7401	DISCONTINUED, CHANGED, OR UNKNOWN
4911	519.6553	TRANS. & UTILITIES - ELECTRIC SERVICES
4920	25.7462	
4922	3.0306	TRANS. & UTILITIES - NATURAL GAS TRANSMISSION
4923	1.4530	TRANS. & UTILITIES - GAS TRANSMISSION AND DISTRIBUTION
4924	7.5324	TRANS. & UTILITIES - NATURAL GAS DISTRIBUTION
4925	0.6203	TRANS. & UTILITIES - GAS PRODUCTION AND/OR DISTRIBUTION
4930	1.2347	DISCONTINUED, CHANGED, OR UNKNOWN
4931	2.6426	TRANS. & UTILITIES - ELECTRIC AND OTHER SERVICES COMBINED
4932	1.2209	TRANS. & UTILITIES - GAS AND OTHER SERVICES COMBINED
4939	1.4615	TRANS. & UTILITIES - COMBINATION UTILITIES, NEC
4941	1178.1700	TRANS. & UTILITIES - WATER SUPPLY
4951	2.4035	
4952	2911.3456	TRANS. & UTILITIES - SEWERAGE SYSTEMS
4953	2884.5839	TRANS. & UTILITIES - REFUSE SYSTEMS
4959	2.0944	TRANS. & UTILITIES - SANITARY SERVICES, NEC
4961	0.7855	TRANS. & UTILITIES - STEAM AND AIR CONDITIONING SUPPLY
4971	2.1651	TRANS. & UTILITIES - IRRIGATION SYSTEMS
5012	0.8917	WHOLESALE TRADE - AUTOMOBILES AND OTHER MOTOR VEHICLES
5013	2.1119	WHOLESALE TRADE - MOTOR VEHICLE SUPPLIES AND NEW PARTS
5015	0.6822	WHOLESALE TRADE - MOTOR VEHICLE PARTS, USED
5031	4.4296	WHOLESALE TRADE - LUMBER, PLYWOOD, AND MILLWORK
5032	5.1346	WHOLESALE TRADE - BRICK, STONE, AND RELATED MATERIALS
5033	0.0004	WHOLESALE TRADE - ROOFING, SIDING, AND INSULATION
5039	1.7741	WHOLESALE TRADE - CONSTRUCTION MATERIALS, NEC

SIC Code	Risk (l/ug)	SIC Code Description
5047	10.8255	WHOLESALE TRADE - MEDICINAL AND HOSPITAL EQUIPMENT
5049	0.0005	WHOLESALE TRADE - PROFESSIONAL EQUIPMENT, NEC
5051	1.0326	WHOLESALE TRADE - METALS SERVICE CENTERS AND OFFICES
5052	0.0699	WHOLESALE TRADE - COAL AND OTHER MINERALS AND ORES
5063	0.0005	WHOLESALE TRADE - ELECTRICAL APPARATUS AND EQUIPMENT
5065	1.7210	WHOLESALE TRADE - ELECTRONIC PARTS AND EQUIPMENT
5070	0.0016	
5074	0.4400	WHOLESALE TRADE - PLUMBING AND HYDRONIC HEATING SUPPLIES
5078	0.2190	WHOLESALE TRADE - REFRIGERATION EQUIPMENT AND SUPPLIES
5082	1.1645	WHOLESALE TRADE - CONSTRUCTION AND MINING MACHINERY
5083	3.2046	WHOLESALE TRADE - FARM AND GARDEN MACHINERY
5084	0.4442	WHOLESALE TRADE - INDUSTRIAL MACHINERY AND EQUIPMENT
5085	7.0982	WHOLESALE TRADE - INDUSTRIAL SUPPLIES
5086	263.6996	DISCONTINUED, CHANGED, OR UNKNOWN
5087	0.3759	WHOLESALE TRADE - SERVICE ESTABLISHMENT EQUIPMENT
5088	1.9737	WHOLESALE TRADE - TRANSPORTATION EQUIPMENT AND SUPPLIES
5092	0.5745	WHOLESALE TRADE - TOYS AND HOBBY GOODS AND SUPPLIES
5093	2.5142	WHOLESALE TRADE - SCRAP AND WASTE MATERIALS
5094	0.0007	WHOLESALE TRADE - JEWELRY AND PRECIOUS STONES
5111	0.2088	WHOLESALE TRADE - PRINTING AND WRITING PAPER
5112	0.9362	WHOLESALE TRADE - STATIONARY AND OFFICE SUPPLIES
5113	0.1220	WHOLESALE TRADE - INDUSTRIAL AND PERSONAL SERVICE PAPER
5122	0.9000	WHOLESALE TRADE - DRUGS, PROPRIETARIES, AND SUNDRIES

SIC Code	Risk (l/ug)	SIC Code Description
5129	0.0597	
5136	0.9362	WHOLESALE TRADE - MEN'S AND BOYS' CLOTHING
5141	0.4039	WHOLESALE TRADE - GROCERIES, GENERAL LINE
5142	1.0705	WHOLESALE TRADE - PACKAGED FROZEN FOODS
5143	0.0042	WHOLESALE TRADE - DAIRY PRODUCTS, EXCEPT DRIED OR CANNED
5144	0.9624	WHOLESALE TRADE - POULTRY AND POULTRY PRODUCTS
5145	0.6977	WHOLESALE TRADE - CONFECTIONERY
5146	0.9643	WHOLESALE TRADE - FISH AND SEAFOODS
5148	0.0000	WHOLESALE TRADE - FRESH FRUITS AND VEGETABLES
5149	1.1330	WHOLESALE TRADE - GROCERIES AND RELATED PRODUCTS, NEC
5153	1.1302	WHOLESALE TRADE - GRAIN AND FIELD BEANS
5154	0.6849	WHOLESALE TRADE - LIVESTOCK
5159	0.0048	WHOLESALE TRADE - FARM-PRODUCT RAW MATERIALS, NEC
5160	0.2426	
5161	7.4111	UNKNOWN (FLORIDA DATA)
5162	0.9362	WHOLESALE TRADE - PLASTICS MATERIALS AND BASIC SHAPES
5169	0.4135	WHOLESALE TRADE - CHEMICALS AND ALLIED PRODUCTS, NEC
5170	5.6085	
5171	12.5305	WHOLESALE TRADE - PETROLEUM BULK STATIONS AND TERMINALS
5172	1.2245	WHOLESALE TRADE - PETROLEUM PRODUCTS, NEC
5181	0.6033	WHOLESALE TRADE - BEER AND ALE
5182	0.6033	WHOLESALE TRADE - WINES AND DISTILLED BEVERAGES
5191	0.8465	WHOLESALE TRADE - FARM SUPPLIES
5192	2.4035	WHOLESALE TRADE - BOOKS, PERIODICALS, AND NEWSPAPERS
5193	0.1766	WHOLESALE TRADE - FLOWERS AND FLORISTS' SUPPLIES

SIC Code	Risk (l/ug)	SIC Code Description
5198	0.2438	WHOLESALE TRADE - PAINTS, VARNISHES, AND SUPPLIES
5199	1.3675	WHOLESALE TRADE - NONDURABLE GOODS, NEC
5211	5.9808	RETAIL TRADE - LUMBER AND OTHER BUILDING MATERIALS
5261	0.0046	RETAIL TRADE - RETAIL NURSERIES AND GARDENS
5311	8.5183	RETAIL TRADE - DEPARTMENT STORES
5399	0.8048	RETAIL TRADE - MISCELLANEOUS GENERAL MERCHANDISE STORES
5411	1.8455	RETAIL TRADE - GROCERY STORES
5431	1.2042	RETAIL TRADE - FRUIT AND VEGETABLE MARKETS
5441	1.2909	RETAIL TRADE - CANDY, NUT, AND CONFECTIONERY STORES
5451	0.6849	RETAIL TRADE - DAIRY PRODUCTS STORES
5461	0.0048	RETAIL TRADE - RETAIL BAKERS
5511	0.5553	RETAIL TRADE - NEW AND USED CAR DEALERS
5531	1.0633	RETAIL TRADE - AUTO AND HOME SUPPLY STORES
5541	36.3153	RETAIL TRADE - GASOLINE SERVICE STATIONS
5551	2.2536	RETAIL TRADE - BOAT DEALERS
5561	0.6849	RETAIL TRADE - RECREATIONAL VEHICLE DEALERS
5599	0.2342	RETAIL TRADE - AUTOMOTIVE DEALERS, NEC
5812	31.6694	RETAIL TRADE - EATING PLACES
5813	0.8983	RETAIL TRADE - DRINKING PLACES
5912	1.0462	RETAIL TRADE - DRUGSTORES AND PROPRIETARY STORES
5921	0.0048	RETAIL TRADE - LIQUOR STORES
5941	0.0048	RETAIL TRADE - SPORTING GOODS AND BICYCLE SHOPS
5983	11.8926	RETAIL TRADE - FUEL OIL DEALERS
5984	3.1383	RETAIL TRADE - LIQUEFIED PETROLEUM GAS DEALERS
5989	1.0402	RETAIL TRADE - FUEL DEALERS, NEC
5999	1.6319	RETAIL TRADE - MISCELLANEOUS RETAIL STORES, NEC
6021	0.0048	FIN, INS & REAL EST - NATIONAL COMMERCIAL BANKS
6022	0.6056	FIN, INS & REAL EST - STATE COMMERCIAL BANKS
6023	0.2734	

SIC Code	Risk (I/ug)	SIC Code Description
6141	0.0048	FIN, INS & REAL EST - PERSONAL CREDIT INSTITUTIONS
6162	0.0048	FIN, INS & REAL EST - MORTGAGE BANKERS AND CORRESPONDENTS
6211	1.2042	FIN, INS & REAL EST - SECURITY BROKERS AND DEALERS
6311	1.8470	FIN, INS & REAL EST - LIFE INSURANCE
6324	2.0923	FIN, INS & REAL EST - HOSPITAL AND MEDICAL SERVICE PLANS
6411	2.4035	FIN, INS & REAL EST - INSURANCE AGENTS, BROKERS, AND SERVICE
6512	191.5133	FIN, INS & REAL EST - NONRESIDENTIAL BUILDING OPERATORS
6513	26.1575	FIN, INS & REAL EST - APARTMENT BUILDING OPERATORS
6514	0.2424	FIN, INS & REAL EST - DWELLING OPERATORS, EXCEPT APARTMENTS
6515	6.5709	FIN, INS & REAL EST - MOBILE HOME SITE OPERATORS
6519	0.2232	FIN, INS & REAL EST - REAL PROPERTY LESSORS, NEC
6531	0.4017	FIN, INS & REAL EST - REAL ESTATE AGENTS AND MANAGERS
6552	1.3337	FIN, INS & REAL EST - SUBDIVIDERS AND DEVELOPERS, NEC
6553	1.2558	FIN, INS & REAL EST - CEMETARY SUBDIVIDERS AND DEVELOPERS
6711	5.8024	
6732	0.0048	FIN, INS & REAL EST - EDUCATIONAL, RELIGIOUS, ETC. TRUSTS
7011	1.1462	SERVICES - HOTELS AND MOTELS
7021	0.0048	SERVICES - ROOMING AND BOARDING HOUSES
7032	0.9963	SERVICES - SPORTING AND RECREATIONAL CAMPS
7033	1.1942	SERVICES - TRAILER PARKS AND CAMPSITES
7041	1.2278	SERVICES - MEMBERSHIP-BASIS ORGANIZATION HOTELS
7126	0.9362	
7210	0.6332	
7211	2.4749	SERVICES - POWER LAUNDRIES, FAMILY AND COMMERCIAL
7212	3.7790	SERVICES - GARMENT PRESSING AND CLEANERS' AGENTS
7213	0.5590	SERVICES - LINEN SUPPLY

SIC Code	Risk (l/ug)	SIC Code Description
7215	2.8803	SERVICES - COIN-OPERATED LAUNDRIES AND CLEANING
7216	0.9682	SERVICES - DRY CLEANING PLANTS, EXCEPT RUG
7217	0.9362	SERVICES - CARPET AND UPHOLSTERY CLEANING
7218	0.4153	SERVICES - INDUSTRIAL LAUNDERERS
7219	1.9234	SERVICES - LAUNDRY AND GARMENT SERVICES, NEC
7231	0.0048	SERVICES - BEAUTY SHOPS
7261	0.0062	SERVICES - FUNERAL SERVICE AND CREMATORIES
7299	0.7474	SERVICES - MISCELLANEOUS PERSONAL SERVICES, NEC
7319	1.2942	SERVICES - ADVERTISING, NEC
7334	0.0048	SERVICES - PHOTOCOPYING AND DUPLICATING SERVICES
7342	1.6984	SERVICES - DISINFECTING AND PEST CONTROL SERVICES
7349	79.6403	SERVICES - BUILDING MAINTENANCE SERVICES, NEC
7353	5.8645	SERVICES - HEAVY CONSTRUCTION EQUIPMENT RENTAL
7359	5.5872	SERVICES - EQUIPMENT RENTAL AND LEASING, NEC
7374	0.0048	SERVICES - DATA PROCESSING SERVICES
7377	2.4035	SERVICES - COMPUTER RENTAL AND LEASING
7378	0.0000	SERVICES - COMPUTER MAINTENANCE AND REPAIR
7379	1.0477	SERVICES - COMPUTER RELATED SERVICES, NEC
7381	0.0030	SERVICES - DETECTIVE AND ARMORED CAR SERVICES
7384	0.2318	SERVICES - PHOTOFINISHING LABORATORIES
7389	130.1345	SERVICES - BUSINESS SERVICES, NEC
7391	306.2207	UNKNOWN (FLORIDA DATA)
7395	0.0001	
7397	1.1305	DISCONTINUED, CHANGED, OR UNKNOWN
7399	3.7451	DISCONTINUED, CHANGED, OR UNKNOWN
7513	0.7235	SERVICES - TRUCK RENTAL AND LEASING, NO DRIVERS
7521	0.0001	SERVICES - AUTOMOBILE PARKING
7524	1.2633	
7531	0.0051	DISCONTINUED, CHANGED, OR UNKNOWN
7532	0.0619	SERVICES - TOP AND BODY REPAIR AND PAINT SHOPS

SIC Code	Risk (l/ug)	SIC Code Description
7534	0.8957	SERVICES - TIRE RETREADING AND REPAIR SHOPS
7538	13528.9416	SERVICES - GENERAL AUTOMOTIVE REPAIR SHOPS
7539	1.9615	SERVICES - AUTOMOTIVE REPAIR SHOPS, NEC
7542	1.8811	SERVICES - CAR WASHES
7549	1.1171	SERVICES - AUTOMOTIVE SERVICES, NEC
7629	7.8030	SERVICES - ELECTRICAL REPAIR SHOPS, NEC
7641	0.0461	SERVICES - REUPHOLSTERY AND FURNITURE REPAIR
7692	1.5235	SERVICES - WELDING REPAIR
7694	0.2298	SERVICES - ARMATURE REWINDING SHOPS
7699	4.2604	SERVICES - REPAIR SERVICES, NEC
7812	0.0274	SERVICES - MOTION PICTURE AND VIDEO PRODUCTION
7819	2.4035	SERVICES - SERVICES ALLIED TO MOTION PICTURES
7911	0.9325	SERVICES - DANCE STUDIOS, SCHOOLS, AND HALLS
7933	0.6045	SERVICES - BOWLING CENTERS
7941	1.1104	SERVICES - SPORTS CLUBS, MANAGERS, AND PROMOTERS
7948	0.5428	SERVICES - RACING, INCLUDING TRACK OPERATION
7991	1.3241	SERVICES - PHYSICAL FITNESS FACILITIES
7992	0.8852	SERVICES - PUBLIC GOLF COURSES
7993	0.6292	SERVICES - COIN-OPERATED AMUSEMENT DEVICES
7996	0.9729	SERVICES - AMUSEMENT PARKS
7997	45.0307	SERVICES - MEMBERSHIP SPORTS AND RECREATION CLUBS
7999	2.8204	SERVICES - AMUSEMENT AND RECREATION, NEC
8011	1.2373	SERVICES - OFFICES AND CLINICS OF MEDICAL DOCTORS
8021	1.2018	SERVICES - OFFICES AND CLINICS OF DENTISTS
8043	1.8867	SERVICES - OFFICE AND CLINICS OF PODIATRISTS
8051	36.9684	SERVICES - SKILLED NURSE CARE FACILITIES
8052	0.4218	SERVICES - INTERMEDIATE CARE FACILITIES
8059	46.8104	SERVICES - NURSING AND PERSONAL CARE, NEC
8060	2.4035	
8061	4679.2039	

SIC Code	Risk (l/ug)	SIC Code Description
8062	11838.7553	SERVICES - GENERAL MEDICAL AND SURGICAL HOSPITALS
8063	36.5333	SERVICES - PSYCHIATRIC HOSPITALS
8069	43.2766	SERVICES - SPECIALTY HOSPITALS, EXCEPT PSYCHIATRIC
8071	1331.0205	SERVICES - MEDICAL LABORATORIES
8081	0.4682	
8082	1.2042	SERVICES - HOME HEALTH CARE SERVICES
8092	0.4873	SERVICES - KIDNEY DIALYSIS CENTERS
8099	12.1652	SERVICES - HEALTH AND ALLIED SERVICES, NEC
8211	31.5026	SERVICES - ELEMENTARY AND SECONDARY SCHOOLS
8220	1.4175	
8221	38.5072	SERVICES - COLLEGES AND UNIVERSITIES
8222	102.1150	SERVICES - JUNIOR COLLEGES
8231	0.4817	SERVICES - LIBRARIES
8249	0.8025	SERVICES - VOCATIONAL SCHOOLS, NEC
8299	0.7292	SERVICES - SCHOOLS AND EDUCATIONAL SERVICES, NEC
8321	2.4035	
8322	0.6901	SERVICES - INDIVIDUAL AND FAMILY SERVICES
8331	0.0048	SERVICES - JOB TRAINING AND RELATED SERVICES
8351	1.2042	SERVICES - CHILD DAY CARE SERVICES
8361	1.1243	SERVICES - RESIDENTIAL CARE
8412	1.1428	SERVICES - MUSEUMS AND ART GALLERIES
8421	2.4035	
8422	1.6056	SERVICES - BOTANICAL AND ZOOLOGICAL GARDENS
8611	1.3699	SERVICES - BUSINESS ASSOCIATIONS
8631	2.4035	SERVICES - LABOR ORGANIZATIONS
8641	1.0958	SERVICES - CIVIC AND SOCIAL ASSOCIATIONS
8661	1.1306	SERVICES - RELIGIOUS ORGANIZATIONS
8699	1.4553	SERVICES - MEMBERSHIP ORGANIZATIONS, NEC
8711	0.9853	SERVICES - ENGINEERING SERVICES
8731	71.0295	SERVICES - COMMERCIAL PHYSICAL RESEARCH

