United States
Environmental Protection
Agency

CERI-87-8

Research and Development

EPA

Ground-Water Monitoring Seminar Series

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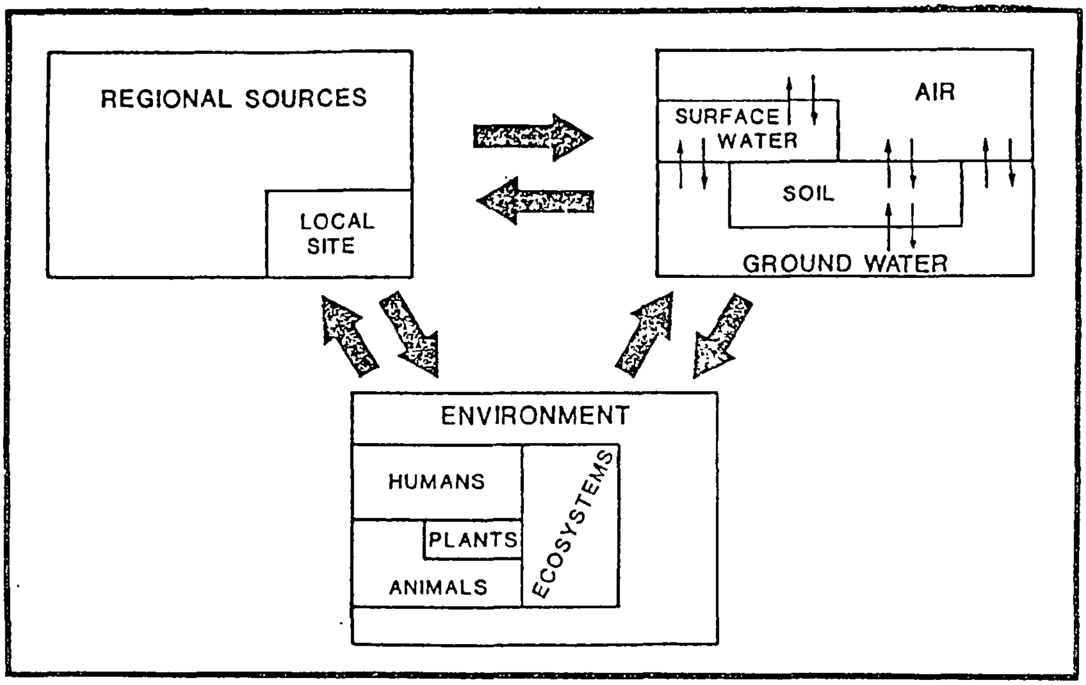
Critical Elements in Site Characterization

Regional and Site Characteristics Affecting Ground-Water Protection Strategies

Universe of Site Characterization



OBJECTIVES

Ground-Water Monitoring

- Detect Leakage
- Assess Contaminant Movement
- Verify Corrective Actions

Site Characterization

- Collect, Analyze, and Assimilate Data
- Develop Reliable Understanding of Hydrologic,Chemical and Physical Parameters
- Predict the Performance of GW Monitoring System

DISTINCTIONS AND DEFINITIONS

- Detections *vs.* Assessment Monitoring
- Piezometers *vs.* Wells
- Water Table *vs.*Depth to Water
- Background *vs.* Monitoring Well
- Corrective *vs.* Remedial Actions
- Facility *vs.* Site

KEY QUESTIONS

Where is this?
What am I looking for?
Where do I look?
Is this what I expect?
What is missing?
What else is needed?

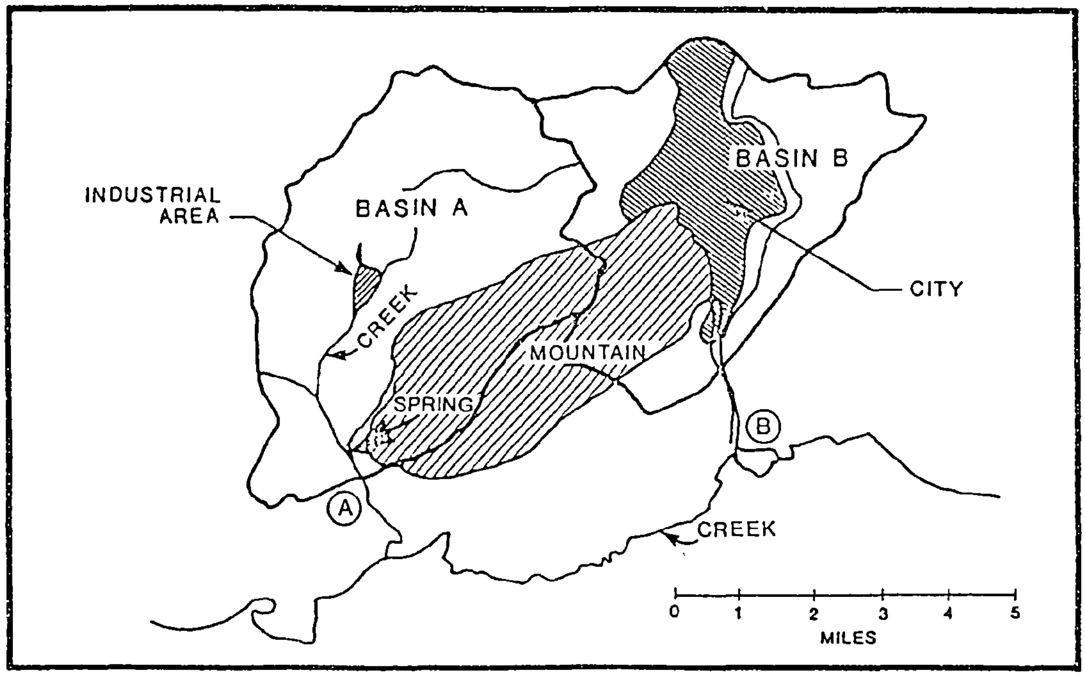
Potential Problem Areas

- Complex Facilities
  - ○ Multiple WMU's
  - ○ Varied Waste Streams
  - ○ Multiple Constituents
  - ○ Past Sins
- Complex Settings
  - ○ Complex Physiography
  - ○ Industrialized Surroundings
  - ○ Sensitive Environments
  - ○ Populous Areas

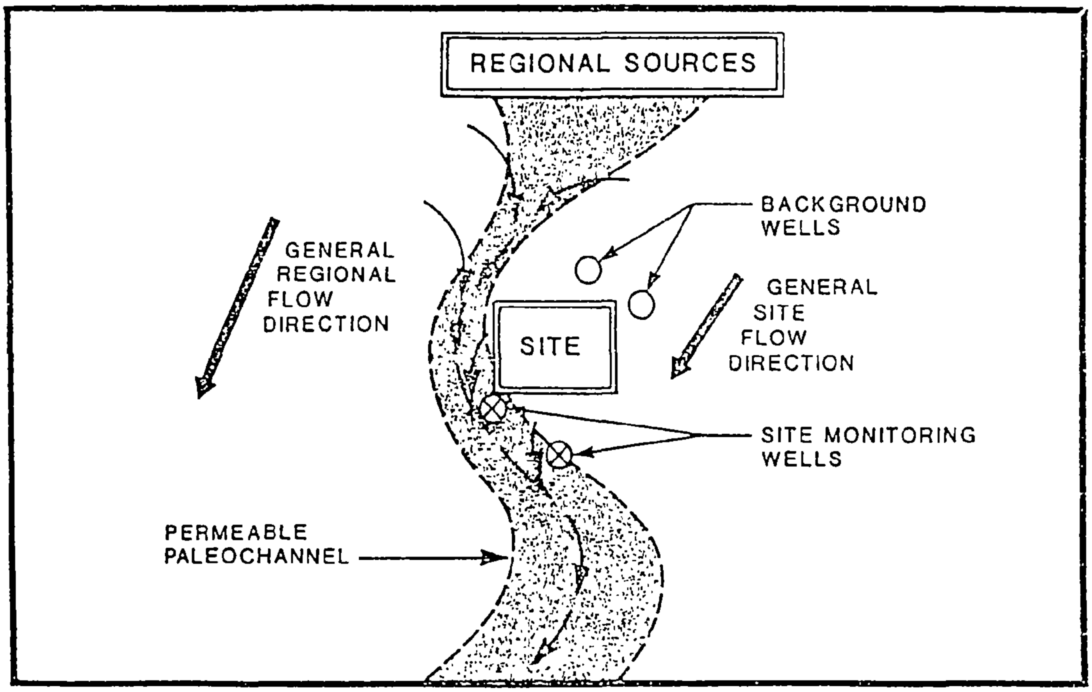
Regional Profiles

- Must Know Level and Time-Variance of Background
- Regional Sources
  - Maps
  - Contamination Contours
  - Both Natural and Man-Made Sources
- Regional Conditions
  - Recharge, Flow and Discharge
  - Natural Features Controlling Flow
  - Man-Made Features Affecting Flow

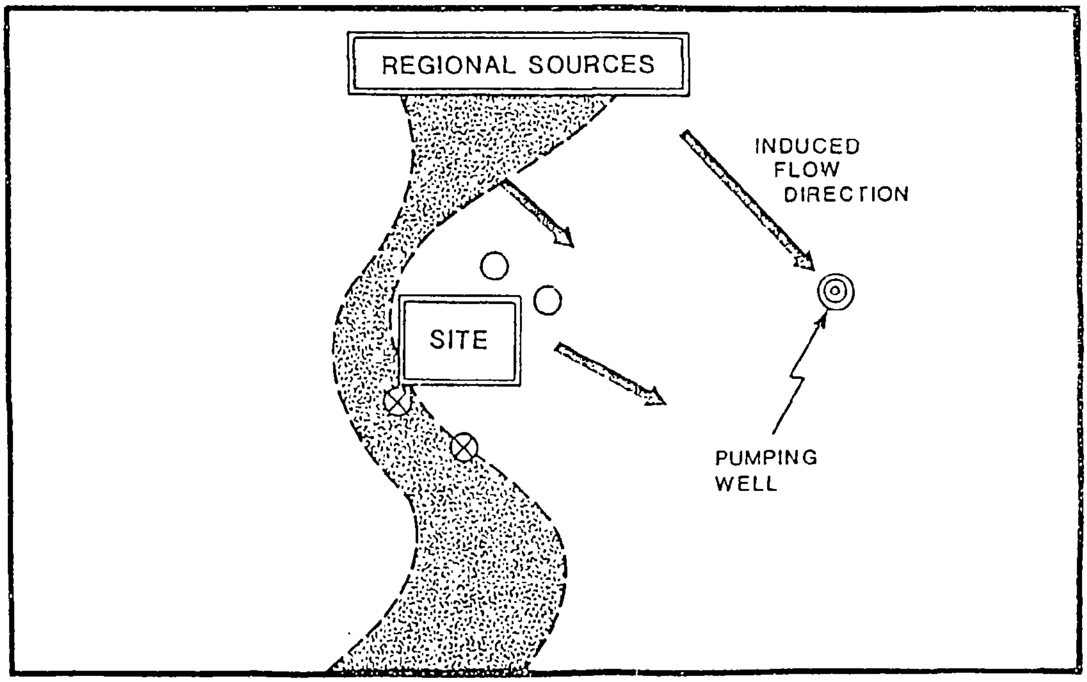
Example of Interconnected Basins



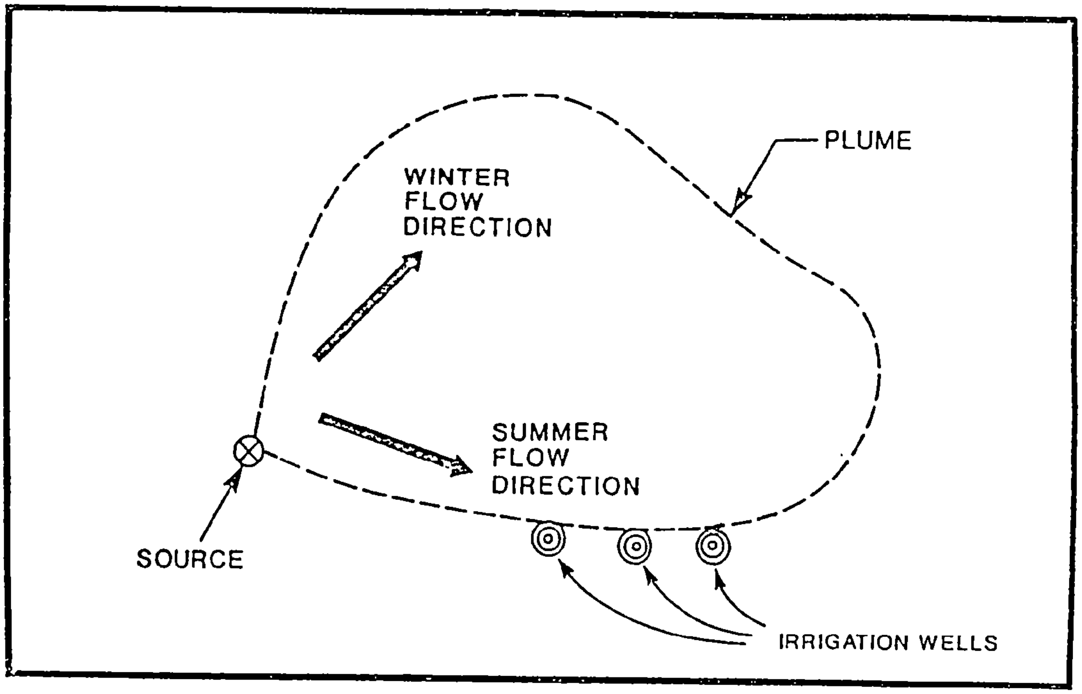
Influences of Regional Sources and Flow-II

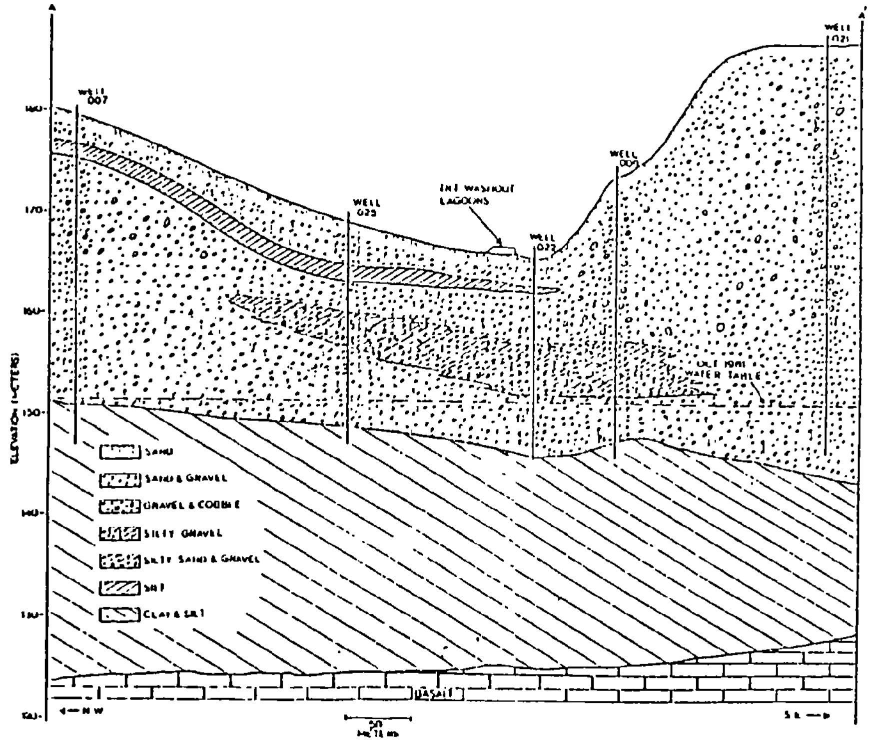


Influences of Regional Sources and Flow-III



Influence of Irrigation Wells in Nebraska
(Simplified)





Hydrogeologic Cross-Section A-A'

WASTE CHARACTERISTICS

Form/Phases

- % solids
- Mixed solvents?
- organic carbon

Composition

- Total, not just indicator parameters
- Normal and upset conditions

Density and Viscosity

Volume and Rate of Generation

Effects of Waste Characteristics

	Release	Transport	Fate
Form	X	X	
Composition	X	X	X
Physical Properties	X	X	
Quantity/Rate	X	X	X

Effects of Facility Characteristics

	Release	Transport	Fate
WMU Design	X	X	
Geohydrology	X	X	X
Siting	X	X	X
Site Complexity		X	X
Past Activities		X	X
Corrective Actions	X	X	X

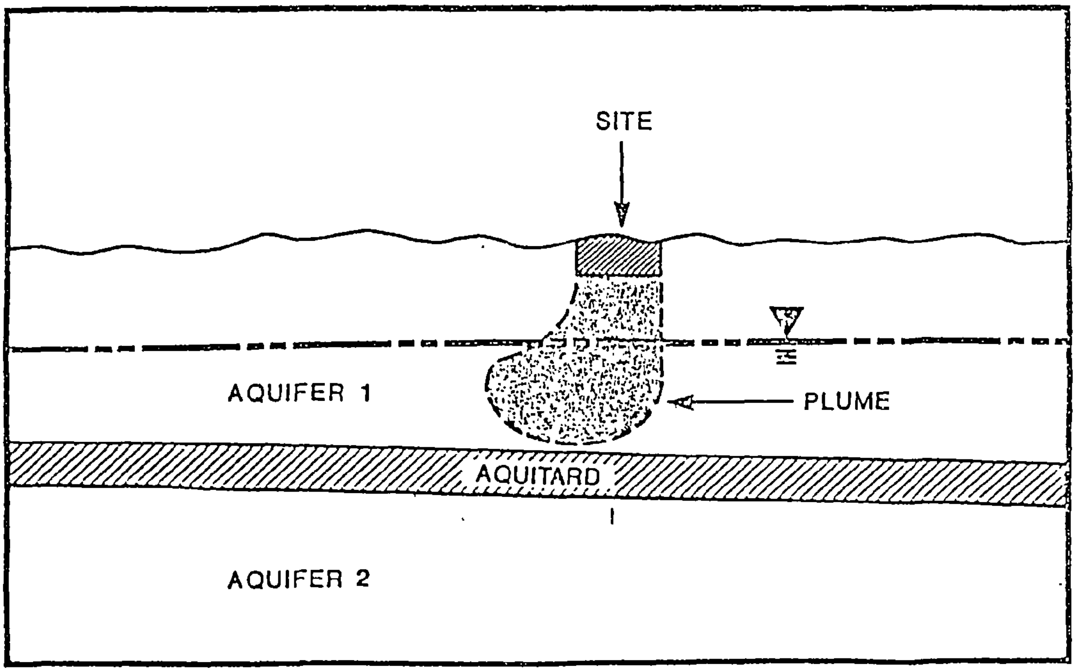
Summary of Data Needs

- Source, Facility and Site Characteristics
- Geologic Structure
- Hydrologic Information
- Other Data (Geochemical, Atmospheric, Meteorological, Environmental)

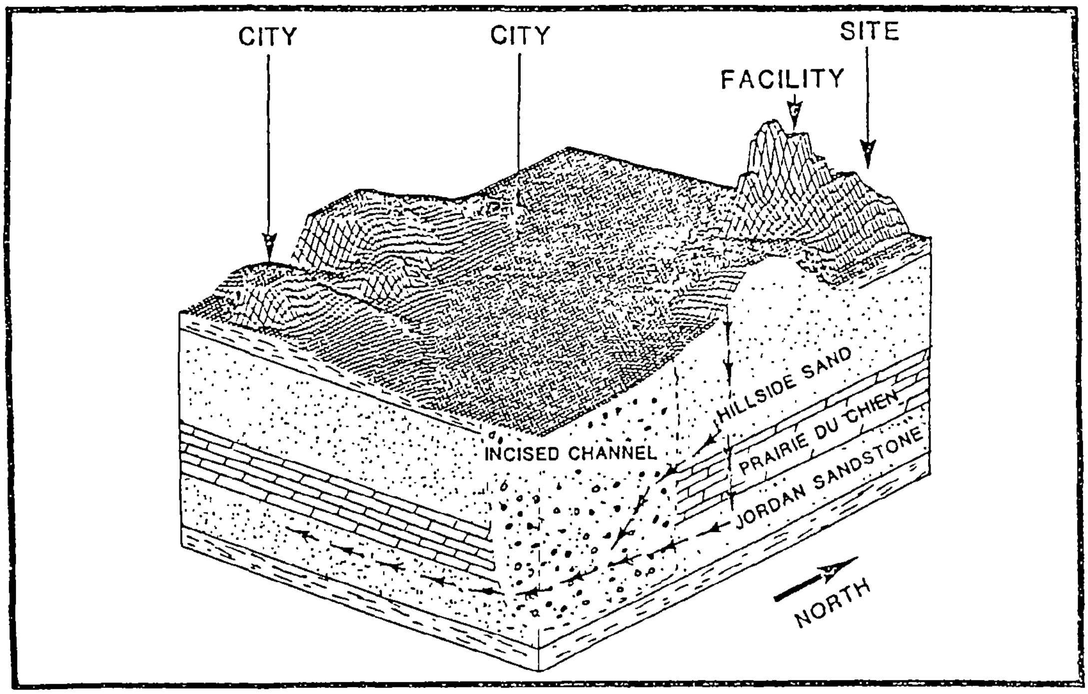
Data Interpretation

- Qualitative: Conceptual Models
  - Initial – Guides Investigations
  - Final – Summarizes Data
- Qualitative: Mathematics
  - Calculations/Graphs
  - Geostatistics
  - Mathematical Modeling

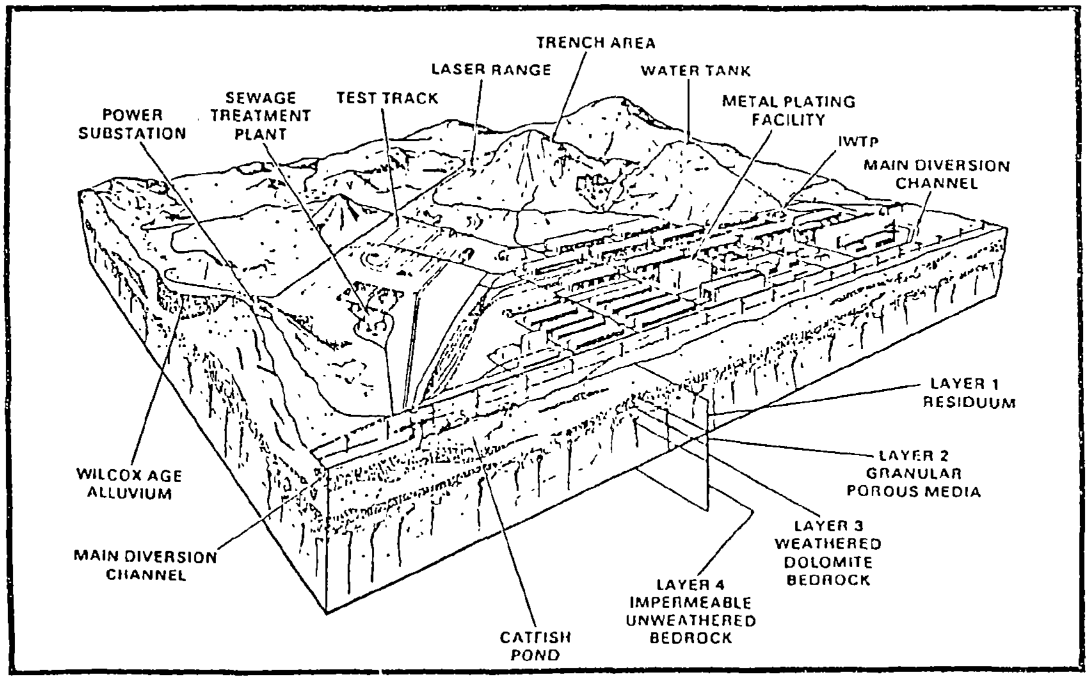
Simple Conceptual Model

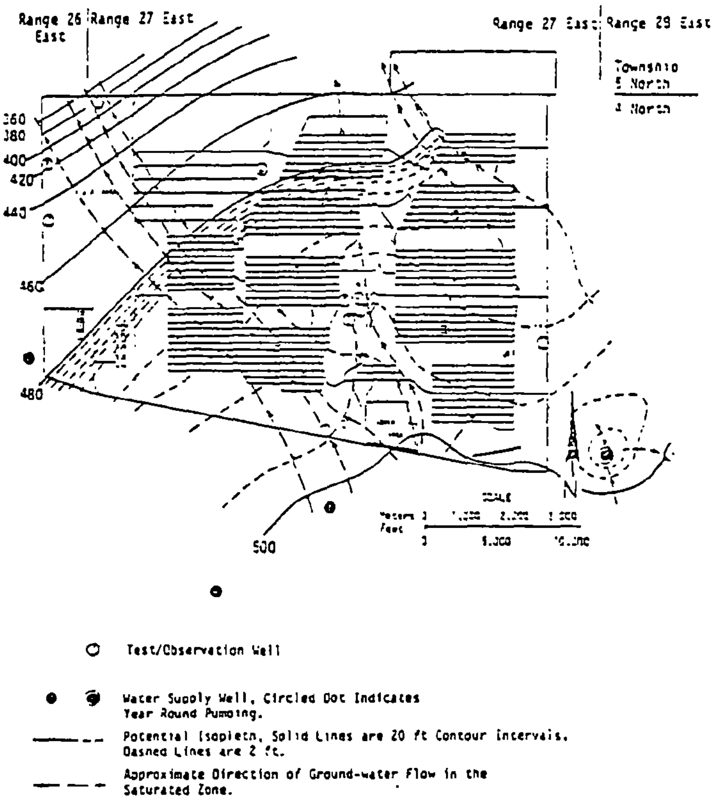


Complex Conceptual Model



Conceptual Model of a Complex Site





Semi-Quantitative Flow-Net of the Alluvial Aquifer

CERTAINTY OF A CONCEPT

m – Number of unique supporting observations

n – Number of subjective suppositions

I – Probability index

$$I = 100\,(1 - 0.5^{m/n})$$

for I = 90%, m/n must be greater than 3

for I = 99%, m/n must be greater than 7

KRIGING ESTIMATORS

UNBIASED -- THE EXPECTED OR AVERAGE ERROR IS ZERO

MINIMUM VARIANCE -- THE MAGNITUDE OF ERROR IS SMALL

EXACT INTERPOLATOR -- KRIGING ESTIMATES AGREE EXACTLY WITH MEASURED DATA; UNLIKE LEAST-SQUARES REGRESSION

KRIGING IS USEFUL FOR:

OBJECTIVELY IDENTIFYING THE NEED FOR ADDITIONAL DATA

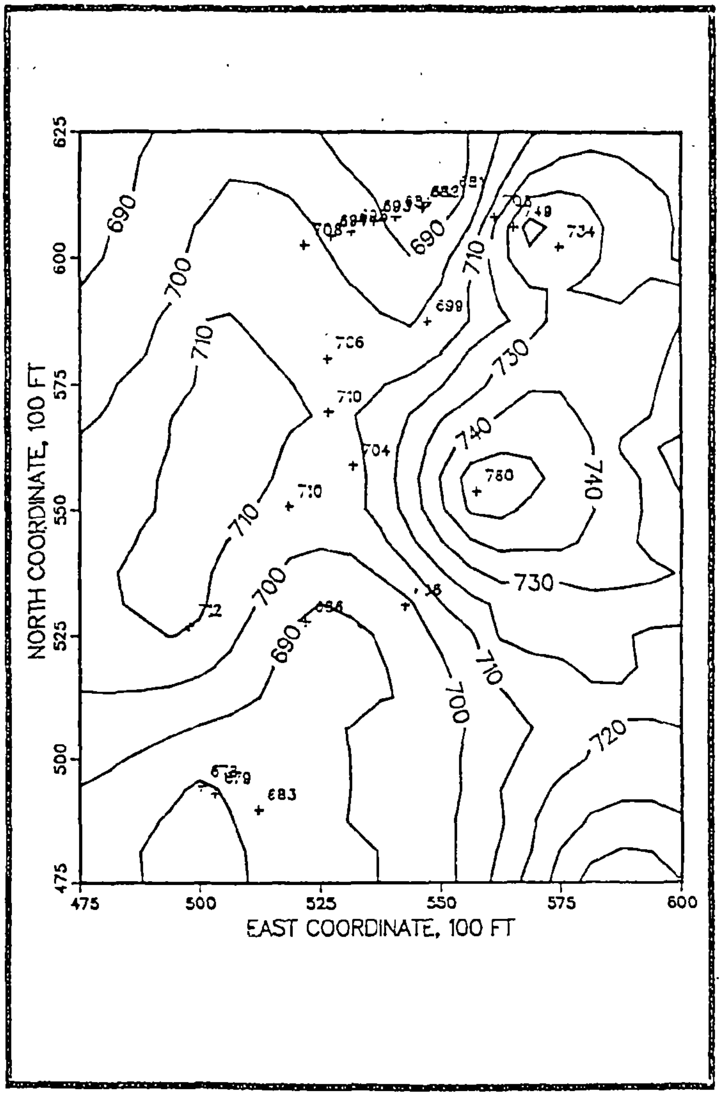
SELECTING NEW WELL LOCATIONS

DETERMINING THE VALUE OF SUBJECTIVE INFERENCES (HAND CONTOURING)

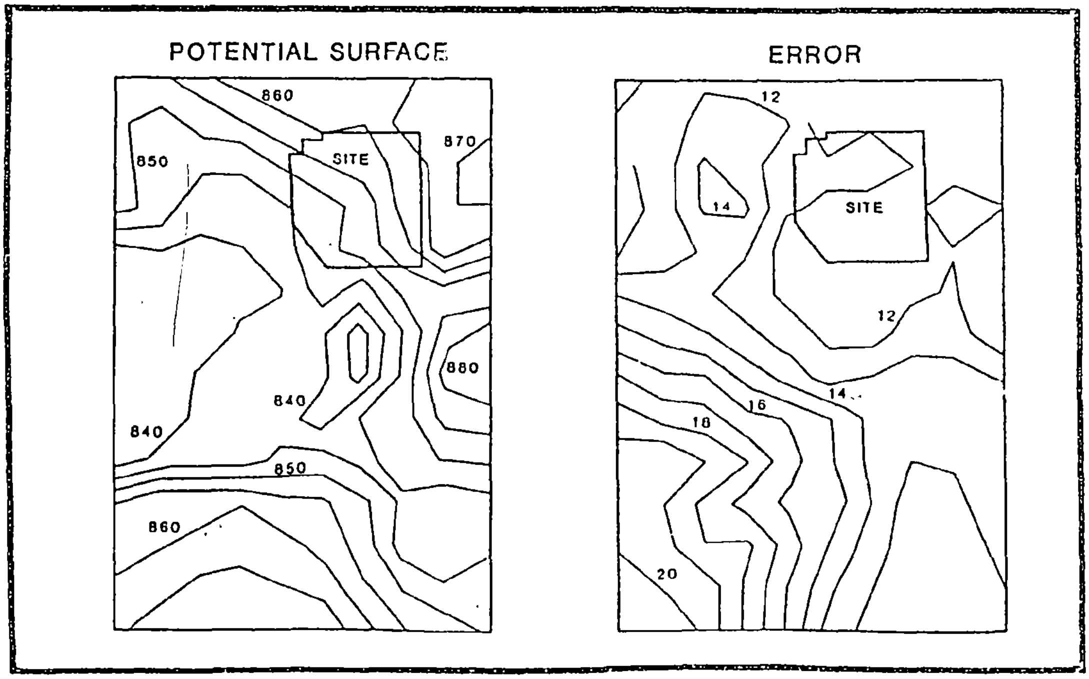
ESTABLISHING DATA VALIDITY

PRODUCING "BEST-FIT" CONTOUR PLOTS FROM IRREGULARLY SPACED DATA

Kriged Potentiometric Surface

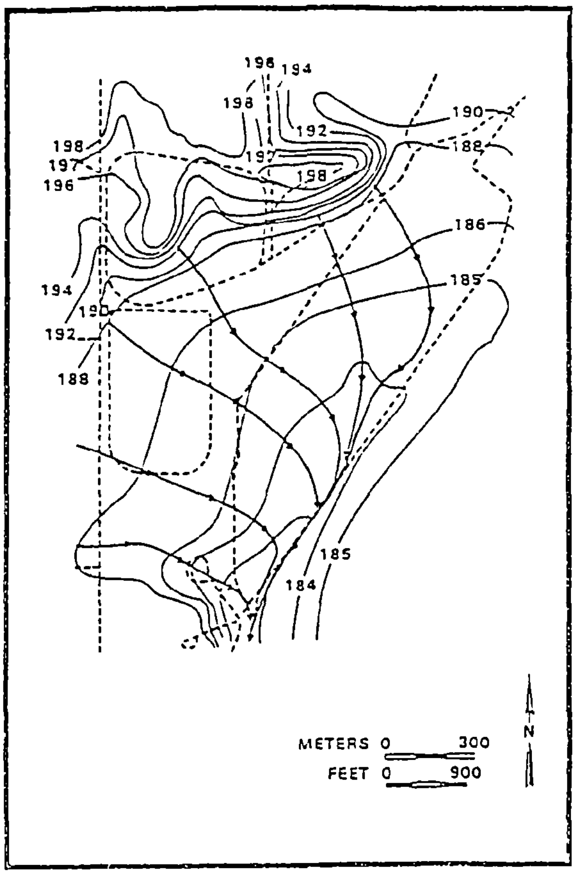


Kriging Outputs

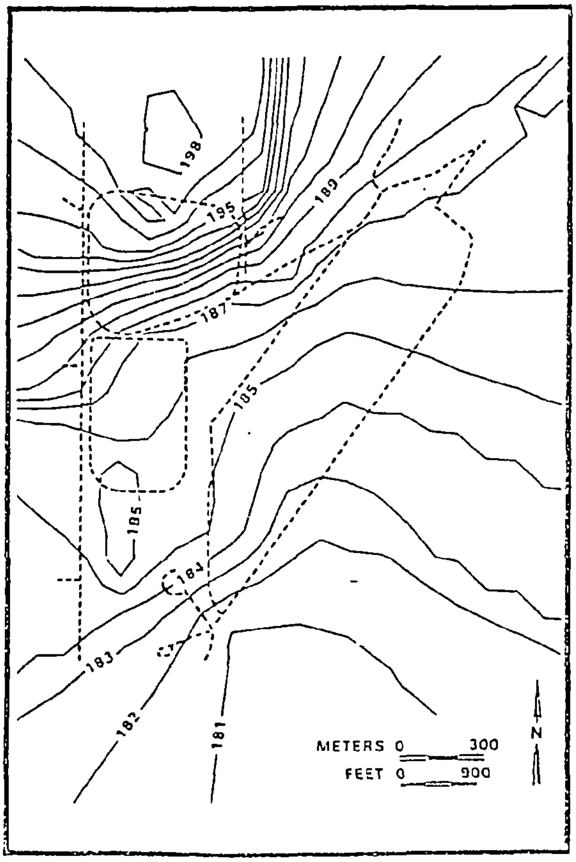

POTENTIAL SURFACE

ERROR

Hand-Drawn Potentiometric Surface



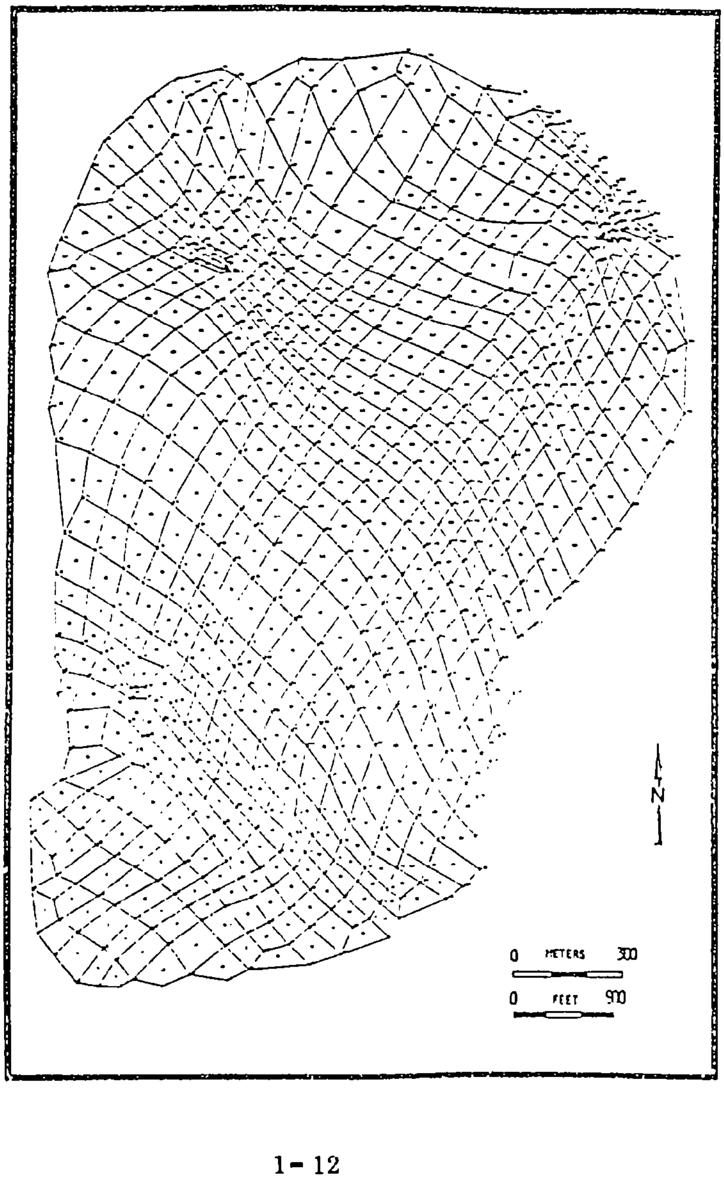
Kriged Potentiometric Surface



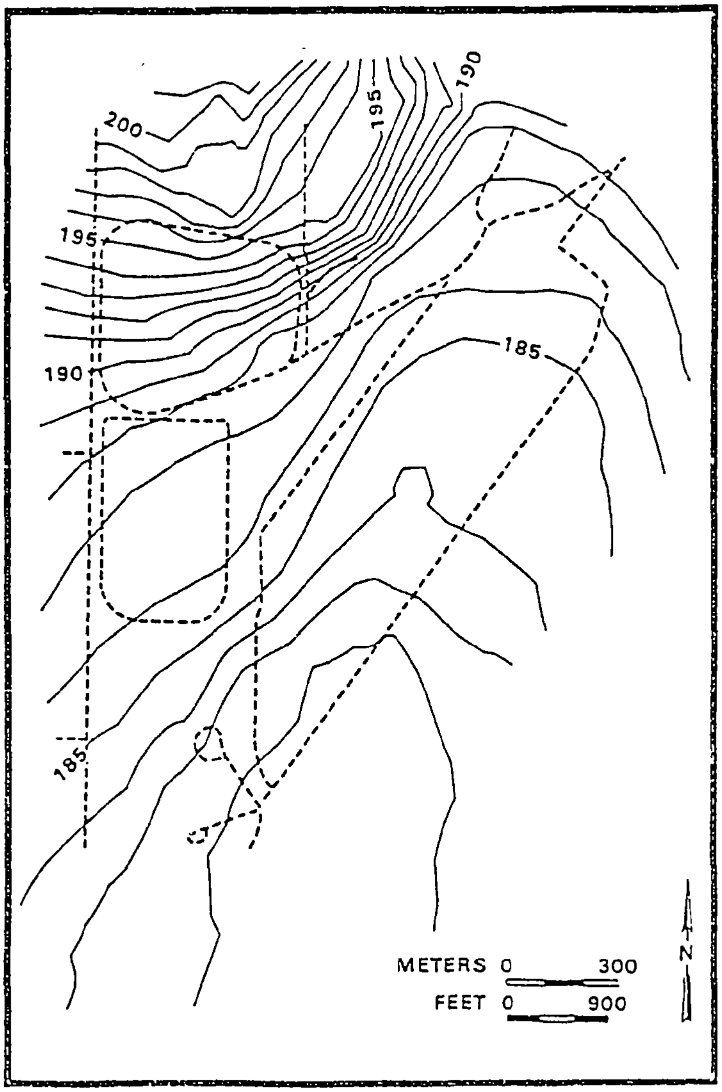
FLOW MODEL DEVELOPMENT AND CALIBRATION
    - POTENTIAL
    - BOUNDARY CONDITIONS
    - STRUCTURE
    - STRESS
    - POROSITY
    - PERMEABILITY

