EPA/X00/X-99/XXX
July 1999

Communication Manhole Water Study:
Characteristics of Water Found in Communications Manholes

By

Robert Pitt and Shirley Clark
Department of Civil and Environmental Engineering
University of Alabama at Birmingham
Birmingham, AL 35294

July 13, 1999

OFFICE OF WATER
U.S. ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C.

Notice

(Preliminary)

The development of this document has been funded wholly or in part by Telcordia, Inc, NYNEX, Bell Atlantic, BellSouth, SNET, GTE, Pacific Bell, Ameritech, U.S. West, and AT&T to the University of Alabama at Birmingham. Although it has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document, it does not necessarily reflect the views of the Agency and no official endorsement should be inferred. Also, the mention of trade names or commercial products does not imply endorsement by the United States government or the project sponsors.

Foreword

Acknowledgements

Many individuals helped carry out this project. Graduate student researchers at the University of Alabama at Birmingham who participated on this characterization project included: Jennifer Harper, Janice Lantrip, Christy Nix, Tim Roberts, Jay Day, and Olga Mirov. Dr. Keith Parmer was instrumental in helping develop special methods to effectively analyze the many different types of samples. In addition, Nayela Khan and Erica Rodgers, summer interns in the NIH/NCRR program also assisted with the project. Thanks are also extended to the many telephone company employees and their consultants who collected the samples from the communication manholes throughout the country for shipping to UAB for evaluation.

Abstract

Before a communication technician enters a manhole, industry practices and OSHA regulations require an inspection of any existing water for possible abnormal conditions. If the water is found suitable for discharge, the technician will pump the water from the manhole, typically using a small submersible device to the storm drain inlet. If the water is not suitable for discharge, a qualified waste vendor is used for removal and disposal in accordance with applicable environmental regulatory requirements. When these special handling procedures are needed, they significantly slow down the repair of telecommunications equipment, thus impacting the public's use of the communications network for emergencies and other essential services. With the increasing concern of the quality of water discharged to the environment, nine major communication companies (Ameritech, AT&T, Bell Atlantic, NYNEX, BellSouth, GTE, Pacific Bell, SNET and U S WEST) sponsored this research project through Telcordia Technologies (previously Bellcore, Inc.) to examine the quality of water found in communication manholes. The major objective of this activity was to identify actual conditions found in manholes and to identify possible predictive methods to better indicate problematic conditions in manholes. The work performed under this project task provides scientific research from the University of Alabama at Birmingham (UAB) on the f characterization of water found in communication manholes.

Almost 700 water samples and about 350 sediment samples from telecommunication manholes were analyzed over a three-year period, representing major land use, age, season, and geographical factors from throughout the U.S. The samples were analyzed for a wide range of common and toxic constituents. This data was evaluated using exploratory data analyses, simple and complex comparison tests, and model building. These complimentary procedures produced supporting information used to examine specific relationships between these main factor categories and other manhole characteristics.

In general, the water in manholes was found to be similar in constituent characteristics to stormwater and snowmelt runoff. Geographical area had the most effect on the data observations, while land use, season, and age influenced many fewer parameters. The most obvious relationship was found for high dissolved solids and conductivity associated with winter samples from snowmelt areas. The high winter concentrations slowly decreased with time, with the lowest concentrations noted in the fall. Another important observation was the association between zinc and toxicity. Samples from manholes located in older area generally had larger zinc concentrations than other samples. Other constituents (especially nutrients and pesticides) were found to have higher concentrations in water collected from manholes in newer residential areas. Very few organic toxicants (phthalate esters, PAHs, and pesticides) were found in the water samples, but about 10 to 25% of the sediment samples had relatively large concentrations of organics. Bacteria analyses indicated some relatively high bacteria counts in a small percentage of the samples. Bacteria were found in lower amounts during sampling periods that were extremely hot or extremely cold.

The data were used to develop and test predictive equations based on site conditions. These models were shown to be valid for most of the data, but the highest concentrations (those of most interest) were not well predicted. Therefore, special comparisons of many site conditions were made for the manholes having water with the highest concentrations of critical constituents for comparison to the other locations. The problem manholes were found for all areas of the country and for most rain conditions. Water clarity and color, along with sediment texture, were found to be significant factors associated with high concentrations in the water, while land use was also noted as a significant factor. These factors can be used to help identify manholes having potential problems, but the rates of false positives and false negatives were found to be high. Therefore, these screening criteria can be used to identify

the most likely problematic manholes, but other methods may also be needed to manage those that could not be identified using these simpler methods.

Contents

1 Summary

1.1 Background

This report addresses the discharge of water found in communication manholes. It represents a statistically designed survey program to describe the quality of water found in manholes.

Communication cables are dispersed throughout the United States in above and below ground structures. Utility poles support aerial communication plant while manholes and conduits support the major underground components of the public communications network. Direct buried plant is generally representative of newly built residential area and is the last link in the network. Each part of a communication network is a critical component to providing quality service to customers. A communication network starts at a strategically located Central Office (CO) building from which multiple communications cables are generally dispersed through an underground pathway of conduits linked by manholes. A CO's function is to provide switching services to customers residing in its geographic area and to connect its customers incoming and outgoing calls.

Underground facilities are designed to provide non-intrusive pathways from COs to points along the network that distribute services to residential customers, to large business customer locations, to government offices and public institutions (including police, fire and other emergency services) and to adjacent COs. Manholes augment the placing and the maintenance of communication plant by providing technicians access to locations with key components along a cable route. Manholes and associated underground facilities also provide the communications infrastructure and network components protection from inclement weather, vandalism, motor vehicle impacts and other hazardous conditions. With the exception of a manhole cover, underground facilities are hidden from public view, and are therefore less disruptive to the public. Although an underground infrastructure of manholes and conduits is traditionally employed in urban environments, it is sometimes used in suburban and rural settings to facilitate the distribution of cables supporting the backbone of network architectures.

Manholes are not designed to eliminate all water from entering the space. The location and physical characteristics of these structures make it very difficult to prevent water intrusion. Surface water run-off and ground water hydrology conditions greatly influence the possibility of water entering a manhole. Industry practices require the proper sealing of underground cable plant to minimize water intrusion. Moisture entering the telephone plant (cable or splice cases) quickly leads to permanent physical damage and potential multiple service outages. If industry practices are correctly followed, the plant can withstand a submerged water environment.

Before a communication technician enters a manhole, industry practices and OSHA regulations require a combustible gas test and then an inspection of any existing water for possible abnormal conditions (e.g. surface oil sheen or strong sewage odors). If the water is found suitable for discharge, the technician will pump the water from the manhole typically using a small submersible device. If the water is not suitable for discharge, a qualified waste vendor is used for removal and disposal in accordance with applicable environmental regulatory requirements. When these special handling procedures are needed, they significantly slow down the repair of telecommunications equipment, thus impacting the public's use of the communications network for emergencies and other essential services.

These manhole entry procedures have been in effect for almost 50 years. However, with the increasing concern of the quality of water discharged to the environment, nine major communication companies (Ameritech, AT&T, Bell

Atlantic, NYNEX, BellSouth, GTE, Pacific Bell, SNET and U S WEST) sponsored this study through Telcordia Technologies (previously Bellcore, Inc.). The work performed under this project will provide scientific research from the University of Alabama at Birmingham (UAB) on the characterization of water found in communication manholes.

1.2 The Study's Objectives

The objectives of this study were to: 1) evaluate and characterize water found in communication manholes, and 2) evaluate relationships with the immediate environment.

1.2.1 Method

An extensive field sampling survey was conducted to characterize the quality of the water and sediment found in manholes. It should be noted that sediment found in manholes is generally tested before it is removed and handled by a qualified waste vendor. This report briefly summarizes the research project objectives, along with the data from these collected samples. These analyses represent typical manhole conditions and generally do not include manholes known to have obvious water quality problems that require "special handling" under current industry practices.

Almost 700 water samples and about 350 sediment samples from telecommunication manholes were analyzed over a three-year period, representing major land use, age, season, and geographical factors from throughout the U.S. The samples were analyzed for a wide range of common and toxic constituents, including many filtered samples to indicate the partitioning of the pollutants of most concern. This data was evaluated using exploratory data analyses, simple and complex comparison tests, and model building. These complimentary procedures produced supporting information used to examine specific relationships between these main factor categories and other manhole characteristics.

1.2.2 Findings

In general, the water in manholes was found to be similar in constituent characteristics to stormwater and snowmelt runoff. Geographical area had the most effect on the data observations, while land use, season, and age influenced many fewer parameters. The most obvious relationship was found for high dissolved solids and conductivity associated with winter samples from snowmelt areas. The high winter concentrations slowly decreased with time, with the lowest concentrations noted in the fall.

Another important observation was the common association between zinc and toxicity. Samples from manholes located in older area generally had larger zinc concentrations than other samples. No overall patterns were observed for zinc concentrations in sediment samples obtained from manholes. Other constituents (especially nutrients and pesticides) were also found to have higher concentrations in water collected from manholes in newer residential areas. Very few organic toxicants (phthalate esters, PAHs, and pesticides) were found in the water samples, but sediment sample organic toxicant concentrations appeared to be well correlated to sediment texture and color. About 10 to 25% of the sediment samples had relatively large concentrations of organics.

Bacteria analyses indicated some relatively high bacteria counts in a small percentage of the samples. Bacteria were found in lower amounts during sampling periods that were extremely hot or extremely cold. Pacific Northwest samples also had the lowest bacteria counts.

The data were used to develop and test predictive equations based on site conditions. These models were shown to be valid for most of the data, but the highest concentrations (those of most interest) were not well predicted. Therefore, special comparisons of many site conditions were made for the manholes having water with the highest concentrations of critical constituents for comparison to the other locations. About half of the water samples having the highest concentrations were repeated samples from the same locations (after complete pumping), but at different seasons, indicating continuous problems and not discrete incidents (except for high dissolved solids which were clearly seasonal). In addition, the problem manholes were found for all areas of the country and for most rain conditions. Water clarity and color, along with sediment texture, were found to be significant factors associated with high concentrations in the water, while land use was also noted as a significant factor. These factors can be used to help identify manholes having potential problems, but the rates of false positives and false negatives were found to be high. Therefore, these screening criteria can be used to identify the most likely problematic manholes, but other methods may also be needed to manage those that could not be identified using these simpler methods.

Another project task involved examination and evaluation of commercially available field test kits that may be used to identify water quality issues of concern (presented in a companion report). This survey found that most all commercially available water screening kits did not meet field requirements including such parameters as accuracy, precision, speed, and the ability to operate under variable and hostile field conditions. The water screening test kits would be subject to an outside environment that at times is harsh and demanding. With weather conditions in many areas ranging from below freezing in the winter to hot humid temperatures in the summer, a robust kit is required. The screening test kits also needs to be transported and stored in communication industry vehicles that were designed to carry tools and materials and do not have specific environmental control working areas or are fully shielded from the elements. In addition, field technicians may lack the expertise required to appropriately operate many of the water screening kits that require the use of highly toxic chemicals. The many commercial field water-screening kits surveyed in this project were found to be inadequate to meet the needs of a communication company’s water testing program.

1.3 Conclusions

The following paragraphs briefly present the basic conclusions obtained from this research effort in characterizing water found in communication manholes and in evaluating screening test kits that could be considered for field evaluations of this water before it is pumped during maintenance and repair operations.

1.3.1 Effects of Discharges of Water from Manholes

- In almost all cases, the water discharged from manholes is expected to have a minimal effect on the environment.

Dissolved solids were the most common constituent found in high concentrations during our research. The high concentrations were caused by snowmelt water flowing into the manholes during snowmelt events, and by salt contaminated groundwater infiltrating into manholes during other times. The most likely discharge location for water from pumped manholes is to a storm sewer system where discharge limits are not clearly defined. Pumped water from communication manholes accounts for a very small volume (generally about 1,000 to 1,500 gallons per pumping operation) compared to snowmelt water and receiving water flows. Therefore, the discharge of this water shouldn’t cause a problem, unless it is discharged during times when the receiving water has recovered from the snowmelt period and when the receiving water flows are extremely low and numerous manholes are being pumped simultaneously.

The following summary presents the human health and aquatic health criteria for pollutants that may be present in waters from manholes. These are receiving water criteria and are not applicable to a “discharge”. In the absence of site specific receiving water studies, which are not practical for consideration here, these can be used as a likely worst-case, conservative, limitation for discharge restrictions. If the discharge meets the receiving water use criteria, then it does not consume any of the assimilative capacity of the receiving water and can not limit the waters’ use. Most of the criteria are expressed with a recommended exceedence frequency of 3 years. This is the EPA’s best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to the pollutant exceeds the criterion. A stressed system, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery.

The following paragraphs on the effects of pollutants on aquatic life and human health are summarized from the U.S. EPA's *Quality Criteria for Water, 1986* (EPA 1986), and updates from the EPA's Internet site. This discussion stresses these published criteria as an indication of the magnitude of the worst-case, conservative, limitation for discharge restrictions. Besides the criteria, the following discussion presents the likelihood of water samples collected from manholes exceeding these numeric criteria.

1.3.1.1 Dissolved solids

The average total dissolved solids (TDS) levels in water samples collected from telecommunication manholes was 471 mg/L. The maximum level observed was 33,000 mg/L (NYNEX, winter). The median conductivity level was 710 µS/cm. The maximum observed conductivity was 44,000 µS/cm (also NYNEX, winter). These maximum observed concentrations are all quite high, and were adversely affected by snowmelt water. It is likely that most winter and spring water samples from areas using de-icing chemicals will have adverse concentrations of these parameters. Subsequent water samples (after complete pumping) had substantially lower concentrations, but were still high, likely from infiltration of salt contaminated shallow groundwaters. Because of the likely groundwater contamination by the deicing salts, the urban receiving waters probably also have elevated dissolved mineral concentrations from groundwater recharge.

The highest TDS values occurred in the winter and dropped with the following seasons, to reach lows in the fall. EPA rain regions 1 and 3 had the highest TDS values, while regions 5 and 7 had the lowest values. About 45% of all samples exceeded the 500 mg/L TDS criterion. Therefore, the dissolved mineral concentrations would frequently exceed this value, especially when manholes are first pumped after the snowmelt season in areas having deicing controls.

1.3.1.2 Turbidity

The observed median suspended solids concentration in the water samples from communication manholes was only 19 mg/L, while the maximum concentration was 3,500 mg/L. The overall median turbidity value was 6.5 NTU, while the peak turbidity was 2,100 NTU. Turbidities in the filtered samples were generally about 0.1 to 0.5 of the values found in the unfiltered samples. The highest turbidity levels were from the summer fall season samples from EPA rain region 1, especially from mid-aged and older residential areas. Slightly more than 10% of the turbidity values exceeded the 50 NTU ("above background") criterion.

1.3.1.3 pH

The observed median pH condition of water samples collected from communication manholes was 7.6. The extreme values were as low as 5.8 (NYNEX spring) and as high as 9.4 (BellSouth summer). Older residential areas had the highest pH values observed, while all older areas had the lowest pH values observed, most in EPA rainfall zones 1 and 2. About eleven percent of the samples were outside of the desirable range of 6.5 to 9.0.

1.3.1.4 Ammonia

The observed median ammonia concentration from water found in communication manholes was 0.03 mg/L, while the maximum concentration observed was 45 mg/L and the 90th percentile was 0.29 mg/L. The very high value was from a new commercial area during the winter in EPA rainfall zone 1. This rainfall zone also had most all of the other very high ammonia values observed.

The ammonia criteria is dependent on pH and temperature. At 30°C and at a pH of 9.0 (possible water conditions in manholes), the associated ammonia criterion is 0.82 mg/L. The median value was much less than this value, less than 5% of all observations were greater than this value.

1.3.1.5 Nitrate

The observed median nitrate concentrations from the water samples collected from telecommunication manholes was 0.9 mg/L, while the peak concentration was 196 mg/L (an unusually high concentration, the 90th percentile concentration was only 2.8 mg/L). The high values were from EPA rainfall zones 1 (winter and fall) and zone 3 (summer). Most of the other observations were all less than 10 mg/L. Only 1% of the samples exceeded the 10 mg/L criterion.

1.3.1.6 Phosphate

The overall median phosphate concentration observed in the water samples collected from the communication manholes was 0.13 mg/L. The maximum value observed was 19.2 mg/L. About 30% of all of the samples exceeded the 250 µg/L criterion. EPA rainfall region 3 had the highest observed values, all from the same manhole, located in an older residential area, during each season (all other phosphate observations in this zone were less than 1 mg/L), while manholes in zone 1 also had high values, especially during the winter and summer.

1.3.1.7 *E. coli* and enterococci

Microorganism conditions were not monitored in the initial water samples collected from the communication manholes. However, *E. coli* and enterococci were monitored during the later samples. The median values were about 5 organisms per 100 mL for both species, while the maximum counts observed exceeded the limits of the test (>2420 organisms per 100 mL). The *E. coli* and *Enterococci* water contact criteria (576 and 151 organisms per 100 mL, respectively) were esceeded by about 5% of the samples for E. coli and about 15% of the samples for enterococci.

1.3.1.8 Copper

The average median total copper concentrations from water samples collected from communication manholes was 8 µg/L. The maximum total copper concentrations observed was 1360 µg/L. The filtered copper concentrations are about 0.1 to 0.5 of the total copper concentrations. The critical acute criterion (one-hour exposure) for copper is about 50 µg/L for freshwater aquatic life, for the very hard water conditions found in manholes. This criterion was exceeded in about 12% of all water samples. The highest values observed were from EPA rainfall zones 1 and 3, especially from older residential areas.

1.3.1.9 Lead

The observed median total lead concentrations in water samples from telecommunication manholes was 5 µg/L, while the peak concentration was 808 µg/L. The older sites had the highest concentrations, especially located in EPA rainfall zones 6, 3, and 1. The one-hour averaged acute criterion for lead at the high hardness levels found in the water samples from manholes is about 200 µg/L, with only about 1% of the samples exceeding this criterion. The lead concentrations in the filtered water samples are about 0.2 to 0.5 of the concentrations in the unfiltered samples.

1.3.1.10 Zinc

The observed median total zinc concentration in water samples from telecommunication manholes was 350 µg/L, while the peak concentration was greater than 20,000 µg/L. About 25% of the unfiltered samples exceeded the acute, 1-hr averaged, criterion for aquatic life (about 700 µg/L) for the very hard water conditions found in the manholes, and about 17% of the filtered samples exceeded this criterion. All areas periodically experienced high zinc levels in the water samples from the manholes.

1.3.1.11 Pesticides (heptachlor, endosulfan, endrin, and methoxychlor)

None of the base-neutral organics (PAHs and phthalate esters) were observed in levels approaching any water quality criterion, while the pesticides heptachlor, endosulfan, and endrin would likely exceed existing guidance whenever they are observed, while some of the methoxychlor detections may be relatively high. Only a few percent of all samples had detectable levels of pesticides.

1.3.2 Sources of Water in Manholes

- The water discharged from communications industry manholes is similar in quality to settled stormwater and to snowmelt runoff.

The most likely potential source of the water found in communication manholes is in-flowing stormwater and snowmelt water. Some manholes are also periodically affected by sanitary sewage and other groundwater contaminants entering the manholes by infiltration. Besides the high dissolved solids content of the snowmelt water, high concentrations of lawn maintenance fertilizers (especially phosphate) from runoff at new residential areas also affect some manholes. Also, periodic high bacteria levels (and the presence of chemical tracers) indicate sewage contamination in a small fraction of the manholes.

The most important constituent having high concentrations that may be associated with internal operations in the manholes is zinc (both in total and filtered forms). The source of the zinc is likely associated with galvanized metal use in the manholes (ladders, cable supports, etc.)

1.3.3 Use of Field Screening Test Kits and Indicating Parameters

- Past research indicates that screening kits are unreliable, not cost effective, and have restricted use in an outside plant environment. Current technology is limited and often requires a substantial degree of knowledge to take valid measurements. In addition, There are no key simple predictive parameters that positively indicate the quality of water found in communication manholes.

Commercially available water screening kits designed for field analyses did not meet the minimum requirements for use on utility vehicles. Screening test kits were evaluated for safety (lack of hazardous chemicals and waste products), accuracy, precision, speed, and the ability to operate under variable and hostile field conditions. Many kits also failed because of demanding storage conditions that would not be available on these vehicles. The time needed to evaluate water samples would also be long for many of the otherwise suitable methods, making emergency repairs difficult.

It would be difficult to select a set of analyses to adequately directly measure the problems that may be encountered in manholes. The companion report recommended the use of chemical tracers to indicate sanitary sewage contamination (detergents, fluorides, ammonia, and potassium, along with currently used gas analyses and visual observations). In addition, the analysis of conductivity (to indicate high dissolved solids), phosphates, and zinc should be added as these were frequently in high concentrations. Unfortunately, the only available kits for some of these parameters are extremely hazardous. The available detergents kits all use organic solvents (benzene or chloroform) for field extractions, and all zinc kits use strong solutions of cyanide. It was concluded that these two critical tests could not be recommended for use, except for the most highly trained personnel under much more controlled conditions than exist in the field during emergency repairs. In addition, kits that can adequately detect pesticide concentrations at suitable levels are also extremely complex and have critical storage requirements. Several of the most promising field procedures were also quite expensive.

Statistical analyses of the water quality data and site parameters identified factors that could be partially helpful to identify potentially problem conditions. Water clarity and water color, along with sediment texture, were found to be significant factors associated with the high concentrations, while land use was also noted as a significant factor. These factors can be used to help identify manholes having potential problems, but the rates of false positives and false negatives would be high.

2 Experimental Design Features for Characterizing Water from Communication Manholes

This report section summarizes the basic elements used to design the field monitoring activities to examine water and sediment quality in telecommunications manholes. Topics covered include selecting the specific experimental design for the measurements and determining the sampling effort. Important references that should be consulted for additional information on experimental design include *Statistical Methods for Environmental Pollution Monitoring* (Gilbert 1987) which contains a good summary of sampling designs and methods to identify trends, unusual conditions, etc., and *Statistics for Experimenters* (Box, *et al*. 1978) which contains detailed descriptions of basic statistical methods for comparing experimental conditions and model building.

When conducting a water quality investigation, several basic questions must be addressed, such as:

- where to sample?
- what to sample?
- how to sample?
- what analytical techniques should be used?
- how many samples are needed?
- how to analyze the data?

This report addresses all of these topics.

An effective experimental design includes both the strategy (sampling plan) that best fits the objectives of the investigation and a determination of the magnitude of the sampling effort. When the experimental design is adequately done, the statistical analysis procedures should be straight-forward. However, there is usually a need to conduct some exploratory data analysis using available data in order to obtain various parameter information needed for the designed sampling activities (distribution type and variation, plus obvious influencing factors, or example).

The main objectives of most environmental monitoring studies may be divided into two general categories: characterization, and/or comparisons. Characterization pertains to quantifying a few simple attributes of the parameter of interest, such as investigating the concentration of copper in sediment. The most important question would be “What is the most likely concentration of the copper?” Other questions of interest include differences in the copper concentrations between different sampling locations or seasons. These additional questions are considered in the second category, namely comparisons. Other comparison questions may concern relating the observed copper concentrations with criteria or standards.

The following list is a simple outline of a typical experimental design sequence:

- Clearly define the objectives (state the hypothesis to be tested, define the equation or model to be used, etc.).
- Estimate the time and space variabilities of the parameters of interest (assumed, based on prior knowledge, or other methods).
- Collect information on the physical conditions of the system to be studied (manhole construction characteristics, surrounding landuse, etc.).

- Determine sampling plan (strata and relationships that need to be defined).
- Determine the statistical procedures that will be used to analyze the data (including field data sheets and laboratory QA/QC plan).
- Determine the number of samples needed (when and where, with budget restraints).
- Determine sampling specifics (volumes, bottle types, preservatives, samplers to be used, etc.).
- Carry out the sampling effort.
- Evaluate the data.

The most important aspect is being able to write down the study objectives and why the data is needed. The quality of the data (accuracy of the measurements) must also be known. Allowable errors need to be identified based on how the information will change a conclusion. Specifically, how sensitive is the data that is to be collected in defining the needed answer?

Box, *et al*. (1978) contains much information concerning sampling strategies, specifically addressing problems associated with randomizing the experiments and blocking the sampling experiments. Blocking (such as in paired analyses to determine the effectiveness of a control device, or to compare upstream and downstream locations) eliminates unwanted sources of variability. Another way of blocking is to conduct repeated analyses (such for different seasons) at the same locations. Most sampling strategies should include randomization and blocking within the final sampling plans.

Based on the objectives and constraints of the telecommunication manhole water and sediment study, stratified random sampling from homogeneous groups was selected. The goal is to define strata that results in little variation within any one strata, and great variation between different strata. Samples are randomly obtained from several population groups that are assumed to be internally more homogeneous than the population as a whole, such as stratifying the water and sediment quality data associated with telecommunication manholes by geographical area, season and land use. This results in the individual groups having smaller variations in the values of the characteristics of interest than in the population as a whole. Therefore, the total sample effort may be less than if the complete population was sampled as a whole. In addition, much additional useful information is likely if the groups are shown to actually be different.

The collected data will also be organized using factorial designs. Repeated measures to the same telecommunication manholes for different seasons will also be done to minimize any inadvertent differences. Simple paired analyses will also be used to contrast the results from the different sample categories. Appendix A contains the decision procedure that was used to select the most desirable experimental design (using the microcomputer program *Designer Research*, from Idea Works, Inc., Columbia, MO). The main features of the selected experimental design includes the following:

- two-level factorial design (two categories, at least, for each variable: age, land use, season and geographical location)
- repeated measures (evaluate manholes for different seasons) to remove independent differences
- manholes will be randomly selected from each strata
- sufficient manholes will be sampled to measure the uncertainties associated with the measurements

3 Summary of Sampling Effort and Strategy

Objectives: The objective of these measurements was to characterize water and sediment found in telecommunication manholes. Important variables affecting the quality of these materials were also identified.

Estimate the time and space variabilities of the parameters of interest: The variabilities (expressed as the coefficient of variability, or COV) of the sediment and water quality parameters were expected to be between 0.5 and 1.0.
Collect information on the physical conditions of the system to be studied: The factors of most interest are season, land use, age, and geographical (rainfall) area. In addition, the field sheet included much additional information of potential interest.

Determine sampling plan and statistical procedures: A stratified random sampling design was followed, with the data organized in a full 2^4 factorial design, with repeat sampling of the same manholes for each season. If a manhole could not be sampled for one season (such as being dry), then another in the same sampling strata was substituted for that season (with an appropriate notation on the field sheet).

Determine the number of samples needed: The goal for the minimum number of samples per strata was 10. This number will enable us to determine the errors associated with the results, which is expected to be less than 25%. In addition, this level of effort enabled comparison tests to be made outside of the factorial design.

3.1 Factorial Experimental Designs

Factorial experiments are described in Box, *et al*. (1978) and in Berthouex and Brown (1994). Both of these books include many alternative experimental designs and examples of this method. Berthouex and Brown (1994) state that "experiments are done to:

1) screen a set of factors (independent variables) and learn which produce an effect,
2) estimate the magnitude of effects produced by experimental factors,
3) develop an empirical model, and
4) develop a mechanistic model."

They concluded that factorial experiments are efficient tools in meeting the first two objectives and are also excellent for meeting the third objective in many cases. Information obtained during the experiments can also be very helpful in planning the strategy for developing mechanistic models. The main feature of factorial experimental designs is that they enable a large number of possible factors that may influence the experimental outcome to be simultaneously evaluated. Even though factorial experiments are best known for their use in controlled laboratory settings, they have also been very useful in organizing environmental data for analysis (Pitt 1987).

Box, *et al.* (1978) present a comprehensive description of many variations of factorial experimental designs. A simple 2^3 design (three factors: temperature, catalyst, and concentrations at two levels each) is shown in Figure 3-1 (Box, *et al.* 1978). All possible combinations of these three factors are tested, representing each corner of the cube. The experimental results are placed at the appropriate corners. Significant main effects can usually be easily seen by comparing the values on opposite faces of the cube. If the values on one face are consistently larger than on the opposite face, then the experimental factor separating the faces likely has a significant effect on the outcome of the experiments. Figure 3-2 (Box, *et al.* 1978) shows how these main effects are represented, along with all possible two-factor interactions and the one three-factor interaction. The analysis of the results to identify the significant factors is straight-forward. One of the major advantage of factorial experimental designs is that the main effect of each factor, plus the effects of all possible interactions of all of the factors, can be examined with relatively few experiments. The initial experiments are usually conducted with each factor tested at two levels (a high and a low level). All possible combinations of these factors are then tested.

Table 3-1 shows the basic experimental design that was used for this study. Four major factors were examined: season, geographical area, age, and land use. These tests therefore require 2^4 (=16) separate data collection/organization strata to examine the main effects and all possible interactions of these four factors. The signs on the table signify the experimental conditions for each main factor for each of the 16 strata. The shaded main factors are the experimental conditions, while the other columns specify the data reduction procedures for the other interactions. A plus sign shows when the factor is to held at the high level, while a minus sign signifies the low level for the main factors.

This table also shows all possible two-way, three-way, and four-way interactions, in addition to the main factors. Simple analyses of the experimental results allows the significance of each of these factors and interactions to be determined. The following list shows the four factors and example levels for tests conducted to identify factors affecting sediment and water quality in the telecommunication manholes:

A: Season (plus: winter; minus: summer)
B: Land Use (plus: commercial and industrial; minus: residential)
C: Age of Development (plus: old; minus: new)
D: Geographical Region (plus: high rain areas; minus: low rain areas)

In some cases, additional data was collected representing additional strata at some of the sampling areas when special conditions were being examined. For example, some of the study participants collected data during the spring and fall seasons and for other land uses.

The above four main factors would require the selection of four sampling strata in each geographical area:

1) old industrial/commercial area
2) new industrial/commercial area
3) old residential area
4) new residential area

The tests are designed to obtain sediment and water quality data from each of these four strata. Each strata will need to contain a sufficient number of measurements to obtain an adequate representation of the manhole characteristics of interest. In order to define the variation of the conditions in each strata, ten telecommunication manholes were sampled in each. As noted in the following subsection, ten samples per strata are expected to result in errors of less than 25 percent for most parameters of interest. The data analysis methods allow many other factors to be evaluated, based on the field form information. For example, paired analyses were conducted to examine the effects of the type of material found in the manholes, and the effects of obvious corrosion on sediment and water quality.

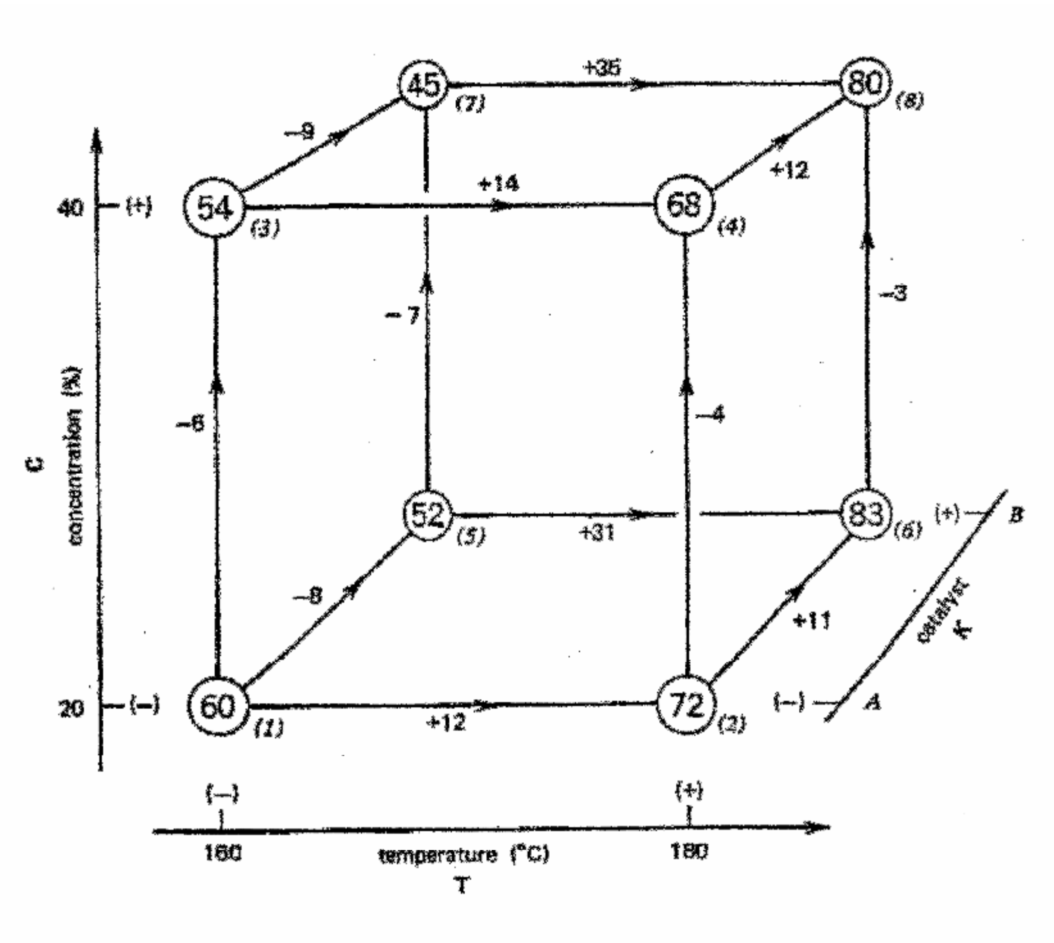


Figure 3-1 Basic Cubic Design of 2^3 Factorial Test (Box, *et al*. 1978)

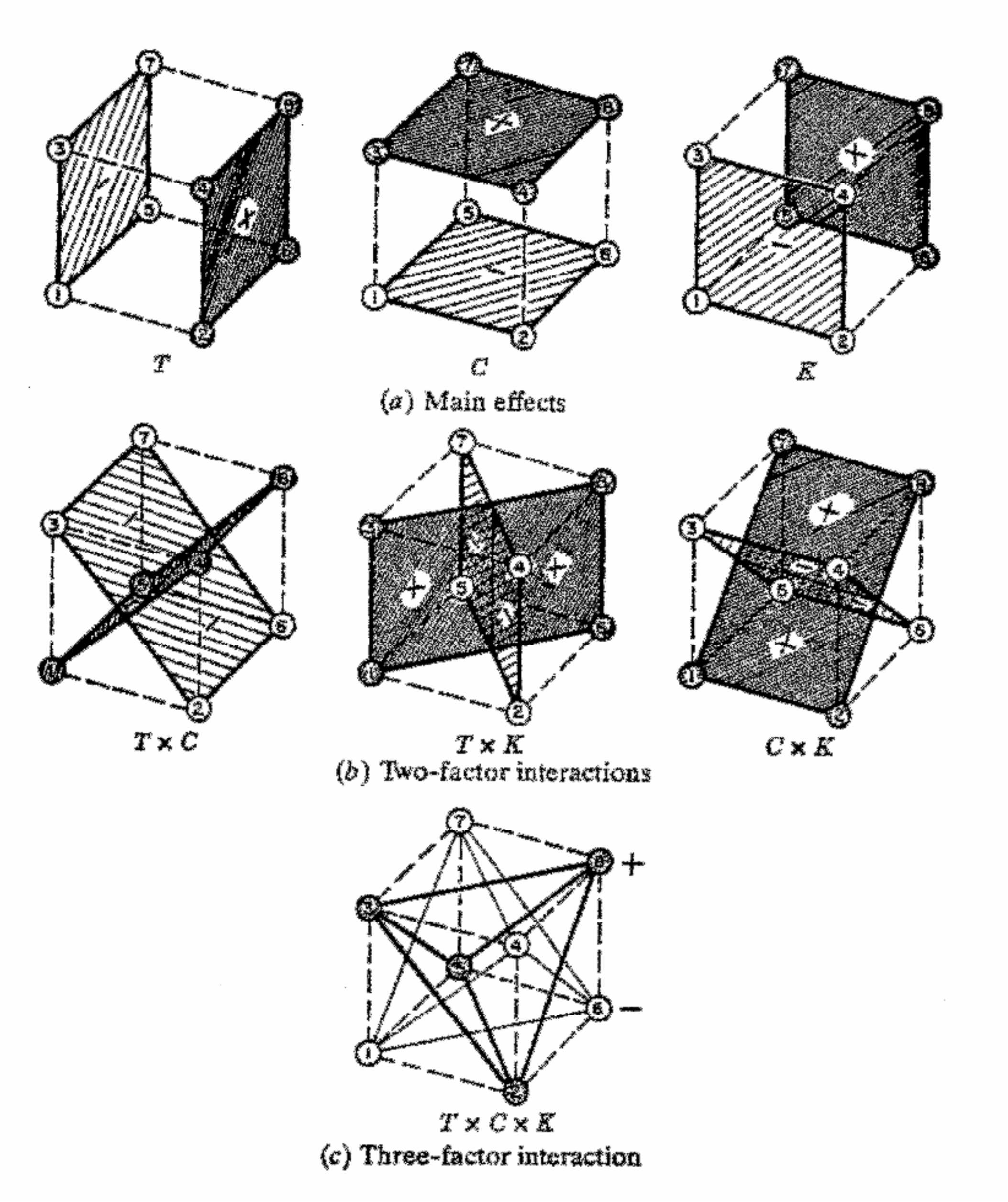


Figure 3-2 Main Effects and Interactions for 2^3 Factorial Test (Box, *et al*. 1978)

Table 3-1 Factorial Experimental Design for Four Factors and 16 Experiments

Experiment #	A	B	C	D	AB	AC	AD	BC	BD	CD	ABC	ABD	BCD	ABCD
1	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2	-	+	+	+	-	-	-	+	+	+	-	-	+	-
3	+	-	+	+	-	+	+	-	-	+	-	-	-	-
4	-	-	+	+	+	-	-	-	-	+	+	+	-	+
5	+	+	-	+	+	-	+	-	+	-	-	+	-	-
6	-	+	-	+	-	+	-	-	+	-	+	-	-	+
7	+	-	-	+	-	-	+	+	-	-	+	-	+	+
8	-	-	-	+	+	+	-	+	-	-	-	+	+	-
9	+	+	+	-	+	+	-	+	-	-	+	-	-	-
10	-	+	+	-	-	-	+	+	-	-	-	+	-	+
11	+	-	+	-	-	+	-	-	+	-	-	+	+	+
12	-	-	+	-	+	-	+	-	+	-	+	-	+	-
13	+	+	-	-	+	-	-	-	-	+	-	-	+	+
14	-	+	-	-	-	+	+	-	-	+	+	+	+	-
15	+	-	-	-	-	-	-	+	+	+	+	+	-	-
16	-	-	-	-	+	+	+	+	+	+	-	-	-	+

Replicate observations enhance the data analysis efforts and grouped standard error values can be calculated to identify the significant factors affecting runoff quality (Box, *et al*. 1978). Repeat sampling at the same locations enables seasonal changes to be best observed by removing inherent variations between different manholes. If samples cannot be obtained at a manhole for some of the needed conditions (such as a manhole being dry during the summer monitoring period), then another manhole in the same strata having water was sampled for that season, if possible, and the sampling sheet noted that a substitute was used.

