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THE NEED TO IDENTIFY AND ASSESS THE POTENTIAL HAZARDS CREATED BY THE PRESENCE OF TOXIC SUBSTANCES IN THE ENVIRONMENT AT RMA HAS BEEN RECOGNIZED, AND EFFORTS ARE UNDERWAY FOR INTERIM CONTAINMENT OF OFF-POST MIGRATION. A COMPREHENSIVE SURVEY WILL BE INITIATED TO GATHER AND ANALYZE ALL NECESSARY INFORMATION WHICH WOULD ENABLE A RATIONAL ASSESSMENT OF THE DEGREE OF CONTAMINATION AND PROVIDE THE DATA BASE NEEDED FOR THE DESIGN OF REMEDIAL MEASURES. THE PURPOSE OF THIS STUDY IS TO PROVIDE THE GUIDELINES FOR SOIL AND WATER SAMPLING PROCEDURES AND FIELD DATA GATHERING AND RECORDING PROTOCOLS TO BE USED IN THE COMPREHENSIVE SURVEY AT RMA.



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# COMPREHENSIVE SURVEY PLAN FOR SOILS & GROUNDWATER CONTAMINATION AT ROCKY MOUNTAIN ARSENAL COLORADO



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15 September 1976

TO: Col. J. Byrne

Enclosed is a copy of a comprehensive survey plan for sampling and mapping soil and ground water contamination at Rocky Mountain Arsenal. This document was prepared in accordance with the Statement of Work dated, 18 February, 1976, under the terms and conditions of contract number DAAA05-76-C-00 27.

Much of the material presented is orginal. The technologies have been successfully tested and used in other research projects by the author and I believe are applicable to the Rocky Mountain Arsenal, Installation Restoration Program.

Nicolay P. Timofeeff

Dr. Nicolay P. Timofeeff
Consultant

cc: Mr. Irwin Glassman
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TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## PREFACE

The production, testing, and disposal of various chemical and biological substances at RMA has lead to suspected contamination of land areas, water, ecology, buildings, and equipment. Little information exists as to the concentration levels, overall extent, or the diffusion process of these substances within the ecosystem. The need to identify and assess the potential hazards created by the presence of toxic substances in the environment at RMA has been recognized, and efforts are underway for interim containment of off-post migration. A comprehensive survey will be initiated to gather and analyze all necessary information which would enable a rational assessment of the degree of contamination on the post and provide the data base needed for the design of remedial measures.

The purpose of this study is to provide the guidelines for soil and water sampling procedures and field data gathering and recording protocols to be used in the comprehensive survey at RMA. The approach developed is aimed at obtaining the maximum likelihood of intercepting the contaminated horizons in three dimensions and thus gaining the optimum benefit for long-run objectives from the field measurements with minimum field effort and thus reducing time and cost by minimizing the possibility of gathering extraneous data.

## INTRODUCTION

A pollutant is any compound or substance that is undesirable where it is. A contaminant or pollutant may become undesirable by being introduced into an environment that is foreign to it. The pollutant is usually toxic to the host environment and will disturb the equilibrium state of the ecosystem. The degree of concern of the presence of contamination depends upon the toxicity level to living organisms, especially man.

Pollutants may be either man-made, released as byproducts of industrial or military processes, or are naturally occurring and become toxic when concentrated, for example salt.

Transport processes often create a pollutant simply by moving a compound to a different environment. Sources of pollutants are usually classed as "point" and "nonpoint." Control measures are simplified whenever the pollution plume is traced to a point source, as compared with diffuse or nonpoint pollutants which discharge into waterways by dispersal pathways.

## FACTORS INFLUENCING CONTAMINANT BEHAVIOR

The success in locating the most probable areas of contamination and in tracing the breadth (source and plume) of such contamination within the ecosystem is dependent upon an accurate interpretation of the means of contaminant emplacement. The dispersion and the accumulation of pollutants in the environment is dependent on a number of inter-related factors. Some of the principal factors are:

The Physical and Chemical Properties of the Contaminants - The important chemical properties of the pollutants are the following: the contaminant phase, concentration, chemical stability, water solubility, ion exchange, adsorption, equilibrium with the host environment, and regional geochemical properties. These properties determine the chemical behavior of the contaminants, whether they are present as a solution in water or are dispersing as a solid.

The Form of Transport - The form of transport determines the dispersion process and influences accumulation. It is possible by evaluating the manner that the pollutants were transported and knowing their pathways to predict the major contaminated areas. Contaminants of greatest concern at RMA are transported either: (1) as solid particles (particulate) occurring in a crystalized form or combined with dust or soil particles, or (2) as a fluid in solution with water. For example, the movement of pesticides on sediment is affected by the enrichment process. Pesticides are adsorbed primarily on organic soil colloids which remain in suspension longer than the coarse soil particles. Most mobile herbicides, on the other hand, rarely contaminate the groundwater because the adsorption capacity in most soils above the water table is sufficient to retain the chemicals until they decompose. However, in an area with a high percolation potential, groundwater contamination is possible.

The partitioning of the compounds between water and soil transport is necessary in determining the mass movement of chemicals in run-off. The quantity of a compound dissolved in water is obtained from water solubilities of the chemicals. The amount adsorbed at different solution concentrations can be calculated by mixing solutions of the chemicals with known quantities of soil. (This study is currently in progress for DIMP by the Aerojet Ordnance and Manufacturing Company, Downey, California.)

The transporting medium for particulate contaminants is either wind or surface water movement. The contaminants, therefore, concentrate in areas controlled by these transporting media -- on or close to the ground surface. The transporting media for liquid contaminant, on the other hand, is either surface run-off, subsurface run-off, or groundwater run-off. These contaminants tend to concentrate much deeper in the unconsolidated mantle.

The Characteristics of the Physical Site - The characteristics of the site include: (1) Geologic properties of the aquifier such as texture, porosity, permeability, transmissivity, heterogeneity of the subsurface regolith, thickness of the unsaturated zone of aeration, thickness of the saturated groundwater zone boundary conditions, and (2) The geomorphology, the topography, and the surficial cover. This includes slope, aspect, surface relief (high relief is indicative of high sediment delivery ratio), channel density, the condition of the channels (whether clogged or open, meandering, or straight), stream gradients, the relief/length ratio. The geomorphology of a terrain provides potential channels, sinks, or traps for pollutant, and (3) The stratigraphy and character of the sediments in the aquifer. This would include the ionic exchange capacity of the minerals in clay and soil, which has a direct bearing on contaminant sorption and leaching. The type of both primary and secondary minerals present and the oxidation reduction reactions which affect some of the pollutants and the leach ability of the sediments.

Climate - Humid environments are those in which the annual precipitation exceeds evapotranspiration rates. They have a net water surplus which transports the mobile compounds faster and to greater depths. In arid climates such as RMA, much of the water is removed by evapotranspiration; and soil moisture is brought to the surface by capillary action. Contaminated groundwater may be transported to the surface and the contaminants are deposited on the ground surface. The duration and intensity of storm activity influences groundwater recharge and possible flushing of the contaminant from the soil. Flow is upward during periods of high evapotranspiration, provided there is no ponding and downward when water is available (as under the water ponds and bog areas). The micro climate also influences the viscosity and surface tension properties of soil water solution, which is temperature-dependent. Soils drain slowly during cold weather, and water is retained as storage when frozen. As a solution freezes, salts concentrate in the nonfrozen liquid, and it is not unusual to find brines in partially frozen soils. These brines become selectively mobile because of their hydraulic properties. During the spring after the frozen ground thaws at RMA, much of the groundwater recharge results from snowmelt. If the concentrations of pollutants in soil water reaches high enough levels, precipitation (or salting out) may occur.

The Geohydrolic Conditions - Hydrologic transport is the movement of compounds in or by water and may occur along surface or subsurface channels at RMA. Hydrologic transport is therefore dependent upon the amount of water and the pathways of: (1) Surface run-off traveling over the ground surface; (2) Subsurface run-off that has infiltrated the surface soil and moves laterly through the upper soil horizon within the zone of aeration; and (3) Groundwater run-off below the groundwater table in the zone of saturation. Each must be known before the transport of pollutants and hydrodynamic dispersion can be described in detail.

The hydraulic conductivity (K variable in Darcy's Law) of sediments is the transmissive properties of a porous medium. Generally, in hydrolic calculations, this value is averaged vertically assuming a homogeneous aquifer and substituting it for transmissivity, expressed as $T = Kh$, where h is the saturated thickness. The transmissivity can be determined by pump tests.

An analysis of the dynamics of groundwater flow permits a reliable computation of the level of contamination of the aquifer in space through time. Changes in chemical concentrations in the groundwater system are due to: (1) Convective transport, expressing the amount of dissolved chemicals moving with the flowing groundwater; (2) Addition or removal of contaminants through chemical and physical reactions taking place in the water or between water and soil; (3) Mixing with recharge water of different concentrations; and (4) Hydrodynamic dispersion in which molecules or ionic diffusion and minute changes in velocity of flow in the porous media causes the paths to diverge from the normal direction of groundwater movement.

Grouping - Certain elements tend to group together into compound associations in a specific environment due to similar migration capacities (relative mobilities). The tendency for compounds to group together simplifies the mapping task in that by testing for either indicator or pathfinder elements, it is possible to trace the spatial behavior of the pollutants.

Contaminant Migration through Soil Erosion - Several contaminated areas exist on RMA which are sources of ground surface pollution by soil movement. Field soil losses have been estimated to range from three to eight tons per acre per year. A ton of dry soil is approximately one cubic yard in volume. Spread uniformly over an acre of surface, it would have a depth of less than one-hundredth of an inch. Erosion hazards both by wind and due to rainfall and surface run-off are local in nature. This can be significant in areas which are not protected by a vegetative cover (example Basins A, C, and most of the Arsenal during the winter months when vegetation is dormant). The annual soil losses from sheet and rill erosion by rainfall can be determined by the Universal Soil Loss Equation (USLE).

The equation is:

$$A = f\,(RKLSCP)$$

Where A is estimated average annual soil loss measured in tons per acre.

R is the rainfall and run-off erosivity index.

K is the soil erodibility factor. It is the average soil loss per unit of R and depends on soil properties (see Figure ).

LS is dimensionless topographic factor that represents the combined effects of slope, length, and steepness.

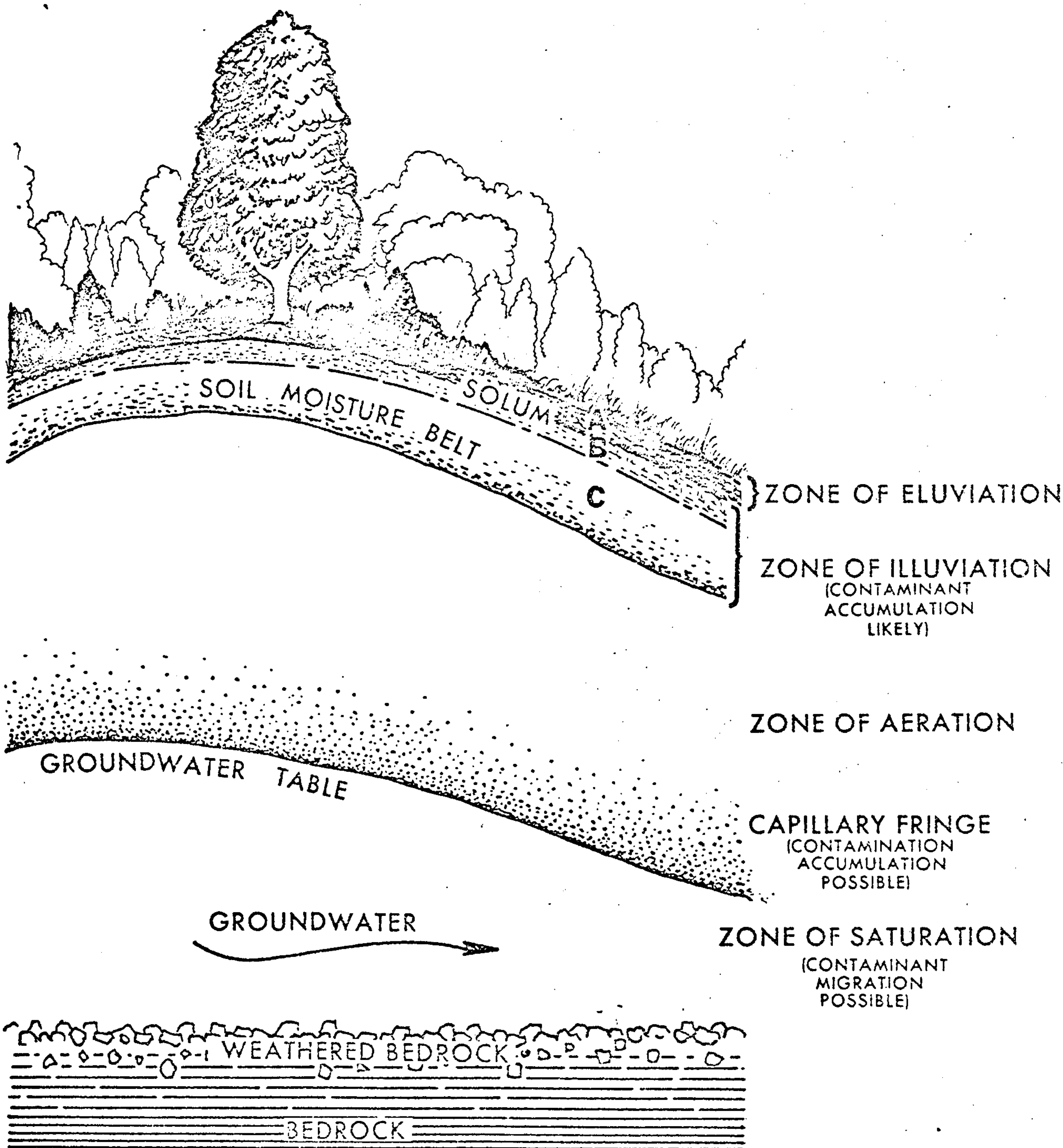
C is the cover and management factor.

P is the support - practice factor for land use.

The USLE can provide a measure of the contaminated sediment delivered to a stream.

The object of the RMA environmental sampling program is to be able to identify, measure, and characterize each of the contaminated horizons.

Generally, immediately underneath a contaminated source, each layer in the unconsolidated mantle collects the contaminants from above, mixes, absorbs, reacts, and then drains the soil to field capacity to supply lechate to the layer below. Thus, the process proceeds




**CROSS-SECTION OF UNCONSOLIDATED MANTLE**

FIGURE 1

## STRATIFICATION OF THE UNCONSOLIDATED MANTLE

When a vertical section is made through the unconsolidated mantle, a series of distinct layers or zones are observed which differ in their chemical and physical properties. See Figure The uppermost A horizon varies from a few inches to several feet in thickness and represents the elúvial (washed out) layer. Varying amounts of organic material is added to this. Materials removed from the A horizon are carried downward in solution and are deposited in the B horizon; however, the fine colloidal clays are mechanically removed by descending soil water (illuvial layer). Impervious hardpan and claypan layers may develop in the B horizon by the accumulation of downward moving material which include iron and aluminum minerals, including clays. The A and B horizon together form the solum. In arid climates, calcium carbonate, sodium sulphates, and other salts may accumulate just below the B horizon in the C layer. The C layer or parent material does not exhibit a high degree of alteration; however, it may display weathering, including oxidation, hydration, and lime accumulations.

A mature soil profile exhibits well developed horizons; however, layering may be indistinct or lacking in young soils. Topography affects both soil profile development and contaminante emplacement. On steep slopes, the soil horizons are much thinner or may never develop because erosion removes weather products as rapidly as they form. Topography controls the rate of surface run-off, the infiltration of water, the position of the water table, the depth of penetration of chemical weathering processes, and contaminant migration. Local and regional relief affect the hydrolic gradient which governs the circulation of water through the soil and unconsolidated mantle.

Knowledge of the soil profiles developed within a suspected contaminated area is necessary to enable a constant relative sampling procedure to be maintained. All samples must be taken from the same horizon, otherwise they will not be comparable. Also, a uniform sampling procedure increases the probability of locating the contaminated zones. See Figure

An analysis of the vegetative cover can provide valuable information about the character of the contamination below ground surface. For example, deep-rooted plants may penetrate the pollution plume in the overburden and be brought to the surface and enriched in the soil

THE SOIL PROFILE

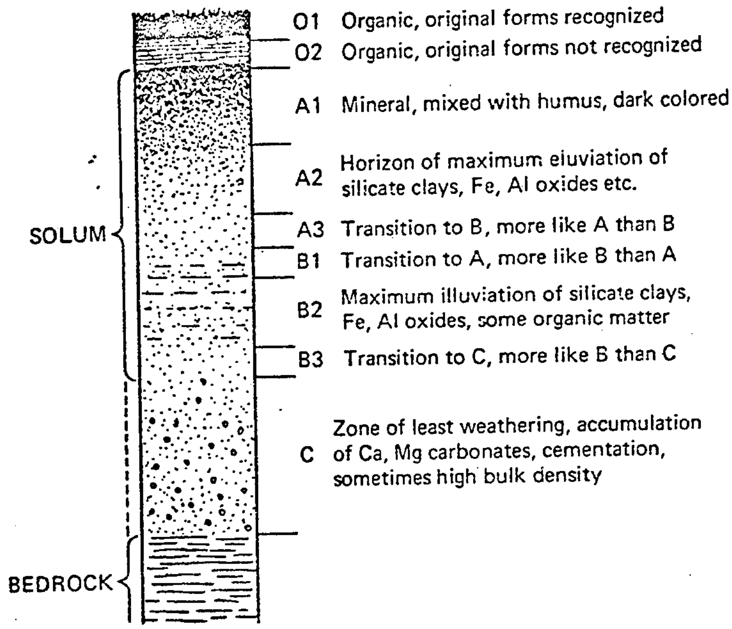
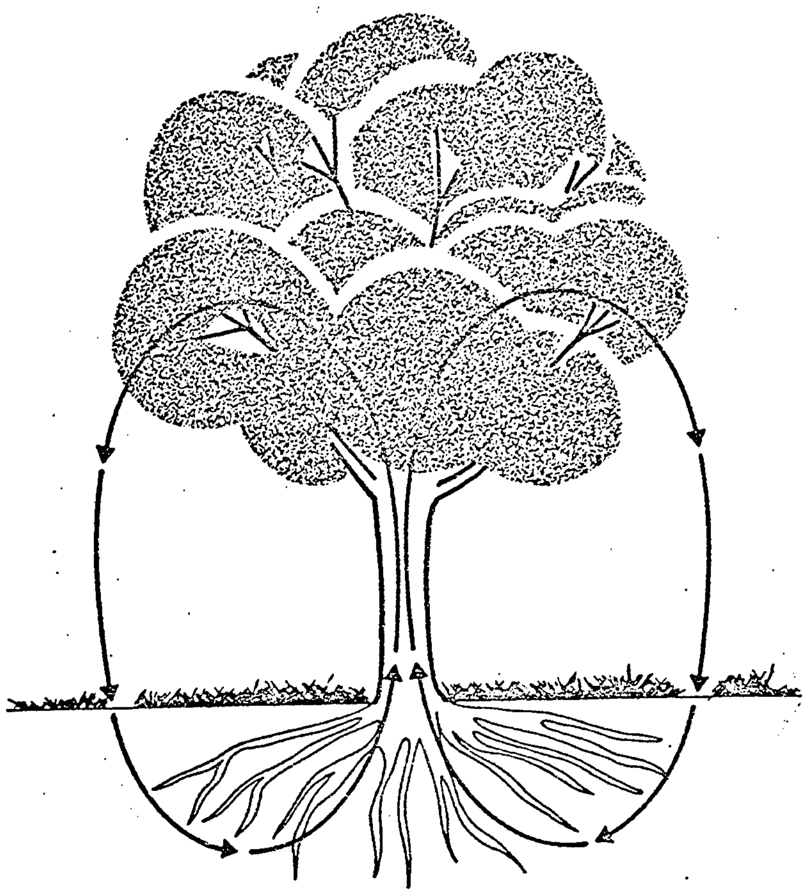



Figure 2



Nutrient recycling is an important factor in determining the relationship between vegetation and the soil that develops.

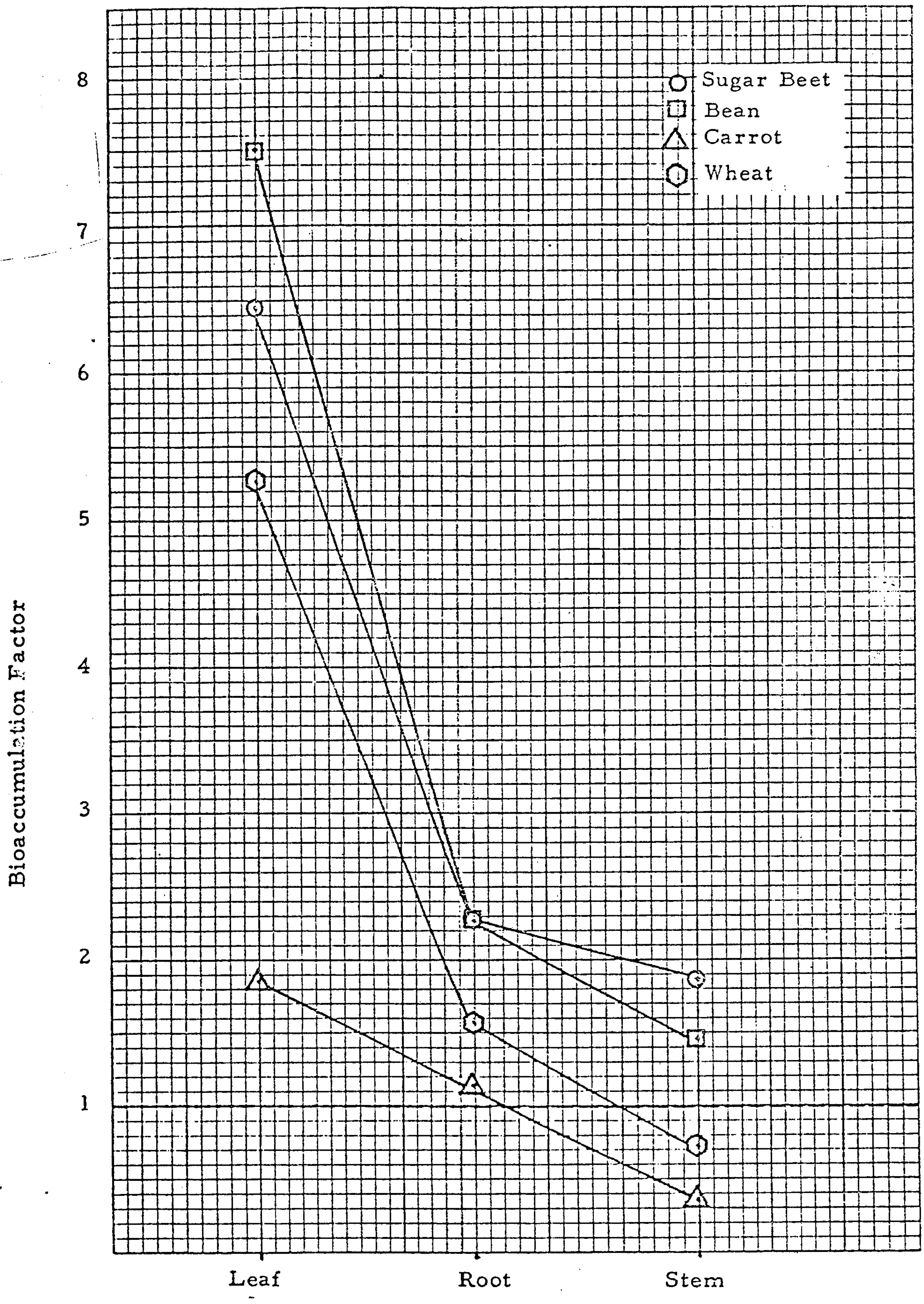
Figure 3

Bioaccumulation of DIMP by Plant Parts in

20 ppm Irrigation (37 days from Original Inoculation)

| Plant Part | Total DIMP added to Pot Vol of 20ppm Irr. (cc) | Total DIMP added to Pot Wt. of DIMP (mg) | DIMP Conc. In Tissue (ppm) | Bio-Accumulation Factor |
|---|---|---|---|---|
| Sugar Beet - | 9500 | 190 | | |
| Root | | | 45.6 | 2.28 |
| Stem | | | 37.1 | 1.86 |
| Leaf | | | 129.2 | 6.46 |
| Carrot - | 9200 | 184 | | |
| Root | | | 12.4 | 0.62 |
| Stem | | | 6.6 | 0.33 |
| Leaf | | | 36.9 | 1.85 |
| Bean - | 9200 | 184 | | |
| Root | | | 45.4 | 2.27 |
| Stem | | | 28.9 | 1.45 |
| Leaf | | | 150.0 | 7.50 |
| Wheat - | 9200 | 184 | | |
| Root | | | 31.5 | 1.58 |
| Stem | | | 14.2 | 0.71 |
| Leaf | | | 105.5 | 5.28 |

Figure 4




Bioaccumulation of DIMP by plant parts.
Soil culture, 37 days exposure to 20 ppm DIMP in irrigation water.
Figure 5

layer by decay of the vegetation in the production of humus. The concentration of elements in plants is dependent on a variety of physical, chemical, and organic factors which control intake of nutritional solutions. Geobotanic survey may be valuable to monitor contaminant movement in the soil, especially in areas where soils profiles are young or poorly developed. See Figure Results from biochemical sampling tend to be hetrogeneous, and care should be taken to assure representative samples and their interpretation. Seasonal variations in concentration occur within plant tissue in response to nutritional requirements of the plants. Different vegetative species have selective absorption capacities for intake for different elements which may vary considerably. Lysimeter studies conducted by Aerojet Ordnance and Manufacturing Company, Downey, California, have indicated that DIMP will bioaccumulate at much higher concentrations in the leaves of plants than either plant roots or stems (see Figure ). The leaves account for the greatest proportion of organic matter addition to the soils which results in a concentration of pollutants in humus in the A1 horizon. The information gathered from geobotanical surveys will be used in conjunction with soil and water surveys.

## SOILS OF THE ROCKY MOUNTAIN ARSENAL

There are eight soil series and four land types at RMA. A soil series is a subdivision of soil families -- the most generalized soil description. A soil series is a "group of soils developed from the same kind of parental material by the same genetic combination of processes and whose horizons are quite similar in their arrangement and general characteristics." Soils series are divided into specific mapping units.

ASCALON SERIES - Consists of well drained soils occurring on level to moderately sloping land on uplands. They are formed in loamy material containing varying amounts of sand and gravel. The infiltration capacity of Ascalon soils is moderate to high, and the available soil moisture is high. This soil is suitable for plant root development.

Representative Profile - The surface layer is brown sandy loam approximately six inches thick and noncalcareous. The upper part of the subsoil is brown sandy loam and sandy clay loam about 15 inches thick. It is noncalcareous. The lower part of the subsoil is brown sandy loam about six inches thick, highly calcareous, and contains much visible lime. The underlying material is a highly calcareous, pale-brown to very pale brown fine sandy loam. It is found at a depth of 27 to 60 inches or more.

Mapping Units

(AsB) Ascalon sandy loam, one to three percent slopes. This unit is found on upland ridges and benches. Surface run-off is slow to medium, and the hazard of water erosion is slight to moderate. Soil blowing is a severe hazard in unprotected areas.

(AsC) Ascalon sandy loam, three to five percent slopes. This unit is found in areas adjacent to major streams, but it is only on the higher upland ridges and side slopes. It has a thinner surface layer and subsoil than the representative profile. Surface run-off is medium. The hazard of water erosion is moderate. Soil blowing is severe in unprotected fields.

(AsD) Ascalon sandy loam, five to nine percent slopes. Located on uplands near the edges of the breaks adjacent to stream channels. The surface layer and subsoil are thinner than the representative profile.

(ArC) Ascalon-vona sandy loams, one to five percent plagues. Ascalon sandy loam, one to three percent slopes (AsB) makes up 45 percent of this complex and occupies the smoother and lower lying areas. Vona sandy loam, three to five percent slopes make up 35 percent and is normally in the more sloping part of the landscape. A few small flowouts are on the higher ridge points.

BLAKELAND SERIES - Consists of somewhat excessively drained soils occurring on gently sloping to moderately sloping on uplands. These soils formed in wind and water worked sandy material. Blakeland soils absorb water rapidly, and the available water capacity is low. The entire profile becomes unusually hard as it dries. When dry, these soils hold a nearly vertical bank. Permeability is rapid. The entire soil is suitable for plant roots.

Representative Profile - The surface layer is grayish-brown loamy sand about five inches thick and noncalcareous. The next layer is brown sandy loam about four inches thick and is noncalcareous. The underlying material from a depth of about 9 inches to 60 inches or more is noncalcareous, brown loamy sand and pale-brown sand.

(BoD) Blakeland loamy sand three to nine percent slopes. Occurs on uplands. Surface run-off is medium to slow. The hazard of soil blowing is severe.

(Bt) Blakeland - truck ton association - Blakeland loamy sand, three to nine percent slopes, constitutes at least 60 percent of this association, occurring in areas of semidune relief, though it is also on long, narrow ridges. Truck ton loamy sand, three to nine percent slopes makes up 20 - 40 percent of mapped areas. It is depressional or has the more gentle slopes. The hazard of soil blowing is moderate but is very severe where adequate cover is not maintained.

(Gr) Gravelly Land - Shale Outcrop Complex - this complex consists of steep and hilly land types. Areas are generally elongated and roughly parallel river channels. The complex consists of very shallow, clayey soils and raw shale overlain by a discontinuous layer of gravel deposits four inches to many feet thick. These deposits are old enough that some soil is forming in places within the gravelly cap layer. Little if any soil is forming in the shaly exposed areas, which is eroding by moderate wind and water action. Some areas contain steep colluvium of mixed materials. All of this complex is subject to severe erosion.

Loamy Alluvial - Only one unit of loamy alluvial is present at RMA.

(Lu) Loamy alluvial land is found in drainageways. Slopes are less than three percent. It is subject (in varying degrees) to flooding from adjacent slopes and main stream channels.

The profile consists of a surface layer, commonly dark-colored loam or clay loam about six to ten inches thick and normally noncalcareous. The underlying material is stratified loam, silt loam, and clay loam containing varying amounts of fine sand, sand, and fine gravel. It is 20 to more than 60 inches thick, brown to dark brown in color, and in places it has a weak structure. It is normally calcareous. Sand or sand and gravel, stratified with their lenses of silt and loam, are in some places below a depth of 36 inches.

Water is absorbed at a moderate rate, and their available water capacity is high. They are normally well drained. Natural fertility is high. The hazard of water erosion is severe in all cultivated areas.

NUNN SERIES - Consists of well drained, nearly level soils on terraces. These soils formed in loamy alluvial material. Water is absorbed at a moderate rate, and the available water capacity is high. Permeability is slow in soils with a clay loam surface layer and moderately slow in those with a loam surface layer. The entire soil is suitable for plant roots.

Representative Profile - The surface layer is a grayish-brown loam about six inches thick and noncalcareous. The subsoil is dark grayish-brown and grayish-brown clay about 17 inches thick. It is noncalcareous. The underlying material below a depth of 23 inches is light yellowish-brown and grayish-brown loam and silt loam. It is highly calcareous and stratified.

(NIA) Nunn loam, zero to one percent slopes. This soil is on stream terraces along most of the major drainageways in the county. Surface run-off is slow, and the hazard of water erosion is slight. The hazard of soil blowing is moderate in cultivated fields without protective cover.

The profile of this unit is similar to the reprensentative profile, except for a thicker surface layer and subsoil and less susceptible to erosion.

(NuB) Nunn clay loam, one to three percent slopes. This soil is found on stream terraces along major streams. Areas are long and narrow and roughly parallel to stream channels. Run-off is medium, and the hazard of water erosion is moderate. Soil blowing can be controlled by adequate cover. The profile is similar to the representative profile, but it has a more clayey surface layer and a thinner subsoil.

PLATNER SERIES - Consists of well drained nearly level to gently sloping soils on uplands. These soils are formed in old alluvium. They absorb water slowly, and the available water capacity is high. Permeability is slow, and the entire soil is suitable for plant roots.

Representative Profile - The surface layer is grayish-brown loam about nine inches thick and noncalcareous. The upper part of the subsoil is brown clay, about nine inches thick. It is noncalcareous. The lower part of the subsoil is light-gray clay loam about 10 inches thick. It is highly calcareous, and part of the lime is visible as splotches. The underlying material below a depth of 28 inches is very pale brown loam that is highly calcareous. At a depth of about 49 inches, it is a white and very pale brown sandy loam that is highly calcareous and contains some fine gravel.