TRANSPORT MODEL DEVELOPMENT AND CALIBRATION
    - DISPOSAL HISTORY AND AMOUNTS
    - DISPERSION (LONGITUDINAL AND TRANSVERSE)
    - RETARDATION FACTOR
    - DEGRADATION
    - VOLATILIZATION

Finite Element Model Grid



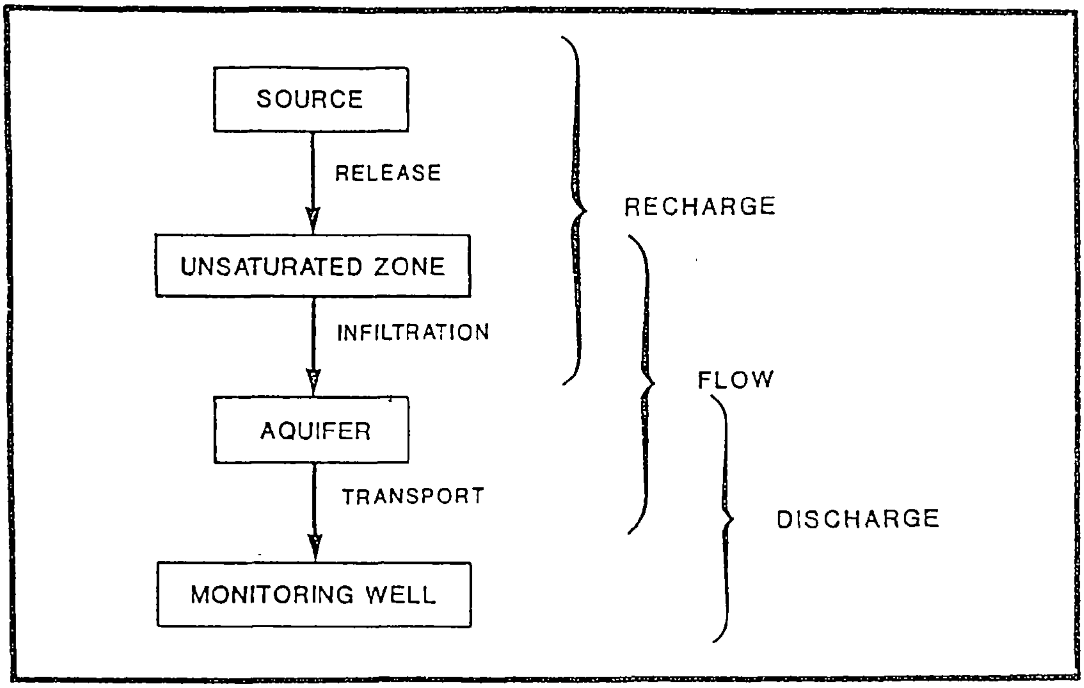
Model-Predicted Potentiometric Surface



Critical Elements in Site Characterization

Hydrogeologic Settings, Subsurface Hydraulics,
and Ground-Water Quality Impacts

Flow and Transport Characteristics



Hydrogeologic Settings

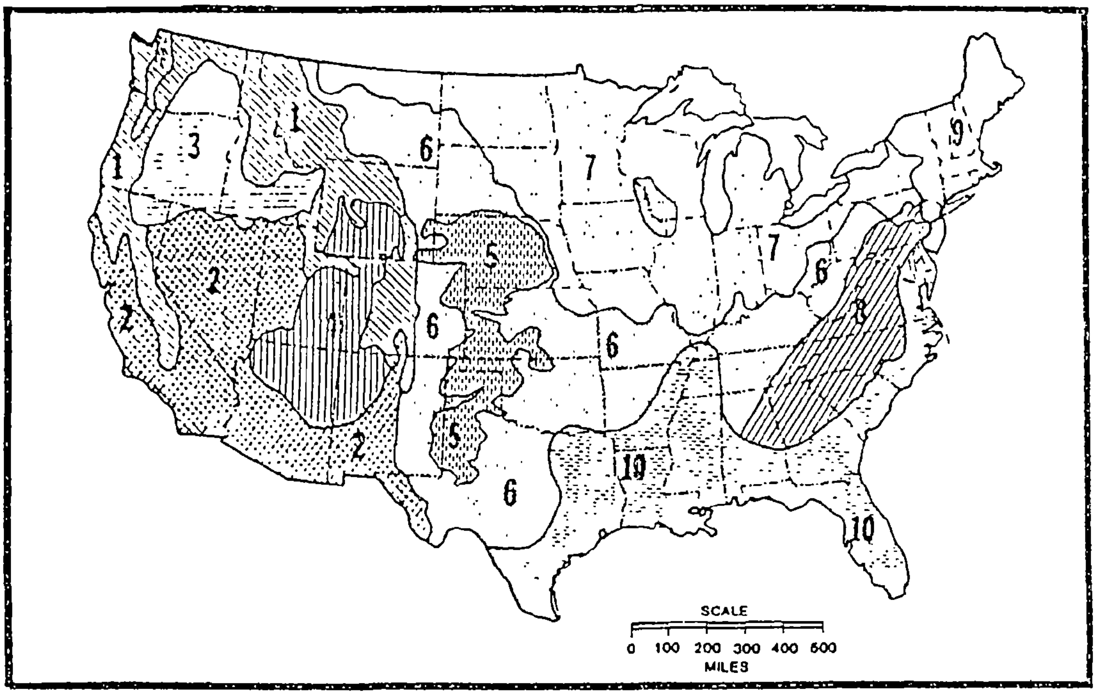
- Has Common Hydrogeologic Characteristics
- Useful in Developing Initial Conceptual Model
- Factors
  - Geologic Fabric
  - Recharge
  - Discharge
  - Topography
  - Depth to Ground Water
- Natural Ground-Water Constituents
  - Inorganics
  - Organics
  - Gases

HYDROGEOLOGIC SETTINGS

Considerations

- Depositional Enviroments: Permeability
- Aquifer Interconnection: Recharge/Discharge
- Depth to Ground Water: Time of Travel
- Unsaturated media: Sorption

Principal Groundwater Regions in the U.S.

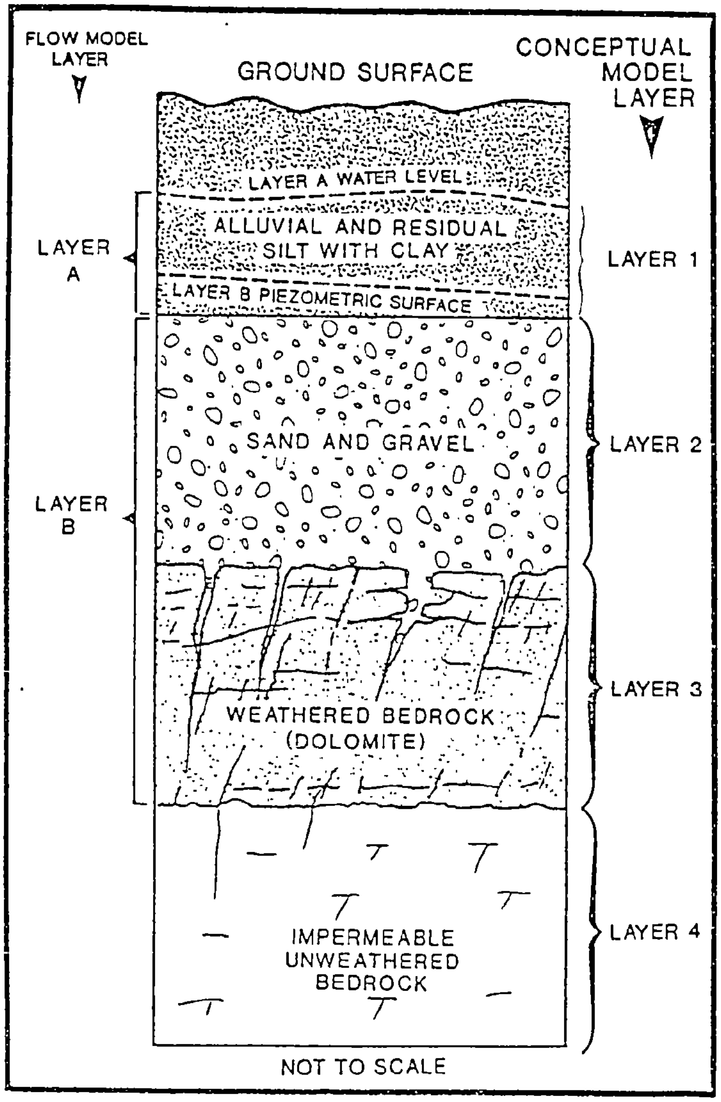


Ranges of DRASTIC Parameters for Piedmont and Blue Ridge Region

	Min	Max
Depth to Water Table, ft	5	100+
Net Recharge, in/yr	0	10
Topography, %	2	18+
Hydraulic Conductivity, GPD/ft ^{2}	1	2,000

Soil Media	Absent, Loam, Clay Loam, Sandy Loam
Aquifer Media	Metamorphic/Igneous; Sand and Gravel; Thin Bedded SS, LS, SH; Weathered Metamorphic/Igneous

Typical Piedmont Flow System



Basic Flow Equations

$$V = K\Delta h/\Delta x$$

$$v = \frac{K}{n_e} \frac{\Delta h}{\Delta x}$$

$$v = \frac{kdg}{un_e} \frac{\Delta h}{\Delta x}$$

$$K = f(\text{water, formation})$$

$$k = f(\text{formation})$$

FLOW DIRECTION

LOCAL FLOW DIRECTION = f (local gradient)

GROSS FLOW DIRECTION = $K \Sigma$ (local gradient)
= $K \int$ (local flow gradients)

UNCERTAINTIES DUE TO:

- TIME INEQUIVALENCE
- MEASUREMENT ERROR
- SPATIAL INEQUIVALENCE

SPATIAL CONSIDERATIONS

HYDROSTRATIGRAPHIC EQUIVALENCE BASED ON:

GEOLOGIC FABRIC (STRUCTURES, STRATIGRAPHY)

HYDROLOGIC CHARACTERISTICS (MEAN VALUES, HETEROGENEITY AND ANISOTROPY OF HYDROLOGIC PARAMETERS)

HYDROCHEMICAL EQUIVALENCE BASED ON:

PROPERTIES OF THE FLOW SYSTEM (HYDROSTRATIGRAPHY, RECHARGE, VELOCITY, DIFFUSION, AND DISPERSION)

CONTAMINANT CHARACTERISTICS (DENSITY, SOLUBILITY, VISCOSITY, CONCENTRATION, CHEMICAL PROPERTIES)

TEMPORAL CONSIDERATIONS

GROUND-WATER RECHARGE

GROUND-WATER WITHDRAWAL (DISCHARGE)

PERCHING

FLOW RATE

FLOW RATE = f (permeability, porosity, gradient)

UNCERTAINTY IN GRADIENT AS BEFORE

UNCERTAINTY IN POROSITY IS SMALL

UNCERTAINTY IN FLOW RATE = f (uncertainty in permeability)

FIELD PERMEABILITY ≠ LAB PERMEABILITY
(Samples and Procedures not representative)

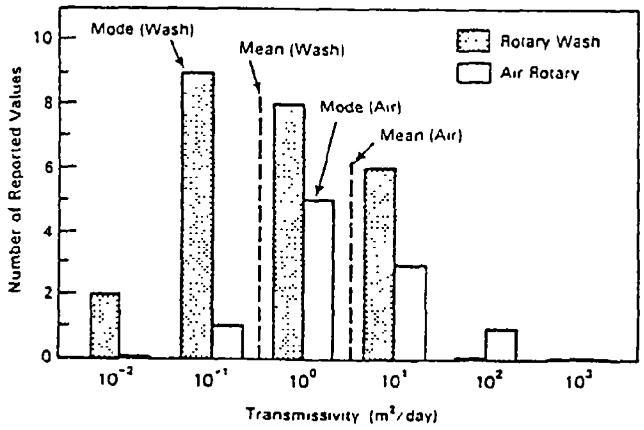
Factors Affecting Conductivity Measurements

Medium	*Factor*	*Measured in Lab?*
Soil	Fractures, Desiccation	No
	Sand Stringers	No
	Sample Integrity	No
Aquifer	Fractures, Solution Cavities	?
	Vertical Component	Yes
	Horizontal Component	No
	Sample Integrity	?

Aquifer Hydraulic Conductivity Variations

Generic Classification	Data Range in Orders of Magnitude	Mean Value, cm/s
Fractured crystalline silicates	3.0	1.53×10^{-3}
Fractured-solutioned carbonates	4.0	6.42×10^{-2}
Porous consolidated carbonates	4.6	1.16×10^{-2}
Porous consolidated silicates	3.0	1.79×10^{-3}
Porous unconsolidated silicates	5.9	5.55×10^{-2}
Fractured consolidated silicates-shale	4.0	2.4×10^{-3}

Transmissivity Distribution for Rotary Wash and Air Drilled Wells



FOUR TRENDS REVEALED BY PUMPING TEST DATA:

SANDS AND GRAVELS HAVE HIGHER TRANSMISSIVITIES THAN FRACTURED BEDROCK, REGARDLESS OF THE DRILLING METHOD

BEDROCK WELLS DRILLED BY ROTARY WASH HAVE LOWER TRANSMISSIVITIES THAN BEDROCK WELLS DRILLED BY AIR ROTARY, REGARDLESS OF THE TYPE OF SCREEN OR SAND PACK

FOUR-INCH DIAMETER MONITOR WELLS HAVE HIGHER TRANSMISSIVITIES THAN TWO=INCH DIAMETER WELLS (ALL DRILLED BY AIR ROTARY)

TRANSMISSIVITIES OF SIX-INCH DIAMETER WELLS WERE LESS THAN FOUR=INCH DIAMETER WELLS

HYDROLOGIC ERROR ROOTS

1. 3-D Well Location
2. Improper Well Construction
    - Diameter
    - Installation Techniques
3. Improper Measurements
    - Length of Well Tests
    - Type of Well Test
4. Improper Interpretation

SAMPLING UNCERTAINTIES

GROUNDWATER
- Inadequate development and purging
- Improper construction
- Fracture flow - chemostratigraphic equivalence
- Domestic and Production Wells
- Improper Sampling Methods
- Preservation and Shipping
  (anaerobic, static) → (aerobic, agitated)

SOILS & SEDIMENTS
- Cross Contamination
- Spikes
- Representativeness

DATA SUSPECTS

CONTAMINANT LEVEL	SUSPECT
HIGH	• IMPROPER SAMPLING • MISSING ANALYTES • CONTAMINATION OF OTHER SAMPLES
LOW	• SAMPLE CONTAMINATION • DEGRADATION • IMPROPER SAMPLING

PERMEABILITY VALUES	SUSPECT
HIGH	• IMPROPER TESTING OR ANALYSIS • MISCONCEPTUALIZATION
LOW	• IMPROPER WELL CONSTRUCTION • LABORATORY MEASUREMENTS

Contaminant Properties Affecting Transport

PROPERTIES AFFECTING FLOW AND TRANSPORT

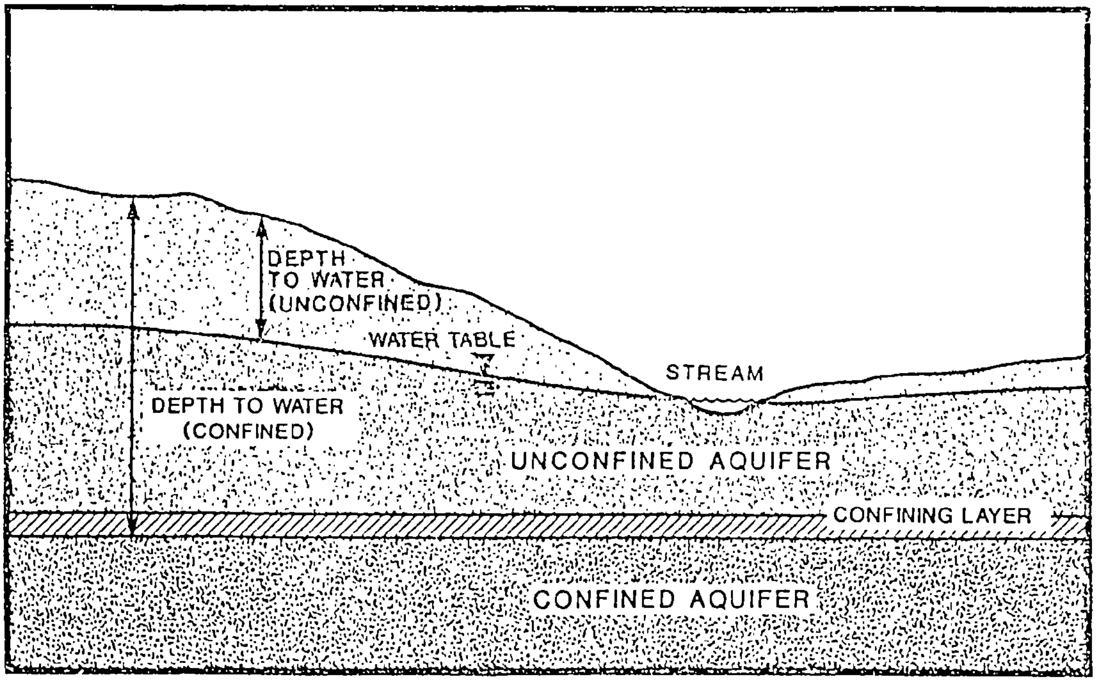
Physical Properties

- Density
- Solubility
- Viscosity
- Surface Tension

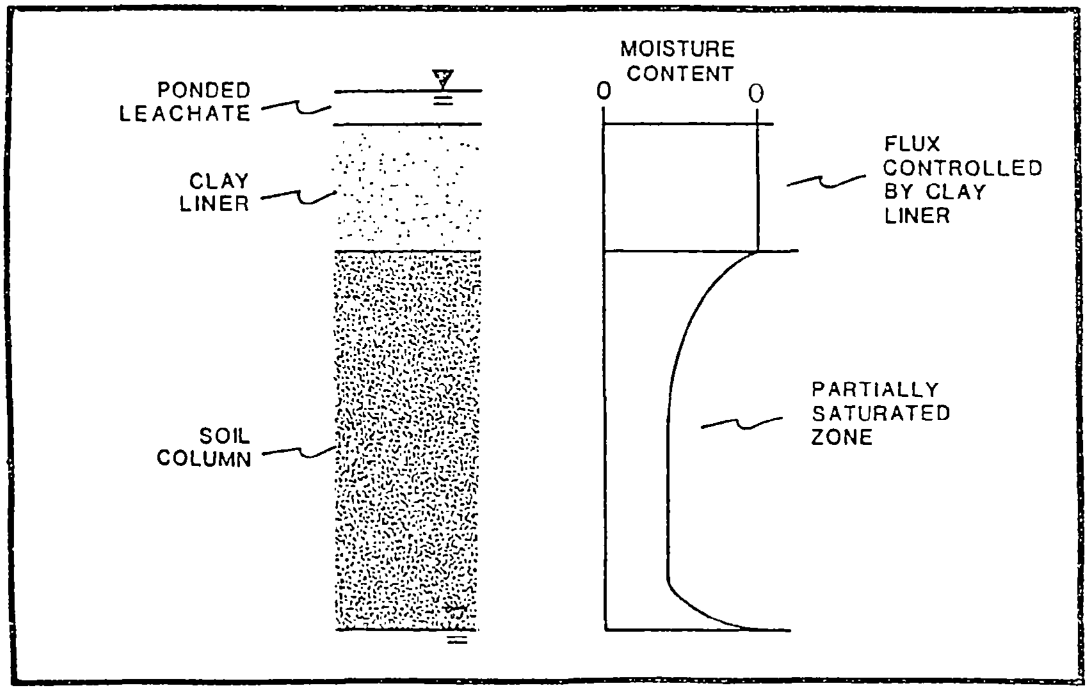
Chemical Properties

- Oxidation-Reduction Behavior
- Sorption/Retardation
- Degradation

Depth to Water in a Confined and Unconfined Aquifer



Infiltration Through Clay Liner and Soil Column



Time of Travel Formulas

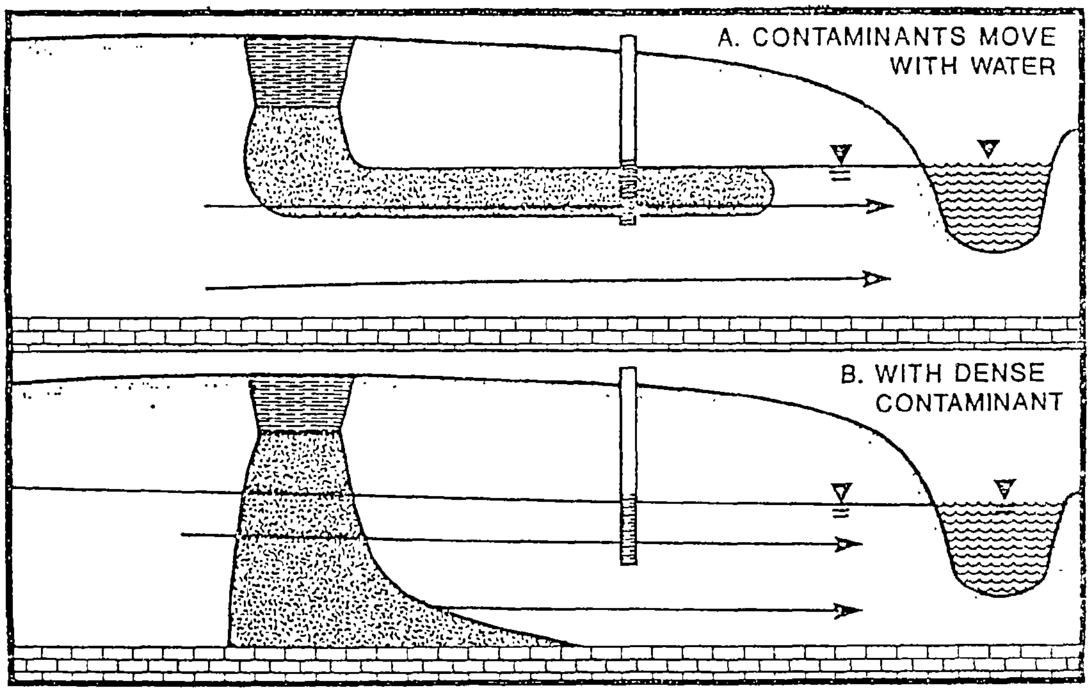
$$T = \frac{L\left(\frac{8}{K_{sat}}\right)^{m}\theta_{sat}}{q}$$

Unsaturated Steady State

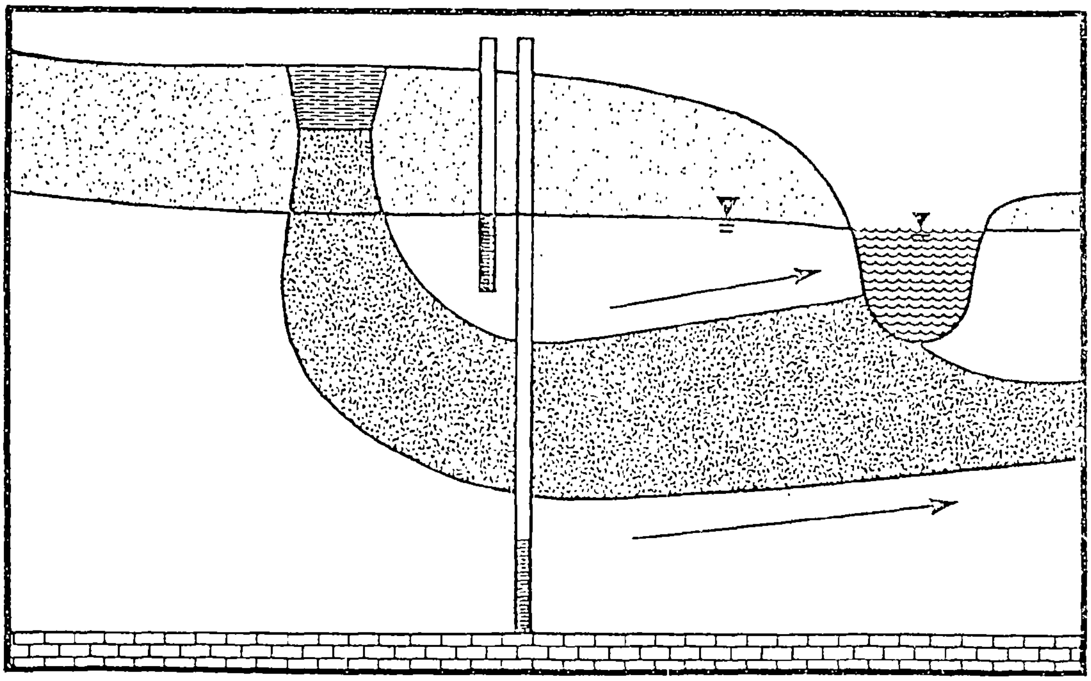
$$T = \frac{L^2\ n_e}{\Delta H\ K_{sat}}$$

Saturated Steady State

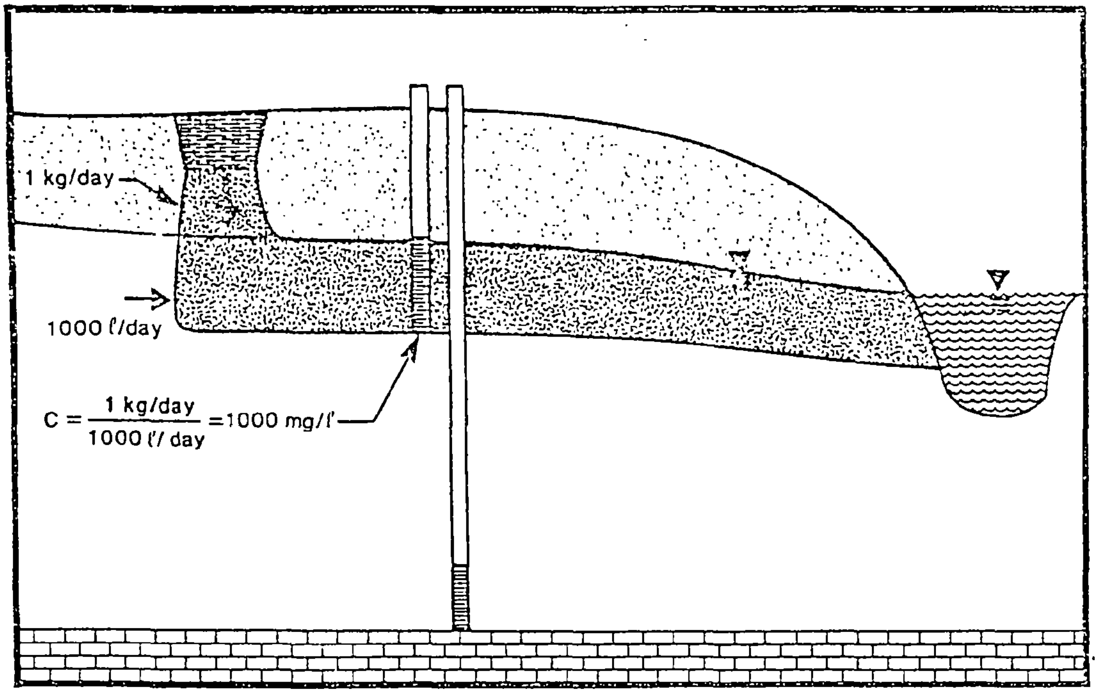
Contaminant Movement in Discharge Area



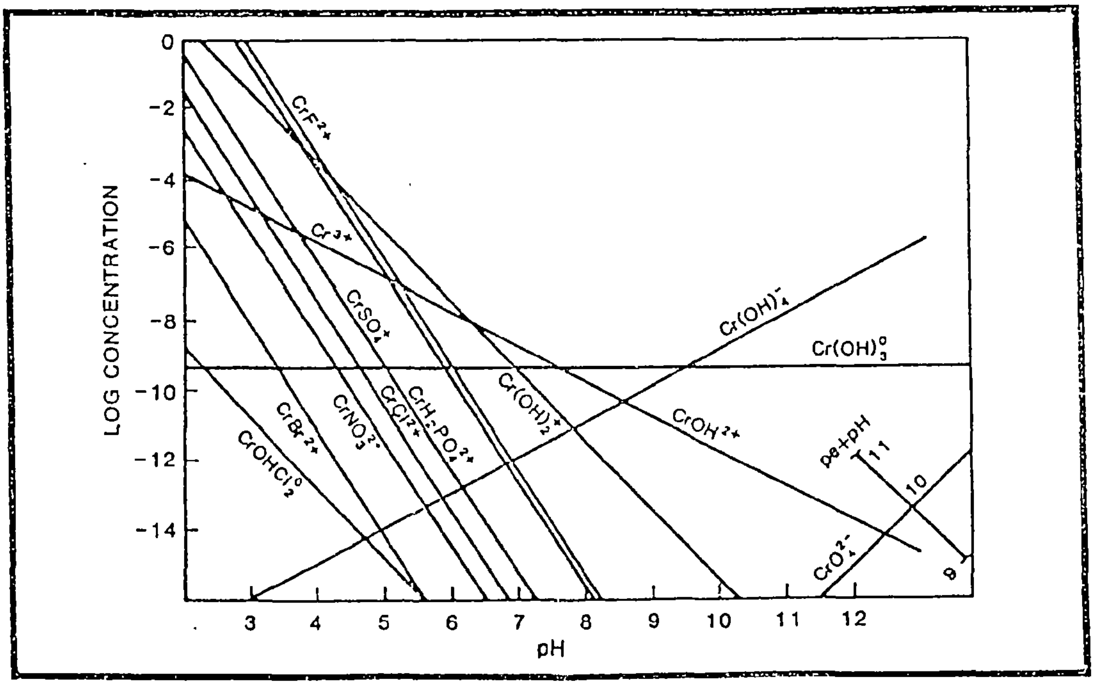
Movement of Dense Soluble Contaminant Plume in Discharge Area



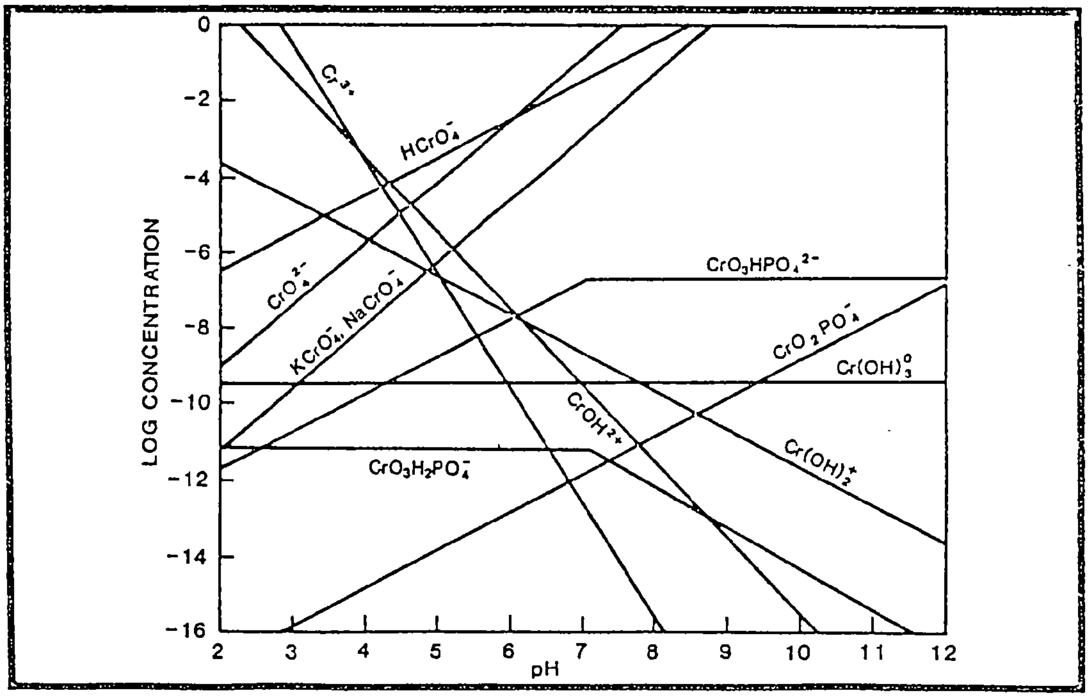
Mixing of Release and Flux to Produce Downgradient Concentration



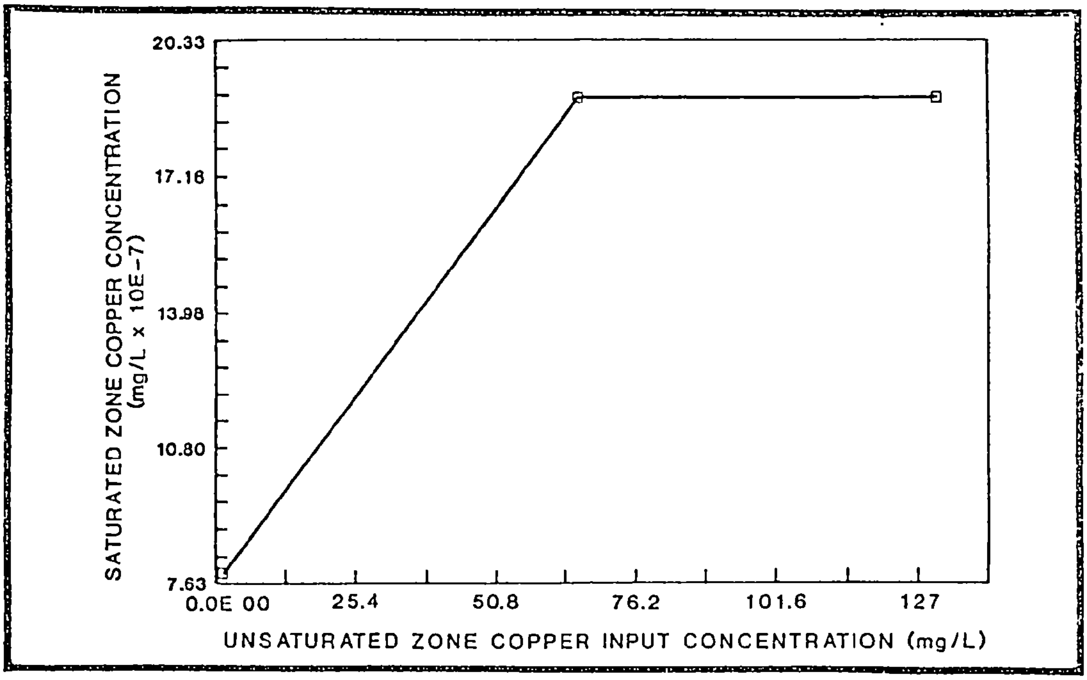
Solubility of Various Chromium Species Under Reducing Conditions