SIC Code	Risk (l/ug)	SIC Code Description
8733	10.5661	SERVICES - NONCOMMERCIAL RESEARCH ORGANIZATIONS
8734	1.6456	SERVICES - TESTING LABORATORIES
8741	1.2042	SERVICES - MANAGEMENT SERVICES
8744	16070.7602	SERVICES - FACILITIES SUPPORT SERVICES
8810	0.0002	
8811	1.6655	SERVICES - PRIVATE HOUSEHOLDS
8911	1.1268	UNKNOWN (FLORIDA DATA)
8922	7.2139	DISCONTINUED, CHANGED, OR UNKNOWN
8928	1.3699	
8999	0.5974	SERVICES - SERVICES, NEC
9010	0.0055	
9100	0.0048	
9111	3.0067	PUBLIC ADMIN. - EXECUTIVE OFFICES
9131	2.4035	PUBLIC ADMIN. - EXECUTIVE AND LEGISLATIVE COMBINED
9189	0.3443	
9199	0.9941	PUBLIC ADMIN. - GENRAL GOVERNMENT, NEC
9211	2.4035	PUBLIC ADMIN. - COURTS
9221	1.9118	PUBLIC ADMIN. - POLICE PROTECTION
9222	0.0048	PUBLIC ADMIN. - LEGAL COUNSEL AND PROSECUTION
9223	9861.0433	PUBLIC ADMIN. - CORRECTIONAL INSTITUTIONS
9224	5.1692	PUBLIC ADMIN. - FIRE PROTECTION
9311	0.0005	PUBLIC ADMIN. - FINANCE, TAXATION, AND MONETARY POLICY
9411	0.0014	PUBLIC ADMIN. - ADMINISTRATION OF EDUCATIONAL PROGRAMS
9431	3.3204	PUBLIC ADMIN. - ADMINISTRATION OF PUBLIC HEALTH PROGRAMS
9441	2.4035	PUBLIC ADMIN. - ADMIN. OF SOCIAL AND MANPOWER PROGRAMS
9451	809.2604	PUBLIC ADMIN. - ADMINISTRATION OF VETERANS' AFFAIRS

SIC Code	Risk (l/ug)	SIC Code Description
9510	0.6246	
9511	226.5606	PUBLIC ADMIN. - AIR, WATER, AND SOLID WASTE MANAGEMENT
9512	1.3449	PUBLIC ADMIN. - LAND, MINERAL, WILDLIFE CONSERVATION
9531	0.4845	PUBLIC ADMIN. - HOUSING PROGRAMS
9611	0.0048	PUBLIC ADMIN. - ADMIN. OF GENERAL ECONOMIC PROGRAMS
9621	350.9948	PUBLIC ADMIN. - REGULATION, ADMIN. OF TRANSPORTATION
9631	3.1383	PUBLIC ADMIN. - REGULATION, ADMINISTRATION OF UTILITIES
9641	0.8296	PUBLIC ADMIN. - REGULATION OF AGRICULTURAL MARKETING
9651	22.3973	PUBLIC ADMIN. - REGULATION OF MISC. COMMERCIAL SECTORS
9661	3.5903	PUBLIC ADMIN. - SPACE RESEARCH AND TECHNOLOGY
9711	9.1623	PUBLIC ADMIN. - NATIONAL SECURITY
9999	1204.0862	PUBLIC ADMIN. - NONCLASSIFIABLE ESTABLISHMENT

Appendix D: GIS Interpolation - Kriging, A Discussion

Appendix D: GIS Interpolation - Kriging, A Discussion

The following discussion is largely based on text from Burrough and McDonnell, 1998, and ESRI ArcInfo references.

Interpolation is a procedure of predicting values for areas in between known sample sites. This procedure is performed by converting point data into raster format and applying an interpolation methodology. In the case of creating an elevation of the water-table surface, sample points of water-table elevation were acquired from surface hydrology and GWSI well-processed data. The water-table point data were then converted to a grid and the interpolation method called kriging was applied. The rationale used in interpolation is that points closer together are more likely to be similar than points which are farther apart. When data are abundant, most interpolation techniques give similar results. When data are sparse, however, the assumptions made about the underlying variation that have been sampled and the choice of method and its parameters can be critical if one is to avoid misleading results.

Kriging, is a geostatistical method of interpolation which generates an estimated surface from a scattered set of points with values; kriging uses a method of spatial autocorrelation based on regional variable theory. Regional variable theory assumes that the spatial variation in the phenomenon of concern or Z value, in this case the elevation of the water-table, is statistically homogeneous throughout the surface. This means that the same pattern of spatial variation can be observed at all locations on the surface. This hypothesis of spatial homogeneity is fundamental to regionalized variable theory.

Regionalized variable theory assumes that the spatial variation of any variable can

be expressed as the sum of three major components. These are:

- a) a structural component, having a constant mean or trend
- b) a random, but spatially correlated component, known as the regionalized variable, and
- c) a spatially uncorrelated random noise or residual error term

Let x be a position in 1, 2, or 3 dimensions. Then the value of a random variable Z at x is given by

$$Z(x) = m(x) - E'(x) + E''$$

where $m(x)$ is the deterministic function describing the structural component of Z at x , $E'(x)$ is the term denoting the stochastic locally varying but spatially dependent residuals from $m(x)$, $E'(x)$ is the regionalized variable; E'' is a residual, spatially independent Gaussian noise term having zero mean and variance δ^2 .

The first step is to decide on a suitable function for $m(x)$. In the simplest case, where no trend or drift is present, $m(x)$ equals the mean value in the sampling area or expected difference between any two places x and $x+h$ separated by a distance vector h , will be zero

$$E[Z(x) - Z(x+h)] = 0$$

where $Z(x)$, $Z(x+h)$ are the values of random variable Z at locations x , $x+h$. Also, it is assumed that the variance of differences depends only on the distance between sites, h , so that

$$E[\{Z(x) - Z(x+h)\}^2] = E[\{E'(x) - E'(x+h)\}^2] = 2\gamma h$$

where γh is known as the semi-variance. The two conditions, stationarity of difference

and variance of differences, define the requirement for the intrinsic hypothesis of regionalized variable theory. This means that once structural effects have been accounted for, the remaining variation is homogenous in its variation so that the difference between sites are merely a function of the distance between them.

$$Z(x) = m(x) + \gamma(h) + E''$$

$$\text{when } \gamma(h) = E'(x)$$

If the conditions specified by the intrinsic hypotheses are fulfilled, the semi-variance can be estimated from the sample data:

$$\hat{\gamma}(h) = 1/2n \sum_{i=1}^n \{z(x_i) - z(x_i - h)\}^2$$

where n equals the number of pairs of sample points of observations of the values of attribute z separated by distance h.

A plot of $\hat{\gamma}(h)$ against h is known as the experimental variogram. The experimental

variogram is the first step toward a quantitative description of the regionalized variation.

The variogram provides useful information for interpolation, optimizing sampling and determining spatial patterns. To do this, however, a theoretical model must be fit to the experimental variogram

The typical experimental variogram, curve fitted through experimentally derived data points, displays several important features (Figure D1).

A) At large values of lag, h, it levels off. The horizontal part is known as

the sill; it implies that at these values of the lag, there is no spatial dependence between data points because all estimates of variances of differences will be invariant with sample separation distance.

- B) The curve rises from a low value of $\gamma(h)$ to the sill, reaching it at a value of h known as the range. This is the critically important part of the variogram because it describes how inter-site differences are spatially dependent. Within the range, the closer the sites are together, the more similar they are likely to be. The range gives as an answer to the question posed in weighted moving averages about how large the window should be. Clearly, if the distance separating an unvisited site from a data point is greater than the range, then that data point can make no useful contribution to the interpolation; it is too far away.
- C) The fitted model does not pass through the origin, but cuts the y -axis at a positive value of $\gamma(h)$. The positive value of $\gamma(h)$ as $h \rightarrow 0$ is an estimate of E'' , the residual, spatially uncorrelated noise. E'' is known as the nugget; this is the variance of measured errors, combined with that from spatial variation at distances much shorter than the sample spacing, which cannot be resolved.

The variogram is an essential step on the way to determining optimal weights for interpolation. When the nugget variance E'' so dominates the local variation that the experimental shows no tendency to diminish as $h \rightarrow 0$, the interpretation is that the data are so noisy that interpolation is not sensible. In this situation, the best estimate of $z(x)$ is

the overall mean computed from all sample points in the region of interest without taking spatial dependence into account, interpolation is meaningless and a waste of time and money.

The form of the variogram can be quite revealing about the kind of spatial variation present in an area, and can help to decide how to proceed further. Several models can be employed such as the spherical model, exponential model and gaussian model. If the variation is very smooth and the nugget variance E'' is very small compared to the random variation $E'(x)$, then the variogram can often be best fitted by a curve having an inflection, such as the gaussian model (Figure D1); the gaussian model is best for interpolation of an elevation surface such as topographic elevation or the elevation of the water-table. The semi-variance for the gaussian model is calculated using the following formula:

$$\gamma(h) = C_0 + C_1 \{1 - \exp(-h/a)^2\}$$

$\gamma(h)$ = Semi-variance

C_0 = Nugget

C_1 = Semi-variance distribution for range

h = Lag

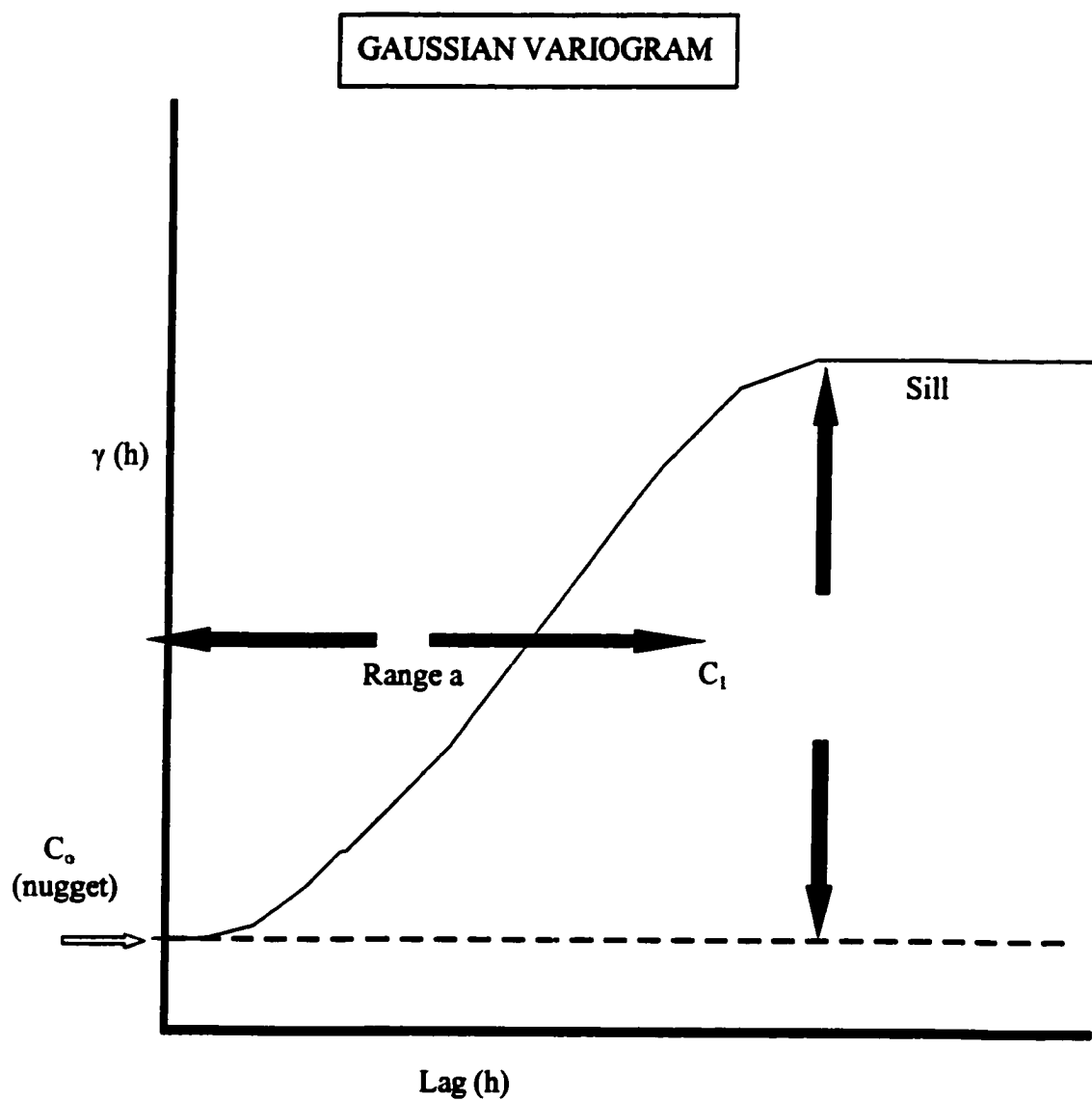
a = Range

The range of the variogram provides clear information about the size of the search window that should be used. If the distance from a data point to an unsampled point exceeds the range, then it is too far away to make any contribution; if all data points are further away than the range, the best estimate is the general mean. These distances can be

modified by anisotropy, which modifies the shapes of the search neighborhood from a circle to an ellipse.

Kriging was performed on water-elevation data points within individual HUC code boundaries in NYS. The gaussian model for ordinary kriging was employed. The search radii employed were 7,000 or 6,000 meters. The search points selected was 12. The interpolated water-table elevation surfaces of the individual HUC codes were sutured (mosaic) together to form the water-table elevation grid for NYS (Figure 18).

Figure D1. Example of the commonly used Gaussian variogram.



Appendix E: NYS CERCLA Files Pump/Slug Test Data

Table E1, CERCLA pump/slug test data interpretation methods are by Bower and Rice (1976), and Hvorslev (1951).

Superfund Site I.D.	Well	Formation Code	Top of Screened Interval (ft)	Bottom of Screened Interval (ft)	Hydraulic Conductivity (m/s)	Geologic Description
0202439	MW-104		35.00	45.00	4.90e-05	fine sand, well-sorted, glacial
0202439	MW-107		64.00	74.00	9.00e-06	fine-medium sand to fine sand w silt glacial
0202439	MW-102		8.00	18.00	1.90e-04	fine-coarse sand to fine sand, well-sorted
0202439	MW-113		7.00	17.00	6.50e-05	fine-medium sand, well-sorted
0202439	MW-116		10.00	20.00	3.00e-04	fine-medium sand
0202439	MW-118		32.50	42.50	2.60e-05	fine-medium sand, trace silt
0202439	MW-120		5.00	15.00	2.80e-07	sand and gravel w silt to silt
0202439	MW-121		4.00	14.00	6.60e-06	sand and gravel w silt to silt
0202439	MW-122		7.50	17.50	2.20e-06	Fine sand to silty sand
0202439	MW-125		6.00	11.00	3.90e-08	Fine sand with clay layers
0202439	MW-129		15.00	25.00	9.00e-07	Medium sand w clay silt lenses
0202439	MW-132		4.30	9.30	3.80e-07	Silty fine sand
0202439	MW-136		5.00	15.00	3.90e-07	fine-medium sand w silt
0202439	MW-138		16.00	26.00	2.50e-07	fine-medium sand
nyd98077					2.12e-03	Upper glacial pump test
ase copp	MW-1S				9.23e-07	glaciolacustrine silty sand
ase copp	MW-2S		12.50	17.50	5.07e-06	glaciolacustrine silty sand
brooklyn	MW-6	af	4.80	5.20	4.00e-05	poorly sorted fill - sand

Superfund Site I.D.	Well	Formation Code	Top of Screened Interval (ft)	Bottom of Screened Interval (ft)	Hydraulic Conductivity (m/s)	Geologic Description
aa landf	GWAA-6	af	30.57	48.57	2.72e-02	construction fill
aa landf	GWAA-8	af	22.57	49.29	3.42e-02	construction fill
brooklyn	MW-7	af	4.80	5.20	1.40e-05	poorly sorted fill - sand
brooklyn	MW-1	af			3.50e-05	poorly sorted fill - sand
brooklyn	MW-10	af	2.70	7.30	8.10e-05	poorly sorted fill - sand
brooklyn	MW-9	af	3.70	6.30	7.10e-05	poorly sorted fill - sand
aa landf	GWAA-7	af	24.51	43.38	5.50e-03	construction fill
0203481	DC-5A	Dob	10.00	60.50	1.14e-05	Mid Clarence-Mid Edgecliff
0203481	DC-11A	Dob	72.40	92.40	1.69e-03	Lower Clarence-Mid Scajaquada
0203481	DC-3A	Dob	7.00	43.00	5.70e-04	Upper Clarence-Mid Edgecliff
0203481	DC-4A	Dob	30.70	46.00	1.56e-06	Lower Clarence-Mid Edgecliff
0203481	DC-2A	Dob	10.00	41.50	2.43e-03	Mid to Lower Camillus
0203481	DC-12A	Dob	13.00	65.00	1.81e-03	Upper Clarence-Bois Blanc
0203481	DC-1A	Dob	10.00	60.00	8.18e-04	Lower Clarence-Upper Falkirk
0203481	DC-6A	Dob	10.00	30.00	1.11e-03	Lower Clarence-Lower Edgecliff
0203481	DC-10A	Dob	5.00	60.00	2.62e-05	Lower Clarence-Mid Scajaquada
3m ontar	MW-1	glacial	20.00	35.00	2.40e-04	sand and gravel
3m ontar	MW-3	glacial	8.00	23.00	1.60e-04	sand and gravel
3m ontar	MW-6	glacial			1.38e-04	sand and gravel
3m ontar	MW-5	glacial	17.00	32.00	2.50e-04	sand and gravel