(PlB) Planter loam, zero to three percent slopes. This unit is found on uplands. Surface run-off is slow, and the hazard of water erosion is moderate to slight. The hazard of soil blowing is severe in dry farmed areas unless protected by plants or stubble.

(Sm) Sandy Alluvial Land - Consists of an unstable accumulation of gravelly and sandy alluvium. It is in and adjacent to beds of intermittent streams. During periods of heavy rain, the streambeds are subject to flooding and channels are relocated and sediment is shifted and redeposited at slightly different locations. During dry spells, this land type is extremely droughty.

The material of this soil was transported by water from the sand and gravel beds in or adjacent to the area. It is stratified because of periodic flooding. Thin lenses or small pockets of silt, clay, and sand are also mixed with the gravel.

This land type differs from wet alluvial land primarily in that it is coarser textured throughout and is not affected by the water table.

STONEHAM SERIES - Consists of well drained, nearly level to moderately sloping soils on uplands. These soils formed in loamy, old alluvial material. Water is absorbed at a moderate rate, and the available water capacity is moderate. Permeability is moderate. The entire soil is suitable for roots.

Representative Profile - The surface layer is light grayish-brown loam about five inches thick and is noncalcareous. The subsoil is brown sandy clay loam about eight inches thich and noncalcareous. The underlying material is light-gray sandy loam and gravelly loam that is highly calcareous. At a depth of 30 inches, it is pale-brown gravelly sandy loam that is highly calcareous. It extends to a depth of about 60 inches.

(StD) Stoneham loam, three to nine percent slopes, is found on uplands near major stream channels in scattered areas. Run-off is generally medium (but rapid if the soil is unprotected). The hazards of water erosion and soil blowing are severe in cultivated areas.

TRUCK-TON SERIES - Consists of well drained to somewhat excessively drained, nearly level to moderately sloping soils on uplands. These soils formed in wind-worked sandy material. They absorb water rapidly, and the available water capacity is low. Permeability is rapid, and the entire soil is suitable for roots.

Representative Profile - The surface layer is grayish-brown and dark grayish-brown loamy sand about nine inches thick. It is noncalcareous. The upper part of the subsoil is dark-brown and brown sandy loam about 12 inches thick. It is noncalcareous. The lower part of the subsoil is yellowish-brown loamy sand about 11 inches thick; also noncalcareous. The underlying material is yellowish-brown coarse sand that extends to a depth of 60 inches or more.

(TeD) Truck-ton loamy sand, three to nine percent slopes. Found mostly along major stream channels. Surface run-off is medium, and the hazards of soil blowing and water erosion are severe.

(TuB) Truck-ton sandy loam, one to three percent slopes. The profile is similar to the representative profile except for a sandy surface layer and a thicker surface layer and subsoil surface run-off is slow to medium, and the hazard of water erosion is slight. The hazard of soil blowing is severe.

(TuD) Truck-ton sandy loam, two to nine percent slopes. The profile is similar to the representative profile except for a sandy loam surface layer. Run-off is medium, and the hazard of water erosion is moderate. The hazard of soil blowing is severe.

VONA SERIES - Consists of well drained, nearly level to moderately sloping soils on uplands. They were formed in wind-deposited material. The soils absorb water rapidly, and the available water capacity is moderate. Permeability is rapid, and the entire soil is suitable for plant roots.

Representative Profile - The surface layer is light brownish-gray loamy sand about nine inches thick. It is noncalcareous. The subsoil is pale-brown coarse sandy loam about 13 inches thick; also is noncalcareous. The underlying material is light yellowish-brown sandy loam and very pale brown, highly calcareous loamy sand that contains lime visible as splotches.

(VnD) Vona loamy sand, three to nine percent slopes. Surface run-off is medium, and the hazard of soil blowing is severe.

(VoC) Vona sandy loam, three to five percent slopes. The profile is similar to the representative profile except for a sandy loam surface layer and a thinner subsoil. The hazards of water erosion and soil blowing are severe.

WELD SERIES - Consists of well drained, nearly level soil on uplands. The soils were formed in wind-worked loamy materials. The soils absorb water at a moderate rate, and the available water capacity is high. Permeability is slow, and the entire soil is suitable for plant roots.

Representative Profile - The surface layer is brown loam about six inches thick. It is noncalcareous. The upper part of the subsoil is dark brown clay about six inches thick. It is noncalcareous. The lower part of the subsoil is pale-brown and very fine sandy loam about 20 inches thick. It is highly calcareous, and much of the lime is visible as splotches. The underlying material is highly calcareous, pale-brown silt loam and light yellowish-brown fine sandy loam.

(WmB) Weld loam, one to three percent slopes. This soil is found on uplands. Surface run-off is medium, and the hazard of water erosion is moderate to severe. The hazard of soil blowing is severe in clay farmed areas, if rainfall is below normal.

(Wt) Wet Alluvial Land - This is found on the nearly level bottom lands of the larger streams next to stream channels. The land is wet most of the time and is flooded by streamflow once to several times a year during periods of high water.

Materials are extremely variable in texture, consisting of stratified layers of dark-colored silt, loam, and clay. The layers are generally less than six inches thick and are underlain by sand, fine sand, and some gravel at depths of one to three feet. They are wet at a depth of two feet most of the time and are commonly wet to the surface throughout the growing season. Water tolerant plants form the vegetative cover.

# Soil Profire legend.

**SAND**

coarse sand

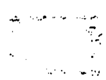
sand

loamy sand

yellow ochre

**CLAY**

clay



Lemon yellow

**Loam**

gravelly loam

gravelly sandy loam

dk brown

[illegible]rse sandy loam

sandy loam

fine sandy loam

burnt ochre

very fine sandy loam

loam

siena brown

silt loam

terra cotta

sandy clay loam

silty clay loam

heavy clay loam

clay loam

light clay loam

flesh

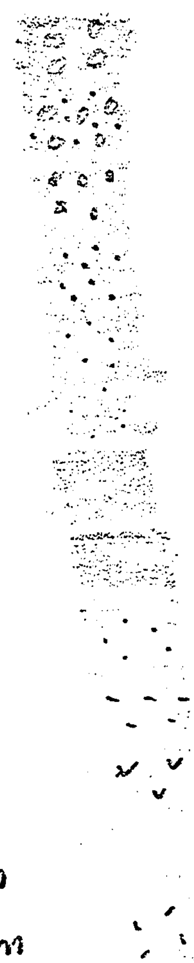


Figure 7

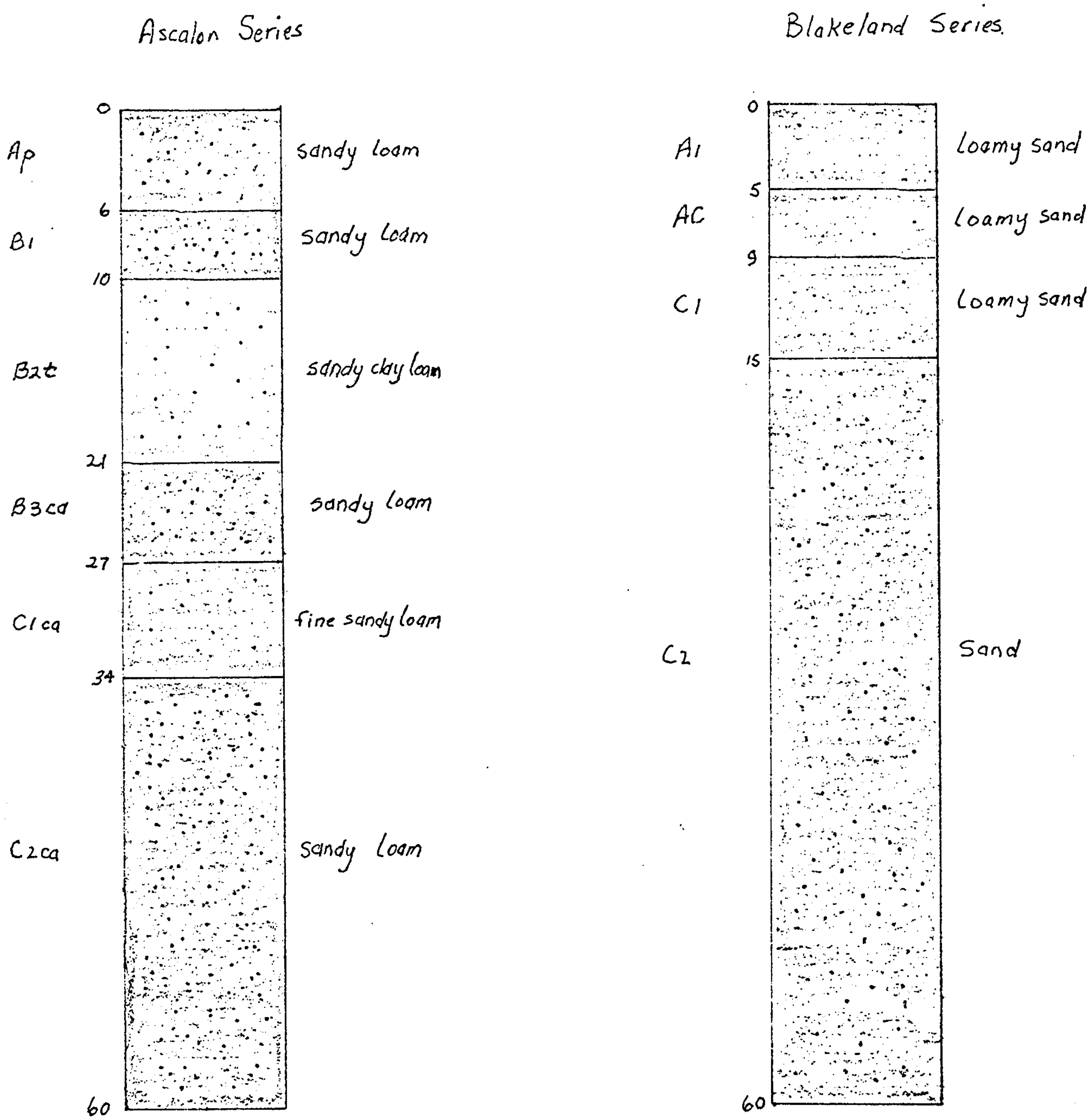

Ascalon Series
0
Ap
sandy loam
6
B1
sandy loam
10
B2t
sandy clay loam
21
B3ca
sandy loam
27
C1ca
fine sandy loam
34
C2ca
sandy loam
60
Blakeland Series
0
A1
loamy sand
5
AC
loamy sand
9
C1
Loamy sand
15
C2
Sand
60

Figure 8

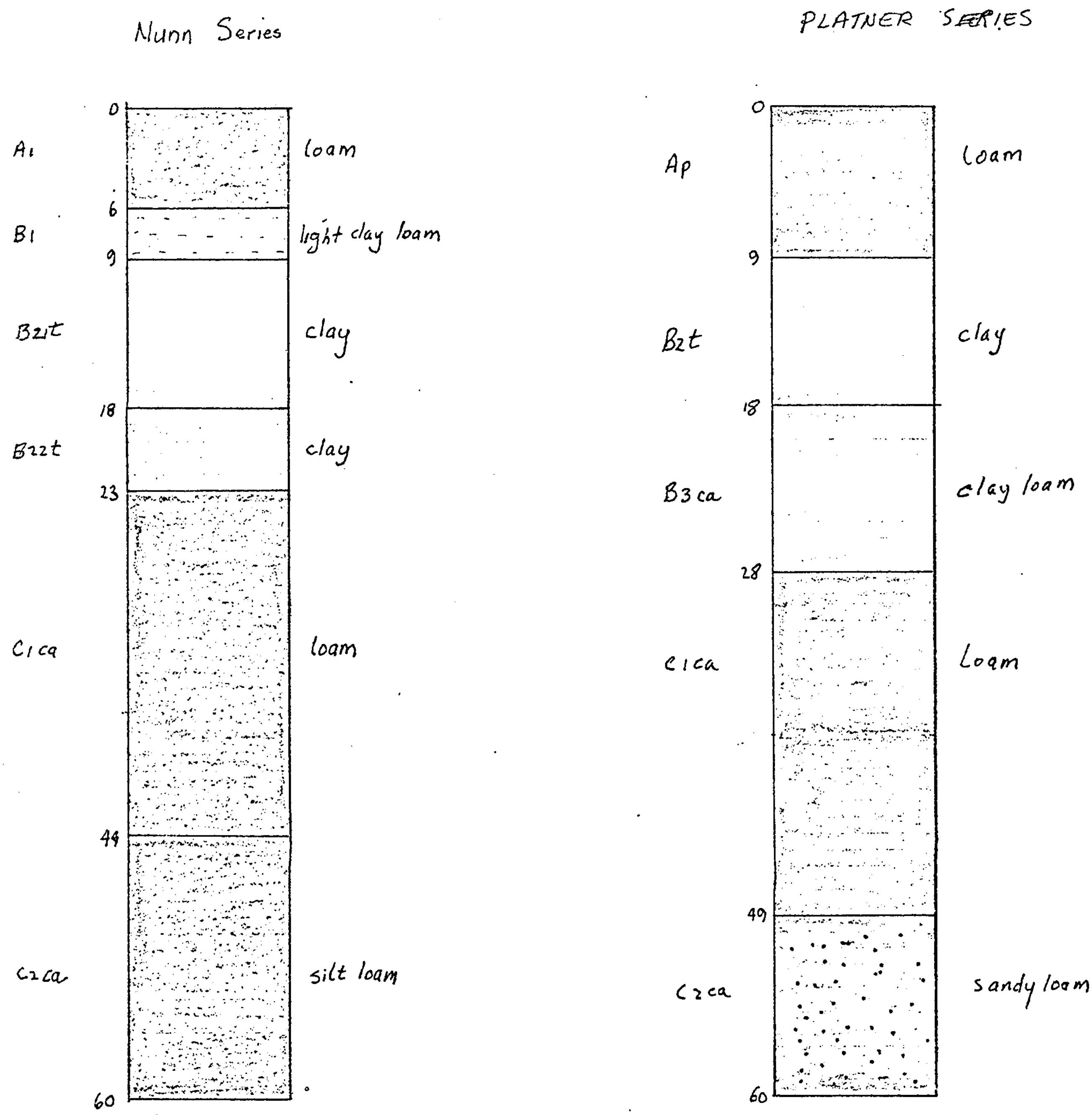

Nunn Series
0
A1
loam
6
B1
light clay loam
9
B21t
clay
18
B22t
clay
23
C1ca
loam
44
C2ca
silt loam
60
PLATNER SERIES
0
Ap
loam
9
B2t
clay
18
B3ca
clay loam
28
C1ca
Loam
49
C2ca
sandy loam
60

Figure 9

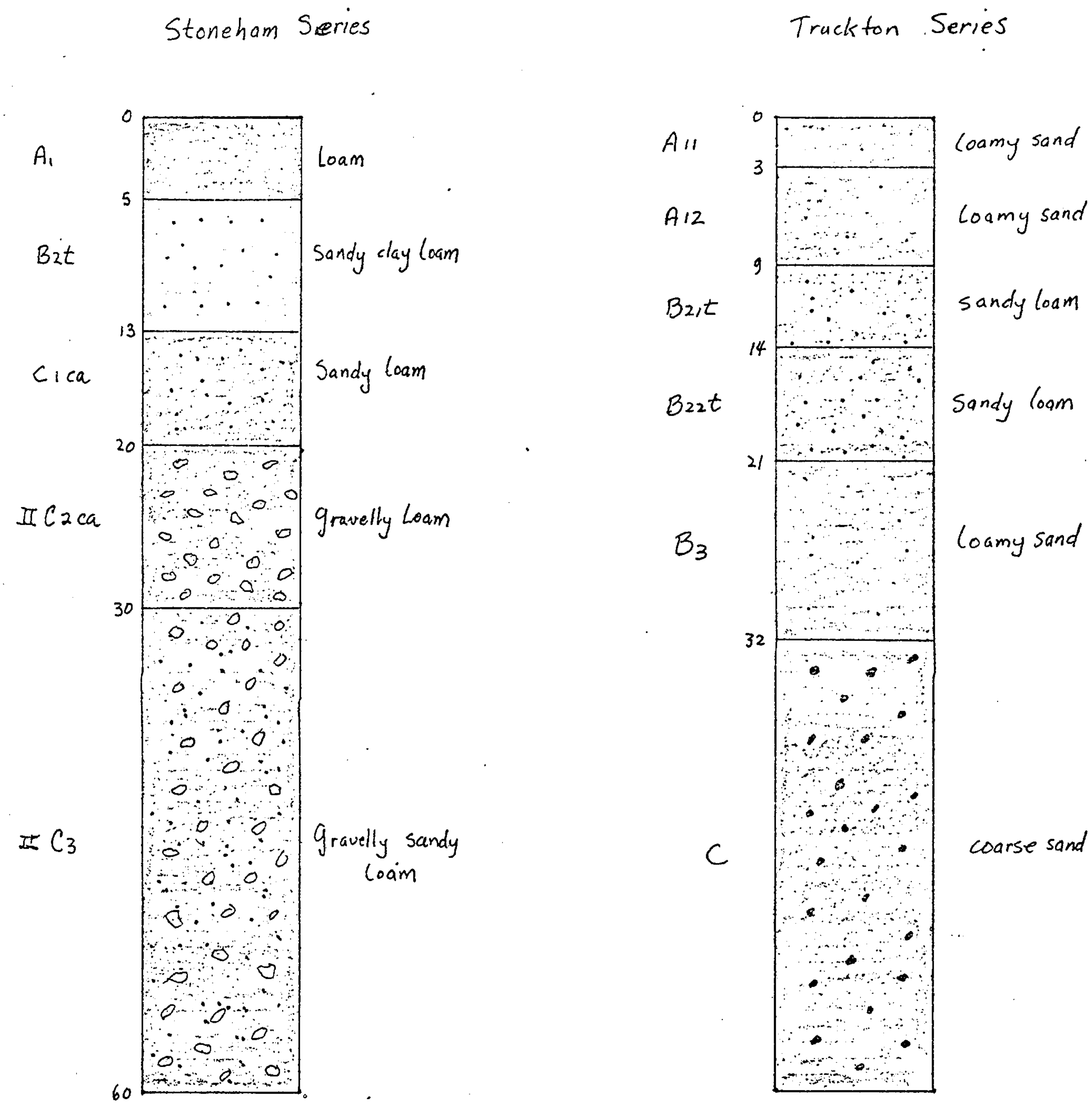

Stoneham Series
0
A1
Loam
5
B2t
Sandy clay loam
13
C1ca
Sandy loam
20
II C2ca
Gravelly Loam
30
II C3
Gravelly sandy loam
60
Truckton Series
0
A11
Loamy sand
3
A12
Loamy sand
9
B21t
sandy loam
14
B22t
Sandy loam
21
B3
Loamy sand
32
C
coarse sand

Figure 10

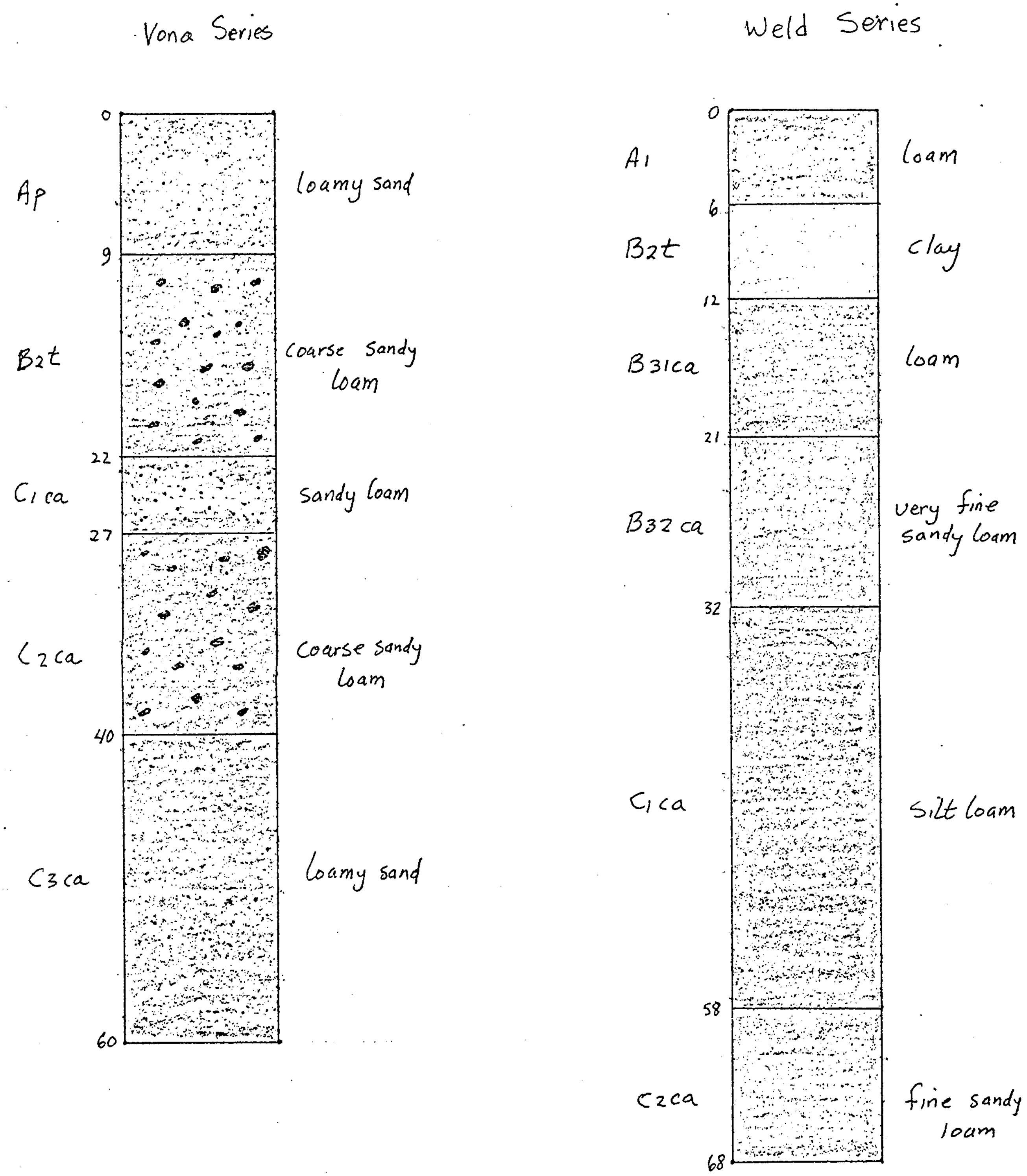

Vona Series
0
Ap
loamy sand
9
B2t
Coarse sandy loam
22
C1ca
sandy loam
27
C2ca
Coarse sandy loam
40
C3ca
loamy sand
60
Weld Series
0
A1
loam
6
B2t
clay
12
B31ca
loam
21
B32 ca
very fine sandy loam
32
C1ca
silt loam
58
C2ca
fine sandy loam
68

Figure 11

## SAMPLING METHODS

One of the objectives of the comprehensive survey is to appraise the internal organization of contaminant distribution; the location of the elements of the distribution with respect to each other. The "spatial structure" represents the location of each element relative to each of the others and also the location of each element relative to all of the contaminants taken together; that is, the internal locational organization of contaminant distribution in space. The "spatial processes," on the other hand, are mechanisms which produce the spatial structure of the contaminant distribution.

Spatial structure is a determinant of spatial process as much as process is a determinant of structure. For example, the geohydrologics characteristics of the Arsenal environment control groundwater movement, which also affects contaminant migration and the spatial pattern of contamination. An understanding of the spatial process can be achieved by the deductive approach, using the system's concept which requires fewer samples then would be required to map out the spatial pattern.

Contaminant emplacement and migration will be approached from the systems viewpoint. Systems modeling necessitates a clear definition of the objectives of the study, to identify and model the components of the system andsubsystems, and to elucidate their mutual relationships, especially with regard to the spatial patterns.

System modeling has the ability to handle a dynamic process. It has the ability to look at the total ecosystem, makes efficient use of information gathered, has the ability of checking consistency, has the ability of information integration, is applicable both as a planning tool and an analysis tool, and is an excellent means of organizing data for decision makers. The process response system, incorporating both morphological and cascading subsystems, can serve as a working model to demonstrate the linkage between form and process. The strength and direction of connectivity between the components is analyzed by statistical methods. Such methods can range from analysis of variance, correlation and multiple regression, to cross-spectral analysis.

The problem in sampling and the selection of a sampling design for meaningful data collection is predicated by the research objectives.

The purpose of sampling is to accurately portray the nature of the environment from which the samples were taken. These are two standard categories of sampling methods, probability sampling and nonprobability, or judgment sampling.

1. Probability Sampling - Probability sampling, based upon random selection, is used in modeling and forecasting the behavior of naturally occurring environmental systems. It requires that each element have an equal chance of being chosen; that is, independent of any event in the selection process. Random selection procedures eliminate conscious or unconscious bias by the scientist and enables the researcher to use probability theory as a method for estimates of population parameters and estimates of error.

a. Simple Random Sampling - After a sampling frame has been established, numbers are assigned to each of the elements in the list. The elements to be measured are then selected randomly from the list. If spatial patterns are to be sampled, then a grid overlay is used and the X and Y coordinates are selected randomly to identify either the coordinate intersection to be measured as a point sample or the appropriated grid cell to be measured as an area samples.

b. Systematic Sampling - The first element is selected randomly, then every $K^{th}$ element in the total list is chosen for inclusion in the sample. Periodicity and cyclical patterns that coincide with the sampling interval may be missed and may bias the results.

c. Stratified Sampling - Stratification organizes the population into homogeneous subsets (with heterogeneity between subsets) and an appropriate number of elements are measured from each. Stratification ensures proper representation of the variables describing the parent population. An appropriate number of elements are drawn from homogeneous subsets of the population. This minimizes sampling error.

d. Multi-Stage Cluster Sampling - Cluster sampling involves sampling groups of elements (clusters) followed by selection of elements within the clusters. Multi-stage cluster sampling involves the repetition of listing and sampling. As the homogeneity increases within each cluster, relatively fewer elements may be needed to adequately represent a given natural cluster. However, a larger number of clusters may be needed as the diversity among clusters increases.

e. Hierarchied Sampling (Nested Sampling) - A region is first subdivided into major areas of equal size. Several major areas are then chosen at random and partitioned into smaller sub regions. The sub regions are randomly selected and further subdivided. Hierarchied sampling ensures that every part of the target region is represented.

f. Disproportionate Sampling and Weighing - A probability sample is one in which each population element has a known nonzero probability of selection, even though different elements may have different probabilities. If controlled, probability sampling procedures can be used and may be representative of the population from which it was drawn, if each sample element is assigned a weight equal to the inverse of its probability of selection.

2. Nonprobability Sampling: a, Purposive or judgment sampling -- a researcher may sample with prior knowledge of the population, its elements and research objectives. This is useful to pretest a sample plan or to select a typical or representative sample.

b. Quota Sampling - Quota sampling begins with a matrix describing the characteristics of the target population. The ration of the population occurring in various categories is known. A predetermined proportion is selected for sampling from each cell of the matrix.

c. Traverses - Traverse sampling is the technique used to sample the environment along a straight line whose length and direction have been determined. Traverse sampling may be used to gather data without disturbing the environment. The assumption that the sum of the intercepts along a traverse line can be used to estimate the proportion of the total area occupied by the phenomenon being intercepted. The intercept lengths reflect the spatial geometry and the degree of fragmentation of the occurrences of the attribute being sampled in the region.

Probability sampling avoids conscious or unconscious bias in element selection which closely represents the population of all elements. Probability sampling permits estimates of sampling error. The selection of a particular sampling design depends upon the accuracy and precision required; the efficiency and feasibility of a particular procedure; and the cost in time, manpower, and money. The design selected also depends upon the objectives of the investigation, the structure or functional characteristics of the population.

A combination of the purposive sampling approach (which allows intensive study of structure and relationships and therefore hypothesis formulation) with a probability sampling approach (which allows the hypotheses to be formally tested with respect to a given population) is advocated for environmental studies.

Estimating the Sample Size

Sampling involves a compromise between precision and economy. A parameter can only be defined with 100 percent accuracy by measuring or counting the whole population. The smaller the sample, the wider the margin of error of any estimate made from it. A homogeneous population produces samples with smaller sampling errors than does a heterogeneous population. If the margin of error that can be tolerated for a particular purpose is known, it is possible to calculate the minimum sample size required and thereby same time in the collection of an unnecessarily large sample. Different methods in environmental studies can be used depending on whether the samples are to be measured or counted. Both involve prior collection of a pilot sample of about 30 observations. These samples must be collected by the same methods that are to be employed in the full sample; and they can be used as part of the full sample, provided they do not affect the selection of additional items.

The formular for finding the required sample size using measured data is: $n = (\frac{zs}{d})^2$, where n is the required size of the sample, s is the standard deviation of the pilot sample, d is the tolerable margin of error at a specified level of confidence, and z is a constant taken from the z-table (table of probabilities associated with values of z in a normal distribution) corresponding to the same level of confidence. Therefore, if the pilot sample has a standard deviation of 10 and if the margin of error that can be tolerated is 2.5 at the 95 percent level, then the required sample size is $n = (2 \times 10/2.5)^2 = 64$.

The formula for finding the sample size using counted data is $n = p\% \times q\% \times (z/d)^2$ percent, where n, z, and d have the same meanings as in paragraph above and where p and q are the percentages of the pilot sample belonging and not belonging to the specified category respectively.

## GEOGRAPHIC COORDINATE SYSTEM USED AT RMA

Several different coordinate systems have been used in the past on RMA. Each coordinate system has its own merits. However, there exists a need to coordinate all of the data-gathering tasks into one standardized reference system. The identification code of each sample collected will be located with reference to the State Plane Coordinate System, and all existing data will be converted to this system.

1. State Plane Coordinates represent a system set up for each state by the U. S. Department of Commerce, Coast and Geodetic Survey, to be used by the private land surveyors of those states. The system consists of a rectangular coordinate grid that covers the entire state, which is oriented due north and is reduced to sea level. These coordinates can be tied into a more universal Geographic Coordinate, which utilizes latitude and longitude. Any point to be referenced within the state can be identified on the State Plane Coordinate Grid. This has the advantage of being more flexible and universal when tracing data that extends beyond the Arsenal boundaries.

2. RMA Coordinate System - This system was established in 1942 on the original survey of the Arsenal. The origin of the system was a Geological Survey monument named Sand 1936 (now destroyed). The grid is oriented to magnetic north. Out of about 160 coordinate points established in the past, only eight points have been recorded. This system is completely independent of all other coordinate systems used in the area. The origin of this grid system is located in the southwest corner, such that all X and Y values on the Arsenal are positive numbers. Many of the original Arsenal design plans use the RMA Coordinate System. This system is inadequate for IR needs because negative coordinates would occur for locations beyond the Arsenal.

3. The U. S. Rectangular System is based on a grid consisting of six mile wide east-west tiers and north-south ranges. Each grid cell is a township comprised of 36 one square mile sections which are numerically numbered in snake fashion beginning in the northeast corner. Each one mile block of land or section has its own grid system and is therefore difficult to use.

4. The Section Grid is a coordinate system set up for each one mile block within a section of land. The southwest corner of the section is arbitrarily set at 1,000 feet north and 1,00 feet east. This small grid is used with very little control surveying. To set up this grid, only the boundaries of the section need to be measured. A control survey is then completed to locate the section corners on another, more universal, system. The section coordinates can then be converted to the control survey grid. This is a localized grid system which is easy to use for specific tasks.

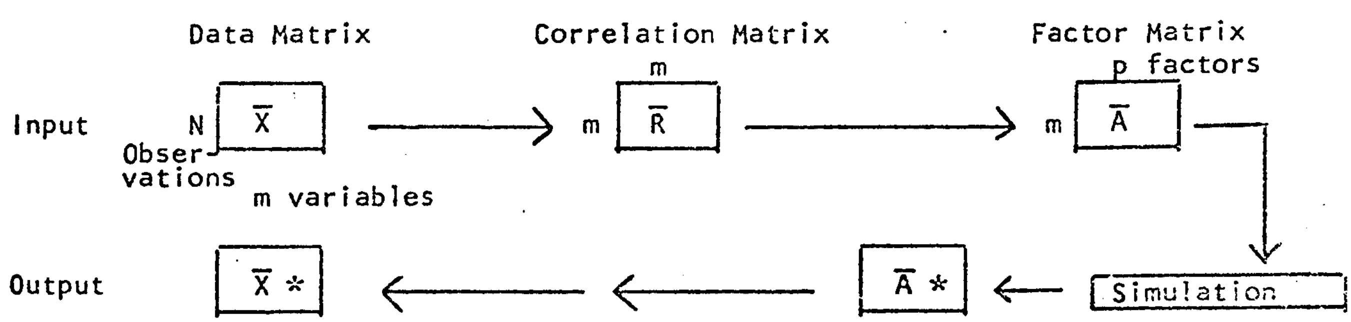
## PRINCIPAL COMPONENT FACTOR ANALYSIS

Factor analysis is a statistical technique which is used to reduce a square symmetric (mxm) matrix to a related rectangular (mxp) matrix such that $m>p$. The initial matrix is a correlation coefficient matrix consisting of m variables. The output matrix presents restructuring the pattern of correlations into p clusters of characteristics, accounting for much of the variance of the m set of initial variables.