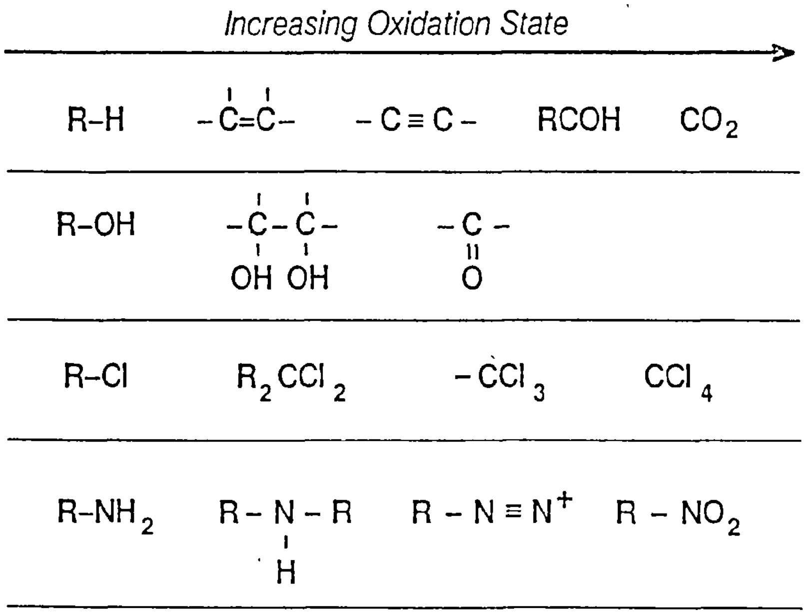
Solubility of Various Chromium Species Under Oxidizing Conditions



Reduction of Copper Concentrations from Unsaturated Zone to Saturated Zone



"Oxidation States" of Functional Groups



$R\text{-}H$	$-\overset{\mid}{C}=\overset{\mid}{C}-$	$-C\equiv C-$	$RCOH$	CO_2
$R\text{-}OH$	$-\underset{OH}{\overset{\mid}{\underset{\mid}{C}}}-\underset{OH}{\overset{\mid}{\underset{\mid}{C}}}-$	$-\underset{O}{\underset{\parallel}{C}}-$		
$R\text{-}Cl$	R_2CCl_2	$-CCl_3$	CCl_4	
$R\text{-}NH_2$	$R-\underset{H}{\underset{\mid}{N}}-R$	$R-N\equiv N^+$	$R-NO_2$	

SORPTION/ATTENUATION

Freundlich Sorption

$$C_S = K_D C_W{}^n$$

Soil Sorption

$$K_{OC} = K_D / f_{OC}$$

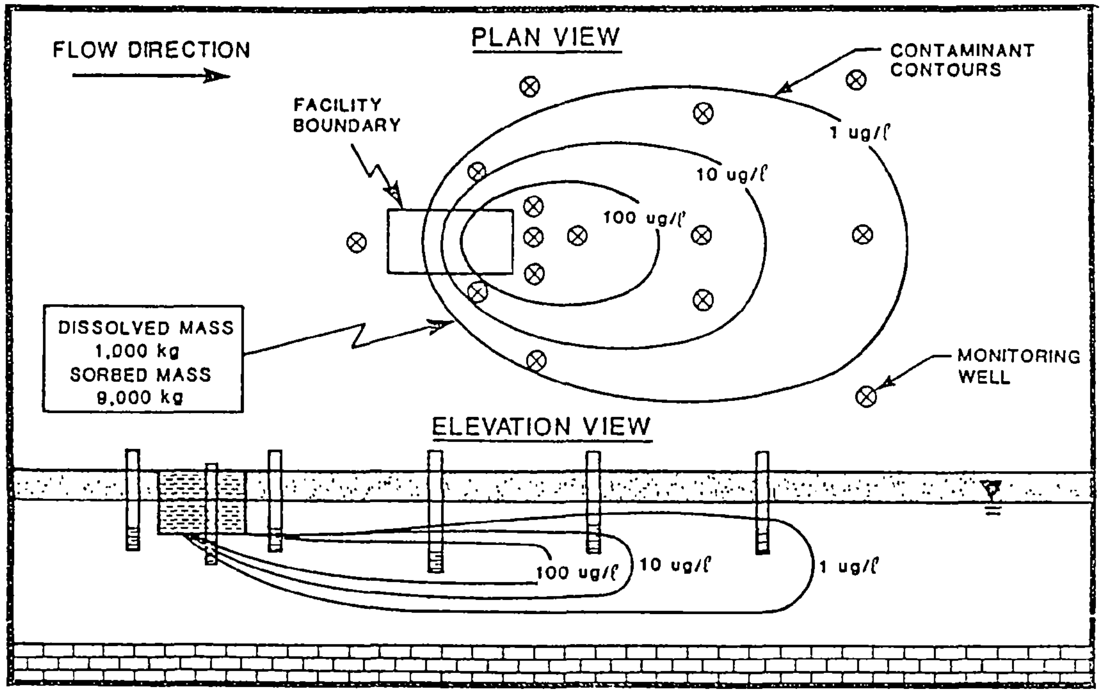
$$C_S = K_{OC} f_{OC} C_W{}^n$$

Retardation Factor

$$R = \frac{V(\text{Water})}{V(\text{contaminant})}$$

$$R = 1 + BK_D / ne$$

Delineation of Contaminant Plume to Calculate Contaminant Mass



Estimating Sorption (Organics)

For Water:

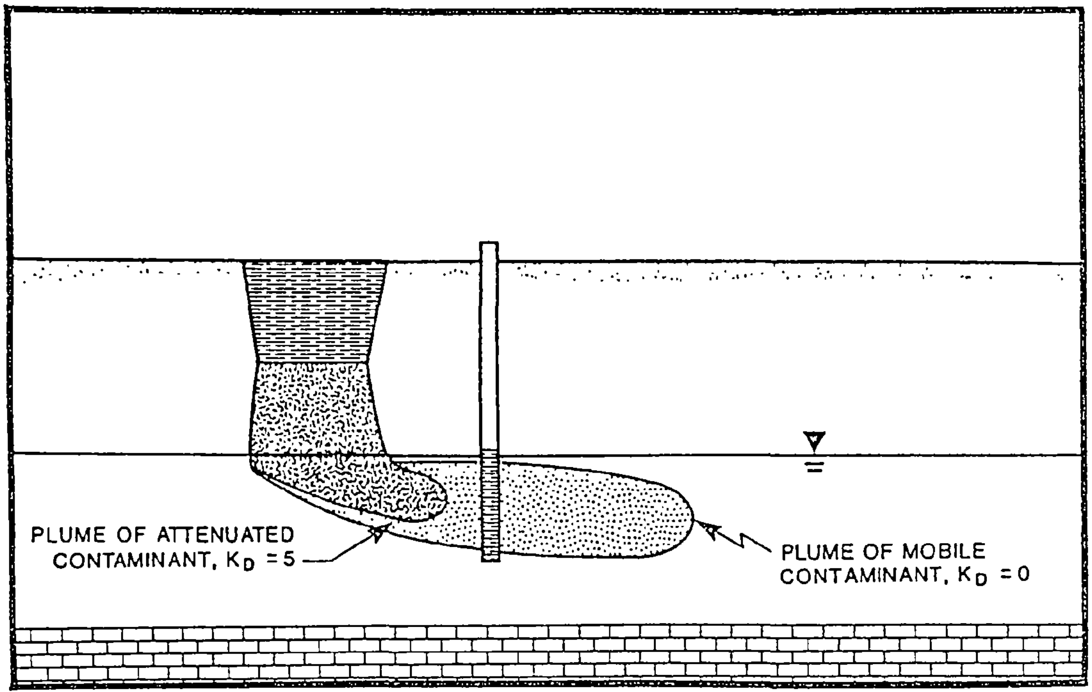
$$\log K_{OC} = -0.55 \log S + 3.64$$

$$\log K_{OC} = 0.937 \log K_{OW} - 0.006$$

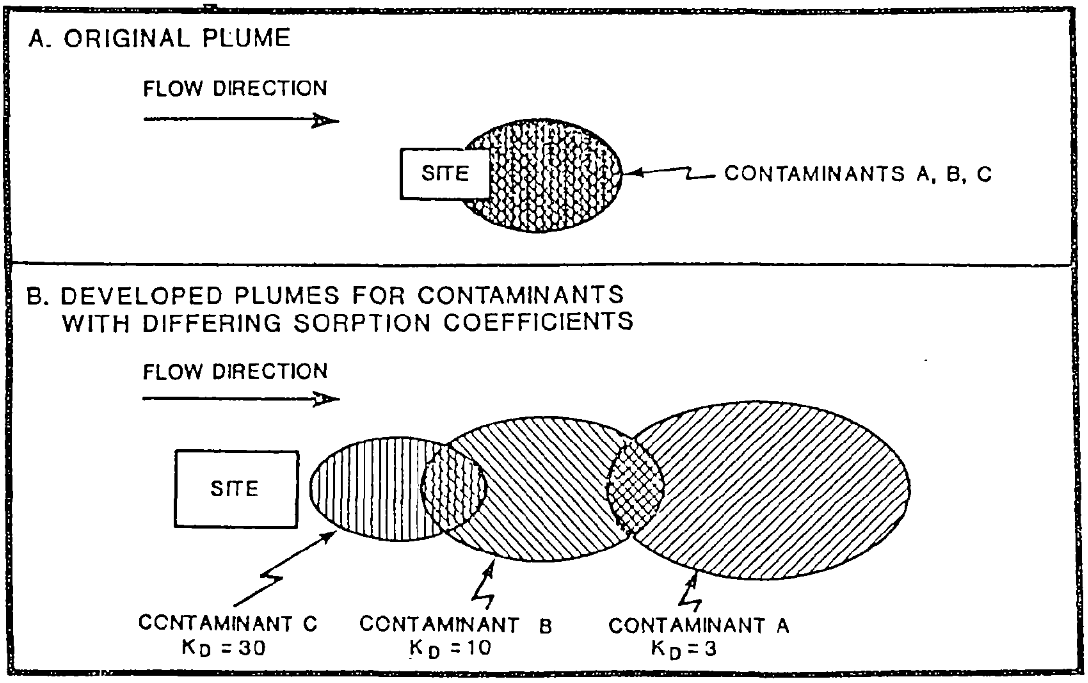
For Oily Wastes:

$$C(\text{Sample}) = S(\text{Water}) \left(1 + f_{OW} K_{OW} \right)$$

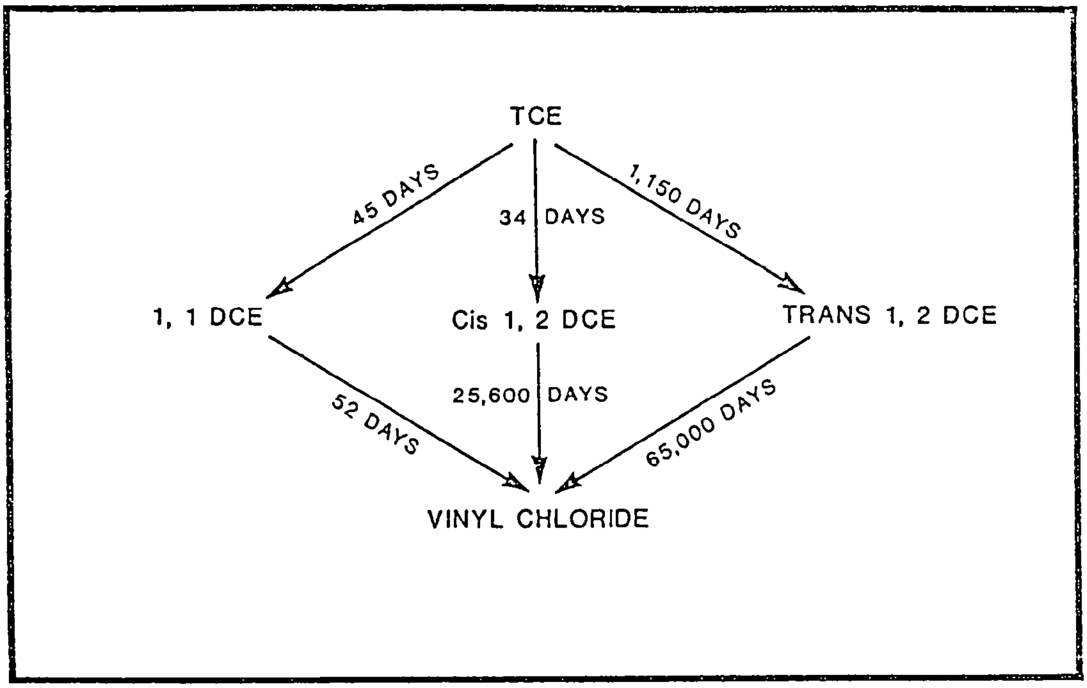
Relative Migration of Plumes of Mobile and Attenuated Contaminants



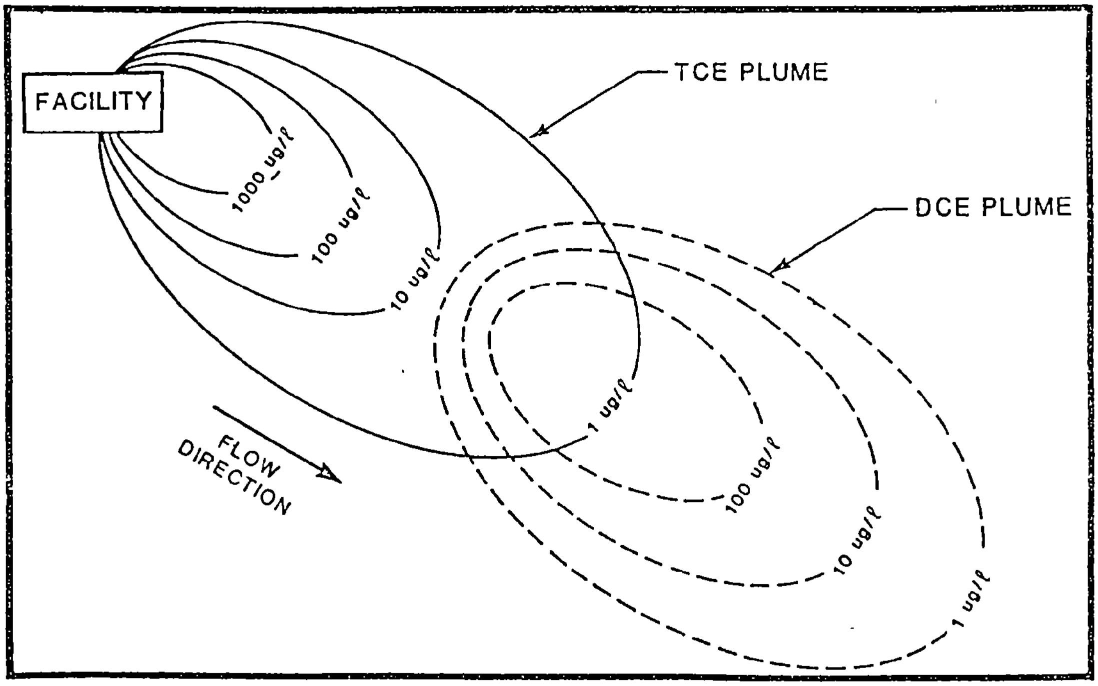
Multiple Contaminant Plumes



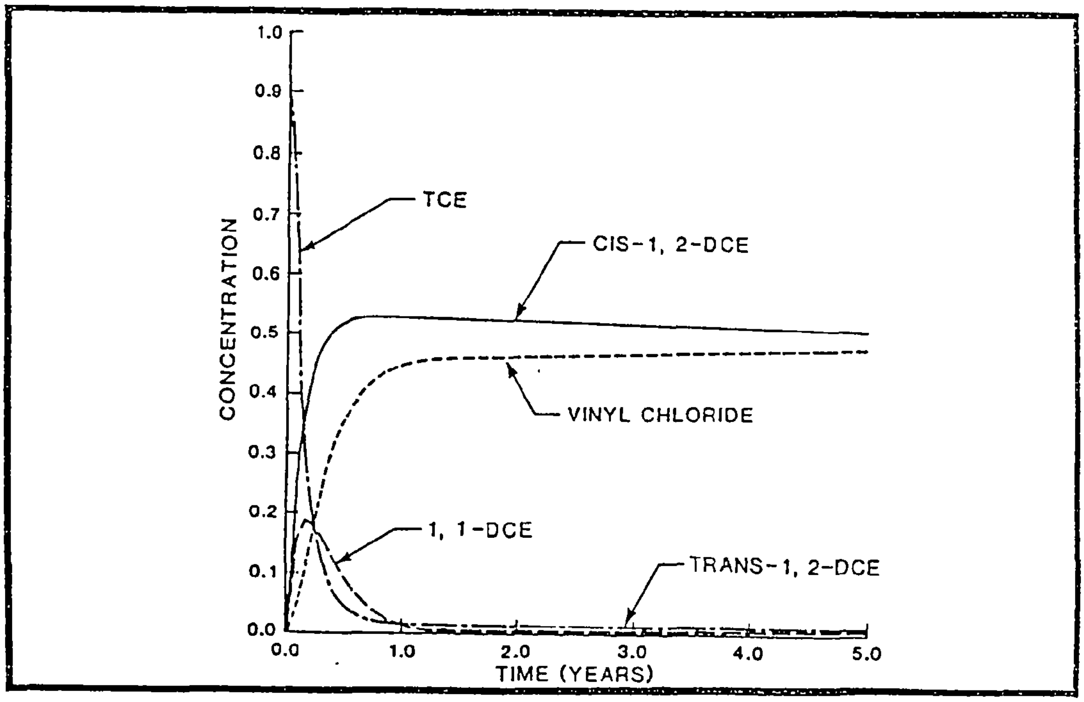
Degradation Reaction of Trichloroethylene



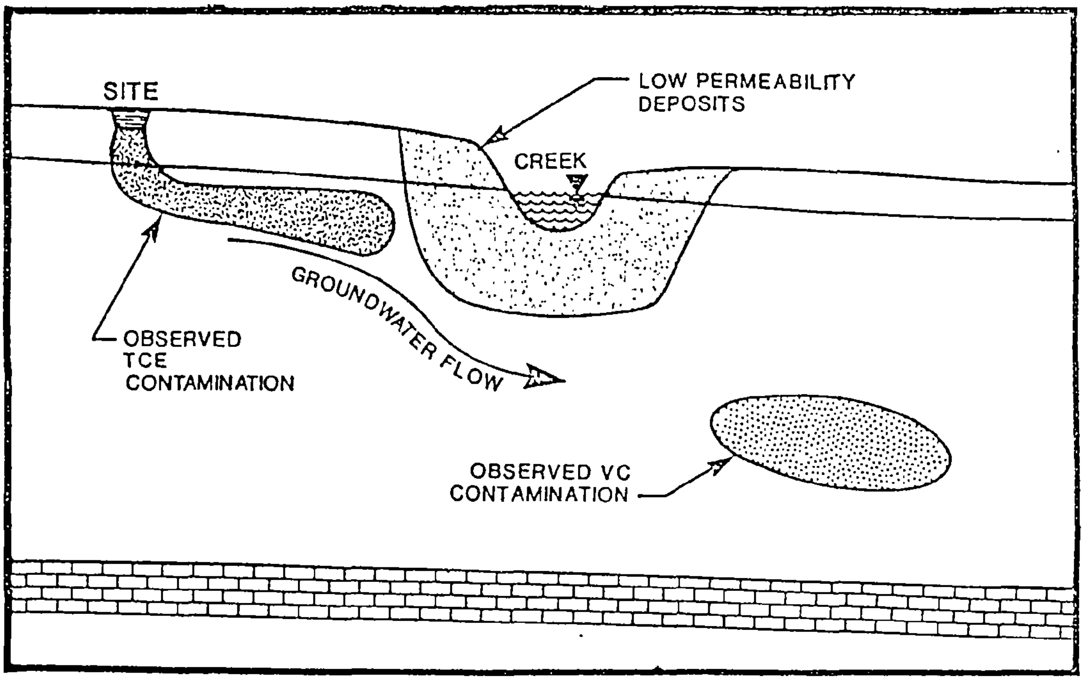
Contaminant Plumes Showing Movement of Degradation Products

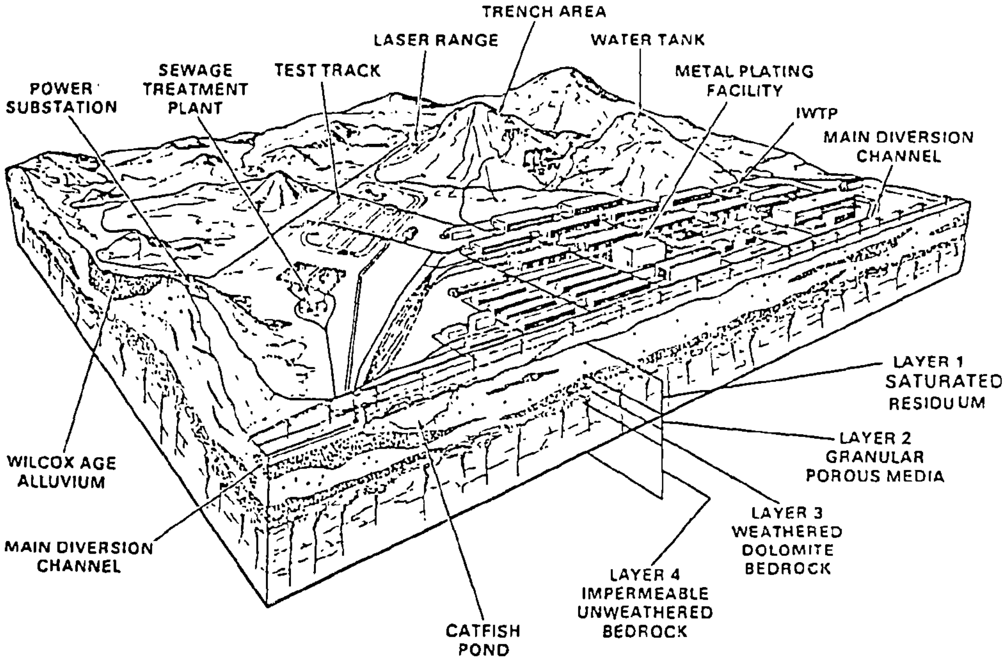


TCE Decay Profiles

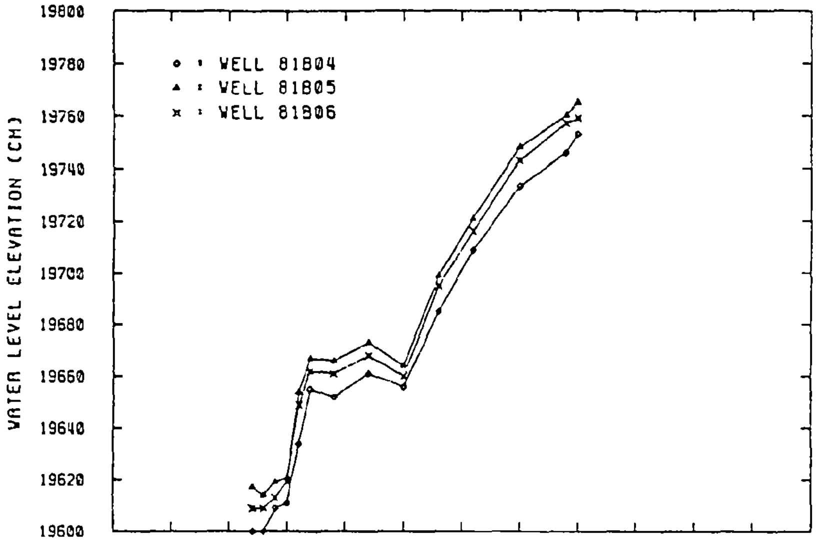


Multiple Contaminants Plumes Showing Degradation Products

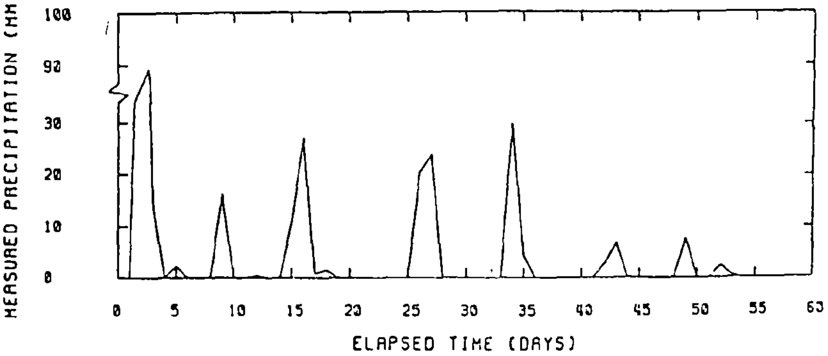


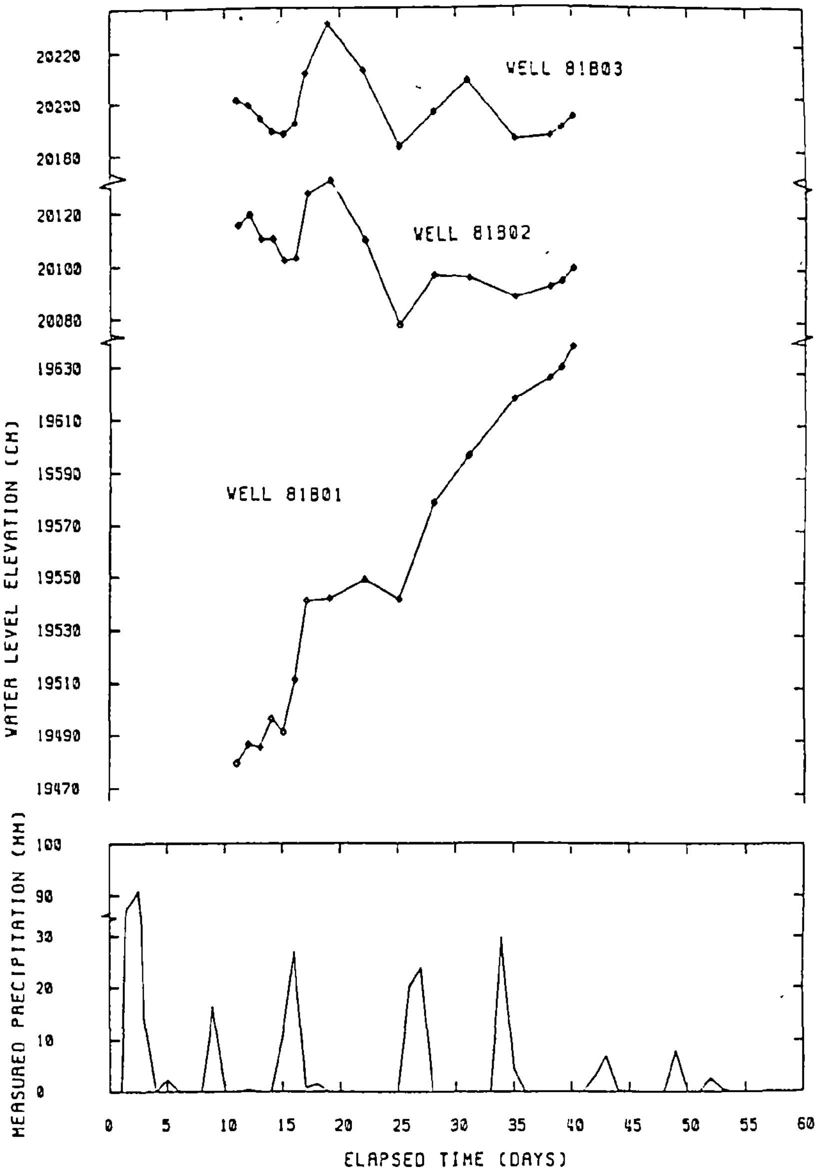


WATER LEVEL MEASUREMENTS



RAINFALL HISTORY




WELL 81B03
WELL 81B02
WELL 81B01
20220
20200
20180
20120
20100
20080
19630
19610
19590
19570
19550
19530
19510
19490
19470
WATER LEVEL ELEVATION (CM)
MEASURED PRECIPITATION (MM)
100
90
30
20
10
0
0
5
10
15
20
25
30
35
40
45
50
55
60
ELAPSED TIME (DAYS)

MONITORING SYSTEM DESIGN

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Overview Of Presentation

Indirect Methods for Characterizing Subsurface Migration

- Aerial Photographs
- Environmental Surveys
  - Existing Well Surveys
  - Surface Water Surveys
  - Biota Surveys
  - Geological/Hydrological/Soil Surveys
- Geophysical Surveys
  - Methods
  - Magnetometry
  - Metal Detection
  - Electromagnetic Conductivity (EM)
  - Resistivity
  - Seismic
  - Ground-Penetrating Radar (GPR)
  - Borehole Geophysical Devices
  - Cost
  - Factors in the Selection of Geophysical Techniques
  - Evaluation of Geophysical Data
- Soil Gas Surveys

Direct Methods For Characterizing Subsurface Migration

- Soil and Rock Sampling
- Hydrologic Measurement
- Aquifer Testing

Monitoring System Design

- Overview of Monitoring Program Design
- Objectives of Monitoring
- Monitoring System Components
- Data for System Design
  - Selecting Well Locations
  - Selecting Well Depths
  - Selecting Well Configurations
- Hypothetical Example 1--Pattern of Contamination
- Hypothetical Example 2--Evolution of a Monitoring System

Problems in Monitoring System Design

- Planning Problems
- Implementation Problems
- Site Condition Problems
- Special Problems
  - Irregularly Shaped Aquifers
  - Fracture Flow
  - Aquifer-Contaminant Interactions
  - Non-Aqueous Phase Liquids

Case Histories

Monitoring
System
Design

Monitoring System Design

- Indirect Methods for Characterizing Subsurface Migration
- Direct Methods for Characterizing Subsurface Migration
- Using Direct and Indirect Data in System Design
- Problems in Monitoring System Design

Indirect Methods For Characterizing Subsurface Migration

- Background Records and Literature
- Aerial Photography
- Environmental Surveys
- Geophysics
- Soil-Gas Analysis

Indirect Methods: Aerial Photography

Types of Information Provided

- Historical Development of Site
- Indications of Waste or Leachate
- Geologic, Topographic, and Hydrologic Features

Indirect Methods: Aerial Photography

Types of Aerial Images

- Oblique Photos
- Perpendicular Photos
- Stereoscopic Photos
- Infrared Images
- Other Types of Images

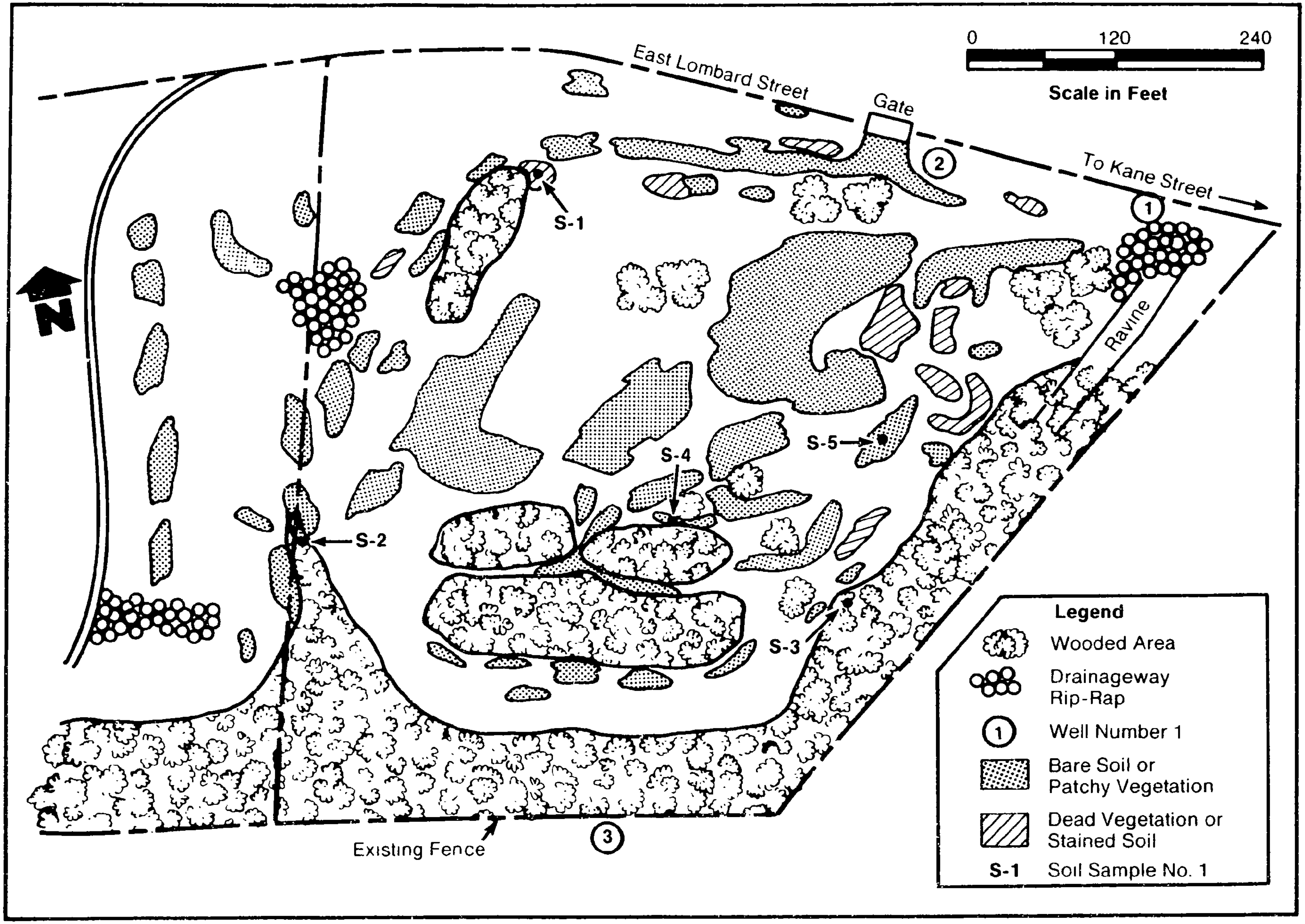
Indirect Methods:
Aerial Photography

Sources of Aerial Images

- Government Sources (EPA, USGS, SCS, Archives)
  - Relatively Inexpensive (Less Than $50)
  - Long Delivery Times (4 to 10 Weeks)
  - Availability Limited by Scale
- Private Sources
  - Relatively Expensive ($20 to $200)
  - Short Delivery Times (2 Days to 2 Weeks)
  - Availability Limited by Date

Indirect Methods: Environmental Surveys

- Existing Well Surveys
- Surface Water Surveys
- Biota Surveys
- Geologic/Soil Surveys



DISTRIBUTION OF SITE VEGETATION

Indirect Methods: Geophysics

- Magnetometry
- Metal Detection
- Electromagnetic Conductivity
- Resistivity
- Seismic Reflection and Refraction
- Ground Penetrating Radar
- Borehole Methods

Indirect Methods: Geophysics

Magnetometry Surveys

- Measure Intensity of Earth's Magnetic Field
- Local Magnetic Anomalies Can be Related to Buried Ferrous Metal
- Depth of Survey up to 50 Feet
- Intensity of Response Related to Mass of Ferrous Metal

Indirect Methods: Geophysics

Types of Magnetometer

- Fluxgates
- Total Field
- Gradiometer

Indirect Methods: Geophysics

Metal Detection Surveys

- Indicate Distortion of Electromagnetic Fields by Metallic Substances
- Detect Ferrous and Non-Ferrous Metals
- Depth of Survey up to 15 Feet
- Intensity of Response Related to Surface Area of Metal

Indirect Methods: Geophysics

Electromagnetic Conductivity (EM) Surveys

- Measure Conductivity of Groundwater and Rock Material
- Anomalies Can be Related to Ionic Concentrations
- Depth of Survey up to 200 Feet
- Survey Depth Related to Electrode Spacing and Orientation
- Used Primarily for Profiling

Indirect Methods: Geophysics

Resistivity Surveys

- Measure Resistance of Subsurface Materials to Electrical Current
- Can be Related to Stratigraphy or Groundwater Quality
- Used Primarily for Vertical Sounding
- Survey Depth Related to Electrode Spacing

Indirect Methods: Geophysics

Seismic Surveys

- Measure Changes in Energy Waves Transmitted Through Soil and Rock
- Used to Delineate Subsurface Stratigraphy
- Seismic Refraction Used for Shallow Studies
- Seismic Reflection Used for Deep Studies

Indirect Methods: Geophysics

Ground Penetrating Radar (GPR) Surveys

- Measures Reflection of Energy Pulses Off "Targets"
- Can Identify Stratigraphic Layers, Groundwater, Buried Waste
- Depth of Penetration Highly Variable, Up to 100 Feet
- Signal Attenuated Rapidly by Clays and Water

Indirect Methods: Geophysics

Borehole Logs

- Temperature
- Specific Conductance
- Downhole TV
- Caliper
- Resistivity
- Gamma
- Neutron
- Others

Indirect Methods: Geophysics

Costs for Geophysical Surveys

	Cost Ranges/Day[1]	Field Capacity/Day
Magnetometer	$1,935-$3,890	50-150 Stations
Conductivity	$1,970-$3,960	50-150 Stations
Resistivity	$2,090-$4,655	8-20 Stations
GPR	$2,585-$6,100	5,000-10,000 Linear Feet

[1] Travel Costs and Survey Grid Not Included.