Because of the usefulness and adaptability of factorial experimental designs, Berthouex and Brown (1994) recommend that they “should be the backbone of an experimenter’s design strategy.”

3.2 Experimental Design for Sample Collection Effort

An important aspect of any research is the assurance that the samples collected represent the conditions to be tested and that the number of samples to be collected are sufficient to provide statistically relevant conclusions. Because this study is interested in characterizing water quality data from telecommunication manholes, an experimental design process can be used that estimates the number of needed samples based on the allowable error, the variance of the observations, and the degree of confidence and power needed. A model that can be used (after Cameron, undated) is as follows:

$$n = [COV(Z_{1-\alpha} + Z_{1-\beta})/(error)]^2$$

where n = number of samples needed

α= false positive rate (1-α is the degree of confidence. A value of α of 0.05 is usually considered statistically significant, corresponding to a 1-α degree of confidence of 0.95, or 95%)

β= false negative rate (1-β is the power. If used, a value of β of 0.2 is common, but it is frequently ignored, corresponding to a β of 0.5)

$Z_{1-\alpha}$ = Z score (associated with area under normal curve) corresponding to $1-\alpha$. If α is 0.05 (95% degree of confidence), then the corresponding $Z_{1-\alpha}$ score is 1.645 (from standard statistical tables).

$Z_{1-\beta}$= Z score corresponding to $1-\beta$ value. If β is 0.2 (power of 80%), then the corresponding $Z_{1-\beta}$ score is 0.85 (from standard statistical tables). However, if power is ignored and β is 0.5, then the corresponding $Z_{1-\beta}$ score is 0.

Error = allowable error, as a fraction of the true value of the mean

COV = coefficient of variation, the standard deviation divided by the mean (Data set assumed to be normally distributed)

This equation is only approximate, as it requires that the data set be normally distributed. In most cases, water quality constituent concentrations are more closely log-normally distributed. However, if the coefficient of variation (COV) values are low (less than about 0.4), then there is likely no significant difference in the predicted sampling effort. Manhole water samples are generally expected to have COV values of greater values. Therefore, this equation is only appropriate as an approximation. However, the statistical procedures to be used to evaluate the data will consider the exact degree of confidence of the pollutant concentrations.

Figure 3-3 is a plot of this equation showing the approximate number of samples needed for an α of 0.05 (degree of confidence of 95%), and a β of 0.2 (power of 80%). As an example, if an allowable error of about 25% is desired (a reasonable goal) and the COV is estimated to be 0.4 (for the manholes in a specific community), then about 20 manholes would have to be sampled.

3.3 Number of Samples Needed for Comparisons between Different Sites or Times

The comparison of paired data sets is commonly used when evaluating the differences between two contrasting sampling strata (locations, seasons, land uses, geographical areas, manhole material, nearby traffic, etc.). An equation (Cameron, undated) that can be used to estimate the needed sample numbers for a paired comparison is:

$$n = 2 [(Z_{1-\alpha} + Z_{1-\beta})/(\mu_1 - \mu_2)]^2 \sigma^2$$

where: α = false positive rate ($1-\alpha$ is the degree of confidence. A value of α of is usually considered statistically significant, corresponding to a $1-\alpha$ degree of confidence of 0.95, or 95%)

β = false negative rate ($1-\beta$ is the power. If used, a value of β of 0.2 is common, but it is frequently

ignored, corresponding to a β of 0.5.)

$Z_{1-\alpha}$ = Z score (associated with area under normal curve) corresponding to $1-\alpha$

$Z_{1-\beta}$ = Z score corresponding to $1-\beta$ value

μ_1 = mean of data set one

μ_2 = mean of data set two

σ = standard deviation (same for both data sets, same units as μ. Both data sets are also assumed to be normally distributed.)

This equation is only approximate, as it requires that the two data sets be normally distributed and have the same standard deviations. Many water quality parameters are likely closer to being log-normally distributed. If the coefficient of variation (COV) values are low (less than about 0.4), then there is likely no real difference in the predicted sampling effort.

Figure 3-4 (Pitt and Parmer 1995) is a plot of this equation (normalized using COV and differences of sample means) showing the approximate number of sample pairs needed for an α of 0.05 (degree of confidence of 95%), and a β of 0.2 (power of 80%). As an example, if the COV values are 0.75 (similar to what is expected for the telecommunication manhole water and sediment characteristics) and ten samples are collected from each strata (as recommended), then differences of about 90% can be detected with 95% confidence and with a 20% rate of false negatives.

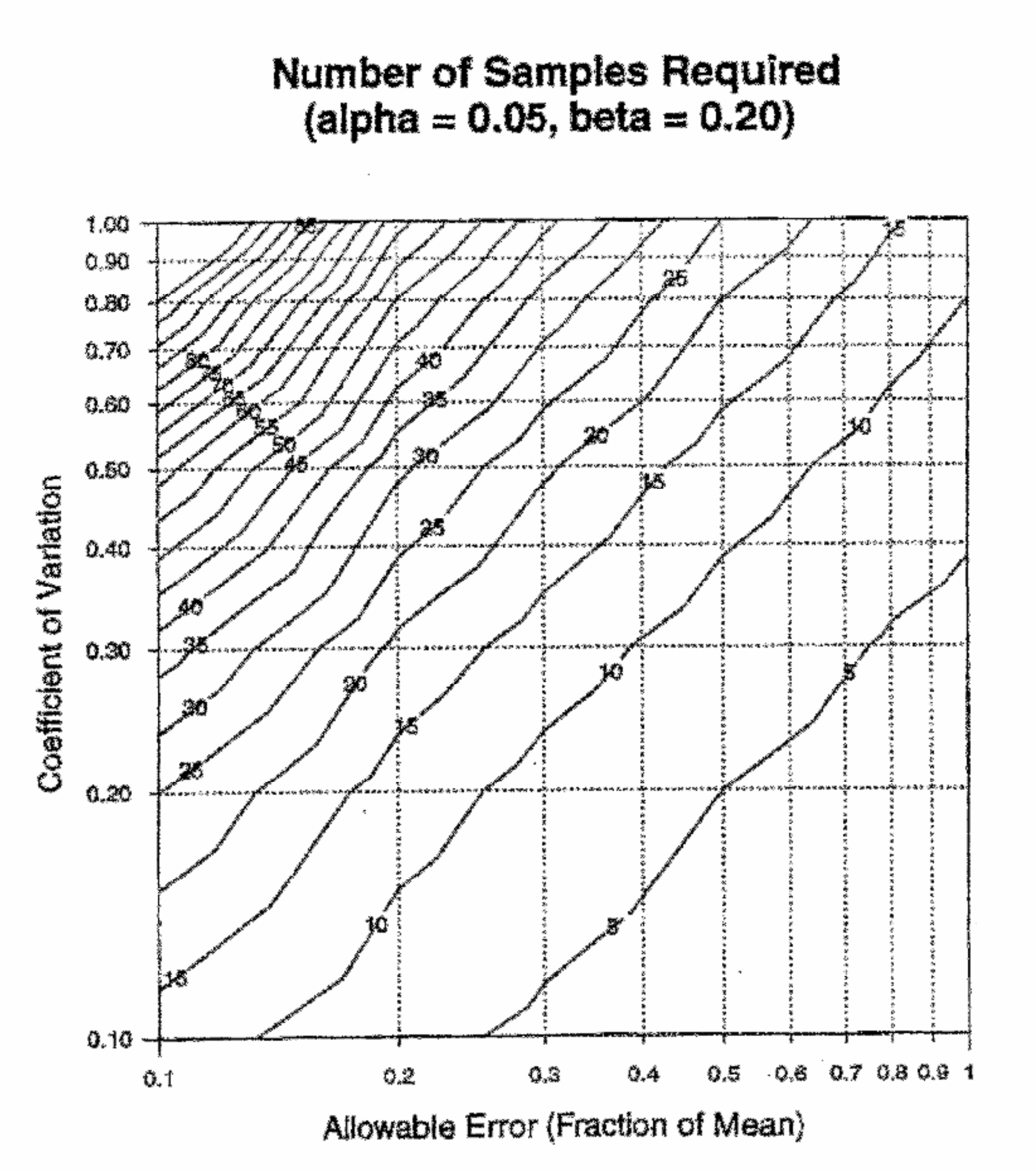


Figure 3-3 Sampling Requirements for Power of 80% and Confidence of 95%

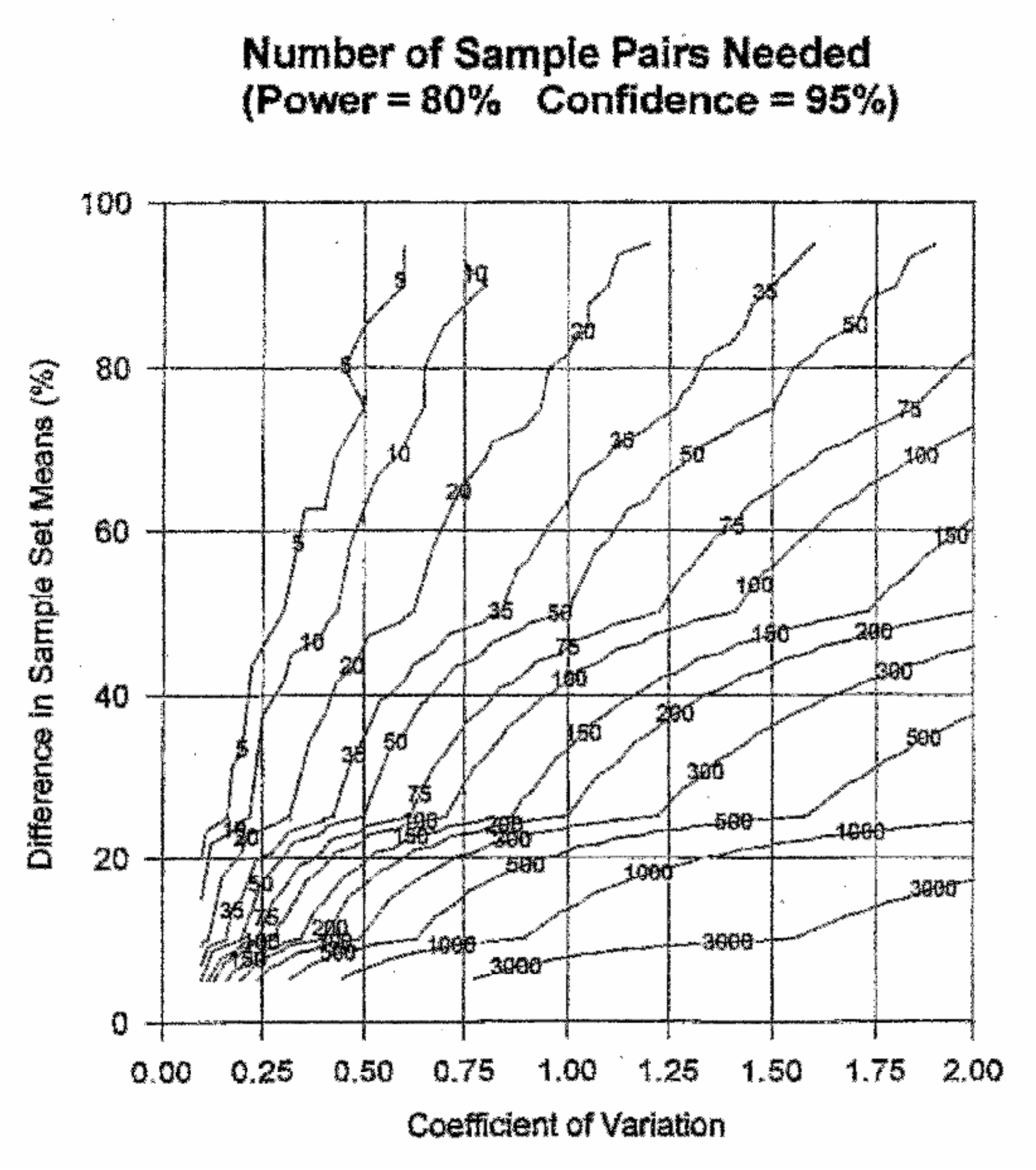


Figure 3-4 Sample Effort Needed for Paired Testing (Power of 80% and Confidence of 95%)

3.4 Determining Sample Concentration Variations

Figure 3-5 (Pitt and Lalor 1995) can be used to estimate the COV value for a parameter by knowing the 10th and 90th percentile ratios (the "range ratio"), assuming a log-normal distribution. This is used to make initial estimates for COV that are needed to calculate the approximate number of samples that actually need to be sampled and analyzed. In many cases, the approximate range of likely concentrations can be estimated for a parameter of interest. The extreme values are not well known, but the approximate 10th and 90th percentile values can be estimated with better confidence. As an example, assume that the 10th and 90th percentile values of a water quality constituent of interest was estimated to be about 0.7 and 1.5 mg/L, respectively. The resulting range ratio is therefore 1.5/0.7 = 2.1 and the estimated COV value is 0.25, from Figure 3-5.

Also shown on Figure 3-5 is an indication of the location of the median value, compared to the 10 percentile value and the range ratio. As the range ratio decreases, the median becomes close to the midpoint between the 10th and 90th percentile values. Therefore, at low COV values, the differences between normal distributions and log-normal distributions diminish, as indicated previously. As the COV values increase, the mean values are located much closer to the 10th percentile value. In log-normal distributions, no negative concentration values are allowed, but very large positive "outliers" can occur. In the above example, the median location is about 0.4, for a range ratio of 2.1. The following calculation shows how the median value can be estimated using this "median location" value:

median location = 0.4 = $(X_{50}-X_{10})/(X_{90}-X_{10})$

therefore $X_{50}-X_{10}= 0.4(X_{90}-X_{10})$.

$(X_{90}-X_{10})$ = 1.5 mg/L - 0.7 mg/L = 0.8 mg/L.

Therefore $X_{50}-X_{10} = 0.4\ (0.8)$ = 0.32 mg/L, and X_{10} = 0.7 mg/L, X_{50} = 0.32 mg/L + 0.7 mg/L = 1.0 mg/L.

For comparison, the average of the 10th and 90th percentile values is 1.1 mg/L. Because these two values are quite close, the concentration distribution is likely close to being normally distributed and the equation shown previously can be used to estimate the required number of samples needed. Log transformations of real-space data descriptors (COV and median) can be used in modifications of these equations, but with little change in overall estimated effort for most cases.

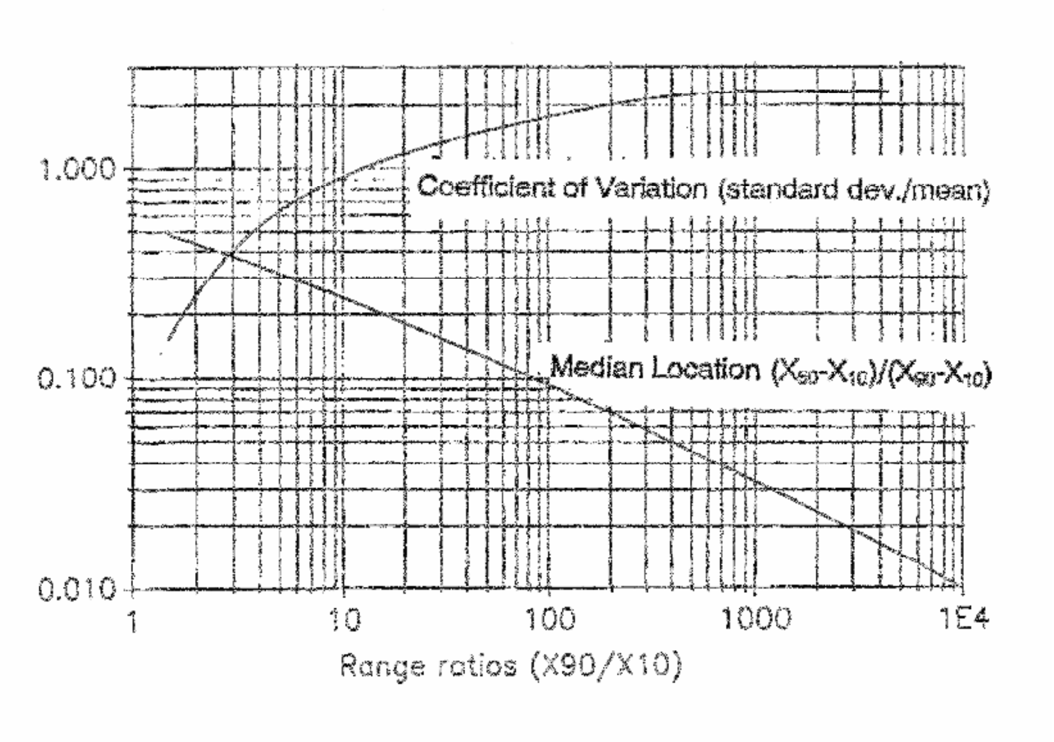


Figure 3-5 Relationships between data ranges and coefficient of variation

3.5 Detection Limit Requirements

There are a number of different types of detection limits defined for laboratory use. Most instrument manufactures present a minimum readable value as the instrument detection limit (IDL) in their specifications for simple test kits. The usual definition of IDL, however, is a concentration that produces a signal to noise ratio of five. The method detection limit (MDL) is a more conservative value and is established for the complete preparation and analysis procedure. The practical qualification limit (PQL) is higher yet and is defined as a routinely achievable detection limit with a relatively good certainty that any reported value is reliable. *Standard Methods* (APHA, *et al.* 1989) estimates that the relationship between these detection limits is approximately: IDL:MDL:PQL = 1:4:20. Therefore, the detection limit shown in much of the manufacturer's literature is much less than what would be used by most analytical laboratories.

A quick (and conservative) estimate of the needed method detection limit (with at least a 90% confidence) can be made by knowing only the median concentration and the concentration variation of the contaminant, based on numerous Monte Carlo probability calculations presented by Pitt and Lalor (1995):

COV value:	Multiplier for MDL:
<0.5 (low)	0.8
(5) to 1.25 (medium)	0.23
>1.25 (high)	0.12

As an example, if the contaminant has a low COV (<0.5), then the estimated required MDL is about 0.8 times the estimated median contaminant concentration.

3.6 Required Sample Analytical Precision

The precision (repeatability) of an analytical method is another important consideration in its selection. Precision, as defined in *Standard Methods* (APHA, *et al.* 1992), is a measure of the closeness with which multiple analyses of a given sample agree with each other. It is determined by repeated analyses of a stable standard, conducting replicate analyses on the samples, or by analyzing known standard additions to samples. Precision is expressed as the standard deviation of the multiple analysis results.

Figure 4-1 is a summary of probability plots prepared by Pitt and Lalor (1995) and indicates one approach that can be used to calculate the needed analytical precision for a specific research objective. This figure was prepared as an aid in resolving one percent contamination levels at a 90 percent confidence level and was developed for COV values ranging from 0.16 to 1.67. It indicates the needed analytical precision (as a fraction of the uncontaminated flow's low concentration). This figure was developed for contamination levels between zero and 15 percent. If the analytical precision is worse than these required values, then small contamination levels may not be detected. Therefore, even with adequate analytical detection limits, poor analytical precision may not allow adequate identification of low levels of contamination. As an example, if the median contaminant concentrations differ by a factor of 10 in two flow components, but have high concentration variations (high COV values), a precision of between 0.015 to 0.03 of the lower baseflow median contaminant concentration is needed, for each percent contamination that needs to be detected. If the median contaminant concentration in the cleaner baseflow is 0.15 mg/L (with a corresponding contaminant median concentration of 10 times this amount, or 1.5 mg/L, in the contaminating source flow), then the required analytical precision is about 0.015 X 0.15 = 0.002 mg/L to 0.03 X 0.15 = 0.005 mg/L per one percent contamination detection. If at least five percent contamination is needed to be detected, then the minimum precision can be increased to 5 X 0.002 = 0.01 mg/L.

The method noted previously can be used to estimate the detection limit requirements for the above example:

low COV in the cleaner baseflow: 0.8 X 0.15 mg/L = 0.12 mg/L
medium COV in the cleaner baseflow: 0.23 X 0.15 mg/L = 0.035 mg/L
high COV in the cleaner baseflow: 0.12 X 0.15 mg/L = 0.018 mg/L.

The required analytical precision would therefore be about one-half of the lowest detection limit needed, and about 1/12 of the largest estimated required detection limit. In most cases, the required minimum precision (expressed as a COV) should be in the range of about 0.1 to 1, with the most restrictive precision needed for constituents having low COV values (in order to have the additional variability associated with analytical methods kept to an insignificant portion of the total variability of the results).

4 Data Analysis for Comparing Multiple Sets of Data

Making comparisons of data sets is a fundamental objective of this investigation. The presence of influencing factors, such as season, land use, geographical location, materials present, etc., may all affect the data observations. Berthouex and Brown (1994) and Gilbert (1987) present excellent summaries of the most common statistical tests that are used for these comparisons in environmental investigations. The significance test results (the α value) will indicate the level of confidence that the two sets of observations are the same. In most cases, an α level of less than 0.05 is used to signify significant differences between two sets of observations. Even if the α level is significant (less than 0.05), the pollutant difference may not be very important. The importance of the differences in the pollutant concentrations will be graphically presented using grouped box plots indicating the range and variations of the concentrations at each of the sampling locations.

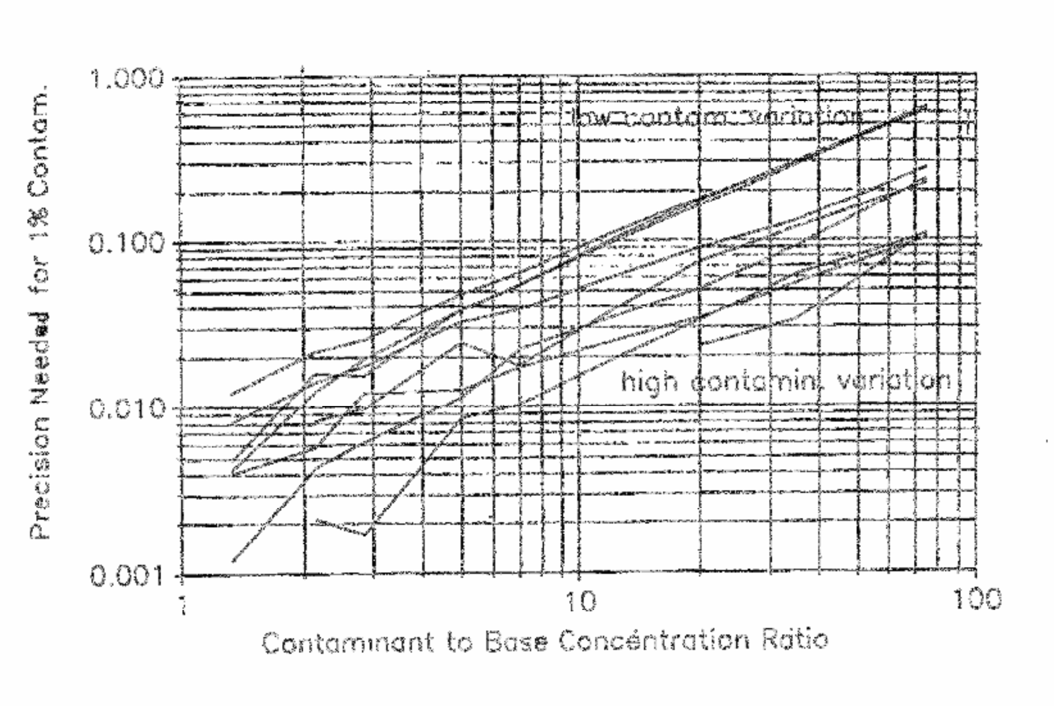


Figure 4-1 Analysis Precision Needed for Detection of One Percent Contamination 90% Confidence

The main types of comparison tests are separated into independent and paired tests. These can be further separated into tests that require specific probability distribution characteristics (parametric tests) and tests that do not have as many restrictions based on probability distribution characteristics of the data (nonparametric data). If the parametric test requirements can be met, then they should be used as they have more statistical power. However, if information concerning the probability distributions is not available, or if the distributions do not behave correctly, then the somewhat less powerful nonparametric tests should be used. Paired sampling (repeated samples from the same manholes) results in much more efficient analyses as major sources of variations are likely to be eliminated and they should therefore be used preferentially over independent (non-paired tests). Paired tests can be used to investigate the effects of land use, material used, etc. Paired experimental designs ensure that uncontrolled factors influence both sets of data observations equally (Berthouex and Brown 1994).

The parametric tests used for comparisons are the t-tests (both independent and paired t-tests). All statistical analyses software and most spreadsheet programs contain both of these basic tests. These tests require that the variances of the sample sets be the same and do not vary over the range of the values. These tests also require that the probability distributions be Gaussian. Transformations can be used to modify the data sets to these conditions. Log-transformations can be used to produce Gaussian distributions of most water quality data. In all cases, it is necessary to confirm these requirements before the standard t-tests are used.

Nonparametrics: Statistical Methods Based on Ranks by Lehman and D'Abrera (1975) is a comprehensive general reference on nonparametric statistical analyses. Gilbert (1987) presents an excellent review of nonparametric alternatives to the t-tests, especially for environmental investigations from which the following discussion is summarized. Even though the nonparametric tests remove many of the restrictions associated with the t-tests, the t-tests should be used if justifiable. Unfortunately, seldom are the t-test requirements easily met with environmental data and the slight loss of power associated with using the nonparametric tests is much more acceptable than misusing the t-tests. Besides having few data distribution restrictions, many of the nonparametric tests can also accommodate a few missing data, or observations below the detection limits. The following paragraphs briefly describe the features of the nonparametric tests used to compare data sets.

4.1 Nonparametric Tests for Paired Data Observations

The sign test is the basic nonparametric test for paired data. It is simple to compute and has no requirements pertaining to data distributions. A few "not detected" observations can also be accommodated. Two sets of data are compared and the differences are used to assign a positive sign if the value in one data set is greater than the corresponding value in the other data set, or a negative sign is assigned if the one value is less than the corresponding value in the other data set. The number of positive signs are added and a statistical table (such as in Lehman and D'Abrera 1975) is used to determine if the number of positive signs found is unusual for the number of data pairs examined.

The Wilcoxon signed rank test (not to be confused with the Wilcoxon rank sum test, which is for independent data observations) has more power than the sign test, but it requires that the data distributions be symmetrical (but with no specific distribution type). Without transformations, this requirement may be difficult to justify for water quality data. This test requires that the differences between the data pairs in the two data sets be calculated and ranked before checking with a special statistical table (as in Lehman and D'Abrera 1975). In the simplest case for monitoring the effectiveness of treatment alternatives, comparisons can be made of inlet and outlet conditions to determine the level of pollutant removal and the statistical significance of the concentration differences. StatXact-Turbo (CYTEL, Cambridge, MA) is a microcomputer program that computes exact nonparametric levels of significance, without resorting to normal approximations. This is especially important for relatively small data sets.

Friedman's test is an extension of the sign test for several related data groups. There are no data distribution requirements and the test can accommodate a moderate number of "non-detectable" values, but no missing values are allowed.

4.2 Nonparametric Tests for Independent Data Observations

As for the t-tests, paired test experimental designs are superior to independent designs for nonparametric tests because of their ability to cancel out confusing properties. However, paired experiments are not always possible, (such as comparing geographical differences and material use in manholes) requiring the partial use of independent tests. The Wilcoxon rank sum test is the basic nonparametric test for independent observations. The test statistic is also easy to compute and compare to the appropriate statistical table (as in Lehman and D'Abrera 1975). The Wilcoxon rank sum test requires that the probability distributions of the two data sets be the same (and therefore have the same variances). There are no other restrictions on the data distributions (they do not have to be symmetrical, for example). A moderate number of “non-detectable” values can be accommodated by treating them as ties.

The Kruskal-Wallis test is an extension of the Wilcoxon rank sum test and allows evaluations of several independent data sets, instead of just two. Again, the distributions of the data sets must all be the same, but they can have any shape. A moderate number of ties and non-detectable values can also be accommodated. The Kruskal-Wallis test was frequently used for comparing the water collected from manholes during this project.

5 SAMPLING AND ANALYTICAL PROCEDURES

5.1 Constituents To Be Monitored

This research project focused on the following constituents potentially in elevated concentrations in the waters found in manholes:

Petroleum products (Polycyclic aromatic hydrocarbons)
Sewage (evaluated by ammonia, potassium, and detergents/fluorescence)
Lead

Additional potential indicators of problem conditions that were investigated included the following constituents:

Conductivity
pH
Hardness
Turbidity
Suspended solids
Volatile solids
TOC/VOC/COD
Nitrates
Phosphate
Copper
Chromium
Zinc
Phenols
Pesticides and herbicides
Sediment texture

Table 5-1 summarizes the sample types (filtered and unfiltered water and sediment samples) for each of the analyses.

Besides these listed constituents, portable air monitors used for safe entry determinations also provide important information, especially for combustible gases, H_2S, oxygen, and carbon dioxide concentrations of the overlying gas in the manholes.

Table 5-1 Constituents for Testing Water and Sediment from Communication Manholes

Constituent	Unfiltered Water	Filtered Water	Sediment
Solids	X	X	X
Volatile solids	X	X	X
Turbidity	X	X	
Particle size	Selected		
pH	X		
Conductivity	X		
Hardness	X		
Color	X	X	
Phosphate	X		
Nitrate	X		
Ammonia	X		
COD	X	X	X
Detergents	X		
Boron	Selected		
Fluoride	X		
Potassium	X		
Odor, color and texture			X
Total coliform bacteria	Selected		
E. coli	Selected		
Enterococci	Selected		
Toxicity (Microtox screening method)	X	X	
Chromium	Selected		
Copper	X	X	X
Lead	X	X	X
Zinc	X	X	X
Metal scan (ICP)			Selected
PAHs and phenols (GC/MSD)	X	Selected	Selected
Pesticides (GC/ECD)	X	Selected	Selected

5.2 Sampling Procedures

Table 5-2 is the data collection form that was completed for each sample collected. The following paragraphs summarize the procedures used for collecting manhole water and sediment samples during this project:

1) Fill out the sample sheet and take photographs of the surrounding area and the manhole.

2) Pump the water from the manhole, being careful not to stir the bottom sediment. Pump slowly and carefully from just below the water surface. A floating pump is preferred.

3) Obtain a time-composite sample of the water as it is being pumped from the manhole. Divide the expected pumping time into tenths and obtain 1 L of water at the end of each of the ten time periods directly from the pump system outlet. Stop pumping when the water level is within 6 inches of the bottom sediment, or when the pump is too close to the bottom of the manhole and is causing agitation of the sediment. Each subsample can be poured into a large clean container during this sampling period. At the end of the sampling period, this composite sample is mixed and poured (using a sample splitter) into the appropriate sample bottles (with preservatives) for delivery to the analytical laboratory.

4) Continue to pump down the remaining water to the sediment layer, without sampling the agitated sediment and water mixture.

5) Obtain a sediment sample composited from nine generally evenly spaced locations in the manhole. Divide the manhole bottom into nine sections and obtain about 0.5 L of wet sediment from each section using a polypropylene sample scoop. Combine the nine sub-samples into a large clean polypropylene container and mix. A composite sample is then placed in the suitable container for delivery to the analytical laboratory.

6) Fill out the labels on each sample container with the sample designation, date, and sampler’s name.

7) Fill out the chain-of-custody form. The typical information provided on a chain-of-custody form is as follows:

    - The sampling location (street address and manhole number if available).
    - The sample identification number.
    - The type of test or analytical procedure.
    - The name of the person who relinquishes the samples.
    - The date and time of sample collection.
    - The date and time when samples are relinquished.
    - The name of the person who should receive the sampling results.

8) After the sediment and water sampling is completed, the sampling equipment must be cleaned using clean water and non-phosphate laboratory detergent and rinsed using clean water.

A possible alternative to sampling while pumping out the manhole water (the preferred approach) is to take a depth-integrated water sample. This can be done using a peristaltic pump and slowly lowering the intake line through the water column, or by using a small submersible pump and lowering the pump itself. This would result in a water sample obtained from all depths. The pump would discharge the water into a large container where it would be mixed and composited before preservation. As in step #3 above, the main problem is to obtain a water sample that is not influenced by agitated bottom deposits. Therefore, the pumping should stop about 6 inches above the bottom of the manhole sediment, or when sediment agitation is noted.