The p set of final vectors then constitutes, a set of surrogate variables (called factors), which represent the m set of variables.

Within IR, we will deal exclusively with principal component factor analysis which selects an orthogenal rather than an oblique (correlated factor) solution and which assigns all of the variance for interpretation rather than only part of it.

Principal components method is preferred because of orthogonality and the uniqueness of the solution. There is only one principal components solution to a correlation matrix, thus the factor structure is not likely to be an artifact of procedure. The factors in the solution are uncorrelated and are statistically independent. Therefore, surrogate variables are independent by design. If there are N observation drill sites in each cluster and each site provides information with respect to m variables, then at each point in time a data matrix $\overline{X}_t$ (N x m) is obtained. Simulation of time trends may result in error because the significant correlations among the variables are likely to be interdependent. However, the correlation structure among the m variables can be reduced into p orhoganal components, with which them variables are associated by means of linear equations. Time trends of the p components may now be analyzed without fear of independence problems. The results of the simulations representing p components can be reconstructed back to the original variables. For example, the following flow diagram illustrates the steps in factorial simulation:




*These matrices are simulated.

Principal component analysis can be used in problems which involve an analysis of spatial structure of contamination and spatial taxonomy. For example, an area of interest such as the northern boundary is subdivided into N subareas or clusters. For each subarea, information on m descriptive variables is measured. This constitutes a data matrix $\bar{X}$ (N x m). The questions we now pose are:

1. How may the internal variations of the m variables over the entire area be parsimoniously described?

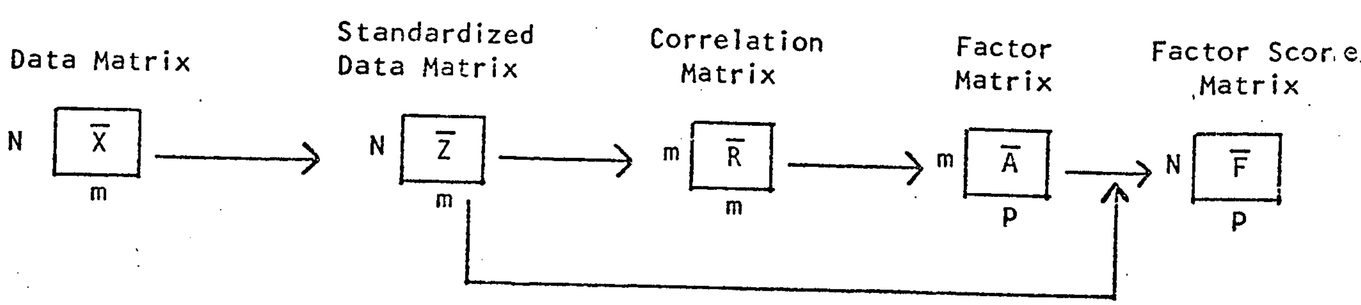
2. How may the subareas be arranged to reveal the similarity and difference so as to assign a meaningful regional structure?

A data matrix consisting of variables measured at strategically located sites positioned to describe the environment can be subjected to correlation analysis to reveal how the descriptive variables are intercorrelated and therefore the degree to which they report redundant information.

Principal components analysis can be used. The oringal variables may be correlated and numerous. The patterns of variation may be independent and confusing. These can be reduced to p factors which, on the other hand, are few and independent and thus describe the region more parsimoniously. Furthermore, there is no way of knowing which of the variables are the most powerful descriptive tools; whereas, the principal components method ranks the factors in descending order of ability to interpret the correlation matrix variance. If factor $\bar{f}_1$ interprets 42 percent of the variance and factor $\bar{f}_2$ 34 percent, we can ascertain which is more general and by how much.

For mapping and regionalizing, it is desirable to be able to estimate the strength of each factor within each tract. For this purpose, the matrix $\bar{A}$ (m x p) which gives the relationships between the variables and the factors is combined with a matrix $\bar{Z}$ (N x m) of standardized values of the initial variables. The result is a matrix of dimension (N x p) which estimates the strength of each factor in each subarea of observation. This is called the factor score matrix $\bar{F}$. The sequence is as follows:

Flow Diagram of Principal Components Analysis
of a Data Matrix



Each row of the factor score matrix of a given sampling bore hole (or subarea) across the independent dimensions represented by the columns. It is therefore actually a point in the p-dimensional space of the factor structure. One may therefore evaluate the similarity or difference between subarea i and subarea j by means of the pythagorean theorem which evaluates the distance between any two points in a p-dimension space.

$$(1) \quad d_{ij}^2 = (e_{i1} - e_{j1})^2 + (e_{i2} - e_{j2})^2 + \ldots + (e_{ip} - e_{jp})^2$$

Equation (1) may be evaluated for every pair of subareas, and the set of $\{d_{ij}^2\}$ will then form the $\bar{D}^2$ matrix. Analysis of this matrix -- especially by such techniques as discriminant analysis -- will cluster those subareas which most resemble one another into families linked into a regional hierarchy of subareas. The grouping of the $\{d_{ij}^2\}$ by discriminant analysis will be presented at a later date.

The Procedure of Principal Components Analysis

If we consider the matrix $\bar{Z}$ (N z m) of standardized values of the N subareas on the m variables, we may regard each variable as a vector in a N dimensional space of orthogonal axes. The columns of the matrix, in this case, form the vectors which define each variable's positions in this space. Since we are dealing with a standardized value matrix, all vectors are of equal (and unit) length. The similarity of any variable to any other is therefore measured by the angle between them. But, the cosine of the angle between two standardized vectors in a space of N dimensions is given by the inner vector product between them. The cosine function varies between -1 and +1 and is, in fact,

$$(2) \quad \cos \theta_{ij} = \frac{\bar{z}_i \cdot \bar{z}_j}{N}$$

the correlation coefficient between the $i^{th}$ and $j^{th}$ variable. Thus, we find $\bar{R}$, the correlation coefficient matrix, by expression (3).

$$(3) \quad \bar{R} = \frac{\bar{Z}' \cdot \bar{Z}}{N}$$

$\bar{R}$ is a matrix which measures the angles between variable vectors. The principal components solution starts by discovering how orthogonal axes may be passed through this pattern of intersecting vectors so that each axis will, as far as it is possible, coincide with the center of a "cone" of vectors (i.e., be correlated with it). This is analogous with the physicist's problem of finding the resultant of a set of force vectors. In the F matrix case, the resultant is found by solving the characteristic equation of the matrix.

In ordinary algebra, an expression of the type

$$(4) \quad ay = gy$$

implies that a = g. In matrix algebra, a common factor on each side of the equation does not imply the equality.

$$(5) \quad \bar{A}\bar{Y} = \lambda \bar{Y}$$

In expression (5), $\bar{A}$ may be a (m x m) matrix, and $\bar{Y}$ may be a (m x 1) vector. $\lambda$ may be a scalar, and it will then be true that the left hand term and right hand term will both be (m x 1) vectors; yet $\bar{A} \neq \lambda$. Scalars such as $\lambda$ and vectors such as $\bar{Y}$, which have this property with respect to a given matrix, $\bar{A}$, are called eigenvalues and eigenvectors. When the correlation coefficient matrix $\bar{R}$ is factored into eigenvalues and eigenvectors (factor analysis), the eigenvalues are orthogonal and have the properties which we seek. Furthermore, the eigenvalues prove to be scaling coefficients such that they are proportional to the amount of variance interpreted by each factor. Any factor with a $\lambda > 1.0$ interprets more variance than an unmodified variable alone, while any factor with a $\lambda < 1.0$ is of relatively weak explanatory power. Generally, the researcher rejects factors with $\lambda < 1.0$, and the $\Sigma\lambda_i$ of these rejected factors is proportional to the unexplained variance in the model.

The factor loading matrix $(\bar{A})$ is synthesized from the eigenvalues and eigenvectors so that

$$(5) \quad \bar{R}\,\bar{A} = \bar{A}\,\bar{\Lambda}$$

where $\bar{\Lambda}$ is a diagonal matrix whose elements on the principal diagonal are the $\lambda$'s.

A matrix $\bar{F}$ can then be derived whose columns are vectors $\bar{f}_1$, $\bar{f}_2$, ... corresponding to the scores of each factor in a certain tract, by seeking some relationship based upon the property that

$$(6) \quad \bar{z} = \bar{A}\,\bar{f}$$

which is to say that $\bar{z}$ (a column vector of the standardized variables) for the tract and $\bar{f}$ (a column vector of the factors) are linearly related through $\bar{A}$. Then, premultiplying by $\bar{A}$ gives

$$(7) \quad \bar{A}'\bar{z} = \bar{A}'\bar{A}\,\bar{f}$$

and finally

$$(8) \quad \bar{f} = (\bar{A}'\,\bar{A})^{-1}\,\bar{A}'\bar{z}$$

Expression (8) provides the means for estimating the values of the p factors for all the tracts. These are the values which may be mapped.

Rotation of the factor structure to any one of an infinite number of configurations will yield different resultants. The most useful rotation for IR is that which uses the varimax criterion. The purpose of this is to place the component axes in the unique position where as much of each factor as possible is interpreted by strong loadings by as few variables as possible. This rotation simplifies factor structure in that each factor axis is placed as parallel as possible to a limited number of variable vectors.

Rotation serves a very useful purpose in clarifying the interpretation of the model by a rule of parsimony. Furthermore, the varimax rotation, oke the principal components solution, yields a unique solution whose factors are orthogonal -- but with the added advantage of simplicity of interpretation.

## FACTOR ANALYSIS OF CONTAMINANTS ALONG THE NORTHERN BOUNDARY

The following example will illustrate the use of principal component factor analysis for (1) data reduction, (2) analysis of spatial structure, and (3) spatial mapping.

Twenty-four bore hole samples were drilled 250 feet apart in two parallel east to west lines along the northern boundary at RMA. Chemical analysis was performed on the groundwater collected from each sample and tested for eight compounds (eight variables). The raw data matrix (24 x 8) is shown on Table 1, in which the rows represent the bore holes (samples, N), and the columns represent the variables (m).

Table 3 is an eight by eight correlation matrix (M x M), which represents the product moment correlation between each of the eight compounds analyzed. When the number of variables in the set is small, it is easy to evaluate those variables which correlate highly with each other. When the number of variables increases, it becomes difficult to identify those variables which are intercorrelated and group together as clusters. These groups can be isolated as orthogonal factors. Table 6 shows three factors represented as columns. The variables in this (m x p) matrix are shown as the rows where the factor loadings and the factors represent their relationships.

The $cl^-$ ion, DIMP and the Na ion load up on factor 1; therefore, they must also be highly intercorrelated and occur as a group in this data set.

## RAW DATA MATRIX

VARIABLES: V1 = $Cl^-$ (PPM), V2 = Na (PPM), V3 = $SO_4^=$ (PPM), V4 = $NO_2/NO_3$ (PPM), V5 = Hardness (PPM), V6 = pH, V7 = DIMP (PPB), V8 = DCPD (PPB)

| SAMPLES | V1 V2 V3 V4 V5 V6 V7 V8 |
|---|---|
| A-1 | 44541204550.206407.6222000031 |
| A-2 | 27630001950.043207.8609400290 |
| A-3 | 33530002100.043857.4807301600 |
| A-4 | 07507500850.091207.9000920073 |
| A-5 | 23026304151.404707.5904000000 |
| A-6 | 22027306552.956507.8001700000 |
| A-7 | 50034307500.127257.4015000000 |
| A-8 | 20037309552.557057.9100820000 |
| D-1 | 28031302590.043507.7712000290 |
| D-2 | 21420801520.062757.9105300240 |
| D-3 | 09507501300.061808.0100660000 |
| D-4 | 24526805503.006407.6702700000 |
| D-5 | 52552505300.186507.5529000000 |
| D-6 | 36527002000.044757.6507501200 |
| D-7 | 24519501800.213407.7004800088 |
| D-8 | 22532508552.008557.6701500010 |
| UD-1 | 24221402000.144207.6005700320 |
| UD-2 | 24023403250.045007.6504200010 |
| UD-4 | 44561501550.057407.4919000000 |
| UD-5 | 32527003950.044357.7407000093 |
| UD-6 | 17034510003.158507.6200630000 |
| UD-7 | 28529002100.062957.9809600093 |
| UD-8 | 20420003002.004658.2603400012 |
| UD-3 | 16925306153.306657.5202400000 |

TABLE 1

| VARIABLE | | MEAN | ST.DEV. |
|---|---|---|---|
| $Cl^-$ | 1 | 273.125011 | 115.321591 |
| Na | 2 | 289.125000 | 117.819796 |
| $SO_4^=$ | 3 | 407.333340 | 273.620590 |
| $NO_2/NO_3$ | 4 | .906667 | 1.241141 |
| Hardness | 5 | 506.249996 | 203.855494 |
| pH | 6 | 7.722917 | .200531 |
| DIMP | 7 | 735.541687 | 735.724869 |
| DCPD | 8 | 181.250010 | 394.055733 |

TABLE 2

CORRELATION MATRIX

| | 1 $Cl^-$ | 2 Na | 3 $SO_4^=$ | 4 $NO_2/NO_3$ | 5 Hardness | 6 pH | 7 DIMP | 8 DCPD |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.00000 | | | | | | | |
| 2 | .76139 | 1.00000 | | | | | | |
| 3 | .03735 | .33400 | 1.00000 | | | | | |
| 4 | -.397[illegible] | .01110 | .72653 | 1.00000 | | | | |
| 5 | .36[illegible] | [illegible]6785 | .83121 | .59162 | 1.00000 | | | |
| 6 | -.55539 | -.50381 | -.25455 | .04583 | -.50311 | 1.00000 | | |
| 7 | .89145 | .72437 | -.12501 | -.48784 | .17548 | -.39476 | 1.00000 | |
| 8 | .17279 | -.05811 | -.34515 | -.32579 | -.25761 | -.20842 | .01[illegible]98 | 1.00000 |

TABLE 3

EIGENVALUES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.39514 | 2.68405 | 1.00452 | .45274 | .21404 | .13149 | .08421 | .03387 |

CUMULATIVE PROPORTION OF TOTAL VARIANCE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| .42439 | .75990 | .88546 | .94205 | .96881 | .98525 | .99577 | 1.00000 |

TABLE 4

| VARIABLE | ESTIMATED COMMUNALITY | FINAL COMMUNALITY |
|---|---|---|
| 1 | 1.000005 | .928412 |
| 2 | 1.000005 | .860722 |
| 3 | 1.000005 | .881439 |
| 4 | 1.000005 | .887435 |
| 5 | 1.000005 | .955947 |
| 6 | 1.000005 | .732684 |
| 7 | 1.000005 | .947572 |
| 8 | 1.000005 | .889357 |

TABLE 5

ROTATED FACTOR MATRIX

| | VARIABLE | FACTOR 1 | FACTOR 2 | FACTOR 3 |
|---|---|---|---|---|
| $Cl^-$ | 1 | .95432 | .05771 | .11978 |
| Na | 2 | .86626 | -.32869 | -.04775 |
| $SO_4^=$ | 3 | .07578 | -.93095 | -.09502 |
| $NO_2/NO_3$ | 4 | -.36283 | -.86278 | -.10680 |
| Hardness | 5 | .42726 | -.87938 | -.00878 |
| pH | 6 | -.59616 | .32518 | -.52109 |
| DIMP | 7 | .93632 | .23634 | -.12260 |
| DCPD | 8 | .02320 | .31009 | .89032 |

TABLE 6

FACTOR SCORES

| SAMPLES | CASE | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|---|
| A-1 | 1 | 1.63071 | .14408 | -.63347 |
| A-2 | 2 | .04633 | .92987 | -.24377 |
| A-3 | 3 | .13449 | .57079 | 3.43871 |
| A-4 | 4 | -1.46349 | 1.25532 | -.37236 |
| A-5 | 5 | -.28705 | -.26986 | .07464 |
| A-6 | 6 | -.63546 | -1.16170 | -.26449 |
| A-7 | 7 | 1.47940 | -.57263 | .13603 |
| A-8 | 8 | -.50271 | -1.52047 | -.57213 |
| D-1 | 9 | .27072 | .78231 | -.12060 |
| D-2 | 10 | -.55679 | 1.02852 | -.26528 |
| D-3 | 11 | -1.44698 | 1.19991 | -.75781 |
| D-4 | 12 | -.46282 | -1.09225 | .01025 |
| D-5 | 13 | 2.46890 | .09476 | -.85149 |
| D-6 | 14 | .16364 | .59346 | 2.25481 |
| D-7 | 15 | -.35982 | .69941 | -.03682 |
| D-8 | 16 | -.22932 | -1.60303 | .04838 |
| UD-1 | 17 | -.21799 | .51007 | .64720 |
| UD-2 | 18 | -.17469 | .23713 | -.05952 |
| UD-4 | 19 | 2.12827 | .10989 | -.45420 |
| UD-5 | 20 | .15308 | .39788 | -.23061 |
| UD-6 | 21 | -.48184 | -2.18231 | .18710 |
| UD-7 | 22 | .00252 | 1.04124 | -.93460 |
| UD-8 | 23 | -1.01234 | .24606 | -1.39069 |
| UD-3 | 24 | -.64515 | -1.44025 | .39619 |
| | | Var 1 = $Cl^-$<br>2 = Na<br>7 = DIMP | Var 3 = $SO_4$<br>4 = $NO_2/NO_3$<br>5 = Hardness | Var 8 = DCPD |

TABLE 7

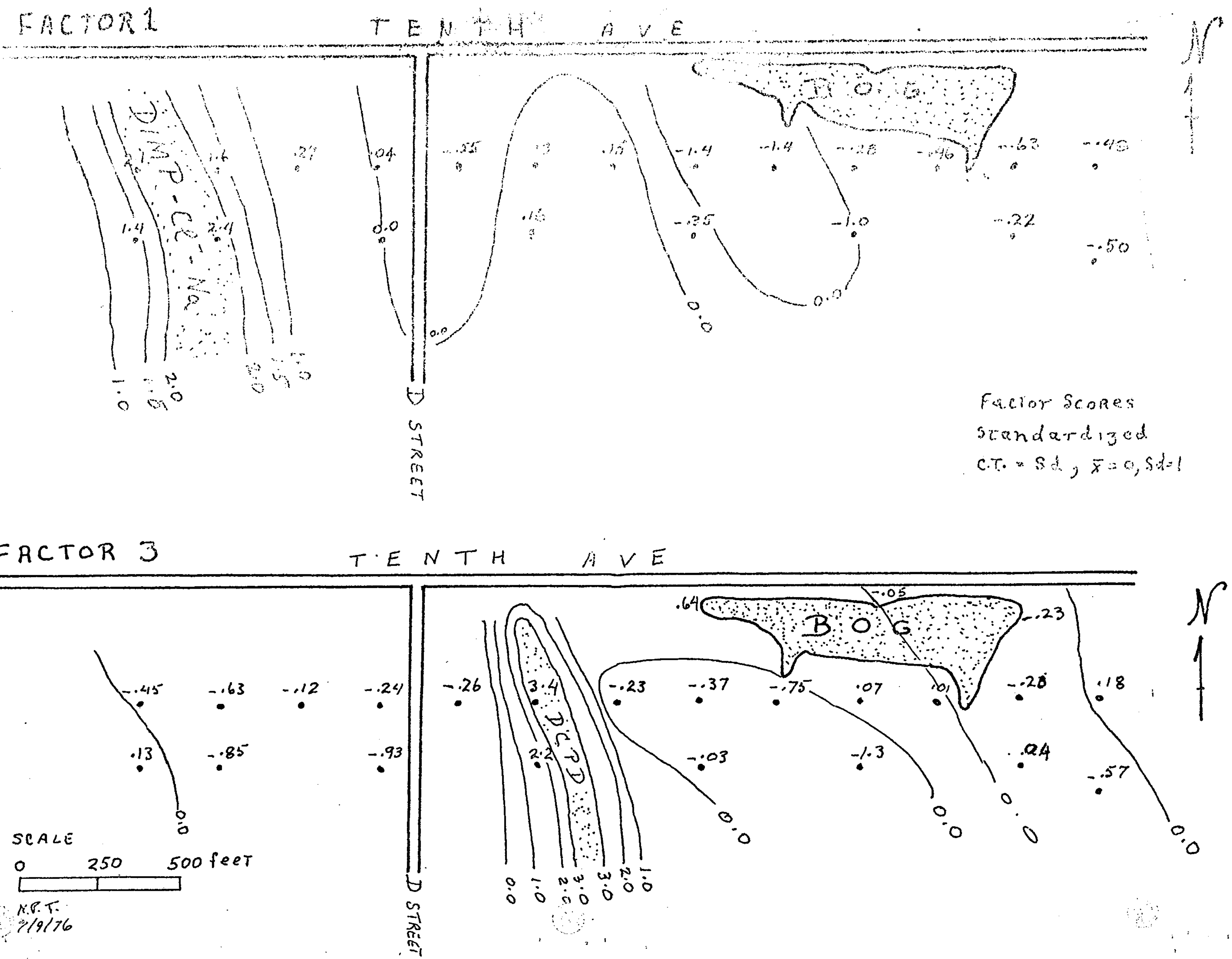

FACTOR 1
TENTH AVE
D STREET
DIMP-Cl⁻-Na
BOG
Factor Scores
standardized
C.T. = Sd., x̄ = 0, Sd=1
FACTOR 3
TENTH AVE
D STREET
DCPD
BOG
SCALE
0
250
500 feet
N.P.T.
7/9/76

Figure 12

Factor 2 represents the $SO_4^=$ ion, $NO_2/NO_3$, and hardness variable group. DCPD behaves independently represented as Factor 3 in this data set. It is possible from the factor loading to identify which variable (model variable) has the highest correlation with the respective factor. This model variable can then represent the group in future tests and thus permit data reduction with minimum information loss.

Table 4 gives the eigenvalues which can be interpreted as the proportion of the variance in the data matrix which is explained by each of the factors. By weighting the proportion each eigenvalue is of the total, we can determine the relative explanatory power of each of the factors in terms of the total common variance in the data set. Factor 1 accounts for 42 percent of the total variance, while Factor 2 explains 33 percent. All three factors together explain 88 percent of the total variance in this example.

Table 7 gives the factor scores. These numbers represent the weight of each of the factors at each of the 24 drill sites. By mapping and contouring the factor scores for each of the factors separately, we can construct maps showing multivariate distribution representing the spatial behavior of groups of contaminants which behave spatially together. See map .

This information is invaluable in (1) tracing each of the contaminant migration paths independently, (2) determining the source of contamination, and (3) determining the position and direction for further sampling.

## SAMPLING SITE CHARACTERIZATION & DRILL CORE LOGGING

### OVERVIEW

Soils are organized natural bodies which vary markedly, both horizontally across the surface of land and vertically as seen in cross section. The vertical section provides the best means of examining soil. The component layers that form the basic unit for the classification of soils, in turn, provides a basic framework for the analysis and mapping of the behavior of the pollutants in the ground.

The profile form which expresses the overall visual impact of the physical soil properties in their association with one another serves as the basis for the following key. The profile is regarded as a physical system and those physical properties capable of observation and record which may incorporate other features or properties, either physical, chemical, or biological are used as the critical ones to distinguish subtle changes in the environment and contaminant behavior.

An attempt has been made to identify and code most of the relevant parameters which best describe the physical characteristics of the soil. The following list of variables are to be measured at each sampling site in the comprehensive survey at RMA. This list includes a coding key which has been successfully used in previous studies and should be used to enter the data gathered into the computerized data bank. The scale for each of the variables describing topography, site drainage, physical soil properties, and bedrock lithology has been designed so that the scale can serve as input directly into numerical analysis and computer graphics routines. The key is flexible in that if necessary, it can be expanded without detriment to those portions of the key already completed.

## PHYSICAL VARIABLES

Each sampling site will be identified by a ten digit index located on the State Plane Coordinate System. The first five characters of the index represent the X axis of the east-west State Plane Coordinates measured to the nearest foot, and the last five characters represent the Y axis.

### A. Topographic Variables

1. Elevation is the height of a given point above mean sea level. Elevation is a critical variable which is used in most calculations to provide information on relative position.

Units = feet (height above mean sea level)

2. Local relief is the difference in elevation between the highest and lowest points. It measures the physical size of the topographic features.

Units = feet (difference between highest and lowest points)

3. Ruggedness is a combination of gully depth measured in feet and gully count per 100 square yard site. Ruggedness measures the degree of direction of a landform and provides information about the degree and stage of landform erosion. It also indirectly measures the pattern of surface water flow.

(a) Depth in feet

| | |
|---|---|
| > 1 foot | 1 |
| 1 - 6 feet | 2 |
| 6 - 15 feet | 3 |
| > 15 feet | 4 |

(b) Count across 100 yards square site

| | |
|---|---|
| None | 0 |
| 1 - 5 | 1 |
| 5 - 10 | 2 |
| > 10 | 3 |

4. Slope describes the angular inclination of the surface at the sampling site. It is measured as a ratio of the amount of drop (h) in 100 feet of length ($\ell$).

Units = ratio $h \div \ell$ (recorded as a decimal number)

5. Slope geometry represents the shape of the sloping surface and is an important variable in characterizing soil erosion or soil accumulation on the ground surface.

(a) Shape

| | |
|---|---|
| Convex | 1 |
| Concave | 2 |
| Straight | 3 |

(b) Relative location

| | |
|---|---|
| Top | 1 |
| Middle | 2 |
| Bottom | 3 |

6. Aspect describes the directional orientation of a topographic feature with reference to north. It is most convenient to divide the compass direction into 16 divisions.

| | |
|---|---|
| N.N.E. | 01 |
| N.E. | 02 |
| E.N.E. | 03 |
| E. | 04 |

| | |
|---|---|
| E.S.E. ------------------- | 05 |
| S.E. --------------------- | 06 |
| S.S.E. ------------------- | 07 |
| S. ----------------------- | 08 |
| S.S.W. ------------------- | 09 |
| S.W. --------------------- | 10 |
| W.S.W. ------------------- | 11 |
| W. ----------------------- | 12 |
| W.N.W. ------------------- | 13 |
| N.W. --------------------- | 14 |
| N.N.W. ------------------- | 15 |
| N. ----------------------- | 16 |

7. Drainage is characterized by two different components. Site drainage describes the movement or potential for movement of water and moisture -- the amount of water contained in the soil.

(a) Site drainage

| | |
|---|---|
| Shedding ----------------- | 01 |
| Normal ------------------- | 02 |
| Receiving ---------------- | 03 |
| Regular flooding, Short Term -------------------- | 04 |
| Regular flooding, Long Term -------------------- | 05 |
| Occasional flooding, Short Term -------------------- | 06 |
| Occasional flooding, Long Term -------------------- | 07 |

(b) Moisture

| | |
|---|---|
| Dry (becomes darker when wet) | |
| $D_1$ (air dry) ------------ | 01 |
| $D_2$ ----------------------- | 02 |
| $D_3$ ----------------------- | 03 |
| Moderately moist | |
| $MM_1$ ---------------------- | 04 |
| $MM_2$ ---------------------- | 05 |
| $MM_3$ (wilting point) ----- | 06 |
| Moist | |
| $M_1$ ----------------------- | 07 |
| $M_2$ ----------------------- | 08 |
| $M_3$ (field capacity) ----- | 09 |

| Wet | | | |
|---|---|---|---|
| $W_1$ | ---------------------- | 10 | (material will wet |
| $W_2$ | ---------------------- | 11 | and stick to fingers |
| $W_3$ | ---------------------- | 12 | when molded) |

B. Soil Physical Properties

1. Depth to sample in the vertical distance measured from the ground surface to the top and the bottom of the sample.

units = feet (measured to the nearest hundreth of foot)

2. Horizon is a layer within the soil profile having morphological characteristics and properties different from those layers which occur below and/or above it. Horizons are usually parallel to the land surface, except where tongues of material from one horizon may penetrate vertically into the neighboring horizon. The horizons are recognized by the nature of their organization. $A_O$ results largely from biologic processes. The A horizon results from biologic processes and those physico-chemical processes that occur at surfaces. The B horizon results from physio-chemical processes which occur below surfaces that are relatively deep seated. C horizons are recognized by their lack of pedologic development and remains of geologic organization. The D horizons result from some earlier cycle of soil-forming process; and thus, their pedologic organization contrasts with that found in the solum of the soil with which they are associated. Weathered bedrock is an example.

Eight categories will be recognized in this study. They are given in descending order: the $A_O$ horizon is the surface soil layer and is composed of organic material; the $A_1$ horizon is the topmost mineral layer with a high content of humified organic matter, relatively dark in color and has a maximum biological activity for any given soil profile; the $A_2$ horizon is the zone of maximum leaching (eluviation), it may be defined by color difference. It may be bleached to a white color or sporadic by bleaches which appear irregular or as blocks less than one-fourth inch in thickness at the interface with the B layer. The B horizon is a transition zone between the A and B horizons though accumulation of material (illuviation) starts to take place. The B horizon is characterized by a concentration of clay and/or iron and/or aluminum and/or translocated organic material and/or having a structure or consistency different from A or C. B also has stronger colors. The $B_2$ horizon is the zone of maximum illuviation of mineral and organic matter; the B-C horizon is a transition zone between the illuvial B horizons and the unconsolidated material of the C horizon. The C horizon is unconsolidated material which may or may not be of the same parent material from which the upper horizons are formed. It is not in the zone of major biological activities; the D horizon is weathered bedrock.

| Horizon | | |
|---|---|---|
| $A_0$ | --------- | 1 |
| $A_1$ | --------- | 2 |
| $A_2$ | --------- | 3 |
| $B_1$ | --------- | 4 |
| $B_2$ | --------- | 5 |
| B-C | --------- | 6 |
| C | --------- | 7 |
| D | --------- | 8 |

3. Horizon thickness -- represents the size of the horizon.

units = feet measured to nearest .01 of a foot.

4. Horizon boundary is a zone of change occurring between soil horizons ranging from the sharp and clearly defined to diffuse. The boundary defines the nature of the change and is specified by two terms -- one a measure of the thickness or width of the transition zone between horizons, the other a measure of its shape.

(a) Shape

1 - Even = boundary is almost a plane surface
2 - Wavy = boundary waves, depressions formed are wider than their depths
3 - Irregular = boundary waves, depressions formed are deeper than their widths
4 - Broken = boundary is discontinuous

(b) Sharpness

1 - Sharp = < 2 cm
2 - Clear = 2 - 5 cm
3 - Gradual = 5 - 10 cm
4 - Diffuse = > 10 cm

5. Color is defined in terms of hue, value, and chroma using the Munsell soil color charts. Hue is a function of the wave length of

the light. Value is the intensity of color and chroma the relative purity or saturation of a color. Color should be recorded for moist soil only.

Color (moist)

1 Hue

| | |
|---|---|
| 2, 5 YR ------------- | 32 |
| 5 YR ---------------- | 16 |
| 7, 5 YR ------------- | 8 |
| 10 YR --------------- | 4 |
| 2, 5 Y -------------- | 2 |
| 5 Y ----------------- | 1 |

2 Value

1-2-3-4-5-6-7-8

3 Chroma

1-2-3-4-5-6-7-8

6. pH measures the hydrogen ion concentration of soil. It is a fundamental property of both physical and chemical characteristics of both the organic and inorganic constituents of the soil.

units = dimensionless number of nearest .1

7. Soil texture is a measure of the size and proportion of individual gain present in the soil. Texture can be measured by the behavior of a small handful of soil when moistened and kneaded into a ball and then pressed out between thumb and forefinger. The approximate percentage content of clay (particles less than 0.002 mm in diameter) and silt (particles between 0.02 and 0.002 mm in diameter) and sand (range from 2 mm to 0.02 mm diameter with an arbitrary separation of coarse and fine sand at 0.2 mm particle diameter) provide a guide for classification.

a. The field method of determining texture soil is to take a sample of soil sufficient to comfortably fit into the palm of the hand. The soil is moistened with water, a little at a time, and kneaded until the ball of soil, so formed, just fails to stock to the fingers. More soil or water may be added to attain this condition, which is known as the sticky point and approximates field moisture capacity for that soil. Kneading and moistening are continued until there is no apparent change in the soil ball, usually a working time of one to two minutes. The soil ball, or bolus, is now ready for shearing manipulation; bu t the behavior of the soil during bolus formation is also indicative of its texture. The behavior of the bolus and of the ribbon produced by shearing (pressing out) between thumb and forefinger characterizes the texture.

b. A much more reliable method of determining soil texture is by sieving the soil samples.