Indirect Methods: Geophysics

Factors in Method Selection

Magnetometry - for High Mass, Iron Deposits

Metal Detection - for Shallow, Metallic Deposits Having a High Surface Area

Conductivity - for Profiling Electromagnetic Contrasts

Resistivity - for Sounding Electromagnetic Contrasts

Seismic - for Delineating Geologic Layers Having Different Densities

GPR - for Delineating Low-Clay Deposits and Groundwater

Indirect Methods: Geophysics

Complementary Geophysical Methods

Application	**Primary Methods**	**Secondary Methods**
Buried Non-Metallic Wastes	GPR, EM	Resistivity
Buried Metallic Wastes	Magnetometry, Metal Detection, GPR	EM, Resistivity
Subsurface Geology	GPR, Seismic	EM, Resistivity
Depth to Water	GPR	EM, Resistivity
Leachate Plumes	EM, Resistivity	GPR

Indirect Methods: Geophysics

Data Evaluation Techniques

- Graphical Interpretation
- Method-Specific Models
- Statistical Models

Indirect Methods: Soil Gas

- Measure Chemical Vapors in Soil Voids
- Can be Related to Buried Wastes or Leachate
- Depth of Survey Variable - Typically Less Than 100 Feet
- Can be Qualitative, Semi-Quantitative or Quantitative

Indirect Methods: Soil Gas

Gas-Collection Approaches

- Surface Readings
- Temporary Probes
- Semi-Permanent Probes
- Sorptive Collectors
- Vapor Wells

Indirect Methods: Soil Gas

Analytical Approaches

- Onsite Instrumentation
- Sorptive Collectors for Lab Analysis
- Tedlar Bags for Lab Analysis

Direct Methods for Characterizing Subsurface Migration

- Soil and Rock Sampling
- Hydrologic Measurements
- Aquifer Testing
- Groundwater Sampling

Direct Methods:
Soil and Rock Sampling

- Grab Samples
- Split Spoon Samples
- Shelby Tube Samples
- Soil-Core Samples
- Rock-Core Samples

Direct Methods: Hydrologic Measurements

- Surface Water Discharge and Elevation
- Spring Discharge and Elevation
- Unsaturated Zone Monitoring
- Groundwater Elevations

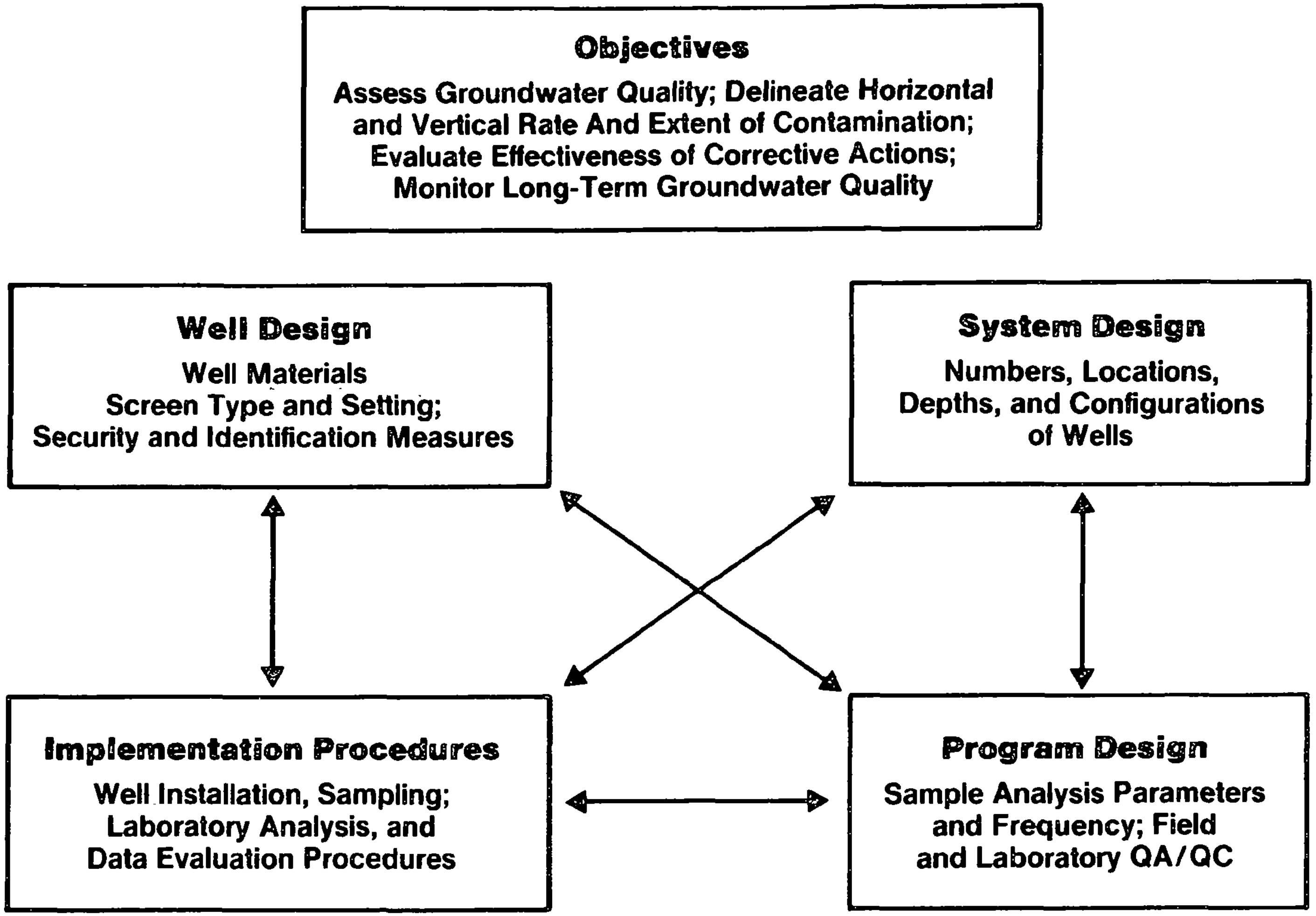
Direct Methods: Hydrologic Measurements

Devices for Measuring Depth to Water

Device	Typical Accuracy	Ease of Use	Purchase Cost	Recording Capabilities
Tape/Popper	0.1	Easy	$15	No
Tape/Marker	0.05	Easy	$20	No
Electrical	0.05	Easy	$200	No
Mechanical	0.1	Difficult	$1,000	Yes
Sonic	1.0	Moderate	$500	Yes
Pressure Transducer	0.03	Moderate	$1,500	Yes

Direct Methods: Aquifer Testing

- Laboratory Tests
- Slug Tests
- Packer Tests
- "Mini" Pump Tests
- Step-Drawdown Tests
- Pump Tests
- Tracer Tests



Objectives

Assess Groundwater Quality; Delineate Horizontal and Vertical Rate And Extent of Contamination; Evaluate Effectiveness of Corrective Actions; Monitor Long-Term Groundwater Quality

Well Design

Well Materials
Screen Type and Setting;
Security and Identification Measures

System Design

Numbers, Locations, Depths, and Configurations of Wells

Implementation Procedures

Well Installation, Sampling; Laboratory Analysis, and Data Evaluation Procedures

Program Design

Sample Analysis Parameters and Frequency; Field and Laboratory QA/QC

Elements of Groundwater Monitoring

Combining Direct and Indirect Data

Some Objectives for Groundwater Monitoring

- Assess Groundwater Quality
- Delineate Horizontal Extent of Contamination
- Delineate Vertical Extent of Contamination
- Evaluate Effectiveness of Corrective Actions

Combining Direct and Indirect Data

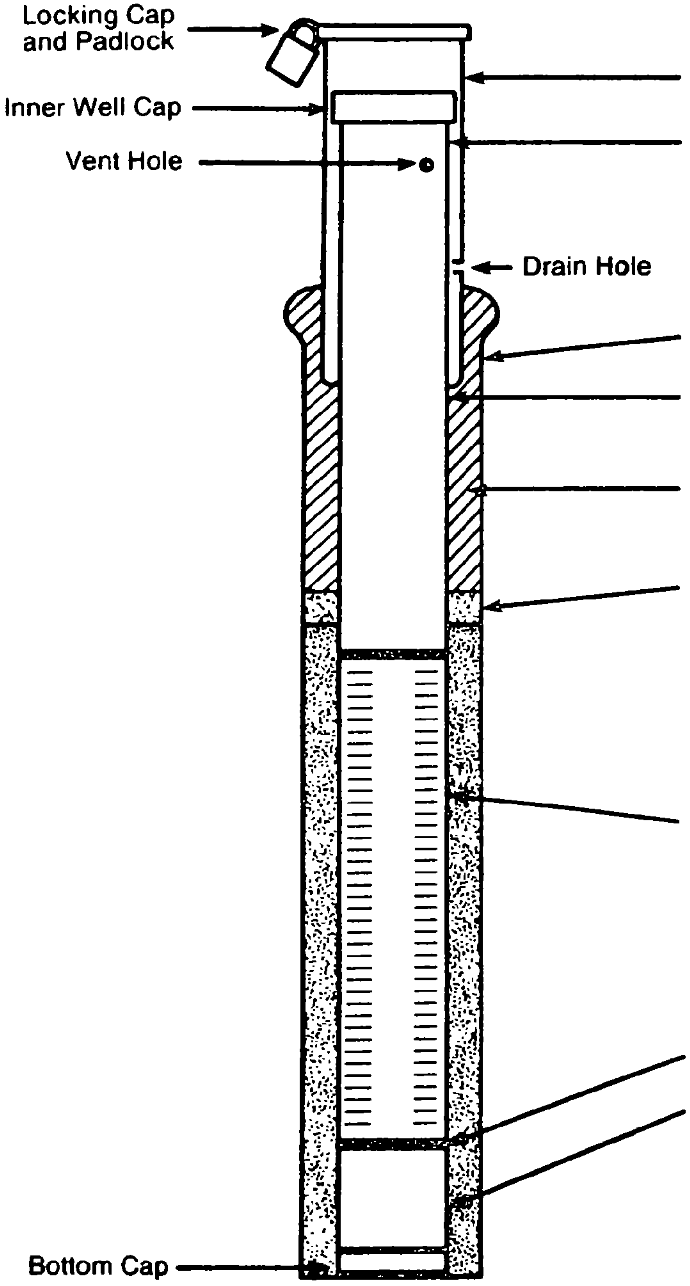
Monitoring System Components

Well Design - Well Materials, Screen Type and Setting, and Security and Identification Measures

System Design - Numbers, Locations, Depths, and Configurations of Wells

Program Design - Sample Analysis Parameters and Frequency, and QA/QC

Implementation Procedures - Well Installation and Sampling, Laboratory Analysis, and Data Evaluation



Protective Casing ________________
Stickup ________________
Traffic Pad ________________
Well Development ________________
Borehole Diameter ________________
Casing Diameter ________________
Material ________________
Grout: Material/Mixture ________________
Setting ________________
Plug: Material ________________
Setting ________________
Sandpack: Material ________________
Gradation ________________
Setting ________________
Screen: Material ________________
Length ________________
Type ________________
Opening Size ________________
Setting ________________
Coupling ________________
Sump Length ________________

SUMMARY OF SPECIFICATIONS FOR SHALLOW WELL COMPLETION

Combining Direct and Indirect Data

Data for System Design

Number of Wells - Objectives of Monitoring System
Existing Records and Data

Well Locations - Objectives of Monitoring System
Existing Records and Data
Aerial Photographs
Environmental Surveys
Geophysics
Soil Gas Survey
Site Access

Combining Direct and Indirect Data

Data for System Design (Continued)

Well Depths - Objectives of Monitoring System
Existing Records and Data
Geophysics
Soil and Rock Samples
Hydrologic Measurements

Well Configurations - Objectives of Monitoring System
Existing Records and Data
Geophysics
Soil and Rock Samples
Hydrologic Measurements

Selecting Well Locations

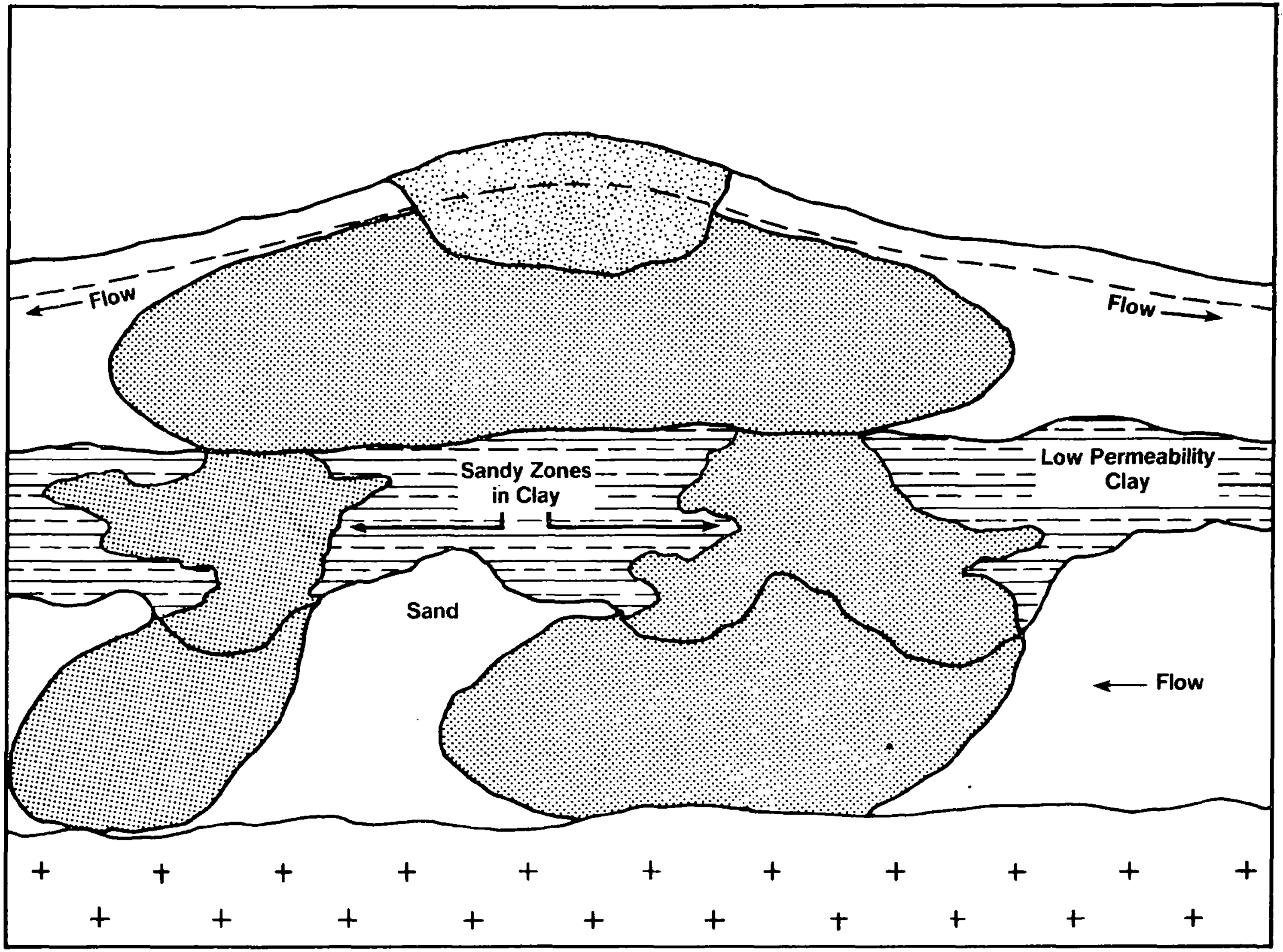
Aerial Photographs: Stressed Vegetation
Fracture Traces
Geomorphic Anomalies

Environmental Surveys: Existing Well Contamination
Spring Contamination
Surface Water Contamination

Selecting Well Locations

Geophysics: EM Anomalies
“Hard-Target” Anomalies
“Soft-Target” Anomalies

Other Factors: Objectives of Monitoring System
Existing Records and Data
Soil-Gas Anomalies
Access and Clearance
Contaminant Geochemistry



Source Repa and Kufs, 1985

Example of a Situation in Which Different Groundwater Flow Directions and Geologic Heterogeneities Can Influence the Monitoring System Design

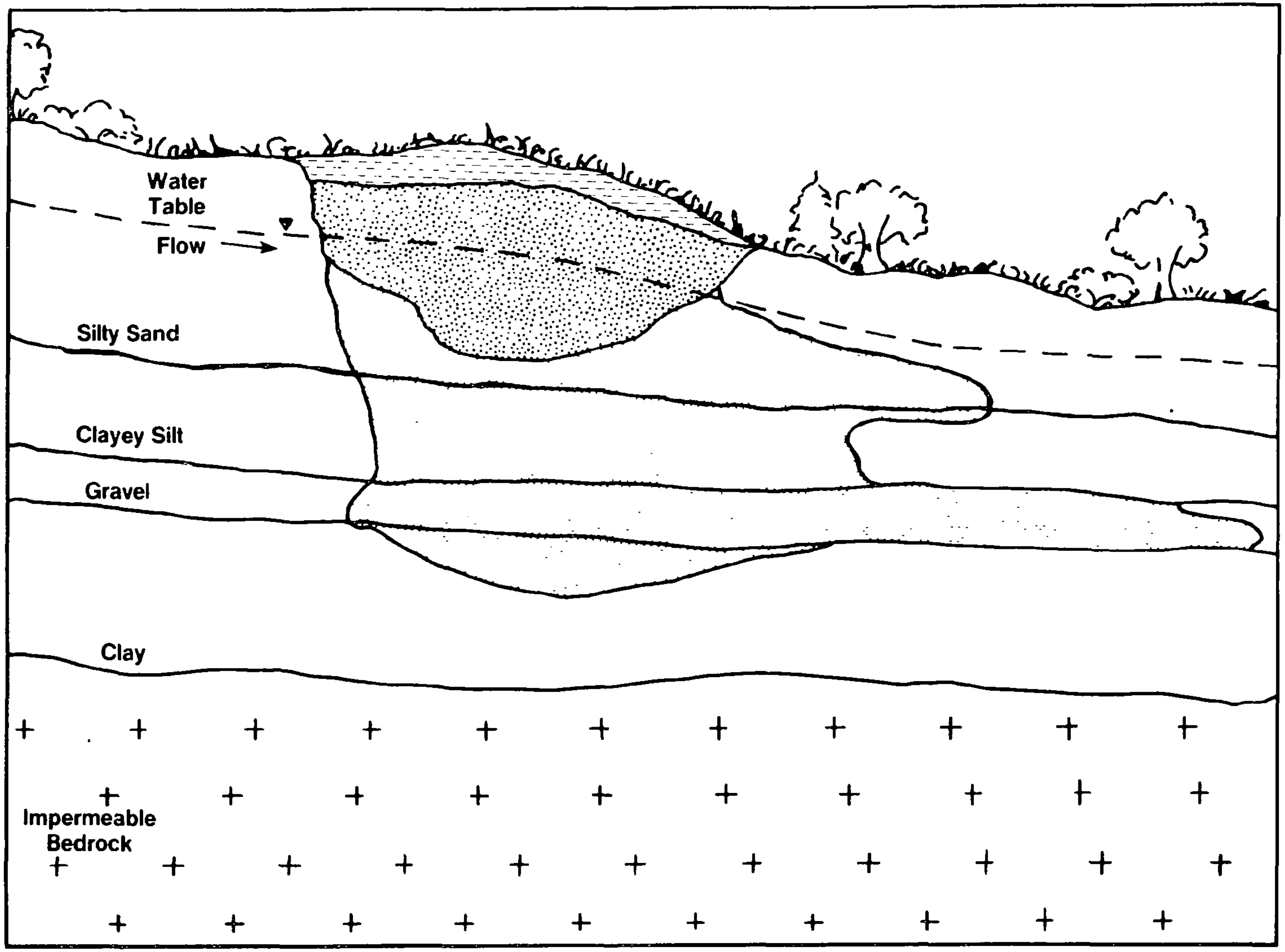
Selecting Well Depths

Environmental Surveys: Depth to Water in Existing Wells
Elevations of Surface
Waters and Springs

Geophysics: Stratigraphy (From GPR, Seismic, or
Resistivity Surveys)
Depth-to-Water Estimates

Direct Data: Soil and Rock Samples
Hydrologic Measurements

Other Factors: Objectives of Monitoring System
Existing Records and Data
Contaminant Geochemistry

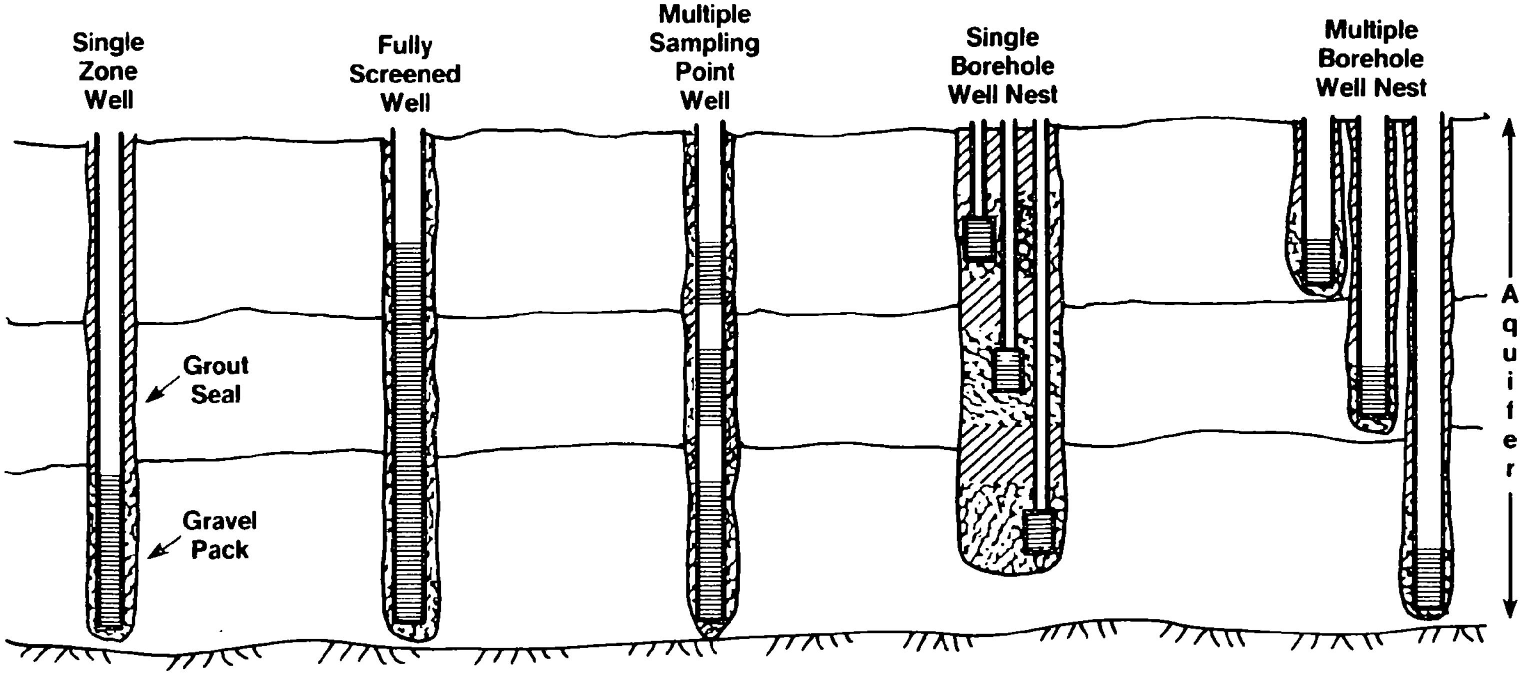


Source Repa and Kufs, 1985

Example of a Situation in Which Geologic Units of Different Hydraulic Conductivities Can Influence the Design of a Monitoring System

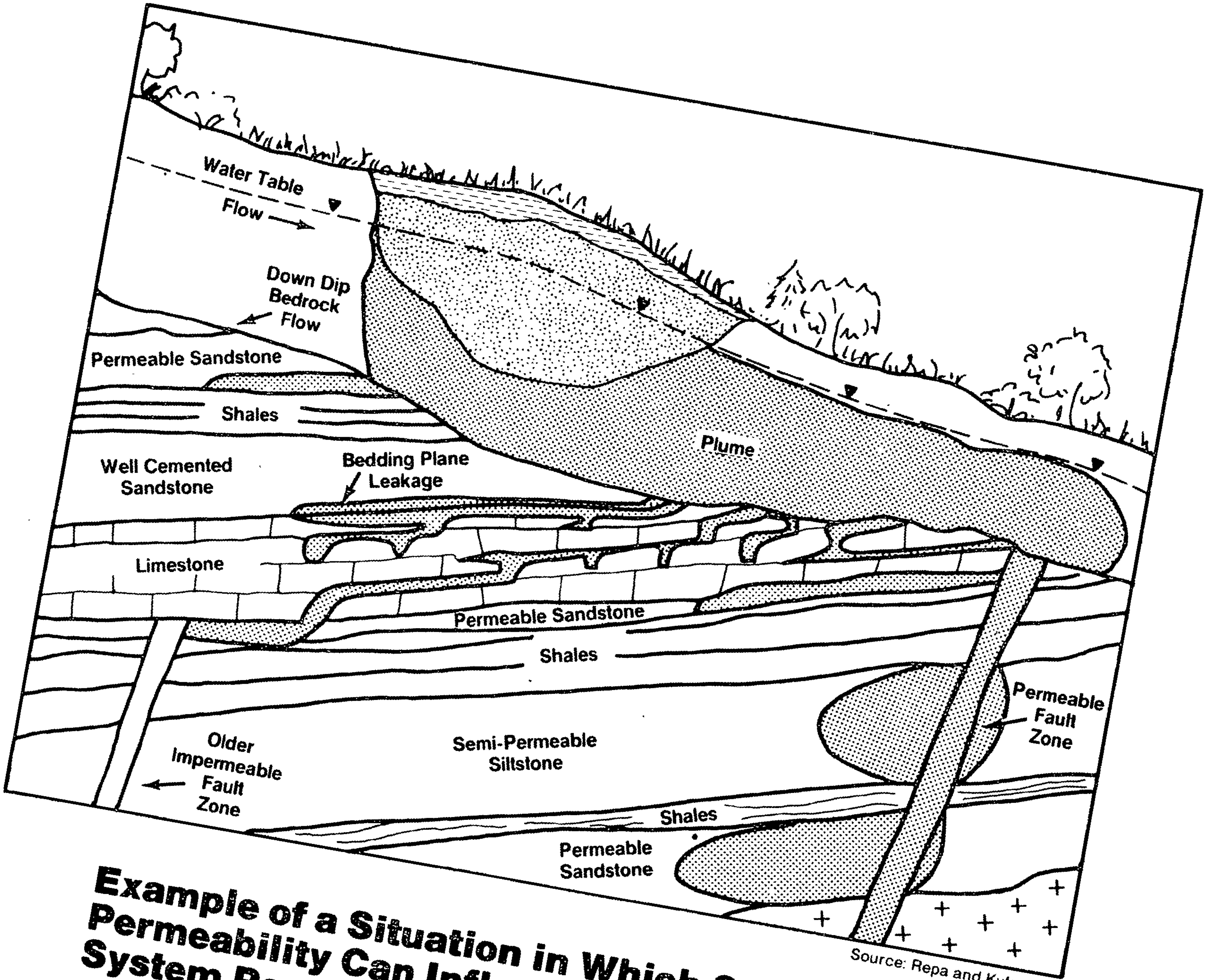
Selecting Well Configurations

- Objectives of Monitoring System
- Existing Records and Data
- Contaminant Geochemistry
- Stratigraphy and Hydrogeology



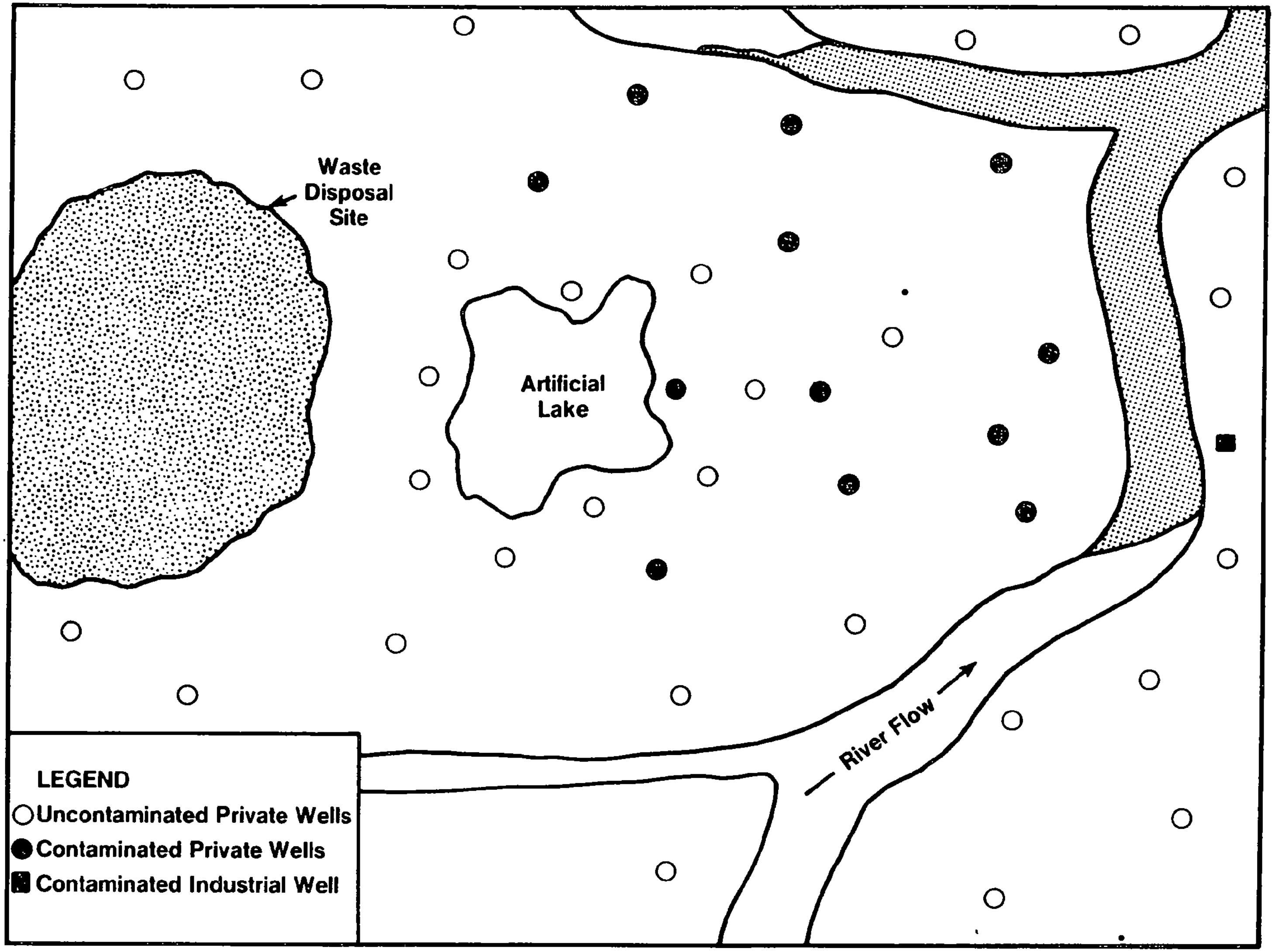
Source Repa and Kufs, 1985

Well Configurations Used for Groundwater Monitoring



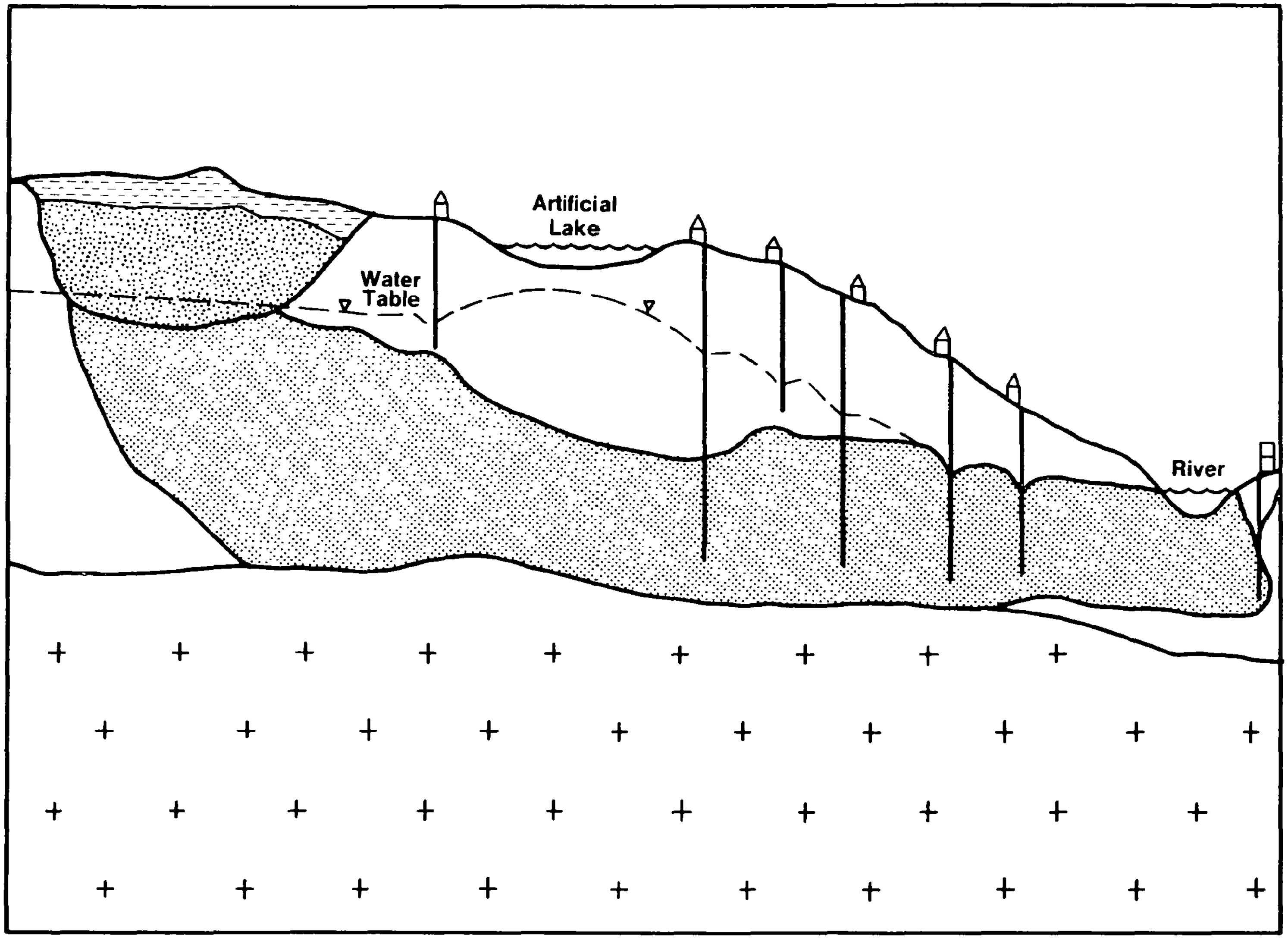
Source: Repa and Kufs, 1985

Example of a Situation in Which Secondary Permeability Can Influence Monitoring System Results