Sampling the sediment with overlaying water in place is more difficult. The simplest method would be to scoop the sediment into a small square container attached to the end of a pole, but the container would need a lid that is controlled from the street level so it can be closed when bringing the sample to the surface. Another approach is to use a lake bottom sampler. Specifically, a small Eckman or Ponar dredge sediment sampler, which is typically used for sand, silt, and mud sediments (similar to most manhole sediments) should be most useful. A corer type sampler probably would not be useful because of the relatively shallow depths. An exception may be a freezing core sampler, where liquid CO_2 is pumped inside a stainless steel tube (with the bottom end sealed with a point) to freeze sediment to the outside of the tube. Again, the sediment would have to be at least several inches deep. In all cases, multiple sediment samples would have to be obtained (such as the nine noted above) and composited. Needless to say, the water sample would have to be obtained first, as the sediment sampling will create substantial disturbance and resuspension of sediment in the water column. All sampling equipment must also be constructed of non-contaminating materials. Stainless steel, polypropylene, or Teflon™ are the obvious choices.

The specific sample volume, bottle type, and preservative requirements were determined by the UAB Environmental Engineering Laboratory. We have developed modifications that require minimal amounts of sample to decrease shipping costs. All samples were shipped in ice chests to our facility using over-night courier. We then filtered the appropriate samples at our laboratory to reduce problems with filtering in the field.

The water samples for each manhole were shipped in the following sample bottles:

- three 500 mL amber glass containers with Teflon lined screw caps
- three 500 mL HDPE (high density polyethylene) plastic containers with screw caps

A total of 3 L of each water sample was therefore needed. In addition to the water samples, sediment samples were shipped in the following sample bottles:

- one 500 mL amber glass wide mouth container with Teflon lined screw cap
- one 500 mL HDPE (high density polyethylene) wide mouth plastic container with screw cap

Samplers wore latex gloves and safety glasses when handling the samples. The sample jars were filled completely with the sample and the caps were screwed on securely, minimizing the amount of air space in the sample jars. Sample container lids were taped on (using black electrical tape after first drying the bottle) to reduce loosening of the lid and loss of the sample. Paper chain of custody paper seals were also sometimes used over the lid seal, but are not adequate by themselves to keep the lids from loosening. Care was taken to prevent the samples from freezing during shipping.

Once the samples were collected, the sample container label was filled out completely and then logged onto a shipping list for each shipping container. Shipping containers were usually plastic coolers, holding samples from about 3 manholes in each. Adequate packing (preferable as many blue ice packs as could fit, plus bubble wrap) was used inside the shipping container to insure that the sample bottles did not rub or bang against each other en route. Newspapers (flat, not wadded) could also be placed on top of the samples and blue ice packs, directly under the lid, to further fill up space. It was preferred that glass bottles were wrapped with bubble wrap. Sufficient “blue ice” or other cooling packs (preferably in hard plastic containers and not in plastic bags that can tear or puncture during shipping) was used to insure that the coolers stayed cool during shipment. Water ice was only used if cold blue ice packs were not available. The sample containers were sent via overnight courier and generally arrived before Friday to allow sufficient time to filter, preserve, and conduct the critical analyses (such as pH and bacteria) before the weekend. The laboratory was notified when sampling was scheduled and the shipment was confirmed by fax.

Pre-cleaned sample containers were generally obtained by the samplers from suppliers such as I-Chem (through Fisher Scientific 800-766-7000), or Eagle Picher (800-331-7425). Fisher’s catalog numbers and prices are as follows:

I-Chem #	Fisher #	Cost	Description

241 -0500	05-719-74	$34.49/case of 12	wide mouth 0.5 L amber glass jars with lids and labels
311 -0500	05-719-242	$67.80/case of 24	wide mouth 0.5 L HDPE jars with lids and labels

Similar Eagle Picher sample containers are as follows:

122) 16A	case of 12 - $25.24	wide mouth 0.5 L amber glass jars with lids and labels
151500WWM	case of 24 - $45.63	wide mouth 0.5 L HDPE jars with lids and labels

5.2.1 Preservation, Transportation, and Storage

Once the samples arrived in our laboratory, they were logged in, sorted for further processing, and filtered and preserved, as needed. A reading of pH was conducted and the bacteria tests were started immediately when the samples arrived in the laboratory. Within a day, chilled samples were filtered through a 0.45 µm membrane filter (using an all glass filtering apparatus for organics and plastic for heavy metals), as appropriate. The filtered and unfiltered sample portions were then divided and preserved as follows:

- unfiltered samples in two 250 mL amber glass bottles (Teflon lined lids) (no preservative) for total forms of toxicity, COD, and GC analyses (using MSD and ECD detectors).

- filtered sample in one 250 mL amber glass bottle (Teflon lined lids) (no preservative) for filtered forms of toxicity, COD, and GC analyses (using MSD and ECD detectors).

- unfiltered sample in one 250 mL high density polyethylene (no preservatives) for solids, turbidity, color, particle size, and conductivity.

- filtered sample in one 250 mL high density polyethylene (no preservatives) for anion and cation analyses (using ion chromatography), hardness, dissolved solids, and alkalinity.

- unfiltered sample in one 250 mL high density polyethylene (HNO_3 preservative to $pH<2$) for total forms of heavy metal, using the graphite furnace atomic adsorption spectrophotometer.

- filtered sample in one 125 mL high density polyethylene (HNO_3 preservative to $pH<2$) for filtered forms of heavy metal, using the graphite furnace atomic adsorption spectrophotometer.

All samples were chilled on ice or in a refrigerator to 4°C (except for the HNO_3 preserved samples for heavy metal analyses) and analyzed within the holding times shown below. The HNO_3 preserved samples were held at room temperature until digested.

5.2.2 Holding Times

The following list shows the holding times for the various groups of constituents:

- immediately after sample collection: pH and bacteria
- within 24 hours: toxicity, ions, color, and turbidity
- within 7 days: GC extractions, solids, and conductivity
- within 40 day: GC analyses
- within 6 months: heavy metal digestions and analyses

Table 5-2 Data Collection Form

Date: _________ Person Filling Out Form: _________________ Telephone: _______________

Location of Manhole (Address): ____

Photographs: roll # ______Exposures: ________Field pH of manhole water: ________

Is there water in the manhole? Yes ____ No ____

If yes, how much? (depth) _______ feet/inches

Manhole known to be contaminated? Yes______ No______ Since when?_______________

Similar problems with manholes in vicinity? Yes_____ No______

Odor: gasoline, sewage, other: ________ Clarity: clear, cloudy, dark Color: __________

Is there sediment in the manhole? Yes ______ No _____Sediment color: __________

If yes, how much? (depth) __________ feet/inches

Is the manhole heavily corroded? Yes_______ No______

Weather: Temperature _______ Precipitation ? Yes_____ No ______

Where appropriate circle the information that best fits the field situation for each category and fill in the blanks where needed.

Location of the Manhole

Roadway traffic:	Light	Medium	Heavy
Topography:	Flat	Moderate slope >5%	Steep slope >20%
Location of manhole:	Bottom of slope	Middle of slope	Top of slope
	Side of road	In roadway	Off road
Likelihood of ground water entering manhole:	Low	Medium	High
Likelihood of surface water entering manhole:	Low	Medium	High
Road type:	Asphalt (FABC)	Concrete	Other:

Additional Comments: ____

____

____

____

____

____

____

____

____

____

____

Data Collection Form (Continued)

Materials Found in Manholes

Cable type:	Lead	Plastic - copper	Fiber
# of cables in manhole:	Lead:	Copper:	Fiber:
Inner - pan:	Yes	No	
Ladder:	Yes	No	
Brick construction:	Yes	No	
Duct:	Tile	Plastic	Steel
Side lateral:	To pole	To apparatus	To building
Ducts plugged:	Yes	No	
Manhole dimensions:	Height:	Length:	Width:
If known, indicate recent work operation by craft:	Splicing	Cable removal: lead or non-lead? (indicate)	Cable placing

Additional Comments:____

____

____

External Environment

Distribution of Area:	Rural	Urban	Suburban
Housing Density:	Single dwelling	Multiple dwellings	High-rise
Commercial:	Shopping center	Strip commercial	Large malls
Industrial:	Manufacturing	Chemical	Other
Traffic near Manhole Location:	Light	Medium	Heavy
Average Age Adjacent to Manhole:	0-10 years	11-20 years	21+ years
Adjacent to:	Parking lots	Golf course	Gas station
	Farm	Forest	Wetlands
	Reservoir	Lake	Stream
	Coastal	River	Salt/fresh water
Recent Rainfall (past two weeks):	Light (<0.5”)	Moderate (0.5 - 2”)	Heavy (>2”)

Additional Comments:____

____

____

____

____

____

____

____

____

Data Collection Form (continued)

Water Pump

Pump used for sampling:	Submersible	Prime pump (non-submersible)	Other
Trailer mounted pump:	Yes	No	
Powered by:	Electric	Gasoline/Diesel	Hydraulic
Diameter of hose:	1 - <2”	2 - <3”	>3”
Flow rate:	<100 GPM	100 - <200 GPM	>200 GPM

Indicate pump manufacture and model:
____

Hazardous gas analyses of manhole vapor (on-site analyses):

hydrogen sulfide (H_2S), ppm: ______________________

lower explosive limit, % (or methane,CH_4, ppm),: ______________

other gas analyses: ___________________________

Additional Comments:____
____
____
____
____
____

6 Data from Telecommunication Manhole Monitoring Program

6.1 Sampling Effort

Table 6-1 lists the numbers of samples that were sent to UAB for analyses from the nine participating companies, by season.

As noted previously, each strata needs about 10 separate telecommunication manhole samples in order to estimate the quality characteristics with an error level of about 25 percent. The goal of each participant is to obtain samples from four groups of manholes (having 10 each) for each season:

1) old industrial/commercial (or central city) area
2) new industrial/commercial (or central city) area
3) old residential (or suburban) area
4) new residential (or suburban) area

The same manholes are to be sampled during each season to minimize additional variation. The main seasons for sampling are winter and summer. Therefore, each participant was to collect a total of 40 samples per season, for at least these two seasons. The collection of additional samples for other seasons or land uses will enable further comparisons to be made.

Table 6-2 lists the cities being sampled during this program, while Figure 6-1 shows their geographical distribution and associated EPA rainfall region. Thirty-two states, plus the District of Columbia have been represented in this sampling effort. All EPA Rain Regions are also represented, although Regions 5, 8, and 9 had fewer samples. The sampled cities represent annual rainfalls ranging from about 7 inches (Phoenix) to about 65 inches (Pensacola). It was obviously much more difficult to find manholes having standing water in the arid regions.

Table 6-1 Telecommunications Vault Samples sent to UAB for Analysis

	Winter 1995/96	Spring 1996	Summer 1996	Fall 1996	Winter 1996/97	Spring/ Summer 1997	Fall/ Winter 1997	Winter 1997/98	Summer 1998	Winter 1998/99	Total
NYNEX	15	15	20	20	0	6	0	0	0	0	76
Bell Atlantic	14	0	26	22	24	20	0	0	0	0	106
BellSouth	3	36	36	32	31	0	0	0	0	0	138
SNET	0	0	0	20	20	0	0	0	0	0	40
Pacific Bell	0	0	0	0	0	21	23	0	0	0	44
GTE	0	0	0	0	0	24	23	16	0	0	63
U.S. West	0	0	0	0	0	0	0	35	35	0	70
Ameritech	0	0	0	0	0	0	0	40	40	0	80
AT&T	0	0	0	0	0	0	0	0	40	40	80
TOTAL	32	51	82	94	75	71	46	91	115	40	697

Table 6-2 Sampling cities and their locations.

MANHOLE WATER AND SEDIMENT STUDY SAMPLING LOCATIONS BY COMPANY AND STATE Note: (EPA Rainfall Zone Number, Average Annual Precipitation [in.]) after city name						
Ameritech	**Illinois** Frankfort (4, 35) Joliet (1, 33) Lemont (1, 33) New Lenox (1, 33)	**Indiana** Gary (1, 33) Indianapolis (2, 39) Merrillville (1, 33) St. John (1, 33)	**Michigan** Ann Arbor (1, 31) Dearborn (1, 31) Detroit (1, 31) Rockwood (1, 31) Southgate (1, 31)	**Ohio** Columbus (1/2, 37) Dublin (2, 37) Hilliard (2, 37) Graves City (2, 37)	**Wisconsin** Madison (1, 37)	
AT & T	**Missouri** St. Louis (4, 34)	**Montana** Billings (8, 15)	**Nebraska** Omaha/Lincoln (9, 30)	**Idaho** Boise (8,11)		
Bell Atlantic	**District of Columbia** (2, 39)	**Maryland** Baltimore (2, 42) Edgemere (2, 42) Prince Georges Cty. (2, 42)	**New Jersey** Fairfield (1, 42) Garfield (1, 42) Lincoln Park (1, 42)	**Pennsylvania** Monroeville (1, 41) Moon Township (1, 36) New Kensington (1, 36) Philadelphia (1, 41) Pittsburgh (1, 36) Trooper (1, 41) West Mifflin (1, 36)	**Virginia** Arlington (2, 44) Richmond (2, 44)	**West Virginia** Beckley (2, 40) Charleston (2, 42)
BellSouth	**Alabama** Birmingham (3, 55) Center Point (3, 55) Homewood (3, 55) Hoover (3, 55)	**Florida** Ft. Lauderdale (3, 58) Jacksonville (3, 53) Miami (3, 58) Orlando (3, 53) Pensacola (3, 65)	**Georgia** Conyers (3, 49) Decatur (3, 49) Fairington (3, 49)	**Louisiana** Baton Rouge (4, 60) Lafayette (4, 60) Lake Arthur (4, 60) Oakdale (4, 60)	**North Carolina** Asheville (2, 48)	
GTE	**Illinois** Bloomington (1, 35) Rantoul (1, 35) Dekalb (1, 33)	**Indiana** Lafayette (2, 39) Terre Haute (2, 39) Valparaiso (1, 33)	**Oregon** Beaverton (7, 37) Coos Bay (7, 46) Hillsboro (7, 37) Reedsport (7, 46) Tigard (7, 37)	**Washington** Anacortes (7, 39) Bothell (7, 39) Burlington (7, 39) Camas (7, 37) Everett (7, 39) Marysville (7, 39) Monroe (7, 39) Mount Vernon (7, 39) Mukilteo (7, 39)		

Table 6.2 Sampling cities and their locations (Cont.)

MANHOLE WATER AND SEDIMENT STUDY SAMPLING LOCATIONS BY COMPANY AND STATE (cont.)

Note: (EPA Rainfall Zone Number, Average Annual Precipitation [in.]) after city name

NYNEX	**Maine** Kennebunk (1, 44) Sanford (1, 44)	**New Hampshire** Manchester (1, 39)	**New York** Brewster (1, 44) Brooklyn (1, 44) Newburgh (1, 44) Peekskill (1, 44) White Plains (1, 44)			
Pacific Bell	**California** Corona (6, 15) Del Mar (6, 9) Irvine (6, 15) La Mesa (6, 9) Petaluma (6, 19) Sacramento (6, 17) San Diego (6, 9) Santa Cruz (6, 19) Van Nuys (6, 15)					
SNET	**Connecticut** Hartford (1, 44) Mystic (1, 44) New Haven (1, 44) Norwalk (1, 44)					
U.S. West	**Arizona** Phoenix (6, 7)	**Colorado** Castle Rock (9, 15) Denver (9, 15) Golden (9, 15) Parker (9, 15)	**New Mexico** Albuquerque (5, 8)	**Utah** Salt Lake City (8, 15)		

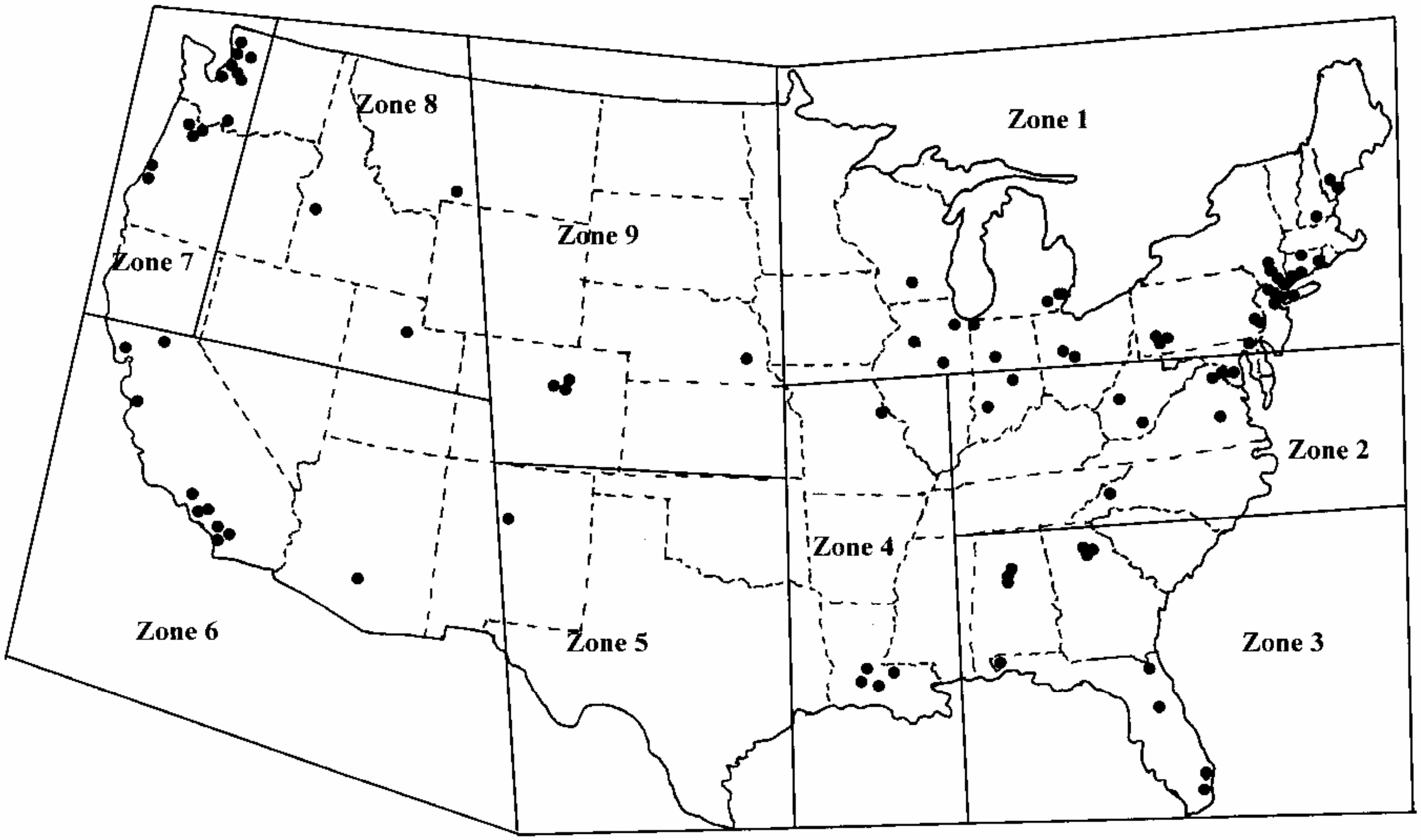


Figure 6-1 Map of US with sampling cities and EPA Rain Zones

BellSouth, U.S. West, Ameritech, and AT&T are close to having collected 40 samples for each of the two main seasons. BellSouth, NYNEX and Bell Atlantic also collected samples from all four seasons. SNET and Pacific Bell collected somewhat fewer samples. The total number of samples collected was close to the number as originally planned (at 80 per participant), but with half the number of manholes sampled per some season, but twice as many seasons represented for some areas. Very close to the total number of samples identified as our overall goal (720) was collected (697). About 390 sediment samples were also collected from the manholes for analysis.

6.2 Summary of Data from Current Sampling Efforts

6.2.1 Information and Data Collected

Available data are presented in Appendix C. These data include all of the results for NYNEX, Bell Atlantic, BellSouth, SNET, Pacific Bell, GTE, Ameritech, U.S. West, and AT&T that have been analyzed and reviewed to date. Information generally available and included in Appendix C are listed in Table 6-3.

6.2.2 Data Summaries

Most of the constituents have several hundred to almost 700 analyses available. Table 6-4 summarizes these data, showing statistical summaries for the constituents that had at least 10 observations that were greater than the detection limit.

Table 6-3 Constituents and Manhole Parameters Evaluated

Company	Sample #s	Manhole Location	Season	Year	Age	Land Use	Temp at Sampling (°F)
Precip. at Sampling	Water depth (ft)	Water volume (gal)	Surface sheen description	Water odor	Water clarity	Water color	Sediment depth (ft)
Sediment volume (ft^3)	Sediment Color (Field obs.)	Manhole corroded?	Roadway Traffic	Topography	Manhole location	Likelihood of GW contamination	Likelihood of SW contamination
Road type	Manhole size	Ladder in MH?	Brick construction?	Cable type?	Duct type?	Area distribution	Housing density
Commercial buildings	Industrial buildings	Traffic near MH	MH adjacent to?	Recent rainfall	Total solids	Dissolved solids	Volatile total solids
Volatile dissolved solids	Volatile suspended solids	Suspended solids	% of sediment volatile	Turbidity (unfiltered)	Turbidity (filtered)	pH	Toxicity (unfiltered)
Toxicity (filtered)	COD (unfiltered)	COD (filtered)	COD in sediment	Color (unfiltered)	Color (filtered)	Conductivity	Total coliforms
E. coli	Enterococci	detergents	fluoride	nitrate	phosphate	hardness	ammonia
potassium	boron	Zinc (unfiltered)	Zinc (filtered)	Zinc in sediment	Copper (unfiltered)	Copper (filtered)	Copper in sediment
Lead (unfiltered)	Lead (filtered)	Lead in sediment	Chromium (unfiltered)	Chromium in sediment	Cadmium in sediment	Aluminum in sediment	Barium in sediment
Calcium in sediment	Cobalt in sediment	Magnesium in sediment	Manganese in sediment	Nickel in sediment	Strontium in sediment	Vanadium in sediment	Phenol (unfiltered)
bis(2-chloroiso-propyl)-ether unfiltered	bis(2-chloroiso-propyl)-ether filtered	naphthalene unfiltered	naphthalene filtered	4-chloro-3-methylphenol unfiltered	4-chloro-3-methylphenol filtered	dimethyl-phthalate unfiltered	dimethyl-phthalate filtered
diethyl-phthalate unfiltered	diethyl-phthalate filtered	hexachloro-benzene unfiltered	hexachloro-benzene filtered	pentachloro-phenol unfiltered	pentachloro-phenol filtered	phen-anthrene unfiltered	phen-anthrene filtered
caffeine unfiltered	caffeine filtered	di-n-butyl-phthalate unfiltered	di-n-butyl-phthalate filtered	benzylbutyl-phthalate unfiltered	benzylbutyl-phthalate filtered	bis(2-ethylhexyl)-phthalate unfiltered	bis(2-ethylhexyl)-phthalate filtered
coprostanol unfiltered	coprostanol filtered	phenol	bis(2-chloroiso-propyl)ether	naphthalene	hexachloro-butadiene	4-chloro-3-methylphenol	hexachloro-cyclopentadiene
dimethyl-phthalate	2,6-dinitro-toluene	acend-phthene	diethyl-phthalate	fluorene	4-chlorophenyl-phenylether	hexachloro-benzene	hexachloro-chlorophenol
phendnthrene	anthracene u	carbazole	di-n-butyl-phthalate	fluoranthene	pyrene	benzylbutyl-phthalate	chrysene
bis(2-ethylhexyl)-phthalate	di-n-octyl-phthalate	benzo(b)-fluoranthene	benzo(k)-fluoranthene	benzo(a)-pyrene	coprostanol	indeno (1,2,3-c,d)-pyrene	dibenz(a,h)-anthracene
Benzo(a) anthracene	Sediment odor	Sediment color	Sediment texture				

Table 6-4. Statistical Summary of Data

	Temp at Sampling (^oF)	Water depth (ft)	Sediment depth (ft)	Manhole height (ft)	Manhole width (ft)	Manhole length (ft)	Total Solids (mg/L)	Dissolved Solids (mg/L)	Suspended Solids (mg/L)	Volatile Total Solids (mg/L)
Number of Analyses	614	648	559	625	575	575	685	683	683	685
Number of Detectable	614	614	380	625	575	575	685	683	549	685
Percent Detectable	100	94.8	68	100	100	100	100	100	80.4	100
COV	3.24	1.31	0.68	3.6	2.6	2.6	0.58	0.54	0.32	0.57
1st Percentile	25.0	0	0	4.0	2.5	2.5	89	69	nd	14
5th Percentile	32.0	0	0	5.5	2.7	2.7	146	118	nd	22
10th Percentile	35.0	0.3	0	6.0	4.0	4.0	199	160	nd	31
15th Percentile	38.0	0.7	0	6.2	4.0	4.0	239	208	nd	36
20th Percentile	40.0	1.0	0	7.0	4.0	4.0	280	238	1	42
25th Percentile	45.0	1.3	0	7.0	4.0	4.0	314	278	4	48
30th Percentile	45.0	1.7	0	7.0	5.0	5.0	351	308	6	53
35th Percentile	50.0	2.0	0	7.0	5.0	5.0	385	342	9	59
40th Percentile	50.2	2.4	0	7.5	5.0	5.0	437	379	12	64
45th Percentile	55.0	2.8	0	8.0	6.0	6.0	487	424	15	71
50th Percentile	60.0	3.0	0.1	8.0	6.0	6.0	546	471	19	80
55th Percentile	64.2	3.5	0.1	8.0	6.0	6.0	625	544	25	92
60th Percentile	66.0	4.0	0.1	9.0	6.0	6.0	694	612	33	104
65th Percentile	70.0	4.0	0.2	9.5	6.0	6.0	770	712	41	119
70th Percentile	70.0	4.5	0.2	10.0	6.0	6.0	894	824	56	139
75th Percentile	75.0	5.0	0.3	10.0	6.0	6.0	1062	968	73	160
80th Percentile	76.0	5.6	0.3	10.5	6.1	6.1	1306	1144	98	188
85th Percentile	80.0	6.0	0.3	11.1	8.0	8.0	1665	1541	144	246
90th Percentile	85.0	7.0	0.3	12.0	9.0	9.0	2228	1935	208	337
95th Percentile	88.0	8.0	0.5	12.3	10.0	10.0	3597	3435	414	484
100th Percentile	105.0	13.0	1.5	15.1	18.0	18.0	32950	32756	3505	3264

Table 6-4. Statistical Summary of Data (continued)

	Volatile Dissolved Solids (mg/L)	Volatile Suspended Solids (mg/L)	Suspended Solids (mg/L)	% of Volatile Solids - Sediment	Turbidity Unfiltered (NTU)	Turbidity Filtered (NTU)	pH	Toxicity Unfiltered (I25% reduction)	Toxicity Filtered (I25% reduction)	COD Unfiltered (mg/L)
Number of Analyses	683	683	593	387	685	685	684	681	682	681
Number of Detectable	682	463	580	384	685	684	684	450	441	594
Percent Detectable	99.9	67.8	97.8	99.2	100	99.9	100	66.1	64.7	87.2
COV	0.66	0.23	0.35	1.16	0.25	0.53	13.32	0.84	0.82	0.69
1st Percentile	6	nd	nd	0.5	0.3	0.1	6.2	nd	nd	nd
5th Percentile	16	nd	2	1.1	0.6	0.2	6.6	nd	nd	nd
10th Percentile	24	nd	3	1.7	1.0	0.2	6.8	nd	nd	nd
15th Percentile	29	nd	4	2.3	1.4	0.3	7.0	nd	nd	1
20th Percentile	33	nd	5	3.0	1.8	0.4	7.1	nd	nd	4
25th Percentile	37	nd	6	3.6	2.2	0.4	7.2	nd	nd	6
30th Percentile	43	nd	7	4.0	2.7	0.5	7.3	nd	nd	8
35th Percentile	49	2	8	4.6	3.3	0.5	7.4	1	nd	10
40th Percentile	53	5	10	5.4	4.3	0.6	7.5	5	4	12
45th Percentile	60	7	11	5.8	5.3	0.7	7.5	9	8	13
50th Percentile	67	9	13	6.1	6.5	0.8	7.6	12	12	16
55th Percentile	75	12	14	6.7	8.2	0.9	7.7	17	16	19
60th Percentile	85	17	17	7.3	9.6	1.0	7.7	22	21	21
65th Percentile	99	20	21	8.7	11.9	1.1	7.8	29	27	24
70th Percentile	113	25	25	9.7	15.1	1.2	7.9	39	34	26
75th Percentile	132	32	34	11.0	17.8	1.5	7.9	51	45	32
80th Percentile	158	42	46	12.4	22.8	1.8	8.0	63	57	38
85th Percentile	192	51	66	14.3	32.8	2.1	8.1	76	74	47
90th Percentile	256	74	119	17.3	68.8	2.7	8.3	86	85	62
95th Percentile	371	126	308	21.4	127.4	3.9	8.4	97	95	118
100th Percentile	2093	3025	2123	67.8	2097.0	42.0	9.4	100	100	372

Table 6-4. Statistical Summary of Data (continued)

	COD Filtered (mg/L)	g COD/kg dry sediment	Color Unfiltered	Color Filtered	Conductivity (µS/cm)	Total Coliform (MPN/100 mL)	E. coli (MPN/100 mL)	Enterococci (MPN/100 mL)	Detergents (mg/L)	Fluoride (mg/L)
Number of Analyses	681	359	684	683	684	310	310	265	661	679
Number of Detectable	549	278	679	638	684	288	179	199	613	625
Percent Detectable	80.6	77.4	99.3	93.4	100	92.9	57.7	75.1	92.7	92
COV	0.63	0.72	0.52	0.68	0.54	0.69	0.23	0.3	0.88	1.27
1st Percentile	nd	nd	2	nd	47	nd	nd	nd	nd	nd
5th Percentile	nd	nd	6	nd	145	nd	nd	nd	nd	nd
10th Percentile	nd	nd	10	3	213	1	nd	nd	0.10	0.08
15th Percentile	nd	nd	11	5	280	5	nd	nd	0.10	0.12
20th Percentile	1	nd	14	6	350	11	nd	nd	0.10	0.15
25th Percentile	3	10600	15	8	408	22	nd	1	0.10	0.18
30th Percentile	5	17624	16	10	460	39	nd	1	0.10	0.21
35th Percentile	6	25580	18	10	510	59	nd	1	0.10	0.24
40th Percentile	8	33820	20	12	570	97	nd	2	0.10	0.26
45th Percentile	10	41470	21	13	640	146	1	4	0.25	0.30
50th Percentile	11	58800	23	15	713	205	2	6	0.25	0.33
55th Percentile	13	68200	25	15	830	365	3	9	0.25	0.35
60th Percentile	15	84080	29	18	976	411	4	11	0.25	0.38
65th Percentile	17	94900	32	20	1090	752	6	19	0.25	0.40
70th Percentile	20	109160	39	23	1255	1093	13	30	0.25	0.43
75th Percentile	23	127100	45	25	1510	>2420	16	57	0.25	0.48
80th Percentile	27	154280	60	30	1832	>2420	26	93	0.25	0.53
85th Percentile	32	189400	75	36	2500	>2420	84	200	0.50	0.64
90th Percentile	39	222160	100	47	3300	>2420	299	513	0.50	0.74
95th Percentile	57	600000	125	70	5670	>2420	565	1280	0.75	0.97
100th Percentile	269	600000	1000	500	44000	>2420	>2420	>2420	3.00	2.19

Table 6-4. Statistical Summary of Data (continued)

	Nitrate (mg/L)	Phosphate (mg/L)	Hardness (mg/L as CaCO3)	Ammonia (mg/L)	Potassium (mg/L)	Boron (mg/L)	Zinc Unfiltered (µg/L)	Zinc Filtered (µg/L)	Zinc Sediment (mg/kg)	Copper Unfiltered (µg/L)
Number of Analyses	680	682	684	683	680	261	680	677	302	684
Number of Detectable	652	633	684	521	645	247	674	661	282	576
Percent Detectable	95.9	92.8	100	76.3	94.9	94.6	99.1	97.6	93.4	84.2
COV	0.23	0.31	1.11	0.13	0.38	0.56	0.57	0.88	0.7	0.33
1st Percentile	nd	nd	14	nd	nd	nd	9	nd	nd	nd
5th Percentile	0.1	nd	39	nd	nd	nd	51	18	nd	nd
10th Percentile	0.3	0.01	59	nd	1.0	nd	86	41	78	nd
15th Percentile	0.4	0.03	72	nd	2.0	0.1	104	64	256	nd
20th Percentile	0.5	0.04	90	nd	2.0	0.1	135	78	395	2
25th Percentile	0.6	0.05	103	0.01	3.0	0.1	175	98	508	3
30th Percentile	0.6	0.06	119	0.01	3.0	0.1	199	124	653	4
35th Percentile	0.7	0.07	135	0.01	3.9	0.1	222	151	784	5
40th Percentile	0.7	0.09	151	0.02	4.0	0.2	252	177	935	6
45th Percentile	0.8	0.11	167	0.02	5.0	0.2	297	210	1144	7
50th Percentile	0.9	0.13	190	0.03	6.0	0.2	346	240	1288	8
55th Percentile	1.0	0.15	209	0.03	6.9	0.2	396	274	1601	10
60th Percentile	1.1	0.18	226	0.04	8.0	0.2	462	317	1867	11
65th Percentile	1.2	0.23	247	0.06	10.0	0.2	520	366	2305	14
70th Percentile	1.4	0.26	276	0.08	11.0	0.2	598	416	2765	18
75th Percentile	1.5	0.30	302	0.11	15.0	0.3	709	501	3090	22
80th Percentile	1.9	0.37	349	0.15	18.0	0.3	867	631	3762	28
85th Percentile	2.2	0.45	400	0.22	23.0	0.4	1022	768	4835	41
90th Percentile	2.8	0.65	469	0.29	34.0	0.5	1299	989	6870	71
95th Percentile	4.3	0.90	638	0.59	64.1	0.7	1654	1471	10399	147
100th Percentile	196.0	19.20	2000	45.00	760.0	6.2	22220	3018	33894	1357

Table 6-4. Statistical Summary of Data (continued)

	Copper Filtered (µg/L)	Copper Sediment (mg/kg)	Lead Unfiltered (µg/L)	Lead Filtered (µg/L)	Lead Sediment (mg/kg)	Chromium Unfiltered (µg/L)	Chromium Sediment (mg/kg)	Cadmium Sediment (mg/kg)	di-n-butyl-phthalate unfiltered µg/L	di-n-butyl-phthalate filtered µg/L
Number of Analyses	680	340	685	682	340	20	346	346	605	120
Number of Detectable	524	250	564	409	274	15	149	89	18	10
Percent Detectable	77.1	73.5	82.3	60	80.6	75	43.1	25.7	3	8.3
COV	0.25	0.38	0.41	0.34	0.35	0.52	0.39	0.39	0.17	0.27
1st Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
5th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
10th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
15th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
20th Percentile	nd	nd	1	nd	10	nd	nd	nd	nd	nd
25th Percentile	1	nd	1	nd	37	nd	nd	nd	nd	nd
30th Percentile	2	10	2	nd	60	nd	nd	nd	nd	nd
35th Percentile	3	28	2	nd	97	1	nd	nd	nd	nd
40th Percentile	3	42	3	nd	127	1	nd	nd	nd	nd
45th Percentile	4	63	4	1	163	1	nd	nd	nd	nd
50th Percentile	5	97	5	1	202	1	nd	nd	nd	nd
55th Percentile	6	142	7	1	274	2	nd	nd	nd	nd
60th Percentile	8	157	8	2	319	3	7	nd	nd	nd
65th Percentile	9	179	10	2	467	4	30	nd	nd	nd
70th Percentile	11	215	13	3	618	4	49	nd	nd	nd
75th Percentile	13	274	18	4	814	5	125	9	nd	nd
80th Percentile	16	349	26	5	1012	6	264	131	nd	nd
85th Percentile	20	432	41	7	1550	8	17575	35150	nd	nd
90th Percentile	30	770	67	12	2650	13	37400	74800	nd	nd
95th Percentile	49	1310	113	24	4954	17	62200	124400	nd	2.7
100th Percentile	1183	8838	808	173	37261	45	119500	239000	4.7	7.6

Table 6-4. Statistical Summary of Data (continued)

	benzylbutyl-phthalate unfiltered µg/L	benzylbutyl-phthalate filtered µg/L	bis(2-ethylhexyl)-phthalate unfiltered µg/L	bis(2-ethylhexyl)-phthalate filtered µg/L	coprostanol unfiltered µg/L	coprostanol filtered µg/L	delta BHC µg/L	heptachlor µg/L	aldrin µg/L
Number of Analyses	605	119	604	120	596	119	577	577	509
Number of Detectable	7	8	7	10	21	10	60	9	22
Percent Detectable	1.2	6.7	1.2	8.3	3.5	8.4	10.4	1.6	4.3
COV	0.09	0.16	0.1	0.19	0.16	0.24	0.11	0.08	0.18
1st Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
5th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
10th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
15th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
20th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
25th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
30th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
35th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
40th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
45th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
50th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
55th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
60th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
65th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
70th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
75th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
80th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
85th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
90th Percentile	nd	nd	nd	nd	nd	nd	0.004	nd	nd
95th Percentile	nd	3.4	nd	5.8	nd	15.0	0.071	nd	nd
100th Percentile	21.0	47.3	14.6	55.0	79.6	75.2	5.677	0.580	0.304

Table 6-4. Statistical Summary of Data (continued)

	endosulfan I μg/L	alpha chlordane μg/L	4.4'-DDE μug/L	endrin μg/L	endosulphan II μg/L	endosulfan sulfate μg/L	4,4'-DDT μg/L	endrin ketone μg/L	methoxychlor μg/L
Number of Analyses	577	118	527	527	527	578	578	568	578
Number of Detectable	9	5	74	5	7	6	11	17	23
Percent Detectable	1.6	4.2	14	0.9	1.3	1	1.9	3	4
COV	0.12	0.16	0.33	0.07	0.1	0.07	0.14	0.11	0.19
1st Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
5th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
10th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
15th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
20th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
25th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
30th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
35th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
40th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
45th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
50th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
55th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
60th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
65th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
70th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
75th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
80th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
85th Percentile	nd	nd	nd	nd	nd	nd	nd	nd	nd
90th Percentile	nd	nd	0.041	nd	nd	nd	nd	nd	nd
95th Percentile	nd	nd	0.078	nd	nd	nd	nd	nd	nd
100th Percentile	0.037	0.108	0.355	1.075	0.099	0.580	0.057	0.960	0.200

6.3 Evaluation of Data Groupings and Associations

The data was reviewed to identify correlations between various manhole characteristics and sediment and water quality. In addition, relationships between different parameters were also examined to find measurements that correlated with one another.