Superfund Site I.D.	Well	Formation Code	Top of Screened Interval (ft)	Bottom of Screened Interval (ft)	Hydraulic Conductivity (m/s)	Geologic Description
3m ontar	MW-4	glacial	9.00	24.00	9.80e-05	sand and gravel
3m ontar	MW-2	glacial	17.00	32.00	1.40e-04	sand and gravel
ase copp	MW-3D	Obr	10.00	51.30	1.60e-06	fractured limestone
ase copp	MW-2D	Obr	22.50	29.50	1.16e-05	fractured limestone
ase copp	MW-1D	Obr	18.20	32.20	7.67e-06	fractured limestone
agwchmg	MW-9	og	3.00	13.00	3.00e-04	sand and gravel
agwchmg	MW-6	og	9.00	19.00	5.00e-05	sand and gravel
agwchmg	MW-5	og	10.00	20.00	2.00e-05	sand and gravel
agwchmg	MW-8	og	10.00	20.00	5.00e-06	sand and gravel
agwchmg	MW-2	og	5.00	15.00	1.00e-05	sand and gravel
0203481	DC-4B	Sab	50.00	70.00	9.95e-04	Basal Edgecliff-Mid Falkirk
0203481	DC-15A	Sab	10.00	65.00	2.59e-03	Lower Clarence-Upper Falkirk
0203481	DC-7	Sab	13.80	85.00	1.72e-05	Basal Clarence-Mid Falkirk
0203481	DC-6B	Sab	34.80	54.80	1.98e-03	Bois Blanc-Mid Falkirk
0203481	DC-7RB	Sab	103.00	123.00	2.35e-02	Falkirk
0203481	DC-10B	Sab	64.80	84.80	5.34e-03	Falkirk
0203481	DC-7RA	Sab	10.00	95.10	6.53e-06	Basal Clarence-Upper Falkirk
0203481	DC-2B	Sab	49.80	69.80	5.09e-04	Basal Edgecliff-Mid Falkirk
0203481	DC-1B	Sab	60.00	80.00	1.50e-03	Falkirk
0203481	DC-17A	Sab	10.00	63.80	8.48e-05	Basal Edgecliff-Lower Falkirk

Superfund Site I.D.	Well	Formation Code	Top of Screened Interval (ft)	Bottom of Screened Interval (ft)	Hydraulic Conductivity (m/s)	Geologic Description
0203481	DC-8B	Sab	38.40	58.40	9.65e-04	Lower Scajaquada-Mid Falkirk
0203481	DC-12B	Sab	85.00	105.00	5.76e-03	Mid Scajaquada-Mid Falkirk
0203481	DC-5B	Sab	60.00	80.00	6.73e-04	Mid Edgecliff-Mid Falkirk
0203481	DC-16	Sab	5.00	64.00	7.86e-05	Lower Clarence-Upper Falkirk
0203481	DC-14A	Sab	4.80	24.80	1.74e-02	Falkirk
0203481	DC-8A	Sab	15.00	35.50	7.20e-04	Basal Edgecliff-Upper Scajaquada
0203481	DC-3B	Sab	48.00	68.00	1.57e-04	Falkirk
0203481	DC-5D	Scv	144.50	164.50	6.50e-03	Lower Camillus
0203481	DC-12D	Scv	138.80	158.80	1.66e-03	Mid Camillus
0203481	DC-14B	Scv	40.00	60.00	2.26e-02	Upper Camillus
0203481	DC-13B	Scv	40.00	60.00	4.80e-02	Lower Camillus-Upper Syracuse
0203481	DC-13A	Scv	10.00	25.00	6.31e-04	Mid Camillus
0203481	DC-9C	Scv	159.00	179.00	1.67e-03	Syracuse
0203481	DC-9B	Scv	130.00	150.00	9.07e-03	Lower Camillus-Upper Syracuse
0203481	DC-9A	Scv	15.00	35.50	3.96e-04	Lower Falkirk-Upper Camillus
0203481	DC-8D	Scv	110.30	130.30	1.38e-02	Lower Camillus
0203481	DC-8C	Scv	66.80	86.80	1.22e-03	Basal Falkirk-Upper Camillus
0203481	DC-15B	Scv	160.00	180.00	2.25e-02	Syracuse
0203481	DC-17B	Scv	144.60	164.60	2.81e-03	Syracuse
0203481	DC-10D	Scv	109.70	129.70	8.76e-03	Mid Camillus

Superfund Site I.D.	Well	Formation Code	Top of Screened Interval (ft)	Bottom of Screened Interval (ft)	Hydraulic Conductivity (m/s)	Geologic Description
0203481	DC-7RC	Scv	140.00	160.00	8.05e-03	Mid Camillus
0203481	DC-10C	Scv	88.00	108.00	1.85e-03	Basal Falkirk-Upper Camillus
0203481	DC-11B	Scv	139.90	159.90	8.12e-03	Upper-Mid Camillus
0203481	DC-7RD	Scv	187.90	201.90	2.34e-02	Basal Camillus-Upper Syracuse
0203481	DC-6D	Scv	111.80	131.80	1.81e-02	Lower Camillus
0203481	DC-6C	Scv	69.80	89.80	3.67e-03	Upper Camillus
0203481	DC-3D	Scv	125.00	145.00	1.58e-02	Lower Camillus
0203481	DC-3C	Scv	80.00	100.00	1.49e-04	Upper Camillus
0203481	DC-12C	Scv	115.00	135.00	2.36e-02	Basal Falkirk-Upper Camillus
0203481	DC-5C	Scv	110.50	130.50	2.12e-03	Upper-Mid Camillus
0203481	DC-4C	Scv	110.30	130.30	3.17e-03	Mid Camillus
0203481	DC-2C	Scv	85.40	105.40	3.88e-04	Basal Falkirk-Upper Camillus
0203481	DC-1D	Scv	135.00	155.00	4.98e-03	Lower Camillus
0203481	DC-4D	Scv	135.00	155.00	9.54e-03	Basal Camillus-Upper Syracuse
0203481	DC-2D	Scv	130.50	150.50	1.46e-03	Lower Camillus
0203481	DC-1C	Scv	100.00	120.00	1.10e-02	Upper-Mid Camillus
aa landf	GWAA-1	t	4.00	14.00	3.24e-03	gill
aa landf	GWAA-5	t	11.65	16.27	1.07e-03	gill
aa landf	GWAA-4	t	3.72	13.72	1.50e-03	gill
aa landf	GWAA-3	t	13.14	17.65	5.99e-04	gill

Superfund Site I.D.	Well	Formation Code	Top of Screened Interval (ft)	Bottom of Screened Interval (ft)	Hydraulic Conductivity (m/s)	Geologic Description
an landf	GWAA-2	t	4.35	14.14	6.54e-03	till
airmont	ACMW- 1	TRhc	52.00	69.00	1.74e-07	conglomerate
airmont	ACMW- 3	TRhc	23.00	51.00	1.06e-06	conglomerate and sandstone
airmont	ACMW- 2	TRhc	22.00	32.00	1.38e-04	conglomerate and sandstone
0204091	MW03	usda	14.00	24.00	1.00e-03	Stratified drift - fine to very fine sand
0204091	MW04	usda	15.00	25.00	1.10e-03	Stratified drift - fine sand
0204091	MW02	usda	10.00	20.00	5.50e-03	Stratified drift - fine sand
0204091	MW01	usda	20.00	30.00	1.30e-03	Stratified drift - sand, silt + clay

Appendix F: Sequence Stratigraphy: A Presentation of Terms

Appendix F: Sequence Stratigraphy: A Presentation of Terms

Stratigraphy is the study of sedimentary rock layers, strata; sequence stratigraphy is the study of strata within a framework of chronostratigraphically significant surfaces, surfaces of approximate equal time (Freidman and Sanders, 2000). Sloss (1963) defined a stratigraphic sequence as rock-stratigraphic units of higher rank than group, magagroup, or supergroup, traceable over major areas of continent and bounded by unconformities of interregional scope; his major stratigraphic sequences Sauk, Tippacano, Kakaskia, Absaroka, Zuni and Tejas are packaged between globally observed unconformities. Vail (1977) advanced the concept of sequence stratigraphy by proposing the concepts of seismic stratigraphy. Vail showed that facies packages can be defined by sequence terms; and that highstand, lowstand, or transgressive facies tracts were dependent on cyclic changes of sea-level. Sequence stratigraphy depends on depositional changes resulting from a cyclical response to base level fluctuations. A cyclic hierarchy from parasequence to parasequence sets to mesosequences exists (Friedman, Sanders and Kopaska-Merkel, 1992). An inference of high-stand, transgressive or low-stand facies tracts can also be postulated from outcrop stratigraphic investigation. The terms and definitions presented set a common ground for understanding the following sections.

Sequence Stratigraphy

Stratigraphy is the study of sedimentary rock layers, strata; sequence stratigraphy is the study of strata within a framework of chronostratigraphically significant surfaces, surfaces of approximate equal time. Sloss (1963) defined a stratigraphic sequence as rock-stratigraphic units of higher rank than group, magagroup, or supergroup, traceable

over major areas of continent and bounded by unconformities of interregional scope; his major stratigraphic sequences Sauk, Tippacano, Kakaskia, Absaroka, Zuni and Tejas are packaged between globally observed unconformities. Vail (1977) advanced the concept of sequence stratigraphy by proposing the concepts of seismic stratigraphy. Vail showed that facies packages can be defined by sequence terms; and that highstand, lowstand, or transgressive facies tracts were dependent on cyclic changes of sea-level. Sequence stratigraphy depends on depositional changes resulting from a cyclical response to base level fluctuations. A cyclic hierarchy from parasequence to parasequence sets to mesosequences exists (Friedman, Sanders and Kopaska-Merkel, 1992). An inference of high-stand, transgressive or low-stand facies tracts can also be postulated from outcrop stratigraphic investigation. The terms and definitions presented below (Friedman and Sanders, 2000) set a common ground for understanding the Bedrock Geology portion of the Results section above.

Sequence Stratigraphy, Terms and Definitions

Onlap - where horizontal strata terminate against a sloping surface underlain by older deposits (or gently dipping strata end against a surface whose inclination is in the same direction but is greater than the dip angle of the strata).

Downlap - initially dipping strata may end against a surface in such a way that the younger layers extend farther along the surface than the older layers.

Discordance or Angular Unconformity - if the lower strata were deformed so that

they are no longer parallel to the layers within the covering strata.

Toplap - is a stratigraphic relationship in which the updip ends are truncated at a depositional surface.

Autocyclic succession - are deposited when materials within the depositional setting are redistributed without any change in total setting, in the total energy, or in the material input.

Alloccyclic successions - are patterned successions that result from changes in the depositional setting (such as a change in sea level), in the supply of energy, or in the material input.

Parasequence - a relatively conformable, genetically related succession of beds and bedsets bounded by marine-flooding surfaces and their correlative surfaces.

Parasequences are progradational or aggradational, and so are typically composed of an upward shoaling succession of facies. Parasequence boundaries are essentially time lines and parasequence correlations can be used to construct a very accurate chronostratigraphic framework. For this reason, parasequences are more than the upward-shallowing cycles or vertical facies associations known in the literature for more than 100 years.

Parasequence set - a succession of genetically related parasequences forming a distinctive stacking pattern bounded by major marine flooding surfaces.

Parasequence stacking patterns with parasequence sets are progradational, aggradational and retrogradational.

Facies tract - are genetically related parasequence sets that are a result of submergence or emergence of the shelf within one cycle of eustasy and respond to sediment supply.

Lowstand facies tract - is produced when base level reaches the shelf edge or lower. Canyons are cut into the undathem deposits (Rich, 1951) and vast quantities of sediment are delivered to the heads of submarine canyons; subaqueous fan complexes are created. As emergence of the undathem persists, a lowstand wedge of sediments (fan complexes) may develop on the clinoform, slope and rise deposits associated with a highstand facies tract. (On a continental platform, the lowstand facies tract is represented by an unconformity, within a foreland basin, the early stages of the lowstand facies tract, eustatic sea level fall, may restrict the basin, leaving the flanks exposed to erosion.)

Transitional facies tract - is produced when sediment supply to the basin floor is cut off as base level rises above the undathem deposits. Parasequence sets onlap

the upper slope and lower shelf until maximum transgression and associated maximum flooding surface is reached. The parasequence sets exhibit retrogradation.

Highstand facies tract - is produced when sediment supply overtakes submergence and progradation takes place. During the highstand facies tract prograding sediment packages can reach the shelf edge and supply sediments to the continental slope and rise by slumping, debris flows, liquified cohesionless flow and turbidity currents. Parasequence sets exhibit progradation or aggradation across the submerged shelf.

Mesosequence - a relatively conformable genetically related succession of strata bounded by unconformities and their correlative conformities. In this definition “relatively conformable” means that within the sequence there are no unconformities; “genetically related” means that all the strata within the bounded unconformities or their relative conformities are deposited during the same cycle of sea level change, and that these strata have no relationship to the strata beneath the lower bounding unconformity.

Appendix G: NYS Stratigraphic Column, with Regional Hydrogeologic Parameters

Appendix G. NYS Stratigraphic Column, with hydrogeologic parameters.

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd.Cond m/s.	Porosity Porosity %
CENOZOIC	QUARTERNARY	H O C E N E		Artificial Fill	af	3	1.0×10^{-7}	34
				Colluvial Fan	cof	5	1.0×10^{-7}	34
				Colluvium	co, col	5	1.0×10^{-7}	34
				Alluvial Fan	alf	10	1.0×10^{-4}	34
				Recent Alluvium	al	10	5.0×10^{-3}	30
				Alluvial Terrace	alt	10	5.0×10^{-3}	30
				Swamp Deposits	pm	20	1.0×10^{-3}	34
				Dune	d	10	5.0×10^{-4}	30
				Beach	b	10	5.0×10^{-3}	30
				Barrier Island	bi	10	5.0×10^{-3}	30
				Marine Delta	md	5	5.0×10^{-3}	30
				Undifferentiated Sand	s	20	5.0×10^{-4}	30
				Undifferentiated Silt and Clay	sc	50	5.0×10^{-9}	45
				Till	t	10	5.0×10^{-7}	32
		P L E I S T O C E N E		Undifferentiated Stratified Drift	usda	10	1.0×10^{-6}	34
				Undifferentiated Drift Complex	udc	20	1.0×10^{-6}	34
				Alluvial Inwash	ali	10	5.0×10^{-2}	30
				Inwash	ki	20	5.0×10^{-2}	30
				Kame Deposits	k	30	5.0×10^{-2}	30
				Colluvial Diamicton	cd	30	1.0×10^{-7}	34
				Ablation Moraine	ta	10	5.0×10^{-7}	34
				Kame Moraine	km	30	5.0×10^{-2}	30
				Till Moraine	tm	30	5.0×10^{-7}	32
				Outwash Sand and Gravel	og	20	5.0×10^{-4}	30
				Fluvial Sand and Gravel	fg	20	5.0×10^{-3}	30
				Pleistocene Alluvium	alp	10	5.0×10^{-3}	30
				Fluvial Deltaic Sand	fds	10	5.0×10^{-3}	30
				Subaqueous Fan	sf	30	5.0×10^{-2}	30
				Lacustrine Beach	lb	5	5.0×10^{-3}	30
				Lacustrine Sand	ls	20	5.0×10^{-4}	30
				Lacustrine Delta	ld	5	5.0×10^{-2}	30

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd.Cond m/s.	Porosity Porosity %
				Lacustrine Silt and Clay	lsc	50	5.0×10^{-8}	45
MESOZOIC	CRETACEOUS	UPPER		Monmouth Group, Matawan Group, Magothy Fm	Km		1.0×10^{-7}	35
	CRETACEOUS	UPPER		Raritan Fm	Kr		1.0×10^{-7}	35
	JURASSIC	UPPER		Dikes	KJk		1.0×10^{-8}	5
MESOZOIC					KJd		1.0×10^{-8}	5
				Laccolith	KJtp		1.0×10^{-8}	5
				Hammer Creek Fm	Trhc		5.0×10^{-8}	2
					Trb		5.0×10^{-8}	5
	TRIASSIC	UPPER	Newark	Brunswick Fm	Trbg		5.0×10^{-8}	5
					Trba		1.0×10^{-8}	5
				Stockton Fm	Trs		5.0×10^{-8}	5
				Ladentown Basalt	Trl		1.0×10^{-8}	2
				Palisades Diabase	Trp		1.0×10^{-8}	2
	PENNSYLVANIAN	LOWER	Pottsville	Olean Conglomerate, Connoquenessing Fm	Pp		5.0×10^{-8}	5
	MISSISSIPPIAN	LOWER	Pocono	Cuyahoga Fm, Corry Sandstone, Knapp Fm	Mp		1.0×10^{-8}	5
					Opgr		1.0×10^{-8}	2
					Opqd		1.0×10^{-8}	2
					Obg		1.0×10^{-8}	2
	DEVONIAN	UPPER		Peekskill Pluton				
			Conewango	Oswayo Fm, Venango Fm, Cattarugus Fm	Dco		1.0×10^{-8}	5
			Conneaut	Ellicott Fm, Dexterville Fm, Germania Fm, Whitesville Fm, Hinsdale Sandstone, Wellsville Fm, Cuba Sandstone	Dct		1.0×10^{-8}	5
			Canadaway	Northeast Shale, Shumla Siltstone	Dcys		1.0×10^{-8}	2
				Westfield Shale, Lapna Siltstone	Dcyl		1.0×10^{-8}	2
				Gownada Shale,	Dcyd		1.0×10^{-8}	2