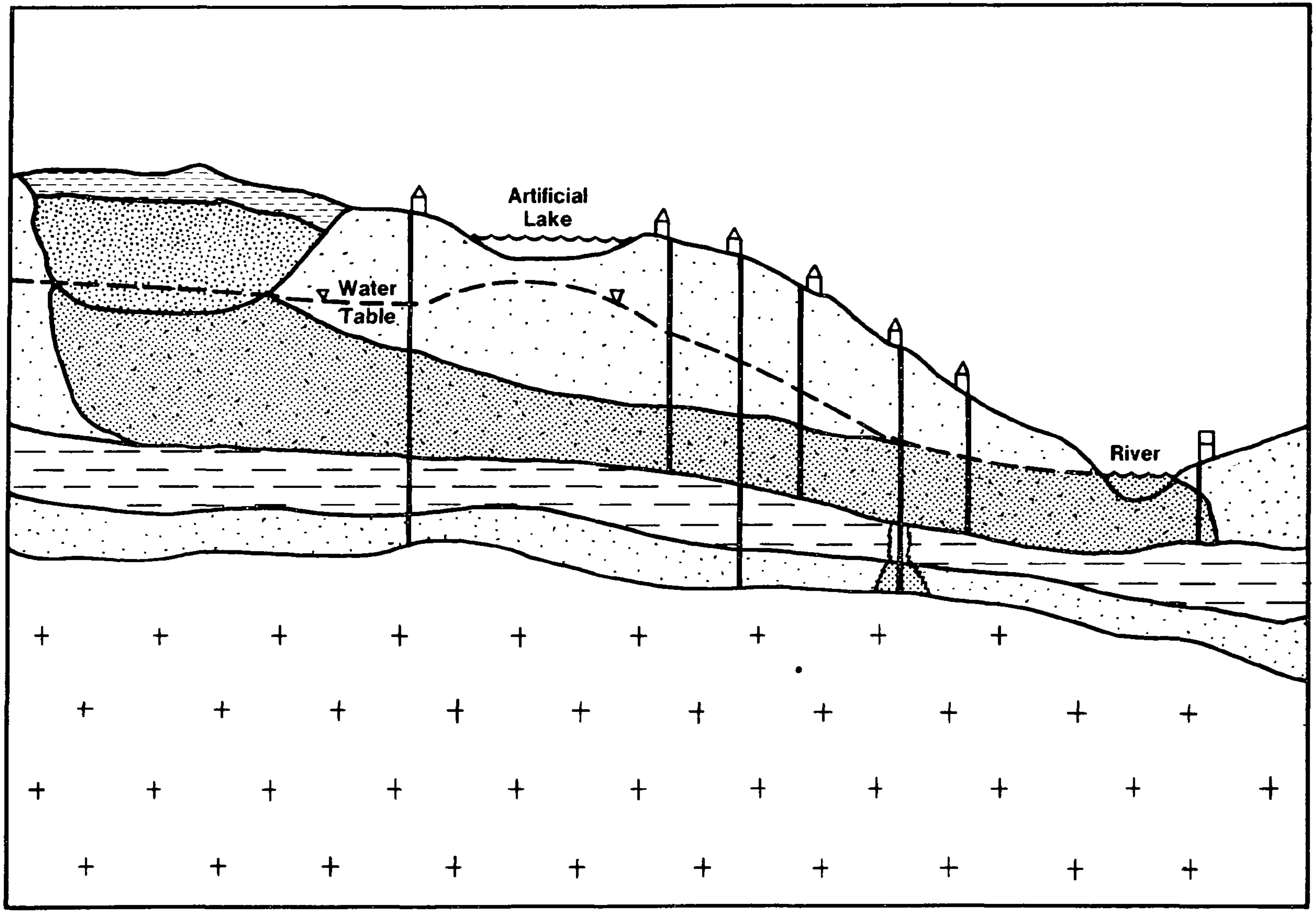
Source. Repa and Kufs, 1985

Result of Sampling Existing Wells at a Hypothetical Site



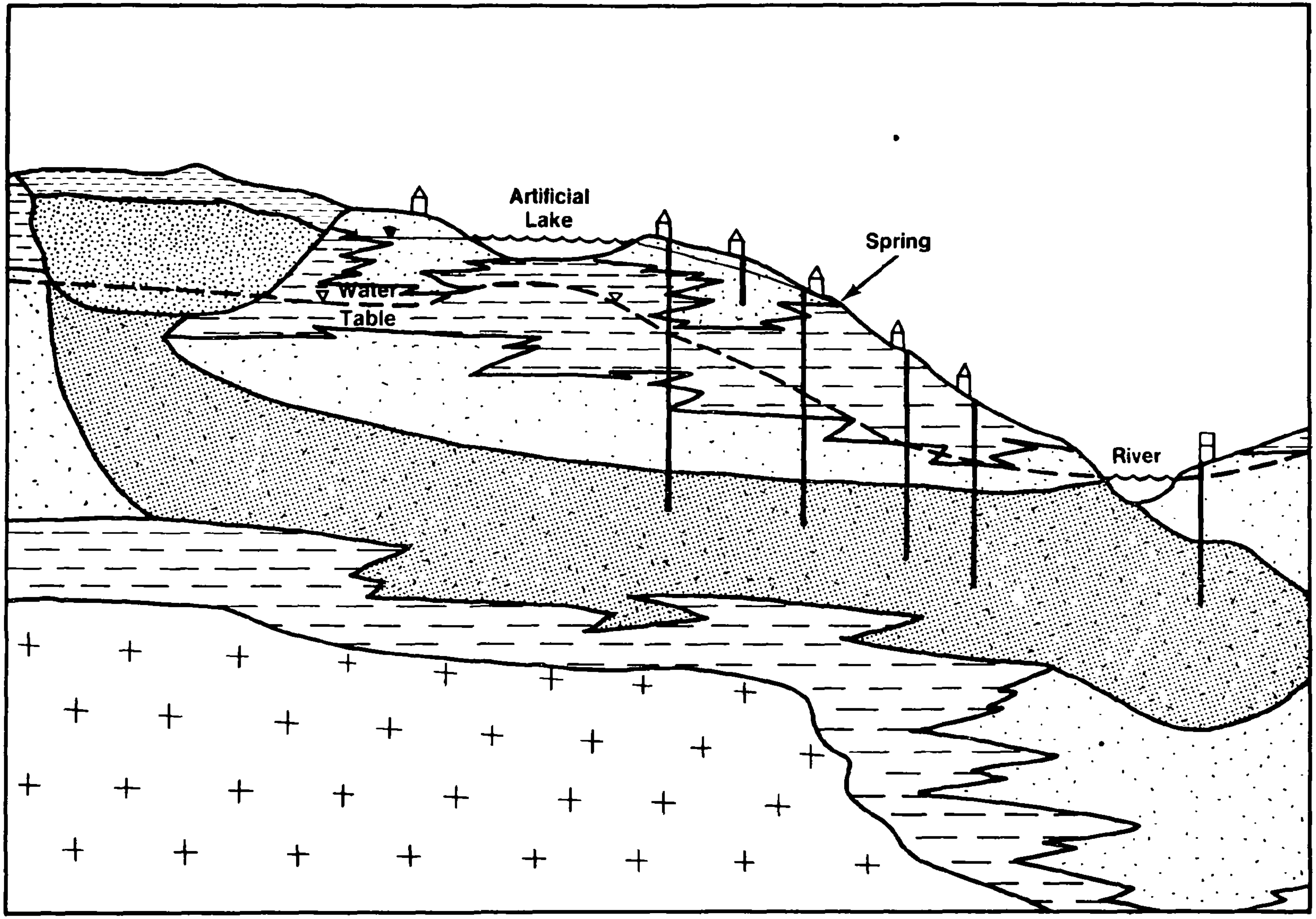
After Repa and Kufs, 1985

Example of a Situation in Which Well Construction and Depth Influence the Pattern of Contamination



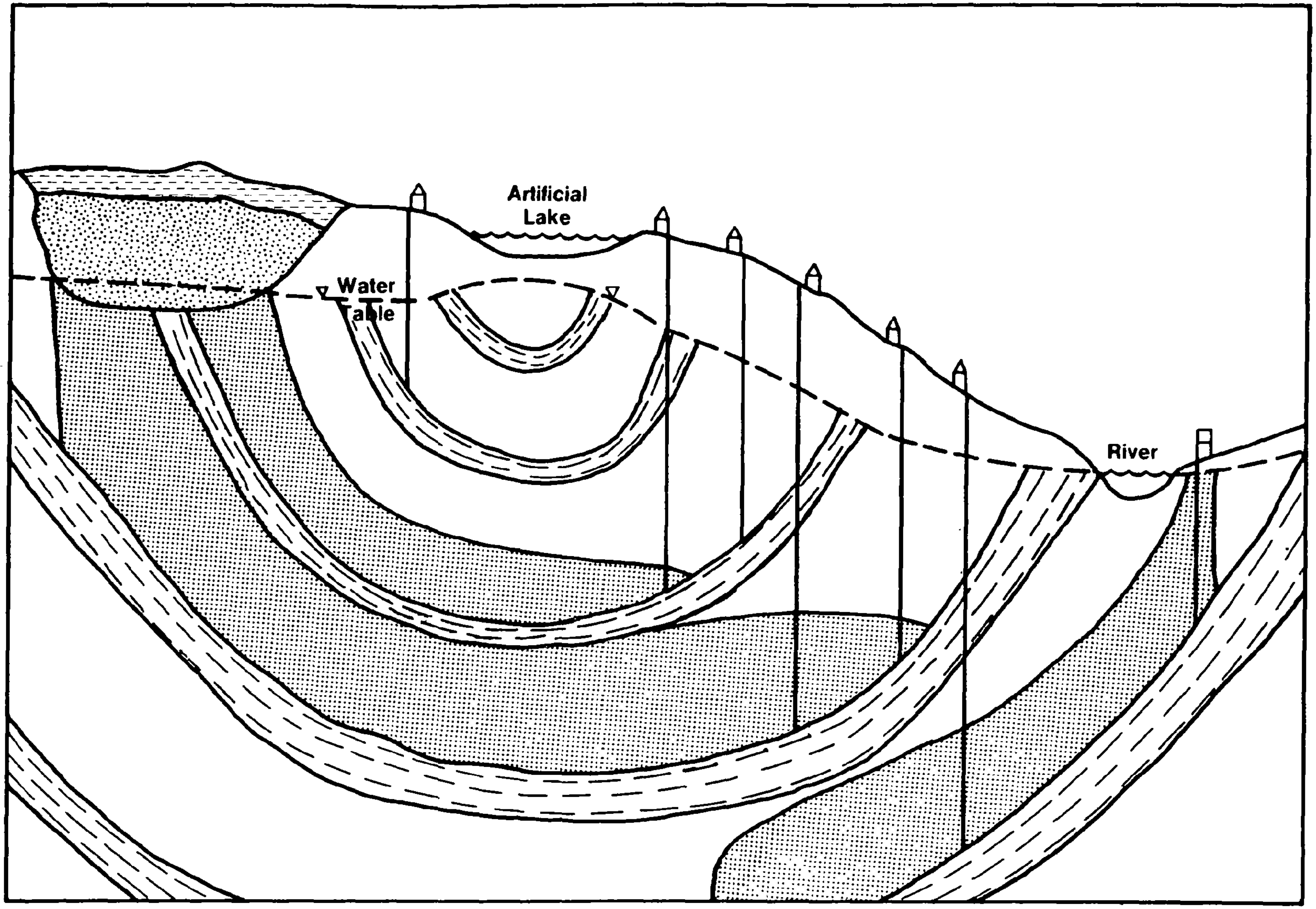
After: Repa and Kufs, 1985

Example of a Situation in Which Well Depth Influences the Pattern of Contamination



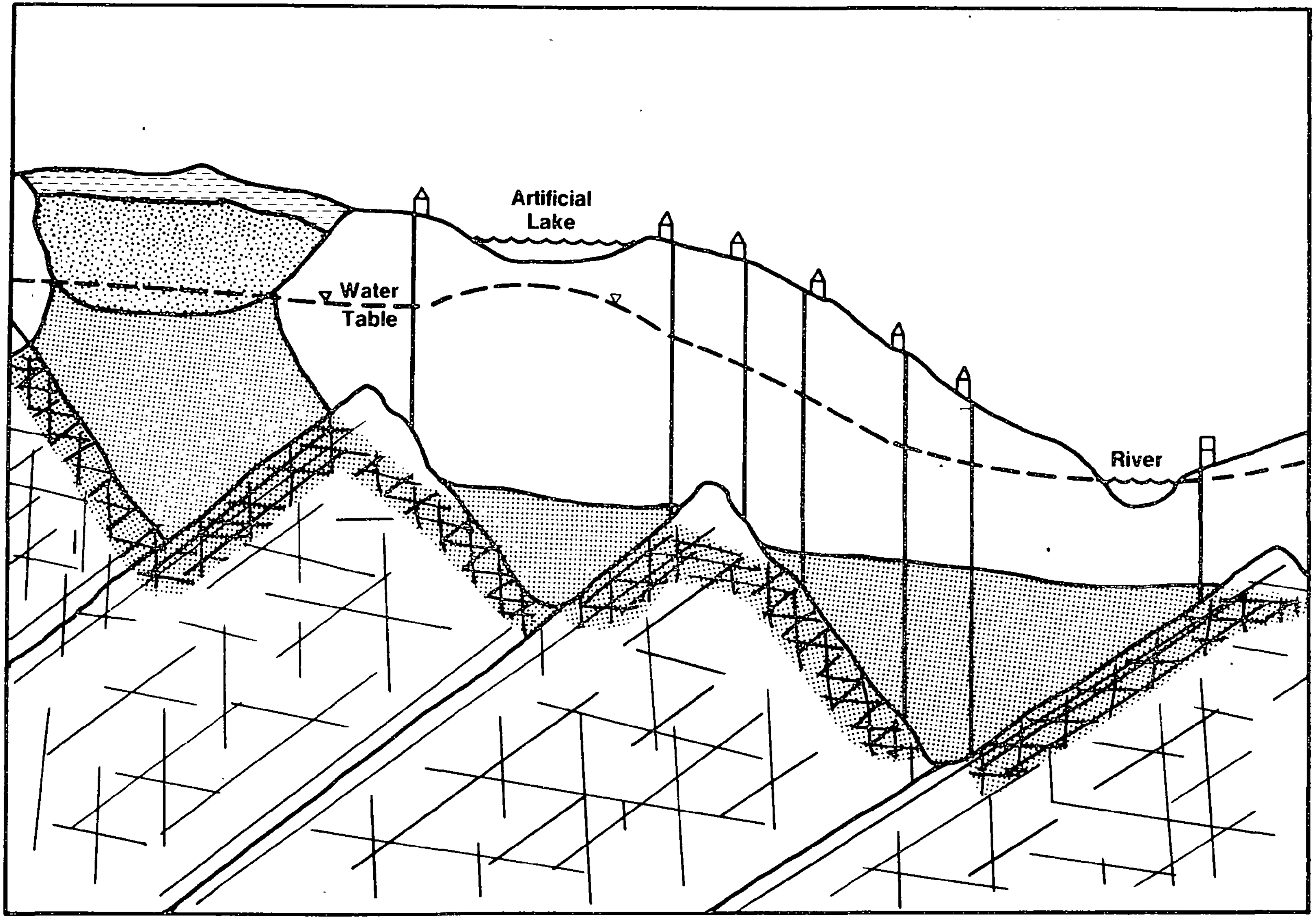
After: Repa and Kufs, 1985

Example of a Situation in Which Different Water-Bearing Zones Influence the Pattern of Contamination



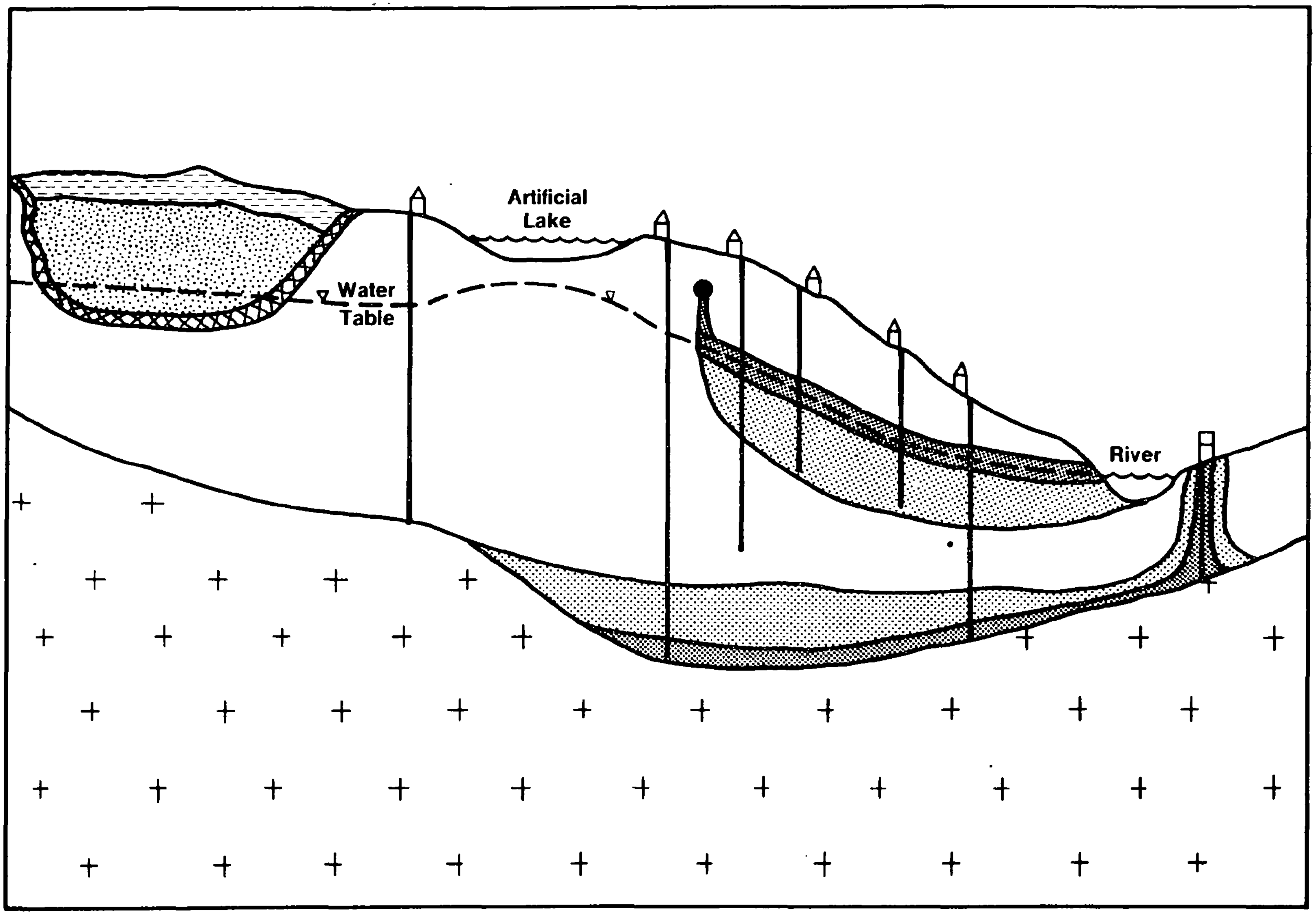
After: Repa and Kufs, 1985

Example of a Situation in Which Rock Structure and Well Depth Influence the Pattern of Contamination



After: Repa and Kufs, 1985

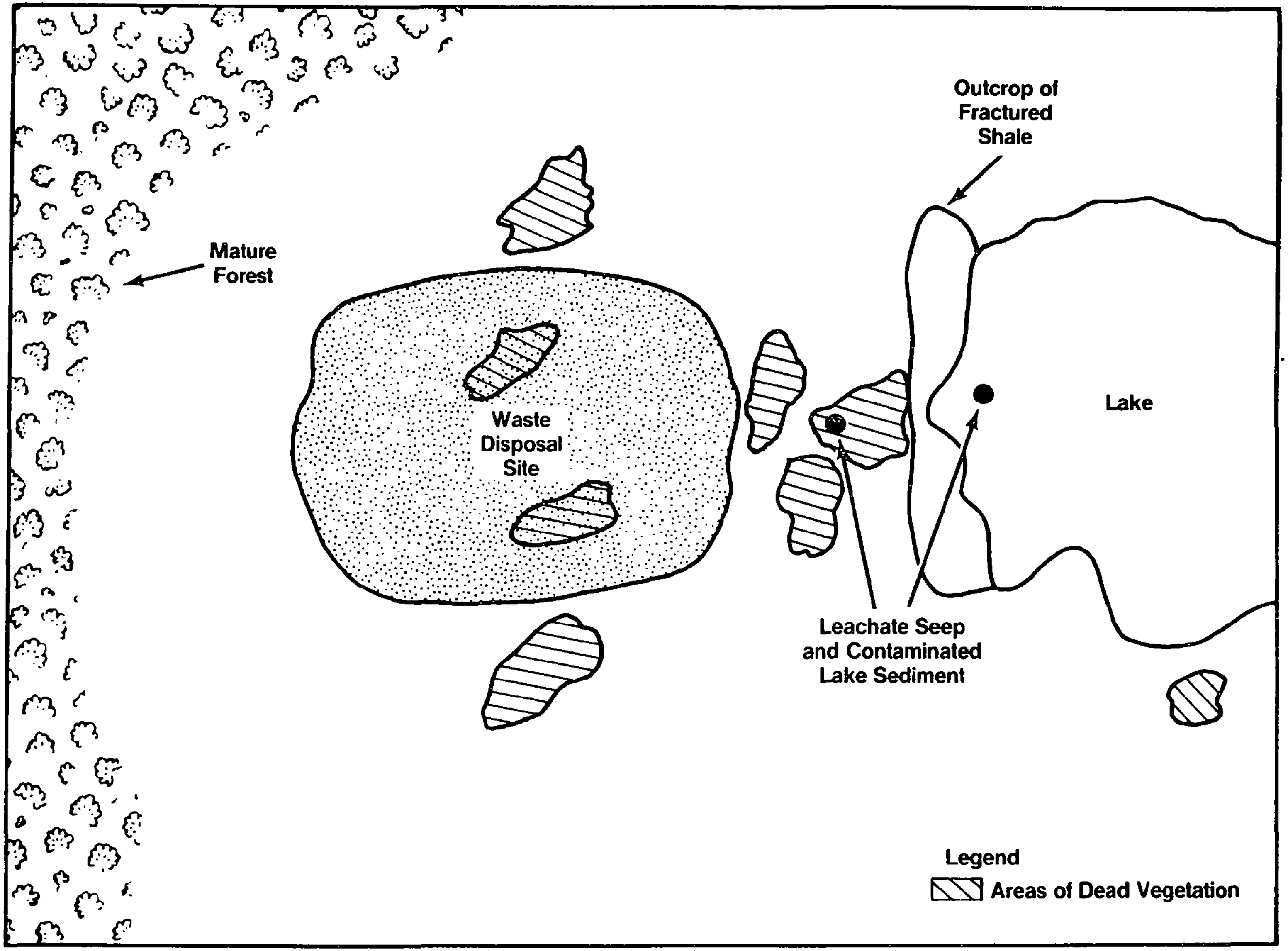
Example of a Situation in Which Rock Faults and Fractures Influence the Pattern of Contamination



After: Repa and Kufs, 1985

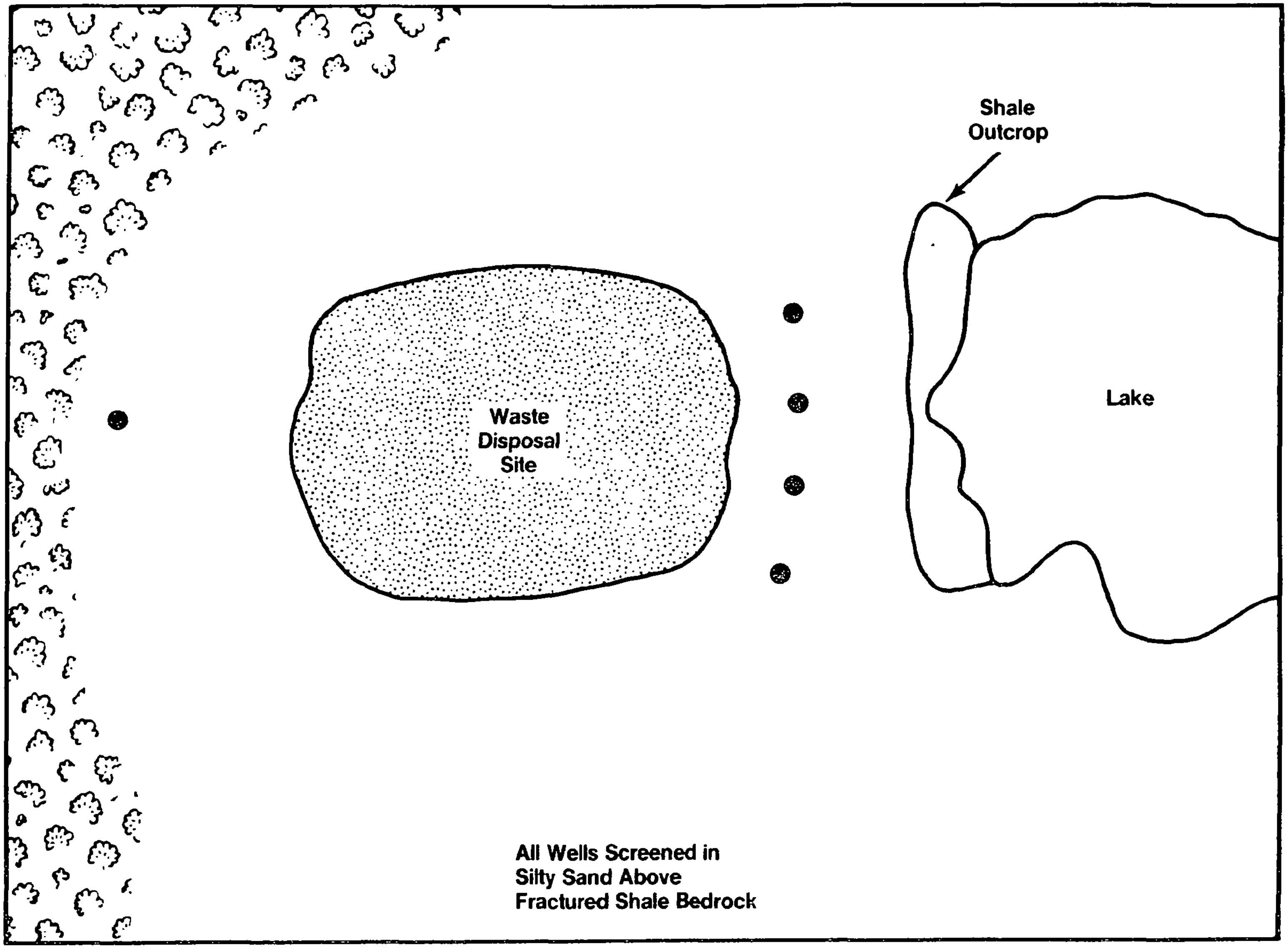
Example of a Situation in Which Contaminant Solubility and Density Influence the Pattern of Contamination