The most obvious correlation of the data with site conditions and with other parameters was for the very high winter dissolved solids and conductivity values in EPA Rain Region 1 compared to other seasons and areas. The snowmelt runoff during the winter seasons in the northeast dramatically affected the winter season quality of water found in manholes for NYNEX and Bell Atlantic, especially for TDS and conductivity. In addition, increased dissolved solids and conductivity values were also found in some east coast manholes that were tidally influenced by close-by brackish waters. Because of the very high chloride ion concentrations, several of the analytical methods were subjected to large interferences (especially the major ions by ion chromatography). These samples were re-analyzed using other methods less subject to interference to better determine the maximum concentrations, especially for nitrates.

The immense amount of data collected during this project and the adherence to the original experimental design enabled a comprehensive statistical evaluation of the data. Several steps in data analysis were performed, including:

- exploratory data analyses (mainly probability plots and grouped box plots),
- simple correlation analyses (mainly Pearson correlation matrices and associated scatter plots),
- complex correlation analyses (mainly cluster and principal component analyses, plus Kurskal-Wallis comparison tests), and
- model building (based on complete 2^4 factorial analyses of the most important factors)

The following discussion presents the results of these analyses.

6.3.1 Exploratory Data Analyses

Appendix D contains a series of plots that represent data relationships and groupings, arranged by parameter sets (solids, common parameters, bacteria, other sewage indicators, nutrients, heavy metals, and organics). Included for most parameters are the following plots:

- grouped box and whisker plots for all data, by season
- grouped box and whisker plots showing all residential and commercial/industrial data, separated by season and age,
- grouped box and whisker plots for all data by EPA rainfall zone and season
- grouped box and whisker plots separating data by company, season, age, and land use.
- overall probability plots
- probability plots separated by land use
- probability plots separated by age of development
- probability plots separated by season

The data indicate that the sampling effort needed as previously described was appropriate. Some of the parameters have high COV values, while others are more moderate, as expected. In almost all cases, the overall data for each constituent was best described using log-normal probability plots (the notable and obvious exception is for pH). This requires the use on nonparametric statistical methods, or transformations of the data using $\log_{10}$. The following discussion presents some of the obvious trends and relationships noted from these plots:

6.3.1.1 Manhole Conditions, Sizes and Water and Sediment Accumulations

Numerous site conditions were described for each sampling period. The most potentially interesting were the land uses and age of development of the surrounding area, plus the season of sampling. Most of the data has been separated and evaluated with these groupings, in addition to a geographical grouping made possible by nation-wide participation of local, regional, and national telephone companies. Other useful information collected pertained to the manhole construction characteristics, especially cable type used, the presence of ladders in the manholes, and the presence of corrosion. a

The widths of the sampled manholes ranged from about 2.5 to 18 ft (median of 6 ft), their lengths ranged from about 4 to 40 ft (median of 10 ft), and their heights ranged from about 4 to 15 ft (median of 8 ft). The depth of water found in the manholes at the time of sampling ranged from about 0.1 to 13 ft (median of 3 ft). The corresponding water volume ranged from <100 to about 15,000 gallons (median of about 1500 gallons).

The depth of sediment found in the sampled manholes ranged from none to about 1.5 ft, with a median of about 0.1 ft. More than 45% of the sampled manholes did not have any notable sediments. The sediment volumes ranged from none to about 240 ft^3, with a median of about 5 ft^3.

Figure 6-2 is a grouped box plot examining relationships of cable types and metal concentrations. It is seen that the cable type (lead, copper, or neither) did not appear to have any significant association with the copper, lead, or zinc water concentrations, except that manholes that contained lead cables actually had reduced unfiltered zinc concentrations and the manholes that contained copper cables appeared to have reduced filtered zinc concentrations. These two exceptions are likely associated with other manhole attributes that may be correlated with cable type (such as age of construction). The presence of copper cables in manholes are seen to be associated with elevated copper and lead concentrations in the sediment. It was thought that the presence of copper cables would be associated with elevated copper in the water found in manholes and the presence of lead cables would be associated with elevated lead in the water found in manholes. This was not the case. However elevated copper was found in the sediments from manholes that had copper cables. Of course, the cable “type” is not reflective of the material exposed to the water, as all cables are sheathed in plastic. The inner components of the cables (copper or lead, for example) would more likely affect the sediment characteristics as debris from cable splicing could drop to the manhole floor and be covered by the sediment. Pieces of this debris would then be incorporated into sediment samples collected for analysis.

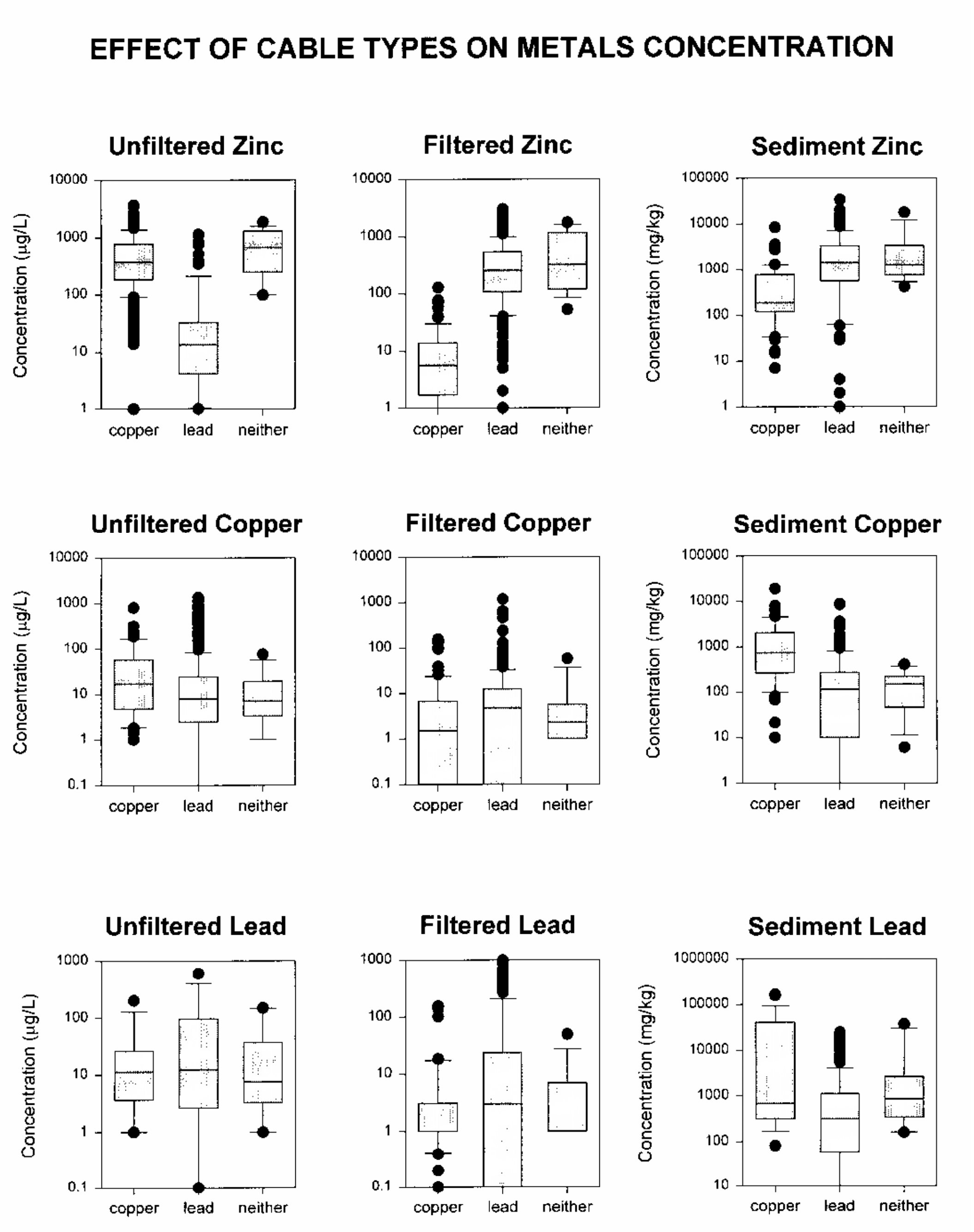


Figure 6-2 Effect of cable types on metals concentrations found in water and sediment obtained from telecommunication manholes.

A similar plot (Figure 6-3) shows the associations of the metal concentrations in manholes having ladders (assumed to be galvanized metal, a primary source of zinc). Again, no large differences are evident, except possibly for elevated metals in the water found in manholes that do not have ladders (the opposite of what was expected). There is a slight increase in sediment zinc concentrations in manholes having ladders, however (as expected). Of course, there are many other galvanized metal components in manholes besides ladders, including cable support brackets (racks), etc. The presence of these materials in almost all manholes could be the reason why the effects of galvanized ladders on zinc water concentrations was masked.

The third series of plots (Figure 6-4) shows associations between metal concentrations for manholes with noted corrosion vs. manholes without corrosion. It was assumed that corroded components in manholes would be associated with elevated metal concentrations. However, no obvious patterns were found, except that the sediment metal concentrations appeared to actually be greater in manholes that did not have obvious corrosion. Analyses reported later in this report indicated that elevated concentrations of many constituents were found in newer manholes, presumably affected by runoff from newly constructed areas. These newer areas would likely have less corrosion than older manholes that were found to generally have better quality water.

6.3.1.2 Solids Measurements in Water and Sediment Samples from Telecommunication Manholes

The highest total solids observations were from older commercial and industrial area manholes. Winter water samples had the highest concentrations, followed by spring and summer observations, while the fall samples had the lowest concentrations. Almost all of the total solids were in the dissolved form (with a median TDS concentration of about 450 mg/L), with only small contributions from the suspended solids (median SS concentration of 20 mg/L). About 15% of the total and dissolved solids were in volatile forms, while about 50% of the suspended solids were in volatile forms.

The highest dissolved solids concentrations found in water obtained from telecommunication manholes were observed during the winter sampling periods, with some TDS concentrations greater than 10,000 mg/L. The highest values were observed in samples from EPA rainfall zone 1 (specifically at NYNEX older residential sampling locations during the winter). Older commercial and industrial Bell Atlantic sites showed distinct trends in TDS by season, with the highest values observed during the winter, and then with steadily decreasing values through the year, with the lowest observed values during the fall season. Spring and summer values were still moderately high, even though the manholes were pumped dry during the sampling efforts. This implies that most older manholes experienced slow, but definite water exchanges with time. The high TDS values associated with winter snowmelt inflow decreased by about ten-fold by the fall, likely by the less saline inflowing stormwater during the late spring, summer, and early fall seasons, or they may have been affected by local groundwaters that change in dissolved solids with time. A similar pattern was also observed at the SNET older residential, and the Ameritech mid-aged and older residential locations. Therefore, this pattern is very likely common to most areas using de-icing salts. Similar patterns were also observed for many of the conductivity measurements. Many of the AT&T manholes in northern areas that were pumped and sampled in the summer of 1998 also had high TDS values, but the following winter samples were much lower in TDS, possibly because these winter samples may have been collected previous to the snowmelt season. Some of the coastal manholes were noted to be directly affected by tidal conditions, with continuous high dissolved solids and conductivity conditions, implying that some manholes also allow rapid infiltration of surrounding groundwaters.

There were no apparent overall trends for turbidity by season, although the overall range observed was quite large (from <1 to about 2,000 NTU, with a median value of about 7 NTU). Filtration through 0.45 µm membrane filters reduced the turbidity values significantly (the maximum was reduced to about 45 NTU and the median to about 0.8 NTU). The largest turbidity values observed were from water samples collected from mid-aged and older residential area manholes located in EPA rainfall zones 1 and 3 (some samples from Bell Atlantic older residential area manholes approached 2,000 NTU). Samples from EPA rainfall zone 3 (especially newer residential area BellSouth samples) do indicate seasonal differences in turbidity, where the summer and (especially) fall samples averaged several times greater than the winter and spring samples. The BellSouth new residential area samples collected during the fall also had some of the highest turbidity values observed (several hundred NTU). A less distinct, but similar pattern, may also occur for EPA rainfall zone 2 samples.

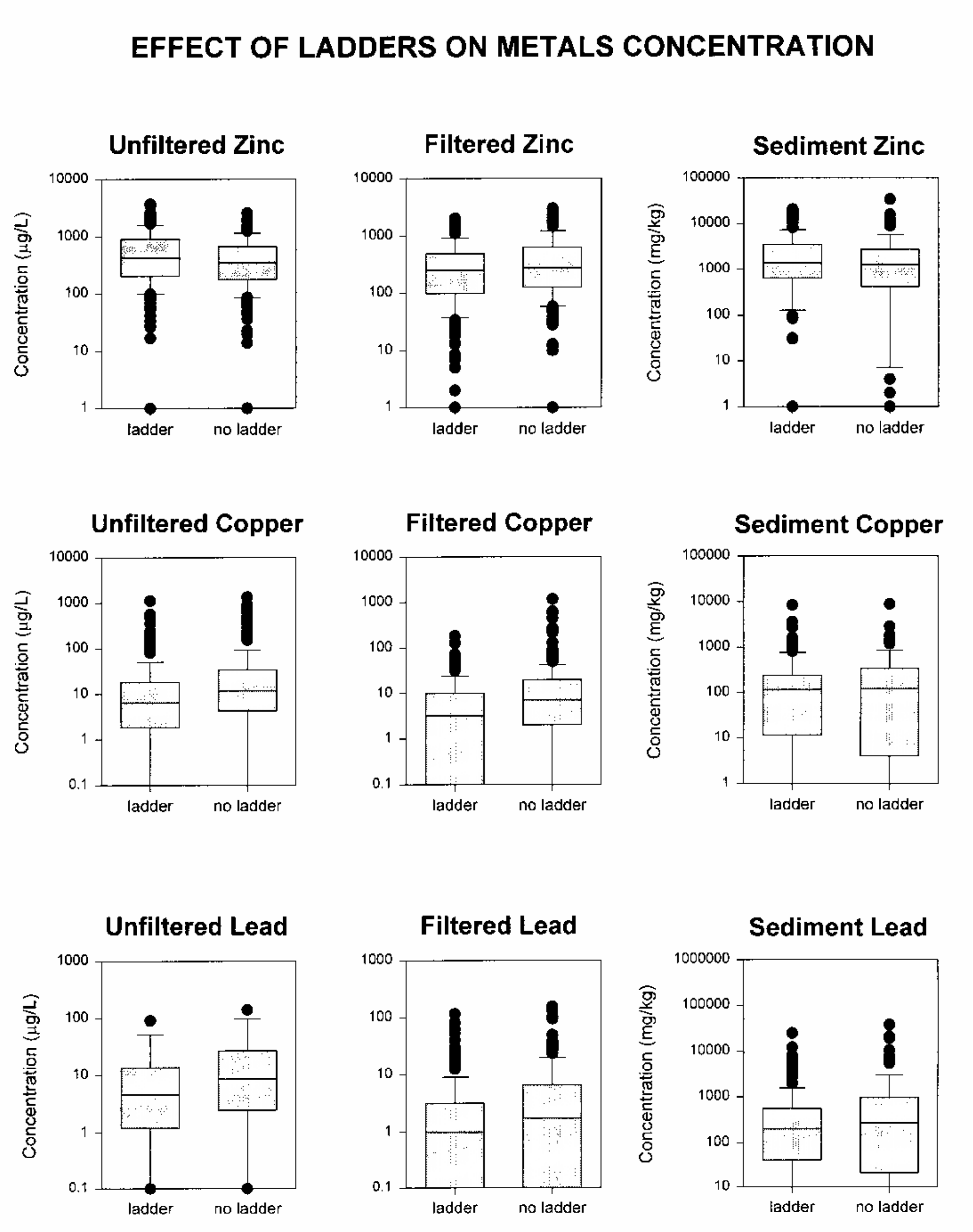


Figure 6-3 Effect of ladders in manholes on metal concentrations found in water and sediment obtained from telecommunication manholes.

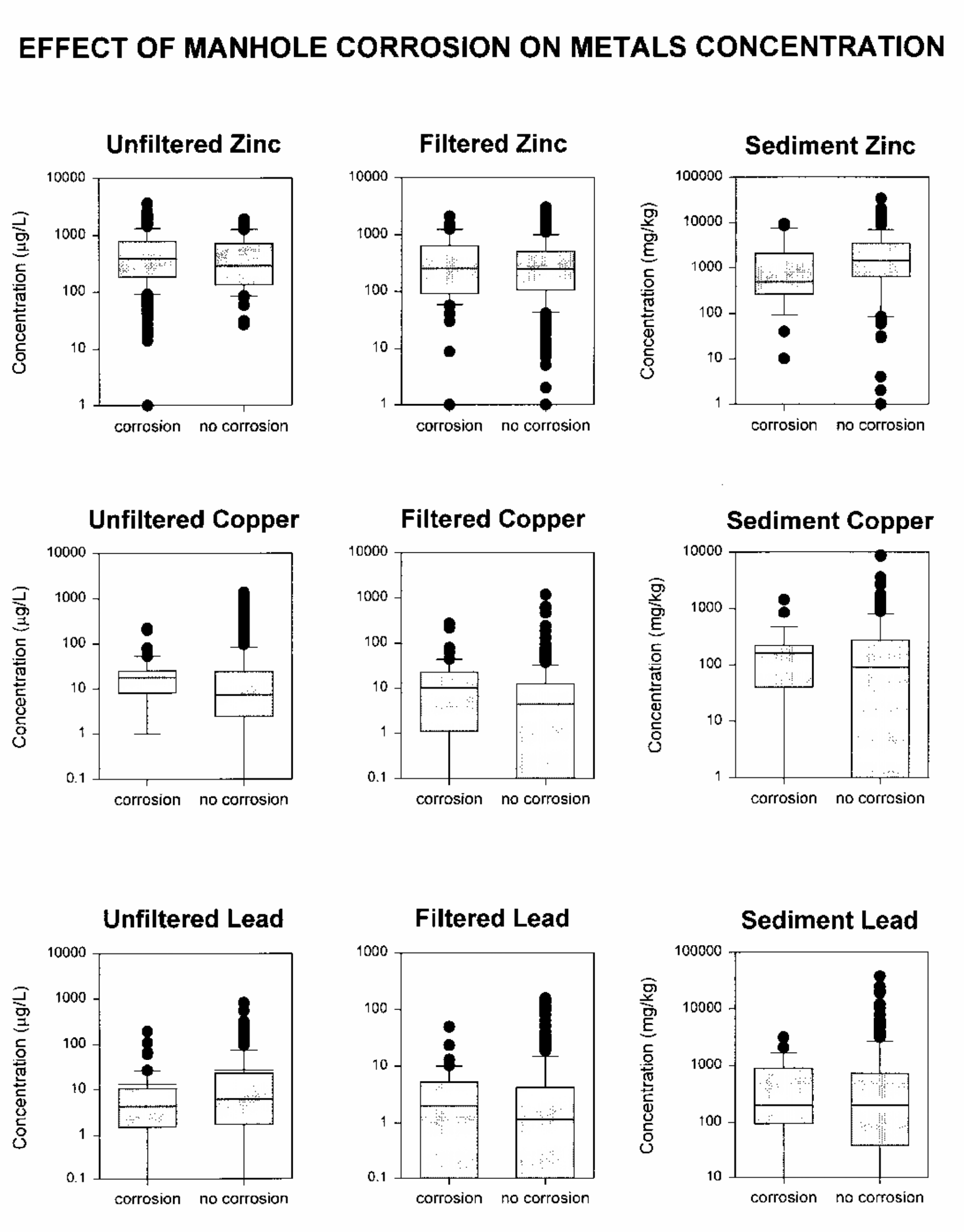


Figure 6-4 Effects of corrosion in manholes on metal concentrations found in water and sediment obtained from telecommunication manholes.

The sediment sampled from the telecommunication manholes had volatile contents ranging from <1 to about 70%, while the median volatile content was about 6%. There were no obvious relations of sediment volatile content for different seasons, land uses, or age of development.

6.3.1.3 Common Constituent Measurements in Water and Sediment Samples from Telecommunication Manholes

A possible overall trend indicates lower pH values from spring water samples (median of about 7), higher pH values from winter and summer samples (medians of about 7.3), and the highest pH values (median of about 8) from fall samples. The fall samples from all manholes from both residential and commercial/industrial areas were much higher than for the other three seasons. Only EPA rain regions 1, 2, and 3 had fall and spring samples, and all three of these areas experienced high fall samples. Rain regions 5, 6, and 9 showed lower summer pH values than for the winter samples.

There was also a wide range in color of the water samples, with no apparent overall relationships with season, age, or land use. In rain region 2, the summer and fall samples had higher colors than the winter and spring samples, especially for samples from older commercial/industrial areas. Many of the newer samples (from GTE, SNET, and PacBell sampling) also had much more color in the fall samples than in the winter samples. Residential area samples also had higher levels of color than samples from industrial and commercial areas.

COD did not vary greatly for different land uses, seasons, or age of development. About 20% of the samples did not have detectable COD, but maximum values approached 400 mg/L, and the median value was about 15 mg/L. Filtration reduced the overall COD values by about 30%, with the median filterable COD being about 10 mg/L, and the maximum filterable COD approaching 300 mg/L. The sediment COD values ranged from about 1,000 to 300,000 mg/kg, with the median about 85,000 mg/kg. These sediment COD values appear high, but about 75% of the volatile solids observations of the sediment had more than 10% volatile solids. The sediment samples from manholes from new areas had much lower COD values than sediment samples from older areas.

The hardness values of spring water samples were generally higher (harder), while the fall samples were generally lower (softer) than for the other seasons.

There was no overall pattern observed for ammonia measured in water collected from telecommunication manholes. The highest observations (up to 45 mg/L) were from samples collected from manholes in EPA rain region 1, especially during the winter and fall. Most of the ammonia observations were quite low, with very few exceptions. The highest nitrate observations (close to 200 mg/L) were from new commercial and industrial samples for rain zones 1 and 3. The highest phosphate concentrations observed (about 20 mg/L) were from older manholes from residential areas, although water from older commercial and industrial area manholes also had relatively high phosphate concentrations (up to about 2 mg/L). EPA rain region 3 had the highest phosphate observations for each season.

About 300 water samples were analyzed for *E. coli* and enterococci from the samples collected during the later part of the project. Therefore, few samples were analyzed from the original project participants. Generally, bacteria is much reduced during colder winter periods in stormwater. However, when observing patterns for enterococci, the overall median values were quite similar for all seasons, while the median summer *E. coli* observations were substantially higher than for the other seasons. The bacteria values were highly variable, with similar ranges for the residential and the commercial areas. When examining the data for the different EPA rain regions, the winter samples from zone 1 (a colder area) had much lower bacteria counts less than the corresponding summer samples, while in zone 6 (a hot area) samples had reduced summer bacteria observations. Air temperatures during sampling ranged from about 15^{o}F to 100^{o}F. This implies that either extreme cold or hot weather conditions may reduce bacterial survival, as expected. Similar patterns were also found for enterococci bacteria observations.

Detergent, boron, fluoride, and potassium measurements were used as indicators of sanitary sewage contamination of manholes. Boron concentrations were higher in industrial and commercial areas compared to residential areas, fluoride concentrations were higher during the summer sampling periods, while potassium was highest in older areas. No other patterns were apparent for these constituents.

6.3.1.4 Heavy Metal and Organic Toxicant Measurements in Water and Sediment Samples from Telecommunication Manholes

The toxicity screening tests (using the Azur Microtox® method) conducted on both unfiltered and filtered water samples from telecommunication manholes indicated a wide range of toxicity, with no obvious trends for season, land use, or age. About 60% of the samples are not considered toxic (less than a I25 light reduction of 20%, the light reduction associated with the phosphorescent bacteria after a 25 minute exposure to undiluted samples), about 20% are considered moderately toxic, while about 10% are considered toxic (light reductions of greater than 40%), and 10% are considered highly toxic (light reductions of greater than 60%). Samples from residential areas generally had greater toxicities than samples from commercial and industrial areas. Samples from newer areas were also more toxic than from older areas. Further statistical tests of the data, in addition to reviews of critical concentration effects described in another report volume, indicated that the high toxicity levels were likely associated with periodic high concentrations of salt (in areas using deicing salt), heavy metals (especially filterable zinc, with high values found in most areas) and pesticides (associated with newer residential areas).

Heavy metal concentrations have been evaluated in almost all of the water samples for copper, lead and zinc, and some filtered samples have been analyzed for chromium. From 564 to 674 samples (82 to 99% of all unfiltered samples analyzed) had detectable concentrations of these metals. Filterable lead concentrations in the water were as high as 173 µg/L, while total lead concentrations were as high as 810 µg/L. The winter Ameritech new residential areas had the highest zinc concentrations observed, with one value greater than 20,000 mg/L. The repeat samples from the following summer were much lower and more typical. The initially very high values may indicate increasing zinc concentrations as the water stands in manholes for extended periods.Many of the zinc values were higher than 1,000 mg/L in both filtered and unfiltered samples. Some of the copper concentrations have also been high in both filtered and unfiltered samples (as high as 1,400µg/L). Chromium concentrations as high as 45 µg/L were also detected.

About 390 sediment samples have been analyzed and reviewed for sediment heavy metals. An ICP/MS was used to obtain a broad range of metals with good detection limits. The following list shows the median observed concentrations for some parameters in the sediments (expressed as mg of the metal per kg of dry sediment):

Aluminum	14,000 mg/kg
Barium	50 mg/kg
Calcium	17,000 mg/kg
COD	85,000 mg/kg
Chromium	<10 mg/kg
Copper	100 mg/kg
Lead	200 mg/kg
Magnesium	5,000 mg/kg
Manganese	200 mg/kg
Nickel	<10 mg/kg
Strontium	35 mg/kg
Vanadium	<10 mg/kg
Zinc	1,290 mg/kg

The overall copper patterns indicate that the highest concentrations (over 1,000 µg/L) were found in samples obtained from manholes in older residential areas, especially in EPA rain zone 3, with almost as high copper values observed in some older commercial and industrial areas. Filtration did not significantly reduce the highest copper observations, but reduced most others by about 50%. Sediment from old manholes had greater copper concentrations than sediment from newer manholes.

Lead concentrations were also highest (about 1,000 µg/L) in older residential area manhole water samples, while samples from some older commercial and industrial areas also had high values. Rain zone 3 summer and fall lead observations were substantially larger than corresponding winter and spring observations. A similar, but smaller, difference was also noted for zone 1. This pattern was especially obvious for older commercial and industrial samples collected by BellSouth. Filtration significantly reduced the lead concentrations by about 75%. Filtered samples from zone 3 collected during the summer and fall were still greater than the samples collected during the winter and spring. Sediment from old manholes also had greater lead concentrations than sediment from newer manholes.

Residential area samples generally had larger zinc concentrations than the samples from commercial and industrial areas. Samples from the newest areas also had higher zinc concentrations compared to samples from older areas. Filtration reduced the highest zinc concentrations (about 3,600 µg/L) by about 20%, and most of the other values by about 35%. No overall patterns were observed for zinc concentrations in sediment samples obtained from manholes.

Water samples from more than 600 telecommunication manholes were analyzed and verified for base neutral and acid extractable organic toxicants. About 120 of these samples were partitioned by filtering to identify the quantity of organics associated with the particulates and how much is soluble. Very few detectable organics were found, especially in the filterable fraction, even with the GC/MSD method detection limits ranging from 2 to 5 µg/L. The most common organic compounds found are listed below:

di-n-butyl phthalate: detected in 3.0% of the unfiltered water samples, maximum concentration of 4.7 µg/L
benzylbutyl phthalate: detected in 1.2% of the unfiltered water samples, maximum concentration of 21 µg/L
bis(2-ethylhexyl) phthalate: detected in 1.2% of the unfiltered water samples, maximum concentration of 15 µg/L
coprostanol: detected in 3.5% of the unfiltered water samples, maximum concentration of 80 µg/L

The phthalate ester compounds are probably associated with plastic components in the manholes. Coprostanol was also detected in many of the samples. This compound is used to help identify the presence of fecal contamination as high concentrations may imply sanitary sewage contamination of the water found in the manholes, but pet wastes contained in inflowing stormwater into manholes would also contribute to coprostanol levels. Obviously, the median concentrations of these compounds were below the detection limits.

Water samples from about 580 manholes were analyzed for pesticides, with about 50 also filtered for partitioning pesticide analyses. Again, the pesticides were only detected in small fractions of the samples analyzed, as shown below:

delta BHC: detected in 10.4% of the unfiltered water samples, maximum concentration of 5.7 µg/L
heptachlor: detected in 1.6% of the unfiltered water samples, maximum concentration of 0.58 µg/L
aldrin: detected in 4.3% of the unfiltered water samples, maximum concentration of 0.30 µg/L
endosulfan I: detected in 1.6% of the unfiltered water samples, maximum concentration of 0.04 µg/L
alpha chlordane: detected in 4.2% of the unfiltered water samples, maximum concentration of 0.11 µg/L
4,4’-DDE: detected in 14% of the unfiltered water samples, maximum concentration of 0.36 µg/L
endosulfan sulfate: detected in 1.0% of the unfiltered water samples, maximum concentration of 0.58 µg/L
4,4’-DDT: detected in 1.9% of the unfiltered water samples, maximum concentration of 0.06 µg/L
endrin ketone: detected in 3.0% of the unfiltered water samples, maximum concentration of 0.96 µg/L
methoxychlor: detected in 4.0% of the unfiltered water samples, maximum concentration of 0.2 µg/L

Only two organic compounds were detected in more than 10% of the water samples (delta BHC and 4,4'-DDE). While only one pesticide had an observed concentration greater than 1 µg/L (delta BHC), some of these pesticide concentrations may be considered relatively high.

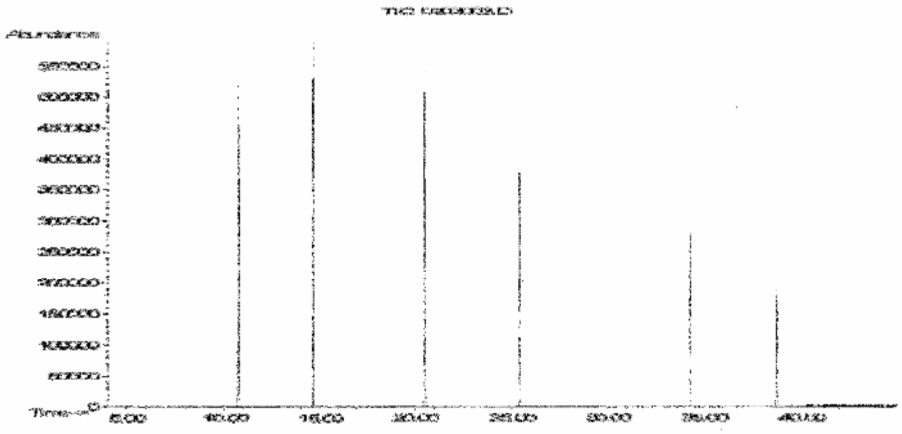
One of the most striking features of the sediment samples was their visibly wide range of physical characteristics such as texture, color, and odor. The sediments ranged in texture from grainy sand to an extremely fine silt or sludge. Color ranged from clear quartz to white sand to red clay to black sludge. Multi-colored sheens were observed on a few sediment samples. Odor of the sediment samples ranged from no detectable odor to a scent of nutrient rich potting soil to clearly discernible diesel or other petroleum compounds, to sulfur and sewage. It was thought that these characteristics would be related to the presence of organic toxicants.

The sediment samples were extracted using EPA method 3545 (Accelerated Solvent Extraction). The extract was further cleaned using gel permeation chromatography, capturing the fraction associated with the mass range of interest. The mass range of the mass spectrometer used in these analyses was optimized for the 40 – 550 atomic mass unit (AMU) range.