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd. Cond m/s.	Porosity Porosity %
PALEOZOIC	DEVONIAN	UPPER		South Wales Shale, Dunkirk Shale				
				Machias Fm, Rushford Sandstone, Caneadea Shale, Canisteo Shale, Hume Shale, Canseraga Sandstone	Dcy		1.0×10^{-8}	5
			Java	Hanover Shale, Wiscoy Fm, Pipe Creek Shale	D		1.0×10^{-8}	5
			Java		D		1.0×10^{-8}	5
			West Falls	Angola Shale, Rhinestreet Shale	Dwf		1.0×10^{-8}	2
				Nunda Fm	Dwn		1.0×10^{-8}	5
				West Hill Fm, Corning Shale	Dwc		1.0×10^{-8}	5
				Honesdale Fm	Dwh		1.0×10^{-8}	5
				New Milford Fm	Dwmn		1.0×10^{-8}	5
				West Hill Fm, Gardeau Fm, Roricks Glen Shale, Beers Hill Shale, Grimes Siltstone	Dwg		1.0×10^{-8}	2
				Gardeau Fm	Dwrg		1.0×10^{-8}	2
				Slide Mountain Fm	Dws		5.0×10^{-8}	5
				Dunn Hill Shale, Millport Shale, Moreland Shale	Dwr		1.0×10^{-8}	2
				Beers Hill Shale, Grimes Siltstone	Dwm		1.0×10^{-8}	2
				Walton Fm	Dww		1.0×10^{-8}	5
			Sonyea	Cashaqua Shale, Middlesex Shale, Rue Point Shale, Rock Stream Siltstone, Putney Shale, Sawmill Creek Shale, Johns Creek Shale,	Ds		1.0×10^{-8}	2

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd.Cond m/s.	Porosity Porosity %
PALEOZOIC	DEVONIAN		Genesee	Montour Shale, Enfield Siltstone, Kattel Fm				
				Walton Fm	Dsw		1.0×10^{-8}	5
				West River Shale, Genundewa Limestone, Penn Yan Shale, Geneseo Shale, North Evans Limestone, Ithica Fm	Dg		1.0×10^{-8}	3
				Oneonta Fm	Dgo		1.0×10^{-8}	5
				Unadilla Fm, Laurens Fm, New Lisbon Fm, Gilboa Fm	Dgu		1.0×10^{-8}	5
		MIDDLE	Hamilton	Tully Limestone	Dt		5.0×10^{-4}	4
				Moscow Fm	Dhmo		1.0×10^{-8}	6
				Ludlowville Fm	Dhld		1.0×10^{-8}	3
				Skaneateles Fm	Dhsk		1.0×10^{-8}	3
				Panther Mountain Fm	Dhpm		1.0×10^{-8}	5
				Plattekill Fm, Ashokan Fm	Dhpl		1.0×10^{-8}	5
				Marcellus Fm	Dhmr		1.0×10^{-8}	6
				Undifferentiated Hamilton	Dhm		1.0×10^{-8}	5
				Skunnemunk Fm, Bellvale Fm	Dh		1.0×10^{-8}	5
				Onondaga Limestone	Dob		5.0×10^{-4}	4
				Onondaga Limestone, Schoharie Fm, Esopus Shale, Carlisle Center Siltstone	Dou		5.0×10^{-8}	3
		LOWER	Helderberg	Oriskany Sandstone	Do		5.0×10^{-8}	6
				Glenerie Fm, Port Jervis Fm	Dgl		5.0×10^{-8}	3
				Port Ewen Limestone, Alsen Limestone, Becraft Limestone, New Scotland Limestone, Kalkberg Limestone, Coeymans Limestone,	Dhg		5.0×10^{-4}	4

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd. Cond m/s.	Porosity Porosity %
PALEOZOIC	DEVONIAN - SILURIAN			Manlius Limestone, Roundout Dolostone				
				Binnewater Sandstone, High Falls Shale, Kanouse Sandstone, Woodbury Creek Fm, Connely Conglomerate, Central Valley Sandstone, New Scotland Limestone, Decker Limestone, Poxono Island Fm, Longwood Shale, Green Pond Conglomerate	DS		5.0×10^{-8}	6
	SILURIAN	UPPER		Akron Dolostone, Bertie Fm	Sab		5.0×10^{-8}	3
				Cobleskill Limestone, Bertie Fm, Camillus Fm, Syracuse Fm, Brayman Shale	Scs		5.0×10^{-8}	3
		UPPER	Salina	Syracuse Fm, Brayman Shale			5.0×10^{-8}	3
				Camillus Fm, Syracuse Fm, Vernon Fm	Scv		1.0×10^{-8}	4
				Camillus Fm, Syracuse Fm	Scy		1.0×10^{-8}	4
				Cobleskill Limestone, Bertie Fm, Camillus Fm	Scs		5.0×10^{-8}	3
				Syracuse Fm	Ssy		5.0×10^{-8}	4
				Vernon Fm	Sv		1.0×10^{-8}	3
				Guelph Dolostone, Oak Orchard Dolostone, Eramosa Dolostone, Goat Island Dolostone, Gasport Limestone, Penfield Dolostone, Sconondoa Fm, Ilion Shale	Si		5.0×10^{-8}	4
			Lockport	Roundout Fm, Binnewater Sandstone, High Falls Shale,	Srp		5.0×10^{-8}	6

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd.Cond m/s.	Porosity Porosity %
PALEOZOIC	SILURIAN			Warwarsing Limestone, Decker Limestone, Bossardville Limestone, Poxono Island Fm				
				Bloomsbrug Fm, Guyard Quartzite, Otisville Shale, Shawangunk Conglomerate	Sbs		1.0×10^{-8}	5
				Decew Dolostone, Rochester Shale, Irondequoit Limestone, Merriton Limestone, Herkimer Sandstone, Kirkland Hematite, Willowvale Shale, Westmoreland Hematite, Sauquoit Fm, Oneida Conglomerate	Scl		5.0×10^{-8}	6
		LOWER	Clinton	Decew Dolostone, Rochester Shale	Sr		1.0×10^{-8}	3
				Thorold Sandstone, Grimsby Fm, Power Glen Shale, Cabot Head Shale, Whirlpool Fm	Sm		1.0×10^{-8}	5
				Undifferentiated Medina Group, Grimsby Fm, Queenston Fm	SmOq		1.0×10^{-8}	5
		UPPER		Mafic Complexes	Oban		1.0×10^{-8}	2
					Od		1.0×10^{-8}	2
					Ohn		1.0×10^{-8}	2
					Oh		1.0×10^{-8}	2
					Oopx		1.0×10^{-8}	2

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd.Cond m/s.	Porosity Porosity %
	N A I C I A N O R D O V I C I A N				Opx		1.0×10^{-8}	2
					Ogb		1.0×10^{-8}	2
				Queenston Fm	Oq		1.0×10^{-8}	2
				Quassaic Quartzite	Oqu		5.0×10^{-8}	5
				Oswego Sandstone	Oo		1.0×10^{-8}	7
		MIDDLE	Lorraine	Pulaski Fm, Whetstone Fm	Opw		1.0×10^{-8}	2
				Frankford Fm	Of		1.0×10^{-8}	2
				Schenectady Fm	Osc		1.0×10^{-8}	5
				Austin Glen Fm	Oag		1.0×10^{-8}	2
			Trenton	Utica Shale	Ou		1.0×10^{-8}	2
				Canajoharie Shale	Oc		1.0×10^{-8}	2
				Iberville Shale	Oi		1.0×10^{-8}	2
				Stony Point Shale	Osp		1.0×10^{-8}	2
				Cumberland Head Argillite	Ocum		1.0×10^{-8}	2
				Normanskill Fm	On		1.0×10^{-8}	2
				Waloomsac Fm	Owl		1.0×10^{-8}	2
				Cobourg Fm, Glens Falls Fm	Ot		5.0×10^{-4}	4
				Balmville Limestone	Oba		5.0×10^{-4}	4
				Undivided Trenton - Black River	Otbr		5.0×10^{-4}	4
			Black River	Chaumont Limestone, Lowville Limestone, Pamela Dolostone, Amsterdam Limestone, Isle La Motte Limestone	Obr		5.0×10^{-4}	4
					Obr		5.0×10^{-4}	4
		MIDDLE	Black River	Taconic Melange	Otm		1.0×10^{-8}	2
			Chazy	Valcut Limestone, Crown Point Limestone, Ste Therese Siltstone, Middlebury Limestone, St. Martin Limestone,	Och		5.0×10^{-8}	3

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd.Cond m/s.	Porosity Porosity %
PALEOZOIC	ORDOVICIAN	LOWER	Beekmantown	Rockcliffe Limestone				
				Chuctanunda Creek Dolostone, Tribes Hill Fm, Gailor Dolostone, Providence Island Dolostone, Fort Cassin Fm, Fort Ann Fm, Cutting Fm, Ogdensburg Dolostone	Obk		5.0×10^{-4}	4
				Serpentinite	Os		1.0×10^{-8}	2
				Copake Fm, Rochdale Fm, Halcyon Lake Dolostone	Ow		5.0×10^{-4}	4
				Manhattan Fm	Om		1.0×10^{-8}	2
					Omb		1.0×10^{-8}	2
					Omc		1.0×10^{-8}	2
					Omd		1.0×10^{-8}	2
					Oma		1.0×10^{-8}	2
				Bedford Gneiss	Ob		1.0×10^{-8}	2
				Harrison Gneiss, Brookfield Diorite Gneiss, Ravenswood Gneiss	Ohr		1.0×10^{-8}	2
				Hartland Fm	Oht		1.0×10^{-8}	2
				Mount Marino Fm, Indian River Fm	Omi		1.0×10^{-8}	2
				Pillow Lava	Opl		1.0×10^{-8}	2
				Poultney Fm	Op		1.0×10^{-8}	2
				Stuyvesant Falls Fm	Osf		1.0×10^{-8}	2
	CAMBRIAN		Wappinger	Horses along normal faults	OCh		5.0×10^{-4}	4
				Slivers	OCs		5.0×10^{-4}	4
				Theresa Fm	OCth		5.0×10^{-4}	6
				Fishkill Limestone, Rockdale Fm, Halcyon Lake Dolostone	OCw		5.0×10^{-4}	3
				Stockbridge Fm	OCst		1.0×10^{-8}	2

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd.Cond m/s.	Porosity Porosity %
PALEOZOIC	CAMBRIAN		Beekmantown	Inwood Marble	OCi		1.0×10^{-5}	2
				Little Falls Dolostone, Hout Fm, Whitehall Fm, Ticonderoga Dolostone	Cbk		5.0×10^{-4}	4
				Briarcliff Dolostone, Pine Plains Fm	Cw		5.0×10^{-5}	3
				Theresa (Galway) Fm	Cth		5.0×10^{-5}	6
				Stissing Fm	Cs		5.0×10^{-5}	3
				Potsdam Sandstone	Cp		5.0×10^{-5}	7
				Poughquag Quartzite	Cpg		1.0×10^{-5}	2
				Cheshire Quartzite	Cc		1.0×10^{-5}	2
				Cheshire Quartzite, Dalton Fm	Ccd		1.0×10^{-5}	2
				Elizville Fm	OCe		1.0×10^{-5}	2
				Undifferentiated M Ord - L Camb	OCu		1.0×10^{-5}	2
				Poultney Fm, Hatch Hill Fm, West Castleton Fm	Cpw		1.0×10^{-5}	3
				Germantown Fm	Cg		1.0×10^{-5}	3
				Mettawee Slate	Cm		1.0×10^{-5}	2
				Nassau Fm	Cn		1.0×10^{-5}	2
				Austerlitz Phyllite	Ca		1.0×10^{-5}	2
				Greenstones tuffs and basalts	Cgt		1.0×10^{-5}	2
				Rensselaer Graywacke	Cr		1.0×10^{-5}	2
				Everett Schist	Cev		1.0×10^{-5}	2
UPPER PROTEROZOIC				Fordham Gneiss	f		1.0×10^{-5}	2
				Fordham Gneiss	fa		1.0×10^{-5}	2
				Fordham Gneiss	fb		1.0×10^{-5}	2
				Fordham Gneiss	fc		1.0×10^{-5}	2
				Fordham Gneiss	fd		1.0×10^{-5}	2
				Fordham Gneiss	fe		1.0×10^{-5}	2
UPPER PROTEROZOIC				Yonkers Gneiss	y		1.0×10^{-5}	2
				Poundridge Gneiss	pg		1.0×10^{-5}	2
				Intrusive Pegmatite Dikes	p		1.0×10^{-5}	2

Era	Age	Series	Group	Formation	Map Code	Thickness m	Hyd.Cond m/s.	Porosity Porosity %
MIDDLE PROTEROZOIC				Metagabbro	gb		1.0×10^{-8}	2
				Metanorthosite	a		1.0×10^{-8}	2
				Gneiss	bqp		1.0×10^{-8}	2
					bqpq		1.0×10^{-8}	2
				Marble	cs		1.0×10^{-8}	2
				Gneiss	garb		1.0×10^{-8}	2
				Marble	mb		1.0×10^{-8}	2
				Quartzite and Schist	qt		1.0×10^{-8}	2
				Gneiss	bqpc		1.0×10^{-8}	2
				Marble	mb		1.0×10^{-8}	2
				Gneiss	qtcs		1.0×10^{-8}	2
				Gneiss and Quartzite	qtig		1.0×10^{-8}	2
					rg		1.0×10^{-8}	2
					sc		1.0×10^{-8}	2
				Gneiss	amg		1.0×10^{-8}	2
					mug		1.0×10^{-8}	2
					ach		1.0×10^{-8}	2
				Metanorthosite	ack		1.0×10^{-8}	2
				Anorthositic Metamorphic	amu		1.0×10^{-8}	2
					ffg		1.0×10^{-8}	2
					hqs		1.0×10^{-8}	2
				Gneiss	hs		1.0×10^{-8}	2
					phgs		1.0×10^{-8}	2
					phqs		1.0×10^{-8}	2
					ps		1.0×10^{-8}	2
					bg		1.0×10^{-8}	2
				Gneiss	bhg		1.0×10^{-8}	2
					hg		1.0×10^{-8}	2
					qpg		1.0×10^{-8}	2
				Amphibolite	am		1.0×10^{-8}	2
					hbg		1.0×10^{-8}	2
				Gneiss	lg		1.0×10^{-8}	2
					phg		1.0×10^{-8}	2

Appendix H: List of CERCLA NPL Groundwater Contamination Sites in NYS

Facility Name	Address	City	State	ZIP Code	County
LITTLE VALLEY	INTERSECT OF RTES 242, 353, AND BAKER RD	LITTLE VALLEY	NY	14755	CATTARAUGUS
PLATTSBURGH AIR FORCE BASE	PLATTSBURGH AFB	PLATTSBURGH	NY	12901	CLINTON
BROOKHAVEN NATIONAL LABORATORY (USDOE)	53 BELL AVE	UPTON	NY	11961	SUFFOLK
SYOSSET LANDFILL	150 MILLER PLACE	OYSTER BAY	NY	11791	NASSAU
RAMAPO LANDFILL	RTE 59	RAMAPO	NY	10974	ROCKLAND
POLLUTION ABATEMENT SERVICES	55 SENECA ST	OSWEGO	NY	13126	OSWEGO
YORK OIL CO.	N LAWRENCE RD	MOIRA	NY	12957	FRANKLIN
FMC CORP. (DUBLIN ROAD LANDFILL)	DUBLIN ROAD	TOWN OF SHELBY	NY	14103	ORLEANS
MATTIACE PETROCHEMICAL CO., INC.	GARVIES POINT ROAD	GLEN COVE	NY	11542	NASSAU
NIAGARA COUNTY REFUSE	WITMER RD	WHEATFIELD	NY	14150	NIAGARA
JONES CHEMICALS, INC.	100 SUNNY SOL BLVD	CALEDONIA	NY	14423	LIVINGSTON
HOOKE (HYDE PARK)	HYDE PARK BLVD	NIAGARA FALLS	NY	14304	NIAGARA
ANCHOR CHEMICALS	500 W. JOHN STREET	HICKSVILLE	NY	11801	NASSAU
SMS INSTRUMENTS, INC.	120 MARCUS BLVD	DEER PARK	NY	11729	SUFFOLK
CLAREMONT POLYCHEMICAL	501 WINDING ROAD	OLD BETHPAGE	NY	11804	NASSAU
GENZALE PLATING CO.	288 NEW HYDE PARK ROAD	FRANKLIN SQUARE	NY	11010	NASSAU
AMERICAN THERMOSTAT CO.	RTE 23 B	SOUTH CAIRO	NY	12482	GREENE
ROBINTech, INC./NATIONAL PIPE CO.	3421 OLD VESTAL ROAD	TOWN OF VESTAL	NY	13850	BROOME
HOOKE CHEMICAL/RUCO POLYMER CORP	NEW SOUTH ROAD	HICKSVILLE	NY	11801	NASSAU
MARATHON BATTERY CORP.	KEMBLE AVENUE	COLD SPRINGS	NY	10516	PUTNAM
STANTON CLEANERS AREA GROUND WATER CONT.	110 CUTTER MILL ROAD	GREAT NECK	NY	11021	NASSAU
FACET ENTERPRISES, INC.	RTE 14	ELMIRA	NY	14903	CHEMUNG