Result of Environmental Survey



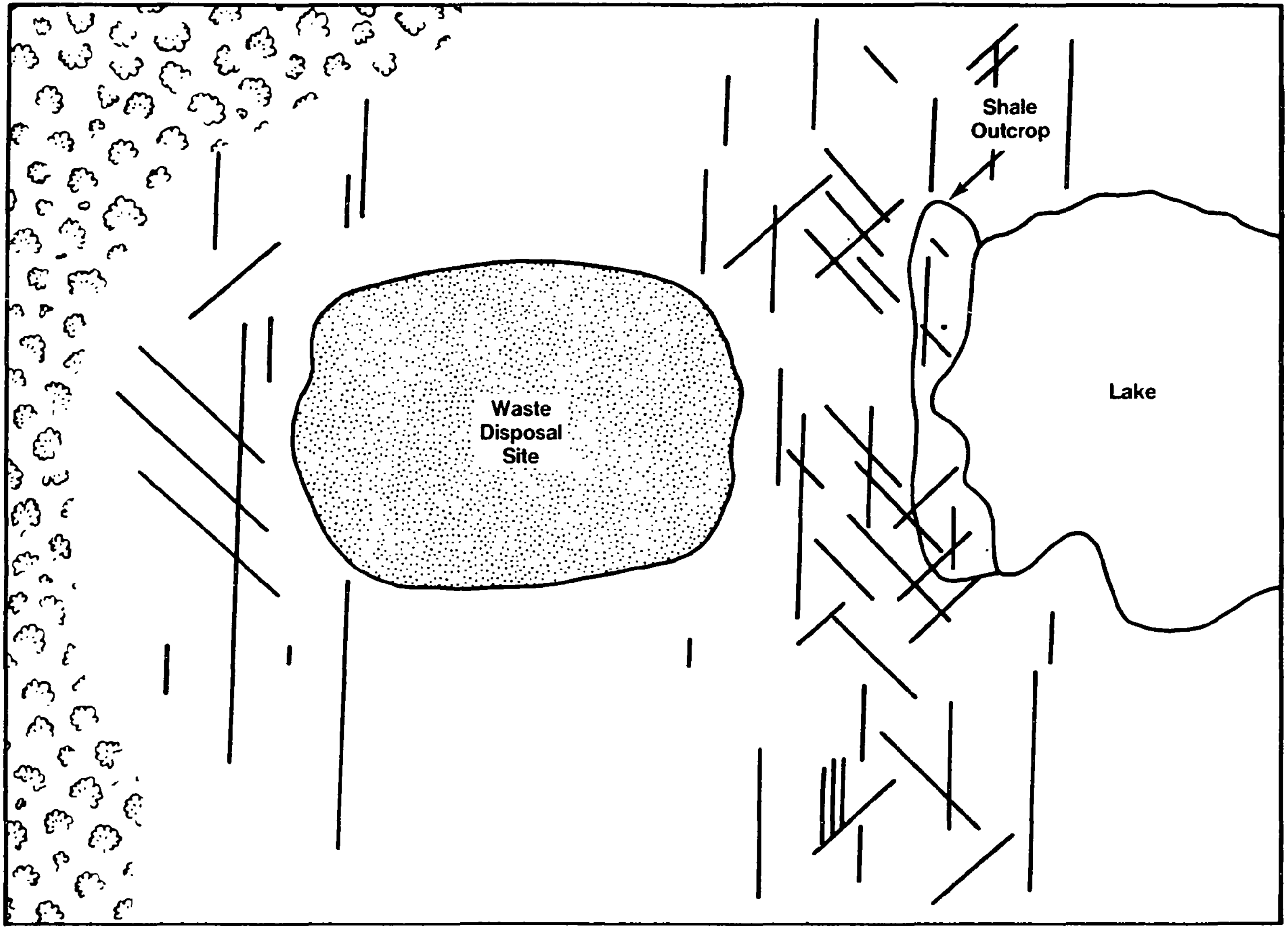
After: Repa and Kufs, 1985

Monitoring System for Assessing Groundwater Quality



After: Repa and Kufs, 1985

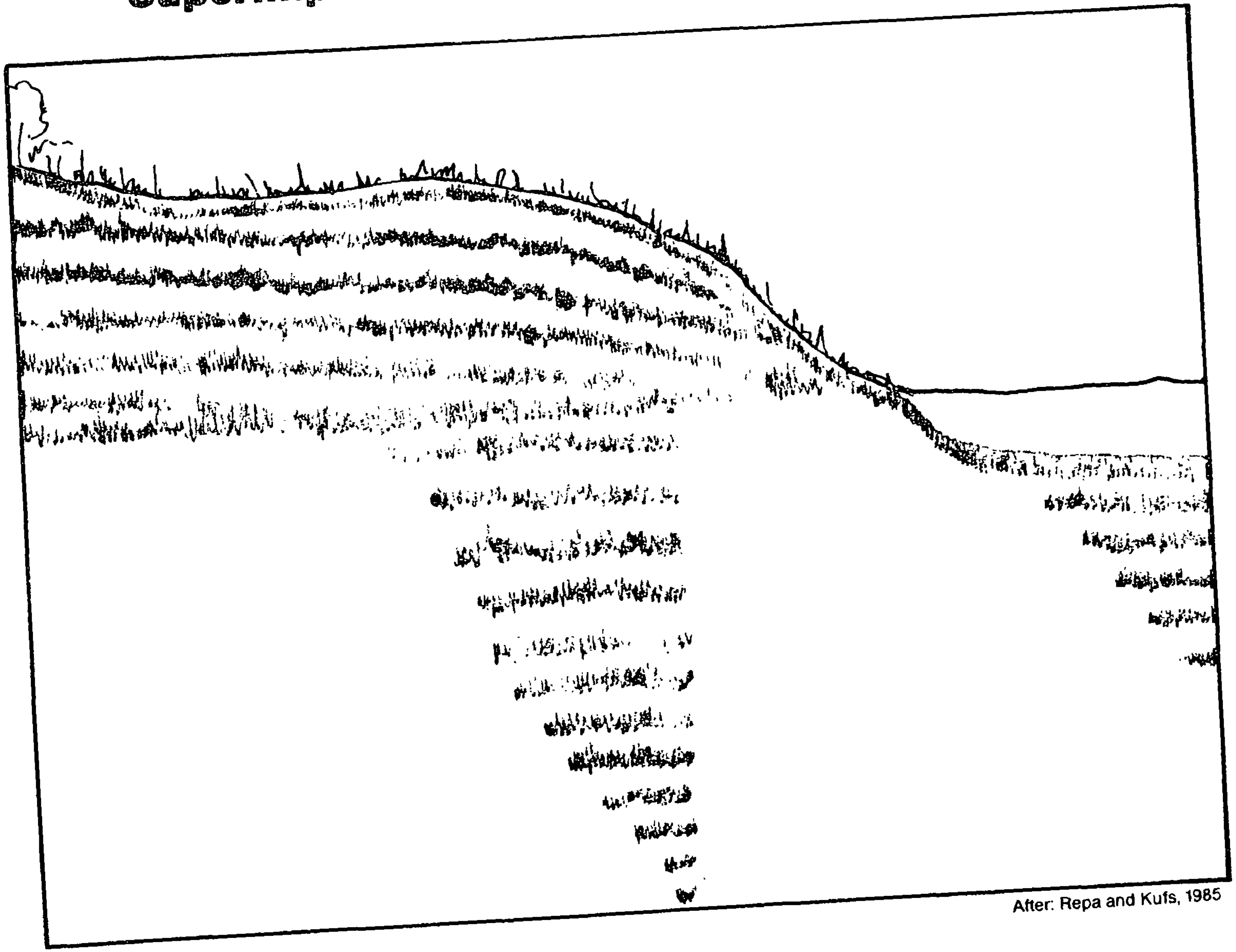
Result of Fracture-Trace Analysis



After: Repa and Kufs, 1985

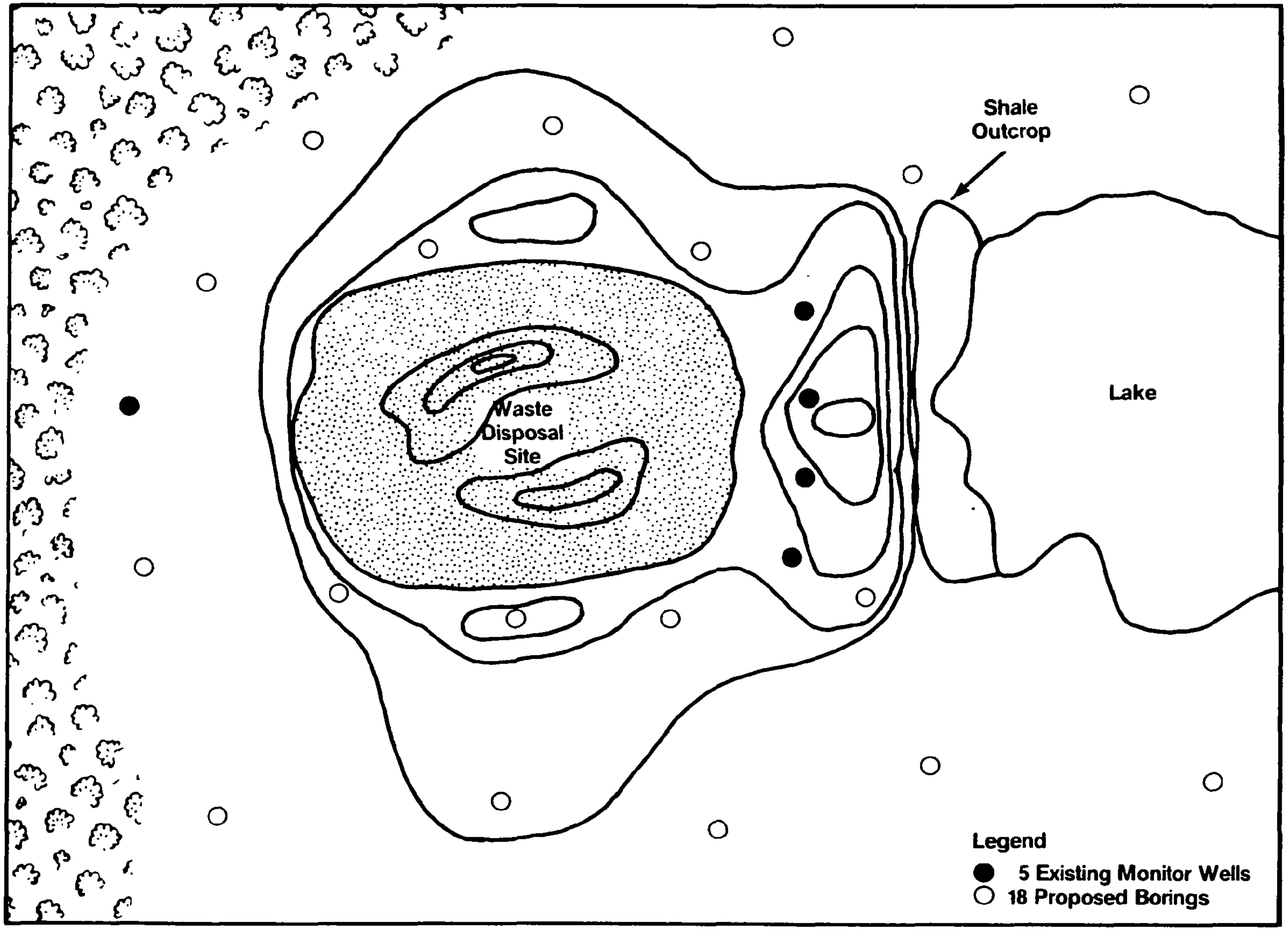
Result of GPR Survey

Superimposed on a Cross Section of the Site



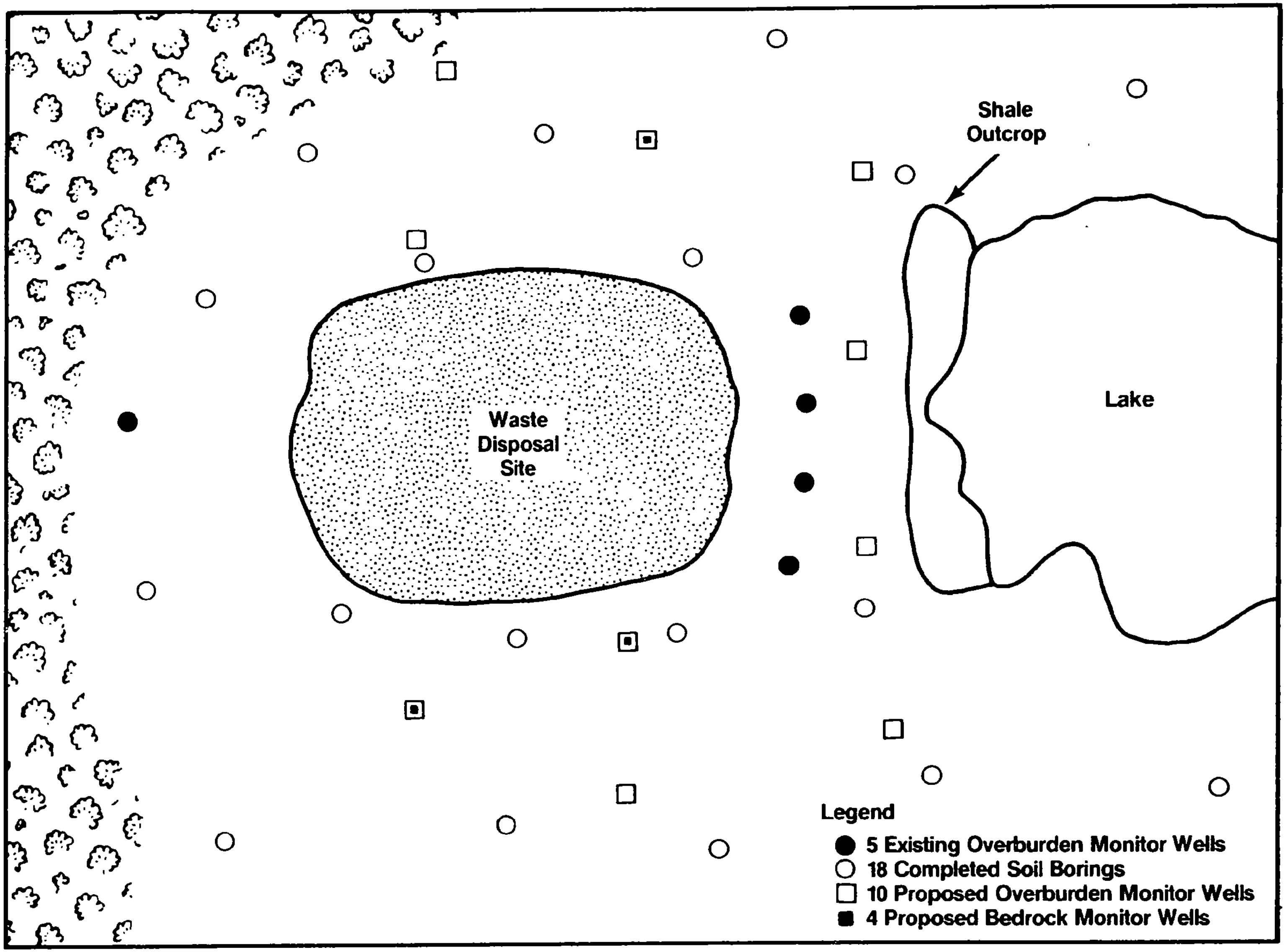
After: Repa and Kufs, 1985

Result of Soil-Gas Survey

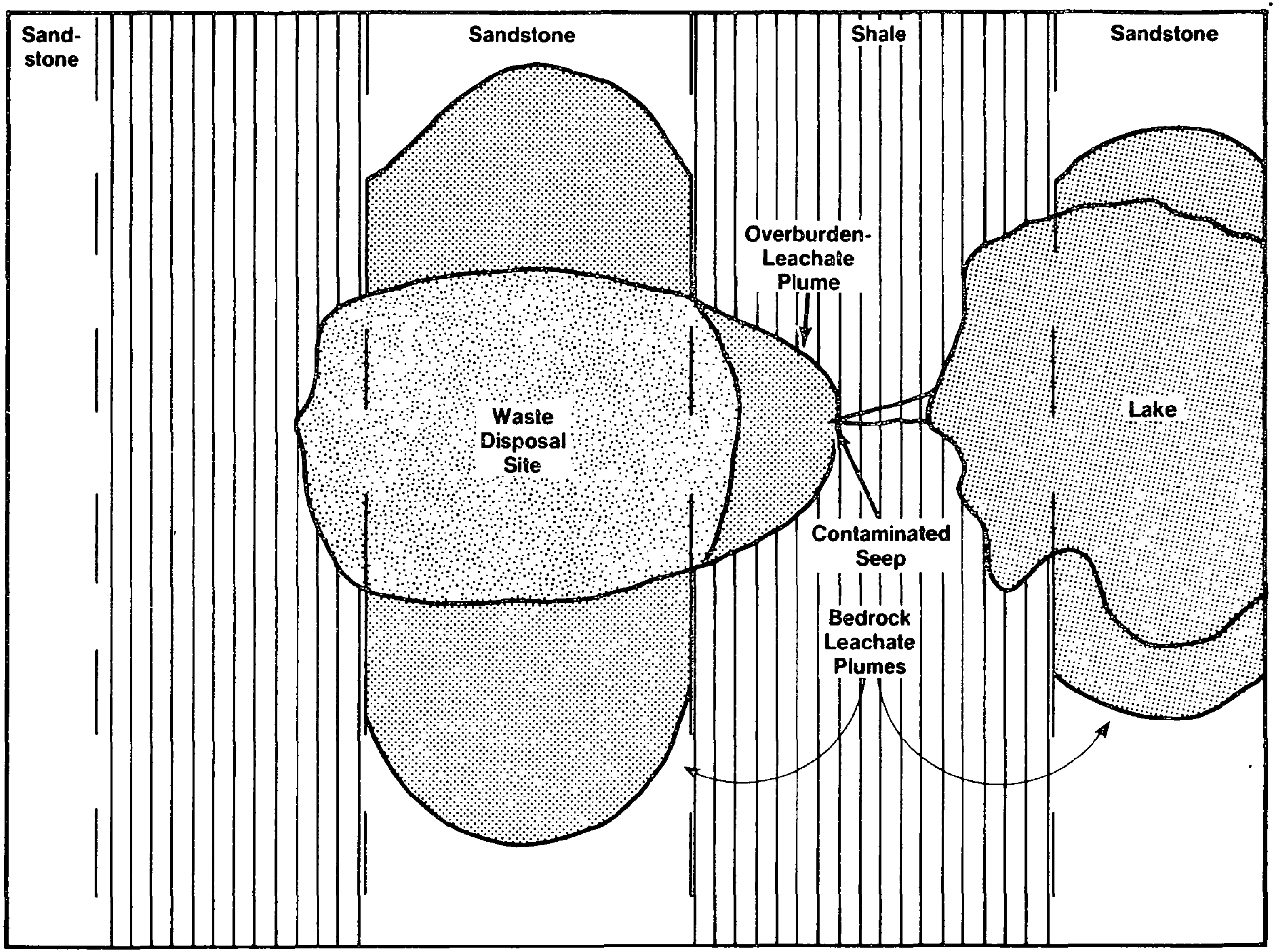


After: Repa and Kufs, 1985

Monitoring System for Assessing Extent of Contamination

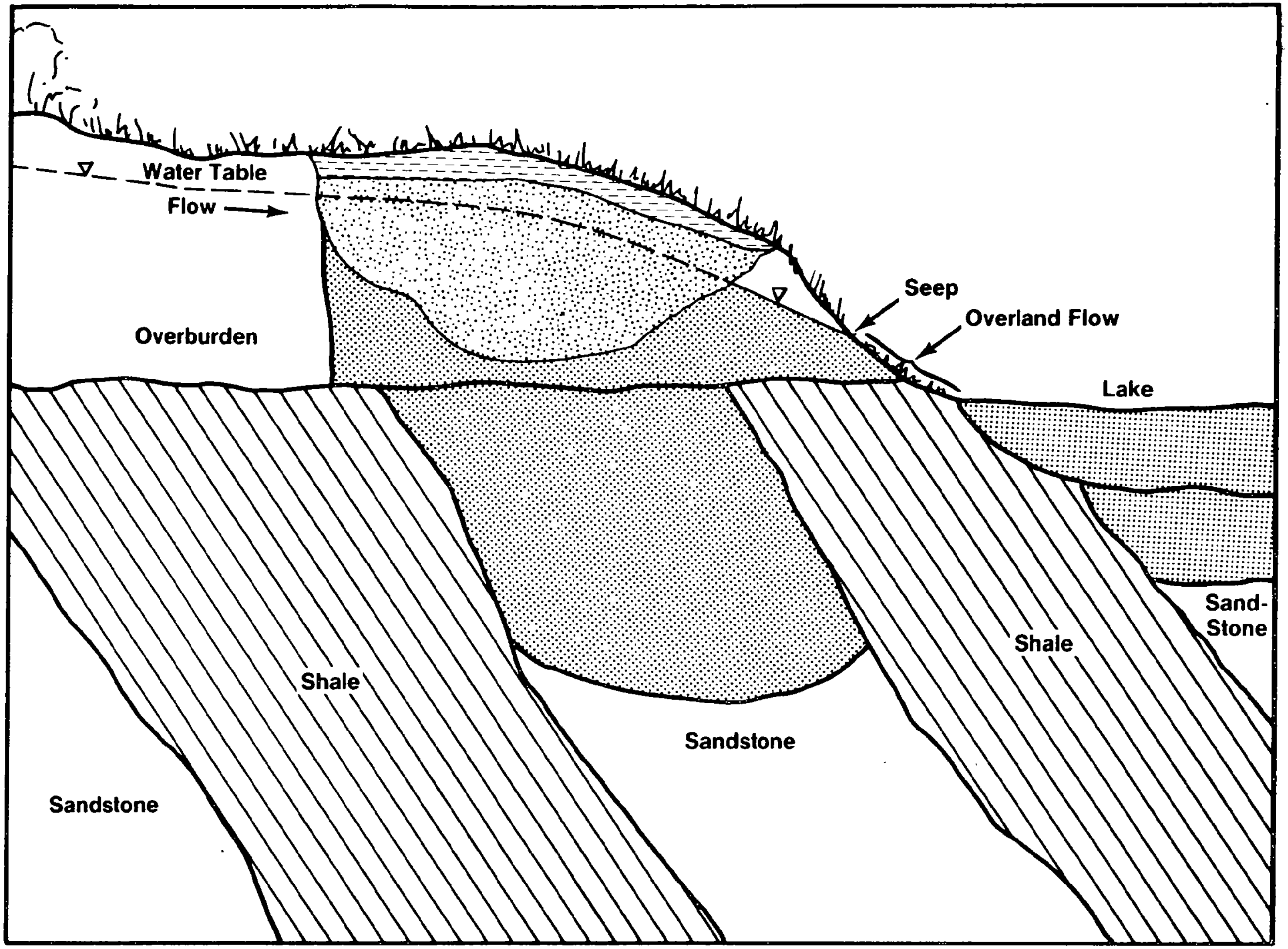


After: Repa and Kufs, 1985



Source Repa and Kufs, 1985

Example of the Effects of Site Geology on Leachate Plume Movement (Map View)



Source Repa and Kufs, 1985

Example of the Effects of Site Geology on Leachate Plume Movement

(Cross Sectional View)

Problems in Monitoring System Design

Planning Problems

- Wells Not Positioned Appropriately
- Screen Lengths Not Correctly Selected
- Periodic Flow Changes Not Addressed

Problems in Monitoring System Design

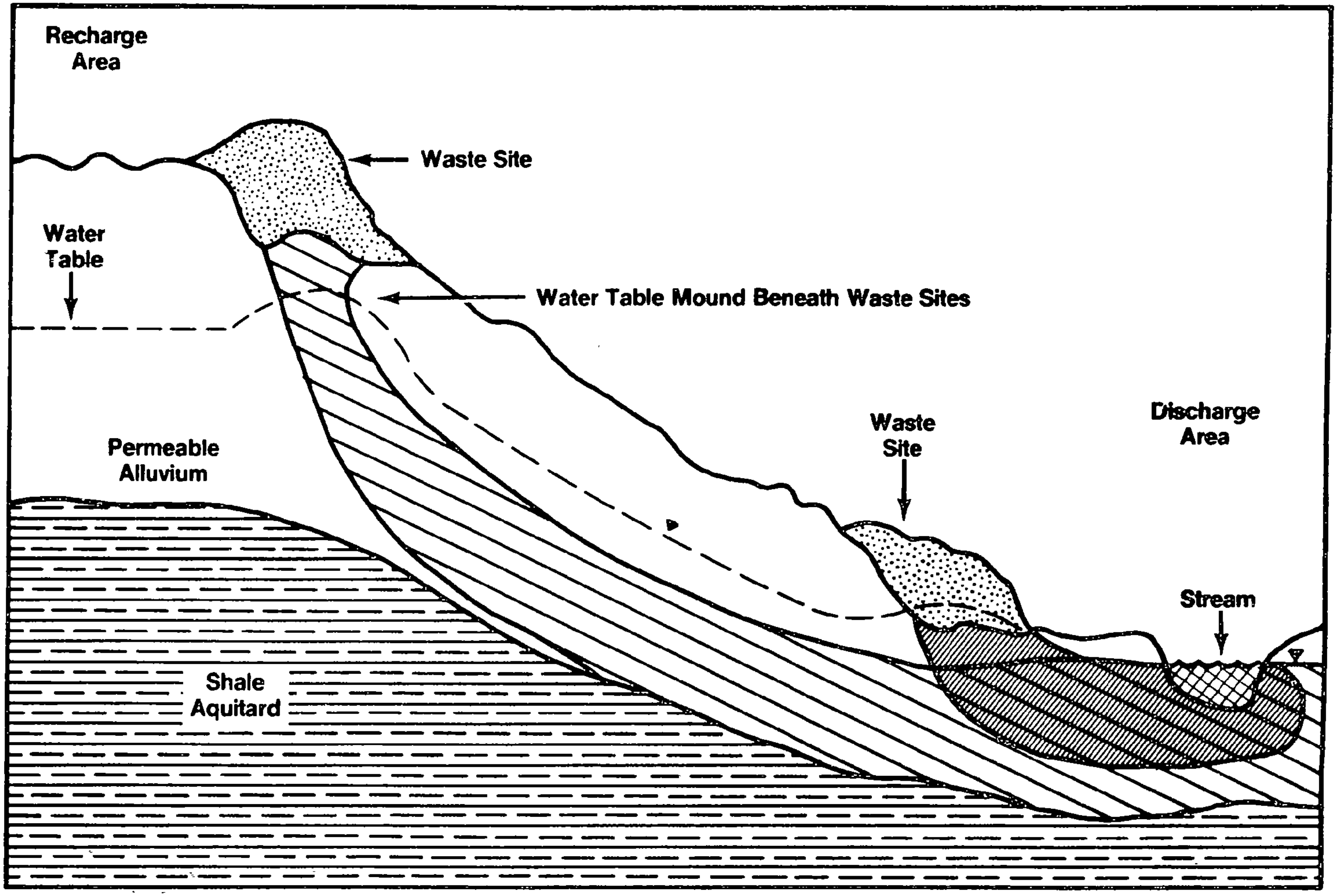
Implementation Problems

- Screen Setting Not Correct
- Well Silts up After Installation
- Gravel Pack Clogged
- Well Seals Leak
- Well Construction Not Documented Adequately

Problems in Monitoring System Design

Site Condition Problems

- Well Does Not Produce
- Water Table Fluctuates Greatly
- Pumping Wells Disrupt Flow Patterns
- Undocumented Waste Sources Confound Results



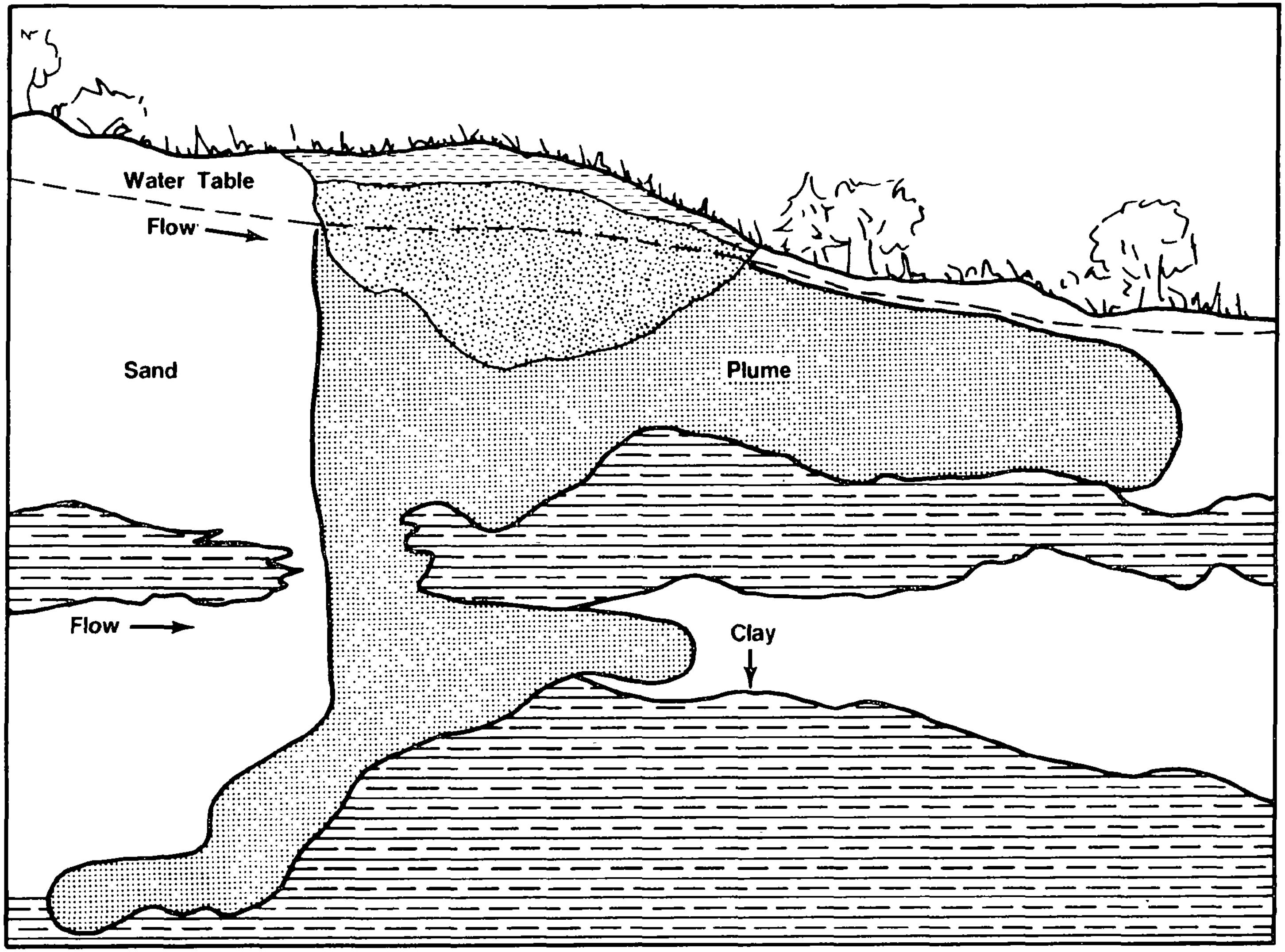
Source: Repa and Kufs, 1985

Example of a Situation in Which Multiple Waste Sources Can Influence Monitoring System Results

Problems in Monitoring System Design

Special Problems

- Irregularly Shaped Aquifers
- Fracture Flow
- Aquifer-Contaminant Interactions
- Non-Aqueous Phase Liquids



Source Repa and Kufs, 1985

Example of a Situation in Which High-Density NAPLs Could Migrate Against the Direction of Groundwater Flow

Problems in Monitoring System Design

Special Problems

- Irregularly Shaped Aquifers
- Fracture Flow
- Aquifer-Contaminant Interactions
- Non-Aqueous Phase Liquids

Problems in Monitoring System Design

Approaches to Irregularly Shaped Aquifers

- Evaluate Aquifer Geometry and Thickness Using Background Information; GPR, Seismic, and Resistivity Surveys; and Soil Borings
- Install Monitoring System in Phases
- Conduct Pump Tests to Identify Boundaries
- Install Additional Wells as Appropriate

Problems in Monitoring System Design

Approaches to Contaminant Flow Through Fractures

- Evaluate Fracture Patterns Using Background Information; Aerial Photographs; Measurements of Outcrops and Cores; and Seismic, GPR or Borehole Geophysical Surveys
- Install Monitoring System in Phases
- Conduct Appropriate Aquifer Tests
- Conduct Chemical Tracer Tests
- Install Additional Wells as Appropriate

Problems in Monitoring System Design

Approaches to Aquifer-Contaminant Interactions

- Evaluate Contaminant and Site Geochemistry Using Background Information
- Install Monitoring System in Phases
- Conduct Laboratory and Field Studies as Appropriate
- Use Theoretical or Statistical Models to Evaluate Monitoring System Data
- Install Additional Wells as Appropriate

Problems in Monitoring System Design

Approaches to Non-Aqueous Phase Liquids

- Low-Density NAPLs: Use Soil-Gas Surveys
  Soil Borings and Methods for
  Mapping Water Table Surfaces
- High-Density NAPLs: Use GPR, Seismic, and Resistivity
  Surveys and Borings to
  Map Site Stratigraphy
- Install Monitoring System in Phases
- Install Additional Wells as Appropriate

MONITORING SYSTEM INSTALLATION

- DATA OBJECTIVES
- WELL DESIGN CONTROLS
- CONSTRUCTION METHODS
- WELL CONSTRUCTION MATERIALS
- INSTALLATION EXAMPLES

DATA OBJECTIVES

- HYDRAULIC PARAMETERS
- WATER-LEVEL DATA
- WATER-QUALITY DATA

HYDRAULIC PARAMETERS

- HYDRAULIC CONDUCTIVITY (K)
- TRANSMISSIVITY (T) AND STORATIVITY (S)
- HOMOGENIETY/BARRIERS
- LEAKANCE

K-TEST DESIGN CONSIDERATIONS

- ISOLATE TEST ZONE
- DEVELOP ZONE AND PACK
- SCREEN DESIGN ALLOWS ADEQUATE FLOW
- COMPATIBLE WITH OTHER USES

PUMPING TEST DESIGN CONSIDERATIONS

- PUMPING WELL
- OBSERVATION WELL

PUMPING WELL

- ONE WELL
- FULLY PENETRATING SCREEN
- LARGE DIAMETER
- STEEL OR PVC
- WRAPPED SCREEN
- MINIMAL OTHER USES

OBSERVATION WELL

- SEVERAL WELLS
- SCREEN SAME INTERVAL AS PUMPING WELL
- STEEL OR PVC
- MINIMAL OTHER USES

HOMOGENIETY/BARRIERS

- MODIFIED PROCEDURES FOR TRANSMISSIVITY TESTS
- MAY REQUIRE MORE OBSERVATION WELLS

LEAKANCE

- MODIFIED PROCEDURES FOR TRANSMISSIVITY TESTS
- VERTICAL FLOW
- SHORT SCREENS ADEQUATE
- WELL NESTS/CLUSTERS
- COMPATIBLE WITH OTHER USES

WATER-LEVEL DATA

- TYPES OF WATER LEVEL MEASUREMENTS
- LEVEL MEASUREMENT DESIGN CONSIDERATIONS

LEVEL MEASUREMENT DESIGN CONSIDERATIONS

- DIAMETER OF MEASURING DEVICE
- ISOLATE SCREEN ZONE
- CLUSTERS
- DRILLED WELLS OR DRIVE POINTS
- SURVEYING IMPORTANT
- COMPATIBLE WITH OTHER USES

WATER-QUALITY DATA

- PURPOSE FOR COLLECTING WATER-QUALITY DATA
- METHODS OF COLLECTING WATER-QUALITY DATA

PURPOSE FOR COLLECTING WATER-QUALITY DATA

- IDENTIFICATION/DETECTION
- CONFIRMATION/ASSESSMENT
- COMPLIANCE/INVESTIGATION

METHODS OF COLLECTING WATER-QUALITY DATA

- WELLS
- LYSIMETERS
- "BARCAD" SAMPLERS

WELL DESIGN CONTROLS

- PLAN OBJECTIVE
- REGULATORY CRITERIA
- GEOLOGIC ENVIRONMENT
- CONTAMINANT CHARACTERISTICS
- OTHER CONSIDERATIONS IN WELL DESIGN
- EXAMPLE DESIGNS

PLAN OBJECTIVE

- HYDRAULIC PARAMETERS
- WATER-LEVEL DATA
- WATER-QUALITY DATA
- MULITIPLE PURPOSES

REGULATORY CRITERIA

- WELL CONSTRUCTION METHODS
- WELL SIZE
- ANNULUS SEALS
- MATERIAL TYPES

GEOLOGIC ENVIRONMENT

- LITHOLOGY
- DEPTH
- MULITPLE AQUIFER

CONTAMINANT CHARACTERISTICS

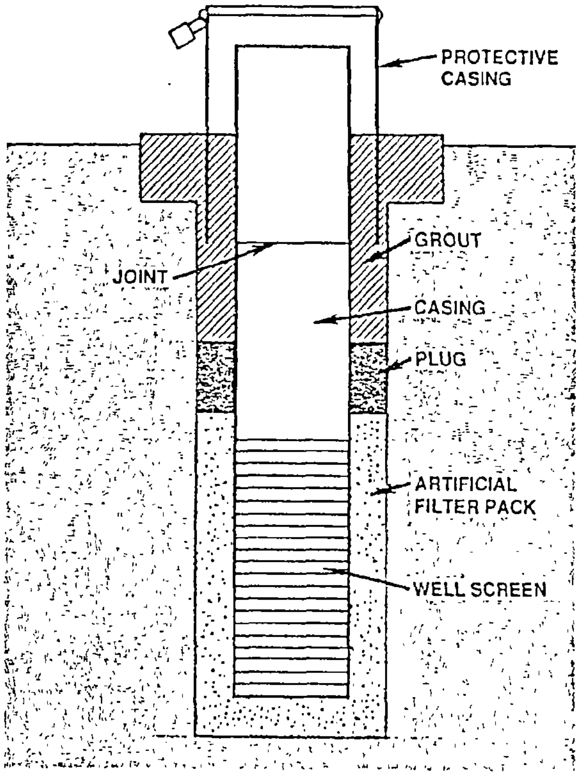
- IMMISCIBLE ORGANICS
- DISSOLVED CONSTITUENTS
- SORPTION/DESORPTION WITH WELL MATERIALS

OTHER CONSIDERATIONS IN WELL DESIGN

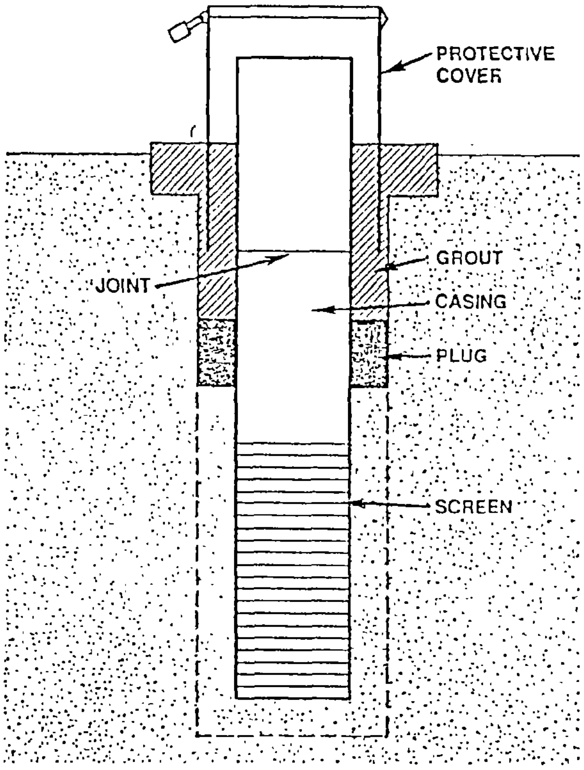
- BOREHOLE SIZE
- MONITORING DEVICE (PUMP)
- DEPTH
- DRILLING METHOD
- MULTIPLE CASINGS

EXAMPLE DESIGNS

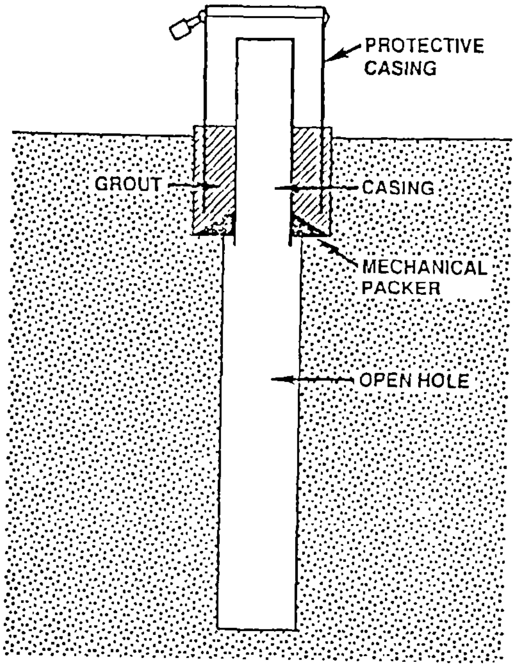
- UNCONSOLIDATED MATERIAL
- HARD ROCK
- MULTLPLE CASED
- WELL NESTS/WELL CLUSTERS
- LONG VS SHORT SCREENS



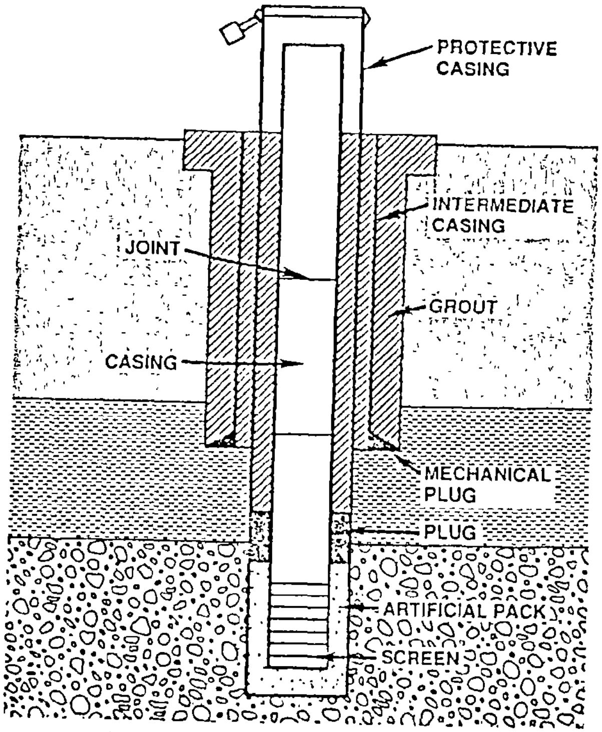
SCHEMATIC DIAGRAM—
ARTIFICIAL PACK WELL



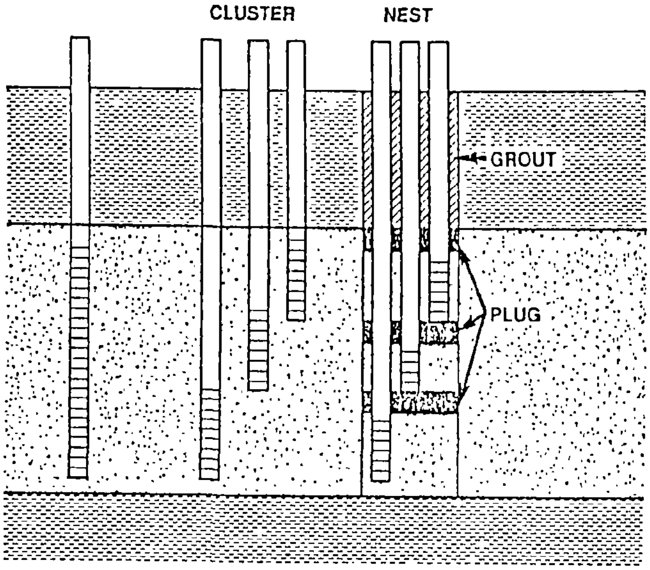
SCHEMATIC DIAGRAM—
NATURALLY PACKED WELL



SCHEMATIC DIAGRAM—
OPEN HOLE CONSTRUCTION



SCHEMATIC DIAGRAM—
MULTIPLE-CASED WELL



SCHEMATIC DIAGRAM—
LONG vs. SHORT SCREENS

CONSTRUCTION METHODS

- COMMON WELL DRILLING METHODS
- APPLICATION
- CABLE TOOL
- ROTARY (ALL FLUIDS)
- AUGERS

COMMON WELL DRILLING METHODS

- CABLE TOOL
- ROTARY
- AUGER

APPLICATION

- GEOLOGIC FORMATION
- COMPATIBILITY WITH WELL CONSTRUCTION TECHNIQUES
- SITE CONDITIONS
- IDENTIFICATION/SAMPLING OF FORMATION AND AQUIFER
- RATE OF PENETRATION

CABLE TOOL

- MECHANICS
- OPERATIONAL CHARACTERISTICS
- ADVANTAGES/DISADVANTAGES

ROTARY (ALL FLUIDS)

- MECHANICS
- OPERATIONAL CHARACTERISTICS
- ADVANTAGES/DISADVANTAGES

AUGERS

- MECHANICS
- OPERATIONAL CHARACTERISTICS
- ADVANTAGES/DISADVANTAGES

WELL CONSTRUCTION MATERIALS

- DRILLING FLUIDS
- WELL CASING
- WELL SCREENS
- FILTER PACK
- ANNULUS SEALERS
- WELL DEVELOPMENT
- ABOVE-GRADE COMPLETION

DRILLING FLUIDS

- PURPOSE OF DRILLING FLUIDS
- MAJOR TYPES OF DRILLING FLUIDS
- PROBLEMS CAUSED BY DRILLING FLUIDS

MAJOR TYPES OF DRILLING FLUIDS

- WATER BASED DRILLING FLUIDS
- AIR BASED DRILLING FLUIDS
- OIL BASED AND OTHERS

WATER BASED DRILLING FLUIDS

- CLEAN WATER
- WATER WITH CLAY ADDITIVES
- WATER WITH POLYMERIC ADDITIVES
- WATER WITH CLAY AND POLYMER ADDITIVES

AIR BASED DRILLING FLUIDS

- DRY AIR
- MIST; DROPLETS OF WATER ENTRAINED IN AIRSTREAM
- FOAM; AIR BUBBLES SURROUNDED BY SURFACTANTS

PROBLEMS CAUSED BY DRILLING FLUIDS

- EFFECTS ON SAMPLE QUALITY
- EFFECTS ON GROUTING, PACKING, ETC
- EFFECTS ON WELL DEVELOPMENT

EFFECTS ON SAMPLE QUALITY

- DILUTION
- SORPTION/DESORPTION
- REDOX CHANGE
- BACTERIOLOGICAL
- ADDITIVES

WELL CASING

- PURPOSE OF CASING
- CONSIDERATIONS IN SELECTING CASING MATERIALS
- MATERIALS USED FOR CASINGS

CONSIDERATIONS IN SELECTING CASING MATERIALS

- CONTAMINANTS SAMPLED
- INERTNESS
- STRENGTH
- INSTALLATION
- COST

MATERIALS USED FOR CASINGS

- PVC (POLYVINYL CHLORIDE)
- FLUOROCARBONS
- MILD STEEL
- STAINLESS STEEL
- OTHERS

ADVANTAGES OF PVC

- LIGHT WEIGHT
- READILY AVAILABLE
- EXCELLENT TO GOOD FOR MANY ORGANICS AND INORGANICS

DISADVANTAGES OF PVC

- WEAKER, LESS RIGID, AND TEMPERATURE SENSITIVE
- MAY REACT WITH SOME ORGANIC COUPOUNDS
- POOR CHEMICAL RESISTANCE TO SOME ORGANIC COMPOUNDS

ADVANTAGES OF FLUOROCARBONS

- LIGHT TO MODERATE WEIGHT
- HIGH IMPACT STRENGTH
- CHEMICALLY INERT TO MOST ORGANIC AND INORGANIC COMPOUNDS

DISADVANTAGES OF FLUOROCARBONS

- LOW TENSILE STRENGTH
- EXPENSIVE
- LIMITED EXPERIENCE

ADVANTAGES OF MILD STEEL

- STRONG, RIGID, NOT TEMPERATURE SENSITIVE
- READILY AVAILABLE
- EXPERIENCE IN SOME CONSTRUCTION SEGMENTS

DISADVANTAGES OF MILD STEEL

- HEAVY
- POOR RESISTANCE TO INORGANIC ACIDS
- REACTIVE WITH METALS
- CUTTING OILS

ADVANTAGES OF STAINLESS STEEL

- HIGH STRENGTH
- RESISTANT TO CORROSION
- MINIMAL REACTION WITH ORGANICS
- EXPERIENCE IN SOME CONSTRUCTION SEGMENTS

DISADVANTAGES OF STAINLESS STEEL

- HEAVY
- MAY LEACH SOME METALS
- CUTTING OILS

OTHERS

- POLYPROPYLENE
- FIBERGLASS
- ABS

WELL SCREENS

- PURPOSE OF SCREENS
- CONSIDERATIONS IN SCREEN DESIGN
- SLOT SIZE
- LENGTH
- INTEGRATED WITH FILTER PACK AND DEVELOPMENT
- COMPOSITE SCREEN/CASING DESIGN
- POROUS PVC OR FLOUROCARBON

CONSIDERATIONS IN SCREEN DESIGN

- MAXIMIZE RAPID SAMPLE RECOVERY
- RETAIN FILTER PACK OR NATURAL FORMATION
- SLOT OPENINGS SHOULD BE OF NON-PLUGGING DESIGN
- FACILITATE EFFECTIVE DEVELOPMENT

SLOT SIZE

- 0.006 INCHES TO 0.020 INCHES
- MAXIMIZE OPEN SPACE
- 15 TO 20 PERCENT OPEN AREA (MINIMUM)
- WRAPPED SCREENS HAVE HIGHEST PERCENTAGE OPEN SPACE

FILTER PACK

- PURPOSE OF FILTER PACK
- NATURAL FORMATION PACKED WELLS
- ARTIFICIALLY PACKED WELLS
- OPEN HOLE COMPLETION

NATURAL FORMATION PACKED WELLS

- RELIES ON NATURALLY OCCURRING FORMATION MATERIAL
- BEST IN HOMOGENEOUS FORMATIONS
- SAND AND GRAVEL SIZE AQUIFER MATERIAL
- REQUIRES EXTENSIVE DEVELOPMENT TIME
- SLOT SIZE SHOULD MAXIMIZE RETENTION OF AQUIFER MATERIAL

ARTIFICIALLY PACKED WELLS

- GEOLOGIC SETTINGS FOR ARTIFICIALLY PACKED WELLS
- DESIGN CONSIDERATIONS FOR ARTIFICIAL PACK
- FILTER SOCKS AND FILTER FABRIC

GEOLOGIC SETTINGS FOR ARTIFICIALLY PACKED WELLS

- FINED GRAINED (CLAY, SILT, ETC)
- HETEROGENEOUS UNCONSOLIDATED
- INCOMPETANT ROCK

DESIGN CONSIDERATIONS FOR ARTIFICIAL PACK

- GRAIN-SIZE DISTRIBUTION OF SCREENED ZONE
- CLEAN
- WELL-ROUNDED GRAINS
- INERT COMPOSITION
- UNIFORM SIZE
- SCREEN SLOT SIZE RETAIN HIGH PERCENTAGE OF PACK
- ANNULUS SIZE
- DRILLING METHOD
- EXTENT ABOVE AND BELOW SCREEN