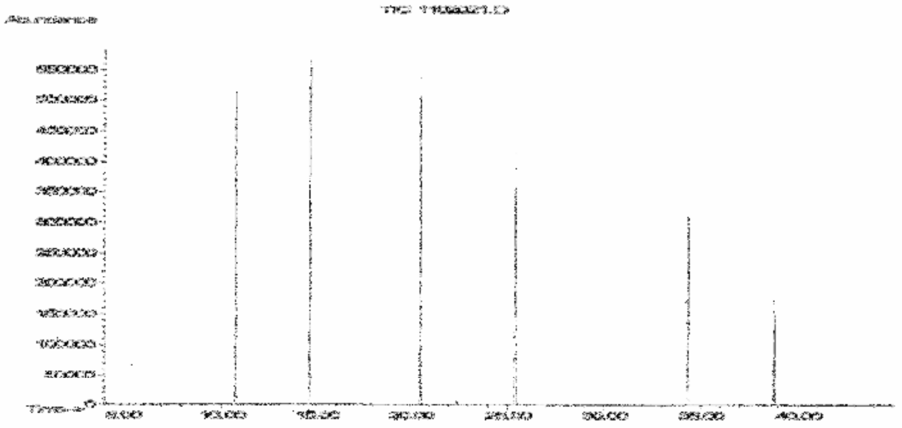
Several classes of compounds were observed to be present during the initial analyses, including non-specific heterocyclic compounds such as low molecular weight (less than 550 AMU) fulvic and humic compounds, sulfur, sulfur compounds, phenols, phthalate esters, petroleum compounds, oxygenated (weathered) petroleum compounds, alkanes, alkenes, heterocyclic aromatic compounds, polycyclic compounds, polycyclic aromatic hydrocarbons, and steroids. In one sample, all of the above were found. Based on the samples that have been completely analyzed, there is an apparent association between physical characteristics and the amount of organic material in the sediment. Sandy or coarse sediments with a light color have lower amounts of fewer organic materials and, as the sediment texture becomes finer, or colors darker, the level and number of organic compounds increases.

The following four chromatographs illustrate the range of conditions observed. Chromatograph 1 is a blank for comparison purposes. The six peaks in the blank are in all chromatographs at the same concentration (6428 µg/kg) and serve as internal standards for quantitative purposes.

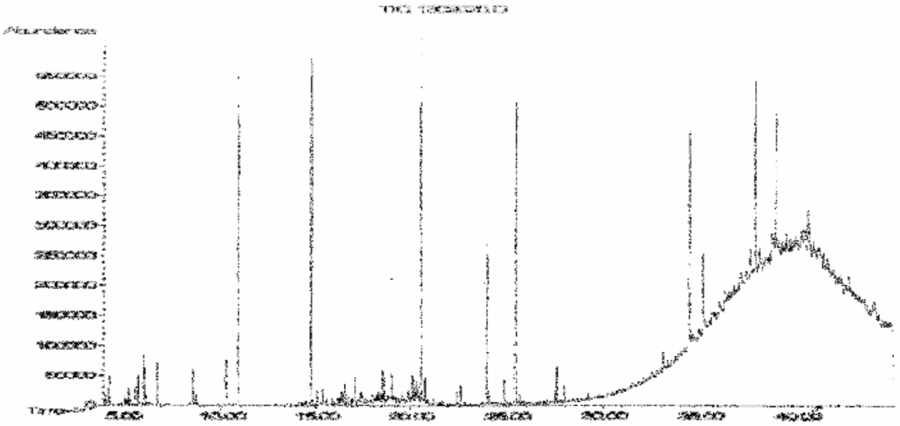
Chromatograph 1. Instrument blank with six internal standards



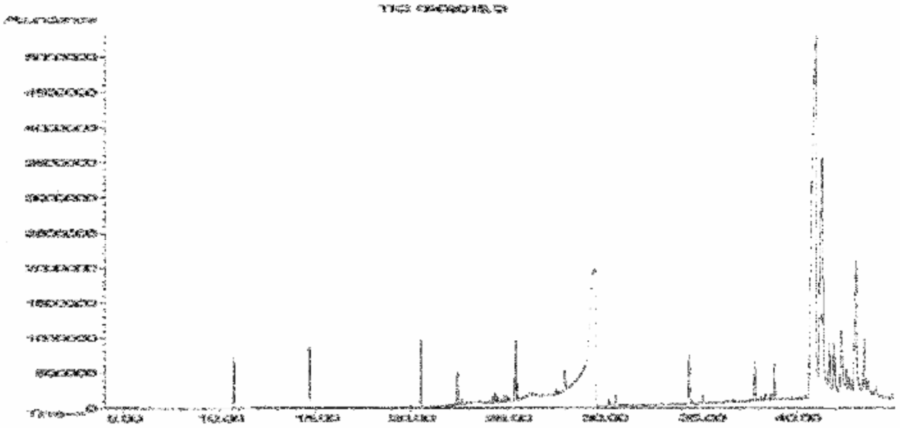
Chromatograph 2. Sample 3036 - wet, coarse quartz and sand



Chromatograph 3. Sample 4883 - wet red-gray clay



Chromatograph 4. Sample 2601 - black sludge



Chromatograph 2 is from a coarse sand and quartz sample, whereas chromatograph 3 is from a clay having a red-gray color. The peaks eluting in the 15-22 min range are alkanes associated with petroleum compounds. The large hump eluting from 30 minutes to the end of the run contains non-specific humic and fulvic compounds, with individual polycyclic aromatic hydrocarbons, phthalate esters, steroids and their degradation products as individual peaks superimposed on top of the humic hump.

Chromatograph 4 is from a black, very fine sludge-type sediment which has a distinct odor of petroleum and sewage. Notice that the large peaks at 29.5 minutes and at 41 minutes are two to ten times the intensity of the internal standards. The "fronting" peak eluting from 21 to 29.5 minutes is a combination of sulfur, sulfur compounds, and a fluorinated sulfur compounds. The large peak at 41 minutes and the large peaks after are steroids associated with sewage followed by poly- and heterocyclic hydrocarbons.

An evaluation of the sediment collected from the telecommunication manholes revealed that most of the sediment was of silt to sand texture, and brown in color, indicating a relatively low level of organic contamination for most sediments found in manholes. About 4% of the samples were clayey and black, indicating potentially high levels of organic contamination, while another 4% were clayey and red, also indicating the potential presence of high levels of organic contaminants. Another 25% are in a marginal category, being dark in color, but not of the finest texture.

6.3.2 Simple Correlation Analyses

Pearson correlations and other association analyses were conducted with the data to identify relationships between the different parameters. This was done to identify sets of parameters that could possibly be used as indicators of problematic conditions, especially by substituting simpler and less expensive analyses for more costly or time-consuming analyses. Tables 6-5 through 6-7 summarize the significant correlations identified through typical Pearson correlation matrix analyses using SYSTAT, version 8. Pearson normalization removed the effects associated with the range and absolute values of the observations. Correlation coefficients approaching 1.0 imply near perfect relationships between the data. These tables show all of the correlation coefficients larger than 0.5, with those greater than 0.75 highlighted in bold. The pair-wise deletion option was also used to remove data in the analysis if data for one observation of a pair of parameters being compared was absent, but keeping the parameter in the complete table for other possible correlations. Also shown on these tables are the highly significant regression slope terms relating the dependent variables to the independent variables. Table 6-5 lists the high correlations associated with obvious relationships. These correlations show that the procedure was sensitive in identifying these obvious pairings. The correlations on this table range from about 0.65 to 0.9, and can be used as a quality control check of the procedure.

Table 6-4 Obvious Pearson Correlations

Independent and Dependent Variables	Pearson Coefficient	Regression slope term
water depth (ft) and water gallons	**0.78**	565
water depth (ft) and percent full	**0.88**	11
water gallons and percent full	0.64	0.016
sediment depth (ft) and sediment quantity (ft^3)	**0.79**	64

Table 6-6 are correlation pairings that are also obvious, and possibly also useful as indicators. Most of the coefficients are relatively high (up to 0.98), indicating mostly strong correlations. These relationships are between obviously related parameters, such as between total solids (TS) and conductivity (Figure 6.5), which has a coefficient of 0.84. The "obvious" relationship between turbidity and suspended solids, however, is relatively poor, at only 0.53 (Figure 6-6). It is therefore possible to use conductivity as a good indicator of TDS for almost all conditions, but using turbidity as a indicator for SS is more problematic. There were also relatively high correlations between filtered and total forms of solids, toxicity, COD, and zinc. The correlations between total and filtered forms of copper and lead were less, but still likely useful. The regression slope terms indicate that the filtered form of toxicity is about 91% of the unfiltered form, implying that very little toxicity reduction is accomplished with filtration. Of course, correlations between unfiltered and filtered constituents should generally be high, as the unfiltered concentrations should always be greater than the filtered concentrations.

Table 6-5 Obvious and Useful Correlations

Independent and Dependent Variables	Pearson Coefficient	Regression slope term
TDS and total solids	**0.98**	1.03
conductivity (µS/cm)and total solids	**0.84**	0.59
conductivity (µS/cm) and TDS	**0.85**	0.57
suspended solids and volatile total solids	0.60	0.58
suspended solids and volatile suspended solids	0.70	0.45
turbidity (NTU) and suspended solids	0.53	1.3
volatile total solids and volatile TDS	0.65	0.49
volatile total solids and volatile SS	**0.86**	0.61
toxicity and filtered toxicity (both light decrease)	**0.79**	0.91
COD and filtered COD	**0.76**	0.58
zinc and filtered zinc (both µg/L)	**0.78**	0.69
copper and filtered copper (both µg/L)	0.69	0.4
lead and filtered lead (both µg/L)	0.69	0.2

Table 6-7 shows the parameter correlations of most interest, as these are not as obvious as those listed above. These correlations are generally weaker than those shown on the previous tables (these range from 0.5 to 0.75), but deserve further investigation. Especially interesting are the frequent correlations between the unfiltered and filtered forms of zinc and the total and unfiltered forms of toxicity, for example. Another useful correlation shown is between copper and lead, indicating the relatively common joint occurrence of these two heavy metals.

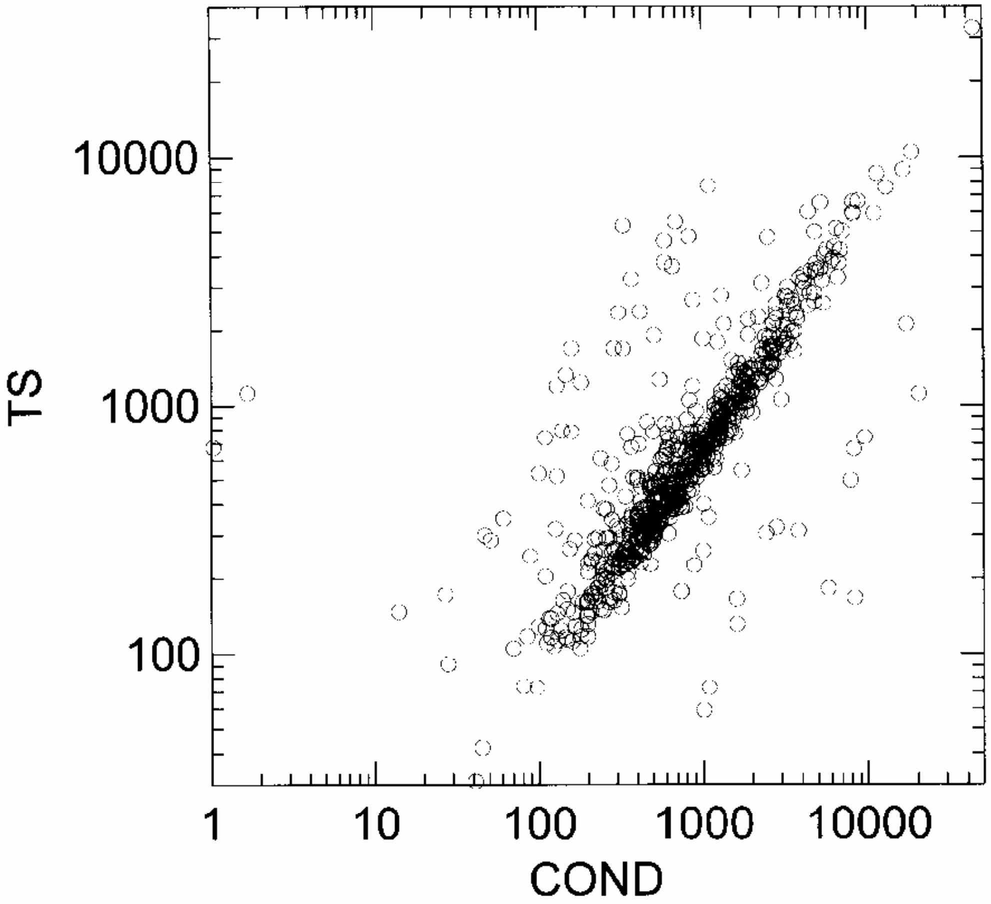


Figure 6-5 Strong correlation (0.84) between total solids and conductivity.

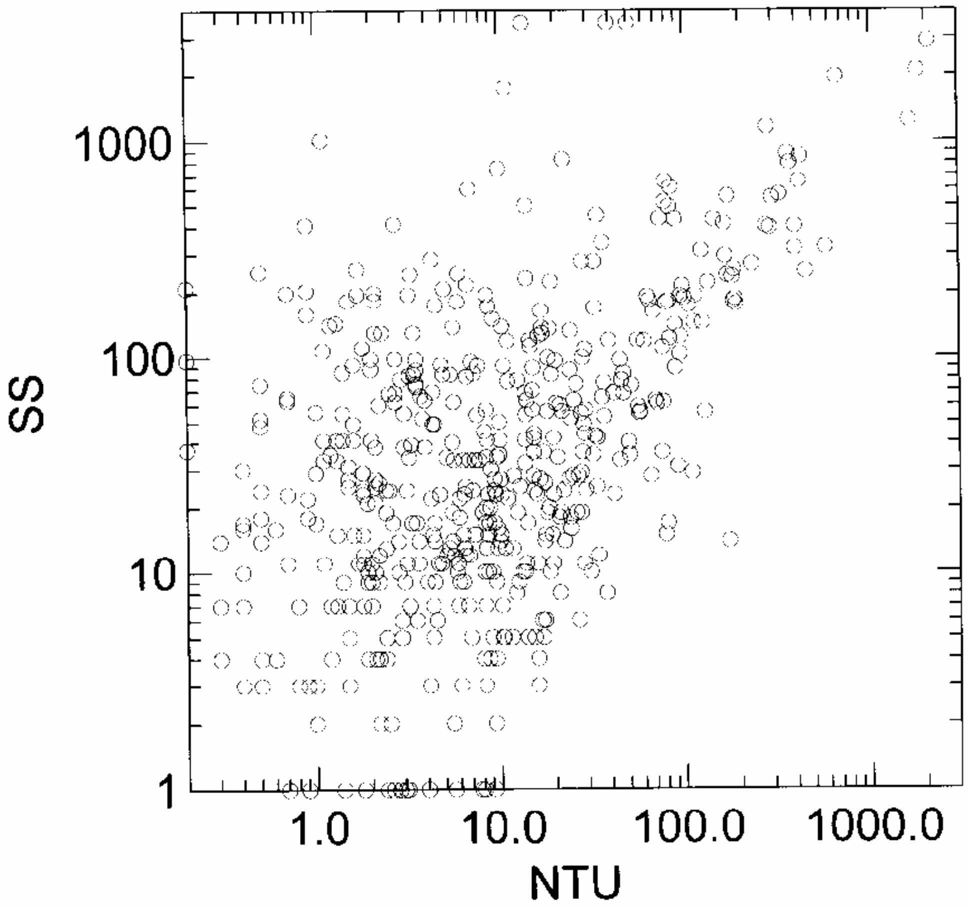


Figure 6-6 Weak correlation (0.53) between suspended solids and turbidity.

Table 6-6 Unexpected and Possibly Useful Correlations

Independent and Dependent Variables	Pearson Coefficient	Regression slope term
volatile TDS and hardness	0.66	1.3
filtered COD and phosphate	0.57	0.021
copper and lead (both µg/L)	0.52	0.32
zinc (µg/L) and toxicity (light decrease)	0.50	0.046
filtered zinc and toxicity (same as above)	0.55	0.058
zinc and filtered toxicity (same as above)	0.50	0.045
filtered zinc and filtered toxicity (same as above)	0.56	0.057
nitrate and ammonia	0.74	0.16

6.3.3 Complex Correlation Analyses

Additional analyses were conducted to identify more complex relationships between measured parameters and with manhole conditions. These analyses do not prove any cause and effect relationship between parameters and conditions, but they do support a "weight-of-evidence" approach for reasonable hypotheses developed through different and supporting statistical methods. The complex correlation procedures used here examine inter-relationships between possible groups of parameters, compared to the pair-wise only comparisons presented earlier. Analyses between sub-groups of measurements, separated by expected important factors, are also presented.

One method to examine complex relationships between measured parameters is by using hierarchical cluster analyses. Figure 6-7 is a tree diagram (dendogram) produced by SYSTAT, version 8, using the water quality data for water samples collected from manholes. A tree diagram illustrates both simple and complex relationships between parameters. Parameters having short branches linking them are more closely related than parameters linked by longer branches. In addition, the branches can encompass more than just two parameters. The length of the short branches linking only two parameters are indirectly comparable to the correlation coefficients (very short branches signify correlation coefficients close to 1). The main advantage of a cluster analyses is the ability to identify complex relationships that cannot be observed using a simple correlation matrix.

In Figure 6-7, the shortest branches connect TDS and TS. As noted previously, almost all of the total solids are dissolved. Conductivity is also closely related to both TDS and TS. Other simple relationships are comparable to the higher correlation coefficients shown previously (Zn and filtered Zn, VTS and VSS, ammonia and nitrates, COD and filtered COD, etc.). There are relatively few complex relationships shown on this diagram: total toxicity is closely related to filtered toxicity and then to zinc and filtered zinc; phosphate is closely related to both copper and filtered copper; and hardness is related to the volatile solids.

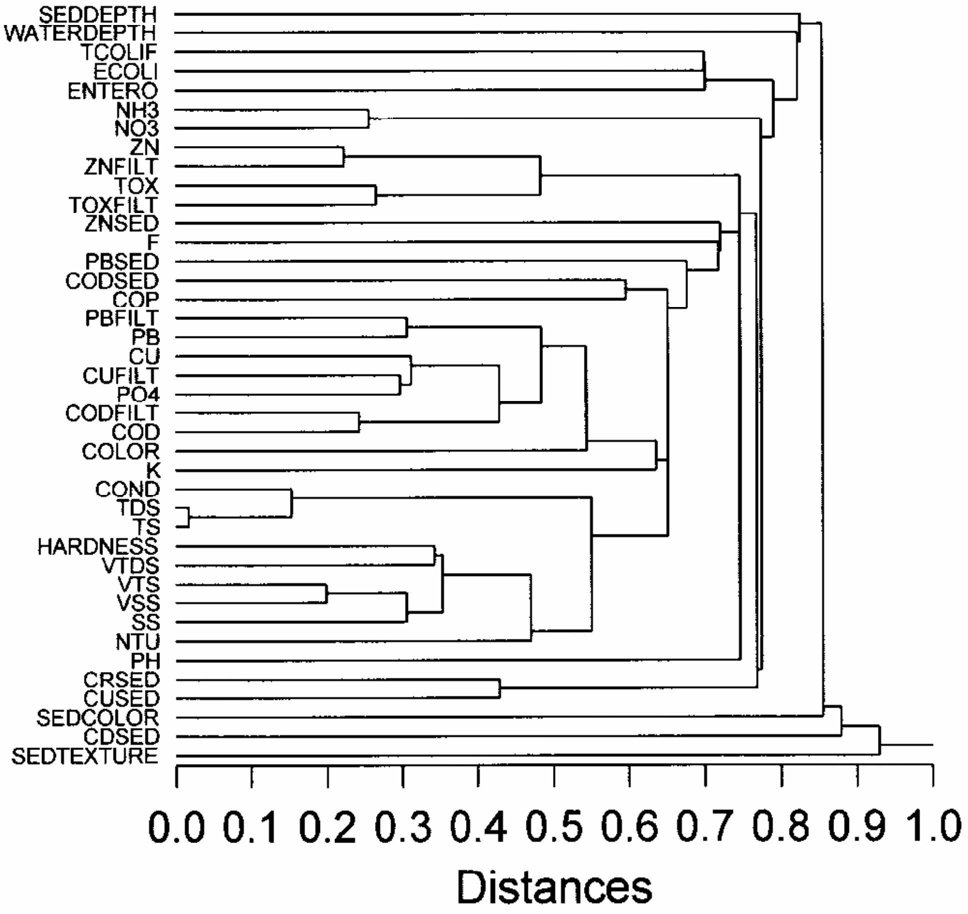


Figure 6-7 Dendogram showing complex relationships between constituents and parameters measured in water and sediment from telecommunication manholes

Another important tool to identify relationships and natural groupings of samples or locations is with principal component analyses (PCA). The data were auto-scaled before PCA in order to remove the artificially large influence of constituents having large values compared to constituents having small values. PCA is a sophisticated procedure where information is sorted to determine the components (usually constituents) needed to explain the variance of the data. Typically, very large numbers of constituents are available for PCA analyses with a relatively small number of sample groups desired to be identified. Component loadings for each principal component were calculated using SYSTAT, version 8, as shown in Table 6-8 (with the percent of the total variance explained for each component also shown).

Table 6-7 Loadings for Principal Components

Principal Component (% of total variance explained)	**1 (20.8%)**	**2 (14.2%)**	**3 (10.1%)**	**4 (9.4%)**	**5 (7.7%)**
Total solids	**0.771**	**-0.557**	0.011	0.190	0.104
TDS	**0.723**	**-0.629**	0.030	0.131	0.036
SS	0.424	0.322	-0.111	0.311	0.353
Turbidity	0.306	0.463	-0.110	0.381	0.381
pH	0.106	0.117	-0.338	-0.416	-0.206
Toxicity	0.269	0.173	0.339	0.154	**-0.674**
COD	**0.726**	0.304	0.057	-0.052	-0.037
Color	0.464	0.431	-0.059	-0.122	0.062
Conductivity	**0.649**	**-0.593**	0.041	0.193	0.058
Fluoride	0.280	-0.186	-0.177	-0.478	-0.045
Nitrate	0.170	0.183	**0.816**	-0.283	0.181
Phosphate	**0.571**	0.233	-0.154	-0.466	0.034
Hardness	0.385	-0.291	0.046	0.041	-0.278
Ammonia	0.107	0.088	**0.821**	-0.284	0.296
Potassium	0.344	0.031	-0.179	**-0.518**	-0.124
Zinc	0.206	0.355	0.265	0.370	**-0.613**
Copper	**0.521**	**0.523**	-0.211	-0.103	-0.056
Lead	0.298	0.488	-0.121	0.335	0.092

These first five components account for about 65% of the total variance of the data. The first two components are mostly dominated by total solids, TDS, COD, conductivity, phosphate, and copper. The third component is dominated mostly by nitrate and ammonia, the forth component is dominated by potassium, while the fifth component is dominated by toxicity and zinc.

Kurskal-Wallis nonparametric analyses were used like a one-way analysis of variance test to identify groupings of data that had significant differences between the groups, compared to within the groups. The groups examined were:

- Age
  - new (50 to 130 observations)
  - medium (65 to 150 observations)
  - old (100 to 300 observations)

- Season
  - winter (90 to 225 observations)
  - spring (50 to 100 observations)
  - summer (80 to 175 observations)
  - fall (50 to 115 observations)

- Land Use
  - commercial (75 to 200 observations)

  - industrial (30 to 65 observations)
  - residential (100 to 335 observations)

- Corrosion present in manhole?
  - yes (10 to 25 observations)
  - no (100 to 535 observations)

- Surface water inflow potential
  - low (85 to 190 observations)
  - medium (100 to 250 observations)
  - high (75 to 150 observations)

- Ladder in manhole?
  - yes (160 to 350 observations)
  - no (100 to 240 observations)

- Brick construction?
  - yes (25 to 40 observations)
  - no (350 to 530 observations)

- Traffic near manhole
  - light (85 to 160 observations)
  - medium (175 to 270 observations)
  - heavy (125 to 175 observations)

- Cable material in manhole
  - copper (200 to 370 observations)
  - copper and lead (50 to 110 observations)
  - neither (10 to 20 observations)

- EPA Rain Region
  - zone 1 (160 to 260 observations)
  - zone 2 (45 to 80 observations)
  - zone 3 (50 to 110 observations)
  - zone 4 (5 to 10 observations)
  - zone 5 (25 to 40 observations)
  - zone 6 (25 to 55 observations)
  - zone 7 (20 to 30 observations)
  - zone 8 (10 to 20 observations)

The number of data observations for each group component are also shown in the above list and has a significant effect on the probability of having a statistically significant difference between some of the group category components. The number of observations for some of the parameters are less than indicated, especially for those having low detection frequencies, or for screening parameters that were not evaluated for all samples. Most of the groupings had a large and relatively even number of observations in each subgroup. However, a few of the subgroups had small counts (such as for corrosion present in manholes, brick constructed manholes, non-metallic cable types, and for a couple of the rain zones). Table 6-9 lists the probabilities that the observed concentrations are the same amongst all of the categories. Probabilities smaller than 0.05 are considered significant and are indicated in bold.

Table 6-8 Kurskal-Wallis Probabilities that Concentrations are the same in each Category

mg/L, unless otherwise noted	**Total Number of Detectable Observations**	**Age**	**Season**	**Land Use**	**EPA Rain Region**
percent full of water	556	0.23	0.27	0.33	**<0.001**
sediment accum (ft^3)	441	**0.001**	0.16	0.069	**<0.001**
Total solids, mg/L	598	0.23	**<0.001**	0.53	**<0.001**
TDS	596	0.67	**<0.001**	0.4	**<0.001**
SS	483	**0.009**	0.25	0.36	0.21
VTS	598	0.1	**<0.001**	0.32	**<0.001**
VTDS	596	**0.028**	**<0.001**	0.13	**<0.001**
VSS	410	0.46	0.093	0.25	**<0.001**
Turbidity, NTU	598	0.67	**<0.001**	**0.002**	**<0.001**
pH	598	**0.03**	**<0.001**	**0.012**	**0.001**
Toxicity	394	**0.007**	0.086	0.14	**<0.001**
Toxicity, filtered	384	**0.001**	0.29	**0.024**	**0.001**
COD	596	**0.048**	**<0.001**	0.078	**<0.001**
COD, filtered	595	**0.001**	**<0.001**	**0.021**	**<0.001**
COD in sediment, mg/kg	320	**0.006**	0.79	**0.005**	**<0.001**
Color, color units	595	**0.026**	**0.032**	**0.035**	**<0.001**
conductivity, µS/cm	598	0.69	**<0.001**	0.53	**<0.001**
Total coliforms, #/100 mL	224	0.1	**<0.001**	0.5	**<0.001**
E. coli, #/100 mL	224	0.97	0.29	0.83	**<0.001**
Enterococci, #/100 mL	224	0.55	**0.001**	0.18	**0.018**
Fluoride, mg/L	594	0.57	**<0.001**	0.056	**<0.001**
NO3	595	0.26	0.064	0.78	**<0.001**
PO4	548	0.24	**<0.001**	0.36	**<0.001**
Hardness	598	**<0.001**	**<0.001**	**0.001**	**<0.001**
NH3	598	0.72	**0.039**	0.15	**<0.001**
K	593	**0.002**	0.11	**0.004**	**<0.001**
B	179	0.86	**0.009**	0.058	**0.031**
Zn, µg/L	541	**<0.001**	0.25	**<0.001**	**0.002**
Zn, filtered, µg/L	536	**<0.001**	0.19	**0.041**	**0.003**
Zn in sediment, mg/kg	275	0.78	0.45	0.56	**0.004**
Cu, µg/L	559	0.26	0.058	**0.009**	**0.008**
Cu, filtered, µg/L	554	0.079	**0.001**	0.063	**<0.001**
Cu in sediment, mg/kg	219	0.18	0.66	0.6	0.18
Pb, µg/L	555	**<0.001**	**0.013**	**0.029**	**0.005**
Pb, filtered, µg/L	552	**0.002**	**0.003**	**0.004**	0.084
Pb in sediment, mg/kg	237	**0.002**	0.58	0.76	0.33
Cr, µg/L	19	0.59	0.14	0.24	0.31
Cr in sediment, mg/kg	105	0.14	**0.001**	0.46	**<0.001**

Table 6.9 Kurskal-Wallis Probabilities that Concentrations are the same in each Category (cont.)

mg/L, unless otherwise noted	Total Number of Detectable Observations	Age	Season	Land Use	EPA Rain Region
Cd in sediment, mg/kg	45	0.055	**0.023**	0.091	0.11
di-n-butyl phthalate, µg/L	19	0.46	0.21	0.27	0.19
coprostanol, µg/L	23	0.061	0.62	0.71	0.15

Table 6.9 Kurskal-Wallis Probabilities that Concentrations are the same in each Category (cont.)

mg/L, unless otherwise noted	Total Number of Detectable Observations	Brick Const.?	Traffic	Cable material	Corrosion present in manhole?	Surface water inflow potential	Ladder in manhole?
Percent full of water	556	0.15	0.76	**0.008**	0.32	**0.004**	0.24
sediment accum (ft^3)	441	**0.029**	**<0.001**	**0.001**	0.054	**0.023**	**<0.001**
Total solids, mg/L	598	**0.041**	0.91	0.068	**0.011**	0.17	**<0.001**
TDS	596	0.094	0.76	**0.006**	**0.004**	0.25	**<0.001**
SS	483	0.22	0.18	0.13	0.76	**0.018**	**0.026**
VTS	598	**0.03**	0.19	**0.003**	0.16	**0.003**	**<0.001**
VTDS	596	0.091	0.12	**<0.001**	0.26	**0.038**	**<0.001**
VSS	410	0.59	0.44	0.98	0.45	**0.022**	**0.002**
Turbidity, NTU	598	**0.013**	0.093	0.29	0.074	0.078	0.18
pH	598	0.52	**<0.001**	**0.006**	0.28	0.37	0.22
Toxicity	394	**0.014**	0.21	0.11	0.95	0.16	**<0.001**
Toxicity, filtered	384	0.063	**0.024**	0.19	0.7	0.3	**0.014**
COD	596	**0.001**	0.055	0.37	0.92	**0.018**	**0.048**
COD, filtered	595	**0.01**	**0.046**	**<0.001**	0.19	0.1	**<0.001**
COD in sediment, mg/kg	320	0.71	0.14	0.93	0.39	0.2	0.66
Color, color units	595	0.37	0.081	0.28	0.28	**0.001**	0.66
conductivity, µS/cm	598	**0.006**	0.54	0.28	**0.011**	**0.024**	**<0.001**
Total coliforms, #/100 mL	224	0.56	0.55	0.23	0.54	0.2	0.42
E. coli, #/100 mL	224	0.64	0.53	0.5	0.3	0.97	0.31
Enterococci, #/100 mL	224	0.79	0.15	0.54	0.66	0.41	**0.025**
Fluoride, mg/L	594	**0.004**	0.15	**0.006**	0.47	**0.016**	**<0.001**
NO3	595	**0.003**	0.088	**0.002**	0.14	0.49	0.58
PO4	548	**<0.001**	0.3	0.85	0.5	**0.002**	**<0.001**

Table 6.9 Kurskal-Wallis Probabilities that Concentrations are the same in each Category (cont.)

mg/L, unless otherwise noted	**Total Number of Detectable Observations**	**Brick Const.?**	**Traffic**	**Cable material**	**Corrosion present in manhole?**	**Surface water inflow potential**	**Ladder in manhole?**
Hardness	598	0.62	0.77	**<0.001**	0.055	**0.006**	**0.033**
NH3	598	0.1	0.31	0.074	0.12	0.37	**0.002**
K	593	0.98	**0.024**	**<0.001**	**0.031**	0.56	**<0.001**
B	179	0.86	0.53	0.75	0.8	0.54	**0.005**
Zn, µg/L	541	0.2	0.53	0.072	0.2	0.54	**0.005**
Zn, filtered, µg/L	536	0.22	0.14	**0.002**	0.62	0.68	0.13
Zn in sediment, mg/kg	275	0.2	0.86	0.99	0.83	0.5	0.96
Cu, µg/L	559	**0.001**	0.98	**0.01**	0.9	0.072	**0.008**
Cu, filtered, µg/L	554	0.35	0.16	0.22	0.52	0.38	**0.001**
Cu in sediment, mg/kg	219	**0.015**	0.2	0.22	0.7	0.89	0.38
Pb, µg/L	555	**0.006**	0.15	**<0.001**	0.1	**0.035**	**<0.001**
Pb, filtered, µg/L	552	**0.05**	0.074	0.2	0.17	**0.018**	**0.001**
Pb in sediment, mg/kg	237	**0.003**	**0.011**	**<0.001**	0.5	0.15	**0.005**
Cr, µg/L	19	0.85	0.19	0.37	0.84	0.15	0.35
Cr in sediment, mg/kg	105	0.17	**0.03**	0.9	0.99	**0.033**	**0.015**
Cd in sediment, mg/kg	45	0.55	0.93	0.39	0.63	**0.006**	**0.004**
di-n-butyl phthalate, µg/L	19	na	0.71	0.082	na	0.29	0.76
coprostanol, µg/L	23	0.49	0.059	0.22	0.068	0.056	0.85

The grouping that affected the most parameters was the EPA Rain Region, followed by the presence of ladders, season, age, surface water inflow potential, brick construction, cable material, and land use. Corrosion and traffic affected the fewest parameters. The parameters affected by the most groupings were sediment accumulation, volatile total solids, filtered COD, hardness, potassium, and lead. Those affected by none of the groupings included chromium, and the organics (likely due to infrequent detections of these compounds). Zinc and copper sediment conditions were both affected by only one grouping each because of their relatively consistent concentrations found in all sediment samples.

Grouped box and whisker plots were prepared for selected parameters and for each grouping that was identified as having a significant difference during the Kurskal-Wallis analyses. The percentage of the manhole volume full of water (Figure E-1, in Appendix E) was affected by region, with wet areas resulting in larger percentages, and dry areas resulting in lower percentages, as expected. In addition, manholes noted as having a low likelihood of inflowing water appear to have slightly lower average "full percentages" than other manholes. It is difficult to hypothesize why cable type would affect the amount of water in the manholes, unless different sealants, or ages of the installations would allow more leakage into manholes having (supposedly) older lead cables.

Larger sediment accumulations (Figure E-2) were associated with older areas, high and medium likelihoods of inflowing water, the use of brick construction, and medium and heavy traffic, all possible mechanisms that may be associated with increased sediment being able to enter a manhole. The west coast samples also had lower sediment accumulations than elsewhere. The absence of ladders, or the use of lead cables, also were associated with high sediment accumulations, with no direct reason, except possibly age of the manhole.

Figure E-3 shows higher total solids and TDS concentrations associated with areas having less rain and lower concentrations in areas having more rain, possibly due to dilution. High TDS is shown for winter seasons, as expected, and the lowest with the fall, as previously noted. Cable type, corrosion, and ladder were also identified as being associated with TDS differences.

Figure E-4 shows high phosphate averaged concentrations associated with the southwest sampling locations, and with summer and winter seasons. Low averaged concentrations were noted in the southeast (although the largest phosphate concentration found was at a southeastern location). Areas having high inflow potential had lower averaged phosphate concentrations than other areas (dilution again?). Ladders and bricks were also identified as being associated with phosphate concentration variations.

Bacteria patterns are shown on Figure E-5, with significant associations of rain region being common to all three bacteria types measured. The Pacific northwest samples generally had the lowest values. Spring was lowest for total coliforms, while winter and fall was lowest for enterococci. The presence of ladders was also noted as having a significant effect on enterococci.