Textural classes

| | | |
|---|---|---|
| S | Sand ---------------- | 01 |
| LS | Loamy sand ---------- | 02 |
| CS | Clayey sand --------- | 03 |
| SL | Sandy loam ---------- | 04 |
| FSL | Fine sandy loam ----- | 05 |
| GL | Gravelly loam ------- | 06 |
| L | Loam ---------------- | 07 |
| SCL | Sandy clay loam ----- | 08 |
| GCL | Gravelly clay loam -- | 09 |
| CL | Clay loam ----------- | 10 |
| SICL | Silty clay loam ----- | 11 |
| CG | Gravelly clay ------- | 12 |
| FSCL | Fine sandy clay loam - | 13 |
| SC | Sandy clay ----------- | 14 |
| SIC | Silty clay ----------- | 15 |
| LC | Light clay ----------- | 16 |
| MC | Medium clay ---------- | 17 |
| HC | Heavy clay ----------- | 18 |

8. Stones are measurable surface features. The abundance is measured as a percentage of cover; size consists of eight categories ranging from gravel (0.2 - 1 cm) to large boulders (< 600 cm); shape can be angular, subangular, rounded, shaley, or tabular; and the lithology of stones is given in 12 petrological types.

(a) Abundance (% cover)

| | | |
|---|---|---|
| Stoneless | < 1 | 0 |
| Slightly stony | 1 - 5 | 1 |
| Stony | 5 - 20 | 2 |
| Very stony | 20 - 50 | 3 |
| Extremely stony | 50 - 75 | 4 |
| Stone dominant | > 75 | 5 |

(b) Size (cm)

| | | |
|---|---|---|
| Gravel | 0.2-1 | 1 |
| Small | 1 - 5 | 2 |
| Medium | 5 - 1 | 3 |
| Large | 10 - 20 | 4 |
| Very large | 20 - 60 | 5 |
| Small boulders | 60 - 200 | 6 |
| Medium boulders | 200 - 600 | 7 |
| Large boulders | > 600 | 8 |

(c) Shape

| | |
|---|---|
| Angular | 1 |
| Subangular | 2 |
| Rounded | 3 |
| Shaley | 4 |
| Tabular | 5 |

(d) Lithology

| | |
|---|---|
| Flint | 1 |
| Soapstone | 2 |
| Limestone | 3 |
| Mudstone | 4 |
| Siltstone and shale | 5 |
| Sandstone | 6 |
| Ironstone | 7 |
| Quartzite | 8 |
| Granite | 9 |
| Gneiss or schist | 10 |
| Ryholite | 11 |
| Andesite | 12 |

9. Roots describe the presence of vegetative matter in the soil measured in terms of quantity and size. Decay of roots provides channels of water flow within the soil.

(a) Quantity

| | |
|---|---|
| Absent --------------- | 0 |
| Present (trace) ------ | 1 |
| Very low ------------- | 2 |
| Low ------------------ | 3 |
| Moderate ------------- | 4 |
| High ----------------- | 5 |

(b) Size

| | |
|---|---|
| Small ---------------- | 1 |
| Small - Medium ------- | 2 |
| Small - Large -------- | 3 |
| Medium - Small ------- | 4 |
| Medium --------------- | 5 |
| Medium - Large ------- | 6 |
| Large - Small -------- | 7 |
| Large - Medium ------- | 8 |
| Large ---------------- | 9 |

10. Structure is concerned with the arrangement of all soil particles. Particles refer to all peds and nonpeds (see both Apedal and Peds). Structure may be described in terms of the three characteristics of the intensity, geometry, and size of the soil aggregates as follows:

(a) Intensity expresses the degree and strength of soil aggregation and may vary with the moisture status of the soil. For purposes of standardization, intensity should be determined when the soil is inthe moderately moist to moist, moisture stages. Four intensities of structure are usually defined as follows:

(1) Structureless in which there is no observable aggregation and the soil is massive, if coherent, and single grain, if not coherent. (Structureless is the same as Apedal.) ---- 0

(2) Weak in which some peds are discernible and when disturbed, less than one-third of the soil material is found to consist of peds. ----- 1

(3) Moderate in which peds are clearly seen and when disturbed, one-third to two-thirds of the soil material is found to consist of peds. ----- 2

(4) Strong in which peds are clearly seen and when disturbed, more than two-thirds of the soil material is found to consist of peds. ------ 3

NOTE that both moderate and strong grades of structure qualify a soil for Peds evident, whereas the structureless state and weak grade of structure qualify a soil for Peds, few, if any.

(b) Geometry

| | |
|---|---|
| Angular blocky or cubic (ABL) ---------- | 1 |
| Subangular blocky or cubic (SABL) ------ | 2 |
| Angular prismatic (APR) ---------------- | 3 |
| Subangular prismatic (SAPR) ------------ | 4 |
| Polyhedral > six sides (PH) ------------ | 5 |
| Parallelepedal (PLL) ------------------- | 6 |
| Platy (PL) ----------------------------- | 7 |
| Spheroidal-solid (SSPH) ---------------- | 8 |
| Spheroidal-visible voids (VSPH) -------- | 9 |

(c) Size

Given in inches or fraction

11. Plasticity is a characteristic of wet soils. It is the ability of soil to change its shape as a result of stress and to keep that shape after the removal of the stress.

| | |
|---|---|
| Nonplastic ---------------- | 0 |
| Slightly plastic ---------- | 1 |
| Plastic ------------------- | 2 |
| Very plastic -------------- | 3 |

12. Friability is a characteristic of moist soils. It is a measure of resistance to crushing.

| | |
|---|---|
| Loose -------------------- | 0 |
| Very friable -------------- | 1 |
| Friable ------------------- | 2 |
| Firm ---------------------- | 3 |
| Very firm ----------------- | 4 |
| Extremely firm ------------ | 5 |

13. Porosity - a porous soil material is one characterized by the presence of voids in the soil moss. It is the volume of the total soil bulk not occupied by solid particles. The first component of porosity is void quantity, which is the percentage of nonsolid space ranging from nonporous (< 1%) to extremely porous (> 50%). The second component is pore size, measured in millimeters. Porosity is largely a function of the arrangement of soil particles into aggregates, the type of soil particles, amount of organic material, and degree of compaction.

(a) Void quantity

| | | |
|---|---|---|
| Nonporous | < - 1 ------- | 0 |
| Slightly porous | 1 - 5 -------- | 1 |
| Porous | 5 - 10 ------- | 2 |
| Porous | 10 - 20 ------ | 3 |
| Very porous | 20 - 50 ------ | 4 |
| Extremely porous | > 50 --------- | 5 |

(b) Pore size

| | | |
|---|---|---|
| Very fine | < - 0.5 ------- | 1 |
| Fine | 0.5 - 1 ------- | 2 |
| Medium | 1 - 3 --------- | 3 |
| Large | 3 - 5 --------- | 4 |
| Very large | > 5 ----------- | 5 |

14. Mottling is the presence of spots or alternate streaks of color that differ from the overall color of the soil. Mottling occurs in zones of alternating periods of good and poor aeration. The differences in oxidation states of iron and magnesium result in mottled appearances. Mottles are considered to be masses, blobs, or blotches of subdominant colors, such that color places them in a different value/chroma rating to the matrix color. The glaze or color skin which may occur on the outside of some peds is not considered as mottling. A soil is only considered to be mottled when 10% or more of mottles occur in the soil mass. For mottled soils, the value/chroma rating of the dominant matrix color is taken. Mottling has three components: abundance, measured as a percentage; size in mm; and sharpness of the boundary between mottled and nonmottled soil, measured in mm.

| (a) Abundance | (% cover) | |
|---|---|---|
| None | < 2 ---------- | 0 |
| Few | 2 - 5 -------- | 1 |

| | | |
|---|---|---|
| Common | 5 - 20 -------- | 3 |
| Definite matrix color | 20 - 50 ------- | 4 |
| No matrix color | > 20 ---------- | 5 |
| Definite matrix color | > 50 ---------- | 6 |

(b) Size (mm)

| | | |
|---|---|---|
| Extremely fine | < 1 ----------- | 1 |
| Very fine | 1 - 2 --------- | 2 |
| Fine | 2 - 5 --------- | 3 |
| Medium | 5 - 15 -------- | 4 |
| Large | > 15 ---------- | 5 |

(c) Sharpness (mm)

| | | |
|---|---|---|
| Diffuse | > 2 ----------- | 1 |
| Clear | < 2 ----------- | 2 |
| Sharp | (knifedged) --- | 3 |

15. Secondary precipitates result from the upward capillary movement and removal of soil water through evaporation at the ground surface. This process is important in contaminant movement and concentration in the soil.

(a) Quantity

| | | |
|---|---|---|
| None | --------------- | 0 |
| Few | < 2% ---------- | 1 |
| Common | 2 - 5% -------- | 2 |
| Common | 5 - 20% ------- | 3 |
| Abundant | 20 - 50% ------ | 4 |
| Extra abundant | > 50% --------- | 5 |

(b) Composition

| | |
|---|---|
| Lime ----------------------------------- | 1 |
| Magneste -------------------------------- | 2 |
| Gypsum ---------------------------------- | 3 |
| Silica ---------------------------------- | 4 |
| Fe oxides ------------------------------- | 5 |
| Fe oxides + humus ----------------------- | 6 |
| Mn oxides ------------------------------- | 7 |

(c) Type

| | |
|---|---|
| Irregular concretions | 1 |
| Regular concretions | 2 |
| Layers | 3 |

16. Bedrock

(a) Rock structure

(1) Intensity

| | | |
|---|---|---|
| W. | Weak | 1 |
| M. | Moderate | 2 |
| S. | Strong | 3 |

(2) Geometry

| | | |
|---|---|---|
| B. | Banded | 01 |
| S. | Scoriaceous | 02 |
| A. | Amygdaloidal | 03 |
| P. | Porphyritic | 04 |
| L. | Laminated | 05 |
| M. | Massive | 06 |
| C. | Cleared | 07 |
| S. | Sheared | 08 |
| F. | Contorted | 09 |
| X. | Cross-bedded | 10 |

(3) Size

| | | |
|---|---|---|
| V. | Very coarse | 1 |
| C. | Coarse | 2 |
| F. | Fine | 3 |
| VF | Very fine | 4 |

(b) Rock type

Consolidated sediments (0 - 19)

| | | |
|---|---|---|
| CG | Conglomerate | 01 |
| QT | Quartzite | 02 |
| SS | Sandstone | 03 |
| ST | Siltstone | 04 |
| MS | Mudstone | 05 |
| CS | Claystone | 06 |
| SH | Shale | 07 |
| CH | Chert | 08 |

| | | |
|---|---|---|
| GW | Greywacke | 09 |
| AK | Arkose | 10 |
| LS | Limestone | 11 |
| IS | Ironstone | 12 |
| TI | Tillite | 13 |

Igneous rocks (20 - 39)

| | | |
|---|---|---|
| GR | Granite | 20 |
| GD | Granodiorite | 21 |
| DI | Diorite | 22 |
| RH | Rhyolite | 23 |
| BA | Basalt | 24 |
| AG | Agglomerate | 25 |
| TU | Tuff | 26 |
| SC | Scorria | 27 |
| DO | Dolerite | 28 |
| DB | Disabase | 29 |
| PG | Pegmatite | 30 |
| AP | Aplite | 31 |
| RQ | Reef quartz | 32 |
| PY | Porphyry | 33 |
| PT | Porphyrite | 34 |

Metamorphic rocks (40 - 59)

| | | |
|---|---|---|
| SL | Slate | 40 |
| PH | Phyllite | 41 |
| HF | Hornfels | 42 |
| SH | Schist | 43 |
| GN | Gneiss | 44 |

PAGE ___ OF ___

# INSTALLATION RESTORATION

## PHYSICAL VARIABLES - TOPOGRAPHY

| RMSAGPT | JULIAN DATE | OBS | LOCATION EW | LOCATION NS | ELEV | LR | R D | R C | SL | G S | G L | ASP | DS | DH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 2 3 4 5 6 7 | 8 9 10 11 12 | 13 14 15 | 16 17 18 19 20 | 21 22 23 24 25 | 26 27 28 29 | 30 31 32 | 33 | 34 | 35 36 | 37 | 38 | 39 40 | 41 42 | 43 44 | 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 |

# INSTALLATION RESTORATION

## PHYSICAL VARIABLES - SOIL

| RMSAGPS | JULIAN DATE | OBS | LOCATION EW | LOCATION NS | DEP | H | HT | BS | BP | CH | C V | C C | PH | TX | S A | S S | S P | SL | R O | R S | T I | T G | STS | P L | F | P O | P S | M A | M S | M P | S O | S C | S T | R I | RG | R S | RT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 2 3 4 5 6 7 | 8 9 10 11 12 | 13 14 15 | 16 17 18 19 20 | 21 22 23 24 25 | 26 27 28 | 29 | 30 31 32 | 33 34 | 35 36 | 37 38 | 39 | 40 | 41 42 43 | 44 45 | 46 | 47 | 48 | 49 50 | 51 | 52 | 53 | 54 | 55 56 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 70 | 71 | 72 73 | 74 75 76 77 78 79 |

# INSTALLATION RESTORATION

## ECOLOGY - MONITORING PROGRAM

| RMSAEMP | JULIAN DATE | CUS | LOCATION EW | LOCATION NS | ST | HABI-TAT | CL | SPECIES | TX | AG | EC | CO | TY | PH | COLOR | DEPTH | AREA/ VOLUME | NR SPEC | WEIGHT | TISSUE | DT | DS | SAMPLE NUMBER | COMPOSITE SAMPLE NR | STAT CODE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 2 3 4 5 6 7 | 8 9 10 11 12 | 13 14 15 | 16 17 18 19 20 | 21 22 23 24 25 | 26 | 27 28 29 | 30 | 31 32 33 34 35 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 44 45 | 46 47 48 | 49 50 51 52 | 53 54 55 | 56 57 58 59 | 60 61 62 63 64 | 65 | 66 | 67 68 69 70 71 72 | 73 74 75 76 77 | 78 79 80 |
| | | | | | | | | | | | | | | | | | | | | | | | | | |
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## SAMPLING PLAN FOR RMA

### Dynamic Cluster Sampling

An attractive attribute of dynamic sampling is that as information is gathered, it can be used to direct further sampling without biasing the probability properties of the sample.

Data on soils and groundwater will be gathered from drill sites patterned in clusters of 16 bore holes per cluster, arranged in a 4 x 4 square grid. Each sample will be surveyed, using the x and y coordinates of the State Plane Grid System which in addition, will serve as the identification code for each of the samples. The elevation will also be recorded. Field data on land surface topography, physical properties of soils, groundwater levels, and bedrock will be logged directly onto the coding forms. Soil samples will be collected at the appropriate depth; sent to the soils laboratory where it will be divided into two parts. One part of the sample will go to the MALD (Material Analysis Lab Division) for chemical analysis of various contaminants. The other portion will be analyzed in the soil laboratory for soil moisture, mechanical, and mineral properties. While the analyses are being performed, a second cluster of 16 sites will be drilled and sampled. The results from the first cluster of samples will be mapped to determine the positioning of the third cluster of 16 sampling sites. The cluster will be located in the direction of the maximum concentration of the contaminant being mapped. The analyzed results from the second cluster will likewise be used to determine the positioning of the fourth cluster, etc. This technique of mapping each contaminant and positioning the cluster of samples in the direction of maximum concentration will permit tracking the pollution plume to its origin with minimum exploratory drilling. Periodically, the cluster will be combined, and analysis will be performed on the total combined samples. This will yield an increase in the sample size and an increased relative homogeneity of the elements being sampled. By combining the cluster into a total sample one, in effect, is evaluating the regional pattern of the pollutants as compared to more local, larger scale behavior within each cluster. However, sampling theory requires that all the elements of the cluster be sampled for the results to be statistically valid.

It is possible that several plumes will be encountered, each originating from a different source and containing their own unique grouping of compounds. When this occurs, each plume will be traced to locate all sources.

On-going exploratory drilling along the northern boundary of RMA has revealed the existence of at least two contaminated groundwater plumes. One plume contains DIMP, $Cl^-$, and Na compounds. The other is a DCPD and pesticide plume. Because of the high priority placed upon containment of contaminant migration, this part of the Arsenal would be a logical place to start the sampling program. An alternate site would be at the known contaminant hot spots.

## Sampling Grid Spacing

A test sampling grid, spaced 250 feet apart, will be constructed initially to pretest the sampling method and data-handling procedure. The distance between the sampling bore holes will be set as more data becomes available on the diffusion rates of contaminant concentration with distance. The mathematical relationship between change in concentration level per unit change in distance will be calculated for each contaminant, and the grid spacing will be adjusted to the optimum distance. Preliminary tests show that the best fit regression equation, equating the change in DIMP concentration with distance measured from the center of the DIMP plume is $Y = A + B \log X$. The DIMP concentration values in the inclosed sample contained DIMP added from secondary sources carried by groundwater. This caused additive harmonics, which should be filtered out before a usable equation can be obtained.

## Sampling Horizons

One-foot sections of the sampling core will be collected to serve as the samples for both mechanical and chemical analysis. Soil samples will be taken at six depths, so as to increase the likelihood of intercepting the zones of contaminant concentration. These zones are: (1) The A soil horizon, which is the zone of contaminant built through (a) bioaccumulation in the soil organic matter; (b) upward migration of contaminants by capillary action and surface evaporation of water; and (c) accumulation of pollutants on the ground surface by both wind or surface water transport; (2) The B soil horizon which is the zone of illuviation or accumulation of compounds leached from the upper horizons; (3) A point mid-way in the zone of aeration representing the transition zone; (4) The capillary fringe immediately above the ground water table; (5) A point below the top of the water table; and (6) At the bedrock surface. The soil samples taken in the zone of saturation will provide a ratio of the contamination in the soil compared with that moving in the groundwater. Additional samples will be taken at the top of clay layers or lenses whenever they are encountered, to determine the effect of clay as a point of contaminant concentration. Clay layers in the regolith may behave as selective, physical, chemical, or osmotic filter aided by the greatly reduced rate of downward percolation of groundwater and the possible presence of clays having a high ionic exchange capacity. Groundwater will also be sampled at similar depths.

The typical profile shown in the diagram was constructed by averaging the horizon of each of the soil series occurring at RMA. The A horizon ranges from 0 - 9 inches in thickness, while the B horizon ranges from 9 - 26 inches.

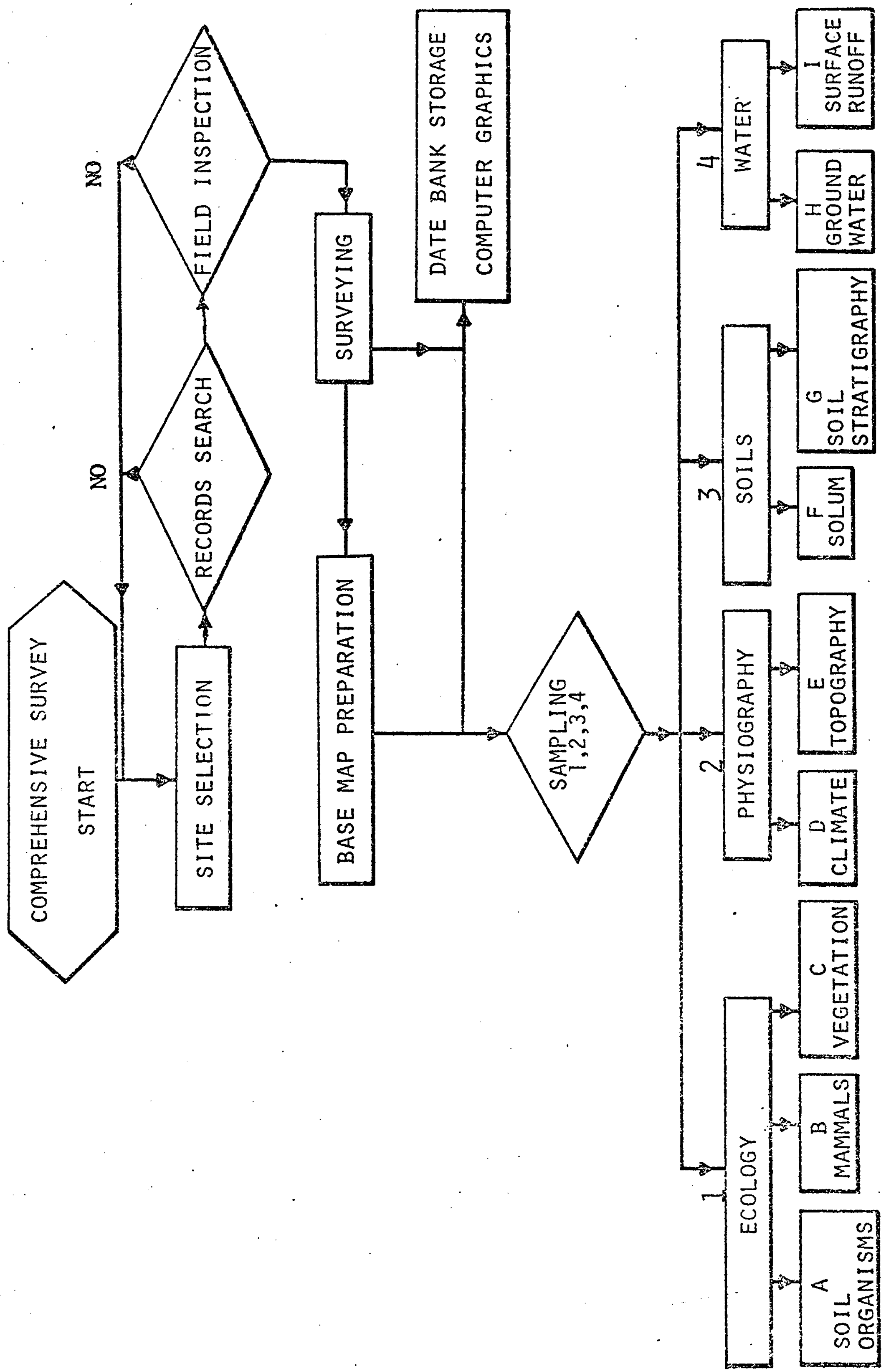
In several places on the Arsenal, the B horizon does not occur; and the soils grade directly from the A to the C horizons. This usually occurs in younger, poorly developed azonal soils. In order to avoid missing data for sites where horizons are absent, all sampling will consistently be taken at uniform depths predetermined to coincide with the soil profile horizons. These depths are given in the schematic illustrating the sampling scheme for a typical boring. Two water samples will be collected at each drill one, one approximately three feet below the water table leve, the other at bedrock surface.

Numerical Analysis and Mapping

Each of the contaminants will be mapped individuall for each of the six horizons sampled, thus providing a three-dimensional view of the contaminant distribution. The maximum concentration encountered at each site will also be mapped to show a plain view of the highest levels occurring on the Arsenal.

Principal component factor analysis will be peformed to determine the correlations and behavior of the contaminants as groups or associations. The information will be obtained from the factor loadings, which will identify new groupings indicating that new pollution plumes were encountered. The maps of the factor scores for each of the factors will provide insight on the spatial distribution of each of the contaminant groups individually and will serve to identify the location and direction of the plume, thus indicating where the next sampling cluster is to be positioned. Factor analysis of the total set of variables will, through the correlation coefficient, provide the linkage web between the contaminants and the physical ecosystem.

The relationships and the linkages will be mappable through the factor scores. Multivariate discriminate analysis, using the factor scores as surrogate weights, will serve as a comparison of similarity and differences between different regions representing either, different contaminated areas of different source areas. The multivariate disciminant function can also serve as a model for simulation.


COMPREHENSIVE SURVEY
START
SITE SELECTION
RECORDS SEARCH
NO
FIELD INSPECTION
NO
BASE MAP PREPARATION
SURVEYING
DATE BANK STORAGE
COMPUTER GRAPHICS
SAMPLING
1,2,3,4
1
ECOLOGY
A
SOIL
ORGANISMS
B
MAMMALS
C
VEGETATION
2
PHYSIOGRAPHY
D
CLIMATE
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TOPOGRAPHY
3
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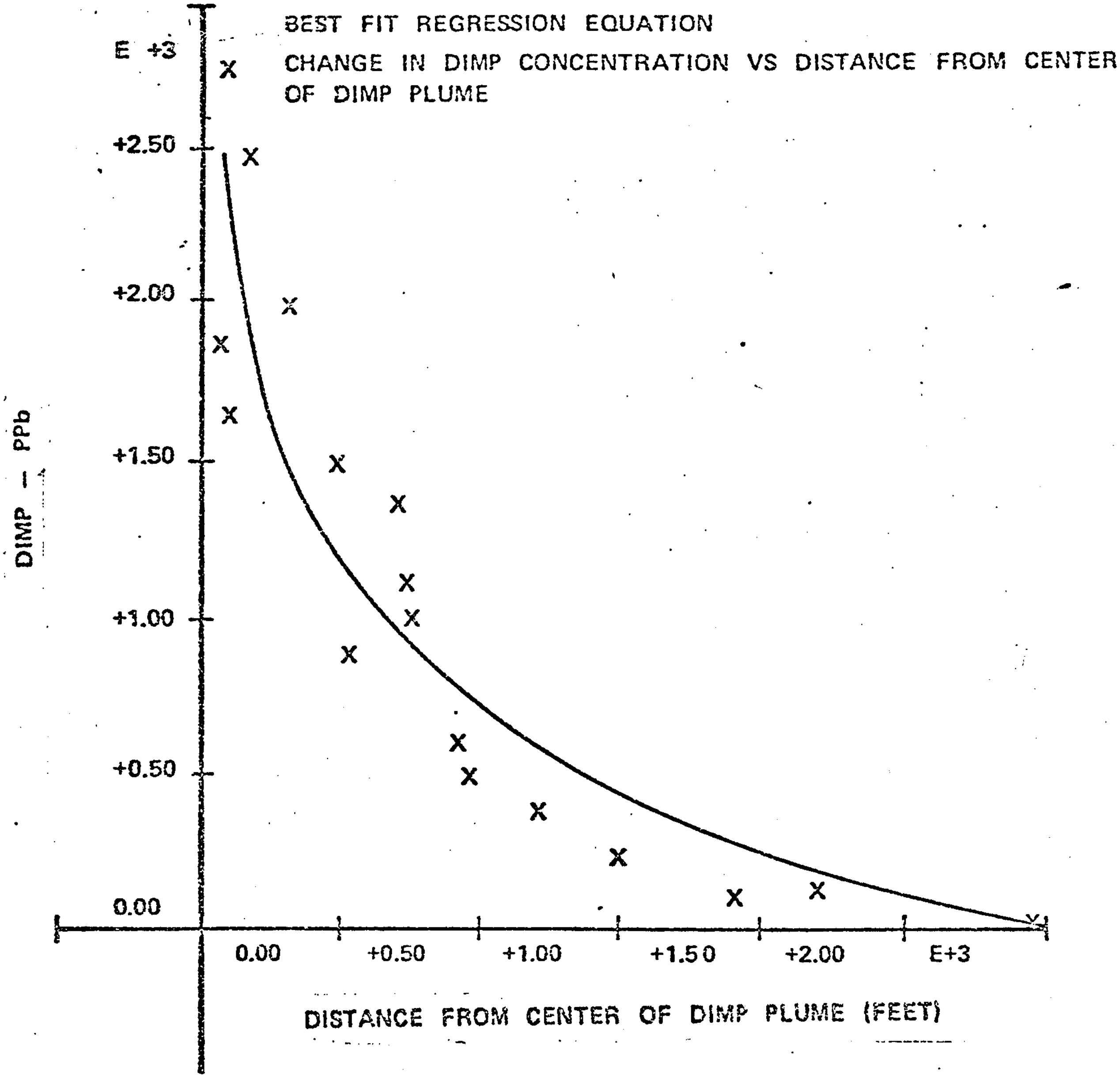
GROUND
WATER
I
SURFACE
RUNOFF

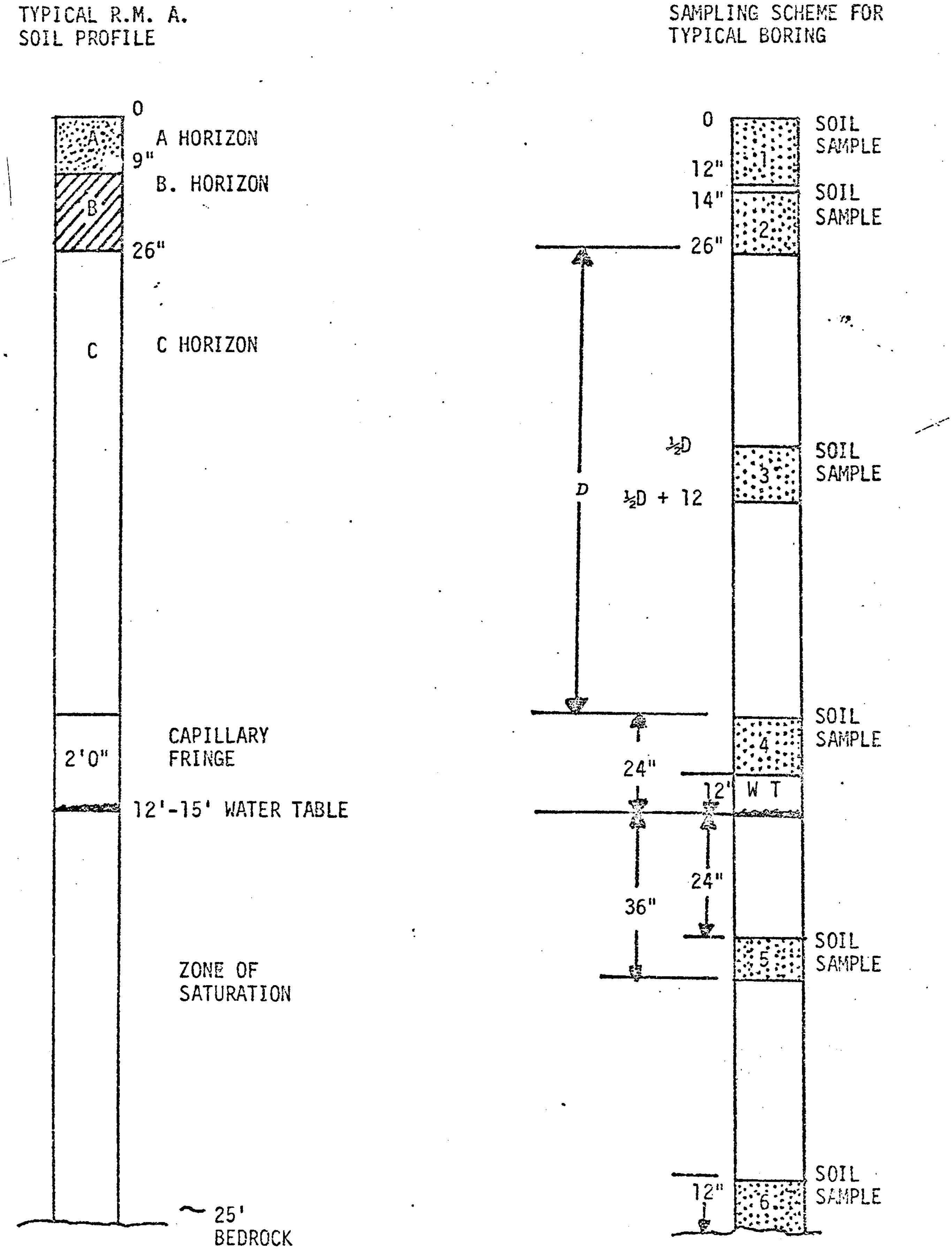
Figure 14b




Y = A + B*LOG (X)
A = 5237.70561151
B = −654.921197714
R-SQUARE = 0.811366280354
RES ERROR
145731.828112
MAX(ABS(RESIDUAL))
651.29042082

DIMP CONCENTRATIONS IN RELATION TO CENTER OF PLUME

Figure 15




SOIL PROFILE AND SAMPLING POSITIONS

Figure 16

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Original

COMPREHENSIVE SURVEY PLAN FOR SOILS & GROUNDWATER CONTAMINATION
AT ROCKY MOUNTAIN ARSENAL
COLORADO



BY: DR. NICOLAY P. TIMOFEEFF
CONSULTANT

15 SEP 76

STATE UNIVERSITY OF NEW YORK AT BINGHAMTON

Binghamton, New York 13901

Department of Geography
Telephone (607) 798-2755

15 September 1976

TO: Col. J. Byrne

Enclosed is a copy of a comprehensive survey plan for sampling and mapping soil and ground water contamination at Rocky Mountain Arsenal. This document was prepared in accordance with the Statement of Work dated, 18 February, 1976, under the terms and conditions of contract number DAAA05-76-C-00 27.