Facility Name	Address	City	State	ZIP Code	County
KENMARK TEXTILE CORP.	921 CONKLIN ST (P.O. BOX 298)	FARMINGDALE	NY	11735	SUFFOLK
GENERAL MOTORS(CENTRAL FOUNDRY DIVISION)	ROOSEVELT TOURIN ROAD	MASSENA	NY	13662	ST. LAWRENCE
SOLVENT SAVERS	UNION VALLEY RD	LINCKLAEN	NY	13052	CHENANGO
WARWICK LANDFILL	PENALUNA RD/OLD TUXEDO/DUTCH H	WARWICK	NY	10990	ORANGE
HOOKEE (102ND STREET)	102 ST	NIAGARA FALLS	NY	14304	NIAGARA
ISLIP MUNICIPAL SANITARY LANDFILL	BLYDENBURG RD/LG ISLAND MOTOR	ISLIP	NY	11788	SUFFOLK
SIDNEY LANDFILL	RICHARDSON HILL RD	SIDNEY	NY	13839	DELAWARE
BATAVIA LANDFILL	GALLOWAY & KELSEY RD	BATAVIA	NY	14020	GENESEE
RICHARDSON HILL ROAD LANDFILL/POND	RICHARDSON HILL RD	SIDNEY CENTER	NY	13839	DELAWARE
TRI-CITIES BARREL CO., INC.	ADJ. TO ROUTE 7	PORT CRANE	NY	13833	BROOME
VOLNEY MUNICIPAL LANDFILL	SILK ROAD	TOWN OF VOLNEY	NY	13069	OSWEGO
GE MOREAU	FT EDWARD & WM ST	SOUTH GLENS FALLS	NY	12803	SARATOGA
CORTESE LANDFILL	SOUTH OF ROUTE 97	VIL OF NARROWSBURG	NY	12764	SULLIVAN
OLEAN WELL FIELD	LAUREN ST	OLEAN	NY	14760	CATTARAUGUS
OLD BETHPAGE LANDFILL	ROUND SWAMP RD	OYSTER BAY	NY	11804	NASSAU
JONES SANITATION	CARDINAL RD	HYDE PARK	NY	12538	DUTCHESS
MALTA ROCKET FUEL AREA	PLAINS RD	MALTA	NY	12020	SARATOGA
SARNEY FARM	BENSON HILL RD	AMENIA	NY	12501	DUTCHESS
SEALAND RESTORATION, INC.	PRAY RD	LISBON	NY	13669	ST. LAWRENCE
SINCLAIR REFINERY	S BROOKLYN AVE	WELLSVILLE	NY	14895	ALLEGANY
APPLIED ENVIRONMENTAL SERVICES	ONE SHORE RD	GLENWOOD LANDING	NY	11545	NASSAU

Facility Name	Address	City	State	ZIP Code	County
FULTON TERMINALS	RTE 57	FULTON	NY	13069	OSWEGO
KENTUCKY AVENUE WELL FIELD	KENTUCKY AVE	HORSEHEADS	NY	14845	CHEMUNG
HOOKEE (S AREA)	BUFFALO AVE	NIAGARA FALLS	NY	14303	NIAGARA
WIDE BEACH DEVELOPMENT	WIDE BEACH RD	BRANT	NY	14027	ERIE
BREWSTER WELL FIELD	MAIN ST /SE	PUTNAM COUNTY	NY	10509	PUTNAM
PORT WASHINGTON LANDFILL	WEST SHORE RD	PORT WASHINGTON	NY	11050	NASSAU
NIAGARA MOHAWK POWER CO(SARATOGA SPINGS)	EAST AVENUE & EXCELCIOR RD	SARATOGA SPRINGS	NY	12866	SARATOGA
NORTH SEA MUNICIPAL LANDFILL	MAJORS PATH	NORTH SEA	NY	11968	SUFFOLK
VESTAL Water-supply WELL 1-1	605 VESTAL PKWY	VESTAL	NY	13850	BROOME
BEC TRUCKING	STEWART RD	VESTAL	NY	13850	BROOME
COLESVILLE MUNICIPAL LANDFILL	EAST WINDSOR RD	TOWN OF COLESVILLE	NY	13813	BROOME
GOLDISC RECORDINGS, INC.	725 BROADWAY	HOLBROOK	NY	11741	SUFFOLK
PREFERRED PLATING CORP.	32 ALLEN BLVD	FARMINGDALE	NY	11735	SUFFOLK
BYRON BARREL & DRUM	TOWN LINE ROAD	BYRON TOWNSHIP	NY	14422	GENESEE
ENDICOTT VILLAGE WELL FIELD	S. GRIPPEN AVENUE	VILLAGE OF ENDICOTT	NY	13760	BROOME
HERTEL LANDFILL	RTE 44/55 BEDELL AVE & TUCKERS	PLATTEKILL	NY	12568	ULSTER
KATONAH MUNICIPAL WELL	JAY STREET	TOWN OF BEDFORD	NY	10536	WESTCHESTER
SUFFERN VILLAGE WELL FIELD	NORTH END OF RAMAPO AVENUE	VILLAGE OF SUFFERN	NY	10901	ROCKLAND
HAVILAND COMPLEX	ROUTE 9G & HAVILAND ROAD	TOWN OF HYDE PARK	NY	12538	DUTCHESS

Facility Name	Address	City	State	ZIP Code	County
GCL TIE & TREATING INC.	DELAWARE AVENUE	VILLAGE OF SIDNEY	NY	13838	DELAWARE
ROSEN BROTHERS SCRAP YARD/DUMP	PENDELTON ST.	CORTLAND	NY	13045	CORTLAND
ONONDAGA LAKE		SYRACUSE	NY	13209	ONONDAGA
MOHONK ROAD INDUSTRIAL PLANT	186 MOHONK ROAD	HIGH FALLS	NY	12440	ULSTER
LEHIGH VALLEY RAILROAD	GULF ROAD	LE ROY	NY	14482	GENESEE
PASLEY SOLVENTS & CHEMICALS, INC.	585 COMMERICAL AVENUE	HEMPSTEAD	NY	11530	NASSAU

REFERENCES

Aller, L., T. Bennett, J.H. Lehr, and R.J. Petty, 1987, DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrgeologic Setting, EPA/600/2-85/018, Ada, OK: R.S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, 622 p.

American Society for Testing and Materials (ASTM), Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process, ASTM Designation: E 1527-94, 24p.

Arnow, T., 1949, The Ground-Water Resources of Albany County, New York, State of New York Department of Conservation, Water Power and Control Commission, Bulletin GW-20

Ashley, G.M. and S.D. Stanford, 1993, Hydrogeology of the Glacial Deposits of New Jersey: An Applied Field Course, Rutgers University, Cook College Office of Continuing Education, 130p.

Athy, L. F., 1930, Density, Porosity and Compaction of Sedimentary Rocks, American Association of Petroleum Geologists Bulletin, v. 17 no. 1, p. 1 - 24.

Benard, H. A. and R. J. LeBlanc, 1965, Resume of the Quarternary Geology of the Northwestern Gulf of New Mexico Province, p. 137-185 in Wright, H. E. and D. G. Frey, eds., The Quarternary of the United States, Princeton, N.J., Princeton University Press, 922 p.

Berdan, J. M., 1954, The Ground-Water Resources of Greene County, New York, State of New York Department of Conservation, Water Power and Control Commission, Bulletin GW-34, 62 p.

Bott, M. H. P., 1973, Shelf Subsidence in Relation to the Evolution of Young Continental Margin, in Implications of Continental Drift to the Earth Sciences, vol. 2, eds. D. H. Tarling and S. K. Runcorn, Academic Press, London & New York, p. 675 - 683.

Bouwer, H., 1978, Flow Proce to Underground From Surface Ponds, Goundwater Recharge Symposium, Phoenix, AZ, November 27-28, 1978, 19 p.

Bouwer, H., and Rice, R.C., 1976, A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells: Water Resources Research, V. 12, No. 3, p. 423-428.

Broughton, J.G., D.W. Fisher, Y.W. Isachsen and L.V. Richard, 1976 Reprint, Geology of New York, University of the State of New York, Enclosure.

Burrough, P. A. and R. A. McDonnell, 1998, Principles of Geographical Information Systems, Oxford University Press Inc., New York, NY, 333 p.

Busciolano, R., J. Monti and A. Chu, 1998, Water-Table and Potentiometric-Surface Altitudes of the Upper Glacial, Magothy, and Lloyd Aquifers on Long Island, New York, in March-April, with a Summary of Hydrogeologic Conditions, USGS Water-Resources Investigations Report 98-4019, Coram, NY 17 p.

Buyce, M. R. and G. M. Friedman, 1975, Significance of Authigenic K-Feldspar in Cambrian-Ordovician Carbonate Rocks of the Proto-Atlantic Shelf in North America, Journal Sedimentary Petrology, Volume 45, p. 808-821.

Cadwell, D. H., 1988, Surficial Geologic Map of New York, Niagara Sheet, New York State Museum - Geological Survey, Map and Chart Series #40.

Cadwell, D. H., 1989, Surficial Geologic Map of New York, Lower Hudson Sheet, New York State Museum - Geological Survey, Map and Chart Series #40.

Cadwell, D. H. and R. J. Dineen, 1987, Surficial Geologic Map of New York, Hudson-Mohawk Sheet, New York State Museum - Geological Survey, Map and Chart Series #40.

Cadwell, D. H. and D. L. Pair, 1991, preliminary compilation by R. J. Dineen, 1989, Surficial Geologic Map of New York, Adirondack Sheet, New York State Museum - Geological Survey, Map and Chart Series #40.

Carney, G. R., 1991. Human Health Risk Index Draft Document. Policy and Analysis Section, US EPA, Region 6.

Coffel, S., 1989, The Lifesaving Guide To Good Water, Ballantine Books, New York, NY, 342 p.

Cosner, O. J., 1984, Atlas of Four Selected Aquifers in New York, EPA Report, Contract number 68-01-6389, Task No. 17, EPA Report, September, 1984, 102p.

DeMers, M. N., 1997, Fundamentals of Geographic Information Systems, John Wiley & Sons, New York, NY, 486 p.

Dickenson, W. R., 1974, ed., Plate Tectonics and Sedimentation, Society of Economic Paleontologists and Mineralogists, Special Publication 22, Tulsa, OK, 204 p.

Dietrich, R. V. and B. J. Skinner, 1979, Rocks and Rock Minerals, John Wiley & Sons, New York, New York, 319 p.

Environmental Systems Research Institute Inc. (ESRI), 1991, Understanding GIS - The Arc/Info Method, ESRI, Inc., 380 New York Street, Redlands, CA 92373.

Environmental Systems Research Institute Inc. (ESRI), 1995, Introduction to ArcView, ESRI, Inc., 380 New York Street, Redlands, CA 92373.

Easterbrook, D.J., 1982, Characteristic Features of Glacial Sediments, p. 1-10, in Scholle, P.A. and D. Spearing (eds.), Sandstone Depositional Environments: Tulsa, OK, AAPG Memoir 31, 410p.

Eyles, N. and C.H. Eyles, 1992, Glacial Depositional Systems: in Walker, R.G. and N.P. James (eds.), Facies Models, Response to Sea Level Change, Geological Association of Canada, p. 73-100.

Feldman, S. M., D. A. Smolensky and J. P. Masterson, 1992. Ground-Water Quality in Bethpage-Hicksville-Levittown Area, Long Island, New York, with Emphasis on Volatile Organic Compounds. USGS, Water-Resources Investigations Report 90-4182, 51p.

Fetter, C. W., 1980, Applied Hydrogeology, Charles E. Merrill Publishing Co., Columbus, OH, 488 p.

Fisher, D. W., Y. W. Isachsen and L. V. Rickard, 1970a, Geologic Map of New York, Hudson-Mohawk Sheet, New York State Museum and Science Service, Map and Chart Series No. 15.

Fisher, D. W., Y. W. Isachsen and L. V. Rickard, 1970b, Geologic Map of New York, Lower Hudson Sheet, New York State Museum and Science Service, Map and Chart Series No. 15.

Flint, R. F., J. E. Sanders and J. Rodgers, 1960, Diamictite a Substitute Term for Symmictite, Geological Society of America Bulletin v. 46, p. 1 - 22.

Freeze, R. A. and J. A. Cherry, 1979, Groundwater, Prentice-Hall, Inc., Englewood Cliffs, NJ, 604 p.

Friedman, G. M., 1979, Sedimentary Environments and Their Products: Shelf, Slope, and Rise of Proto Atlantic (Iapetus) Ocean, Cambrian and Ordovician Periods, Eastern New York State, Guidebook for Field Trips: New England Intercollegiate Geological Conference 71st Annual Meeting, and New York State Geological Association 51st Annual Meeting, Troy, New York, Rensselaer Polytechnic Institute, ed. G.M. Friedman,

p. 47 - 86.

Friedman, G. M., 1990, Vertical Parasequences of Lower Devonian Limestones, Helderberg Escarpment: the Indian Ladder Trail at the John Bod Thacher State Park Near Albany, New York: *Northeastern Geology*, v. 12, nos. ½, p. 14 - 18.

Friedman, G. M., 1995, Flysch and Molasse of the Classical Taconic and Acadian Orogenies: Models for Subsurface Reservoir Settings, Field Trip Guide for the 67th Annual Meeting of the New York State Geological Association, eds. J. I. Garver and J. A. Smith, p. 109 - 143.

Friedman, G. M. and J. E. Sanders, 1978, *Principals of Sedimentology*, John Wiley & Sons, New York, 792 p.

Friedman, G. M. and J. E. Sanders, 2000, Comments About the Relationships Between Ideas and Geologic Terms in Stratigraphy and Sequence Stratigraphy with Suggested Modifications, *American Association of Petroleum Geologists Bulletin*, v. 84, p. 1274 - 1280.

Friedman, G. M., J. E. Sanders and B. Guo, 1993, Pre-Drilling Geologic Work in Connection with Proposed Albany Basin, New York, Deep Scientific Bore Hole to Test Gas Potential of Paleozoic Formation: New York Gas Group, Final Report, 171 p.

Friedman, G. M., J. E. Sanders and D.C. Kopaska-Merkel, 1992, *Principles of Sedimentary Deposits - Stratigraphy and Sedimentology*, Macmillan Publishing Co., New York, NY, 717 p.

Friedman, G. M., J. E. Sanders and I. P. Martini, 1982, Excursion 17A: Sedimentary Facies: Products of Sedimentary Environments in a Cross Section of the Classic Appalachian Mountains and Adjoining Appalachain Basin in New York and Ontario, Field Excursion Guide Book, Internation Association of Sedimentologists, Eleventh International Congress on Sedimentology, McMaster University, Hamilton, Ontario, Canada, August 22 - 27, 1982,

Frimpter, M. H., 1970, Ground-Water Basic Data Orange and Ulster Counties, New York, State of New York Conservation Department, Water Resources Commission, Bulletin 65, 93 p.

Getzen, R. T., 1977, Analog-Model Analysis of Regional Three-Dimensional Flow in the Ground-Water Reservoir of Long Island, New York, USGS Professional Paper 982, U.S. Government Printing Office, Washington D.C., 49 p.

Guo, B., J. E. Sanders and G. M. Friedman, 1990, Columbia Gas Company No. 1

Finnegan Boring, Washington County, New York: Microlithofacies and Petroleum Prospects in Lower Paleozoic Platform Strata Beneath Taconic Allochthon, Northeastern Geology, v. 12, p. 238 - 265.

Highland, J. H., 1981, Hazardous Waste / A Problem for the 1980s, The American Peoples Encyclopedia Yearbook 1981, ed. E. Humphrey, Grolier Incorporated, p. 47 - 53.

Hillenbrand, C. J., W. Hansen and R. Ferri, 1995. Underground Injection Control Program Inspection Targeting on Long Island, NY Using GIS Technology, New York Earth Science and the Environment, Vol. 1, No. 1, p. 23 - 43.

Hollocher, K., 1995, Traverse Across the Taconian Orogen, Field Trip Guide for the 67th Annual Meeting of the New York State Geological Association, eds. J. I. Garver and J. A. Smith, p. 145 - 161.

Hvorslev, M.J., 1951, Time Lag and Soil Permeability in Groundwater Observations: U.S. Army Corps Engrs. Waterways Exp. Sta. Bull. 36, Vicksburg, MS.

Isachsen, Y. W. and D. W. Fisher, 1970, Geologic Map of New York, Adirondack Sheet, New York State Museum and Science Service, Map and Chart Series No. 15.

Isachsen, Y. W., E. Landing, J. M. Lauber, L. V. Rickard and W. B. Rogers, 1991, eds., Geology of New York a Simplified Account, New York State Museum/Geological Survey, The State Education Department, The University of the State of New York, Albany, N. Y., 284 p.

Kammer, J. C. and W. A. Hobba, 1967, The Geology and Availability of Ground Water in the Genesee River Basin, New York and Pennsylvania, United States Department of the Interior Geological Survey.

Kappel, W. M., D. A. Sherwood and W. H. Johnston, 1996, Hydrogeology of the Tully Valley and Characterization of Mudboil Activity, Onondaga County, New York, USGS, Water-Resources Investigations Report 96-4043, Ithica, New York, 71 p.

Keith, B. D. and G. M. Friedman, 1977, A Slope-Fan-Basin-Plain Model, Taconic Sequence, New York and Vermont: Journal of Sedimentary Petrology, v. 47, p. 1220 - 1241.

King, P. B., 1977, The Evolution of North America, Princeton University Press, Princeton, N.J., 197 p.

Kumar, C. S., and B. A. Engel, 1999, Predicting Spatial Distributions of Vulnerability of Indiana Stat Aquifer Systems to Nitrate Leaching Using a GIS, National Center for

Geographic Information and Analysis, University of California - Santa Barbara, 12 p.

LeGrande, H. E., 1983, A Standardized System for Evaluating Waste-Disposal Sites, National Water Well Association, Worthington, Ohio, 49 p.

LeRoy, L. W. and D. O. LeRoy, 1977, Subsurface Geology, Colorado School of Mines, 4th Edition, 941 p.

Levorsen, A. I., 1954, Geology of Petroleum, W. H. Freeman and Company, San Fransico, CA, 703p.

Lewis-Brown, J. C., and E. Jacobsen, 1995, Hydrogeologic and Ground-Water Flow, Fractured Mesozoic Structural-Basin Rocks, Stony Brook, Beden Brook, and Jacobs Creek Drainage Basins, West-Central New Jersey, USGS Water-Resources Investigation Report 94-4147, West Trenton, New Jersey, 83 p.