OPEN HOLE COMPLETION

- SCREEN WITH NO PACK MATERIAL
- NO SCREEN OR PACK MATERIAL

ANNULUS SEALERS

- PURPOSE OF ANNULUS SEALERS
- DESIGN CONSIDERATIONS FOR SELECTING ANNULUS SEALERS
- MATERIALS USED AS ANNULUS SEALERS
- PLUGS
- GROUTS

PURPOSE OF ANNULUS SEALERS

- PREVENT VERTICAL MIGRATION OF CONTAMINANTS
- STABLIZE BOREHOLE
- SUPPORT CASING

DESIGN CONSIDERATIONS FOR SELECTING ANNULUS SEALERS

- BOREHOLE SIZE
- DEPTH
- COLLAPSE STRENGTH OF CASING
- WATER QUALITY
- DRILLING METHOD

MATERIALS USED AS ANNULUS SEALERS

- BENTONITE
- CEMENT
- MECHANICAL DEVICES (PACKERS, BASKETS, CENTRALIZERS)

ADVANTAGES OF BENTONITE

- READILY AVAILABLE
- INEXPENSIVE

DISADVANTAGES OF BENTONITE

- CHEMICALLY REACTIVE (METALS)
- DIFFICULT TO EVALUATE SEAL
- BONDING WITH CASING DIFFICULT

ADVANTAGES OF CEMENT

- AVAILABLE
- INEXPENSIVE
- BONDS WELL WITH CASING
- BOND CAN BE TESTED

DISADVANTAGES OF CEMENT

- CHEMICALLY REACTIVE (pH)
- EQUIPMENT INTENSIVE
- SHRINKS/CRACKS
- GEOTECH DRILLERS HAVE LITTLE EXPERIENCE

PLUGS

- PURPOSE OF PLUGS
- PLACEMENT OF PLUGS
- MATERIALS USED FOR PLUGS

MATERIALS USED FOR PLUGS

- BENTONITE
- MECHANICAL PACKERS
- SAND

GROUTS

- METHODS FOR PLACEMENT OF GROUT
- MATERIALS USED AS GROUT
- GROUTING PRACTICES

GROUTING PRACTICES

- FULLY GROUTED ANNULUS
- PARTIALLY GROUTED ANNULUS
- MULITPLE CASED WELLS

WELL DEVELOPMENT

- PURPOSE OF WELL DEVELOPMENT
- CONSIDERATIONS FOR SELECTING DEVELOPMENT METHOD
- METHODS OF WELL DEVELOPMENT

PURPOSE OF WELL DEVELOPMENT

- PRODUCE SEDIMENT FREE WATER
- MINIMIZE EFFECTS OF DRILLING FLUIDS AND BOREHOLE DAMAGE
- MAXIMIZE WELL YIELD

CONSIDERATIONS FOR SELECTING DEVELOPMENT METHOD

- WELL COMPLETION CONFIGURATION
- SLOT SIZE AND SLOT CONFIGURATION
- DRILLING FLUID USED
- TYPE OF FORMATION
- HANDLING OF DEVELOPMENT FLUIDS

METHODS OF WELL DEVELOPMENT

- OVER PUMPING
- BACKWASHING
- MECHANICAL SURGING
- AIR
- JETTING
- OTHERS

ABOVE-GRADE COMPLETION

- LOCKING STEEL COVER
- GUARD POSTS
- CONCRETE PAD
- IDENTIFICATION NUMBER
- SURVEYING

LOCKING STEEL COVER

- SECURITY
- PROTECTION AGAINST IMPACTS
- WEEP HOLE

GUARD POSTS

- PROTECTION AGAINST IMPACTS
- TRIANGULAR ARRAY
- BRIGHTLY PAINTED

CONCRETE PAD

- DESIGNED TO PREVENT FREEZE/THAW CRACKING
- FLAT WORKING SURFACE

IDENTIFICATION NUMBER

- EASILY VISIBLE
- INSIDE PROTECTIVE COVER

SURVEYING

- LATERAL
- VERTICAL
- MARKED MEASURING POINT

INSTALLATION EXAMPLES

- CASE 1
- CASE 2
- CASE 3
- CASE 4

CASE 1

GEOLOGY

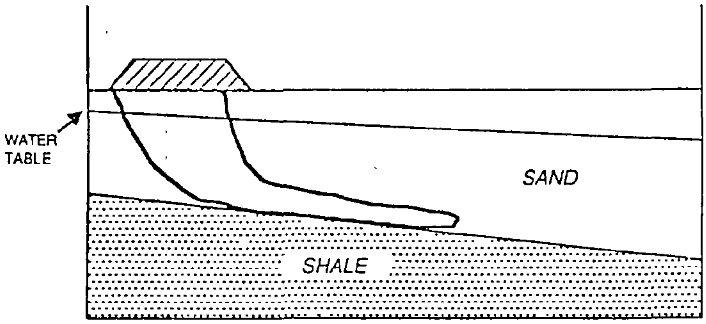
- 60 FT. SAND OVER
- DIPPING SHALE BEDROCK

HYDROGEOLOGY

- WATER TABLE AT 20 FT.
- FLOW DIRECTION SAME AS DIPPING BEDROCK
- SAND K=10^{-3} CM/SEC, SHALE K=10^{-8} CM/SEC

PLUME

- INSOLUBLE IN WATER
- ORGANIC COMPOUNDS
- CONTAMINANTS DENSER THAN WATER



CASE 2

GEOLOGY

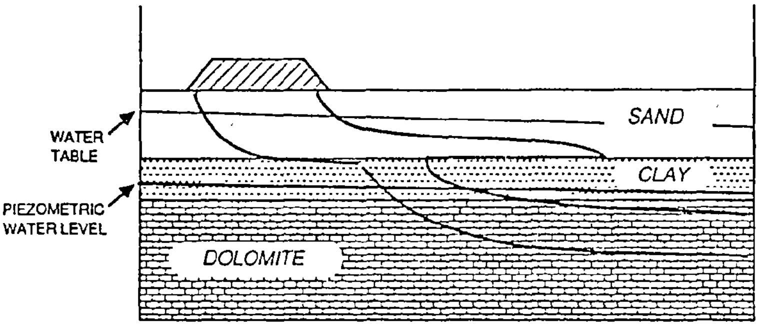
- 25 FT. SAND OVER
- 15 FT. SHALE OVER
- MASSIVE DOLOMITE

HYDROGEOLOGY

- WATER TABLE AT 10 FT.
- PIEZOMETRIC PRESSURE IN DOLOMITE IS LOWER THAN SAND AQUIFER
- FLOW DIRECTION SAME IN BOTH AQUIFERS
- SAND K=10^{-6} CM/SEC, SHALE K=10^{-8} CM/SEC, DOLOMITE K=10^{-5} CM/SEC

PLUME

- SOLUBLE IN WATER
- ORGANIC AND INORGANIC COMPOUNDS



CASE 3

GEOLOGY

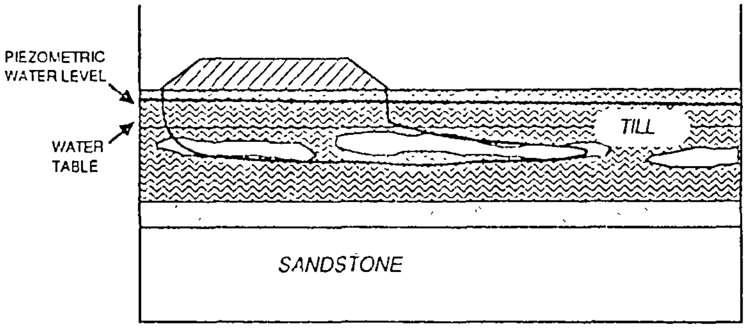
- 35 FT. HETEROGENOUS GLACIAL TILL OVER
- 5 TO 10 FT SAND AND WEATHERED SANDSTONE OVER
- SANDSTONE BEDROCK

HYDROGEOLOGY

- WATER TABLE AT 10 FT
- PIEZOMETRIC PRESSURE IN SANDSTONE AT 5 FT. (CONFINED)
- NATURAL FLOW DIRECTION IN BOTH AQUIFERS SAME DIRECTION
- SAND&SILT LENSES&STRINGERS $K=10^{-4}$ CM/SEC, CLAY $K=10^{-8}$ CM/SEC, SANDSTONE $K=10^{-3}$ CM/SEC

PLUME

- SOLUBLE IN WATER
- INORGANIC
- SOME CONTAMINANTS ARE ALSO NATURALLY OCCURING



CASE 4

GEOLOGY

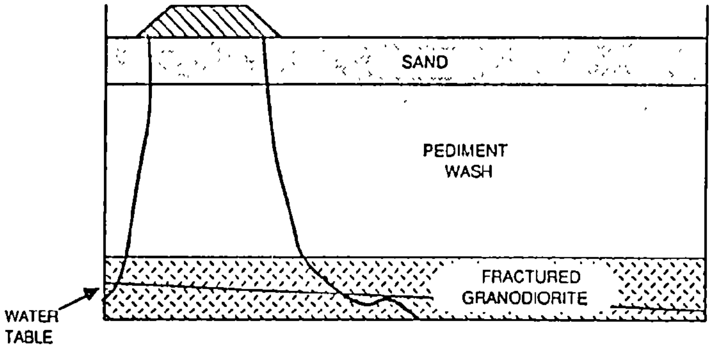
- 30 FT WIND-BLOWN SAND OVER
- 70 FT. UNCONSOLIDATED SANDS AND GRAVELS OVER
- 10 FT WEATHERED GRANODIORITE BEDROCK (SAPROLITE) OVER
- FRACTURED GRANODIORITE

HYDROGEOLOGY

- DEPTH TO SATURATED PORESPACES 130 FT.
- UNSATURATED VERTICAL FLOW TO 130 FT. WITH NO INTERVENING AQUITARDS
- FLOW IS MULTI-DIRECTIONAL IN FRACTURED GRANODIORITE WITH REGIONAL FLOW UNI-DIRECTIONAL
- UNCONSOLIDATED MATERIAL $K=10^{-3}$ CM/SEC, FRACTURED GRANODIORITE $K=10^{-4}$ CM/SEC

PLUME

- SOLUBLE IN WATER
- ORGANIC AND INORGANIC COMPOUNDS



NOT DISCUSSED IN DETAIL

- **Sampling devices (materials and configuration)**
- **Sample containers (materials and configuration)**
- **Blanks, replicates, spikes**
- **Decontamination**
- **Sample preservation and handling**
- **Documentation**
- **Data presentation**
- **Formal QA/QC procedures**

NEGOTIATED TECHNOLOGY, NOT SCIENCE

• **Objective**	• **Requirements**
–Assure that facilites have no deleterious effects, therefore	
–analyze samples representative of adjacent environments, therefore	–Definition of representativeness
–assure representation by removing errors associated with sampling, then	–Identification of sources/ ranges of error
–evaluate deleterious effects, but	–Concentration standards, monitoring protocols
–within reasonable time and cost, at a large number of facilities	–Informed opinion, politics, judgement (state-of-the-practice)

REPRESENTATIVENESS

- **Always requires definition of spatial and temporal scale, and**
- **Can never be linked to an unequivocal determination of accuracy**
- **Therefore, there is a tendency to identify representativeness with**
  - –Standard procedures
  - –Reproducibility of results

SOURCES OF ERROR

- Materials
- Mechanisms
- Procedures
- Human Fault

MONITORING PROTOCOLS

- **Constituents/Properties to be Analyzed**
    - From indicator to complete
- **Frequency of Analyses**
    - Trading space for time
- **Purpose of Analyses**
    - Detection
    - Assessment
    - Compliance
    - Performance
    - Corrective Action

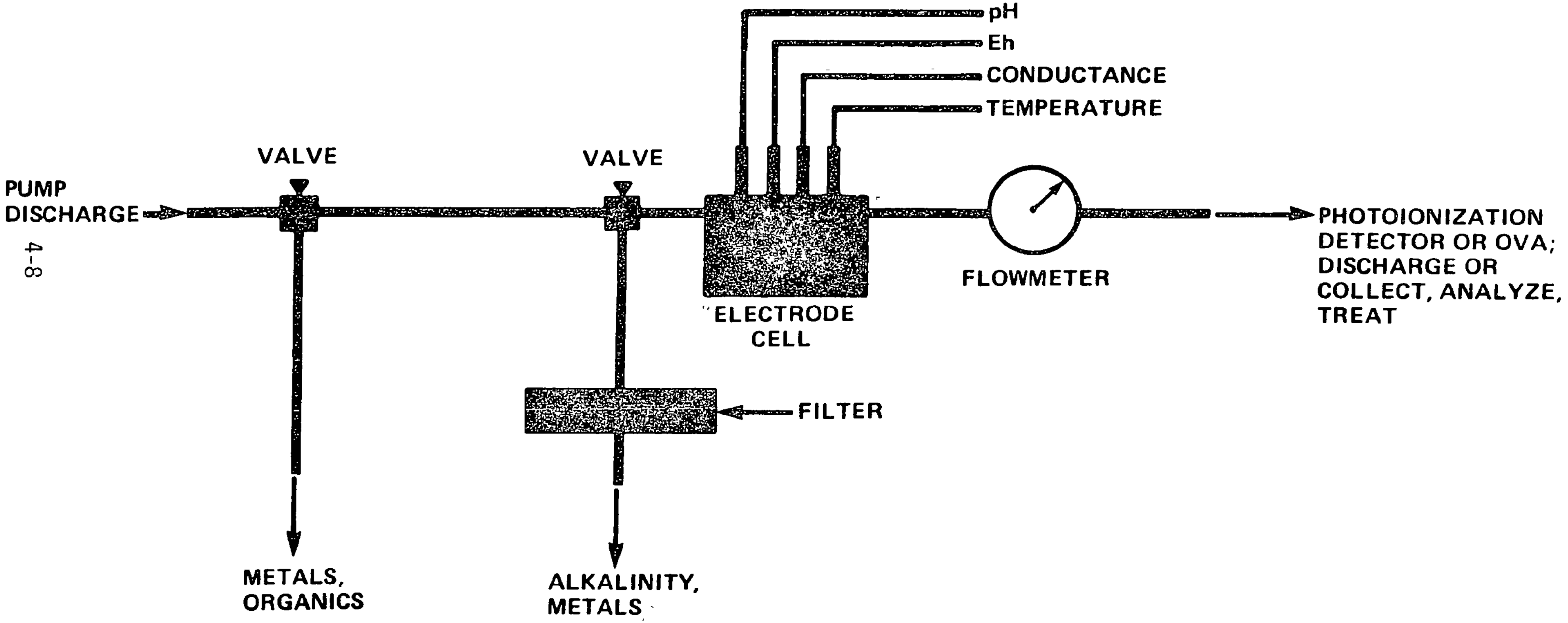
CONCENTRATION STANDARDS

- SDWA
- Clean Water Act
- State Requirements
- Cancer Risk Levels
- Alternate Concentration Limits
- Background

BASIC SAMPLING STEPS

- Measure fluid level(s)
- Detect/sample immiscibles
- Purge well
- Measure field parameters
- Obtain sample

SAMPLE COLLECTION TRAIN



SOURCES OF UNCERTAINTY

- **What is being sampled?**
- **Where and when is it from?**
- **What happens when the sampling device is introduced/activated?**
- **What happens as/after the sample leaves the well?**

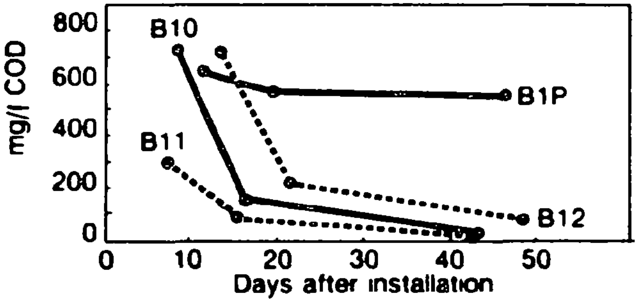
CHEMICAL COMPOSITIONS OF DRILLING ADDITIVES

(From Brobst and Bubka, 1986)

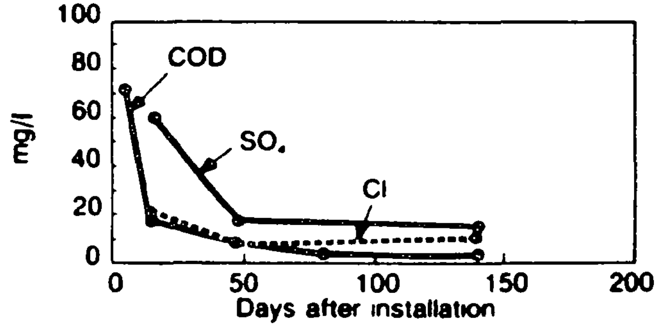
Bentonite	**Approximate Percent**
–Montmorillonite	85
–SiO_2	7
–K,Na,Ca–Aluminosilicates	5
–Illite	2
–$CaCO_3$	0.5
–$CaSO_4 \cdot 2H_2O$	0.5
–Sodium Polyacrylate	0.01
Guar Bean	
–Galactomannan	80.4
–Water	11
–Protein	4
–Fiber	3
–Ash	1
–Fat	0.5
–Methyl Blue	0.1

EFFECTS OF DRILLING FLUID ON SAMPLE CHEMISTRY

(From Groundwater and Wells, 1986)



(a) Undeveloped



(b) Developed

RECOMMENDED MATERIALS

(From Barcelona et. al., 1984)

1) **Fluorocarbon Resins (e.g., Teflon^{TM})**
2) **Stainless Steel (316, 304)**
3) **Polypropylene**
4) **Polyethylene**
5) **Linear Polyethylene**
6) **Viton ^{TM}**
7) **Conventional Polyethylene**
8) **PVC**

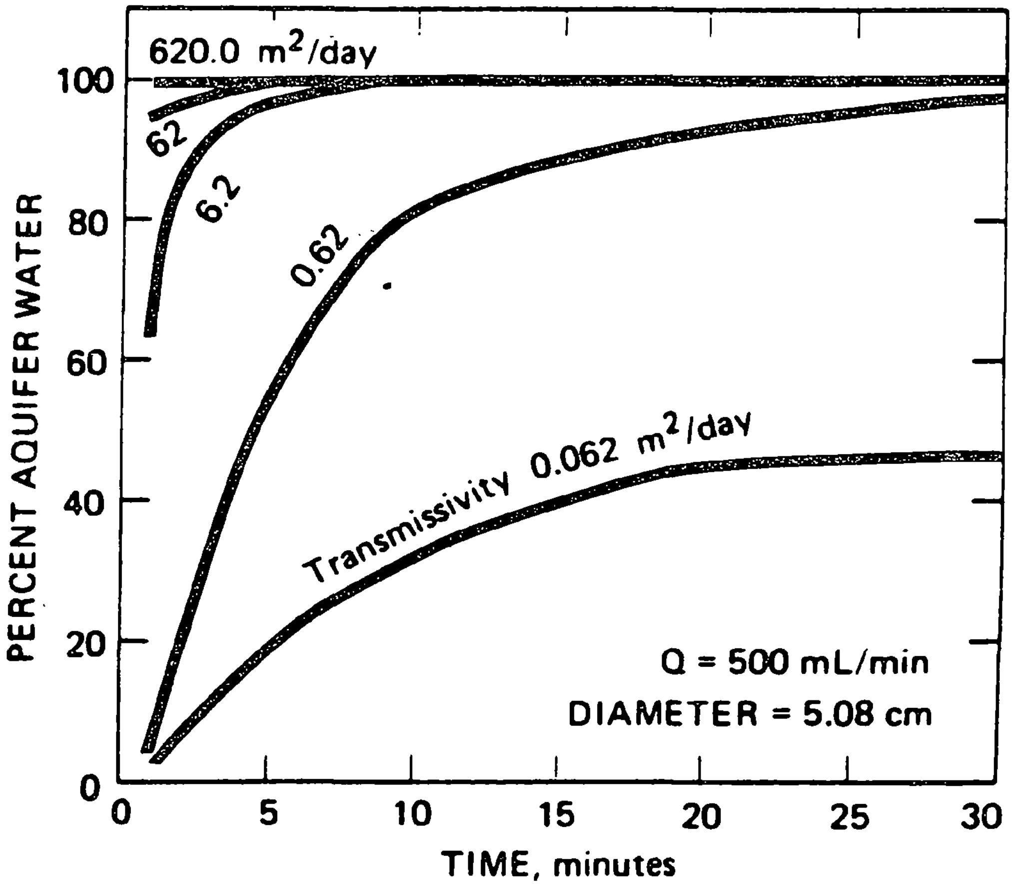
SAMPLE CONTACT RATES (0.4 GPM)

(From Barcelona et. al., 1985)

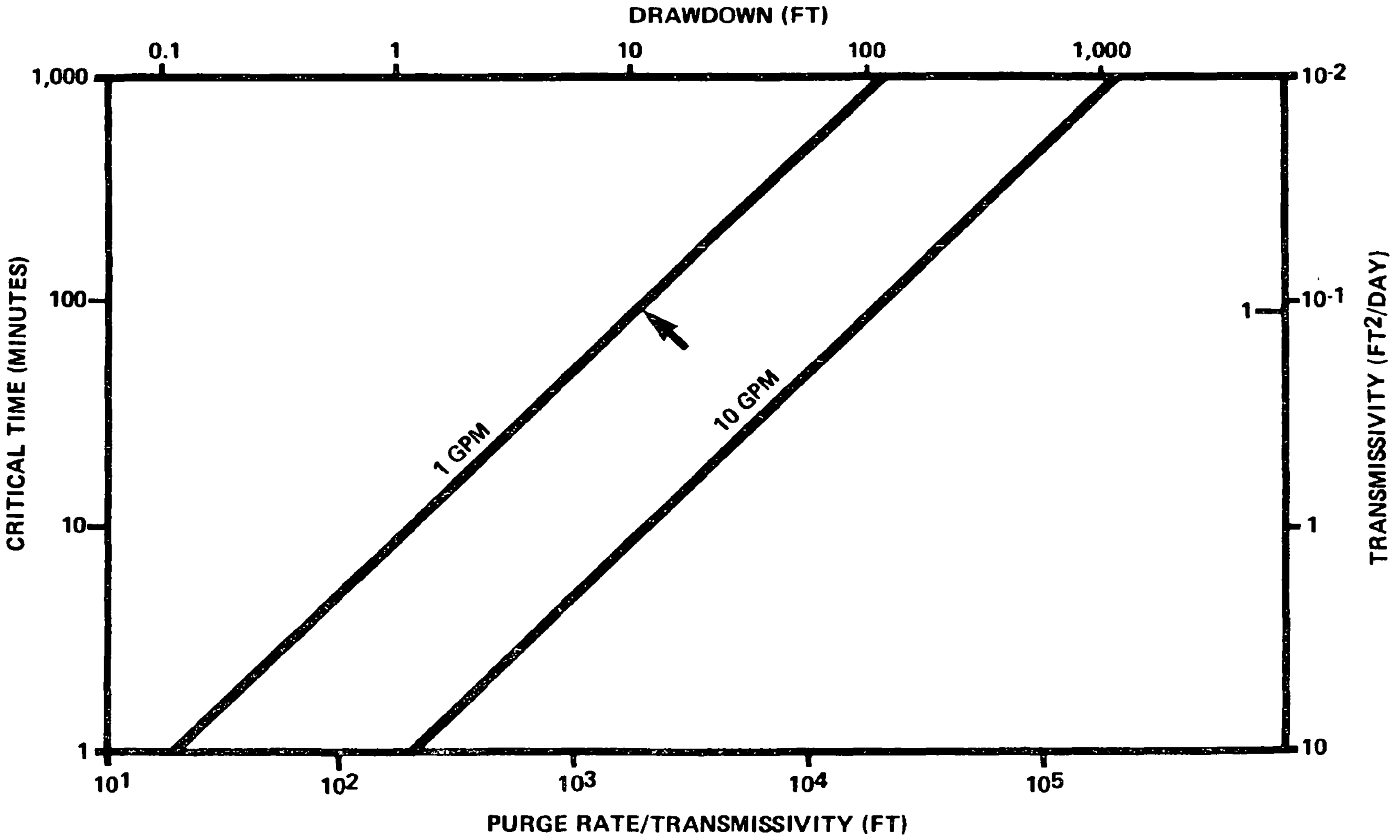
MATERIAL	AQUIFER SOLIDS (SAND)	WELL (2")	TUBING (1/4")
CONTACT RATE (M^2/HR)	66	0.72	4.0
RELATIVE % CONTACT	92	1	6

PERCENT OF AQUIFER WATER VERSUS TIME FOR DIFFERENT TRANSMISSIVITIES

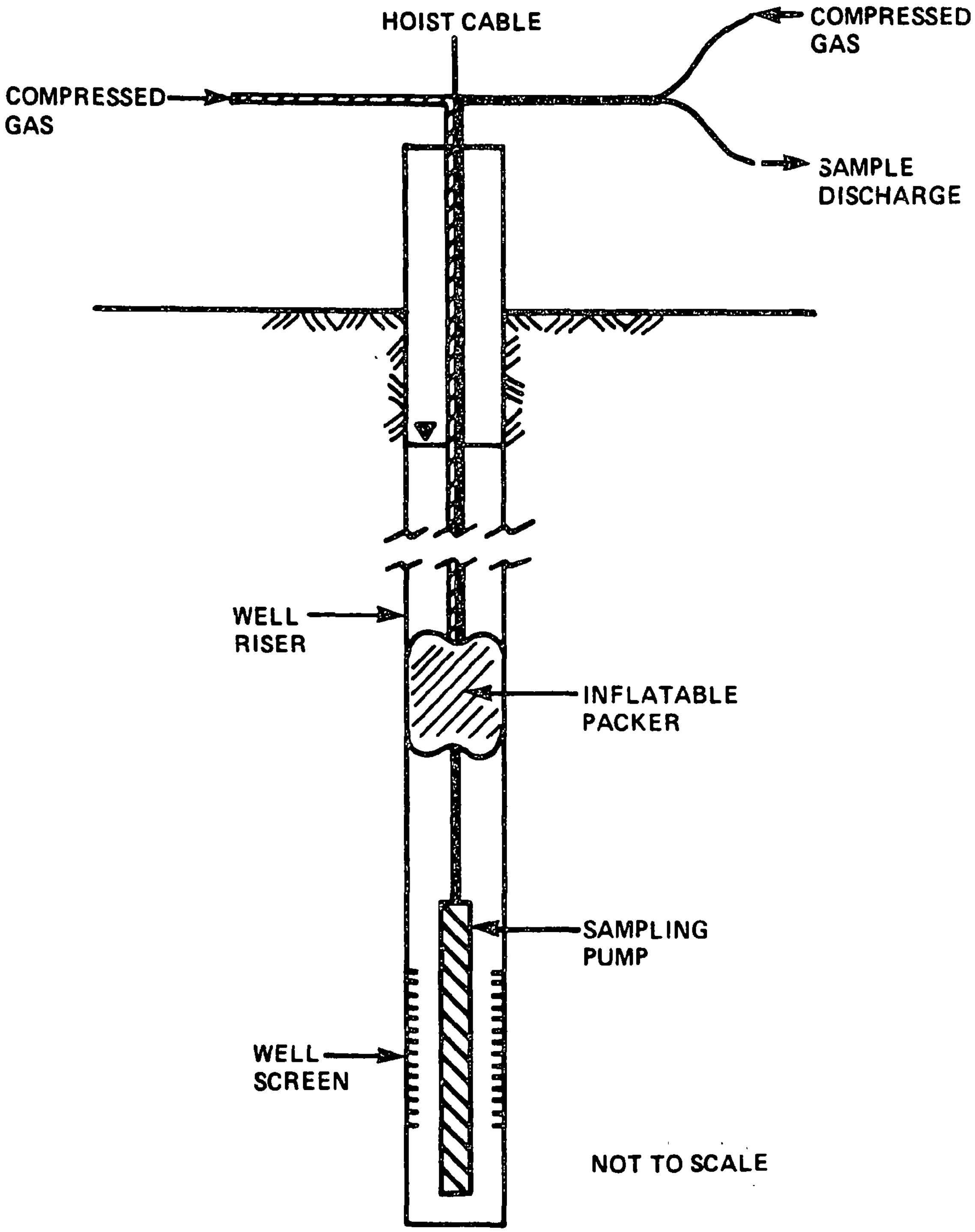
(From Gibb et. al., 1981)



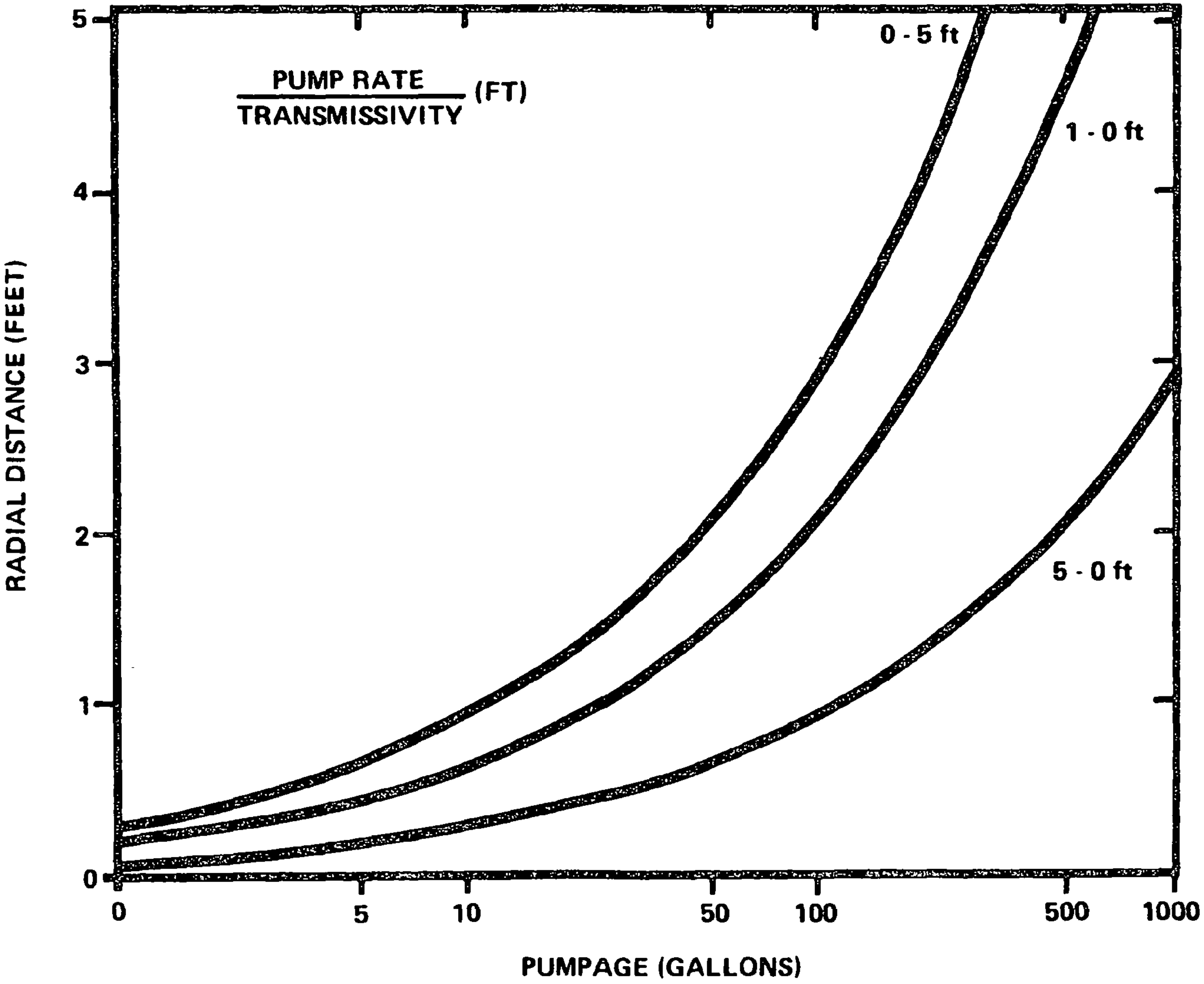
CRITICAL PURGE TIMES (2")