The lack of ladders and bricks in manholes, and newer areas, were associated with higher levels of toxicity (Figure E-6), all opposite of what was originally expected. Copper, lead, and zinc associations are shown on Figures E-7 through E-9. All had significant associations with different subcategories of region and land use. Copper and lead had very similar regional patterns, and all three had higher average concentrations in residential areas. Cable material having copper alone, or with lead, was associated with higher copper and lead water concentrations (the cable "type" does not indicate the material in contact with the water, as all cables are covered in a plastic sheathing, but the metals would affect sediment due to scraps falling to the manhole bottom during cable splicing). However, manholes with ladders had lower copper and zinc concentrations (there are many other sources of galvanized metal in manholes, including cable brackets, etc.). Brick manholes were associated with higher copper and lead water concentrations, possibly because of copper and leaded cables in these older manholes affected the sediments, which in turn affect the water if given sufficient time. Fall samples had higher lead water concentrations, while the other three seasons had slightly lower average lead concentrations. Manholes having high inflow potential also had the lowest averaged lead concentrations. Manholes in older areas had higher averaged lead water concentrations, but lower averaged zinc water concentrations.

Table 6-10 summarizes these associations, separated by expected, opposite, and for unknown reasons.

Table 6-9 Significant Kurskal-Wallis Groupings

	Reasonable Associations	Opposite to Expected Associations	Associations having Unknown Reasons
Water depth in manhole, % of full	Geographical area, Inflowing water potential		Cable type in manhole
Sediment accumulation in manholes, ft^3	Geographical area, Age of surrounding area, Inflowing water potential, Brick construction, Age of surrounding area		Ladder present, Cable type in manhole,
Total solids, mg/L	Geographical area		
TDS, mg/L	Geographical area, Season of sample collection		Cable type, Corrosion present, Ladder present
Phosphate, mg/L	Geographical area, Season of sample collection, Inflowing water potential		Ladder present, Brick construction
Total coliforms, #/100 mL	Geographical area, Season of sample collection		
E. coli, #/100 mL	Geographical area		
Enterococci, #/100 mL	Geographical area, Season of sample collection		Ladder present
Toxicity, I25, % light reduction		Ladder present, Brick construction, Age of surrounding area	
Copper, μg/L	Geographical area, Land use Brick construction Cable type	Ladder present	
Lead, μg/L	Geographical area, Land use Brick construction Cable type Season of sample collection Inflowing water potential Age of surrounding area		
Zinc, μg/L	Geographical area, Land use	Ladder present, Age of surrounding area	

Possible spurious correlations obviously occurred, although most of the associations appear reasonable and support the experimental design that directed the sampling effort. The associations presenting the most potential problems for explanation were manhole characteristics (the presence of ladders, corrosion in manholes, cable types, and brick construction), although age of the surrounding area was also associated with two unlikely associations. The age notation was periodically problematic for the field crews as it was sometimes difficult to obtain a reasonable estimate in areas that were very diverse.

6.3.4 Model Building

The most reasonable correlations (region, land use, age, and season) were used in these analyses to construct predictive models, based on the full-factorial sampling effort. The expanded geographical coverage, due to later-joining project participants from throughout the nation, allowed a geographical factor to also be considered in the final analyses. The sampling effort did not include a sufficient or representative number of manholes to be sampled having other varying conditions of other potentially interesting factors (such as the presence of ladders or corrosion in manholes, or traffic conditions near the manhole). Therefore, the model building process was based solely on the full 2^4 factorial design using region, land use, age, and season, as the main factors, plus all possible interactions.

Again, because of the participation of local telephone companies from throughout the nation, we were able to include a much better representation for the regional factor than originally expected.

Since the experimental design was a full two-level factorial design, the following groupings were used to define the two levels used for each main factor, based on the number of observations in each grouping, the previous grouping evaluations, and the initial exploratory data analyses:

- age: old and medium combined (group A), vs. new (group B)
- season: winter and fall combined (group A), vs. summer and spring combined (group B)
- land use: commercial and industrial areas combined (group A), vs. residential areas (group B)
- region: EPA rain regions 1, 2, 8, and 9 (northern tier) (group A), vs. regions 3, 4, 5, 6, and 7 (milder) (group B)

The 597 sets of data observations used for this analysis were therefore divided into 16 categories corresponding to the complete factorial design, as shown in Table 6-11. Some samples did not have the necessary site information needed to correctly categorize the samples and were therefore not usable for these analyses. The “Group A” categories were assigned “+” values and the “Group B” categories were assigned “-” values in the experimental design matrix for the main factors. These 16 factorial groups account for all possible combinations of the four main factors. Twelve to more than 100 samples were represented in each factorial group and were used to calculate the means and standard errors.

Table 6-10 Factorial Design for Manhole Water and Sediment Characteristics

group	Number of observations in group	region	land use	age	season	region x land use	region x age	region x season	land use x age	land use x season	age x season	region x land use x age	region x land use x season	region x age x season	land use x age x season	region x land use x age x season
		R	L	A	S	RL	RA	RS	LA	LS	AS	RLA	RLS	RAS	LAS	RLAS
1	65	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2	50	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-
3	13	+	+	-	+	+	-	+	-	+	-	-	+	-	-	-
4	13	+	+	-	-	+	-	-	-	-	+	-	-	+	+	+
5	113	+	-	+	+	-	+	+	-	-	+	-	-	+	-	-
6	70	+	-	+	-	-	+	-	-	+	-	-	+	-	+	+
7	13	+	-	-	+	-	-	+	+	-	-	+	-	-	+	+
8	12	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-
9	41	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-
10	36	-	+	+	-	-	-	+	+	-	-	-	+	+	-	+
11	22	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
12	19	-	+	-	-	-	+	+	-	-	+	+	+	-	+	-
13	42	-	-	+	+	+	-	-	-	-	+	+	+	-	-	+
14	47	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-
15	21	-	-	-	+	+	+	-	+	-	-	-	+	+	+	-
16	20	-	-	-	-	+	+	+	+	+	+	-	-	-	-	+

Table 6-11 Results of Full Factorial Statistical Tests on Characteristics of Water and Sediment Samples Collected from Telecommunication Manholes

		Water depth (ft)	Sediment depth (ft)	Manhole height (ft)	Manhole width (ft)	Manhole length (ft)	Water volume (gallons)	Manhole % full of water	Sediment volume (ft^3)	Total Solids (mg/L)	Dissolved Solids (mg/L)	Volatile Total Solids (mg/L)
Overall average:		3.97	0.13	8.85	6.03	10.67	2002.52	45.49	8.33	957.84	884.96	157.67
Total number of observations:		566	536	578	527	493	458	548	433	590	588	590
Calculated polled standard error:		1.02	0.08	0.92	1.06	1.85	890.31	11.04	6.57	489.23	470.53	101.11
Standard error from high level interactions:		0.23	0.01	0.09	0.24	0.56	193.65	2.59	1.71	75.82	76.11	16.51
region	R	**1.10**	**0.12**	**-1.20**	-0.12	-0.29	799.91	**20.78**	**9.09**	**700.34**	**678.59**	**92.78**
land use	L	0.42	0.02	0.53	-0.45	0.31	-101.74	2.01	0.91	127.88	119.74	19.09
age	A	-0.74	0.02	0.21	-0.34	0.01	-299.97	-8.64	1.29	90.01	63.86	-27.72
season	S	-0.33	-0.01	0.01	-0.03	0.02	-261.35	-2.97	-1.33	23.94	15.19	-17.96
region x land use	RL	-0.26	-0.03	-0.45	-0.12	0.01	-100.07	1.30	-2.48	195.61	216.54	9.55
region x age	RA	-0.40	0.02	-0.20	0.09	**1.20**	63.84	-3.97	0.72	-8.82	-50.23	-16.27
region x season	RS	0.19	0.02	0.07	0.12	-0.07	155.42	1.42	1.75	5.38	21.47	-26.46
land use x age	LA	0.07	-0.03	-0.21	**1.20**	-0.34	646.21	0.95	0.75	115.83	112.09	38.23
land use x season	LS	-0.11	0.02	-0.04	0.11	-0.24	-138.18	-0.54	0.78	-119.01	-125.23	-24.96
age x season	AS	0.15	0.01	0.09	0.02	0.24	68.11	1.07	0.51	44.41	25.81	5.36
region x land use x age	RLA	0.25	0.02	0.19	-0.50	**1.23**	313.09	3.05	3.02	-69.60	-76.00	30.84
region x land use x season	RLS	-0.33	-0.01	0.01	-0.03	0.02	-261.35	-2.97	-1.33	23.94	15.19	-17.96
region x age x season	RAS	-0.21	0.00	-0.03	0.17	-0.20	-77.06	-2.84	1.82	81.66	68.50	0.88
land use x age x season	LAS	-0.21	-0.01	0.01	-0.01	-0.12	-109.32	-2.35	-0.50	-57.77	-60.19	8.43
region x age x land use x season	RALS	-0.05	-0.02	-0.04	-0.11	0.07	-57.15	-1.37	-0.46	-115.40	-121.00	-4.12

Table 6.12 Results of Full Factorial Statistical Tests on Characteristics of Water and Sediment Samples Collected from Telecommunication Manholes (cont.)

		Volatile Dissolved Solids (mg/L)	Volatile Suspended Solids (mg/L)	Suspended Solids (mg/L) (direct)	% Volatile Solids of sediment	Turbidity Unfiltered (NTU)	Turbidity Filtered (NTU)	Toxicity Unfiltered (I25% Red)	Toxicity Filtered (I25% Red)	COD Unfiltered (mg/L)	COD Filtered (mg/L)
Overall average:		129.95	51.04	52.81	6.67	28.52	1.50	44.96	44.74	30.80	21.24
Total number of observations:		588	406	540	357	590	590	389	380	588	587
Calculated polled standard error:		88.98	70.46	50.58	3.02	30.07	1.09	17.02	16.95	18.27	13.94
Standard error from high level interactions:		10.62	15.30	11.27	0.94	6.11	0.25	5.58	4.31	4.40	2.60
region	R	**81.74**	15.77	11.15	2.65	18.72	0.26	-12.25	-5.74	-13.72	-7.71
land use	L	0.19	28.89	-19.23	-0.20	-19.27	-0.75	-9.23	**-14.91**	-0.21	-0.67
age	A	-40.60	17.26	11.20	2.00	5.52	-0.16	-8.14	**-13.54**	-4.29	-7.61
season	S	-21.48	-4.41	18.98	-1.81	7.06	-0.36	-6.17	-3.29	-0.84	-1.55
region x land use	RL	10.17	7.74	-25.70	1.46	-16.68	-0.19	6.91	-0.34	-0.90	0.73
region x age	RA	-42.08	41.10	31.68	-1.17	14.91	-0.11	7.13	1.11	4.57	2.64
region x season	RS	-17.99	-2.26	-14.79	-0.43	-7.70	-0.29	5.19	0.41	3.09	4.73
land use x age	LA	32.11	8.07	-17.18	-1.85	-8.14	0.25	0.99	6.23	-9.35	-4.49
land use x season	LS	-16.63	-6.12	-18.13	0.21	-5.79	0.46	2.88	6.45	-3.59	-2.13
age x season	AS	-1.55	9.76	-0.50	0.58	0.60	0.29	2.55	6.02	1.81	0.31
region x land use x age	RLA	6.65	32.73	-3.61	-0.01	-0.40	0.13	-6.26	-3.14	3.99	2.66
region x land use x season	RLS	-21.48	-4.41	18.98	-1.81	7.06	-0.36	-6.17	-3.29	-0.84	-1.55
region x age x season	RAS	-4.05	-1.62	6.25	0.95	3.85	0.25	-8.72	-8.05	-8.17	-4.12
land use x age x season	LAS	3.39	7.52	0.82	0.05	-7.96	-0.21	-0.88	-2.70	2.69	1.60
region x age x land use x season	RALS	-5.49	-4.59	-14.90	0.41	-7.62	-0.27	-1.29	-0.05	2.48	2.17

Table 6.12 Results of Full Factorial Statistical Tests on Characteristics of Water and Sediment Samples Collected from Telecommunication Manholes (cont.)

		COD mg/kg dry sediment	pH	Color Unfiltered	Color Filtered	Conductivity (µS/cm)	Total Coliform (MPN/100 mL)	*E. coli* (MPN/100 mL)	Entero-cocci (MPN/100 mL)	Fluoride (mg/L)
Overall average:		105200.92	8.59	49.19	27.66	1385.60	2056.96	171.56	398.13	0.39
Total number of observations:		333	590	590	590	590	225	225	225	586
Calculated polled standard error:		66053.07	7.95	49.48	24.69	742.01	1119.82	463.24	903.42	0.12
Standard error from high level interactions:		12760.55	1.97	12.98	5.60	129.75	621.91	129.53	326.53	0.05
region	R	**78579.17**	1.88	-4.32	-18.81	**1151.67**	458.14	198.71	-35.17	-0.05
land use	L	4532.72	2.11	-11.37	3.53	205.59	343.48	52.80	155.47	0.04
age	A	16182.47	1.95	-11.94	-12.61	30.29	-539.18	7.47	-399.15	0.00
season	S	-16815.29	-1.76	-5.17	3.27	244.08	-1103.80	-204.06	-363.19	-0.09
region x land use	RL	17137.33	2.10	-16.03	-5.64	450.21	-275.52	59.43	26.35	0.02
region x age	RA	-20079.08	1.98	3.98	7.11	45.29	137.95	-61.74	128.68	-0.05
region x season	RS	-11711.43	-2.06	-20.74	-4.58	-82.80	-1172.79	-204.99	-281.17	-0.02
land use x age	LA	-24373.31	2.00	-4.28	-10.80	86.87	-859.77	-104.25	-254.48	0.05
land use x season	LS	-568.16	-2.11	11.58	4.31	-12.40	-693.41	-118.71	-433.02	-0.02
age x season	AS	21520.74	-2.03	-1.50	-3.35	16.03	662.65	70.36	241.13	0.03
region x land use x age	RLA	-7907.59	2.07	18.68	8.21	-7.55	-101.03	-137.66	-204.62	-0.04
region x land use x season	RLS	-16815.29	-1.76	-5.17	3.27	244.08	-1103.80	-204.06	-363.19	-0.09
region x age x season	RAS	8863.49	-2.07	10.86	1.94	118.46	108.51	113.09	140.94	0.05
land use x age x season	LAS	-14278.79	-1.98	-18.07	-6.58	48.34	271.91	90.94	549.46	0.01
region x age x land use x season	RALS	13652.07	-1.97	-4.66	5.61	-90.35	-787.03	47.31	-193.72	0.03

Table 6.12 Results of Full Factorial Statistical Tests on Characteristics of Water and Sediment Samples Collected from Telecommunication Manholes (cont.)

		Nitrate (mg/L)	Phosphate (mg/L)	Hardness (mg/L as CaCO3)	Ammonia (mg/L)	Potassium (mg/L)	Boron (mg/L)	Zinc Unfiltered (µg/L)	Zinc Filtered (µg/L)
Overall average:		3.06	0.31	273.14	0.37	14.37	0.31	648.57	498.81
Total number of observations:		589	542	590	590	588	180	533	528
Calculated polled standard error:		8.09	0.31	107.02	1.74	13.99	0.52	269.34	247.20
Standard error from high level interactions:		2.02	0.07	21.68	0.43	2.07	0.13	89.21	91.39
region	R	0.28	-0.10	31.82	**0.49**	**-9.10**	0.14	-223.83	-122.58
land use	L	1.93	-0.15	-16.74	0.37	0.63	0.21	-246.26	-101.69
age	A	-2.80	0.19	-67.88	-0.39	2.42	-0.09	-252.09	-230.57
season	S	1.74	0.04	-32.70	0.45	-0.43	0.06	-124.14	-135.70
region x land use	RL	2.21	0.12	27.76	0.39	0.80	0.21	32.86	13.69
region x age	RA	-0.75	-0.14	-38.35	-0.39	-0.56	-0.12	119.95	34.16
region x season	RS	2.44	-0.08	4.28	0.48	1.40	0.12	34.49	28.42
land use x age	LA	-2.29	-0.21	**80.70**	-0.50	-1.92	-0.05	46.59	20.31
land use x season	LS	1.28	-0.07	-1.84	0.40	-3.49	0.15	33.52	-2.17
age x season	AS	-0.89	0.09	6.02	-0.40	-2.45	-0.11	81.38	114.03
region x land use x age	RLA	-1.77	0.13	-15.64	-0.39	-2.98	-0.14	-77.87	-79.89
region x land use x season	RLS	1.74	0.04	-32.70	**0.45**	-0.43	0.06	-124.14	-135.70
region x age x season	RAS	-2.64	0.01	-23.42	-0.37	3.01	-0.15	-127.26	-96.63
land use x age x season	LAS	-1.38	-0.05	17.47	-0.46	-1.77	-0.16	14.34	69.00
region x age x land use x season	RALS	-2.30	0.01	-13.45	-0.46	0.21	-0.11	43.75	53.51

Table 6.12 Results of Full Factorial Statistical Tests on Characteristics of Water and Sediment Samples Collected from Telecommunication Manholes (cont.)

		Zinc sediment (mg/kg)	Copper Unfiltered (µg/L)	Copper Filtered (µg/L)	Copper sediment (mg/kg)	Lead Unfiltered (µg/L)	Lead Filtered (µg/L)	Lead sediment (mg/kg)
Overall average:		3103.21	33.29	16.39	332.35	19.91	4.91	3178.74
Total number of observations:		271	552	546	215	547	544	233
Calculated polled standard error:		3347.84	33.60	20.36	na	17.99	4.77	na
Standard error from high level interactions:		841.43	4.02	3.81	142.50	4.99	1.00	4537.82
region	R	-80.81	-18.45	-16.63	-94.26	-4.57	-3.59	-4786.67
land use	L	-1410.25	-19.08	-9.93	23.15	-10.43	-2.74	-4718.76
age	A	-86.31	26.72	11.44	299.02	9.47	2.22	-3578.94
season	S	-806.70	2.65	5.54	-183.44	3.31	1.68	4510.31
region x land use	RL	5.26	17.28	9.14	64.67	1.92	0.68	4588.65
region x age	RA	-780.38	-9.25	-10.54	-135.48	3.76	-0.43	4451.73
region x season	RS	884.05	-9.42	-1.95	156.63	-4.55	-1.06	-4318.80
land use x age	LA	1021.87	-22.25	-8.17	-80.36	-5.67	-1.51	4490.85
land use x season	LS	357.50	-3.80	-4.51	-39.55	-2.59	-1.96	-4702.65
age x season	AS	469.26	0.93	2.05	-155.72	-2.02	-0.44	-4767.03
region x land use x age	RLA	128.72	7.27	6.13	-18.72	-7.09	0.55	-4459.42
region x land use x season	RLS	-806.70	2.65	5.54	-183.44	3.31	1.68	4510.31
region x age x season	RAS	-192.21	-0.25	-0.03	226.68	6.29	1.08	4874.38
land use x age x season	LAS	-725.52	0.75	0.07	40.99	3.15	0.10	4669.87
region x age x land use x season	RALS	1519.59	-4.49	2.09	120.25	-3.71	0.84	-4142.03

The factorial analyses were conducted using the group means. In addition, all parameters were also transformed by $\log_{10}$ to account for their correct log-normal data distributions. Table 6-12 shows the results of these analyses (using the group mean values). Seventeen parameters were found to have significant models, with the most commonly occurring significant factor being the geographical region. Several parameters had significant interacting factors. All of the calculated effects for each parameters were plotted on probability plots (Figures E-10 through E-14, in Appendix E) to confirm the significant factors, which are indicated in bold type on Table 6-12

Seventeen models were identified that had significant factors or combinations of factors. These models are listed below, along with the calculated values corresponding to the different levels for the significant factors:

Models with significant regional factors alone:

	R+ (northern tier states)	R- (milder climate)
Water depth (ft) = 3.97 + 0.55 R	4.52 ft	3.42 ft
Sediment depth (ft) = 0.13 + 0.06 R	0.19 ft	0.07 ft
Manhole height (ft) = 8.85 – 0.60 R	8.25 ft	9.45 ft
Manhole water (% full) = 45.5 +10.4 R	55.9 %	35.1 %
Sediment volume (ft^3) = 8.3 + 4.5 R	12.9 ft^3	3.8 ft^3
Total solids (mg/L) = 958 + 350 R	1308 mg/L	608 mg/L
TDS (mg/L) = 885 + 339 R	1224 mg/L	546 mg/L
Volatile total solids (mg/L) = 158 + 46 R	204 mg/L	112 mg/L
Volatile dissolved solids (mg/L) = 130 + 82 R	172 mg/L	88 mg/L
Sediment COD (mg/kg) = 105,200 + 39,300 R	144,500 mg/L	65,900 mg/L
Conductivity (µS/cm) = 1390 + 576 R	1960 µS/cm	810 µS/cm
Potassium (mg/L) = 14.4 – 4.6 R	9.8 mg/L	18.9 mg/L

Model with significant land use and age effects alone:

	L+ and A+	L+ and A-	L- and A+	L- and A-
Filtered toxicity (I25%) = 44.7 – 7.5 L – 6.7 A	30.5 %	44.1 %	45.4 %	60.0 %

Models with significant land use and age interactions alone:

	LA+	LA-
Manhole width (ft) = 6.03 + 0.60 LA	6.63 ft	5.43 ft
Hardness (mg/L as $CaCO_3$) = 273 + 40 LA	313 mg/L	233 mg/L

Model with complex interactions with regional, land use, and age factors:

	RLA+	RLA-
Manhole length (ft) = 10.7 + 0.62 RLA	11.3 ft	10.1 ft

Model with complex interactions with regional, land use, and season factors:

	RLS+	RLS-
Ammonia (mg/L) = 0.37 + 0.23 RLS	0.60 mg/L	0.14 mg/L

The effects and interactions are described below:

L+ and A+ (commercial or industrial and medium or old)
L+ and A- (commercial or industrial and new)
L- and A+ (residential and medium or old)
L- and A- (residential and new)

RLA+ (northern tier states and commercial or industrial and old; northern tier states and residential and new; milder climate and commercial or industrial and new; milder climate and residential and old)
RLA- (northern tier states and commercial or industrial and new; northern tier states and residential and old; milder climate and commercial or industrial and old; milder climate and residential and new)

RLS+ (northern tier states and commercial or industrial and winter; northern tier states and residential and summer; milder climate and commercial or industrial and summer; milder climate and residential and winter)
RLS- (northern tier states and commercial or industrial and summer; northern tier states and residential and winter; milder climate and commercial or industrial and winter; milder climate and residential and summer)

Obviously, the more complex interactions are more likely to be random, but the two-way interactions, and especially models having one or two main factors, are much more likely. The models containing only a single factor were mostly identified as being significant during the earlier described statistical tests.

Residual analyses were also conducted for each of these 17 models, as shown on Figure E-15, in Appendix E. The predicted values were compared against all 597 data observations and their differences were plotted on probability plots. Legitimate models would produce residual probability distributions that are mostly random in nature (a straight line on a probability plot). These residual plots show that, in many cases, the upper 15 to 25 percent of the data are not adequately explained by the models. The models are therefore most useful to describe more typical conditions, from the lowest values to the 75th, or possible higher, percentiles. The most extreme conditions that were observed in each category were more associated with factors other than those included in these models. As noted previously, much additional information was gathered and used in the simpler statistical tests previously presented that examined these other factors, but these other data were not adequately represented in each of the 16 major data grouping used in these factorial analyses. The following section examines the extreme conditions in more detail to attempt to identify patterns associated with the manholes that had the poorest water and sediment quality.

6.3.5 Extreme Observations

As noted above, the factorial models developed for predicting the quality of water found in telecommunication manholes were not generally suited for the worst (extreme) cases. Since these situations are typically of high interest, further statistical analyses were conducted to identify patterns and conditions associated with these special manholes. The most important water quality constituents (based on potential exceedences of criteria, or having received the most concern during previous evaluations of water from manholes) were used to rank each separate manhole. The rankings were then averaged to identify the manholes having the poorest quality water. The water quality constituents used for these rankings were as follows:

- Suspended solids
- Turbidity
- Conductivity
- Volatile total solids
- pH
- COD
- Phosphate
- Ammonia
- Nitrate

- Toxicity
- Copper
- Filtered copper
- Lead
- Filtered lead
- Zinc
- Filtered zinc

The observed water quality was ranked according to these constituents and the top ten percent where when compared to the other 90%. The manholes selected in this group of high constituent values are shown on Table 18. Most EPA rain regions and all participating companies are represented in the list. In addition, about half of the samples were from manholes during repeat samplings at other seasons. Since the manholes were sampled during pumping operations (the manholes were almost completely emptied), the repeated poor quality water found in these manholes indicates that the sources of the poor quality water was relatively consistent for these areas and not the result of a single incident.

Table 6-12 Manholes Containing the Highest Water Quality Concentrations

Location	EPA Rain Region	Season	Age	Land Use
Ameritech				
4610 Tokay Blvd, Madison, WI	1	winter	old	resid
4610 Tokay Blvd, Madison, WI	1	summer	old	resid
402 Franklin St., Madison, WI	1	winter	old	resid
402 Franklin St., Madison, WI	1	summer	old	resid
5301 Cottage Grove Road, Madison, WI	1	winter	medium	resid
575 Science Dr., Madison, WI	1	winter	new	indus
Agriculture Drive, Madison, WI	1	summer	new	resid
1548 Carolina, Gary, IN	1	winter	old	resid
East 56th & Rosslyn, Indianapolis, IN	1	winter	old	resid
White & Edward Streets (NE corner), Frankfort, IL	1	winter	old	commer
Rte. 30 & School House Road (NE Corner), New Lenox, IL	1	summer	old	resid
Scovel between Grand Blvd & Vinewood, Detroit, MI	1	summer	old	resid
Grand River & Mackinaw, Detroit, MI	1	summer	old	commer
Old Fort & Woodruff, Rockwood, MI	1	summer	new	resid
Toledo-Dix South of Eureka, Southgate, MI	1	summer	old	commer
AT&T				
12th Avenue No. between 31st and 320 Streets, Billings, MT	8	summer	old	resid
MH #11672 - Highway 3, Billings, MT	8	summer	new	commer
Virginia Lane and Cotton Blvd., Billings, MT	8	summer	old	resid
19th & 20, Omaha, NE	9	winter	old	commer
6th Street & Willow, Omaha, NE	9	summer	old	resid
MH #21 27th & 20, Omaha, NE	9	summer	old	commer
MH #22 29th & 20, Omaha, NE	9	summer	old	commer
MH #112, Angelica, St Louis, MO	4	winter	old	commer
MH #322, St. Louis, MO	4	winter	new	resid
Highway 61/67, St. Louis, MO	4	summer	new	resid
MH #270, Vickers, St. Louis, MO	4	summer	old	commer
MH # 04, HW55 & Richardson Rd, St. Louis, MO	4	summer	new	commer
Bell Atlantic				
Rte. 123 N & Old Meadow Rd., McLean, VA	2	summer	medium	resid
Rte. 123 N & Old Meadow Rd., McLean, VA	2	winter	medium	resid
Marlboro Pike & Green Landing Rd., Prince Georges Cty., MD	2	summer	medium	resid
Marlboro Pike & Green Landing Rd., Prince Georges Cty., MD	2	spring	medium	resid
25 Plymouth St. (N of Rte. 46), Fairfield, NJ	1	spring	New	commer

Table 6-13 Manholes Containing the Highest Water Quality Concentrations (cont.)

Location	EPA Rain Region	Season	Age	Land Use
BellSouth				
8825 Jasper Rd., Jacksonville, FL	3	spring	old	resid
8825 Jasper Rd., Jacksonville, FL	3	summer	old	resid
8825 Jasper Rd., Jacksonville, FL	3	fall	old	resid
8825 Jasper Rd., Jacksonville, FL	3	winter	old	resid
NW 5th St. & 139th Av., Ft. Lauderdale, FL	3	spring	new	commer
NW 5th St. & 139th Av., Ft. Lauderdale, FL	3	summer	new	commer
NW 5th St. & 139th Av., Ft. Lauderdale, FL	3	fall	new	commer
Silver Palm Blvd. & NW 126th, Ft. Lauderdale, FL	3	summer	new	resid
Silver Palm Blvd. & NW 126th, Ft. Lauderdale, FL	3	fall	new	resid
Silver Palm Blvd. & NW 126th, Ft. Lauderdale, FL	3	winter	new	resid
Westward & Lenape Dr., Miami, FL	3	summer	old	resid
Westward & Lenape Dr., Miami, FL	3	fall	old	resid
4800 NW 102nd Av., Miami, FL	3	spring	new	resid
Coptek Rd., Pensacola, FL	3	summer	new	indus
GTE				
MH 0600056, Highway 45 S/LP#2 - Rantoul, IL	1	spring	medium	commer
MH 0600119, Rt 45 S, End of AF#1 - Rantoul, IL	1	fall	medium	resid
MH 1807, GE Rd - Bloomington, IL	1	fall	medium	resid
MH-1-DK-IL	1	winter		
47th & Rucker, Everett, WA	7	fall	old	resid
NE Dallas & NE 14th Avenue, Camas, WA	7	fall	medium	resid
NYNEX				
2011 Flatbush Av., Brooklyn, NY	1	winter	old	commer
2011 Flatbush Av., Brooklyn, NY	1	spring	old	commer
51st St. & 19th Av., Brooklyn, NY	1	summer	old	resid
51st St. & 19th Av., Brooklyn, NY	1	fall	old	resid
Dahill Rd. & 20th Av., Brooklyn, NY	1	winter	old	resid
North St. (across from St. Agnes Hosp.), White Plains, NY	1	winter	old	commer
Washington St. & Hudson St., Peekskill, NY	1	summer	old	resid
PacBell				
University Avenue & Lowell Street, La Mesa, CA	6	summer	old	commer
University Avenue & Lowell Street, La Mesa, CA	6	winter	old	commer
Green River Road & Crest Ridge Drive, Corona, CA	6	summer	new	resid
Green River Road & Crest Ridge Drive, Corona, CA	6	winter	new	resid
River Road & Archilbald Avenue, Norco, CA	6	summer	new	
Navajo Road & Park Ridge Street, San Diego, CA	6	winter	new	resid
SNET				
Norwalk Company Office, Washington St., Norwalk, CT	1	winter	old	commer
Wolcott Hill Rd. corner of Reed St., Weathersfield, CT	1	winter	old	resid

Table 6-13 Manholes Containing the Highest Water Quality Concentrations (cont.)

Location	EPA Rain Region	Season	Age	Land Use
U.S. West				
875 N. Beck Street (300 West), Salt Lake City, UT	8	winter	old	commer
875 N. Beck Street (300 West), Salt Lake City, UT	8	summer	old	commer
53 East Orpheum Ave (150 South), Salt Lake City, UT	8	winter	old	indus
53 East Orpheum Ave (150 South), Salt Lake City, UT	8	summer	old	indus
7th Street & Winged Foot, Phoenix AZ	6	summer	new	commer

Two-way cross-tabulations were used with SYSTAT, version 8, to identify groupings that were different for these top ten percent of the manholes compared to the other 90 percent of the data. The AT&T sites were not included in the analysis due to their being collected after the analyses were completed. The groupings examined were manhole characteristics noted on the field forms and included:

- EPA rainfall region
- Season of sample collection
- Age of surrounding area
- Land use of surrounding area
- General area of manhole
- Traffic in manhole vicinity
- Site topography near manhole
- Road type

- Presence of corrosion
- Ladder in manhole
- Manhole having brick construction
- Cable covering material

- Groundwater contamination potential to manhole
- Surface water contamination potential to manhole
- Rainfall amount near sampling

- Water odor
- Water clarity
- Water color
- Presence of surface sheen on water

- Sediment odor (from UAB lab)
- Sediment color (from UAB lab)
- Sediment texture (from UAB lab)

Pearson Chi-square statistics and the probabilities that the data subsets had the same distributions between the different groupings were calculated by SYSTAT, as shown on Table 6-15 The only groups that had significantly different groupings between the set of extreme observations and the rest of the observations (probabilities ≤ 0.05) were:

- Land use (more residential areas in the extreme group, and more commercial and industrial areas for the other 90% of the samples, opposite to what was originally expected)

- Water clarity (more cloudy and dark water in the extreme group and more clear water for the other 90% of the samples, as would be expected)

- Water color (more light, moderate, dark, and turbid water in the extreme group and more clear water for the other 90% of the samples, as would be expected)

- Sediment texture (more fine clay in the sediment for the extreme group and more coarser silt and sand in the sediment for the other 90% of the samples, as would be expected)

- Site topography (more moderate and steep slopes for the extreme group and more flat slopes for the other 90% of the samples, for unknown reasons)

These findings can be used to indicate a greater likelihood of high water quality constituent concentrations for water found in telecommunication manholes. It is recommended that manholes having noticeable color and/or turbidity, along with sediments having a muddy texture (especially in residential areas) be given special attention.

Unfortunately, the use of these characteristics as the only screening tool results in substantial false negatives and false positives. As an example, combinations of these characteristics were compared to the complete set of manhole samples, with the results summarized in Table 14. As the screening components increased, the number of hits was decreased, with increased "efficiency." The efficiency is calculated as the ratio of the rate of correct hits to total problem sites, compared to the total number of hits to the total number of sites. As an example, if 25% of the total sites were targeted (hits) and 50% of the problem sites were included in these hits, the efficiency would be 2.0. If the efficiency approaches 1.0, the number of problem sites identified is close to what would be expected with a random sampling, with no real benefit from using the screening criteria. As more criteria are included in the screening effort, the efficiency generally increases, but, unfortunately, so does the number of false negatives (ignores actual problems). The best plan may be to minimize the number of false negatives, while having a large efficiency factor. In this case, the use of color or land use may be best, if false negatives are to be reduced the most. If the largest number of correct hits of problem sites is desired for the least effort, then the combination of clarity, color, and texture is best (but with large numbers of false negatives because many problem sites will be missed).

As indicated, manholes having colored and/or turbid water, especially with muddy sediments, should be examined more. Manholes located in residential areas (apparently especially newer areas) may also warrant additional attention, likely due to contaminated runoff water from landscaping maintenance operations. Existing industrial practice targets obviously contaminated manholes (especially obvious hydrocarbon or sewage contamination) for special treatment generally involving licensed waste haulers to remove the water.

Table 6-13 Examination of Screening Criteria to Identify Potentially Problematic Manholes

Characteristics	% of targeted samples correct	% of false positives (% of non-extreme sites included)	% of false negatives (% of total extreme sites missed)	Efficiency (rate of correct hits to total extremes to rate of hits to total observations)
Clarity x color x texture	62%	38%	87%	6.0
Color x land use x topography	24	76	83	2.5
Color x land use	26	74	62	2.5
clarity	20	80	63	2.0
color	17	83	43	1.7

texture	22	78	77	2.2
Land use	14	86	35	1.5
topography	11	89	52	1.1

Table 6-14 Cross-Tabulations of Manhole Characteristics Comparing Extreme Observations with Other Observations

EPA Rain Region	Other 90% of samples	Upper 10% of samples	Total %	Total number
1	42.599%	48.333%	43.160%	265
2	14.079	6.667	3.355	82
3 and 4	19.495	23.333	19.870	122
5 and 9	7.220	0.000	6.515	40
6	8.484	11.667	8.795	54
7	5.415	3.333	5.212	32
8	2.708	6.667	3.094	19
Total %	100.000%	100.000%	100.000%	
Total number	554	60	614	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	11.189	6.000	0.083

Season	Other 90% of samples	Upper 10% of samples	Total %	Total number
winter	37.184%	35.000%	36.971%	227
spring	15.704	11.667	15.309	94
summer	27.798	38.333	28.827	177
fall	19.314	15.000	18.893	116
Total %	100.000%	100.000%	100.000%	
Total number	554	60	614	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	3.264	3.000	0.353

Age of area	Other 90% of samples	Upper 10% of samples	Total %	Total number
new	21.561%	28.814%	22.278%	133
medium	26.580	15.254	25.461	152
old	51.859	55.932	52.261	312
Total %	100.000%	100.000%	100.000%	
Total number	538	59	597	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	4.103	2.000	0.129

Land use	Other 90% of samples	Upper 10% of samples	Total %	Total number
commercial	**44.853%**	29.310%	43.355%	261
industrial	**11.765**	6.897	11.296	68
residential	43.382	**63.793**	45.349	273
Total %	100.000%	100.000%	100.000%	
Total number	544	58	602	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	8.835	2.000	**0.012**

Table 6-15 Cross-Tabulations of Manhole Characteristics Comparing Extreme Observations with Other Observations (cont.)