Mack, F. K. and R. E. Digman, 1962, The Ground-Water Resources of Ontario County, New York, State of New York Department of Conservation, Water Resources Commission, Bulletin GW-48.

Michigan Department of Natural Resources (MDNR), 1983, Site Assessment System (SAS), for the Michigan Priority Ranking System Under the Michigan Environmental Response Act (Act 301, P.A. 1982, C. Iversen, Chairperson, Michigan Document Office CN25624, 91 p.

Muller, E. H. and D. H. Cadwell, 1986, Surficial Geologic Map of New York, Finger Lakes Sheet, New York State Museum - Geological Survey, Map and Chart Series #40.

Nielsen, D. R., J. W. Biggar and K. T. Erh, 1973, Spatial Variability of Field-Measured Soil-Water Properties, California, Agricultural Experimental Station, University of California, Berkeley, Division of Agricultural Sciences, Hilgardia November, 1973, 42(7): p. 215-258.

New York State Department of Conservation (NYSDEC), 1986. Long Island groundwater management program. NYSDEC, Division of Water, 116 p.

New York State Department of Conservation (NYSDEC), 1987, Upstate New York groundwater management program, NYSDEC, Division of Water, 171 p.

Orson, R. A., D. T. Osgood, R. N. Zajac and J. F. Tait, 2000, Sybil Creek Restoration: Baseline Data and Habitat Assessment Prior to Restoration, State of Connecticut Department of Environmental Protection, Office of Long Island Sound Programs, <http://www.branfordlandtrust.org/scepat.html>.

Perlmutter, N. M., 1959, Geology and Ground-Water Resources of Rockland County, New York, With Special Emphasis on the Newark Group (Triassic), State of New York Department of Conservation, Water Power and Control Commission, Bulletin GW-42.

Prudic, D. E., 1986, Ground-Water Hydrology and Subsurface Migration of Radionuclides at a Commercial Radioactive-Waste Burial Site, West Valley, Cattaraugus County, New York, USGS Professional Paper 1325, U.S. Government Printing Office, Washington D.C., 83 p.

Rail, C. D., 1989, Groundwater Contamination - Sources, Control, and Preventative Measures, Technomic Publishing Company, Inc., Lancaster, PA, 139 p.

Rampino, M. R. and J. E. Sanders, 1980, Holocene Transgression in South-Central Long Island, New York, Journal of Sedimentary Petrology, v. 50, p. 1063-1080.

Rich, J. I., 1951, Three Critical Environments of Deposition and Criteria for Recognition of Rocks Deposited in Each of them: Geological Society of America Bulletin, v. 62, p. 1 - 20.

Rickard, L. V. and D. W. Fisher, 1970a, Geologic Map of New York, Finger Lakes Sheet, New York State Museum and Science Service, Map and Chart Series No. 15.

Rickard, L. V. and D. W. Fisher, 1970b, Geologic Map of New York, Niagara Sheet, New York State Museum and Science Service, Map and Chart Series No. 15.

Rodgers, J., 1970, The Tectonic of the Appalachians, New York, John Wiley and Sons, 271 p.

Sleep, N. H., 1971, Thermal Effects of the Formation of Atlantic Continental Margins by Continental Break-Up, Geophysics Journal, abstr, Soc., 24 p 325-350.

Sloss, L. L., 1963, Sequences in the Cratonic Interior of North America, Geological Society of America Bulletin, v. 74, pp. 93 - 114.

Smolensky, D. A., H. T. Buxton and P. K. Shernoff, 1989. Hydrologic framework of Long Island, New York. USGS, Hydrologic Investigations Atlas HA-709.

U.S. Department of Agriculture (USDA), Soil Conservation Service 1993, State Soil Geographic Data Base (STATSGO) Data Users Guide, Miscellaneous Publication Number 1492, 88p.

U.S. Environmental Protection Agency (EPA), 1984, Uncontrolled Hazardous Waste Site

Ranking System, A Users Manual, HW-10, EPA Region 3 Information Resource Center, 60 p.

U.S. Environmental Protection Agency (EPA), 1986, Guidelines for Carcinogen Risk Assessment, 51 Federal Register 33992, September 24, 1986.

U.S. Environmental Protection Agency (EPA), 1988a, Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA,. Interim Final. Office of Emergency and Remedial Response. (OSWER Directive 9355.3-01).

U.S. Environmental Protection Agency (EPA), 1988b, Selection Criteria for Mathematical Models Used in Exposure Assessments; Ground-water Models. Office of Health and Environmental Assessment. EPA/600/8-88/075

U.S. Environmental Protection Agency (EPA), 1989a, Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), Office of Emergency And Remedial Response, U.S. Environmental Protection Agency, Washington, DC 20450, EPA/540/1-89/002 December, 1989

U.S. Environmental Protection Agency (EPA), 1990. National Priorities List Sites: New York. EPA/540/4-90/032, Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency (EPA), 2001, Risked-Based Concentration Table, Superfund Technical Support Section (3HS41), Region 3, Philadelphia, PA, (<http://www.epa.gov/reg3hwmd/risk/riskmenu.htm>).

Vail, P. R. , R. M. Mitchum and S. Thompson, 1977. Seismic Stratigraphy and Global Changes of Sea Level, Part 4; Global Cycles and Relative Changes of Sea Level, p. 83-97 in Payton, C. E., ed., Seismic Stratigraphy, Applications to Hydrocarbon Exploration: Tulsa, OK, American Association of Petroleum Geologists, Memoir 26, 516p.

Van Diver, B.B., 1988, Roadside Geology of New York, Mountain Press Publishing Co., Missoula, MT, 411p.

Van Riper, J. E., 1971, Man's Physical World, McGraw-Hill Book Company, New York, NY, 713 p.

Ver Straeten, C. A. and C. E. Brett, 1995, Lower and Middle Devonian Foreland Basin Fill in the Catskill Front: Stratigraphic Synthesis, Sequence Stratigraphy, and the Acadian Orogeny, Field Trip Guide for the 67th Annual Meeting of the New York State Geological Association, eds. J. I. Garver and J. A. Smith, p. 313 - 356.

Waller, R.M. and A.J. Finch, 1982, Atlas of Eleven Selected Aquifers in New York,

USGS, Water Resources Investigation, Open-File Report 82-553, 255 p.

.

NOTE TO USERS

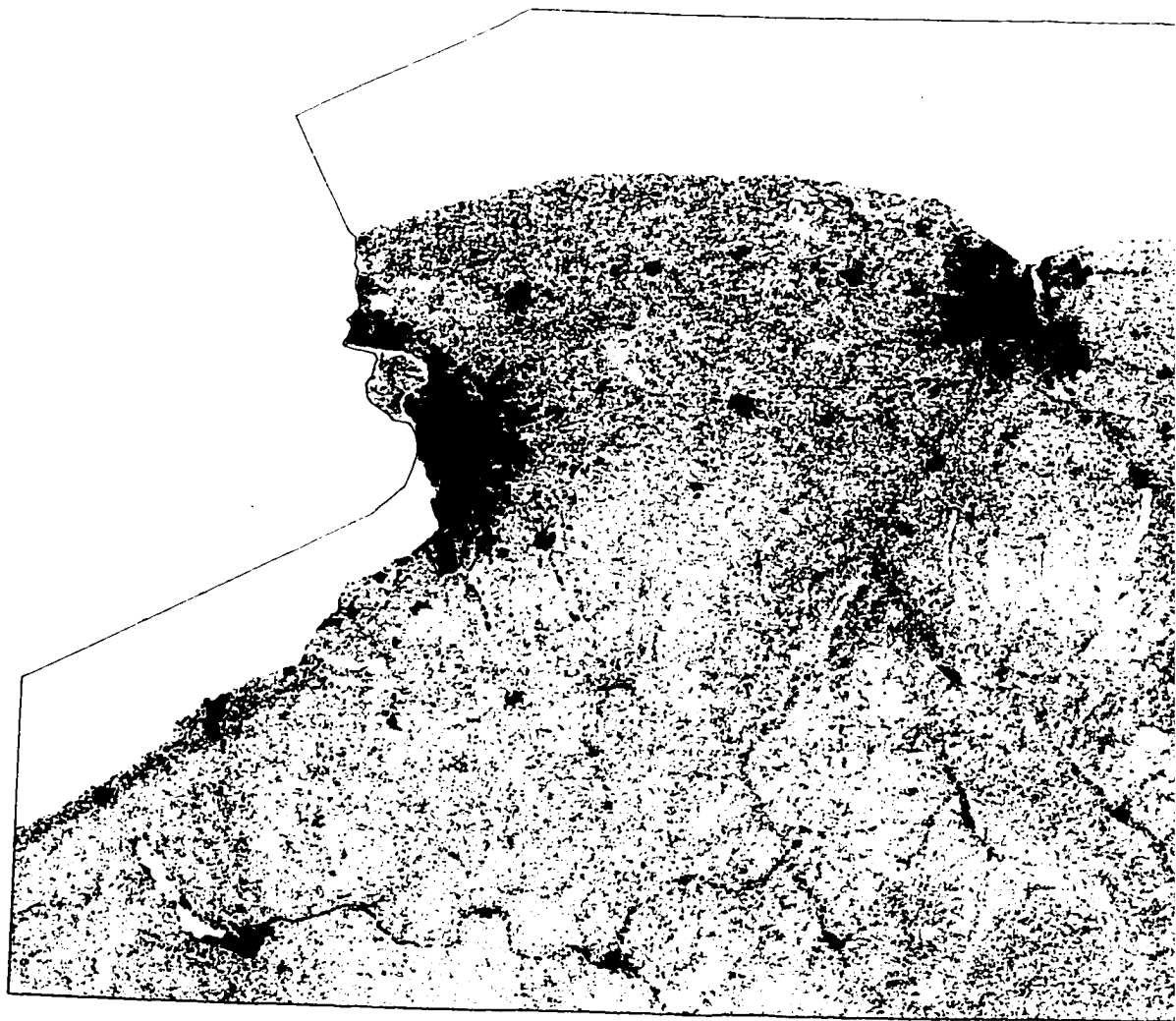
Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

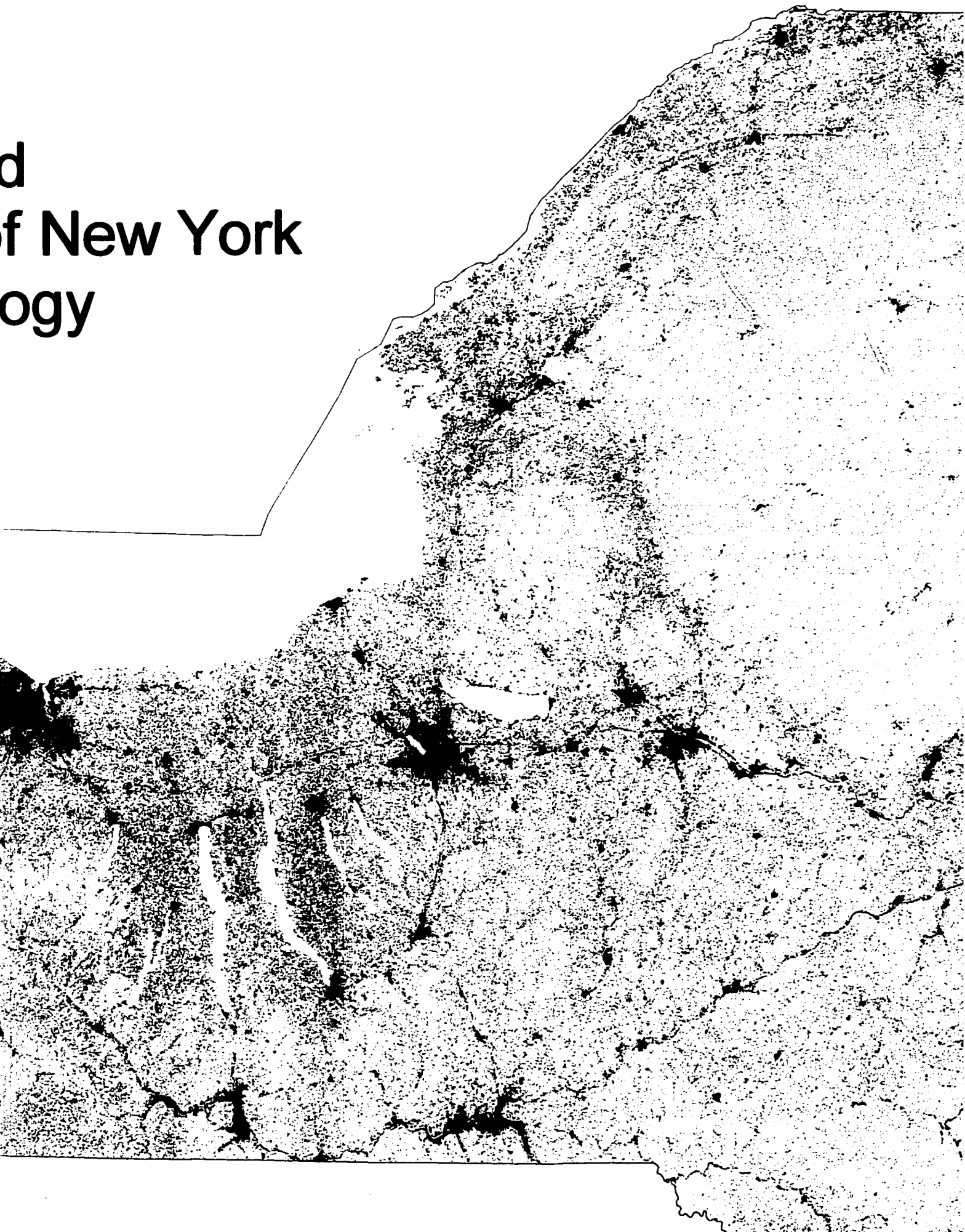
This reproduction is the best copy available.

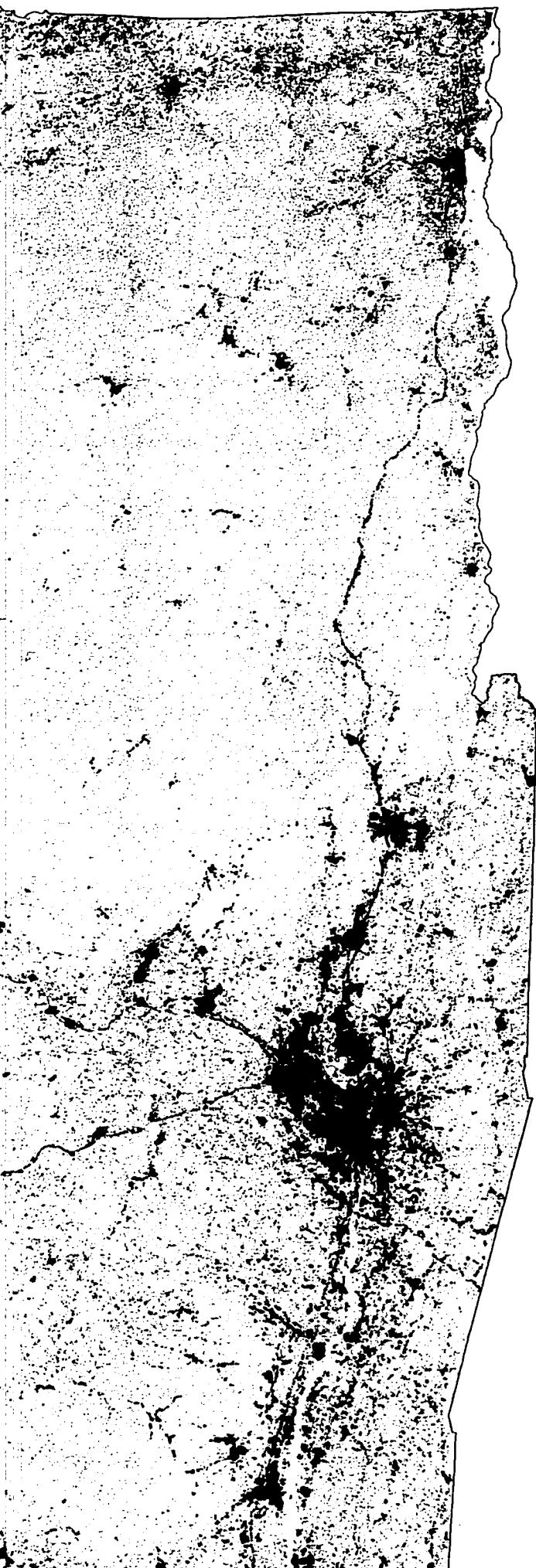
UMI®

Land Use-Risk Grid Groundwater Risk Analysis of Nevada Utilizing GIS Technology Plate 1



d f New York ogy





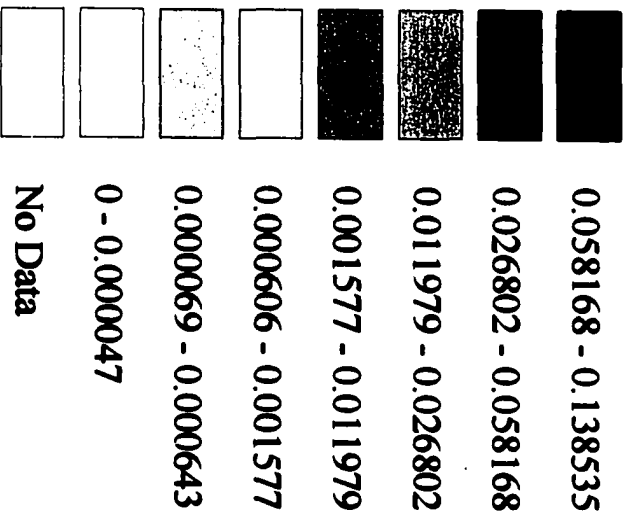
Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Land Use - Risk