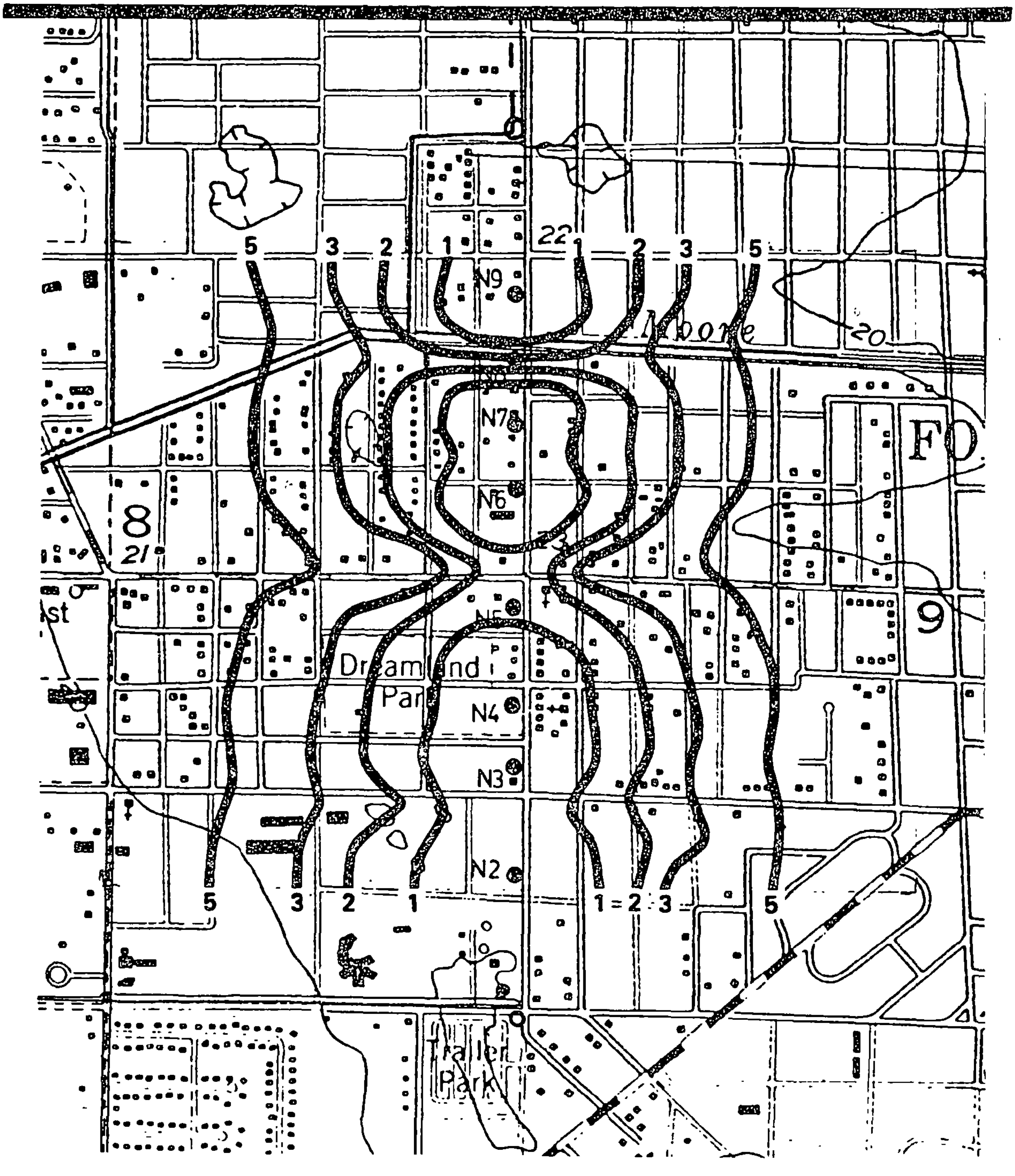
PACKER ISOLATION OF PUMP



DISTANCE OF DRAW VS. PUMPAGE



COMPUTED TRAVEL TIMES (YEARS) IN THE VICINITY OF PUMPING WELLS

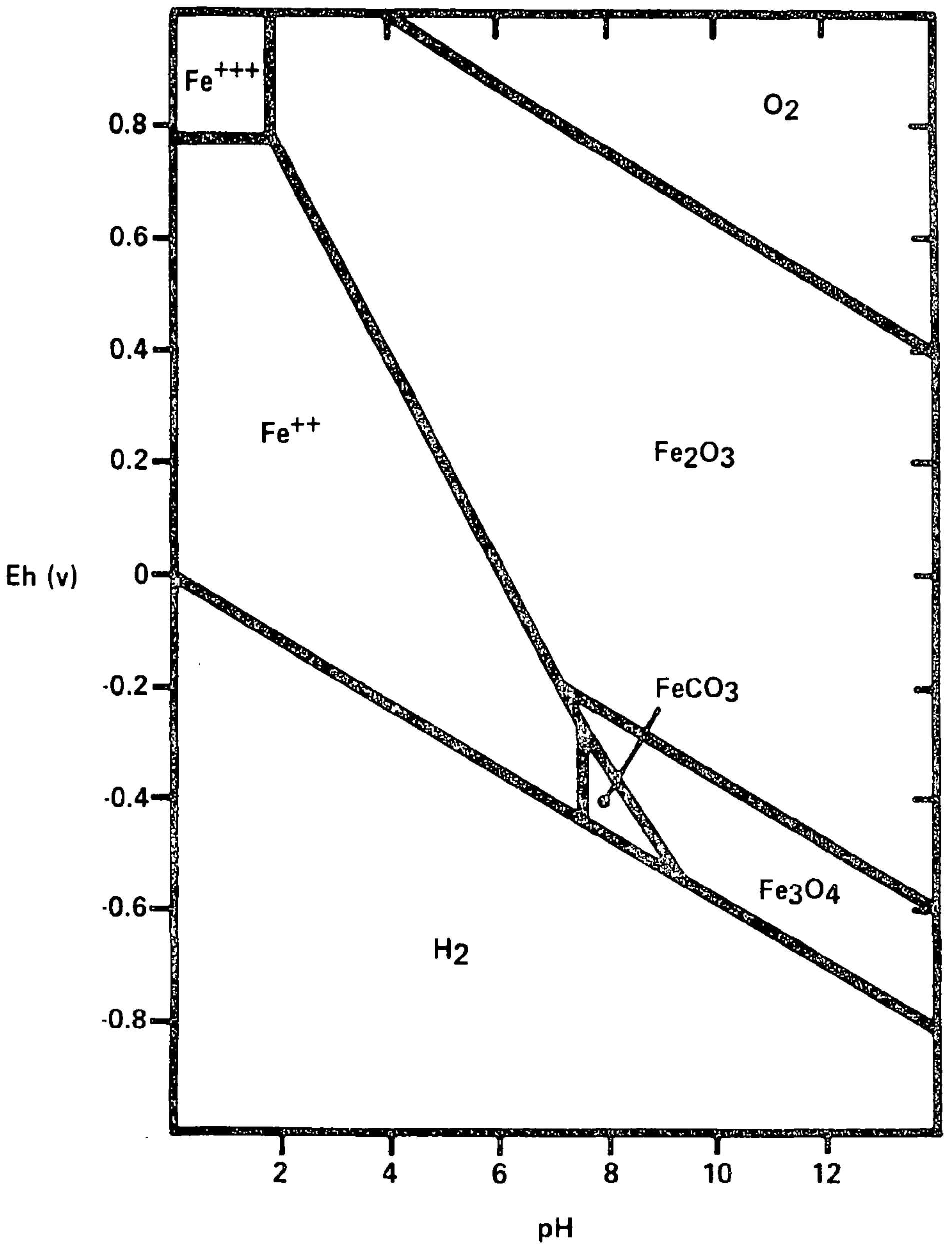


SIGNIFICANT GASES

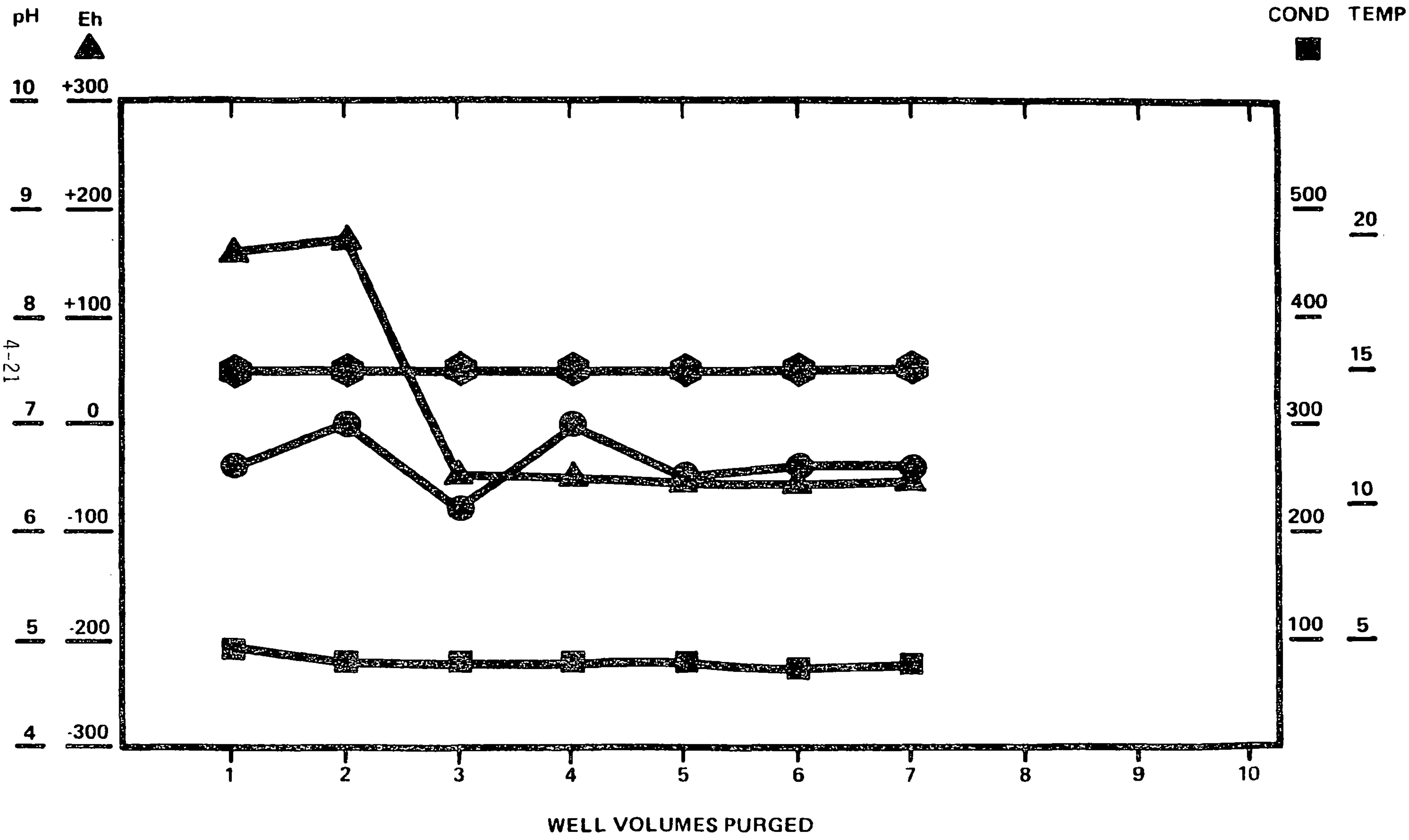
- **Carbon Dioxide (pH)**
- **Oxygen (Eh)**
- **Volatile Organics**
- **Hydrogen Sulfide**
- **Methane**

STABILITY OF IRON SPECIES

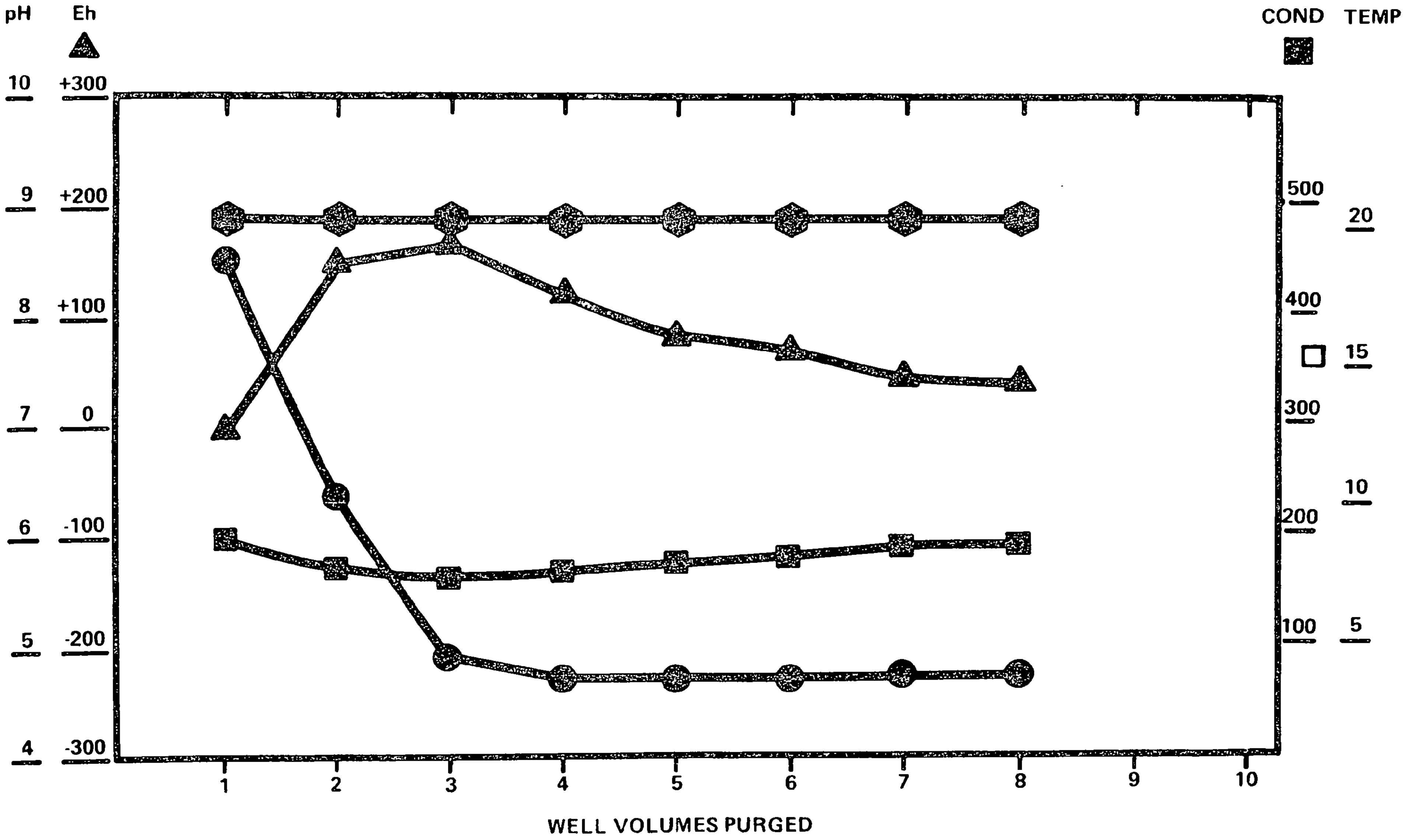
(After Garrels and Christ, 1965)



PURGE PARAMETERS



PURGE PARAMETERS



STABILITY OF IRON SPECIES

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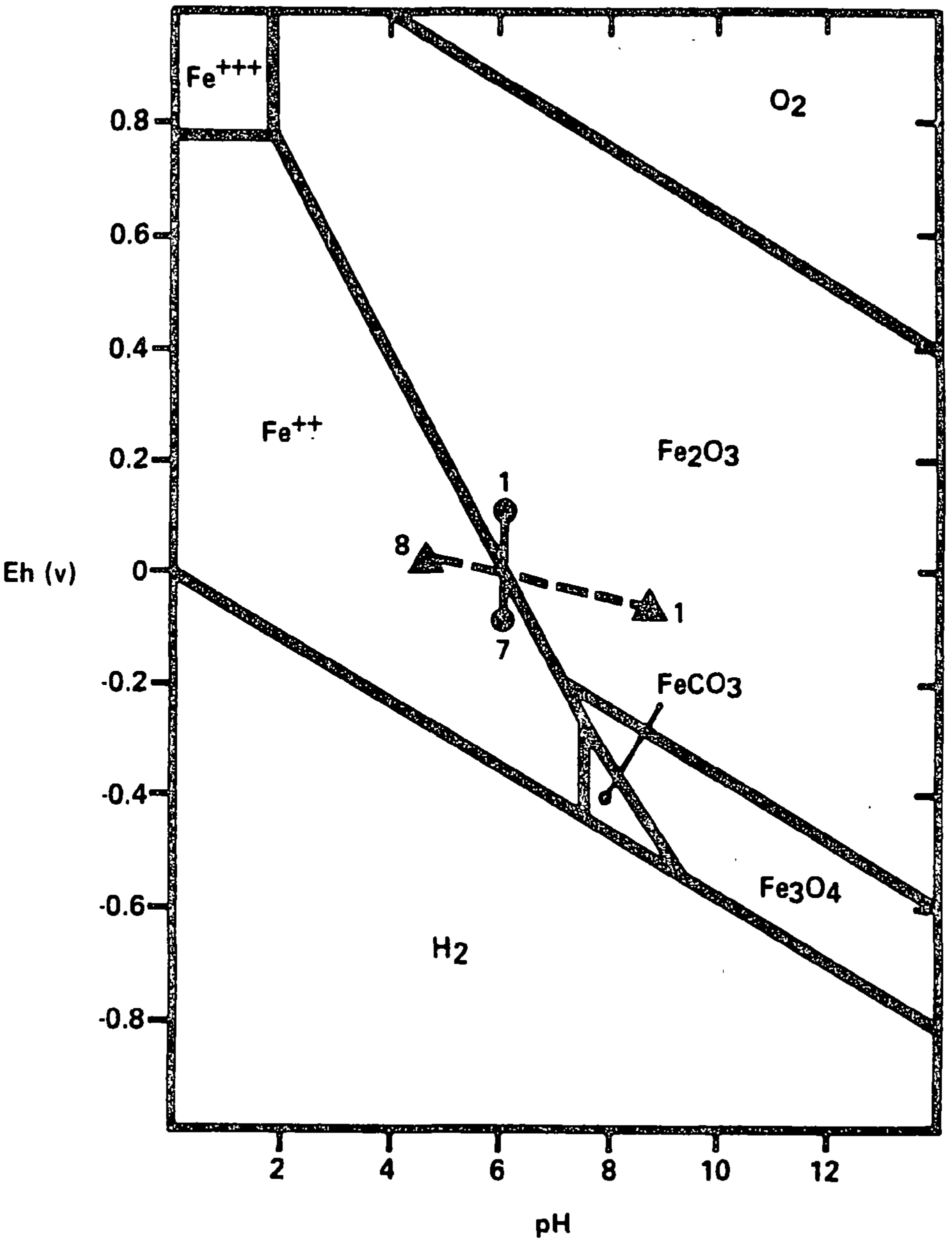
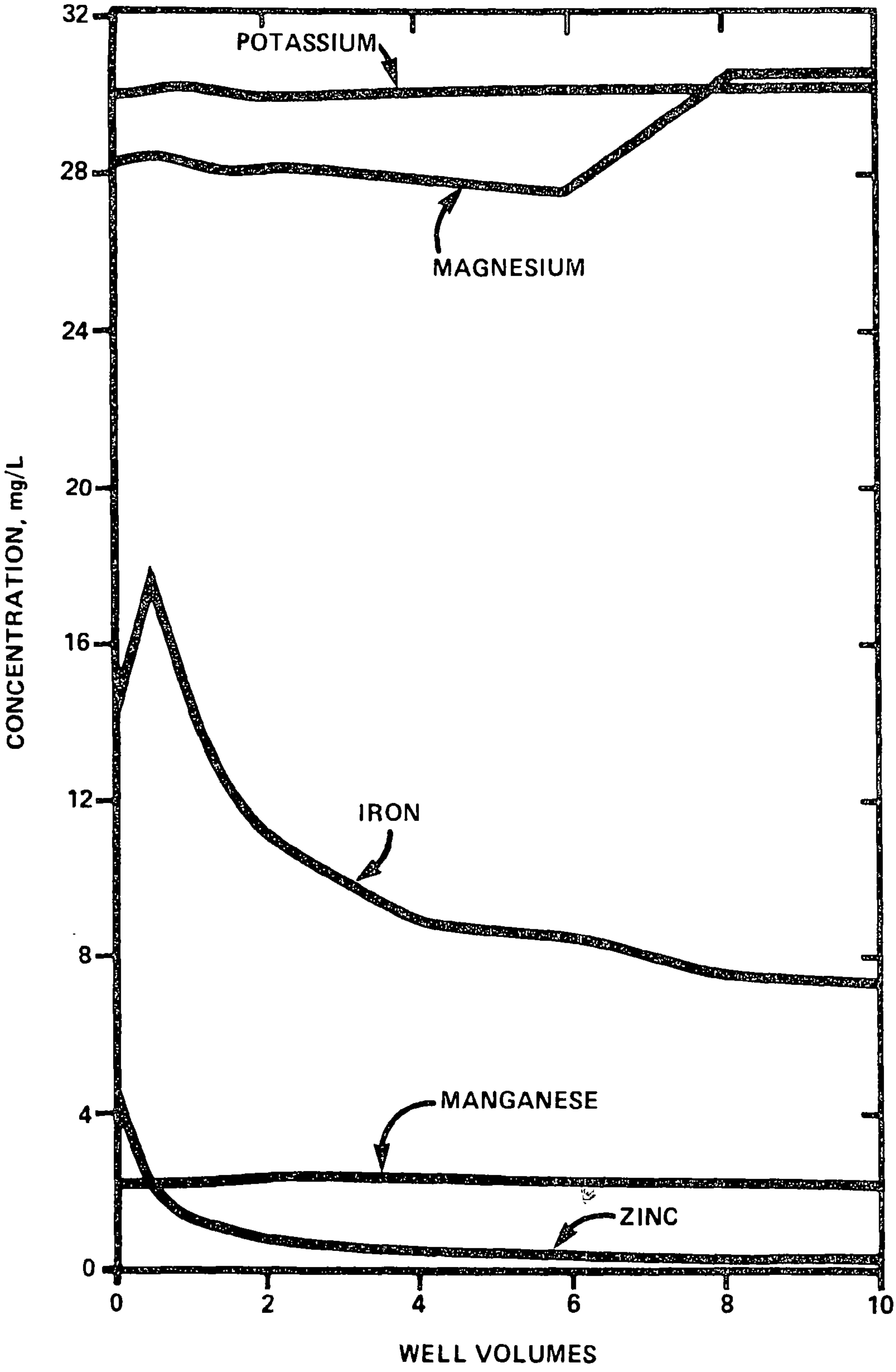
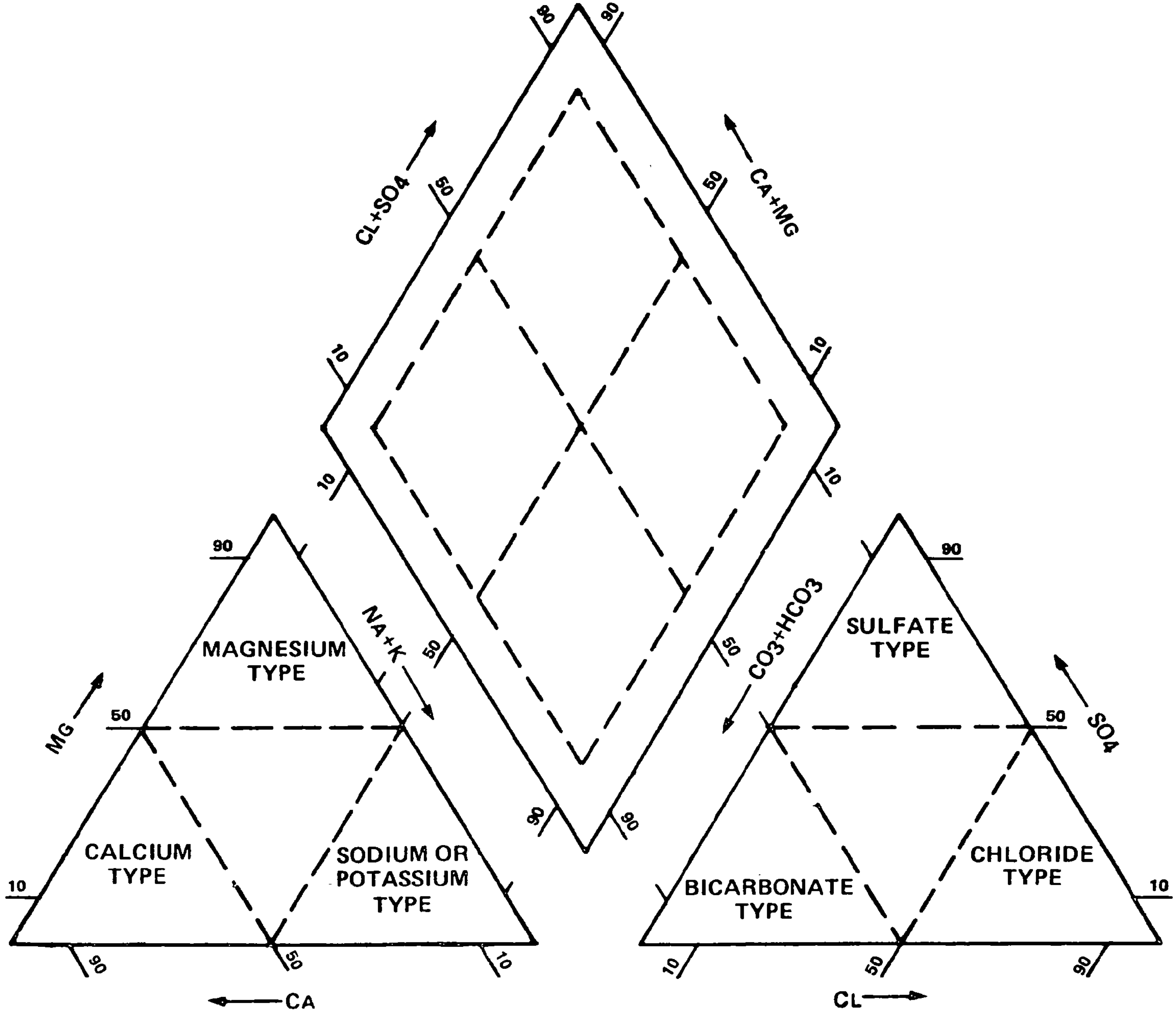


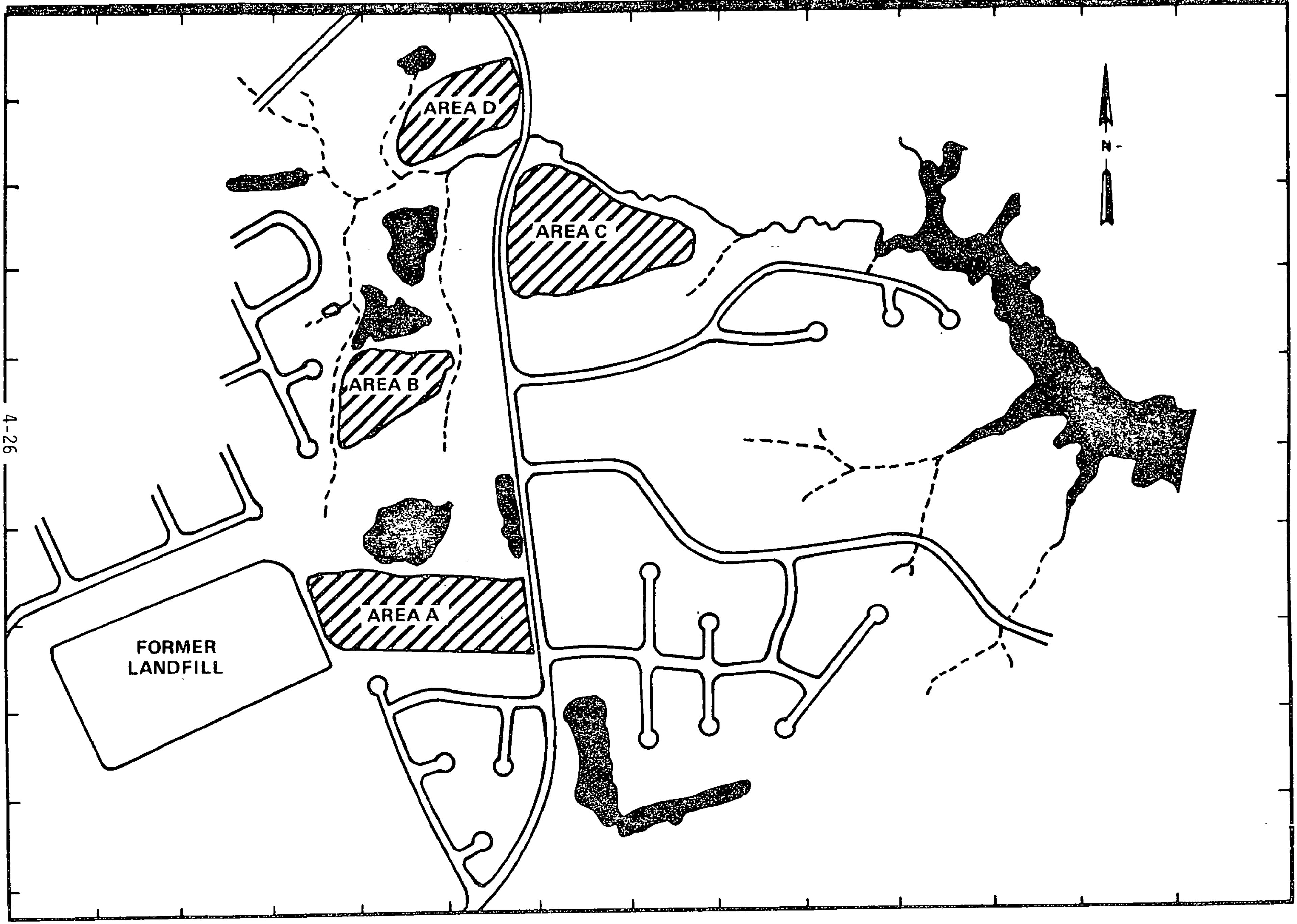
CHEMICAL EFFECTS OF PURGING



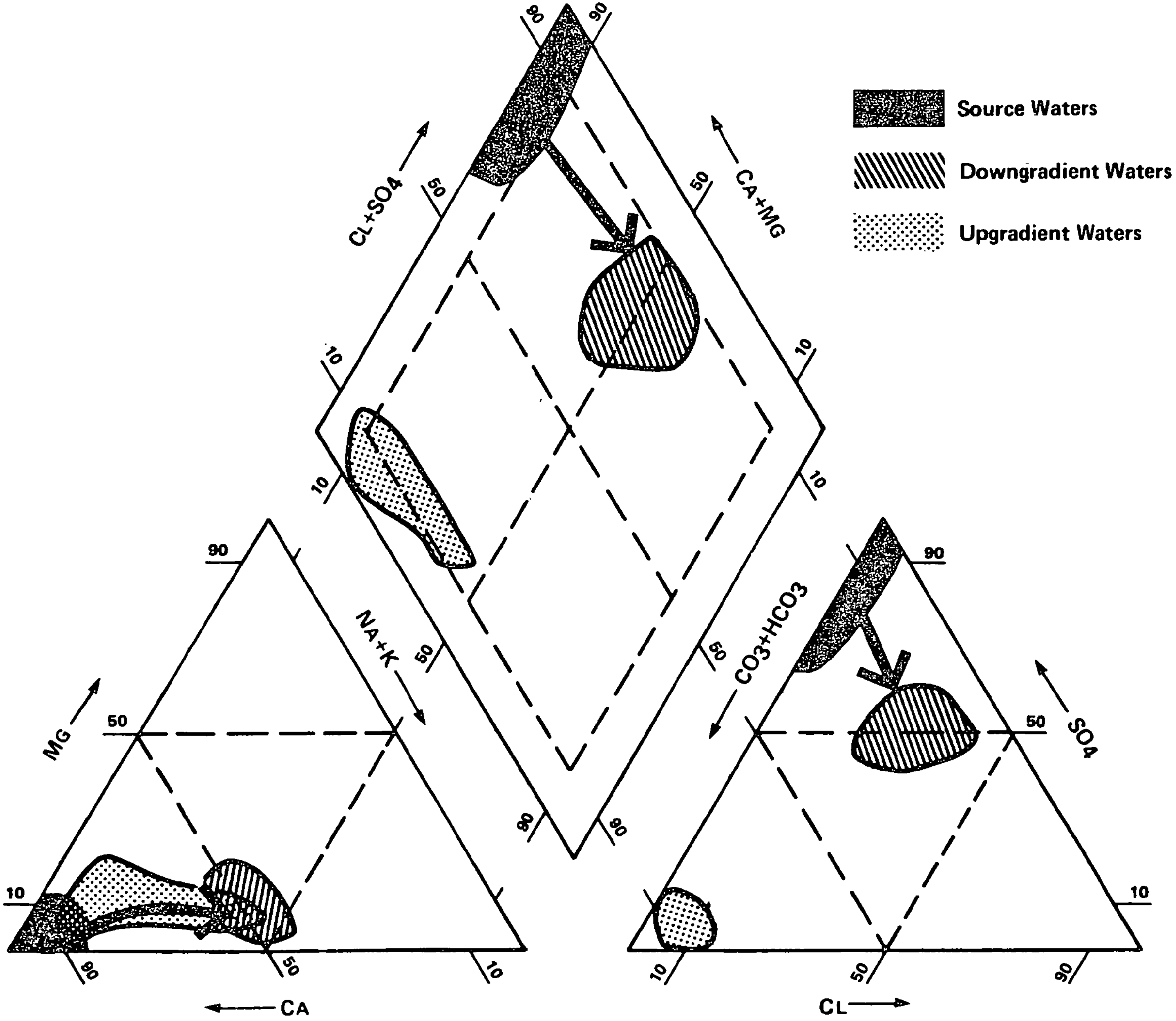
MAJOR ION CLASSIFICATION



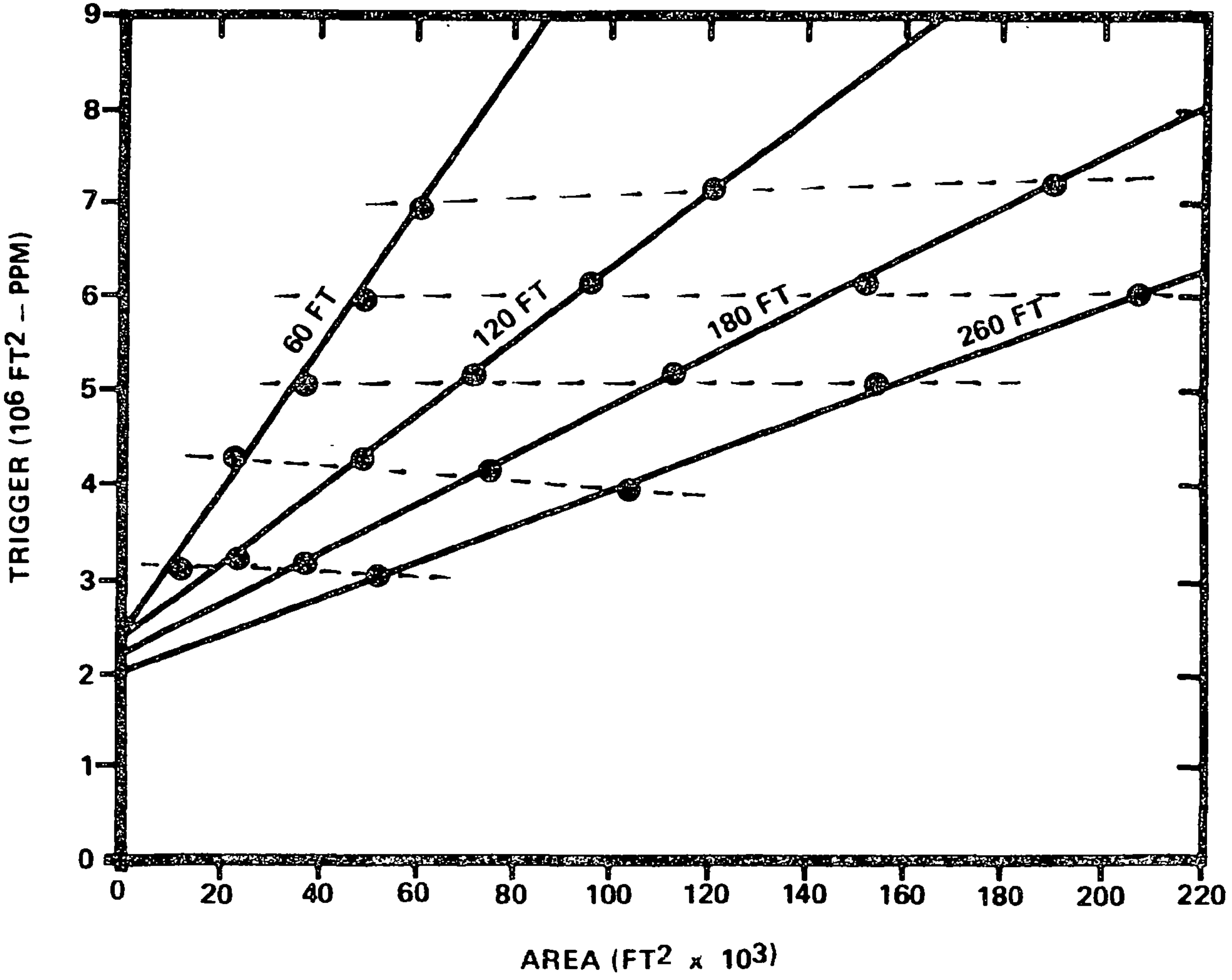
LOCATION OF WASTE DISPOSAL AREAS



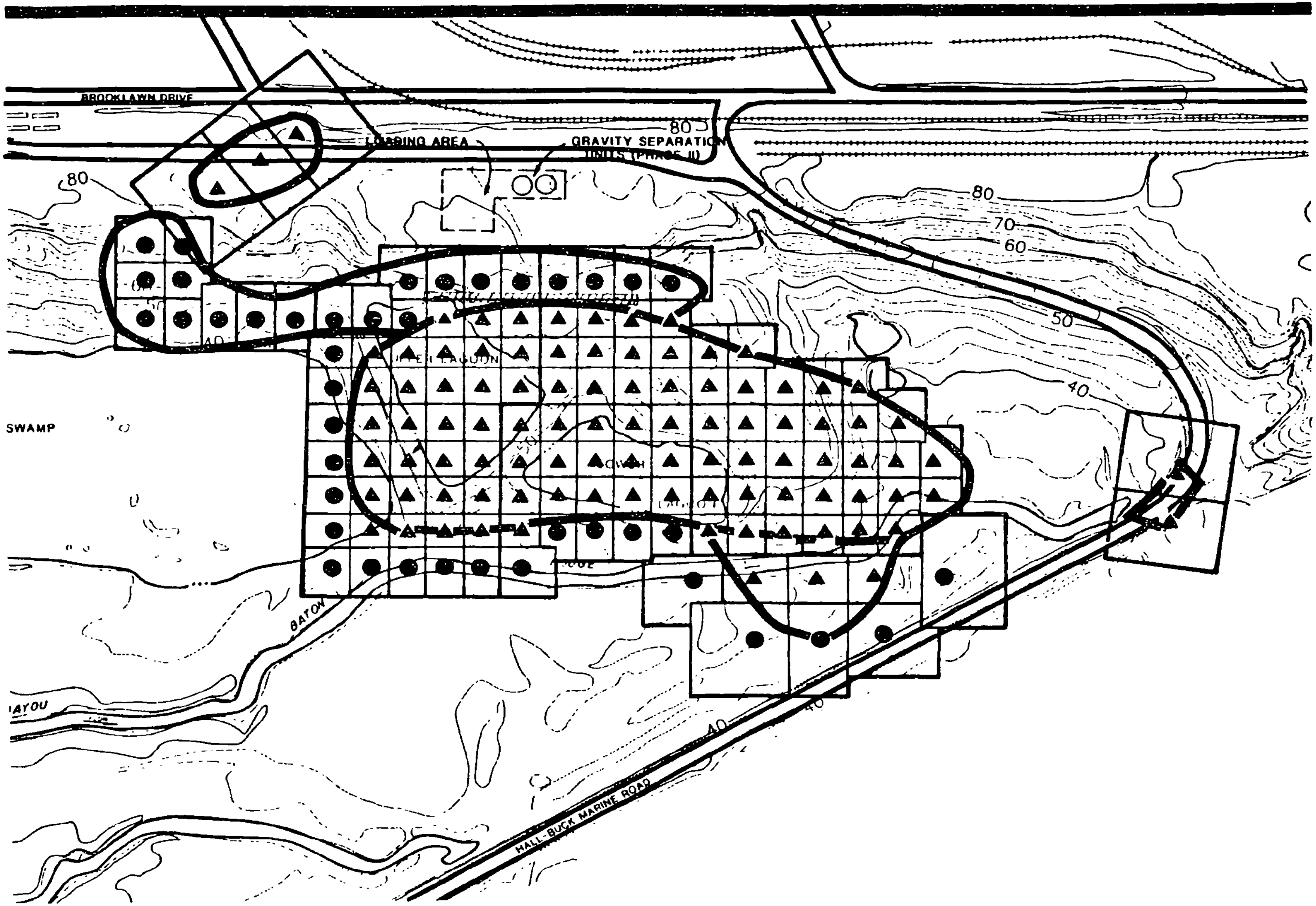
MAJOR ION EFFECTS



COMPUTED TRIGGER LEVELS FOR 1, 2-DCE



DISTRIBUTION OF WELLS AND SOURCE AREAS



SAMPLE ANALYSIS
AND
QUALITY ASSURANCE

COMMUNICATIONS

ANALYTICAL METHODS

QA/QC PLANS

Communications With Lab

- Project Goals
- Parameters Of Concern
- Concentrations Anticipated
- Sampling Methods And Strategy

Communications With Lab (Cont.)
Analytical Method Selection

- Regulatory Preferences
- Interferences
- Detection Limits
- Sample Containers

Communications With Lab (Cont.)

- Numbers of Samples
  - Replicate Samples
  - Field Blanks
- Costs

SELECTION OF ANALYTICAL METHODS

RCRA vs SUPERFUND

RCRA Ground Water Sample Analysis

- Appendix VIII
- Appendix IX
- SW 846
- Other Methods

Superfund Ground Water Sample Analysis

- Hazardous Substances List
- Contract Lab Program (CLP) Proceedures

Quality Assurance

- Chain-of-Custody
- Quality Assessment
- Quality Control Methods

Quality Assessment

- Accuracy
  - Control Samples
  - Standard Reference Solutions
  - Spikes
  - Internal Standards
  - Audits (Performance and Systems)
- Precision
  - Duplicates

Quality Control Methods

- Analytical Methods
- Reagent Control
- Volumetric Glassware
- Equipment Calibration
- Blanks
- Control Samples
- Duplicate Analysis
- Spike Samples
- Data Validation
- Glassware Cleaning
- Maintenance
- Training