Water odor	Other 90% of samples	Upper 10% of samples	Total %	Total number
none	93.721%	92.683%	93.631%	441
other	0.930	2.439	1.062	5
gasoline	1.163	2.439	1.274	6
sewage	4.186	2.439	4.034	19
Total %	100.000%	100.000%	100.000%	
Total number	430	41	471	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	1.569	3.000	0.666

Water Clarity	Other 90% of samples	Upper 10% of samples	Total %	Total number
clear	**77.979%**	46.341%	74.941%	320
cloudy	20.725	**41.463**	22.717	97
dark	1.295	**12.195**	2.342	10
Total %	100.000%	100.000%	100.000%	
Total number	386	41	427	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	30.769	2.000	**0.000**

Water Color	Other 90% of samples	Upper 10% of samples	Total %	Total number
clear	**55.764%**	27.660%	52.619%	221
light	18.231	**19.149**	18.333	77
moderate	13.941	**34.043**	16.190	68
dark	8.311	**8.511**	8.333	35
turbid	3.753	**10.638**	4.524	19
Total	100.000%	100.000%	100.000%	
Total number	373	47	420	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	21.078	4.000	**0.000**

Table 6-15 Cross-Tabulations of Manhole Characteristics Comparing Extreme Observations with Other Observations (cont.)

Surface sheen	Other 90% of samples	Upper 10% of samples	Total %	Total number
none	93.587%	90.909%	93.321%	517
partial	4.609	3.636	4.513	25
entire	1.804	5.455	2.166	12
Total	100.000%	100.000%	100.000%	
Total number	499	55	554	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	3.191	2.000	0.203

Sediment odor	Other 90% of samples	Upper 10% of samples	Total %	Total number
none	66.940%	48.649%	65.261%	263
other	2.186	2.703	2.233	9
gasoline	14.481	24.324	15.385	62
sewage	16.393	24.324	17.122	69
Total	100.000%	100.000%	100.000%	
Total number	366	37	403	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	5.114	3.000	0.164

Sediment color	Other 90% of samples	Upper 10% of samples	Total %	Total number
light	15.877%	16.216%	15.909%	63
medium	51.811	43.243	51.010	202
dark	32.312	40.541	33.081	131
Total	100.000%	100.000%	100.000%	
Total number	359	37	396	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	1.172	2.000	0.557

Sediment texture	Other 90% of samples	Upper 10% of samples	Total %	Total number
clay	13.774%	**37.838%**	16.000%	64
silt	**67.218**	45.946	65.250	261
sand	**19.008**	16.216	18.750	75
Total	100.000%	100.000%	100.000%	
Total number	363	37	400	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	14.620	2.000	**0.001**

Table 6-15 Cross-Tabulations of Manhole Characteristics Comparing Extreme Observations with Other Observations (cont.)

Corrosion present	Other 90% of samples	Upper 10% of samples	Total %	Total number
no	94.902%	98.246%	95.238%	540
yes	5.098	1.754	4.762	27
Total	100.000%	100.000%	100.000%	
Total number	510	57	567	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	1.264	1.000	0.261

Traffic	Other 90% of samples	Upper 10% of samples	Total %	Total number
light	27.379%	40.000%	28.596%	163
heavy	30.680	20.000	29.649	169
Total	100.000%	100.000%	100.000%	
Total number	515	55	570	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	4.725	2.000	0.094

Site topography	Other 90% of samples	Upper 10% of samples	Total %	Total number
flat	**57.221%**	50.847%	56.601%	343
moderate	40.768	**35.593**	40.264	244
steep	2.011	**13.559**	3.135	19
Total	100.000%	100.000%	100.000%	
Total number	547	59	606	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	23.389	2.000	**0.000**

Groundwater contamination potential	Other 90% of samples	Upper 10% of samples	Total %	Total number
low	42.230%	49.153%	42.904%	260
medium	42.596	42.373	42.574	258
high	15.174	8.475	14.521	88
Total	100.000%	100.000%	100.000%	
Total number	547	59	606	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	2.241	2.000	0.326

Table 6-15 Cross-Tabulations of Manhole Characteristics Comparing Extreme Observations with Other Observations (cont.)

Surface water contamination potential	Other 90% of samples	Upper 10% of samples	Total %	Total number
low	32.358%	32.203%	32.343%	196
medium	42.048	49.153	42.739	259
high	25.594	18.644	24.917	151
Total	100.000%	100.000%	100.000%	
Total number	547	59	606	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	1.662	2.000	0.436

Road type	Other 90% of samples	Upper 10% of samples	Total %	Total number
asphalt	96.507%	100.000%	96.849%	584
concrete	3.125	0.000	2.819	17
gravel	0.368	0.000	0.332	2
Total	100.000%	100.000%	100.000%	
Total number	544	59	603	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	2.128	2.000	0.345

Ladder present	Other 90% of samples	Upper 10% of samples	Total %	Total number
no	38.298%	35.714%	38.045%	218
yes	61.702	64.286	61.955	355
Total	100.000%	100.000%	100.000%	
Total number	517	56	573	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	0.143	1.000	0.705

Brick construction	Other 90% of samples	Upper 10% of samples	Total %	Total number
no	93.398%	91.071%	93.170%	532
yes	6.602	8.929	6.830	39
Total	100.000%	100.000%	100.000%	
Total number	515	56	571	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	0.430	1.000	0.512

Table 6-15 Cross-Tabulations of Manhole Characteristics Comparing Extreme Observations with Other Observations (cont.)

Cable material in manhole	Other 90% of samples	Upper 10% of samples	Total %	Total number
Cu	76.484%	60.000%	75.000%	375
Pb	0.440	0.000	0.400	2
Pb, Cu	20.000	33.333	21.200	106
no	3.077	6.667	3.400	17
Total	100.000%	100.000%	100.000%	
Total number	455	45	500	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	6.667	3.000	0.083

General area type	Other 90% of samples	Upper 10% of samples	Total %	Total number
rural	10.420%	6.780%	10.066%	61
suburban	46.984	52.542	47.525	288
urban	42.596	40.678	42.409	257
Total	100.000%	100.000%	100.000%	
Total number	547	59	606	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	1.094	2.000	0.579

Recent rainfall	Other 90% of samples	Upper 10% of samples	Total %	Total number
0.5-2"	47.048%	40.351%	46.392%	270
<0.5"	16.381	19.298	16.667	97
>2"	36.571	40.351	36.942	215
Total	100.000%	100.000%	100.000%	
Total number	525	57	582	

Test statistic	Value	df	Probability that groups are the same
Pearson Chi-square	0.958	2.000	0.619

Appendix A:

Designer Research for Experimental Design Selection

DESIGNER RESEARCH is a trademark of The Idea Works, Inc., 100 West Briarwood, Columbia, Missouri 65203.

Research cases are likely to vary enough in this population so that results for individual cases may not be generalized to the whole population and individual differences may be an important source of variation in the analysis

Effects are likely to vary from setting and setting
Effects are likely to vary over time

The number of independent variables (or factors) to be considered in this study is 2 to 3

Are there any control variables in this study? yes
The number of control variables to be considered in this study is 3 or more

After considering all of the independent variables and conditions and control variables identified earlier, are there still remaining one or more additional variables which are likely to influence the dependent variable and which are not controlled? Yes

Are these other variables which may influence the dependent variable of interest for the study? yes, they are of interest and at least their main effects should be examined.

For the independent variables or factors which influence the dependent variable are you interested in linear effects only

For the independent variables in this study are you interested in all 2-way interactions

For the independent variables or factors in this study you are interested in only some of the possible main effects

The objective of this study is DESCRIPTIVE ANALYSIS: descriptive or interpretive only and there is no intention of assessing possible causal relationships among variables (e.g., a qualitative descriptive study, a public opinion poll, and so on)

You have indicated there are likely to be four or more independent variables in your study and/or three or more control variables. This can make quite a complex study. Would you rather proceed under these assumptions and consider a possibly complex study design

You have indicated there are additional variables which may influence the dependent variable and these variables are of interest to you. If so, these variables should probably also be included among your independent variables for this study. Do you want to choose to not include these additional independent variables in this study

You would like advice regarding all of the above

1 Background information has been determined
2 Fundamental design constraints have been identified
3 Complex designs have been evaluated

4 Timing strategies have been considered
5 Field vs lab studies have been considered
6 Statistical conclusion validity information has been obtained
7 External validity information has been obtained
8 Construct validity information has been obtained
9 Strategies for providing appropriate comparisons have been considered
10 Assignment strategies have been considered
11 monitoring and control strategies have been considered
12 The report has been initialized

Efficient Designs

Recommended Strategies

	Desirability	**Feasibility**
factorial design	0.65	1.00
two-level factorial design (two categories each ind var)	0.88	1.00
fractional factorial design	0.69	1.00
Plackett-Burman design	0.87	1.00
repeated measures to remove inc. differences variation	0.90	0.95
incomplete block design	0.81	0.53

Strategies Not Recommended

	Desirability	**Feasibility**
single factor design	0.03	1.00
three-level factorial design (3 categories per ind var)	0.22	0.90
full-factorial design	0.50	1.00
response surface design	0.90	0.40
evolutionary operation design	0.90	0.10
central composite design	0.63	0.13
Box-Behnken design	0.56	0.40
blocking to control extraneous variables	0.63	1.00
Latin-Square design	0.29	0.80
Graeco-Latin Square or hyper-Graeco Latin Square design	0.51	0.80
crossover design	0.53	1.00
nested design	0.17	0.00
completely randomized design	0.20	0.05

Two-Level Fractional Factorial Design (feasibility: 1.00 and desirability: 0.88)

If, as is often the case, high-order interactions are relatively rare, then when many factors are considered, the full-factorial design is inefficient, using more cells than required to estimate main effects and lower-order interactions. Two-level fractional factorial designs are of the form:

$$2^{k-P}$$

where k is the number of factors, p is the fractionalizing element of the design (e.g., when p is 3 this is a 1/8 fractional factorial), and k-p gives the power for the number of levels. 2^{k-p} gives the number of treatment combinations or cells in the design. Knowing the number of factors, k and the maximum number of treatment conditions which can be afforded, lets one solve for p. $1/2^p$ indicates the fraction of the whole factorial e.g., when p is 3 this is a 1/8 fractional factorial. Generally, a fractional design should include at least treatment combinations.
A fractional design should be used when runs are relatively expensive or the study is a screening experiment, the study is not going to be used to estimate variance, and higher order interactions are insignificant.

References:
Barker, 1985: Chpt. 4
John, 1971: Chpt 7
Montgomery, 1976: Chpt. 8

Feasibility:

Match with objectives	Optimal	Reported
you are interested in linear effects only	10	10

Desirability:

Match with objectives	Optimal	Reported
the desirability of a factorial study	1	0.7
you are interested in linear effects only	10	10
the study is an exploratory one	10	10

Fractional Factorial Design (feasibility: 1.00 and desirability: 0.69)

A full factorial design is one considering all possible combinations of treatments. In contrast, a fractional factorial design is one in which cases are studied for only some of the possible cells. Because fractional factorial designs don't consider all possible cells in the full factorial design, they are more efficient than a full design. However, fractional designs are incapable of estimating some kinds of effects (such as higher-order interaction terms). There are many different types of fractional factorial designs and the precise form needs to be selected carefully to assure a design capable of examining effects likely to be important.

References:

Barker, 1985: Chpts. 5, 7
John, 1971: Chpts. 8,9

Feasibility:

Match with objectives	Optimal	Reported
A fractional factorial design should generally be feasible.		

Desirability:

Match with objectives	**Optimal**	**Reported**
the efficiency of the study is important	8	9
you are interested in all interactions including 2-way and higher	0	0
there are four or more independent var. in this study	10	0
cases are expensive and cost must be considered	10	90
the study is an exploratory one	10	10
independent variables have three or more categories	10	9
independent variables have five or more categories	10	9

Plackett-Burman Design (feasibility: 1.00 and desirability: 0.87)

A Plackett-Burman design is one which permits estimation of orthogonal main effects only. It assumes all two-level and higher-order interactions are not present. The design is a two-level fractional factorial design. It consists of a series of orthogonal (unrelated) saturated (designs in which each cell is represented) resolution III (designs which can estimate main effects only) designs for N-1 factors in N

References:

Plackett and Burman, 1946
John, 1971
Montgomery, 1976: 256-258

Feasibility:

Match with objectives	**Optimal**	**Reported**
feasibility of treating independent variables as dichotomous	1	1

Desirability:

Match with objectives	**Optimal**	**Reported**
desirability of treating independent variables as dichotomous	1	1
desirability of a fractional factorial design	1	1
all main effects are of interest	0	0
the efficiency of the study is important	8	9

Repeated Measures To Remove Individual Difference Variation (feasibility: 0.95 and desirability: 0.90)

A repeated measures design is one which uses subjects as their own controls. In this design, each subject appears in two or more cells. The primary advantage of the repeated measures design is that it makes it possible to control for individual differences, making it more efficient than completely randomized or treatment x blocks designs. This design is particularly useful when there are only a limited number of subjects and they are available for long periods of time or when the objective is to examine performance trends over time.

References:

Myers, 1979: Chpt. 7
Sheskin, 1984: 186-8
Mitchell & Jolley, 1988: 235-42

Feasibility:

Match with objectives	**Optimal**	**Reported**
few cases relative to the number of cells are available	10	9
cases are available for lots of time allowing repeated measures	10	10

Desirability:

Match with objectives	**Optimal**	**Reported**
you want to examine effects which take place over time	10	9
carryover effects are likely to be a problem	0	2
cases are likely to have large or important differences	10	10
the efficiency of the study is important	8	9

Incomplete Block Design (feasibility: 0.53 and desirability: 0.81)

An incomplete block design is one in which not all cells are represented in the data. This is done in an effort to increase the efficiency of the study or when it is not possible to run all treatment combinations. If designed carefully to balance effects, the main effects and lower-order interactions of interest can still be estimated even though far fewer cases are used. When balance is not entirely possible, partially balanced designs may be used instead.

A Youdon Square is one example of an incomplete Latin square in which the number of columns does not equal the number of rows and treatments. A Youden square is a Latin square from which at least one column (or row or diagonal) is missing. It is a symmetric balanced incomplete design. A Lattice design is an incomplete block design with k^2 treatment combinations a partially balanced lattice can be used to reduce the size of the design.

References:

Barker, 1985: 77.177
Montgomery, 1976: Chpt. 5, pp 99-118

Feasibility:

Match with objectives	**Optimal**	**Reported**
independent vars (factors) have same number of categories	0	8
cases available for lots of time allowing repeated measures	5	10
few cases relative to the number of treatment cells	10	9

Desirability:

Match with objectives	Optimal	Reported
desirability of a blocking design	1	0.6
the efficiency of the study is important	10	9
additional cases are expensive and cost must be considered	10	9

Timing Strategies

Recommended Strategies	Desirability	Feasibility
Cross-sectional design	0.69	0.93
case control study	0.78	0.57
overtime (longitudinal) study	0.90	0.65

Strategies Not Recommended	Desirability	Feasibility
Pre- and post-test longitudinal panel study	0.22	0.00
assure an appropriate length of time passes between observations	0.00	0.90
time-series design	0.58	0.00
interrupted time-series design	0.22	0.00
washout period between treatments for same subject	0.40	0.90
prospective study	0.30	0.00
retrospective study	0.65	0.40

Cross-Sectional Design (One Time Only) (feasibility: 0.93 and desirability: 0.69)

A cross-sectional design is one which takes place for most intents and purposes at one point in time. Actually, every test requires some time to take place, but so long as there is no significant intervention or treatment which takes place during the study then it can be regarded as a cross-sectional study. Biggest problem is causal ambiguity, inconsistent with other timing strategies. Cross-sectional design by itself addresses no alternative explanations. However, in conjunction with comparison of other groups and other strategies such as statistical control it can solve many problems. It does not cause problems so much as it fails to resolve them.

References:

Mitchell & Jolley, 1988:253
Blalock, 1964

Feasibility:

Match with objectives	Optimal	Reported
you are able to measure the factors in this study	10	8
you are able to measure the control variables in this study	10	9
confidence you have access to field setting	10	10

for your study		
confidence you have access to subjects for the field study	10	10

Desirability:

Match with objectives	Optimal	Reported
objective of study is to examine causal relationships	0	0
desire to examine effects which take place over time	0	9

Threats to validity reduced or eliminated by this strategy

	Severity
testing	0
instrumentation	10
regression to the mean	10

Threats to validity which may be increased

	Severity
ambiguity of causal direction	0

Other strategies inconsistent with this strategy

	Desirability
pre- and post-test	0.22
study which takes place over time (longitudinal)	0.90
time series design	0.58
interrupted time series design	0.22
crossover design	0.53

Case-Control Study (feasibility: 0.57 and desirability: 0.78)

In case-control studies, cases having an outcome condition are compared to a control group of cases not having the condition. The objective is to identify differences between these otherwise comparable groups which might account for whether the outcome occurs. Case control studies are retrospective studies which use matching to control for variables. They have all of the advantages and problems of matching, however, they do less well than matching due to their retrospective character. Generally, prospective matching would be preferred over case control studies.

References:
Fletcher, Fletcher, and Wagner (1982)
Feasibility:

Match with objectives	Optimal	Reported
feasibility of matching cases in the different groups	1	0.73
feasibility of conducting a retrospective study	1	0.40

Desirability:

Match with objectives	Optimal	Reported
desirability of a retrospective design	1	0.65
extent to which one or more conditions are rare occurrences	10	9

Other strategies inconsistent with this strategy

	Desirability
cross-sectional design	0.69
pre- and post-test design	0.22
prospective design	0.30
time series design	0.58
interrupted time series design	0.22
randomization	0.67
matching	0.71
pseudo-randomization	0.59

Examine Effects Which Take Place Over Time (feasibility: 0.65 and desirability: 0.90)

This is not a design per se, but a broad class of designs for examining effects which take place over time. If this class of designs is recommended, then we must further narrow the design to a more specific variant of this class.

References:

Mitchell & Jolley, 1988:253-4

Feasibility:

Match with objectives	Optimal	Reported
time required for effects of variables to occur not too long	10	9
feasibility of a prospective design	1	0
feasibility of a retrospective design	1	0.40

Desirability:

Match with objectives	Optimal	Reported
objective is to examine causal relationships	10	0
ambiguity about direction of causal influences	10	0
you want to examine effects which take place over time	10	9

Other strategies inconsistent with this strategy

	Desirability
cross-sectional design	0.69

A Laboratory Versus Field Studies

Recommended Strategies

	Desirability	**Feasibility**
Conduct research in the field	1.00	1.00

Strategies Not Recommended

	Desirability	Feasibility
Use observation to collect data (not direct manipulation)	1.00	1.00
Conduct an experiment (use some form of manipulation)	0.00	0.00
Conduct study in a laboratory	1.00	0.00
Take advantage of natural experiments	0.00	0.00
The researcher should do the manipulation him(her)self	0.50	0.00

CONDUCT RESEARCH IN THE FIELD

Appendix B:

Analytical Procedures for Evaluating Water and Sediment found in Telecommunication Manholes

EPA APPROVED, OR OTHER VALIDATED STANDARD METHODS

Table B-1 lists the standard and modified analytical methods recommended for the manhole water samples. Our laboratory has found that many of the standard procedures should be modified to more effectively analyze samples having large amounts of suspended solids and to minimize the required sample volume needed. Reducing the sample volumes (especially for the organic analyses) also significantly reduces the volumes of hazardous laboratory wastes generated. Modifications to the standard methods are described in later discussions.

The sediment samples were analyzed using similar approved methods. The heavy metal analyses required complete digestion, while the organic analyses required accelerated solvent extractions.

NON-STANDARD OR MODIFIED METHODS

The following paragraphs briefly describe modifications to the above standard analytical procedures that we have found to be advantageous for many environmental samples that may have substantial amounts of suspended solids and oily wastes, as expected for many manhole water samples.

EPA method 300 is modified as follows:

For anions:
Summary of Method
Samples are filtered through C18 and cation exchange columns prior to analysis to remove interferences

For cations:
Scope and Application
This method covers the determination of the following inorganic cations: lithium, sodium, potassium, calcium, ammonium, magnesium,

Summary of Method
Samples are filtered through C18 and anion exchange columns prior to analysis to remove interferences

Equipment and Supplies
Cation analytical column utilized is a Dionex Cation exchange column

Table B-1 ***Table of Standard and Modified Methods Recommended for Manhole Water Samples***

Parameter	**Method**
Physical Analyses	
Conductance, Specific Conductance	EPA 120.1
Hardness, Total (mg/L as $CaCO_3$), Titrimetric EDTA	EPA 130.2
Particle size analysis	Coulter Counter Multisizer Iie
pH, Electrometric	EPA 150.1
Residue, non-filterable, gravimetric, dried at 103-105°C	EPA 160.2
Residue, volatile, gravimetric, ignition at 550°C	EPA 160.4
Turbidity, nephelometric	EPA 180.1
Inorganic Analyses	
Chromium	EPA 200.9
Copper	EPA 200.9
Lead	EPA 200.9
Zinc	EPA 200.9
Nitrate	EPA 300.0
Phosphate	EPA 300.0
Ammonium	EPA 300.0 modified
Potassium	EPA 300.0 modified
Organic Analyses	
Chemical Oxygen Demand, colorimetric	EPA 410.4
Chlordane-alpha	EPA 608 modified
Chlordane-gamma	EPA 608 modified
HCH-gamma (Lindane)	EPA 608 modified
Anthracene	EPA 625 modified
Benzo(a)anthracene	EPA 625 modified
Benzo(b)fluoranthene	EPA 625 modified
Benzo(g,h,I)perylene	EPA 625 modified
Benzo(k)fluoranthene	EPA 625 modified
Benzo(a)pyrene	EPA 625 modified
Chrysene	EPA 625 modified
1,3-Dichlorobenzene	EPA 625 modified
1,4-Dichlorobenzene	EPA 625 modified
2,4-Dichlorophenol	EPA 625 modified
Fluoranthene	EPA 625 modified
Pentachlorophenol	EPA 625 modified
Phenanthrene	EPA 625 modified
Phenol	EPA 625 modified
Pyrene	EPA 625 modified
Toxicity Analyses	
Microtox® Analysis	full-strength screen

EPA method 608 and 625 are modified as follows:

Sample Extraction

- Samples are extracted using a separatory funnel technique. If emulsions prevent achieving acceptable solvent recovery with separatory funnel extraction, continuous extraction is used. The separatory funnel extraction scheme described below assumes a sample volume of 250 mL. Prior to the extraction, all glassware is oven baked at 300° C.

- A sample volume of 250 mL is collected in a 400 mL beaker and poured into a 500 mL separation funnel. For every twelve samples extracted, an additional four samples are extracted for quality control and quality assurance. These include three 250 mL composite samples made of equal amounts of the twelve samples and one 250 mL sample of reverse osmosis water. Standard solution additions consisting of 25 μL of 1000 μg/mL base/neutral spiking solution, 25 μL of 1000 μg/mL base/neutral surrogates, 12.5 μL of 2000 μg/mL acid spiking solution , and 12.5 μL of 2000 μg/mL acid surrogates are made to the separation funnels of two of the three composite samples and mixed well. Sample pH is measured with wide range pH paper and adjusted to pH > 11 with sodium hydroxide solution.

- A 10 mL volume of methylene chloride is added to the separatory funnel and sealed by capping. The separatory funnel is gently shaken by hand for 15 sec. And vented to release pressure. The cap is removed from the separatory funnel and replaced with a vented snorkel stopper. The separatory funnel is then placed on a mechanical shaker and shaken for 2 min. After returning the separatory funnel to its stand and replacing the snorkel stopper with cap, the organic layer is allowed to separate from the water phase for a minimum of 10 minutes, longer if an emulsion develops. The extract and any emulsion present is then collected into a 125 mL Erlenmeyer flask.

- A second 10 mL volume of methylene chloride is added to the separatory funnel and the extraction method is repeated, combining the extract with the previous in the Erlenmeyer flask. For persistent emulsions, those with emulsion interface between layers more than one-third the volume of the solvent layer, the extract including the emulsion is poured into a 50 mL centrifuge vial, capped, and centrifuged at 2000 rpm for 2 min. to break the emulsion. Water phase separated by the centrifuge is collected from the vial and returned to the separatory funnel using a disposable pipette. The centrifuge vial with the extract is recapped before performing the extraction of the acid portion.

- The pH of the remaining sample in the separatory funnel is adjusted to pH < 2 using sulfuric acid. The acidified aqueous phase is serially extracted two times with 10 mL aliquots of methylene chloride as done in the previous base/neutral extraction procedure. Extract and any emulsions are again collected in the 125 mL Erlenmeyer flask..

- The base/neutral extract is poured from the centrifuge vial though a drying column of at least 10 cm of anhydrous sodium sulfate and is collected in a 50 mL beaker. The Erlenmeyer flask is rinsed with 5 mL of methylene chloride which is then used to rinse the centrifuge vial and then for rinsing the drying column and completing the quantitative transfer.

- The base/neutral extract is transferred into 50 mL concentration vials and is placed in an automatic vacuum/centrifuge concentrator (Vacuum concentration is used in place of the Kuderna-Danish method). Extract is concentrated to approximately 0.5 mL.

- The acid extract collected in the 125 mL Erlenmeyer flask is placed in the 50 mL centrifuge vial. Again, if persistent emulsions persist, the extract is centrifuged at 2000 rpm for 2 min. Water is drawn from the extract and discarded. Extract is poured through the 10 cm anhydrous sodium sulfate drying column and collected in the 50 mL beaker as before. The Erlenmeyer flask is then rinsed with 5 mL of methylene chloride which is then poured into the centrifuge vial and finally through the drying column.

• The acid extract is then poured into the 50 mL concentration vial combining it with the evaporated base/neutral extract. The combined extract is then concentrated to approximately 0.5 mL in the automatic vacuum/centrifuge concentrator.

• Using a disposable pipette, extract is transferred to a graduated Kuderna-Danish concentrator. Approximately 1.5 mL of methylene chloride is placed in the concentration vial for rinsing. This rinse solvent is then used to adjust the volume of extract to 2.0 mL. Extract is then poured into a labeled Teflon-sealed screw-cap vial and freezer stored until analysis.

Notes for method 608:

Under the alkaline conditions of the extraction step, α-BHC, γ-BHC, endosulfan I and II, and endrin are subject to decomposition.

Florisil cleanup is not utilized unless sample matrix creates excessive background interference.

INTERNAL QC CHECKS

Several quality control activities occur as specified in standard methods, however, standard methods for EPA 625 do not list several QC parameters. These parameters are listed in Table B.2.

Calculation of data quality indicators

Precision

precision, when calculated from duplicate measurements:

$$RPD = \frac{(C_1 - C_2) \times 100\%}{(C_1 + C_2)/2}$$

RPD = relative percent difference

C_1 = larger of the two observed values

C_2 = smaller of the two observed values

if calculated from three or more replicates, use relative standard deviation (RSD) rather than RPD:

$$RSD = \left(s/\bar{y} \right) \times 100\%$$

RSD = relative standard deviation

s = standard deviation

$\bar{y}$ = mean of replicate analyses

Accuracy

For measurements where matrix spikes are used:

$$\%R = 100\% \times \left(\frac{S - U}{C_{sa}} \right)$$

%R = percent recovery

S = measured concentration in spiked aliquot

U = measured concentration in unspiked aliquot

C_{sa} = actual concentration of spike added

For situations where a standard reference material (srm) is used instead of or in addition to a matrix spike:

$$\%R = 100\% \times \left(\frac{C_m}{C_{srm}} \right)$$

%R = percent recovery

C_m = measured concentration of srm

C_{srm} = actual concentration of srm

Method Detection Limit

$$MDL = t_{(n-1,1-\alpha=0.99)} \times s$$

MDL = method detection limit

s = standard deviation of replicate analyses

$t_{(n-1,1-\alpha=0.99)} \times s$ = Student’s t-value appropriate to a 99% confidence level and a standard deviation estimate with n-1 degrees of freedom

Table B-2 Internal QC Checks

Tuning	
• Requirement	50 ng DFTPP
• Frequency	per extraction batch
• Criteria	per method
Surrogates	
	Phenol-d5
	2-Fluorophenol
	2,4,6-Tribromophenol
	Nitrobenzene-d5
	2-Fluorobiphenyl
	p-Terphenyl
	2-Chlorophenol-d4
	1,2-Dichlorobenzene-d4
Internal Standards	
	1,4-Dichlorobenzene-d4
	Naphthalene-d8
	Acenaphthene-d10
	Phenanthrene-d10
	Chrysene-d12
	Perylene-d12
Spike	**Matrix Spike**
• Frequency	5% samples or greater
• Concentration	1 - 5x sample level for
	QA monitoring
	(25-50 µg/L)
• Criteria	Method % rec. limits
Duplicate	**Matrix spike duplicate**
• Frequency	5% samples or 1 per extraction batch (16)
• Criteria	Method % recovery and RPD

Table B-2 Internal QC Checks (Continued)

Sample Analysis	
• Qualitative ID	RRT within +/-0.06 RRT
	units of standard RRT
	Ions >10% in std. Present
	in sample within +/-20% of
	ion abundance in std.
• IS Area	-50 to +100% of cal. Area
• IS RRT	+/- 30 sec of Cal. RT
• Surrogate Criteria	Method % rec. limits
• Quantitative	Within calibration range
QC Check Sample	**Performance Evaluation**
• Frequency	Each study
• Criteria	EPA QC limits
Surrogate Recoveries	
Nitrobenzene-d5	34 - 114 %
2-Fluorobiphenyl	43 - 116 %
p-Terphenyl-d14	33 - 141 %
Phenol-d6	10 - 110 %
2-Fluorophenol	21 - 110 %
2,4,6-Tribromophenol	10 - 123 %
1,2-Dichlorobenzene-d4	16 - 110 %
2-Chlorophenol-d4	33 - 110 %

Summary of Quantitative QA Objectives for Characterizing Telecommunication Manhole Water and Sediment Samples

As noted, the QA objectives for the method detection limit (MDL) and precision (RPD) for the compounds of interest are a function of the anticipated median concentrations in the manholes. The MDL objectives are 0.23 of the median value for sample sets having typical concentration variations (COV values ranging from 0.5 to 1.25). The precision goal is estimated to be in the range of 10 to 100% (Relative Percent Difference of duplicate analyses), depending on the sample variability.

Table B-3 lists the critical constituents, the expected median concentrations in the manhole samples, and the associated MDL and RPD goals for this research. Table B-4 is a summary of the laboratory capabilities for these analyses.

Table B-3 Summary of Quantitative QA Objectives (MDL and RPD) Required for Manhole Water Sample Analyses

Potential Problem Constituent	Units	Expected COV category[1]	Expected Median Conc.	Estimated MDL	Estimated RPD
pH	pH units	low	7.5	must be readable to within 0.3 unit	<0.3 unit
specific conductance	µmhos/cm	low	100	80	<10%
hardness	mg/L as CaCO$_3$	low	50	40	<10%
Turbidity	NTU	low	5	4	<10%
TOC/VOC/VSS	mg/L	medium	50	12	<30%
suspended solids	mg/L	medium	50	12	<30%
Particle size	size distribution	medium	30 µm	7 µm	<30%
ammonia	mg/L	low	1	0.8	<10%
nitrates	mg/L	low	5	4	<10%
phosphate	mg/L	low	0.2	0.16	<10%
detergents	mg/L	medium	0.1	0.06	<30%
potassium	mg/L	low	2	1.5	<10%
Microtox® toxicity screening	I$_{20}$ or EC$_{50}$	medium	I$_{20}$ of 25%	I$_{20}$ of 6%	<30%
chromium	µg/L	medium	40	9	<30%
copper	µg/L	medium	25	6	<30%
lead	µg/L	medium	30	7	<30%
zinc	µg/L	medium	50	12	<30%
1,3-dichlorobenzene	µg/L	medium	10	2	<30%
benzo(a) anthracene	µg/L	medium	30	8	<30%
fluoranthene	µg/L	medium	15	3	<30%
pentachlorophenol	µg/L	medium	10	2	<30%
phenanthrene	µg/L	medium	10	2	<30%
pyrene	µg/L	medium	20	5	<30%
Lindane	µg/L	medium	1	0.2	<30%
Chlordane	µg/L	medium	1	0.2	<30%

[1]

COV value:	Multiplier for MDL:	RDL Objective:
<0.5 (low)	0.8	<10%
(5) to 1.25 (medium)	0.23	<30%
>1.25 (high)	0.12	<50%

Table B-4 Typical Laboratory Quality Assurance Capabilities

Parameter	**Accuracy** [1]	**Precision**	**Detection Limit**
Physical Analyses			
Conductance, Specific Conductance	<5% error	<10 %	5 µS/cm^2
Hardness, Total (mg/L as $CaCO_3$), Titrimetric EDTA	< 10% error	< 10 %	25 mg/L
Particle size analysis	1 micron error	< 5 %	1 micron
pH, Electrometric	< 0.3 units error	< 0.3 units	NA
Residue, non-filterable, gravimetric, dried at 103-105°C	<5% error	< 10 %	10 mg/L
Residue, volatile, gravimetric, ignition at 550°C	<5% error	< 10 %	10 mg/L
Turbidity, nephelometric	< 10 % error	< 10 %	3 NTU
Inorganic Analyses			
Chromium	< 5 % error	< 5 %	1 µg/L
Copper	< 10 % error	< 10 %	1 µg/L
Lead	< 10 % error	< 10 %	5 µg/L
Zinc	< 10 % error	< 10 %	2 µg/L
Nitrate	< 25 % error	< 5 %	1.0 mg/L
Phosphate	< 25 % error	< 5 %	1.0 mg/L
Ammonium	< 25 % error	< 5 %	1.0 mg/L
Potassium	< 25 % error	< 5 %	0.25 mg/L
Organic Analyses			
Chemical Oxygen Demand, colorimetric	< 5 % error	< 5 %	4.5 mg/L
Chlordane-alpha	45-120 %	< 25 %	0.056 µg/L
Chlordane-gamma	45-120 %	< 25 %	0.056 µg/L
HCH-gamma (Lindane)	32-127 %	< 25 %	0.016 µg/L
Anthracene	27-133 %	< 25%	1.9 µg/L
Benzo(a)anthracene	33-143 %	< 25%	7.8 µg/L
Benzo(b)fluoranthene	24-159 %	< 25 %	4.8 µg/L
Benzo(g,h,I)perylene	D-219 %	< 25 %	4.1 µg/L
Benzo(k)fluoranthene	11-162 %	< 25 %	2.5 µg/L
Benzo(a)pyrene	17-163 %	< 25 %	2.5 µg/L
Chrysene	17-168	< 25 %	2.5 µg/L
1,3-Dichlorobenzene	D-172 %	< 25 %	1.9 µg/L
1,4-Dichlorobenzene	20-124 %	< 25 %	4.4 µg/L
2,4-Dichlorophenol	39-135 %	< 25 %	2.7 µg/L
Fluoranthene	26-137 %	< 25 %	2.2 µg/L
Pentachlorophenol	14-176 %	< 25 %	3.6 µg/L
Phenanthrene	54-120 %	< 25 %	5.4 µg/L
Phenol	5-112 %	< 25 %	1.5 µg/L
Pyrene	52-115 %	< 25 %	1.9 µg/L
Toxicity Analyses			
Microtox® Analysis	<10%	< 10 %	I_{20} of 5%

[1] accuracy = percent recovery, unless otherwise noted.