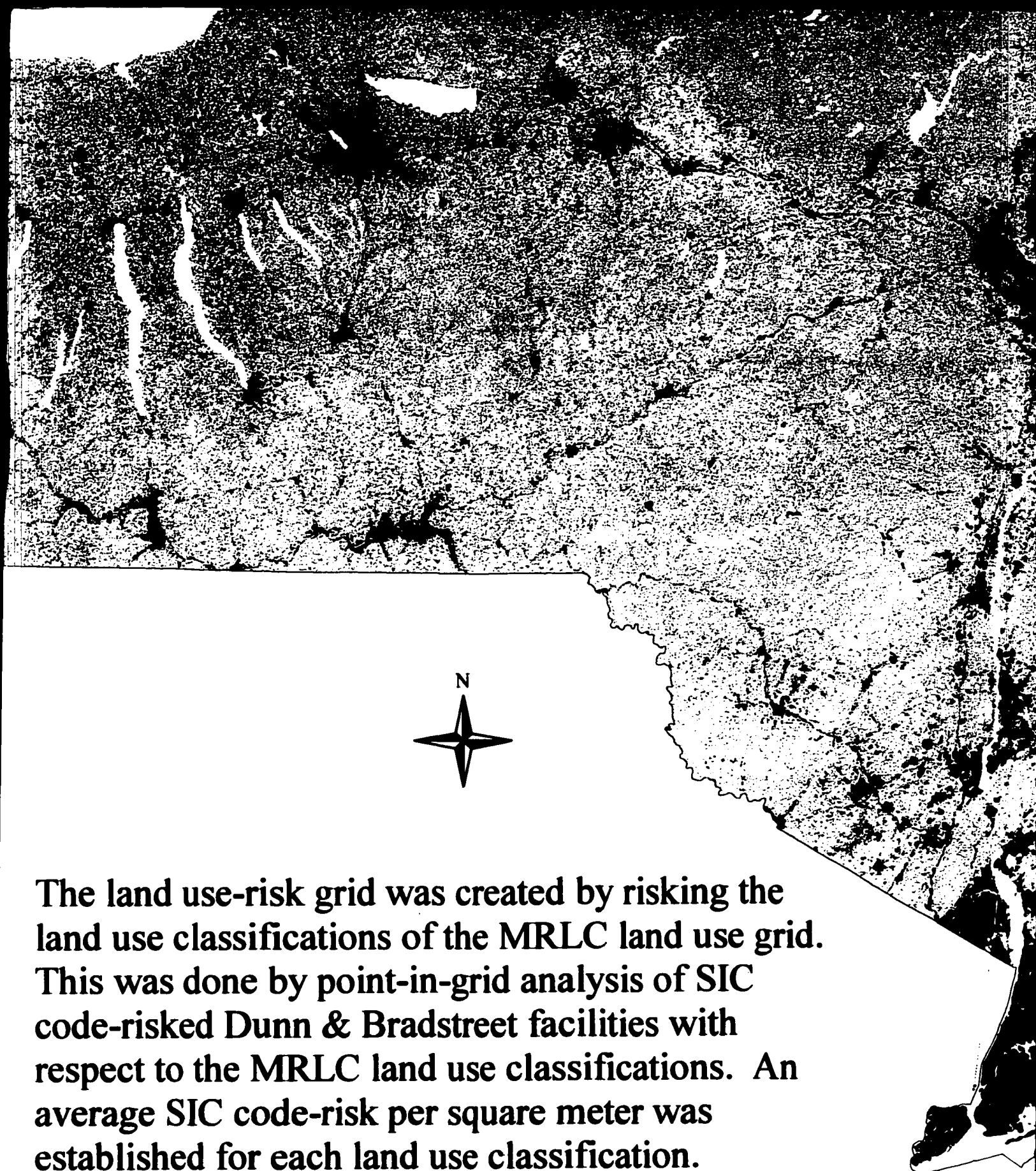
Land Use-Risk Grid (l/ug/m^2)



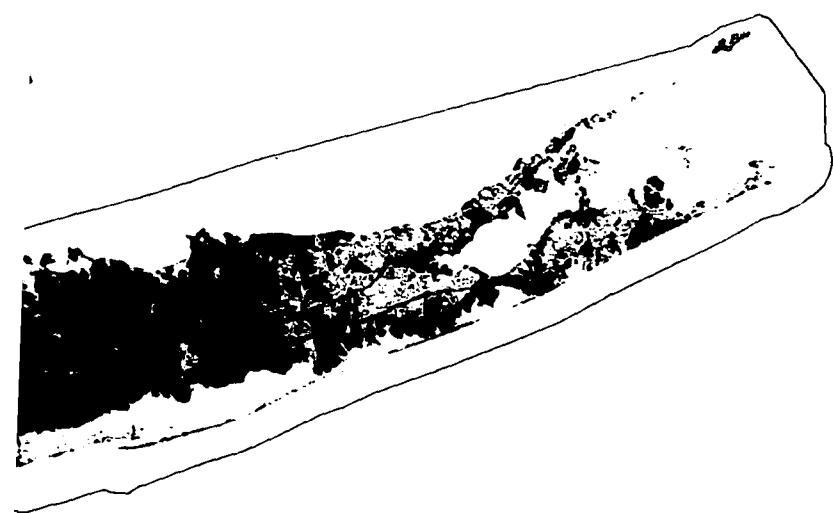
NYS Boundary



Th
lan
Th
coc
res
ave
esti



50 0 50 100



NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

UMI®

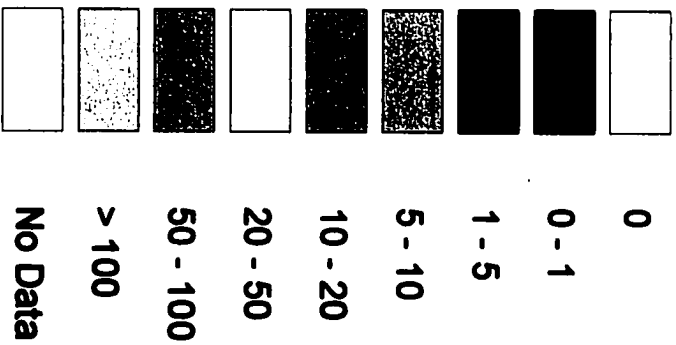


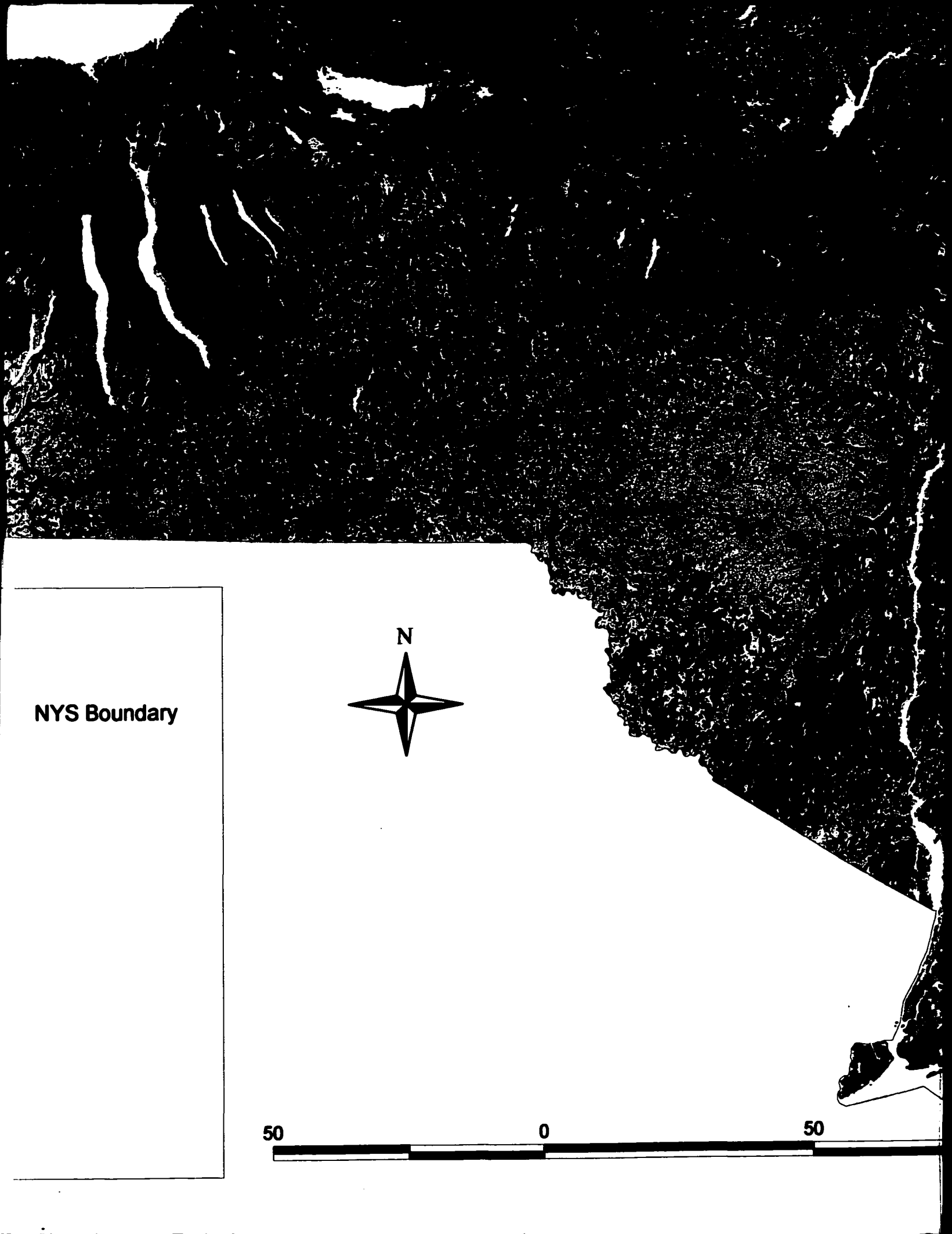
Depth to the Water-Table

NYS Depth to Water-Table Grid, Depth (meters)

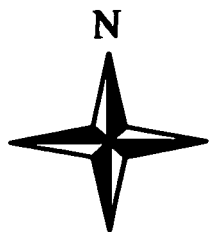


NYS





NYS Boundary



50

0

50



100 Miles



NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

UMI[®]

Aquifer Susceptibility Groundwater Risk Analysis of M Utilizing GIS Technology Plate 3



Aquifer Susceptibility

City of New York ology



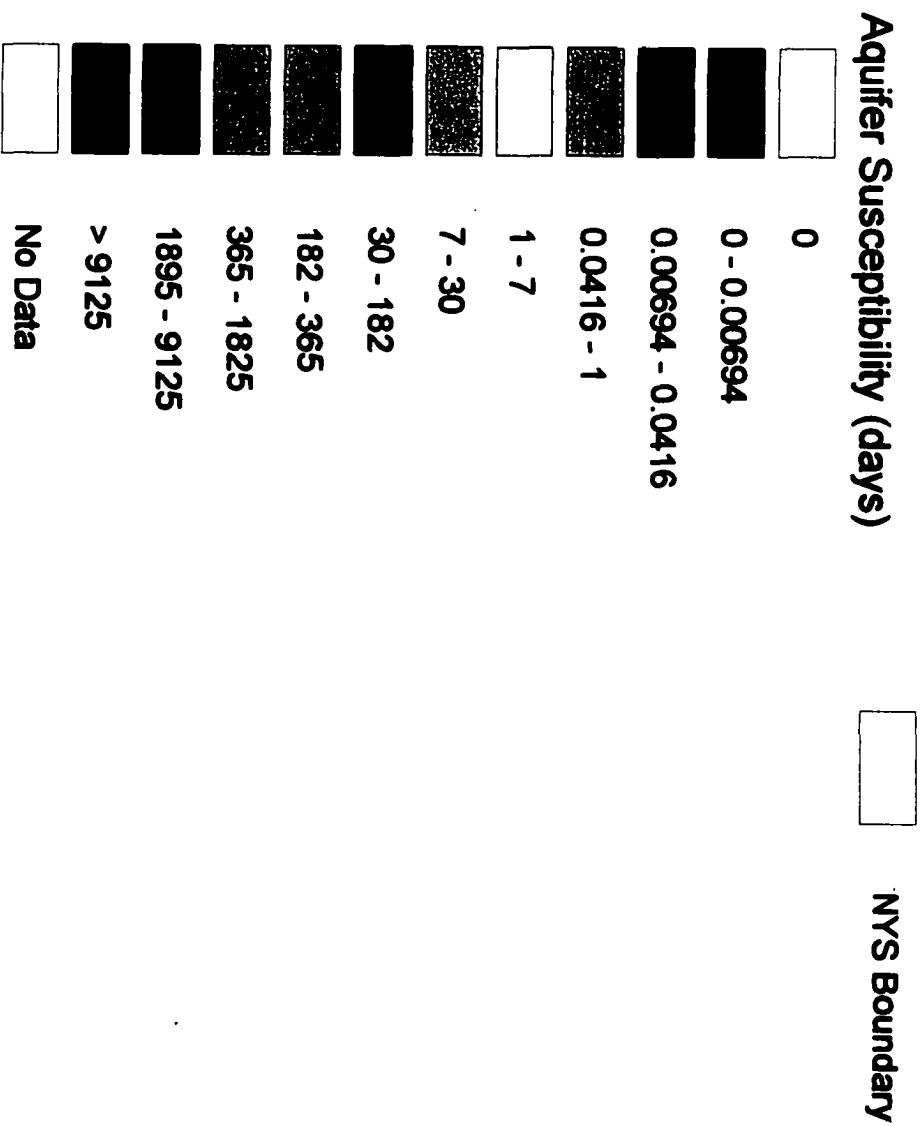
}

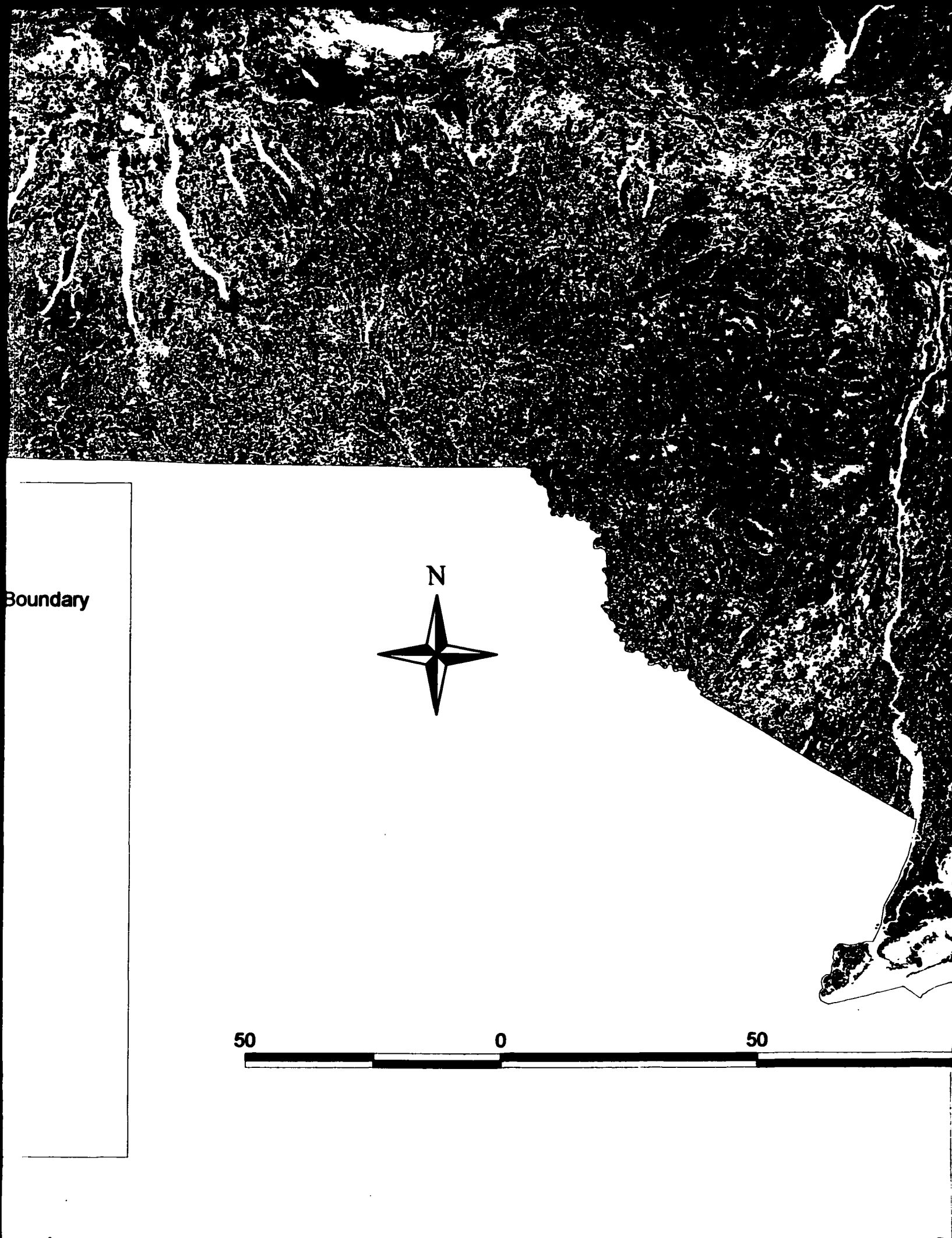
|

.