Much of the material presented is orginal. The technologies have been successfully tested and used in other research projects by the author and I believe are applicable to the Rocky Mountain Arsenal, Installation Restoration Program.

Nicolay P. Timofeeff

Dr. Nicolay P. Timofeeff
Consultant

cc: Mr. Irwin Glassman
Dr. William McNeill
Mr. Edwin W. Berry
Ms. Judith Pitney

TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## PREFACE

The production, testing, and disposal of various chemical and biological substances at RMA has lead to suspected contamination of land areas, water, ecology, buildings, and equipment. Little information exists as to the concentration levels, overall extent, or the diffusion process of these substances within the ecosystem. The need to identify and assess the potential hazards created by the presence of toxic substances in the environment at RMA has been recognized, and efforts are underway for interim containment of off-post migration. A comprehensive survey will be initiated to gather and analyze all necessary information which would enable a rational assessment of the degree of contamination on the post and provide the data base needed for the design of remedial measures.

The purpose of this study is to provide the guidelines for soil and water sampling procedures and field data gathering and recording protocols to be used in the comprehensive survey at RMA. The approach developed is aimed at obtaining the maximum likelihood of intercepting the contaminated horizons in three dimensions and thus gaining the optimum benefit for long-run objectives from the field measurements with minimum field effort and thus reducing time and cost by minimizing the possibility of gathering extraneous data.

## INTRODUCTION

A pollutant is any compound or substance that is undesirable where it is. A contaminant or pollutant may become undesirable by being introduced into an environment that is foreign to it. The pollutant is usually toxic to the host environment and will disturb the equilibrium state of the ecosystem. The degree of concern of the presence of contamination depends upon the toxicity level to living organisms, especially man.

Pollutants may be either man-made, released as byproducts of industrial or military processes, or are naturally occurring and become toxic when concentrated, for example salt.

Transport processes often create a pollutant simply by moving a compound to a different environment. Sources of pollutants are usually classed as "point" and "nonpoint." Control measures are simplified whenever the pollution plume is traced to a point source, as compared with diffuse or nonpoint pollutants which discharge into waterways by dispersal pathways.

## FACTORS INFLUENCING CONTAMINANT BEHAVIOR

The success in locating the most probable areas of contamination and in tracing the breadth (source and plume) of such contamination within the ecosystem is dependent upon an accurate interpretation of the means of contaminant emplacement. The dispersion and the accumulation of pollutants in the environment is dependent on a number of inter-related factors. Some of the principal factors are:

The Physical and Chemical Properties of the Contaminants - The important chemical properties of the pollutants are the following: the contaminant phase, concentration, chemical stability, water solubility, ion exchange, adsorption, equilibrium with the host environment, and regional geochemical properties. These properties determine the chemical behavior of the contaminants, whether they are present as a solution in water or are dispersing as a solid.

The Form of Transport - The form of transport determines the dispersion process and influences accumulation. It is possible by evaluating the manner that the pollutants were transported and knowing their pathways to predict the major contaminated areas. Contaminants of greatest concern at RMA are transported either: (1) as solid particles (particulate) occurring in a crystalized form or combined with dust or soil particles, or (2) as a fluid in solution with water. For example, the movement of pesticides on sediment is affected by the enrichment process. Pesticides are adsorbed primarily on organic soil colloids which remain in suspension longer than the coarse soil particles. Most mobile herbicides, on the other hand, rarely contaminate the groundwater because the adsorption capacity in most soils above the water table is sufficient to retain the chemicals until they decompose. However, in an area with a high percolation potential, groundwater contamination is possible.

The partitioning of the compounds between water and soil transport is necessary in determining the mass movement of chemicals in run-off. The quantity of a compound dissolved in water is obtained from water solubilities of the chemicals. The amount adsorbed at different solution concentrations can be calculated by mixing solutions of the chemicals with known quantities of soil. (This study is currently in progress for DIMP by the Aerojet Ordnance and Manufacturing Company, Downey, California.)

The transporting medium for particulate contaminants is either wind or surface water movement. The contaminants, therefore, concentrate in areas controlled by these transporting media -- on or close to the ground surface. The transporting media for liquid contaminant, on the other hand, is either surface run-off, subsurface run-off, or groundwater run-off. These contaminants tend to concentrate much deeper in the unconsolidated mantle.

The Characteristics of the Physical Site - The characteristics of the site include: (1) Geologic properties of the aquifer such as texture, porosity, permeability, transmissivity, heterogeneity of the subsurface regolith, thickness of the unsaturated zone of aeration, thickness of the saturated groundwater zone boundary conditions, and (2) The geomorphology, the topography, and the surficial cover. This includes slope, aspect, surface relief (high relief is indicative of high sediment delivery ratio), channel density, the condition of the channels (whether clogged or open, meandering, or straight), stream gradients, the relief/length ratio. The geomorphology of a terrain provides potential channels, sinks, or traps for pollutant, and (3) The stratigraphy and character of the sediments in the aquifer. This would include the ionic exchange capacity of the minerals in clay and soil, which has a direct bearing on contaminant sorption and leaching. The type of both primary and secondary minerals present and the oxidation reduction reactions which affect some of the pollutants and the leach ability of the sediments.

Climate - Humid environments are those in which the annual precipitation exceeds evapotranspiration rates. They have a net water surplus which transports the mobile compounds faster and to greater depths. In arid climates such as RMA, much of the water is removed by evapotranspiration; and soil moisture is brought to the surface by capillary action. Contaminated groundwater may be transported to the surface and the contaminants are deposited on the ground surface. The duration and intensity of storm activity influences groundwater recharge and possible flushing of the contaminant from the soil. Flow is upward during periods of high evapotranspiration, provided there is no ponding and downward when water is available (as under the water ponds and bog areas). The micro climate also influences the viscosity and surface tension properties of soil water solution, which is temperature-dependent. Soils drain slowly during cold weather, and water is retained as storage when frozen. As a solution freezes, salts concentrate in the nonfrozen liquid, and it is not unusual to find brines in partially frozen soils. These brines become selectively mobile because of their hydraulic properties. During the spring after the frozen ground thaws at RMA, much of the groundwater recharge results from snowmelt. If the concentrations of pollutants in soil water reaches high enough levels, precipitation (or salting out) may occur.

The Geohydrolic Conditions - Hydrologic transport is the movement of compounds in or by water and may occur along surface or subsurface channels at RMA. Hydrologic transport is therefore dependent upon the amount of water and the pathways of: (1) Surface run-off traveling over the ground surface; (2) Subsurface run-off that has infiltrated the surface soil and moves laterly through the upper soil horizon within the zone of aeration; and (3) Groundwater run-off below the groundwater table in the zone of saturation. Each must be known before the transport of pollutants and hydrodynamic dispersion can be described in detail.

The hydraulic conductivity (K variable in Darcy's Law) of sediments is the transmissive properties of a porous medium. Generally, in hydrolic calculations, this value is averaged vertically assuming a homogeneous aquifer and substituting it for transmissivity, expressed as $T = Kh$, where h is the saturated thickness. The transmissivity can be determined by pump tests.

An analysis of the dynamics of groundwater flow permits a reliable computation of the level of contamination of the aquifer in space through time. Changes in chemical concentrations in the groundwater system are due to: (1) Convective transport, expressing the amount of dissolved chemicals moving with the flowing groundwater; (2) Addition or removal of contaminants through chemical and physical reactions taking place in the water or between water and soil; (3) Mixing with recharge water of different concentrations; and (4) Hydrodynamic dispersion in which molecules or ionic diffusion and minute changes in velocity of flow in the porous media causes the paths to diverge from the normal direction of groundwater movement.

Grouping - Certain elements tend to group together into compound associations in a specific environment due to similar migration capacities (relative mobilities). The tendency for compounds to group together simplifies the mapping task in that by testing for either indicator or pathfinder elements, it is possible to trace the spatial behavior of the pollutants.

Contaminant Migration through Soil Erosion - Several contaminated areas exist on RMA which are sources of ground surface pollution by soil movement. Field soil losses have been estimated to range from three to eight tons per acre per year. A ton of dry soil is approximately one cubic yard in volume. Spread uniformly over an acre of surface, it would have a depth of less than one-hundredth of an inch. Erosion hazards both by wind and due to rainfall and surface run-off are local in nature. This can be significant in areas which are not protected by a vegetative cover (example Basins A, C, and most of the Arsenal during the winter months when vegetation is dormant). The annual soil losses from sheet and rill erosion by rainfall can be determined by the Universal Soil Loss Equation (USLE).

The equation is:

$$A = f\,(RKLSCP)$$

Where A is estimated average annual soil loss measured in tons per acre.

R is the rainfall and run-off erosivity index.

K is the soil erodibility factor. It is the average soil loss per unit of R and depends on soil properties (see Figure ).

LS is dimensionless topographic factor that represents the combined effects of slope, length, and steepness.

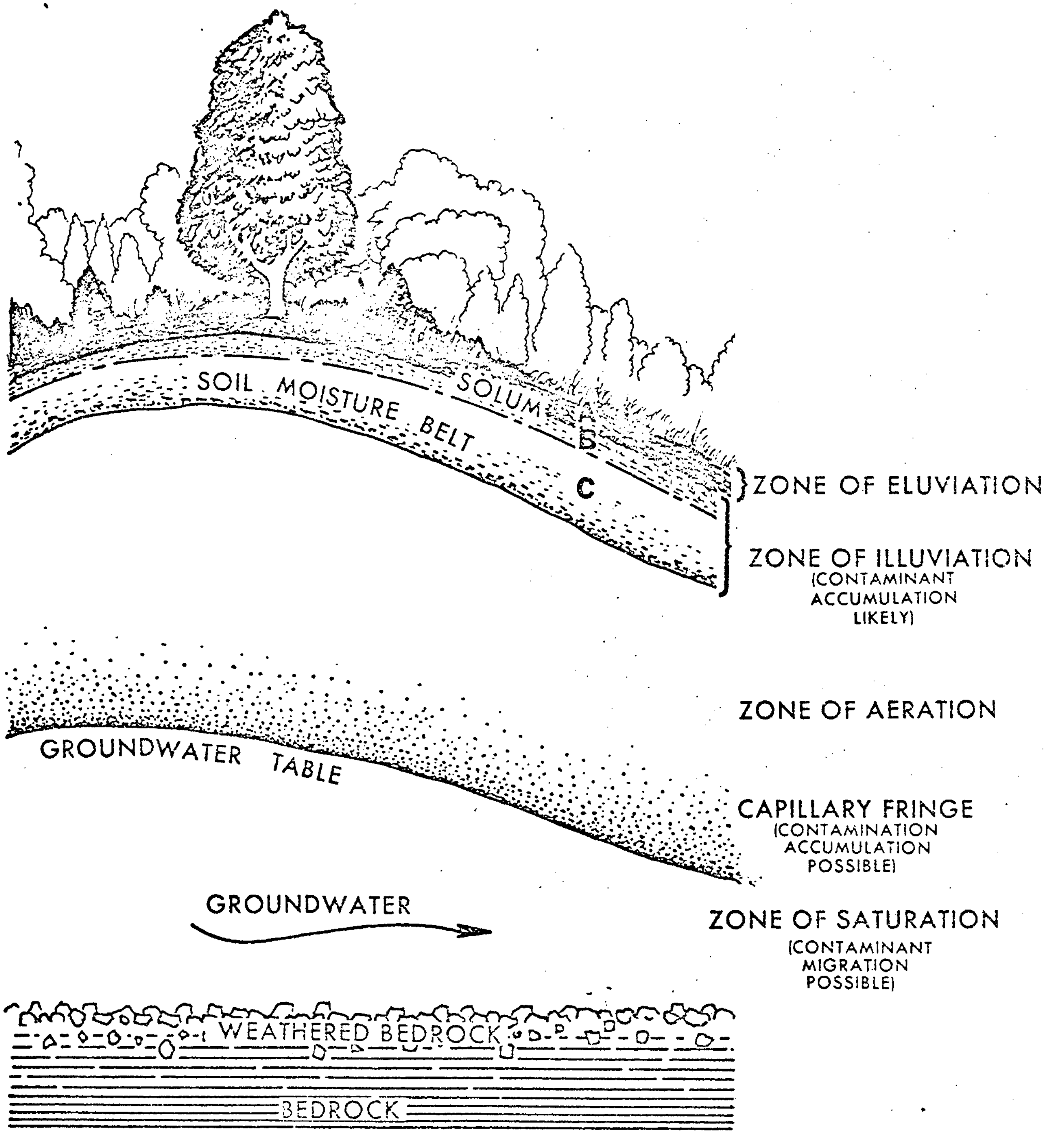
C is the cover and management factor.

P is the support - practice factor for land use.

The USLE can provide a measure of the contaminated sediment delivered to a stream.

The object of the RMA environmental sampling program is to be able to identify, measure, and characterize each of the contaminated horizons.

Generally, immediately underneath a contaminated source, each layer in the unconsolidated mantle collects the contaminants from above, mixes, absorbs, reacts, and then drains the soil to field capacity to supply lechate to the layer below. Thus, the process proceeds




**CROSS-SECTION OF UNCONSOLIDATED MANTLE**

FIGURE 1

## STRATIFICATION OF THE UNCONSOLIDATED MANTLE

When a vertical section is made through the unconsolidated mantle, a series of distinct layers or zones are observed which differ in their chemical and physical properties. See Figure The uppermost A horizon varies from a few inches to several feet in thickness and represents the eluvial (washed out) layer. Varying amounts of organic material is added to this. Materials removed from the A horizon are carried downward in solution and are deposited in the B horizon; however, the fine colloidal clays are mechanically removed by descending soil water (illuvial layer). Impervious hardpan and claypan layers may develop in the B horizon by the accumulation of downward moving material which include iron and aluminum minerals, including clays. The A and B horizon together form the solum. In arid climates, calcium carbonate, sodium sulphates, and other salts may accumulate just below the B horizon in the C layer. The C layer or parent material does not exhibit a high degree of alteration; however, it may display weathering, including oxidation, hydration, and lime accumulations.

A mature soil profile exhibits well developed horizons; however, layering may be indistinct or lacking in young soils. Topography affects both soil profile development and contaminante emplacement. On steep slopes, the soil horizons are much thinner or may never develop because erosion removes weather products as rapidly as they form. Topography controls the rate of surface run-off, the infiltration of water, the position of the water table, the depth of penetration of chemical weathering processes, and contaminant migration. Local and regional relief affect the hydrolic gradient which governs the circulation of water through the soil and unconsolidated mantle.

Knowledge of the soil profiles developed within a suspected contaminated area is necessary to enable a constant relative sampling procedure to be maintained. All samples must be taken from the same horizon, otherwise they will not be comparable. Also, a uniform sampling procedure increases the probability of locating the contaminated zones. See Figure

An analysis of the vegetative cover can provide valuable information about the character of the contamination below ground surface. For example, deep-rooted plants may penetrate the pollution plume in the overburden and be brought to the surface and enriched in the soil

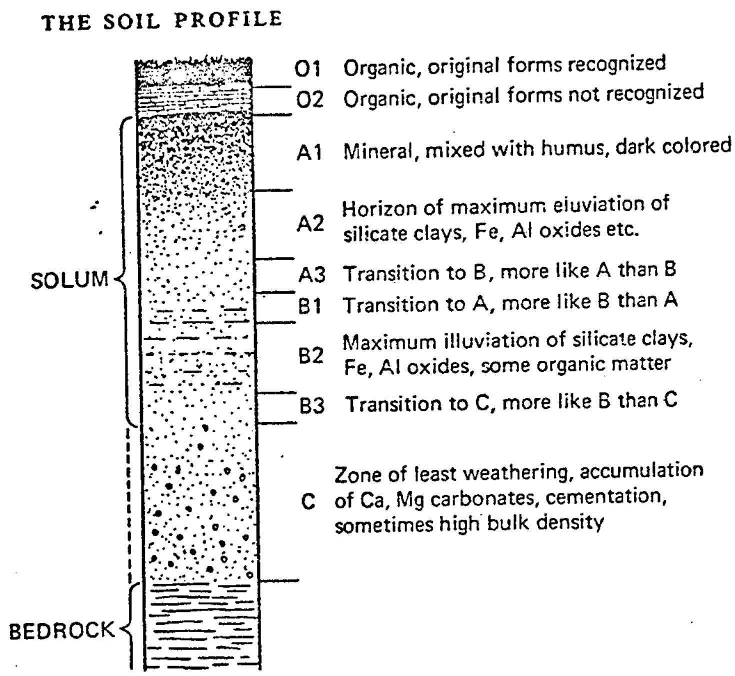
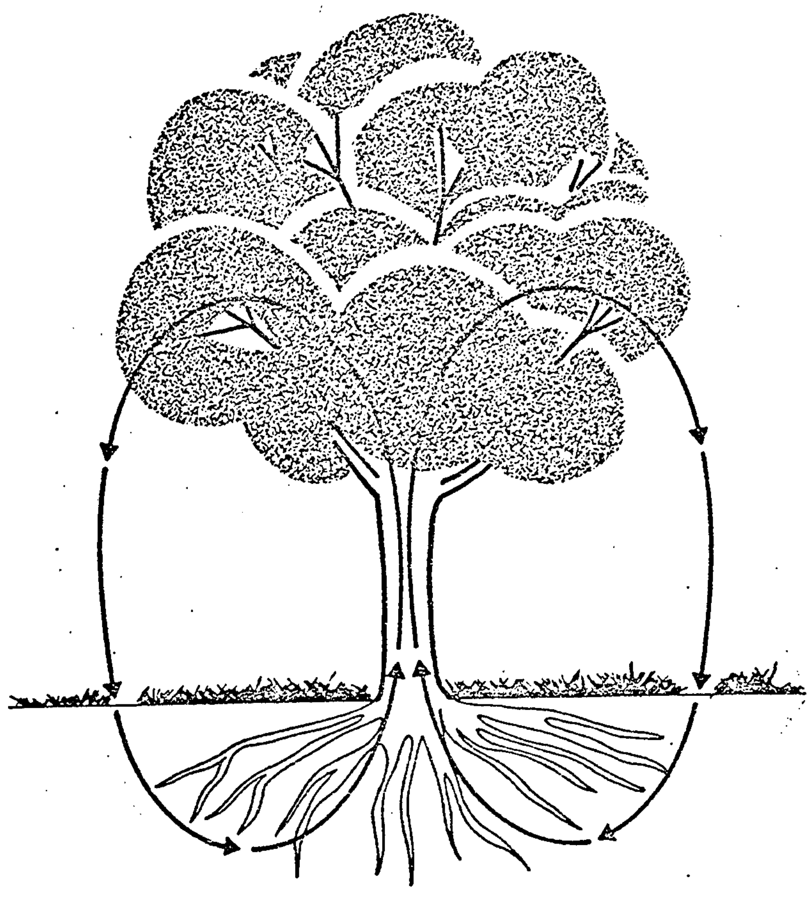



Figure 2



Nutrient recycling is an important factor in determining the relationship between vegetation and the soil that develops.

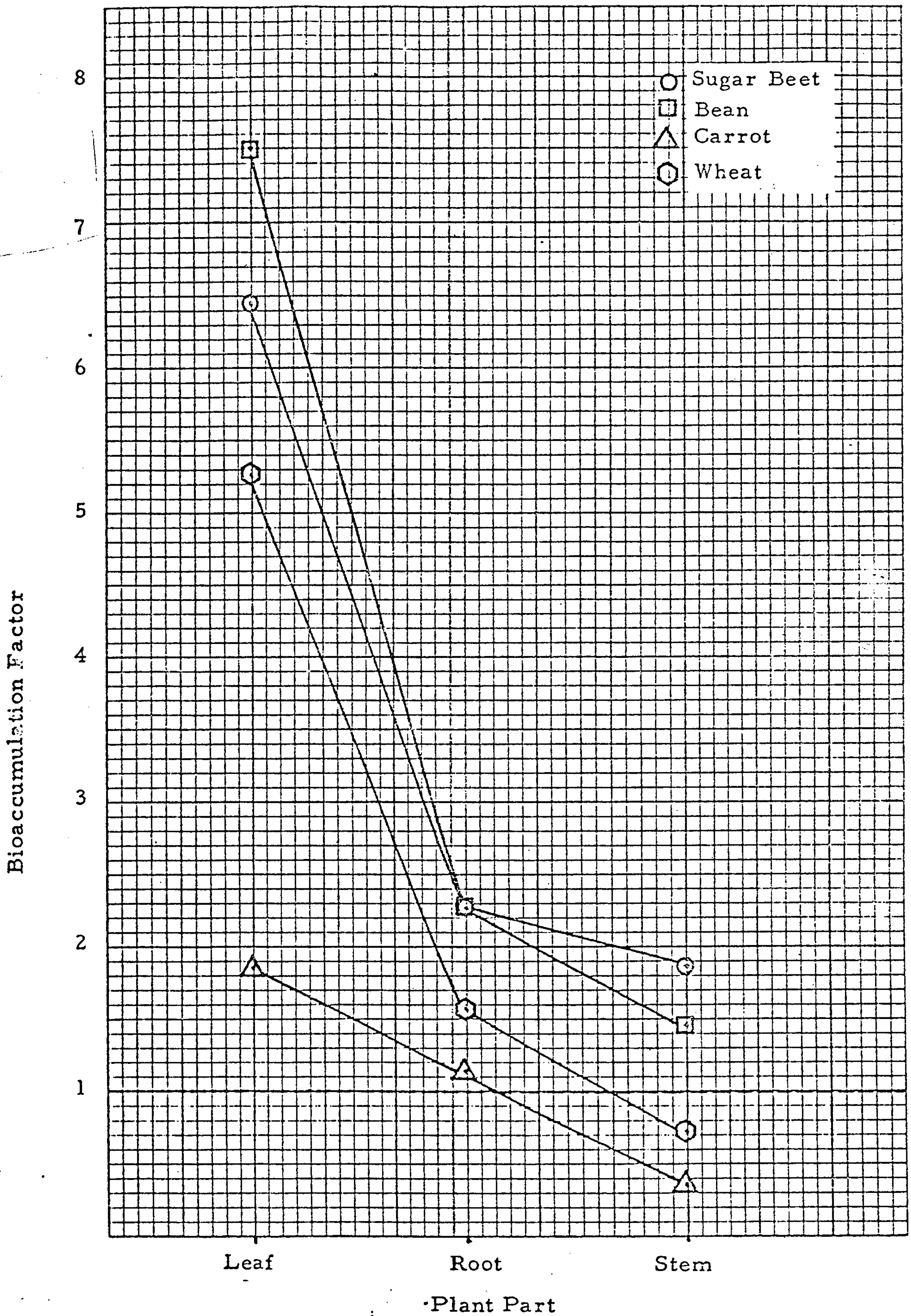
Figure 3

Bioaccumulation of DIMP by Plant Parts in

20 ppm Irrigation (37 days from Original Inoculation)

| Plant Part | Total DIMP added to Pot: Vol of 20ppm Irr. (cc) | Total DIMP added to Pot: Wt. of DIMP (mg) | DIMP Conc. In Tissue (ppm) | Bio-Accumulation Factor |
|---|---|---|---|---|
| Sugar Beet - | 9500 | 190 | | |
| Root | | | 45.6 | 2.28 |
| Stem | | | 37.1 | 1.86 |
| Leaf | | | 129.2 | 6.46 |
| Carrot - | 9200 | 184 | | |
| Root | | | 12.4 | 0.62 |
| Stem | | | 6.6 | 0.33 |
| Leaf | | | 36.9 | 1.85 |
| Bean - | 9200 | 184 | | |
| Root | | | 45.4 | 2.27 |
| Stem | | | 28.9 | 1.45 |
| Leaf | | | 150.0 | 7.50 |
| Wheat - | 9200 | 184 | | |
| Root | | | 31.5 | 1.58 |
| Stem | | | 14.2 | 0.71 |
| Leaf | | | 105.5 | 5.28 |

Figure 4




Bioaccumulation of DIMP by plant parts.
Soil culture, 37 days exposure to 20 ppm DIMP in irrigation water.
Figure 5

layer by decay of the vegetation in the production of humus. The concentration of elements in plants is dependent on a variety of physical, chemical, and organic factors which control intake of nutritional solutions. Geobotanic survey may be valuable to monitor contaminant movement in the soil, especially in areas where soils profiles are young or poorly developed. See Figure Results from biochemical sampling tend to be hetrogeneous, and care should be taken to assure representative samples and their interpretation. Seasonal variations in concentration occur within plant tissue in response to nutritional requirements of the plants. Different vegetative species have selective absorption capacities for intake for different elements which may vary considerably. Lysimeter studies conducted by Aerojet Ordnance and Manufacturing Company, Downey, California, have indicated that DIMP will bioaccumulate at much higher concentrations in the leaves of plants than either plant roots or stems (see Figure ). The leaves account for the greatest proportion of organic matter addition to the soils which results in a concentration of pollutants in humus in the Al horizon. The information gathered from geobotanical surveys will be used in conjunction with soil and water surveys.

## SOILS OF THE ROCKY MOUNTAIN ARSENAL

There are eight soil series and four land types at RMA. A soil series is a subdivision of soil families -- the most generalized soil description. A soil series is a "group of soils developed from the same kind of parental material by the same genetic combination of processes and whose horizons are quite similar in their arrangement and general characteristics." Soils series are divided into specific mapping units.

ASCALON SERIES - Consists of well drained soils occurring on level to moderately sloping land on uplands. They are formed in loamy material containing varying amounts of sand and gravel. The infiltration capacity of Ascalon soils is moderate to high, and the available soil moisture is high. This soil is suitable for plant root development.

Representative Profile - The surface layer is brown sandy loam approximately six inches thick and noncalcareous. The upper part of the subsoil is brown sandy loam and sandy clay loam about 15 inches thick. It is noncalcareous. The lower part of the subsoil is brown sandy loam about six inches thick, highly calcareous, and contains much visible lime. The underlying material is a highly calcareous, pale-brown to very pale brown fine sandy loam. It is found at a depth of 27 to 60 inches or more.

Mapping Units

(AsB) Ascalon sandy loam, one to three percent slopes. This unit is found on upland ridges and benches. Surface run-off is slow to medium, and the hazard of water erosion is slight to moderate. Soil blowing is a severe hazard in unprotected areas.

(AsC) Ascalon sandy loam, three to five percent slopes. This unit is found in areas adjacent to major streams, but it is only on the higher upland ridges and side slopes. It has a thinner surface layer and subsoil than the representative profile. Surface run-off is medium. The hazard of water erosion is moderate. Soil blowing is severe in unprotected fields.

(AsD) Ascalon sandy loam, five to nine percent slopes. Located on uplands near the edges of the breaks adjacent to stream channels. The surface layer and subsoil are thinner than the representative profile.

(ArC) Ascalon-vona sandy loams, one to five percent plagues. Ascalon sandy loam, one to three percent slopes (AsB) makes up 45 percent of this complex and occupies the smoother and lower lying areas. Vona sandy loam, three to five percent slopes make up 35 percent and is normally in the more sloping part of the landscape. A few small flowouts are on the higher ridge points.

BLAKELAND SERIES - Consists of somewhat excessively drained soils occurring on gently sloping to moderately sloping on uplands. These soils formed in wind and water worked sandy material. Blakeland soils absorb water rapidly, and the available water capacity is low. The entire profile becomes unusually hard as it dries. When dry, these soils hold a nearly vertical bank. Permeability is rapid. The entire soil is suitable for plant roots.

Representative Profile - The surface layer is grayish-brown loamy sand about five inches thick and noncalcareous. The next layer is brown sandy loam about four inches thick and is noncalcareous. The underlying material from a depth of about 9 inches to 60 inches or more is noncalcareous, brown loamy sand and pale-brown sand.

(BoD) Blakeland loamy sand three to nine percent slopes. Occurs on uplands. Surface run-off is medium to slow. The hazard of soil blowing is severe.

(Bt) Blakeland - truck ton association - Blakeland loamy sand, three to nine percent slopes, constitutes at least 60 percent of this association, occurring in areas of semidune relief, though it is also on long, narrow ridges. Truck ton loamy sand, three to nine percent slopes makes up 20 - 40 percent of mapped areas. It is depressional or has the more gentle slopes. The hazard of soil blowing is moderate but is very severe where adequate cover is not maintained.

(Gr) Gravelly Land - Shale Outcrop Complex - this complex consists of steep and hilly land types. Areas are generally elongated and roughly parallel river channels. The complex consists of very shallow, clayey soils and raw shale overlain by a discontinuous layer of gravel deposits four inches to many feet thick. These deposits are old enough that some soil is forming in places within the gravelly cap layer. Little if any soil is forming in the shaly exposed areas, which is eroding by moderate wind and water action. Some areas contain steep colluvium of mixed materials. All of this complex is subject to severe erosion.

Loamy Alluvial - Only one unit of loamy alluvial is present at RMA.

(Lu) Loamy alluvial land is found in drainageways. Slopes are less than three percent. It is subject (in varying degrees) to flooding from adjacent slopes and main stream channels.

The profile consists of a surface layer, commonly dark-colored loam or clay loam about six to ten inches thick and normally noncalcareous. The underlying material is stratified loam, silt loam, and clay loam containing varying amounts of fine sand, sand, and fine gravel. It is 20 to more than 60 inches thick, brown to dark brown in color, and in places it has a weak structure. It is normally calcareous. Sand or sand and gravel, stratified with their lenses of silt and loam, are in some places below a depth of 36 inches.

Water is absorbed at a moderate rate, and their available water capacity is high. They are normally well drained. Natural fertility is high. The hazard of water erosion is severe in all cultivated areas.

NUNN SERIES - Consists of well drained, nearly level soils on terraces. These soils formed in loamy alluvial material. Water is absorbed at a moderate rate, and the available water capacity is high. Permeability is slow in soils with a clay loam surface layer and moderately slow in those with a loam surface layer. The entire soil is suitable for plant roots.

Representative Profile - The surface layer is a grayish-brown loam about six inches thick and noncalcareous. The subsoil is dark grayish-brown and grayish-brown clay about 17 inches thick. It is noncalcareous. The underlying material below a depth of 23 inches is light yellowish-brown and grayish-brown loam and silt loam. It is highly calcareous and stratified.

(NIA) Nunn loam, zero to one percent slopes. This soil is on stream terraces along most of the major drainageways in the county. Surface run-off is slow, and the hazard of water erosion is slight. The hazard of soil blowing is moderate in cultivated fields without protective cover.

The profile of this unit is similar to the reprensentative profile, except for a thicker surface layer and subsoil and less susceptible to erosion.

(NuB) Nunn clay loam, one to three percent slopes. This soil is found on stream terraces along major streams. Areas are long and narrow and roughly parallel to stream channels. Run-off is medium, and the hazard of water erosion is moderate. Soil blowing can be controlled by adequate cover. The profile is similar to the representative profile, but it has a more clayey surface layer and a thinner subsoil.

PLATNER SERIES - Consists of well drained nearly level to gently sloping soils on uplands. These soils are formed in old alluvium. They absorb water slowly, and the available water capacity is high. Permeability is slow, and the entire soil is suitable for plant roots.

Representative Profile - The surface layer is grayish-brown loam about nine inches thick and noncalcareous. The upper part of the subsoil is brown clay, about nine inches thick. It is noncalcareous. The lower part of the subsoil is light-gray clay loam about 10 inches thick. It is highly calcareous, and part of the lime is visible as splotches. The underlying material below a depth of 28 inches is very pale brown loam that is highly calcareous. At a depth of about 49 inches, it is a white and very pale brown sandy loam that is highly calcareous and contains some fine gravel.

(PlB) Planter loam, zero to three percent slopes. This unit is found on uplands. Surface run-off is slow, and the hazard of water erosion is moderate to slight. The hazard of soil blowing is severe in dry farmed areas unless protected by plants or stubble.

(Sm) Sandy Alluvial Land - Consists of an unstable accumulation of gravelly and sandy alluvium. It is in and adjacent to beds of intermittent streams. During periods of heavy rain, the streambeds are subject to flooding and channels are relocated and sediment is shifted and redeposited at slightly different locations. During dry spells, this land type is extremely droughty.

The material of this soil was transported by water from the sand and gravel beds in or adjacent to the area. It is stratified because of periodic flooding. Thin lenses or small pockets of silt, clay, and sand are also mixed with the gravel.

This land type differs from wet alluvial land primarily in that it is coarser textured throughout and is not affected by the water table.