Aquifer Susceptibility







Miles

NOTE TO USERS

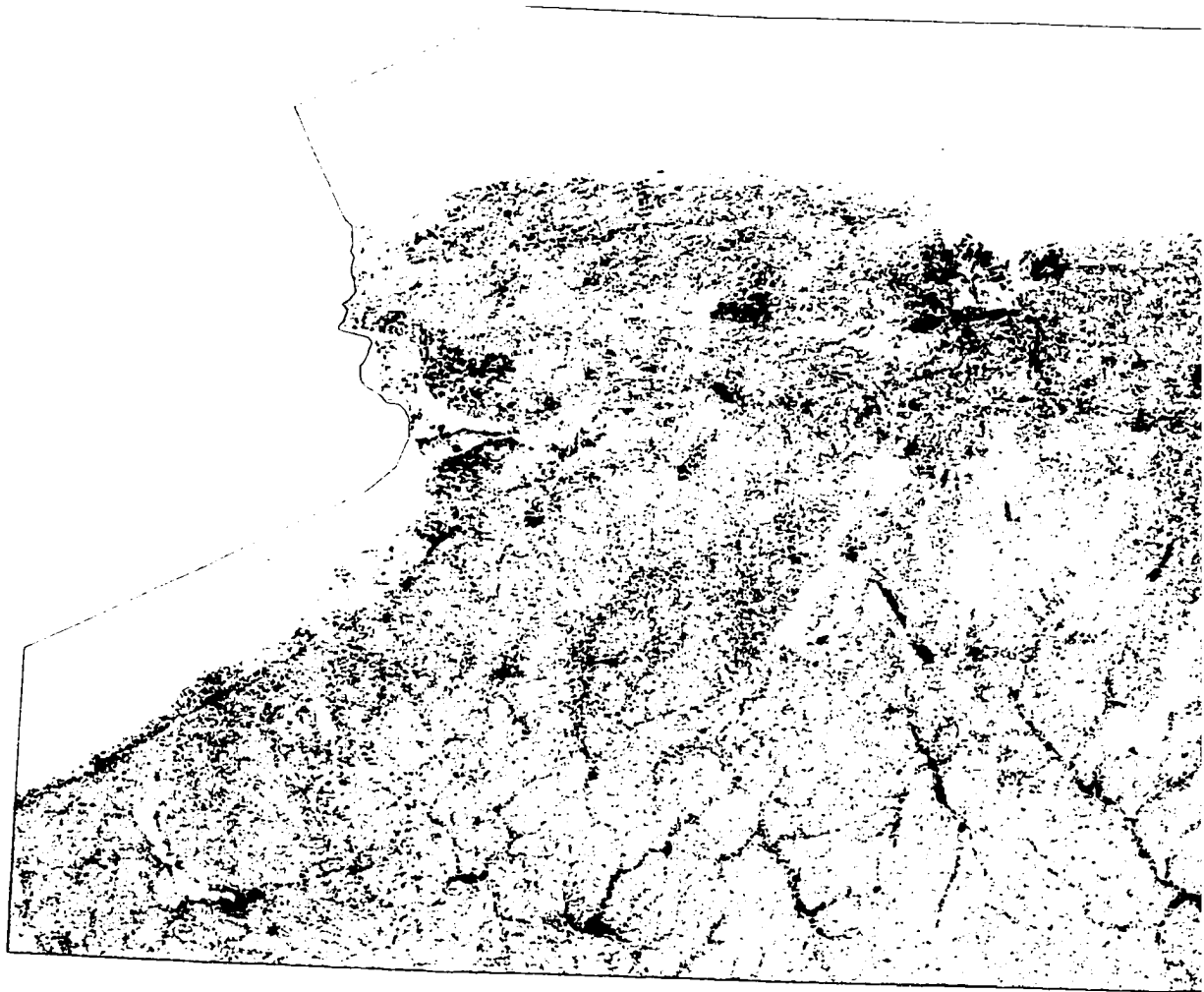
Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

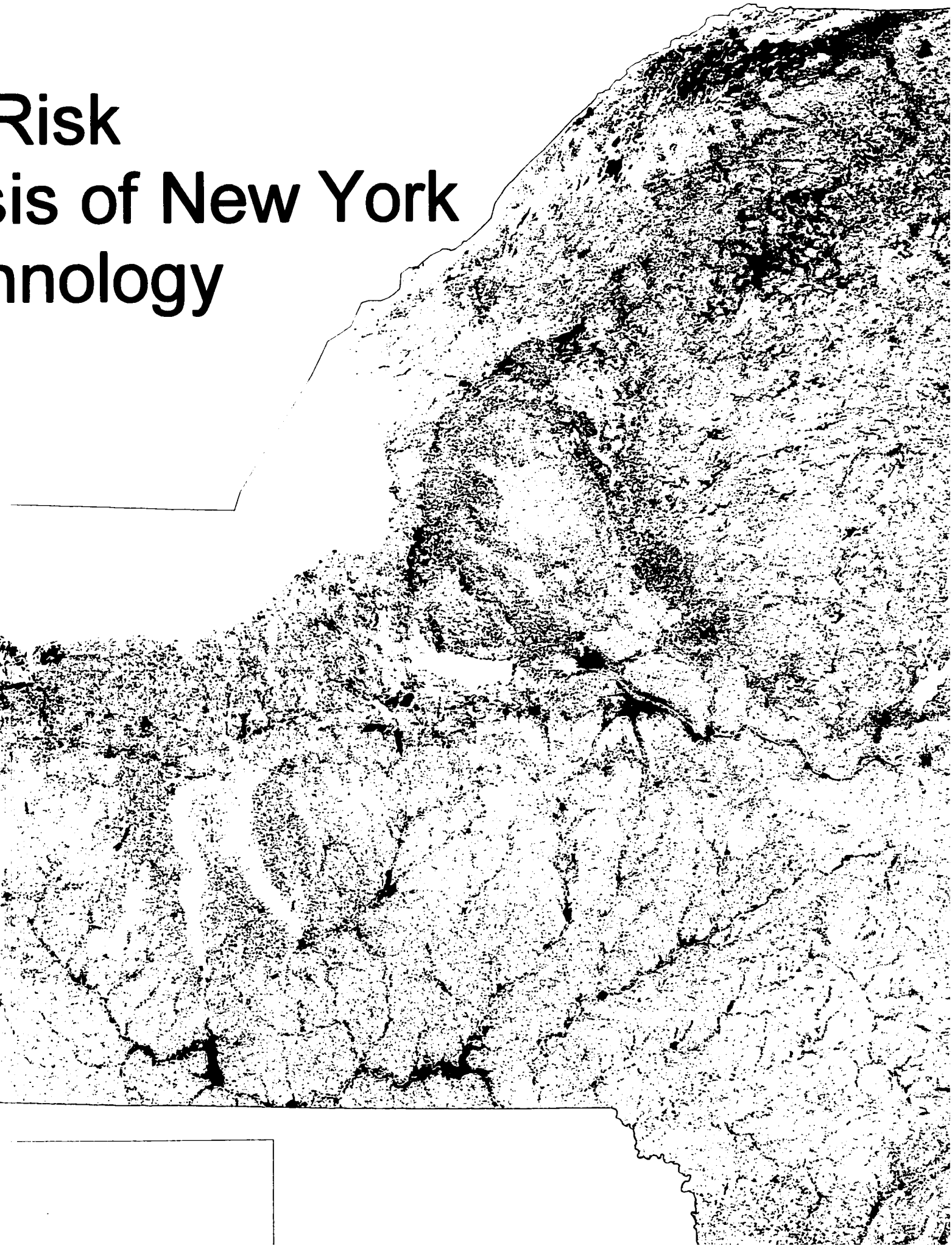
UMI ®

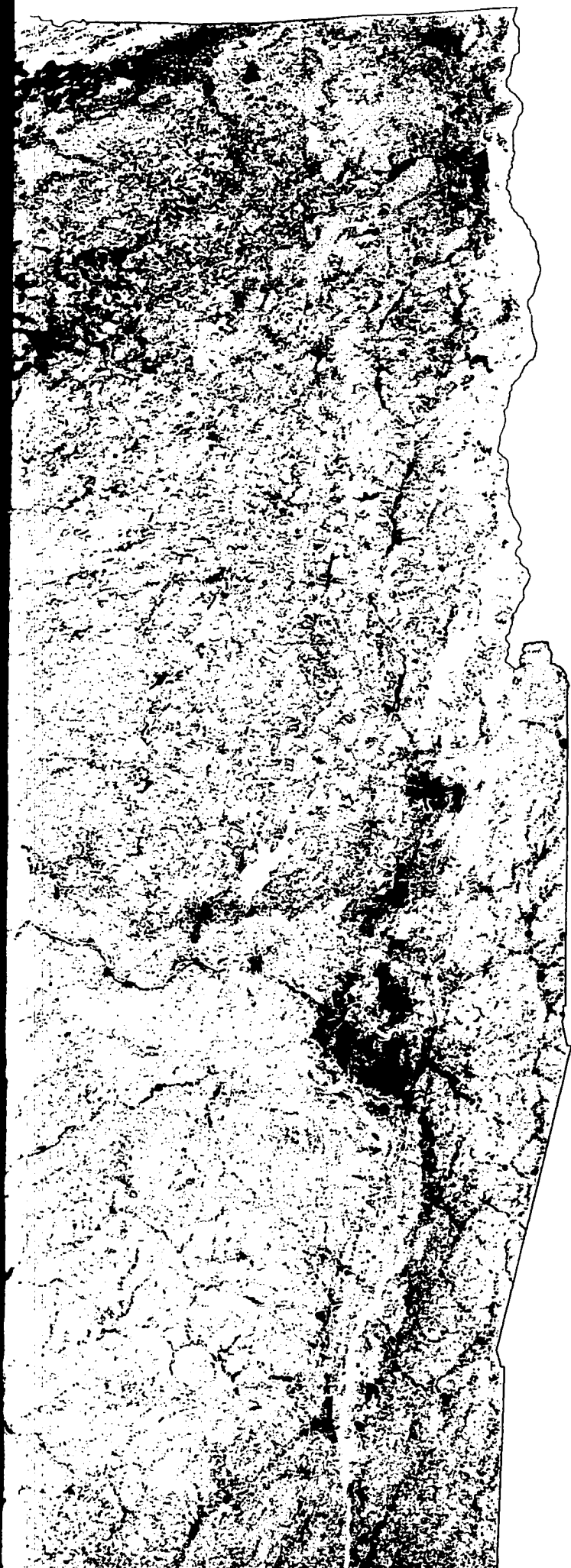
Groundwater-Risk Groundwater Risk Analysis of Utilizing GIS Technology Plate 4



Groundwater-Risk

Risk Assessment of New York Technology







Groundwater-Risk

Groundwater-Risk (l/ug/m²/day)



NYS Bou



> 0.081



0.016 - 0.081



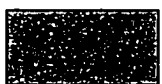
0.0020736 - 0.016



0.0006561 - 0.0020736



0.0001296 - 0.0006561



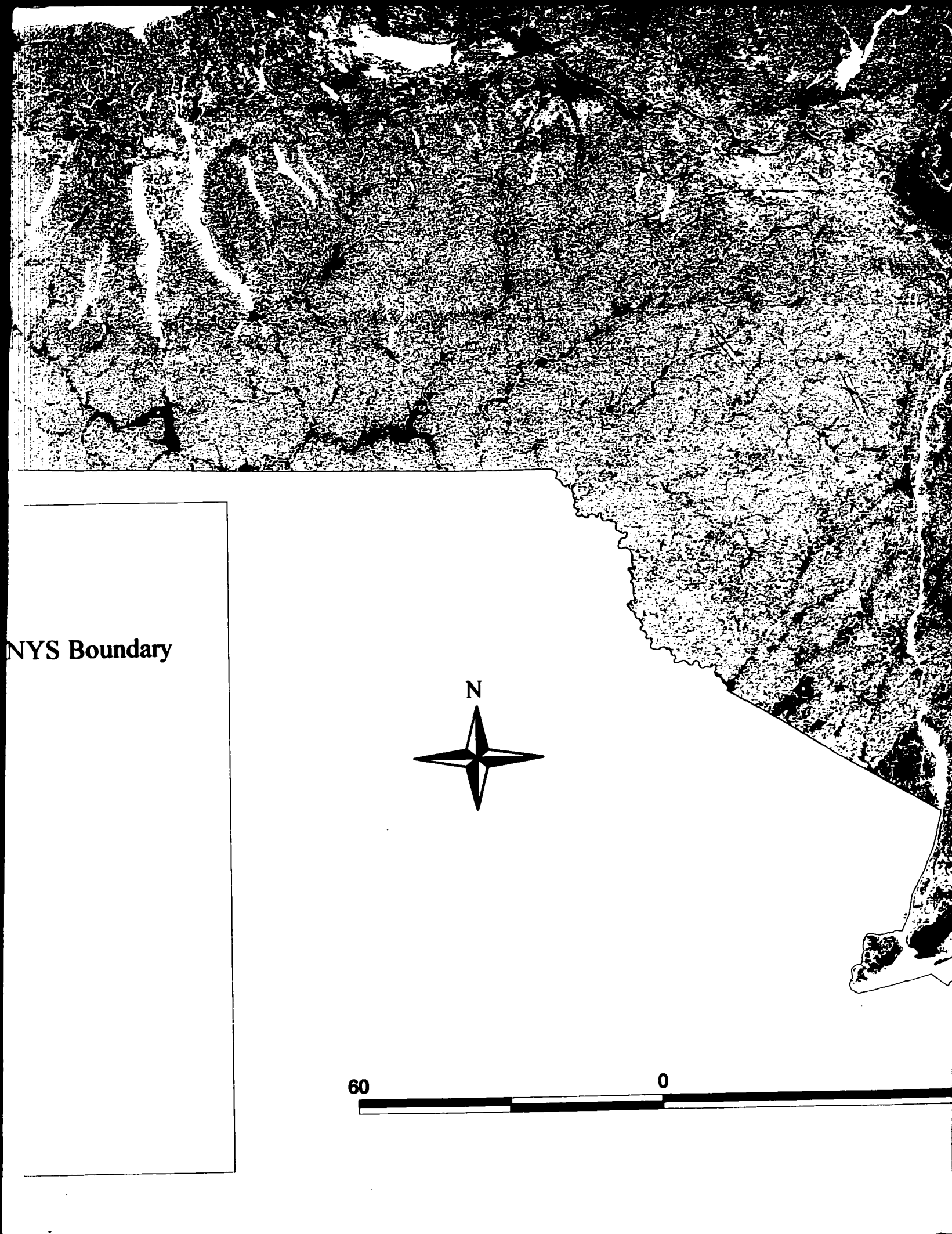
0.0000081 - 0.0001296



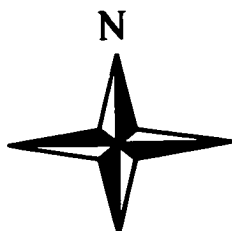
< 0.0000081



No Data

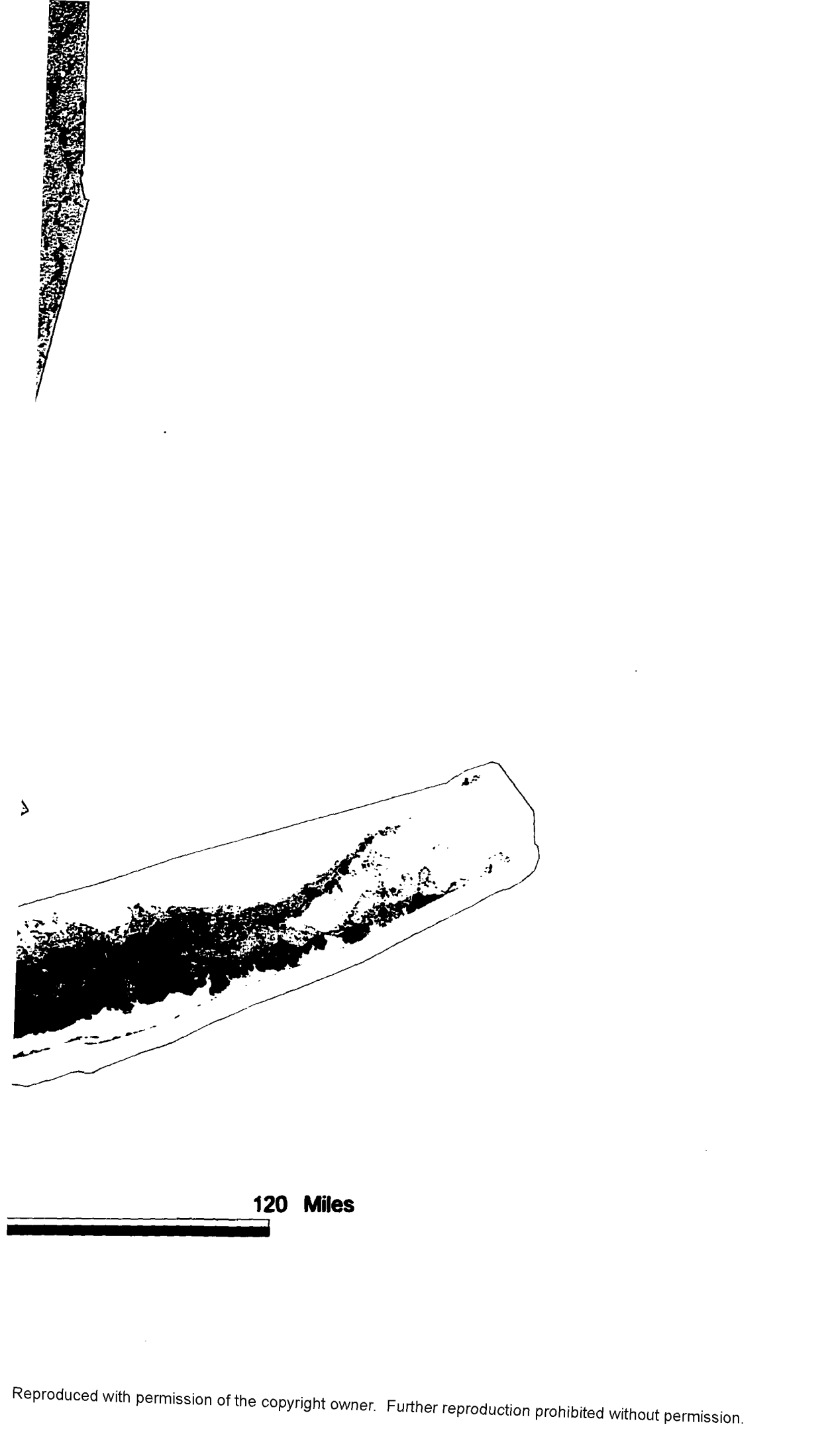


NYS Boundary



60

0



120 Miles