STONEHAM SERIES - Consists of well drained, nearly level to moderately sloping soils on uplands. These soils formed in loamy, old alluvial material. Water is absorbed at a moderate rate, and the available water capacity is moderate. Permeability is moderate. The entire soil is suitable for roots.

Representative Profile - The surface layer is light grayish-brown loam about five inches thick and is noncalcareous. The subsoil is brown sandy clay loam about eight inches thich and noncalcareous. The underlying material is light-gray sandy loam and gravelly loam that is highly calcareous. At a depth of 30 inches, it is pale-brown gravelly sandy loam that is highly calcareous. It extends to a depth of about 60 inches.

(StD) Stoneham loam, three to nine percent slopes, is found on uplands near major stream channels in scattered areas. Run-off is generally medium (but rapid if the soil is unprotected). The hazards of water erosion and soil blowing are severe in cultivated areas.

TRUCK-TON SERIES - Consists of well drained to somewhat excessively drained, nearly level to moderately sloping soils on uplands. These soils formed in wind-worked sandy material. They absorb water rapidly, and the available water capacity is low. Permeability is rapid and the entire soil is suitable for roots.

Representative Profile - The surface layer is grayish-brown and dark grayish-brown loamy sand about nine inches thick. It is noncalcareous. The upper part of the subsoil is dark-brown and brown sandy loam about 12 inches thick. It is noncalcareous. The lower part of the subsoil is yellowish-brown loamy sand about 11 inches thick; also noncalcareous. The underlying material is yellowish-brown coarse sand that extends to a depth of 60 inches or more.

(TeD) Truck-ton loamy sand, three to nine percent slopes. Found mostly along major stream channels. Surface run-off is medium, and the hazards of soil blowing and water erosion are severe.

(TuB) Truck-ton sandy loam, one to three percent slopes. The profile is similar to the representative profile except for a sandy surface layer and a thicker surface layer and subsoil surface run-off is slow to medium, and the hazard of water erosion is slight. The hazard of soil blowing is severe.

(TuD) Truck-ton sandy loam, two to nine percent slopes. The profile is similar to the representative profile except for a sandy loam surface layer. Run-off is medium, and the hazard of water erosion is moderate. The hazard of soil blowing is severe.

VONA SERIES - Consists of well drained, nearly level to moderately sloping soils on uplands. They were formed in wind-deposited material. The soils absorb water rapidly, and the available water capacity is moderate. Permeability is rapid, and the entire soil is suitable for plant roots.

Representative Profile - The surface layer is light brownish-gray loamy sand about nine inches thick. It is noncalcareous. The subsoil is pale-brown coarse sandy loam about 13 inches thick; also is noncalcareous. The underlying material is light yellowish-brown sandy loam and very pale brown, highly calcareous loamy sand that contains lime visible as splotches.

(VnD) Vona loamy sand, three to nine percent slopes. Surface run-off is medium, and the hazard of soil blowing is severe.

(VoC) Vona sandy loam, three to five percent slopes. The profile is similar to the representative profile except for a sandy loam surface layer and a thinner subsoil. The hazards of water erosion and soil blowing are severe.

WELD SERIES - Consists of well drained, nearly level soil on uplands. The soils were formed in wind-worked loamy materials. The soils absorb water at a moderate rate, and the available water capacity is high. Permeability is slow, and the entire soil is suitable for plant roots.

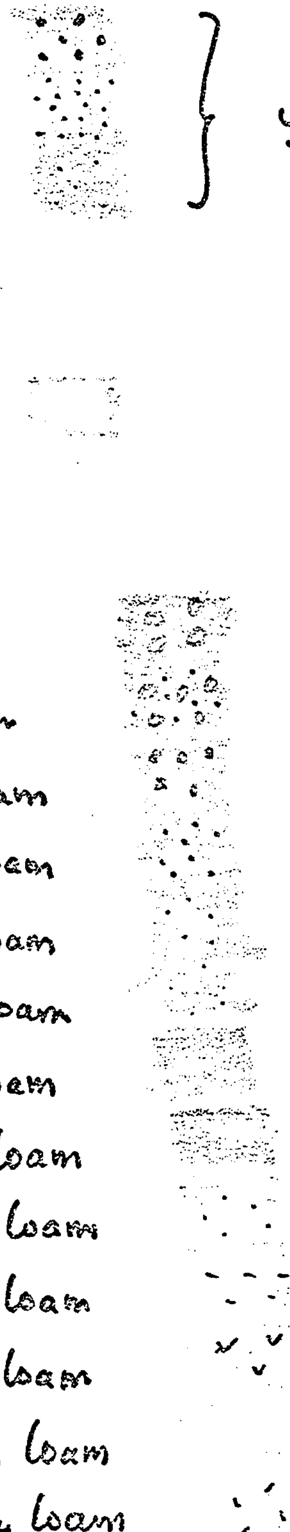
Representative Profile - The surface layer is brown loam about six inches thick. It is noncalcareous. The upper part of the subsoil is dark brown clay about six inches thick. It is noncalcareous. The lower part of the subsoil is pale-brown and very fine sandy loam about 20 inches thick. It is highly calcareous, and much of the lime is visible as splotches. The underlying material is highly calcareous, pale-brown silt loam and light yellowish-brown fine sandy loam.

(WmB) Weld loam, one to three percent slopes. This soil is found on uplands. Surface run-off is medium, and the hazard of water erosion is moderate to severe. The hazard of soil blowing is severe in clay farmed areas, if rainfall is below normal.

(Wt) Wet Alluvial Land - This is found on the nearly level bottom lands of the larger streams next to stream channels. The land is wet most of the time and is flooded by streamflow once to several times a year during periods of high water.

Materials are extremely variable in texture, consisting of stratified layers of dark-colored silt, loam, and clay. The layers are generally less than six inches thick and are underlain by sand, fine sand, and some gravel at depths of one to three feet. They are wet at a depth of two feet most of the time and are commonly wet to the surface throughout the growing season. Water tolerant plants form the vegetative cover.

# Soil Profire legend.



| Soil | Colour |
|---|---|
| **SAND** | |
| coarse sand | yellow ochre |
| sand | yellow ochre |
| loamy sand | yellow ochre |
| **CLAY** | |
| clay | Lemon yellow |
| **Loam** | |
| gravelly loam | dk brown |
| gravelly sandy loam | dk brown |
| c[illegible]rse sandy loam | burnt ochre |
| sandy loam | burnt ochre |
| fine sandy loam | burnt ochre |
| very fine sandy loam | |
| loam | siena brown |
| silt loam | terra cotta |
| Sandy clay loam | flesh |
| silty clay loam | flesh |
| heavy clay loam | flesh |
| clay loam | flesh |
| light clay loam | flesh |

Figure 7

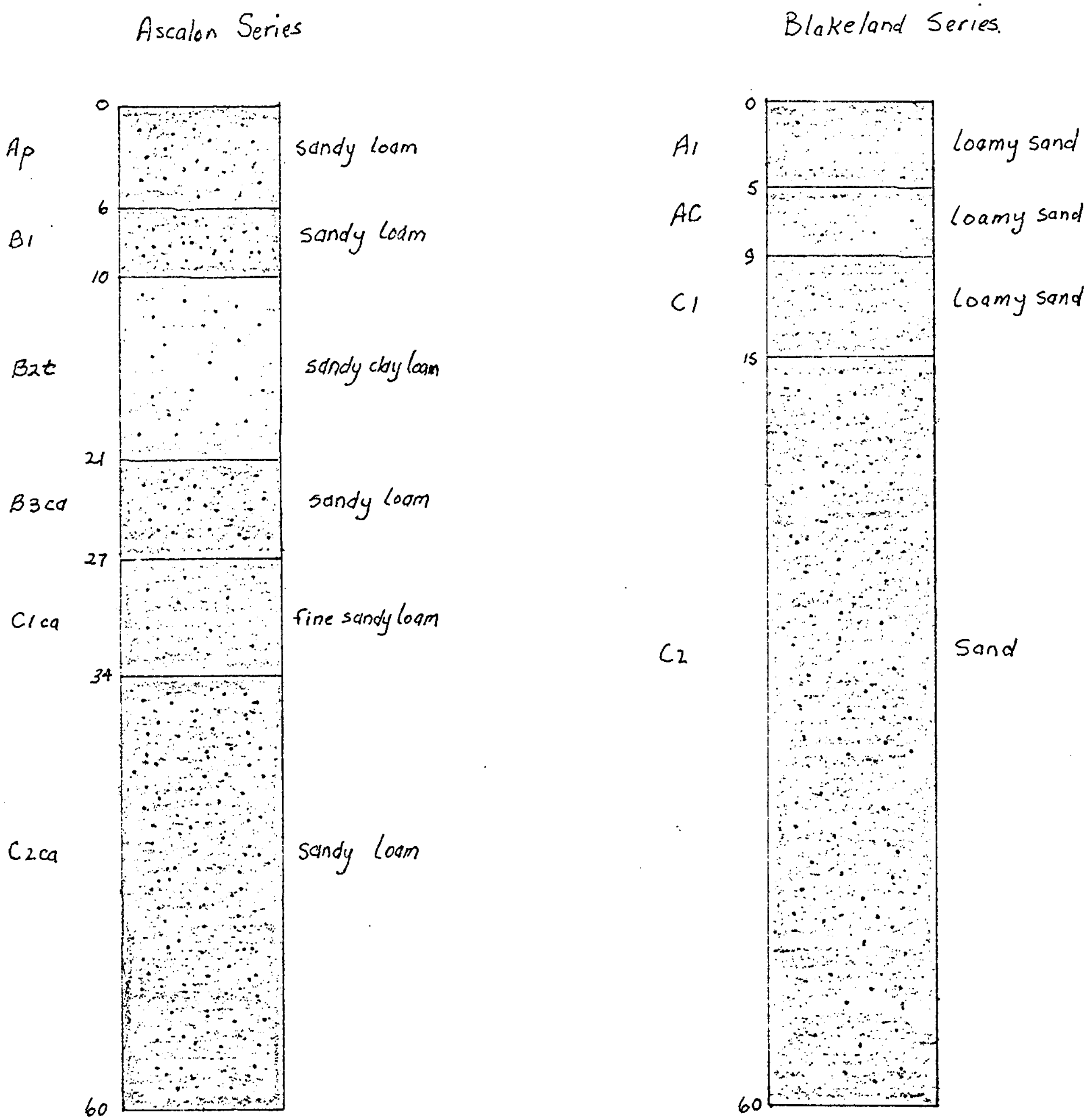

Ascalon Series
0
Ap
sandy loam
6
B1
sandy loam
10
B2t
sandy clay loam
21
B3ca
sandy loam
27
C1ca
fine sandy loam
34
C2ca
sandy loam
60
Blakeland Series.
0
A1
loamy sand
5
AC
loamy sand
9
C1
loamy sand
15
C2
Sand
60

Figure 8

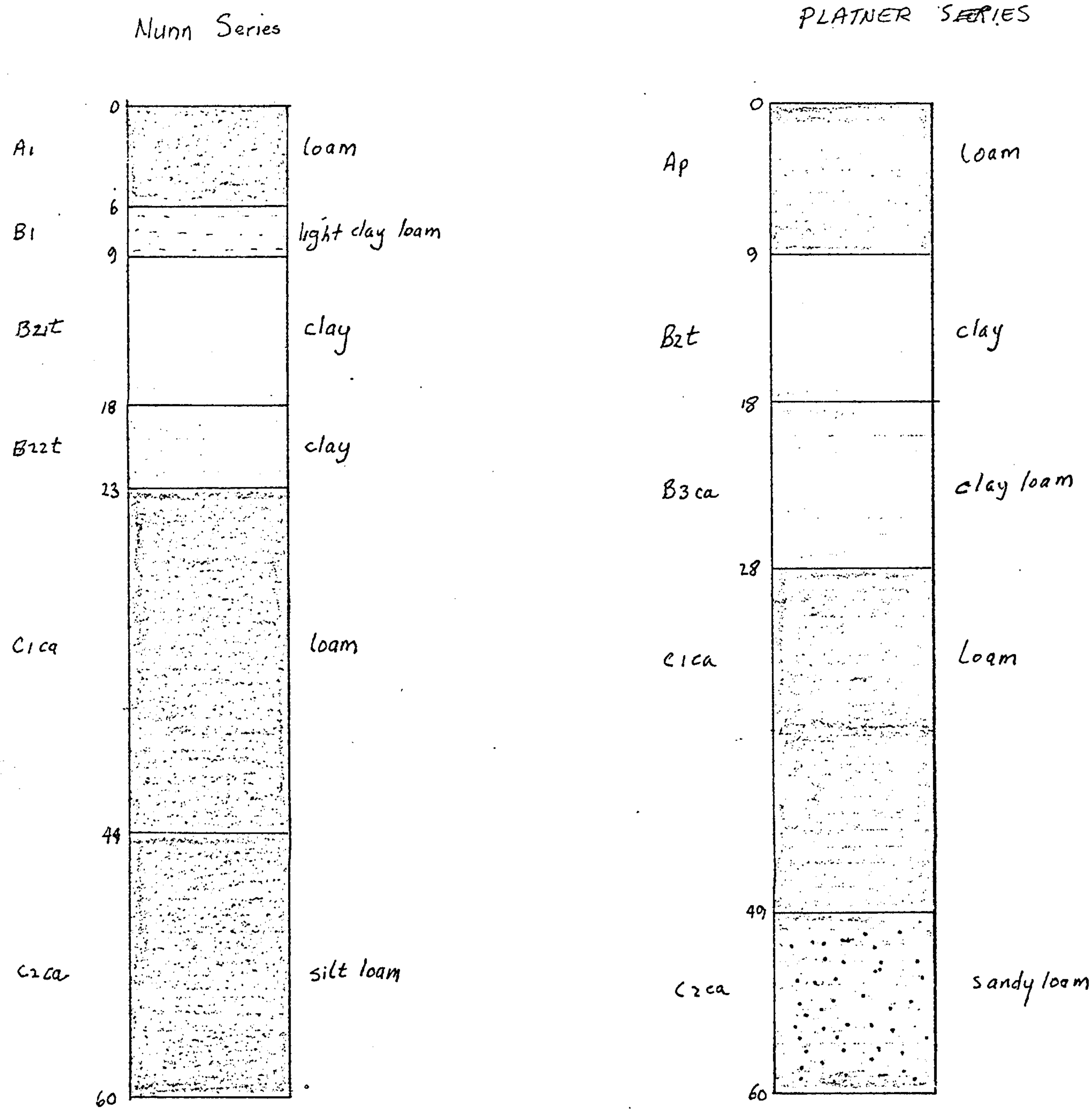

Nunn Series
0
A1
loam
6
B1
light clay loam
9
B21t
clay
18
B22t
clay
23
C1ca
loam
44
C2ca
silt loam
60
PLATNER SERIES
0
Ap
Loam
9
B2t
clay
18
B3ca
clay loam
28
C1ca
Loam
49
C2ca
sandy loam
60

Figure 9

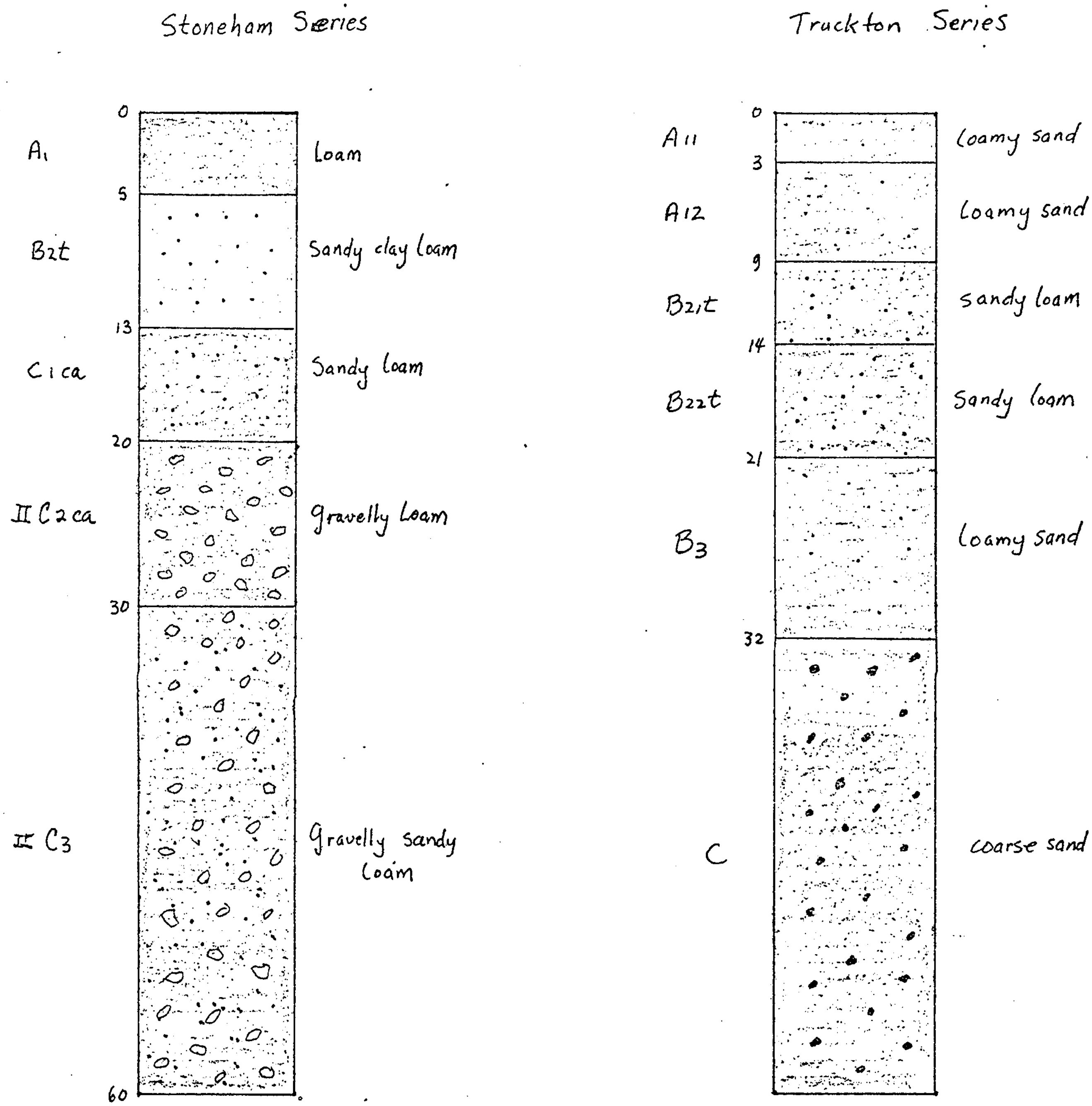

Stoneham Series
Truckton Series
0
A1
Loam
5
B2t
Sandy clay loam
13
C1ca
Sandy loam
20
II C2ca
Gravelly Loam
30
II C3
Gravelly sandy loam
60
0
A11
Loamy sand
3
A12
Loamy sand
9
B21t
sandy loam
14
B22t
Sandy loam
21
B3
Loamy sand
32
C
coarse sand

Figure 10

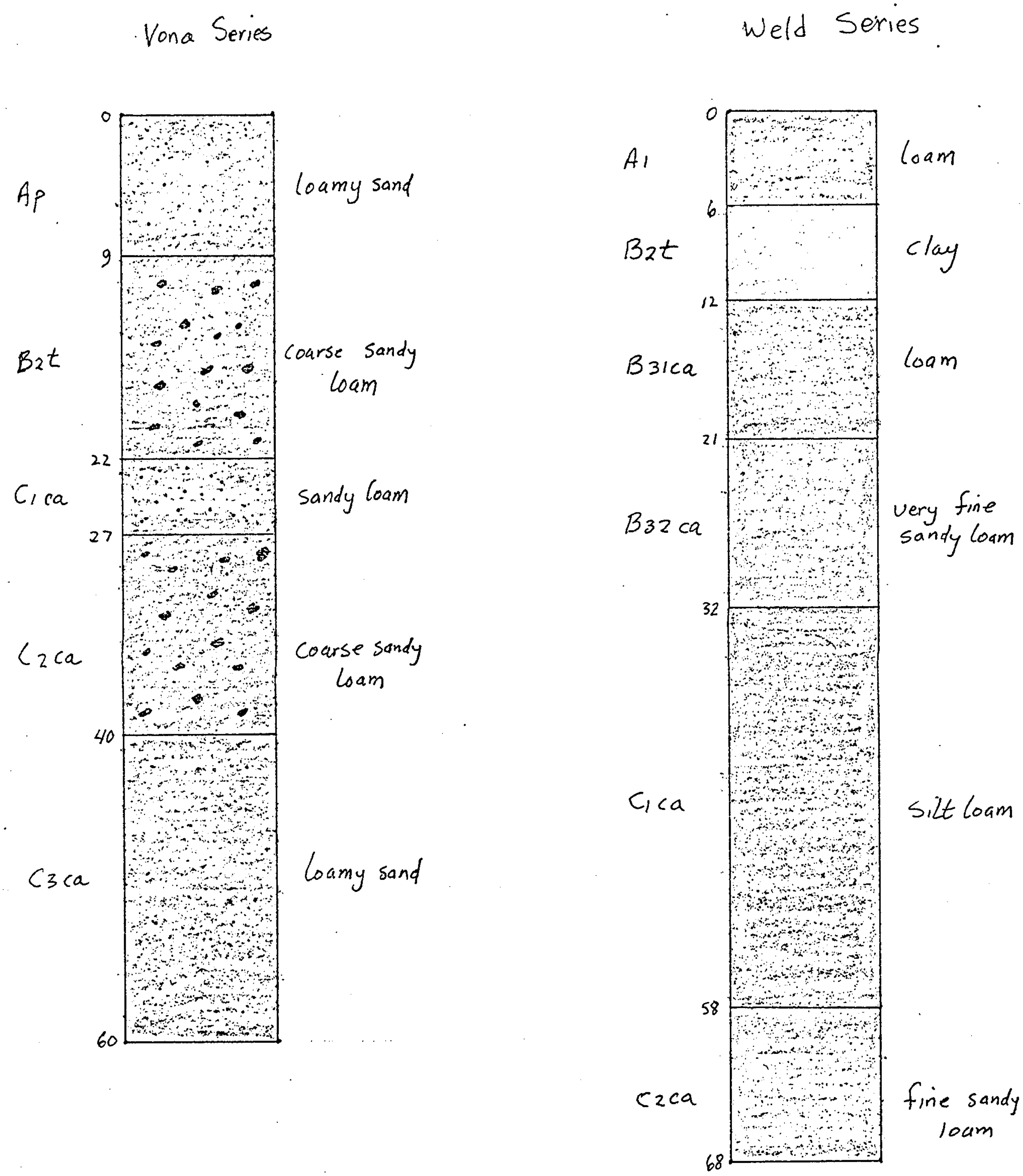

Vona Series
0
Ap
loamy sand
9
B2t
Coarse Sandy loam
22
C1ca
sandy loam
27
C2ca
Coarse sandy loam
40
C3ca
loamy sand
60
Weld Series
0
A1
loam
6
B2t
clay
12
B31ca
loam
21
B32 ca
very fine sandy loam
32
C1ca
Silt loam
58
C2ca
fine sandy loam
68

Figure 11

## SAMPLING METHODS

One of the objectives of the comprehensive survey is to appraise the internal organization of contaminant distribution; the location of the elements of the distribution with respect to each other. The "spatial structure" represents the location of each element relative to each of the others and also the location of each element relative to all of the contaminants taken together; that is, the internal locational organization of contaminant distribution in space. The "spatial processes," on the other hand, are mechanisms which produce the spatial structure of the contaminant distribution.

Spatial structure is a determinant of spatial process as much as process is a determinant of structure. For example, the geohydrologics characteristics of the Arsenal environment control groundwater movement, which also affects contaminant migration and the spatial pattern of contamination. An understanding of the spatial process can be achieved by the deductive approach, using the system's concept which requires fewer samples then would be required to map out the spatial pattern.

Contaminant emplacement and migration will be approached from the systems viewpoint. Systems modeling necessitates a clear definition of the objectives of the study, to identify and model the components of the system andsubsystems, and to elucidate their mutual relationships, especially with regard to the spatial patterns.

System modeling has the ability to handle a dynamic process. It has the ability to look at the total ecosystem, makes efficient use of information gathered, has the ability of checking consistency, has the ability of information integration, is applicable both as a planning tool and an analysis tool, and is an excellent means of organizing data for decision makers. The process response system, incorporating both morphological and cascading subsystems, can serve as a working model to demonstrate the linkage between form and process. The strength and direction of connectivity between the components is analyzed by statistical methods. Such methods can range from analysis of variance, correlation and multiple regression, to cross-spectral analysis.

The problem in sampling and the selection of a sampling design for meaningful data collection is predicated by the research objectives.

The purpose of sampling is to accurately portray the nature of the environment from which the samples were taken. These are two standard categories of sampling methods, probability sampling and nonprobability, or judgment sampling.

1. Probability Sampling - Probability sampling, based upon random selection, is used in modeling and forecasting the behavior of naturally occurring environmental systems. It requires that each element have an equal chance of being chosen; that is, independent of any event in the selection process. Random selection procedures eliminate conscious or unconscious bias by the scientist and enables the researcher to use probability theory as a method for estimates of population parameters and estimates of error.

a. Simple Random Sampling - After a sampling frame has been established, numbers are assigned to each of the elements in the list. The elements to be measured are then selected randomly from the list. If spatial patterns are to be sampled, then a grid overlay is used and the X and Y coordinates are selected randomly to identify either the coordinate intersection to be measured as a point sample or the appropriated grid cell to be measured as an area samples.

b. Systematic Sampling - The first element is selected randomly, then every $K^{th}$ element in the total list is chosen for inclusion in the sample. Periodicity and cyclical patterns that coincide with the sampling interval may be missed and may bias the results.

c. Stratified Sampling - Stratification organizes the population into homogeneous subsets (with heterogeneity between subsets) and an appropriate number of elements are measured from each. Stratification ensures proper representation of the variables describing the parent population. An appropriate number of elements are drawn from homogeneous subsets of the population. This minimizes sampling error.

d. Multi-Stage Cluster Sampling - Cluster sampling involves sampling groups of elements (clusters) followed by selection of elements within the clusters. Multi-stage cluster sampling involves the repetition of listing and sampling. As the homogeneity increases within each cluster, relatively fewer elements may be needed to adequately represent a given natural cluster. However, a larger number of clusters may be needed as the diversity among clusters increases.

e. Hierarchied Sampling (Nested Sampling) - A region is first subdivided into major areas of equal size. Several major areas are then chosen at random and partitioned into smaller sub regions. The sub regions are randomly selected and further subdivided. Hierarchied sampling ensures that every part of the target region is represented.

f. Disproportionate Sampling and Weighing - A probability sample is one in which each population element has a known nonzero probability of selection, even though different elements may have different probabilities. If controlled, probability sampling procedures can be used and may be representative of the population from which it was drawn, if each sample element is assigned a weight equal to the inverse of its probability of selection.

2. Nonprobability Sampling: a, Purposive or judgment sampling -- a researcher may sample with prior knowledge of the population, its elements and research objectives. This is useful to pretest a sample plan or to select a typical or representative sample.

b. Quota Sampling - Quota sampling begins with a matrix describing the characteristics of the target population. The ration of the population occurring in various categories is known. A predetermined proportion is selected for sampling from each cell of the matrix.

c. Traverses - Traverse sampling is the technique used to sample the environment along a straight line whose length and direction have been determined. Traverse sampling may be used to gather data without disturbing the environment. The assumption that the sum of the intercepts along a traverse line can be used to estimate the proportion of the total area occupied by the phenomenon being intercepted. The intercept lengths reflect the spatial geometry and the degree of fragmentation of the occurrences of the attribute being sampled in the region.

Probability sampling avoids conscious or unconscious bias in element selection which closely represents the population of all elements. Probability sampling permits estimates of sampling error. The selection of a particular sampling design depends upon the accuracy and precision required; the efficiency and feasibility of a particular procedure; and the cost in time, manpower, and money. The design selected also depends upon the objectives of the investigation, the structure or functional characteristics of the population.

A combination of the purposive sampling approach (which allows intensive study of structure and relationships and therefore hypothesis formulation) with a probability sampling approach (which allows the hypotheses to be formally tested with respect to a given population) is advocated for environmental studies.

## Estimating the Sample Size

Sampling involves a compromise between precision and economy. A parameter can only be defined with 100 percent accuracy by measuring or counting the whole population. The smaller the sample, the wider the margin of error of any estimate made from it. A homogeneous population produces samples with smaller sampling errors than does a heterogeneous population. If the margin of error that can be tolerated for a particular purpose is known, it is possible to calculate the minimum sample size required and thereby same time in the collection of an unnecessarily large sample. Different methods in environmental studies can be used depending on whether the samples are to be measured or counted. Both involve prior collection of a pilot sample of about 30 observations. These samples must be collected by the same methods that are to be employed in the full sample; and they can be used as part of the full sample, provided they do not affect the selection of additional items.

The formular for finding the required sample size using measured data is: $n = (\frac{zs}{d})^2$, where *n* is the required size of the sample, *s* is the standard deviation of the pilot sample, *d* is the tolerable margin of error at a specified level of confidence, and *z* is a constant taken from the z-table (table of probabilities associated with values of z in a normal distribution) corresponding to the same level of confidence. Therefore, if the pilot sample has a standard deviation of 10 and if the margin of error that can be tolerated is 2.5 at the 95 percent level, then the required sample size is $n = (2\text{x}10/2.5)^2 = 64$.

The formula for finding the sample size using counted data is $n = p\% \times q\% \times (z/d)^2$ percent, where *n*, *z*, and *d* have the same meanings as in paragraph above and where *p* and *q* are the percentages of the pilot sample belonging and not belonging to the specified category respectively.

## GEOGRAPHIC COORDINATE SYSTEM USED AT RMA

Several different coordinate systems have been used in the past on RMA. Each coordinate system has its own merits. However, there exists a need to coordinate all of the data-gathering tasks into one standardized reference system. The identification code of each sample collected will be located with reference to the State Plane Coordinate System, and all existing data will be converted to this system.

1. State Plane Coordinates represent a system set up for each state by the U. S. Department of Commerce, Coast and Geodetic Survey, to be used by the private land surveyors of those states. The system consists of a rectangular coordinate grid that covers the entire state, which is oriented due north and is reduced to sea level. These coordinates can be tied into a more universal Geographic Coordinate, which utilizes latitude and longitude. Any point to be referenced within the state can be identified on the State Plane Coordinate Grid. This has the advantage of being more flexible and universal when tracing data that extends beyond the Arsenal boundaries.

2. RMA Coordinate System - This system was established in 1942 on the original survey of the Arsenal. The origin of the system was a Geological Survey monument named Sand 1936 (now destroyed). The grid is oriented to magnetic north. Out of about 160 coordinate points established in the past, only eight points have been recorded. This system is completely independent of all other coordinate systems used in the area. The origin of this grid system is located in the southwest corner, such that all X and Y values on the Arsenal are positive numbers. Many of the original Arsenal design plans use the RMA Coordinate System. This system is inadequate for IR needs because negative coordinates would occur for locations beyond the Arsenal.

3. The U. S. Rectangular System is based on a grid consisting of six mile wide east-west tiers and north-south ranges. Each grid cell is a township comprised of 36 one square mile sections which are numerically numbered in snake fashion beginning in the northeast corner. Each one mile block of land or section has its own grid system and is therefore difficult to use.

4. The Section Grid is a coordinate system set up for each one mile block within a section of land. The southwest corner of the section is arbitrarily set at 1,000 feet north and 1,00 feet east. This small grid is used with very little control surveying. To set up this grid, only the boundaries of the section need to be measured. A control survey is then completed to locate the section corners on another, more universal, system. The section coordinates can then be converted to the control survey grid. This is a localized grid system which is easy to use for specific tasks.

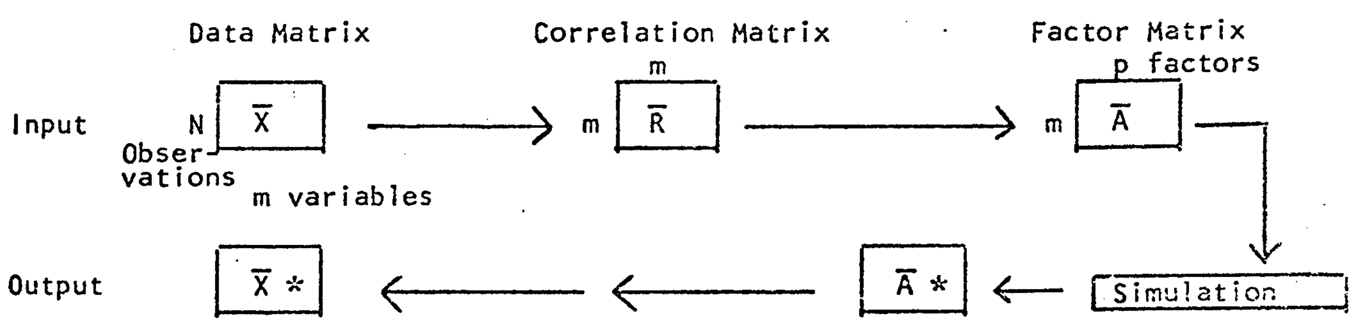
## PRINCIPAL COMPONENT FACTOR ANALYSIS

Factor analysis is a statistical technique which is used to reduce a square symmetric (mxm) matrix to a related rectangular (mxp) matrix such that $m>p$. The initial matrix is a correlation coefficient matrix consisting of m variables. The output matrix presents restructuring the pattern of correlations into p clusters of characteristics, accounting for much of the variance of the m set of initial variables.

The p set of final vectors then constitutes, a set of surrogate variables (called factors), which represent the m set of variables.

Within IR, we will deal exclusively with principal component factor analysis which selects an orthogenal rather than an oblique (correlated factor) solution and which assigns all of the variance for interpretation rather than only part of it.

Principal components method is preferred because of orthogonality and the uniqueness of the solution. There is only one principal components solution to a correlation matrix, thus the factor structure is not likely to be an artifact of procedure. The factors in the solution are uncorrelated and are statistically independent. Therefore, surrogate variables are independent by design. If there are N observation drill sites in each cluster and each site provides information with respect to m variables, then at each point in time a data matrix $\overline{X}_t$ (N x m) is obtained. Simulation of time trends may result in error because the significant correlations among the variables are likely to be interdependent. However, the correlation structure among the m variables can be reduced into p orhoganal components, with which them variables are associated by means of linear equations. Time trends of the p components may now be analyzed without fear of independence problems. The results of the simulations representing p components can be reconstructed back to the original variables. For example, the following flow diagram illustrates the steps in factorial simulation:




*These matrices are simulated.

Principal component analysis can be used in problems which involve an analysis of spatial structure of contamination and spatial taxonomy. For example, an area of interest such as the northern boundary is subdivided into N subareas or clusters. For each subarea, information on m descriptive variables is measured. This constitutes a data matrix $\overline{X}$ (N x m). The questions we now pose are:

1. How may the internal variations of the m variables over the entire area be parsimoniously described?

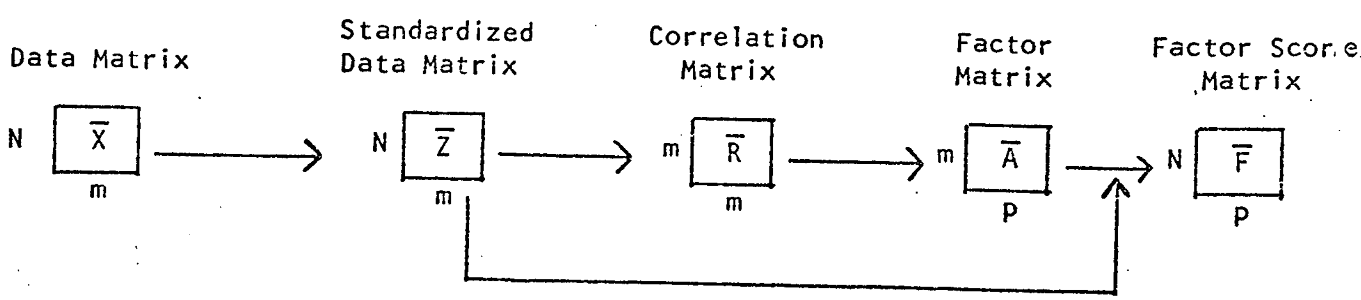
2. How may the subareas be arranged to reveal the similarity and difference so as to assign a meaningful regional structure?

A data matrix consisting of variables measured at strategically located sites positioned to describe the environment can be subjected to correlation analysis to reveal how the descriptive variables are intercorrelated and therefore the degree to which they report redundant information.

Principal components analysis can be used. The oringal variables may be correlated and numerous. The patterns of variation may be independent and confusing. These can be reduced to p factors which, on the other hand, are few and independent and thus describe the region more parsimoniously. Furthermore, there is no way of knowing which of the variables are the most powerful descriptive tools; whereas, the principal components method ranks the factors in descending order of ability to interpret the correlation matrix variance. If factor $\overline{f}_1$ interprets 42 percent of the variance and factor $\overline{f}_2$ 34 percent, we can ascertain which is more general and by how much.

For mapping and regionalizing, it is desirable to be able to estimate the strength of each factor within each tract. For this purpose, the matrix $\overline{A}$ (m x p) which gives the relationships between the variables and the factors is combined with a matrix $\overline{Z}$ (N x m) of standardized values of the initial variables. The result is a matrix of dimension (N x p) which estimates the strength of each factor in each subarea of observation. This is called the factor score matrix $\overline{F}$. The sequence is as follows:

Flow Diagram of Principal Components Analysis
of a Data Matrix



Each row of the factor score matrix of a given sampling bore hole (or subarea) across the independent dimensions represented by the columns. It is therefore actually a point in the p-dimensional space of the factor structure. One may therefore evaluate the similarity or difference between subarea i and subarea j by means of the pythagorean theorem which evaluates the distance between any two points in a p-dimension space.

$$(1) \quad d^2_{ij} = (e_{i1} - e_{j1})^2 + (e_{i2} - e_{j2})^2 + \ldots + (e_{ip} - e_{jp})^2$$

Equation (1) may be evaluated for every pair of subareas, and the set of $\{d^2_{ij}\}$ will then form the $\bar{D}^2$ matrix. Analysis of this matrix -- especially by such techniques as discriminant analysis -- will cluster those subareas which most resemble one another into families linked into a regional hierarchy of subareas. The grouping of the $\{d^2_{ij}\}$ by discriminant analysis will be presented at a later date.

The Procedure of Principal Components Analysis

If we consider the matrix $\bar{Z}$ (N z m) of standardized values of the N subareas on the m variables, we may regard each variable as a vector in a N dimensional space of orthogonal axes. The columns of the matrix, in this case, form the vectors which define each variable's positions in this space. Since we are dealing with a standardized value matrix, all vectors are of equal (and unit) length. The similarity of any variable to any other is therefore measured by the angle between them. But, the cosine of the angle between two standardized vectors in a space of N dimensions is given by the inner vector product between them. The cosine function varies between -1 and +1 and is, in fact,

$$(2) \quad \cos \theta_{ij} = \frac{\bar{z}_i \cdot \bar{z}_j}{N}$$

the correlation coefficient between the i^th^ and j^th^ variable. Thus, we find $\bar{R}$, the correlation coefficient matrix, by expression (3).

$$(3) \quad \bar{R} = \frac{\bar{Z}' \cdot \bar{Z}}{N}$$

$\bar{R}$ is a matrix which measures the angles between variable vectors. The principal components solution starts by discovering how orthogonal axes may be passed through this pattern of intersecting vectors so that each axis will, as far as it is possible, coincide with the center of a "cone" of vectors (i.e., be correlated with it). This is analogous with the physicist's problem of finding the resultant of a set of force vectors. In the F matrix case, the resultant is found by solving the characteristic equation of the matrix.

In ordinary algebra, an expression of the type

$$(4) \quad ay = gy$$

implies that $a = g$. In matrix algebra, a common factor on each side of the equation does not imply the equality.

$$(5) \quad \bar{A}\bar{Y} = \lambda \bar{Y}$$

In expression (5), $\bar{A}$ may be a (m x m) matrix, and $\bar{Y}$ may be a (m x 1) vector. $\lambda$ may be a scalar, and it will then be true that the left hand term and right hand term will both be (m x 1) vectors; yet $\bar{A} \neq \lambda$. Scalars such as $\lambda$ and vectors such as $\bar{Y}$, which have this property with respect to a given matrix, $\bar{A}$, are called eigenvalues and eigenvectors. When the correlation coefficient matrix $\bar{R}$ is factored into eigenvalues and eigenvectors (factor analysis), the eigenvalues are orthogonal and have the properties which we seek. Furthermore, the eigenvalues prove to be scaling coefficients such that they are proportional to the amount of variance interpreted by each factor. Any factor with a $\lambda > 1.0$ interprets more variance than an unmodified variable alone, while any factor with a $\lambda < 1.0$ is of relatively weak explanatory power. Generally, the researcher rejects factors with $\lambda < 1.0$, and the $\Sigma\lambda_i$ of these rejected factors is proportional to the unexplained variance in the model.

The factor loading matrix $(\bar{A})$ is synthesized from the eigenvalues and eigenvectors so that

$$(5) \quad \bar{R}\,\bar{A} = \bar{A}\,\bar{\Lambda}$$

where $\bar{\Lambda}$ is a diagonal matrix whose elements on the principal diagonal are the $\lambda$'s.

A matrix $\bar{F}$ can then be derived whose columns are vectors $\bar{f}_1$, $\bar{f}_2$, ... corresponding to the scores of each factor in a certain tract, by seeking some relationship based upon the property that

$$(6) \quad \bar{z} = \bar{A}\,\bar{f}$$

which is to say that $\bar{z}$ (a column vector of the standardized variables) for the tract and $\bar{f}$ (a column vector of the factors) are linearly related through $\bar{A}$. Then, premultiplying by $\bar{A}$ gives

$$(7) \quad \bar{A}'\bar{z} = \bar{A}'\bar{A}\,\bar{f}$$

and finally

$$(8) \quad \bar{f} = (\bar{A}'\,\bar{A})^{-1}\,\bar{A}'\bar{z}$$

Expression (8) provides the means for estimating the values of the p factors for all the tracts. These are the values which may be mapped.

Rotation of the factor structure to any one of an infinite number of configurations will yield different resultants. The most useful rotation for IR is that which uses the varimax criterion. The purpose of this is to place the component axes in the unique position where as much of each factor as possible is interpreted by strong loadings by as few variables as possible. This rotation simplifies factor structure in that each factor axis is placed as parallel as possible to a limited number of variable vectors.

Rotation serves a very useful purpose in clarifying the interpretation of the model by a rule of parsimony. Furthermore, the varimax rotation, oke the principal components solution, yields a unique solution whose factors are orthogonal -- but with the added advantage of simplicity of interpretation.

## FACTOR ANALYSIS OF CONTAMINANTS ALONG THE NORTHERN BOUNDARY

The following example will illustrate the use of principal component factor analysis for (1) data reduction, (2) analysis of spatial structure, and (3) spatial mapping.

Twenty-four bore hole samples were drilled 250 feet apart in two parallel east to west lines along the northern boundary at RMA. Chemical analysis was performed on the groundwater collected from each sample and tested for eight compounds (eight variables). The raw data matrix (24 x 8) is shown on Table 1, in which the rows represent the bore holes (samples, N), and the columns represent the variables (m).

Table 3 is an eight by eight correlation matrix (M x M), which represents the product moment correlation between each of the eight compounds analyzed. When the number of variables in the set is small, it is easy to evaluate those variables which correlate highly with each other. When the number of variables increases, it becomes difficult to identify those variables which are intercorrelated and group together as clusters. These groups can be isolated as orthogonal factors. Table 6 shows three factors represented as columns. The variables in this (m x p) matrix are shown as the rows where the factor loadings and the factors represent their relationships.

The $cl^-$ ion, DIMP and the Na ion load up on factor 1; therefore, they must also be highly intercorrelated and occur as a group in this data set.

## RAW DATA MATRIX

| VARIABLES | $Cl^-$ | Na | $SO_4^=$ | $NO_2/NO_3$ | Hardness | pH | DIMP | DCPD |
|---|---|---|---|---|---|---|---|---|
| | PPM | PPM | PPM | PPM | PPM | | PPB | PPB |
| | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 |

| SAMPLES | V1 V2 V3 V4 V5 V6 V7 V8 |
|---|---|
| A-1 | 44541204550.206407.6222000031 |
| A-2 | 27630001950.043207.8609400290 |
| A-3 | 33530002100.043857.4807301600 |
| A-4 | 07507500850.091207.9000920073 |
| A-5 | 23026304151.404707.5904000000 |
| A-6 | 22027306552.956507.8001700000 |
| A-7 | 50034307500.127257.4015000000 |
| A-8 | 20037309552.557057.9100820000 |
| D-1 | 28031302590.043507.7712000290 |
| D-2 | 21420801520.062757.9105300240 |
| D-3 | 09507501300.061808.0100660000 |
| D-4 | 24526805503.006407.6702700000 |
| D-5 | 52552505300.186507.5529000000 |
| D-6 | 36527002000.044757.6507501200 |
| D-7 | 24519501800.213407.7004800088 |
| D-8 | 22532508552.008557.6701500010 |
| UD-1 | 24221402000.144207.6005700320 |
| UD-2 | 24023403250.045007.6504200010 |
| UD-4 | 44561501550.057407.4919000000 |
| UD-5 | 32527003950.044357.7407000093 |
| UD-6 | 17034510003.158507.6200630000 |
| UD-7 | 28529002100.062957.9809600093 |
| UD-8 | 20420003002.004658.2603400012 |
| UD-3 | 16925306153.306657.5202400000 |

TABLE 1

| VARIABLE | | MEAN | ST.DEV. |
|---|---|---|---|
| $Cl^-$ | 1 | 273.125011 | 115.321591 |
| Na | 2 | 289.125000 | 117.819796 |
| $SO_4^=$ | 3 | 407.333340 | 273.620590 |
| $NO_2/NO_3$ | 4 | .906667 | 1.241141 |
| Hardness | 5 | 506.249996 | 203.855494 |
| pH | 6 | 7.722917 | .200531 |
| DIMP | 7 | 735.541687 | 735.724869 |
| DCPD | 8 | 181.250010 | 394.055733 |

TABLE 2

CORRELATION MATRIX

| | 1 $Cl^-$ | 2 Na | 3 $SO_4^=$ | 4 $NO_2/NO_3$ | 5 Hardness | 6 pH | 7 DIMP | 8 DCPD |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.00000 | | | | | | | |
| 2 | .76139 | 1.00000 | | | | | | |
| 3 | .03735 | .33400 | 1.00000 | | | | | |
| 4 | -.397[illegible] | .01110 | .72653 | 1.00000 | | | | |
| 5 | .36[illegible] | [illegible]6785 | .83121 | .59162 | 1.00000 | | | |
| 6 | -.55539 | -.50381 | -.25455 | .04583 | -.50311 | 1.00000 | | |
| 7 | .89145 | .72437 | -.12501 | -.48784 | .17548 | -.39476 | 1.00000 | |
| 8 | .17279 | -.05811 | -.34515 | -.32579 | -.25761 | -.20842 | .01[illegible]98 | 1.00000 |

TABLE 3

EIGENVALUES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.39514 | 2.68405 | 1.00452 | .45274 | .21404 | .13149 | .08421 | .03387 |

CUMULATIVE PROPORTION OF TOTAL VARIANCE

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| .42439 | .75990 | .88546 | .94205 | .96881 | .98525 | .99577 | 1.00000 |

TABLE 4

| VARIABLE | ESTIMATED COMMUNALITY | FINAL COMMUNALITY |
|---|---|---|
| 1 | 1.000005 | .928412 |
| 2 | 1.000005 | .860722 |
| 3 | 1.000005 | .881439 |
| 4 | 1.000005 | .887435 |
| 5 | 1.000005 | .955947 |
| 6 | 1.000005 | .732684 |
| 7 | 1.000005 | .947572 |
| 8 | 1.000005 | .889357 |

TABLE 5

ROTATED FACTOR MATRIX

| | VARIABLE | FACTOR 1 | 2 | 3 |
|---|---|---|---|---|
| $Cl^-$ | 1 | .95432 | .05771 | .11978 |
| Na | 2 | .86626 | -.32869 | -.04775 |
| $SO_4^=$ | 3 | .07578 | -.93095 | -.09502 |
| $NO_2/NO_3$ | 4 | -.36283 | -.86278 | -.10680 |
| Hardness | 5 | .42726 | -.87938 | -.00878 |
| pH | 6 | -.59616 | .32518 | -.52109 |
| DIMP | 7 | .93632 | .23634 | -.12260 |
| DCPD | 8 | .02320 | .31009 | .89032 |

TABLE 6

FACTOR SCORES

| SAMPLES | CASE | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|---|
| A-1 | 1 | 1.63071 | .14408 | -.63347 |
| A-2 | 2 | .04633 | .92987 | -.24377 |
| A-3 | 3 | .13449 | .57079 | 3.43871 |
| A-4 | 4 | -1.46349 | 1.25532 | -.37236 |
| A-5 | 5 | -.28705 | -.26986 | .07464 |
| A-6 | 6 | -.63546 | -1.16170 | -.26449 |
| A-7 | 7 | 1.47940 | -.57263 | .13603 |
| A-8 | 8 | -.50271 | -1.52047 | -.57213 |
| D-1 | 9 | .27072 | .78231 | -.12060 |
| D-2 | 10 | -.55679 | 1.02852 | -.26528 |
| D-3 | 11 | -1.44698 | 1.19991 | -.75781 |
| D-4 | 12 | -.46282 | -1.09225 | .01025 |
| D-5 | 13 | 2.46890 | .09476 | -.85149 |
| D-6 | 14 | .16364 | .59346 | 2.25481 |
| D-7 | 15 | -.35982 | .69941 | -.03682 |
| D-8 | 16 | -.22932 | -1.60303 | .04838 |
| UD-1 | 17 | -.21799 | .51007 | .64720 |
| UD-2 | 18 | -.17469 | .23713 | -.05952 |
| UD-4 | 19 | 2.12827 | .10989 | -.45420 |
| UD-5 | 20 | .15308 | .39788 | -.23061 |
| UD-6 | 21 | -.48184 | -2.18231 | .18710 |
| UD-7 | 22 | .00252 | 1.04124 | -.93460 |
| UD-8 | 23 | -1.01234 | .24606 | -1.39069 |
| UD-3 | 24 | -.64515 | -1.44025 | .39619 |

Var 1 = $Cl^-$
2 = Na
7 = DIMP

Var 3 = $SO_4$
4 = $NO_2/NO_3$
5 = Hardness

Var 8 = DCPD

TABLE 7

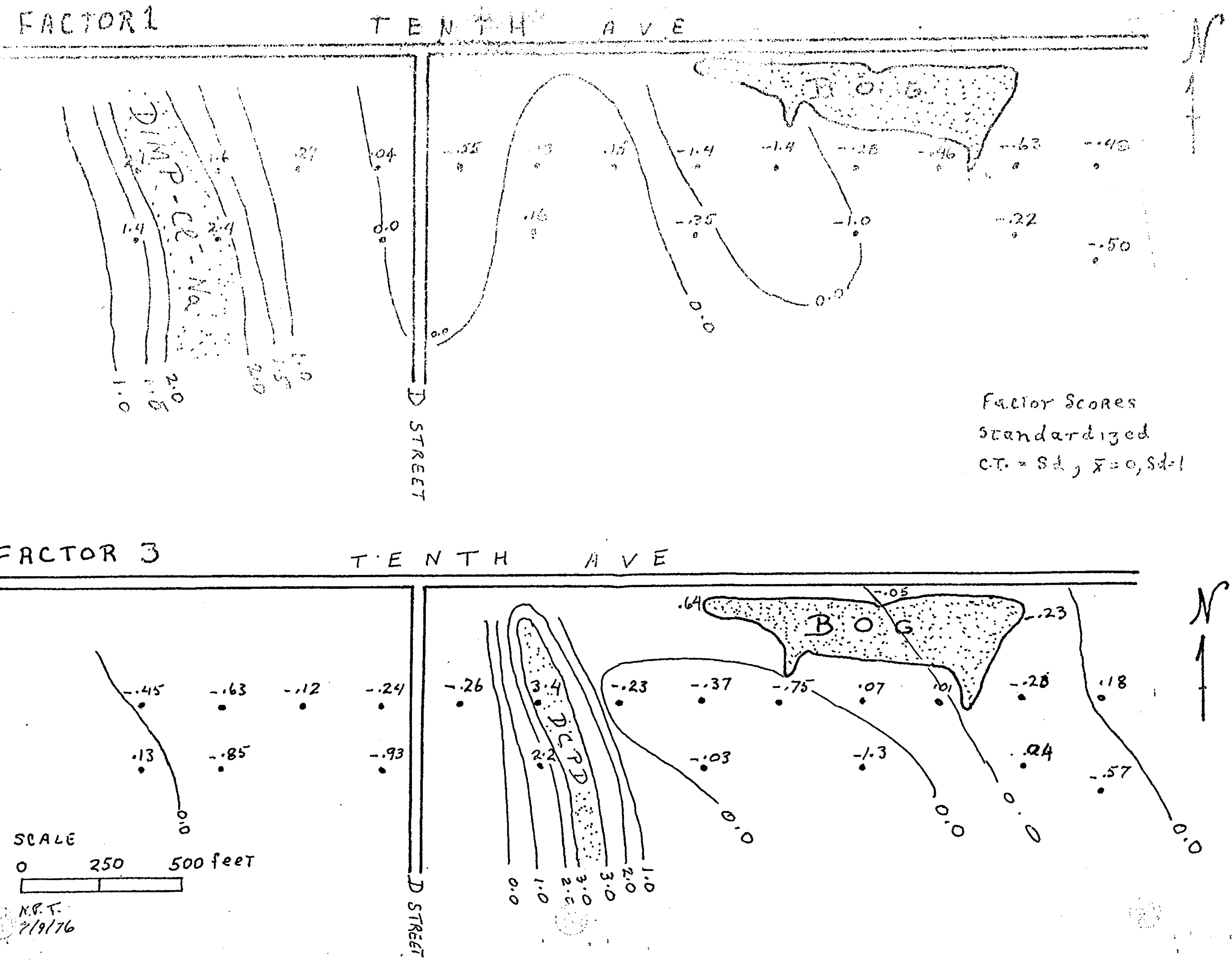

FACTOR 1
TENTH AVE
D STREET
BOG
DIMP-Cl-Na
Factor Scores
standardized
C.T. = Sd, $\bar{x}$ = 0, Sd=1
FACTOR 3
TENTH AVE
D STREET
BOG
DCPD
SCALE
0 250 500 feet
K.R.T.
7/9/76

Figure 12

Factor 2 represents the $SO_4^{=}$ ion, $NO_2/NO_3$, and hardness variable group. DCPD behaves independently represented as Factor 3 in this data set. It is possible from the factor loading to identify which variable (model variable) has the highest correlation with the respective factor. This model variable can then represent the group in future tests and thus permit data reduction with minimum information loss.

Table 4 gives the eigenvalues which can be interpreted as the proportion of the variance in the data matrix which is explained by each of the factors. By weighting the proportion each eigenvalue is of the total, we can determine the relative explanatory power of each of the factors in terms of the total common variance in the data set. Factor 1 accounts for 42 percent of the total variance, while Factor 2 explains 33 percent. All three factors together explain 88 percent of the total variance in this example.

Table 7 gives the factor scores. These numbers represent the weight of each of the factors at each of the 24 drill sites. By mapping and contouring the factor scores for each of the factors separately, we can construct maps showing multivariate distribution representing the spatial behavior of groups of contaminants which behave spatially together. See map .

This information is invaluable in (1) tracing each of the contaminant migration paths independently, (2) determining the source of contamination, and (3) determining the position and direction for further sampling.

## SAMPLING SITE CHARACTERIZATION & DRILL CORE LOGGING

### OVERVIEW

Soils are organized natural bodies which vary markedly, both horizontally across the surface of land and vertically as seen in cross section. The vertical section provides the best means of examining soil. The component layers that form the basic unit for the classification of soils, in turn, provides a basic framework for the analysis and mapping of the behavior of the pollutants in the ground.

The profile form which expresses the overall visual impact of the physical soil properties in their association with one another serves as the basis for the following key. The profile is regarded as a physical system and those physical properties capable of observation and record which may incorporate other features or properties, either physical, chemical, or biological are used as the critical ones to distinguish subtle changes in the environment and contaminant behavior.

An attempt has been made to identify and code most of the relevant parameters which best describe the physical characteristics of the soil. The following list of variables are to be measured at each sampling site in the comprehensive survey at RMA. This list includes a coding key which has been successfully used in previous studies and should be used to enter the data gathered into the computerized data bank. The scale for each of the variables describing topography, site drainage, physical soil properties, and bedrock lithology has been designed so that the scale can serve as input directly into numerical analysis and computer graphics routines. The key is flexible in that if necessary, it can be expanded without detriment to those portions of the key already completed.

## PHYSICAL VARIABLES

Each sampling site will be identified by a ten digit index located on the State Plane Coordinate System. The first five characters of the index represent the X axis of the east-west State Plane Coordinates measured to the nearest foot, and the last five characters represent the Y axis.

### A. Topographic Variables

1. Elevation is the height of a given point above mean sea level. Elevation is a critical variable which is used in most calculations to provide information on relative position.

Units = feet (height above mean sea level)

2. Local relief is the difference in elevation between the highest and lowest points. It measures the physical size of the topographic features.

Units = feet (difference between highest and lowest points)

3. Ruggedness is a combination of gully depth measured in feet and gully count per 100 square yard site. Ruggedness measures the degree of direction of a landform and provides information about the degree and stage of landform erosion. It also indirectly measures the pattern of surface water flow.

(a) Depth in feet

| | |
|---|---|
| > 1 foot ------------------ | 1 |
| 1 - 6 feet ---------------- | 2 |
| 6 - 15 feet --------------- | 3 |
| > 15 feet ----------------- | 4 |

(b) Count across 100 yards square site

| | |
|---|---|
| None ---------------------- | 0 |
| 1 - 5 --------------------- | 1 |
| 5 - 10 -------------------- | 2 |
| > 10 ---------------------- | 3 |

4. Slope describes the angular inclination of the surface at the sampling site. It is measured as a ratio of the amount of drop (h) in 100 feet of length ($\ell$).

Units = ratio h ÷ $\ell$ (recorded as a decimal number)

5. Slope geometry represents the shape of the sloping surface and is an important variable in characterizing soil erosion or soil accumulation on the ground surface.

(a) Shape

| | |
|---|---|
| Convex -------------------- | 1 |
| Concave ------------------- | 2 |
| Straight ------------------ | 3 |

(b) Relative location

| | |
|---|---|
| Top ----------------------- | 1 |
| Middle -------------------- | 2 |
| Bottom -------------------- | 3 |

6. Aspect describes the directional orientation of a topographic feature with reference to north. It is most convenient to divide the compass direction into 16 divisions.

| | |
|---|---|
| N.N.E. ------------------ | 01 |
| N.E. -------------------- | 02 |
| E.N.E. ------------------ | 03 |
| E. ---------------------- | 04 |

| | |
|---|---|
| E.S.E. ------------------- | 05 |
| S.E. --------------------- | 06 |
| S.S.E. ------------------- | 07 |
| S. ----------------------- | 08 |
| S.S.W. ------------------- | 09 |
| S.W. --------------------- | 10 |
| W.S.W. ------------------- | 11 |
| W. ----------------------- | 12 |
| W.N.W. ------------------- | 13 |
| N.W. --------------------- | 14 |
| N.N.W. ------------------- | 15 |
| N. ----------------------- | 16 |

7. Drainage is characterized by two different components. Site drainage describes the movement or potential for movement of water and moisture -- the amount of water contained in the soil.

(a) Site drainage

| | |
|---|---|
| Shedding ----------------- | 01 |
| Normal ------------------- | 02 |
| Receiving ---------------- | 03 |
| Regular flooding, Short Term -------------------- | 04 |
| Regular flooding, Long Term -------------------- | 05 |
| Occasional flooding, Short Term -------------------- | 06 |
| Occasional flooding, Long Term -------------------- | 07 |

(b) Moisture

| | |
|---|---|
| Dry (becomes darker when wet) | |
| $D_1$ (air dry) ------------ | 01 |
| $D_2$ ----------------------- | 02 |
| $D_3$ ----------------------- | 03 |
| Moderately moist | |
| $MM_1$ ---------------------- | 04 |
| $MM_2$ ---------------------- | 05 |
| $MM_3$ (wilting point) ----- | 06 |
| Moist | |
| $M_1$ ----------------------- | 07 |
| $M_2$ ----------------------- | 08 |
| $M_3$ (field capacity) ----- | 09 |

| Wet | | | |
|---|---|---|---|
| $W_1$ | ---------------------- | 10 | (material will wet |
| $W_2$ | ---------------------- | 11 | and stick to fingers |
| $W_3$ | ---------------------- | 12 | when molded) |

B. Soil Physical Properties

1. Depth to sample in the vertical distance measured from the ground surface to the top and the bottom of the sample.

units = feet (measured to the nearest hundreth of foot)

2. Horizon is a layer within the soil profile having morphological characteristics and properties different from those layers which occur below and/or above it. Horizons are usually parallel to the land surface, except where tongues of material from one horizon may penetrate vertically into the neighboring horizon. The horizons are recognized by the nature of their organization. $A_o$ results largely from biologic processes. The A horizon results from biologic processes and those physico-chemical processes that occur at surfaces. The B horizon results from physio-chemical processes which occur below surfaces that are relatively deep seated. C horizons are recognized by their lack of pedologic development and remains of geologic organization. The D horizons result from some earlier cycle of soil-forming process; and thus, their pedologic organization contrasts with that found in the solum of the soil with which they are associated. Weathered bedrock is an example.

Eight categories will be recognized in this study. They are given in descending order: the $A_o$ horizon is the surface soil layer and is composed of organic material; the $A_1$ horizon is the topmost mineral layer with a high content of humified organic matter, relatively dark in color and has a maximum biological activity for any given soil profile; the $A_2$ horizon is the zone of maximum leaching (eluviation), it may be defined by color difference. It may be bleached to a white color or sporadic by bleaches which appear irregular or as blocks less than one-fourth inch in thickness at the interface with the B layer. The B horizon is a transition zone between the A and B horizons though accumulation of material (illuviation) starts to take place. The B horizon is characterized by a concentration of clay and/or iron and/or aluminum and/or translocated organic material and/or having a structure or consistency different from A or C. B also has stronger colors. The $B_2$ horizon is the zone of maximum illuviation of mineral and organic matter; the B-C horizon is a transition zone between the illuvial B horizons and the unconsolidated material of the C horizon. The C horizon is unconsolidated material which may or may not be of the same parent material from which the upper horizons are formed. It is not in the zone of major biological activities; the D horizon is weathered bedrock.

| Horizon | | |
|---|---|---|
| $A_o$ | --------- | 1 |
| $A_1$ | --------- | 2 |
| $A_2$ | --------- | 3 |
| $B_1$ | --------- | 4 |
| $B_2$ | --------- | 5 |
| B-C | --------- | 6 |
| C | --------- | 7 |
| D | --------- | 8 |

3. <u>Horizon thickness</u> -- represents the size of the horizon.

units = feet measured to nearest .01 of a foot.

4. <u>Horizon boundary</u> is a zone of change occurring between soil horizons ranging from the sharp and clearly defined to diffuse. The boundary defines the nature of the change and is specified by two terms -- one a measure of the thickness or width of the transition zone between horizons, the other a measure of its shape.

(a) Shape

1 - Even = boundary is almost a plane surface

2 - Wavy = boundary waves, depressions formed are wider than their depths

3 - Irregular = boundary waves, depressions formed are deeper than their widths

4 - Broken = boundary is discontinuous

(b) Sharpness

1 - Sharp = < 2 cm
2 - Clear = 2 - 5 cm
3 - Gradual = 5 - 10 cm
4 - Diffuse = > 10 cm

5. <u>Color</u> is defined in terms of hue, value, and chroma using the Munsell soil color charts. Hue is a function of the wave length of

the light. Value is the intensity of color and chroma the relative purity or saturation of a color. Color should be recorded for moist soil only.

Color (moist)

1 Hue

| | |
|---|---|
| 2, 5 YR ------------- | 32 |
| 5 YR ---------------- | 16 |
| 7, 5 YR ------------- | 8 |
| 10 YR --------------- | 4 |
| 2, 5 Y -------------- | 2 |
| 5 Y ----------------- | 1 |

2 Value

1-2-3-4-5-6-7-8

3 Chroma

1-2-3-4-5-6-7-8

6. pH measures the hydrogen ion concentration of soil. It is a fundamental property of both physical and chemical characteristics of both the organic and inorganic constituents of the soil.

units = dimensionless number of nearest .1

7. Soil texture is a measure of the size and proportion of individual gain present in the soil. Texture can be measured by the behavior of a small handful of soil when moistened and kneaded into a ball and then pressed out between thumb and forefinger. The approximate percentage content of clay (particles less than 0.002 mm in diameter) and silt (particles between 0.02 and 0.002 mm in diameter) and sand (range from 2 mm to 0.02 mm diameter with an arbitrary separation of coarse and fine sand at 0.2 mm particle diameter) provide a guide for classification.

a. The field method of determining texture soil is to take a sample of soil sufficient to comfortably fit into the palm of the hand. The soil is moistened with water, a little at a time, and kneaded until the ball of soil, so formed, just fails to stock to the fingers. More soil or water may be added to attain this condition, which is known as the sticky point and approximates field moisture capacity for that soil. Kneading and moistening are continued until there is no apparent change in the soil ball, usually a working time of one to two minutes. The soil ball, or bolus, is now ready for shearing manipulation; bu t the behavior of the soil during bolus formation is also indicative of its texture. The behavior of the bolus and of the ribbon produced by shearing (pressing out) between thumb and forefinger characterizes the texture.

b. A much more reliable method of determining soil texture is by sieving the soil samples.

Textural classes

| | | |
|---|---|---|
| S | Sand ---------------- | 01 |
| LS | Loamy sand ---------- | 02 |
| CS | Clayey sand --------- | 03 |
| SL | Sandy loam ---------- | 04 |
| FSL | Fine sandy loam ----- | 05 |
| GL | Gravelly loam ------- | 06 |
| L | Loam ---------------- | 07 |
| SCL | Sandy clay loam ----- | 08 |
| GCL | Gravelly clay loam -- | 09 |
| CL | Clay loam ----------- | 10 |
| SICL | Silty clay loam ----- | 11 |
| CG | Gravelly clay ------- | 12 |
| FSCL | Fine sandy clay loam - | 13 |
| SC | Sandy clay ---------- | 14 |
| SIC | Silty clay ---------- | 15 |
| LC | Light clay ---------- | 16 |
| MC | Medium clay ---------- | 17 |
| HC | Heavy clay ---------- | 18 |

8. Stones are measurable surface features. The abundance is measured as a percentage of cover; size consists of eight categories ranging from gravel (0.2 - 1 cm) to large boulders (< 600 cm); shape can be angular, subangular, rounded, shaley, or tabular; and the lithology of stones is given in 12 petrological types.

(a) Abundance (% cover)

| | | |
|---|---|---|
| Stoneless | < 1 | 0 |
| Slightly stony | 1 - 5 | 1 |
| Stony | 5 - 20 | 2 |
| Very stony | 20 - 50 | 3 |
| Extremely stony | 50 - 75 | 4 |
| Stone dominant | > 75 | 5 |

(b) Size (cm)

| | | |
|---|---|---|
| Gravel | 0.2-1 | 1 |
| Small | 1 - 5 | 2 |
| Medium | 5 - 1 | 3 |
| Large | 10 - 20 | 4 |
| Very large | 20 - 60 | 5 |
| Small boulders | 60 - 200 | 6 |
| Medium boulders | 200 - 600 | 7 |
| Large boulders | > 600 | 8 |

(c) Shape

| | |
|---|---|
| Angular | 1 |
| Subangular | 2 |
| Rounded | 3 |
| Shaley | 4 |
| Tabular | 5 |

(d) Lithology

| | |
|---|---|
| Flint | 1 |
| Soapstone | 2 |
| Limestone | 3 |
| Mudstone | 4 |
| Siltstone and shale | 5 |
| Sandstone | 6 |
| Ironstone | 7 |
| Quartzite | 8 |
| Granite | 9 |
| Gneiss or schist | 10 |
| Ryholite | 11 |
| Andesite | 12 |

9. Roots describe the presence of vegetative matter in the soil measured in terms of quantity and size. Decay of roots provides channels of water flow within the soil.

(a) Quantity

| | |
|---|---|
| Absent --------------- | 0 |
| Present (trace) ------ | 1 |
| Very low ------------- | 2 |
| Low ------------------ | 3 |
| Moderate ------------- | 4 |
| High ----------------- | 5 |

(b) Size

| | |
|---|---|
| Small ---------------- | 1 |
| Small - Medium ------- | 2 |
| Small - Large -------- | 3 |
| Medium - Small ------- | 4 |
| Medium --------------- | 5 |
| Medium - Large ------- | 6 |
| Large - Small -------- | 7 |
| Large - Medium ------- | 8 |
| Large ---------------- | 9 |

10. Structure is concerned with the arrangement of all soil particles. Particles refer to all peds and nonpeds (see both Apedal and Peds). Structure may be described in terms of the three characteristics of the intensity, geometry, and size of the soil aggregates as follows:

(a) Intensity expresses the degree and strength of soil aggregation and may vary with the moisture status of the soil. For purposes of standardization, intensity should be determined when the soil is inthe moderately moist to moist, moisture stages. Four intensities of structure are usually defined as follows:

(1) Structureless in which there is no observable aggregation and the soil is massive, if coherent, and single grain, if not coherent. (Structureless is the same as Apedal.) ---- 0

(2) Weak in which some peds are discernible and when disturbed, less than one-third of the soil material is found to consist of peds. ----- 1

(3) Moderate in which peds are clearly seen and when disturbed, one-third to two-thirds of the soil material is found to consist of peds. ----- 2

(4) Strong in which peds are clearly seen and when disturbed, more than two-thirds of the soil material is found to consist of peds. ------ 3

NOTE that both moderate and strong grades of structure qualify a soil for Peds evident, whereas the structureless state and weak grade of structure qualify a soil for Peds, few, if any.

(b) Geometry

Angular blocky or cubic (ABL) ---------- 1
Subangular blocky or cubic (SABL) ------ 2
Angular prismatic (APR) ---------------- 3
Subangular prismatic (SAPR) ------------ 4
Polyhedral > six sides (PH) ------------ 5
Parallelepedal (PLL) ------------------- 6
Platy (PL) ----------------------------- 7
Spheroidal-solid (SSPH) ---------------- 8
Spheroidal-visible voids (VSPH) -------- 9

(c) Size

Given in inches or fraction

11. Plasticity is a characteristic of wet soils. It is the ability of soil to change its shape as a result of stress and to keep that shape after the removal of the stress.

Nonplastic ---------------- 0
Slightly plastic ---------- 1
Plastic ------------------- 2
Very plastic -------------- 3

12. Friability is a characteristic of moist soils. It is a measure of resistance to crushing.

Loose --------------------- 0
Very friable -------------- 1
Friable ------------------- 2
Firm ---------------------- 3
Very firm ----------------- 4
Extremely firm ------------ 5

13. Porosity - a porous soil material is one characterized by the presence of voids in the soil moss. It is the volume of the total soil bulk not occupied by solid particles. The first component of porosity is void quantity, which is the percentage of nonsolid space ranging from nonporous (< 1%) to extremely porous (> 50%). The second component is pore size, measured in millimeters. Porosity is largely a function of the arrangement of soil particles into aggregates, the type of soil particles, amount of organic material, and degree of compaction.

(a) Void quantity

| | | |
|---|---|---|
| Nonporous | < - 1 ------- | 0 |
| Slightly porous | 1 - 5 -------- | 1 |
| Porous | 5 - 10 ------- | 2 |
| Porous | 10 - 20 ------ | 3 |
| Very porous | 20 - 50 ------ | 4 |
| Extremely porous | > 50 --------- | 5 |

(b) Pore size

| | | |
|---|---|---|
| Very fine | < - 0.5 ------- | 1 |
| Fine | 0.5 - 1 ------- | 2 |
| Medium | 1 - 3 --------- | 3 |
| Large | 3 - 5 --------- | 4 |
| Very large | > 5 ----------- | 5 |

14. Mottling is the presence of spots or alternate streaks of color that differ from the overall color of the soil. Mottling occurs in zones of alternating periods of good and poor aeration. The differences in oxidation states of iron and magnesium result in mottled appearances. Mottles are considered to be masses, blobs, or blotches of subdominant colors, such that color places them in a different value/chroma rating to the matrix color. The glaze or color skin which may occur on the outside of some peds is not considered as mottling. A soil is only considered to be mottled when 10% or more of mottles occur in the soil mass. For mottled soils, the value/chroma rating of the dominant matrix color is taken. Mottling has three components: abundance, measured as a percentage; size in mm; and sharpness of the boundary between mottled and nonmottled soil, measured in mm.

| (a) Abundance | (% cover) | |
|---|---|---|
| None | < 2 ---------- | 0 |
| Few | 2 - 5 -------- | 1 |

| | | |
|---|---|---|
| Common | 5 - 20 -------- | 3 |
| Definite matrix color | 20 - 50 ------- | 4 |
| No matrix color | > 20 ---------- | 5 |
| Definite matrix color | > 50 ---------- | 6 |

(b) Size (mm)

| | | |
|---|---|---|
| Extremely fine | < 1 ----------- | 1 |
| Very fine | 1 - 2 --------- | 2 |
| Fine | 2 - 5 --------- | 3 |
| Medium | 5 - 15 -------- | 4 |
| Large | > 15 ---------- | 5 |

(c) Sharpness (mm)

| | | |
|---|---|---|
| Diffuse | > 2 ----------- | 1 |
| Clear | < 2 ----------- | 2 |
| Sharp | (knifedged) --- | 3 |

15. Secondary precipitates result from the upward capillary movement and removal of soil water through evaporation at the ground surface. This process is important in contaminant movement and concentration in the soil.

(a) Quantity

| | | |
|---|---|---|
| None | --------------- | 0 |
| Few | < 2% ---------- | 1 |
| Common | 2 - 5% -------- | 2 |
| Common | 5 - 20% ------- | 3 |
| Abundant | 20 - 50% ------ | 4 |
| Extra abundant | > 50% --------- | 5 |

(b) Composition

| | |
|---|---|
| Lime ----------------------------------- | 1 |
| Magneste ------------------------------- | 2 |
| Gypsum --------------------------------- | 3 |
| Silica --------------------------------- | 4 |
| Fe oxides ------------------------------ | 5 |
| Fe oxides + humus ---------------------- | 6 |
| Mn oxides ------------------------------ | 7 |

(c) Type

Irregular concretions ----------------- 1
Regular concretions ------------------- 2
Layers -------------------------------- 3

16. Bedrock

(a) Rock structure

(1) Intensity

W. Weak ----------------------- 1
M. Moderate ------------------- 2
S. Strong --------------------- 3

(2) Geometry

B. Banded --------------------- 01
S. Scoriaceous ---------------- 02
A. Amygdaloidal --------------- 03
P. Porphyritic ---------------- 04
L. Laminated ------------------ 05
M. Massive -------------------- 06
C. Cleared -------------------- 07
S. Sheared -------------------- 08
F. Contorted ------------------ 09
X. Cross-bedded --------------- 10

(3) Size

V. Very coarse ---------------- 1
C. Coarse --------------------- 2
F. Fine ----------------------- 3
VF Very fine ------------------ 4

(b) Rock type

Consolidated sediments (0 - 19)
CG Conglomerate --------------- 01
QT Quartzite ------------------ 02
SS Sandstone ------------------ 03
ST Siltstone ------------------ 04
MS Mudstone ------------------- 05
CS Claystone ------------------ 06
SH Shale ---------------------- 07
CH Chert ---------------------- 08

| | | |
|---|---|---|
| GW | Greywacke ------------------ | 09 |
| AK | Arkose --------------------- | 10 |
| LS | Limestone ------------------ | 11 |
| IS | Ironstone ------------------ | 12 |
| TI | Tillite -------------------- | 13 |
| **Igneous rocks (20 - 39)** | | |
| GR | Granite -------------------- | 20 |
| GD | Granodiorite --------------- | 21 |
| DI | Diorite -------------------- | 22 |
| RH | Rhyolite ------------------- | 23 |
| BA | Basalt --------------------- | 24 |
| AG | Agglomerate ---------------- | 25 |
| TU | Tuff ----------------------- | 26 |
| SC | Scorria -------------------- | 27 |
| DO | Dolerite ------------------- | 28 |
| DB | Disabase ------------------- | 29 |
| PG | Pegmatite ------------------ | 30 |
| AP | Aplite --------------------- | 31 |
| RQ | Reef quartz ---------------- | 32 |
| PY | Porphyry ------------------- | 33 |
| PT | Porphyrite ----------------- | 34 |
| **Metamorphic rocks (40 - 59)** | | |
| SL | Slate ---------------------- | 40 |
| PH | Phyllite ------------------- | 41 |
| HF | Hornfels ------------------- | 42 |
| SH | Schist --------------------- | 43 |
| GN | Gneiss --------------------- | 44 |

PAGE ___ OF ___

# INSTALLATION RESTORATION

## PHYSICAL VARIABLES - TOPOGRAPHY

| RMSAGPT | JULIAN DATE | OBS | LOCATION EW | LOCATION NS | ELEV | IR | RD | RC | SL | GS | GL | ASP | DS | DH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 2 3 4 5 6 7 | 8 9 10 11 12 | 13 14 15 | 16 17 18 19 20 | 21 22 23 24 25 | 26 27 28 29 | 30 31 32 | 33 | 34 | 35 36 | 37 | 38 | 39 40 | 41 42 | 43 44 | 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 |

# INSTALLATION RESTORATION

## PHYSICAL VARIABLES - SOIL

| Field | Columns |
|---|---|
| RMSAGPS | 1 2 3 4 5 6 7 |
| JULIAN DATE | 8 9 10 11 12 |
| OBS | 13 14 15 |
| LOCATION EW | 16 17 18 19 20 |
| LOCATION NS | 21 22 23 24 25 |
| DEP | 26 27 28 |
| N | 29 |
| HT | 30 31 32 |
| BS | 33 34 |
| BP | 35 36 |
| CH | 37 38 |
| C V | 39 |
| C C | 40 |
| PH | 41 42 43 |
| TX | 44 45 |
| S A | 46 |
| S S | 47 |
| S P | 48 |
| SL | 49 50 |
| R D | 51 |
| R S | 52 |
| T I | 53 |
| T G | 54 |
| STS | 55 56 57 |
| P L | 58 |
| F | 59 |
| P D | 60 |
| P S | 61 |
| M A | 62 |
| M S | 63 |
| M F | 64 |
| S D | 65 |
| S C | 66 |
| S T | 67 |
| R I | 68 |
| RG | 69 70 |
| R S | 71 |
| RT | 72 73 |
| | 74 75 76 77 78 79 |

# INSTALLATION RESTORATION

## ECOLOGY - MONITORING PROGRAM

| RMSAEMP | JULIAN DATE | CUS | LOCATION EW | LOCATION NS | S T | HABI-TAT | C L | SPECIES | T X | A G | E C | C O | T Y | P H | COLOR | DEPTH | AREA/ VOLUME | NR SPEC | WEIGHT | TISSUE | D T | D S | SAMPLE NUMBER | COMPOSITE SAMPLE NR | STAT CODE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 2 3 4 5 6 7 | 8 9 10 11 12 | 13 14 15 | 16 17 18 19 20 | 21 22 23 24 25 | 26 | 27 28 29 | 30 | 31 32 33 34 35 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 44 45 | 46 47 48 | 49 50 51 52 | 53 54 55 | 56 57 58 59 | 60 61 62 63 64 | 65 | 66 | 67 68 69 70 71 72 | 73 74 75 76 77 | 78 79 80 |
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## SAMPLING PLAN FOR RMA

### Dynamic Cluster Sampling

An attractive attribute of dynamic sampling is that as information is gathered, it can be used to direct further sampling without biasing the probability properties of the sample.

Data on soils and groundwater will be gathered from drill sites patterned in clusters of 16 bore holes per cluster, arranged in a 4 x 4 square grid. Each sample will be surveyed, using the x and y coordinates of the State Plane Grid System which in addition, will serve as the identification code for each of the samples. The elevation will also be recorded. Field data on land surface topography, physical properties of soils, groundwater levels, and bedrock will be logged directly onto the coding forms. Soil samples will be collected at the appropriate depth; sent to the soils laboratory where it will be divided into two parts. One part of the sample will go to the MALD (Material Analysis Lab Division) for chemical analysis of various contaminants. The other portion will be analyzed in the soil laboratory for soil moisture, mechanical, and mineral properties. While the analyses are being performed, a second cluster of 16 sites will be drilled and sampled. The results from the first cluster of samples will be mapped to determine the positioning of the third cluster of 16 sampling sites. The cluster will be located in the direction of the maximum concentration of the contaminant being mapped. The analyzed results from the second cluster will likewise be used to determine the positioning of the fourth cluster, etc. This technique of mapping each contaminant and positioning the cluster of samples in the direction of maximum concentration will permit tracking the pollution plume to its origin with minimum exploratory drilling. Periodically, the cluster will be combined, and analysis will be performed on the total combined samples. This will yield an increase in the sample size and an increased relative homogeneity of the elements being sampled. By combining the cluster into a total sample one, in effect, is evaluating the regional pattern of the pollutants as compared to more local, larger scale behavior within each cluster. However, sampling theory requires that all the elements of the cluster be sampled for the results to be statistically valid.

It is possible that several plumes will be encountered, each originating from a different source and containing their own unique grouping of compounds. When this occurs, each plume will be traced to locate all sources.

On-going exploratory drilling along the northern boundary of RMA has revealed the existence of at least two contaminated groundwater plumes. One plume contains DIMP, $Cl^-$, and Na compounds. The other is a DCPD and pesticide plume. Because of the high priority placed upon containment of contaminant migration, this part of the Arsenal would be a logical place to start the sampling program. An alternate site would be at the known contaminant hot spots.

## Sampling Grid Spacing

A test sampling grid, spaced 250 feet apart, will be constructed initially to pretest the sampling method and data-handling procedure. The distance between the sampling bore holes will be set as more data becomes available on the diffusion rates of contaminant concentration with distance. The mathematical relationship between change in concentration level per unit change in distance will be calculated for each contaminant, and the grid spacing will be adjusted to the optimum distance. Preliminary tests show that the best fit regression equation, equating the change in DIMP concentration with distance measured from the center of the DIMP plume is $Y = A + B \log X$. The DIMP concentration values in the inclosed sample contained DIMP added from secondary sources carried by groundwater. This caused additive harmonics, which should be filtered out before a usable equation can be obtained.

## Sampling Horizons

One-foot sections of the sampling core will be collected to serve as the samples for both mechanical and chemical analysis. Soil samples will be taken at six depths, so as to increase the likelihood of intercepting the zones of contaminant concentration. These zones are: (1) The A soil horizon, which is the zone of contaminant built through (a) bioaccumulation in the soil organic matter; (b) upward migration of contaminants by capillary action and surface evaporation of water; and (c) accumulation of pollutants on the ground surface by both wind or surface water transport; (2) The B soil horizon which is the zone of illuviation or accumulation of compounds leached from the upper horizons; (3) A point mid-way in the zone of aeration representing the transition zone; (4) The capillary fringe immediately above the ground water table; (5) A point below the top of the water table; and (6) At the bedrock surface. The soil samples taken in the zone of saturation will provide a ratio of the contamination in the soil compared with that moving in the groundwater. Additional samples will be taken at the top of clay layers or lenses whenever they are encountered, to determine the effect of clay as a point of contaminant concentration. Clay layers in the regolith may behave as selective, physical, chemical, or osmotic filter aided by the greatly reduced rate of downward percolation of groundwater and the possible presence of clays having a high ionic exchange capacity. Groundwater will also be sampled at similar depths.

The typical profile shown in the diagram was constructed by averaging the horizon of each of the soil series occurring at RMA. The A horizon ranges from 0 - 9 inches in thickness, while the B horizon ranges from 9 - 26 inches.

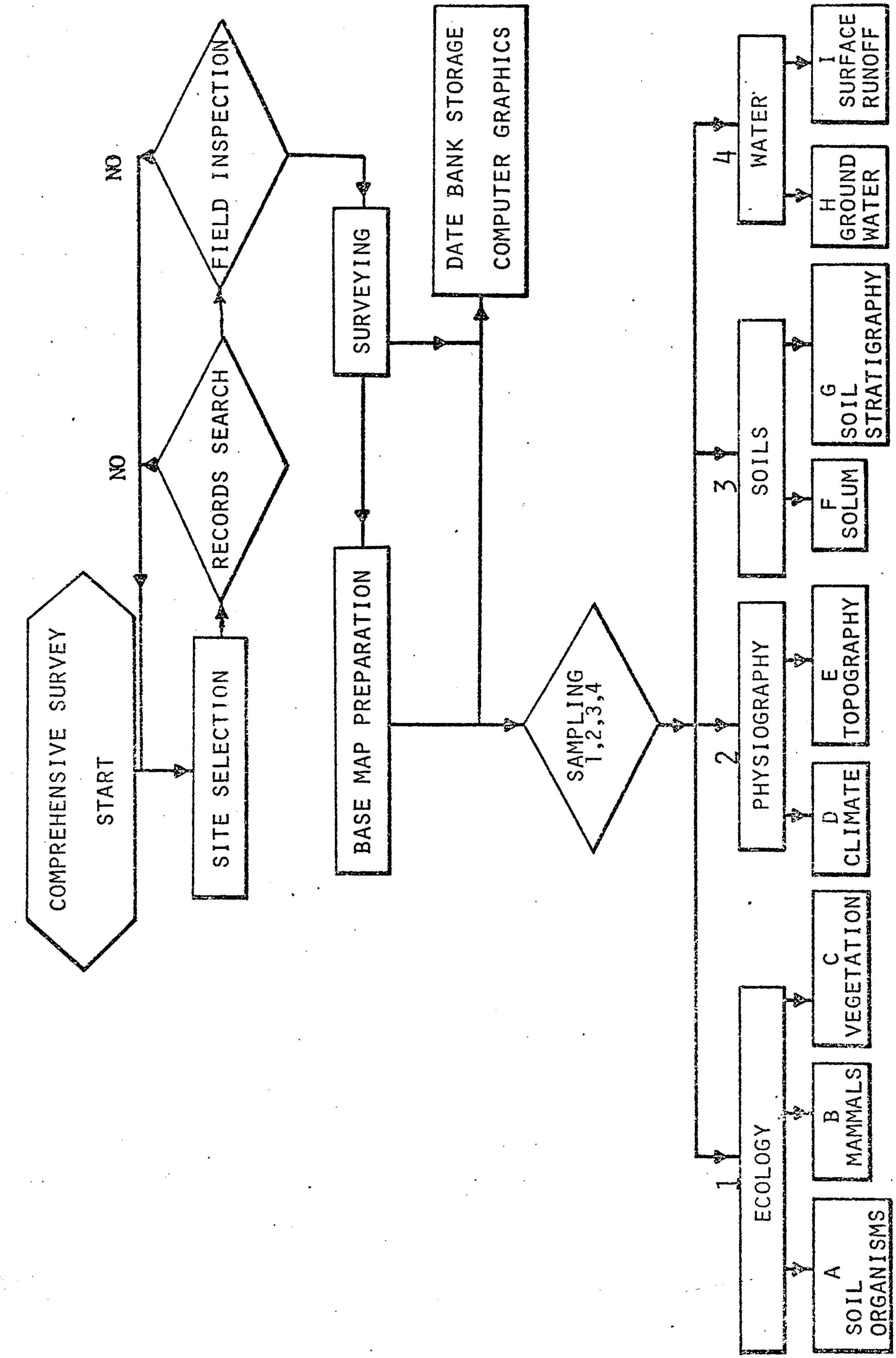
In several places on the Arsenal, the B horizon does not occur; and the soils grade directly from the A to the C horizons. This usually occurs in younger, poorly developed azonal soils. In order to avoid missing data for sites where horizons are absent, all sampling will consistently be taken at uniform depths predetermined to coincide with the soil profile horizons. These depths are given in the schematic illustrating the sampling scheme for a typical boring. Two water samples will be collected at each drill one, one approximately three feet below the water table leve, the other at bedrock surface.

Numerical Analysis and Mapping

Each of the contaminants will be mapped individuall for each of the six horizons sampled, thus providing a three-dimensional view of the contaminant distribution. The maximum concentration encountered at each site will also be mapped to show a plain view of the highest levels occurring on the Arsenal.

Principal component factor analysis will be peformed to determine the correlations and behavior of the contaminants as groups or associations. The information will be obtained from the factor loadings, which will identify new groupings indicating that new pollution plumes were encountered. The maps of the factor scores for each of the factors will provide insight on the spatial distribution of each of the contaminant groups individually and will serve to identify the location and direction of the plume, thus indicating where the next sampling cluster is to be positioned. Factor analysis of the total set of variables will, through the correlation coefficient, provide the linkage web between the contaminants and the physical ecosystem.

The relationships and the linkages will be mappable through the factor scores. Multivariate discriminate analysis, using the factor scores as surrogate weights, will serve as a comparison of similarity and differences between different regions representing either, different contaminated areas of different source areas. The multivariate disciminant function can also serve as a model for simulation.


COMPREHENSIVE SURVEY
START
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1
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2
PHYSIOGRAPHY
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CLIMATE
E
TOPOGRAPHY
3
SOILS
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SOLUM
G
SOIL STRATIGRAPHY
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WATER
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GROUND WATER
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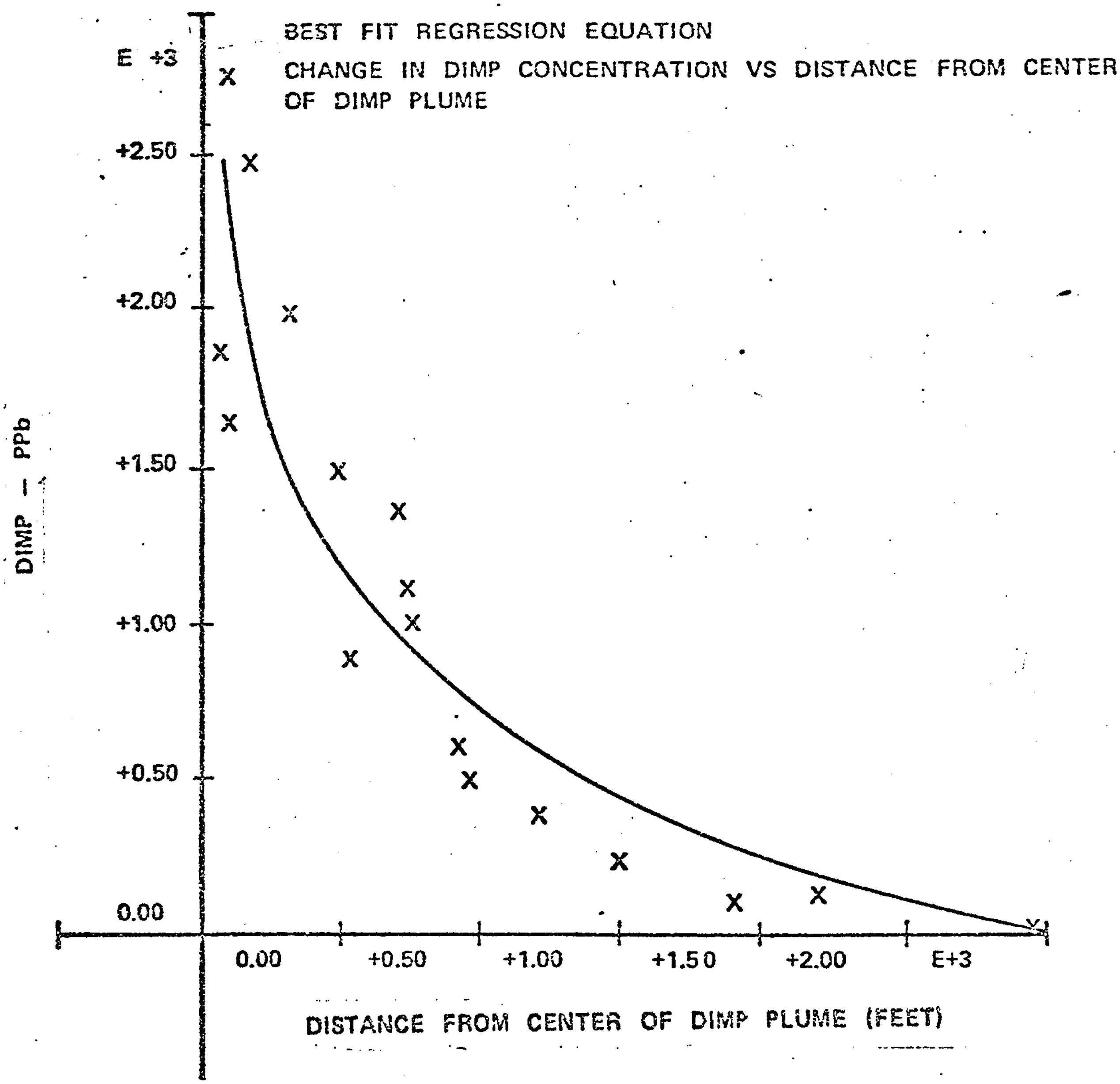
SURFACE RUNOFF

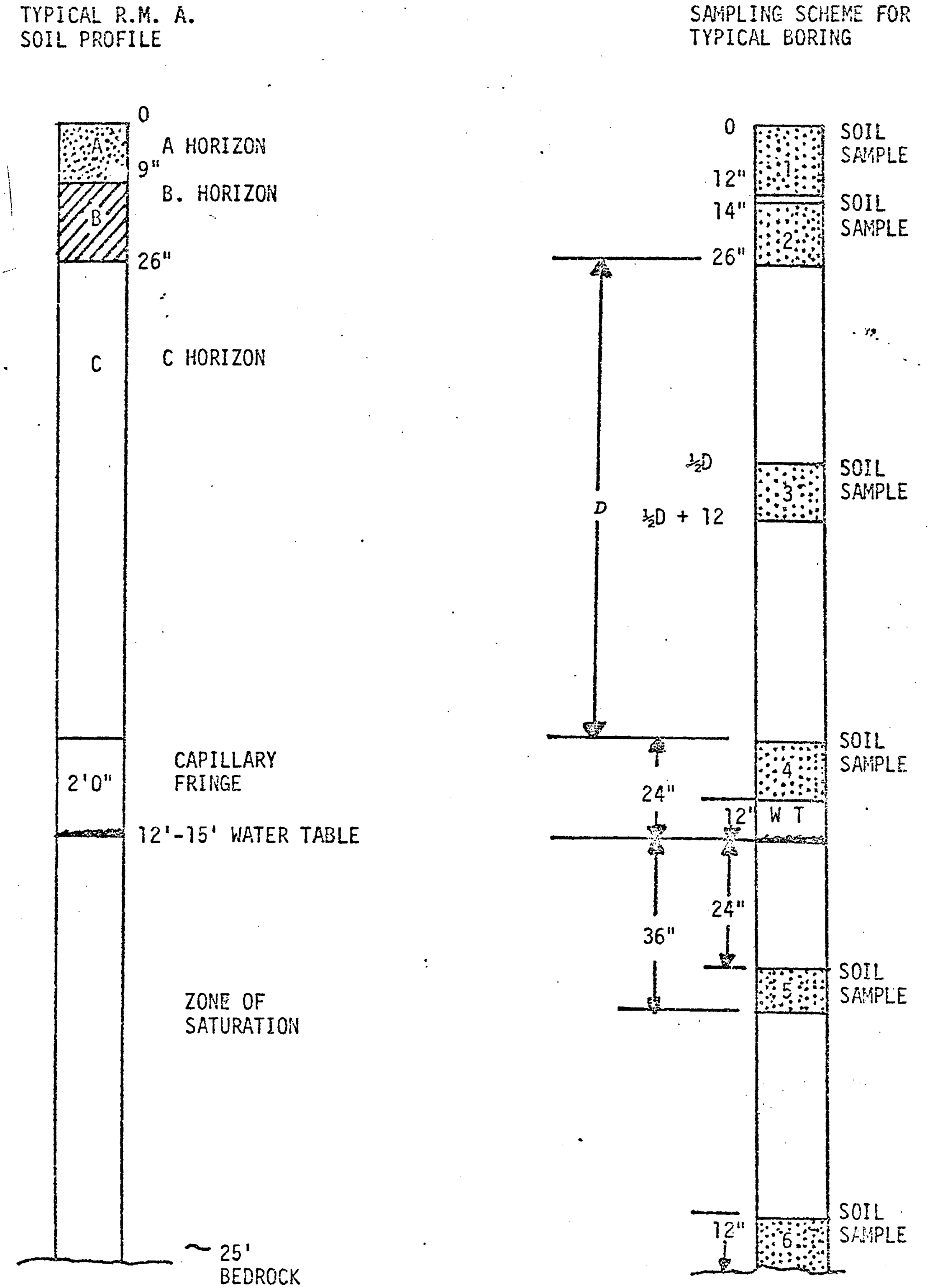
Figure 14b




$Y = A + B * LOG(X)$
$A = 5237.70561151$
$B = -654.921197714$
R-SQUARE = 0.811366280354
RES ERROR
145731.828112
MAX(ABS(RESIDUAL))
651.29042082

DIMP CONCENTRATIONS IN RELATION TO CENTER OF PLUME

Figure 15




SOIL PROFILE AND SAMPLING POSITIONS

Figure 16