Appendix C:

Tabular Quality Data for Water and Sediment Samples Collected from Telecommunication Manholes

Appendix D:

Summary Plots of the Quality Data for Water and Sediment Samples Collected from Telecommunication Manholes

Appendix E:

Plots for Correlation Analyses and Modeling Building and Verification

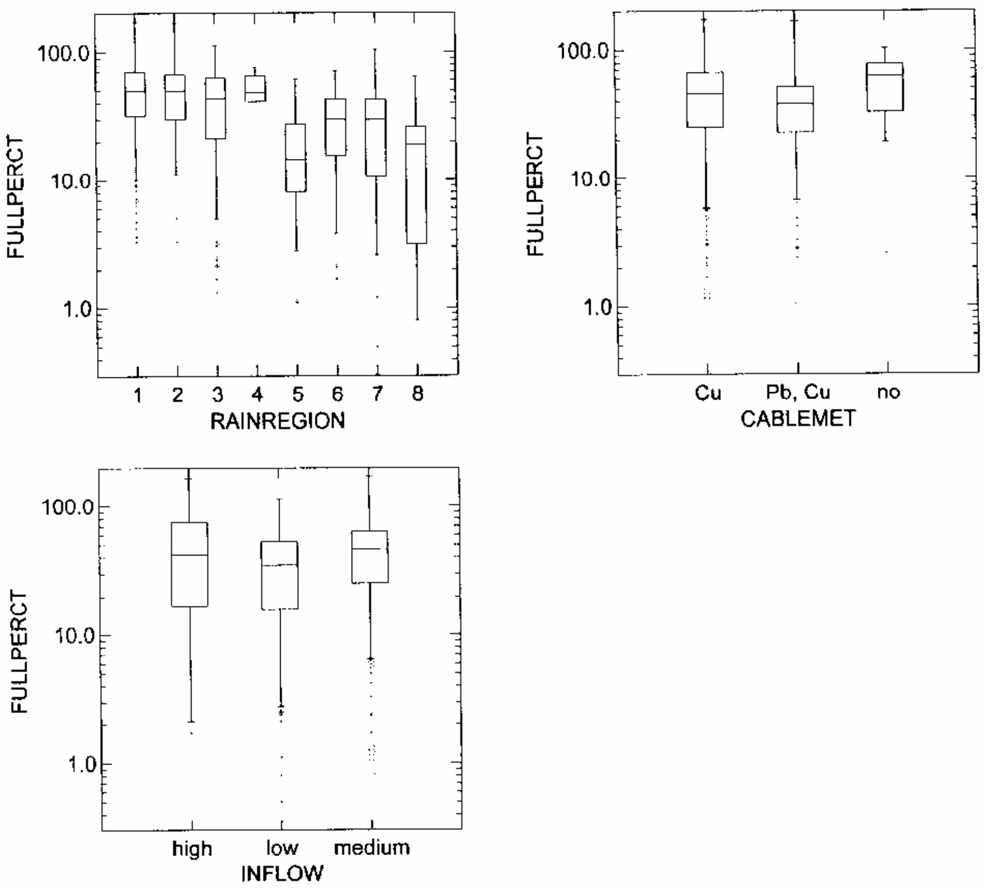


Figure E-1. Statistically significant groupings for the amount of water (percent full) found in telecommunication manholes.

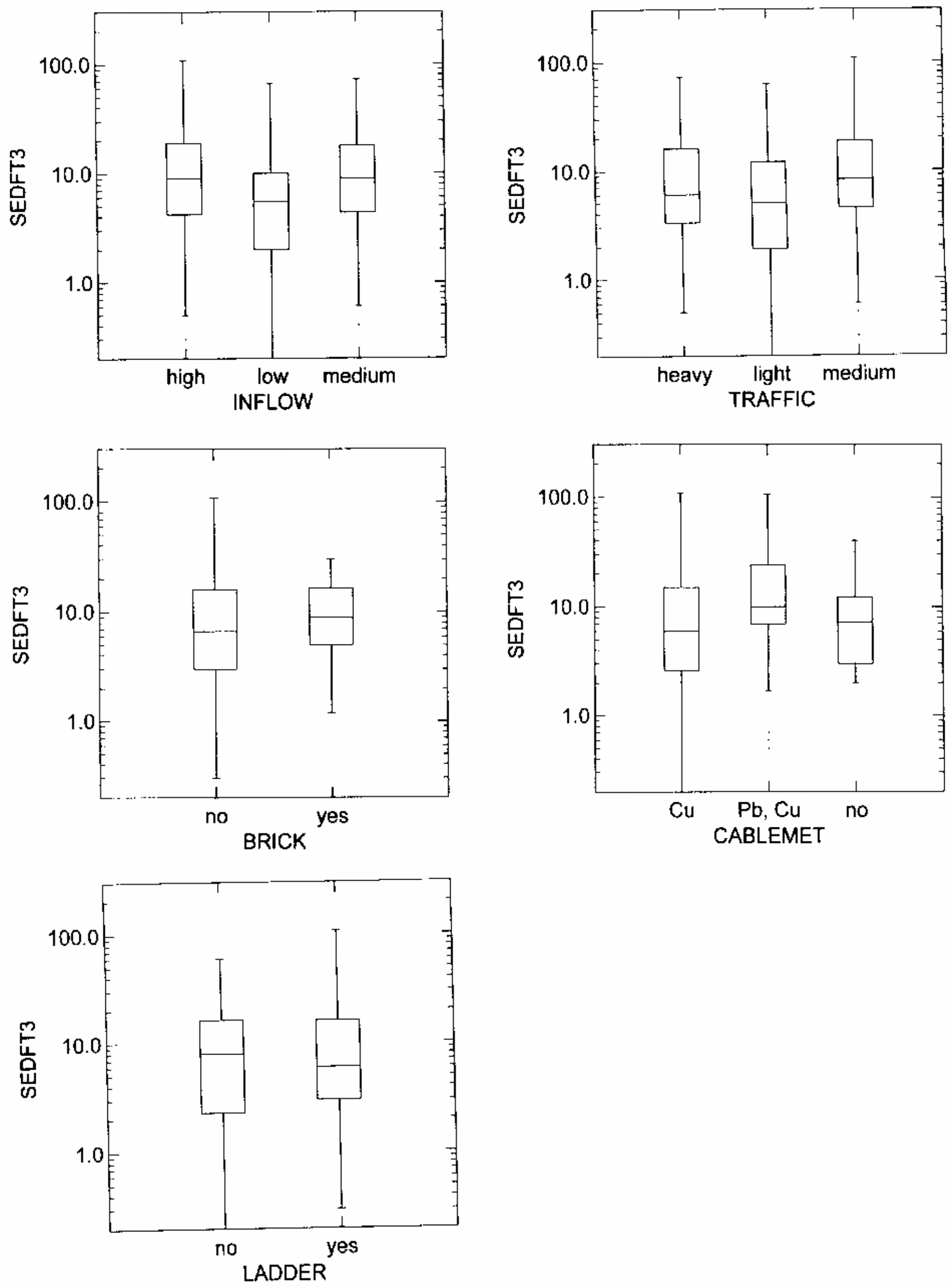


Figure E-2. Statistically significant groupings for "sediment quantity, ft^3" found in telecommunication manholes.

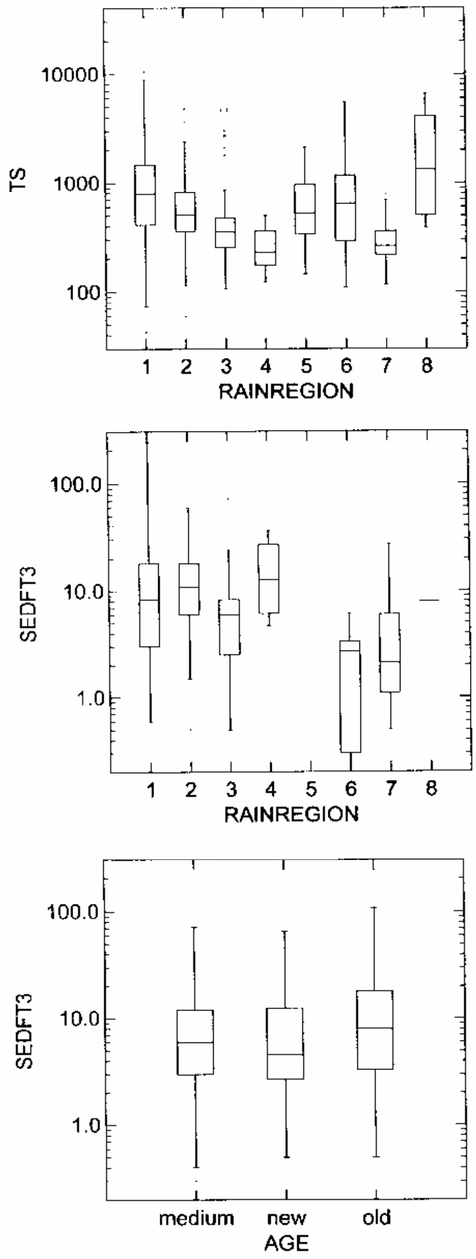


Figure E-2. Statistically significant groupings for "sediment quantity, ft^3" found in telecommunication manholes (cont.).

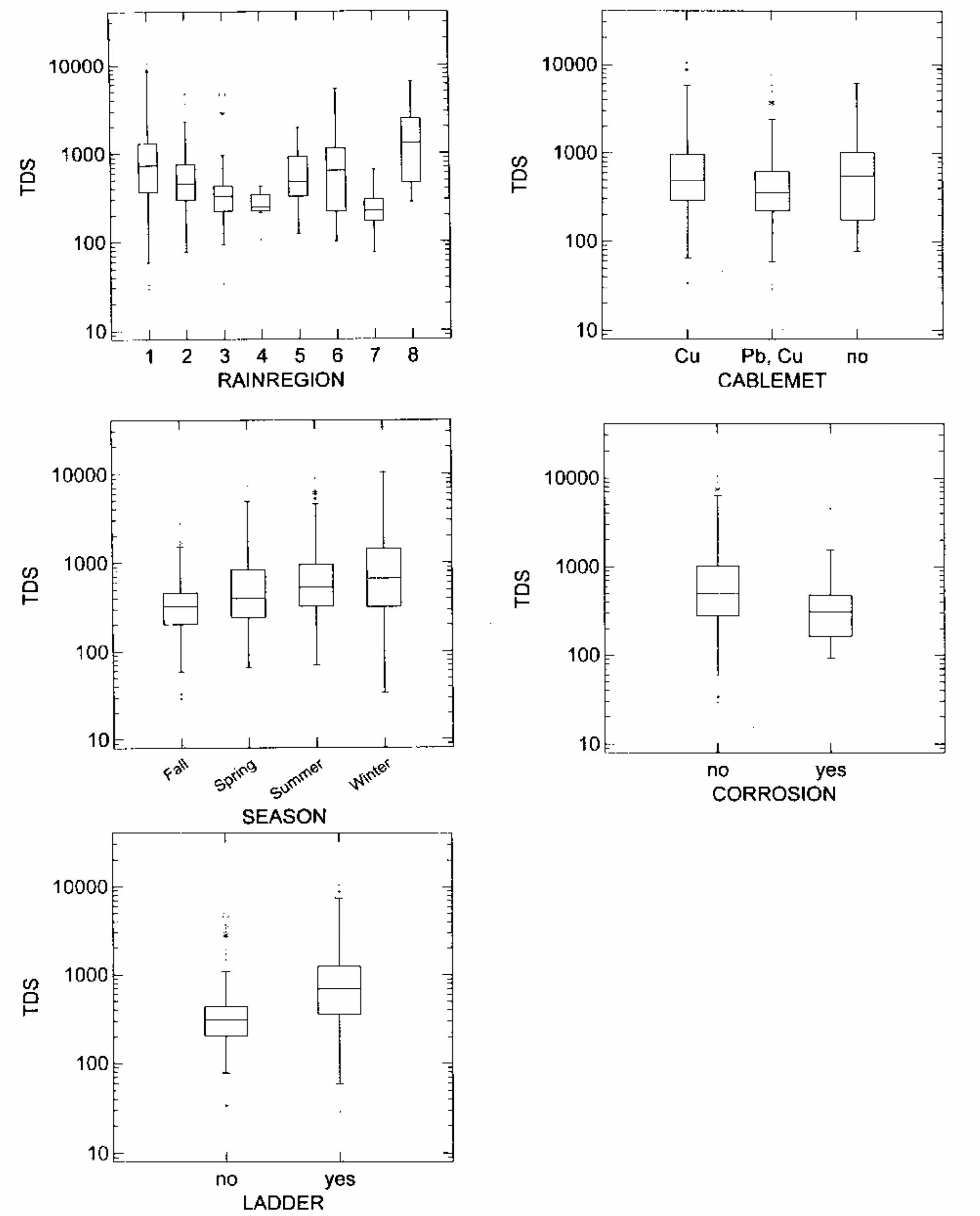


Figure E-3. Statistically significant groupings for "total dissolved solids" concentrations found in water from telecommunication manholes.

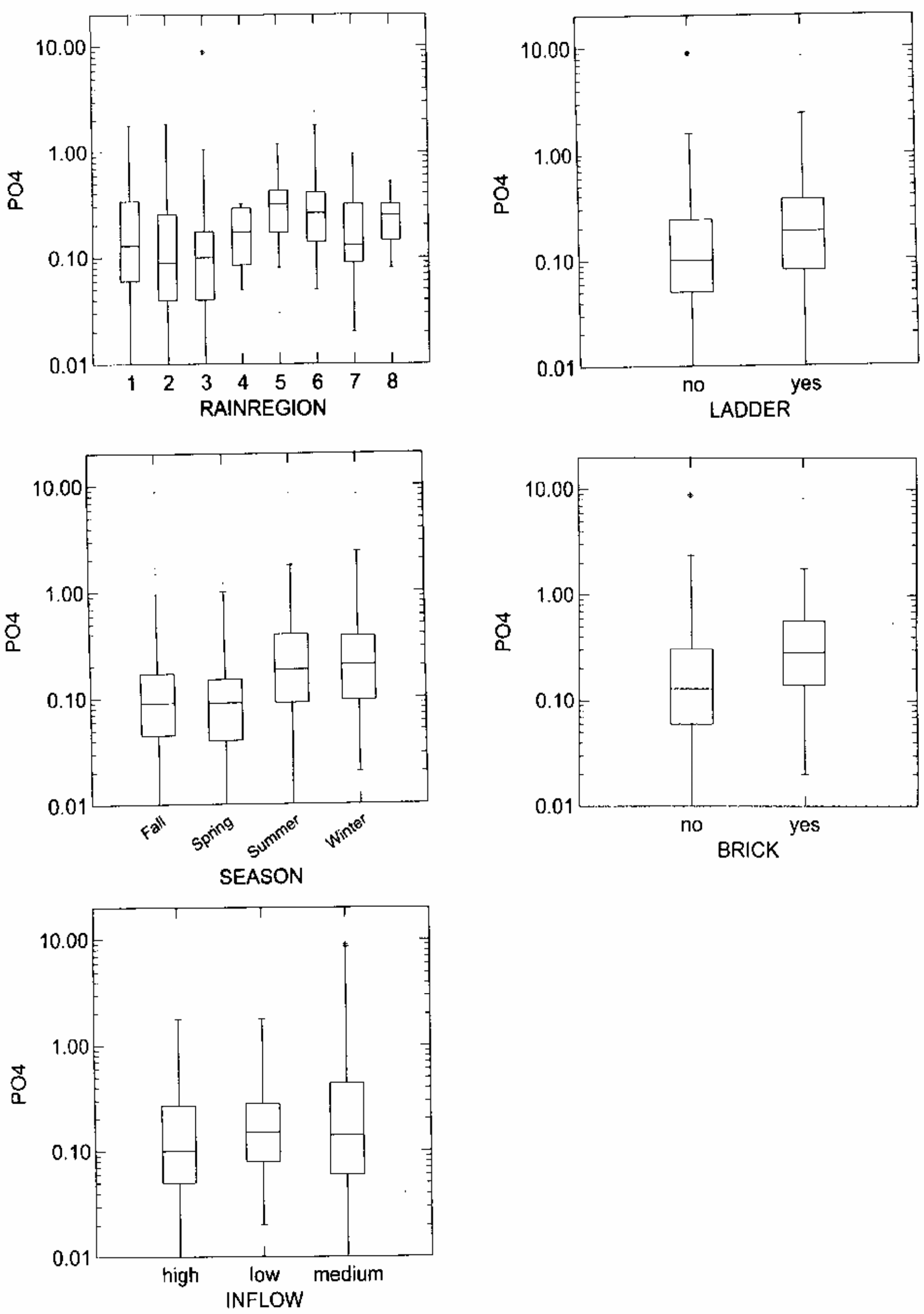


Figure E-4. Statistically significant groupings for "phosphate" concentrations found in water from telecommunication manholes.

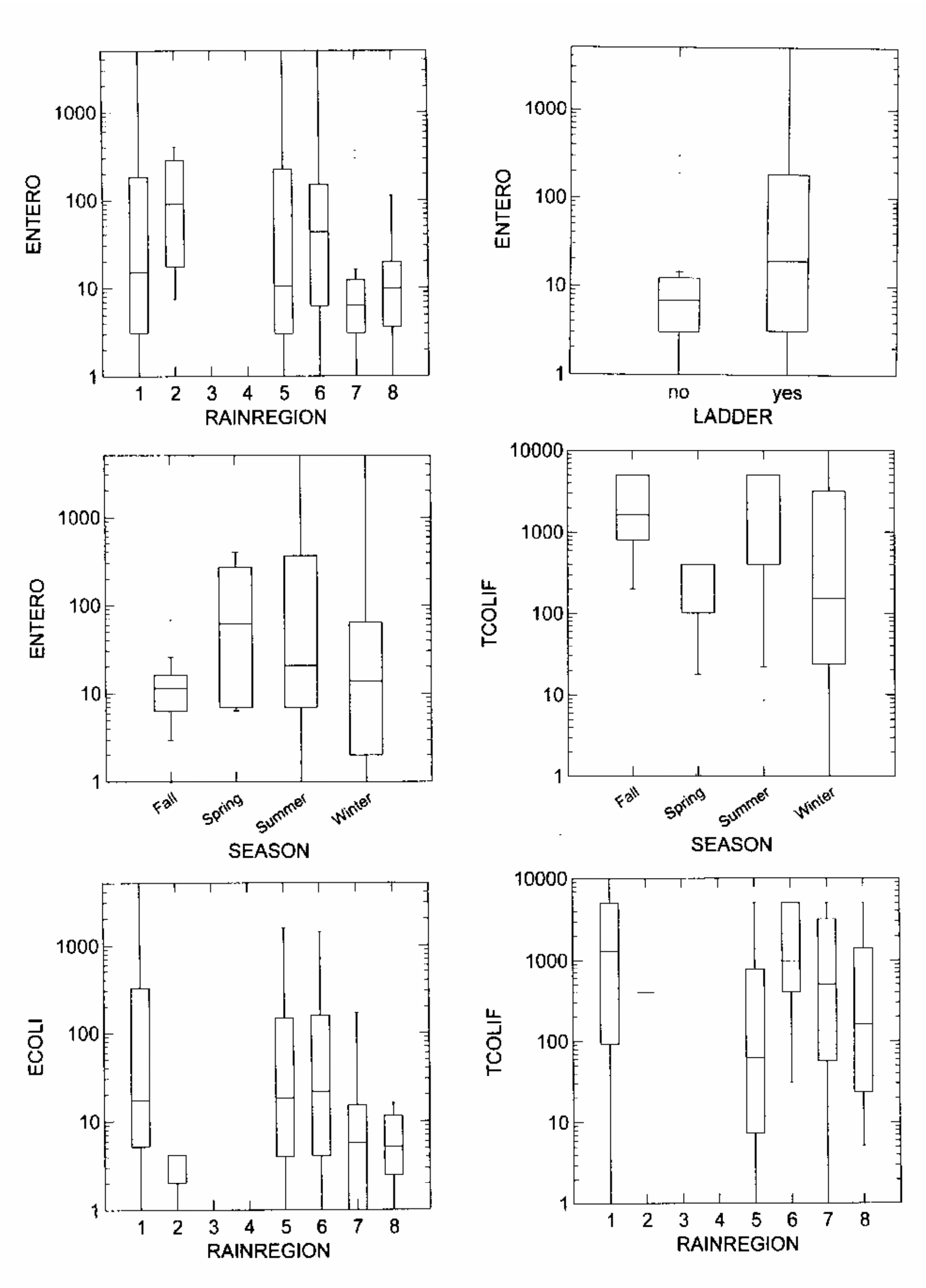


Figure E-5. Statistically significant groupings for "bacteria" counts found in water from telecommunication manholes.

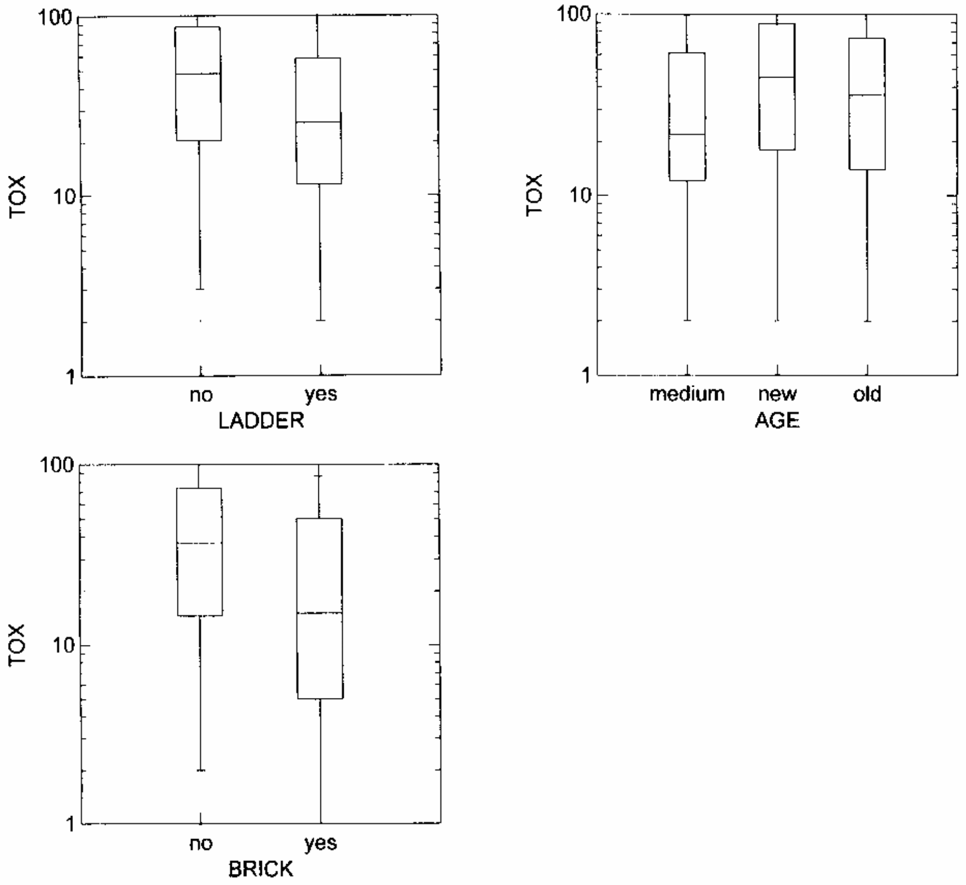


Figure E-6. Statistically significant groupings for “Azur Microtox toxicity” found in water from telecommunication manholes.

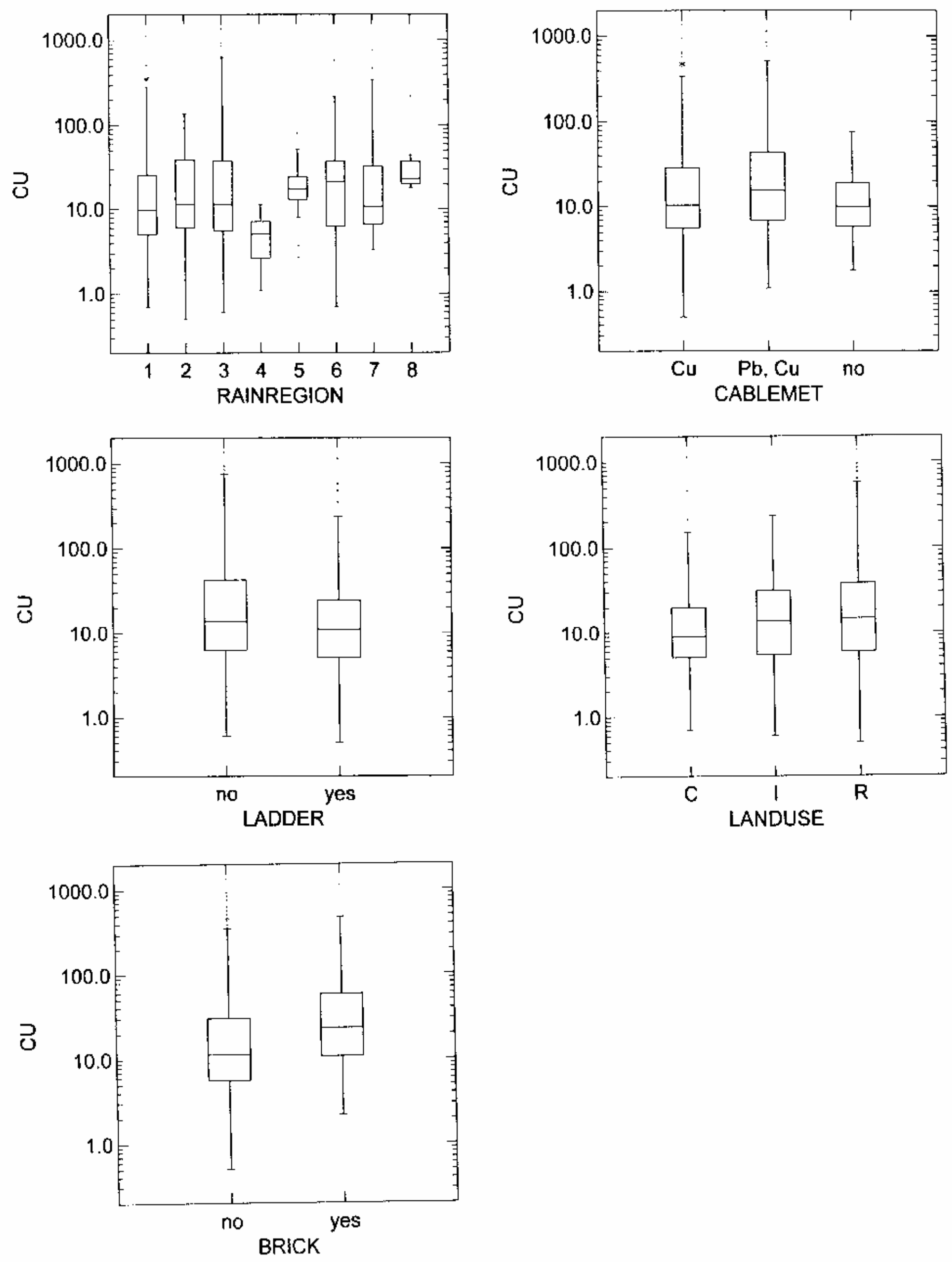


Figure E-7. **Statistically significant groupings for "copper" concentrations found in water from telecommunication manholes.**

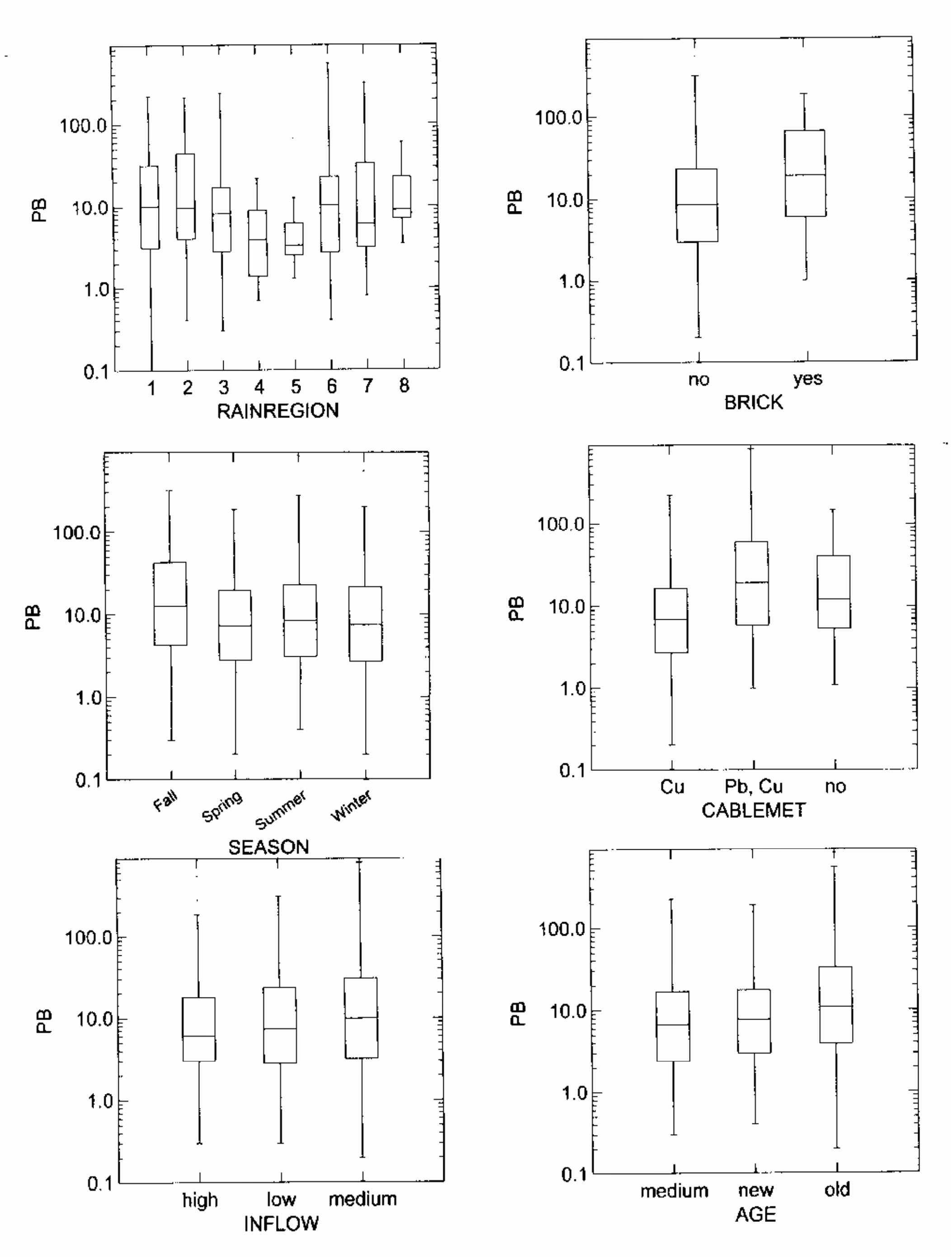


Figure E-8. Statistically significant groupings for "lead" concentrations found in water from telecommunication manholes.

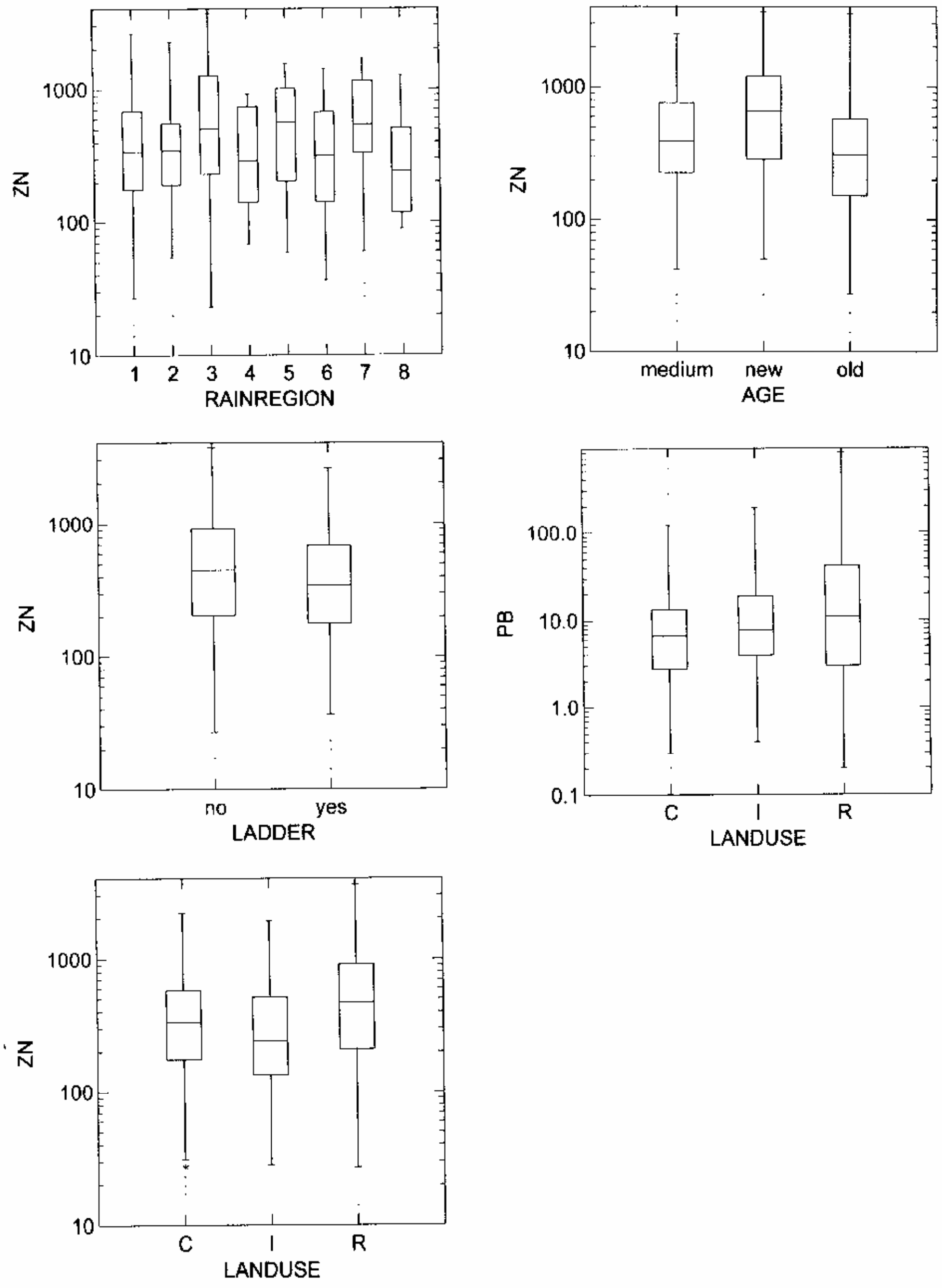


Figure E-9. Statistically significant groupings for "zinc" concentrations found in water from telecommunication manholes.

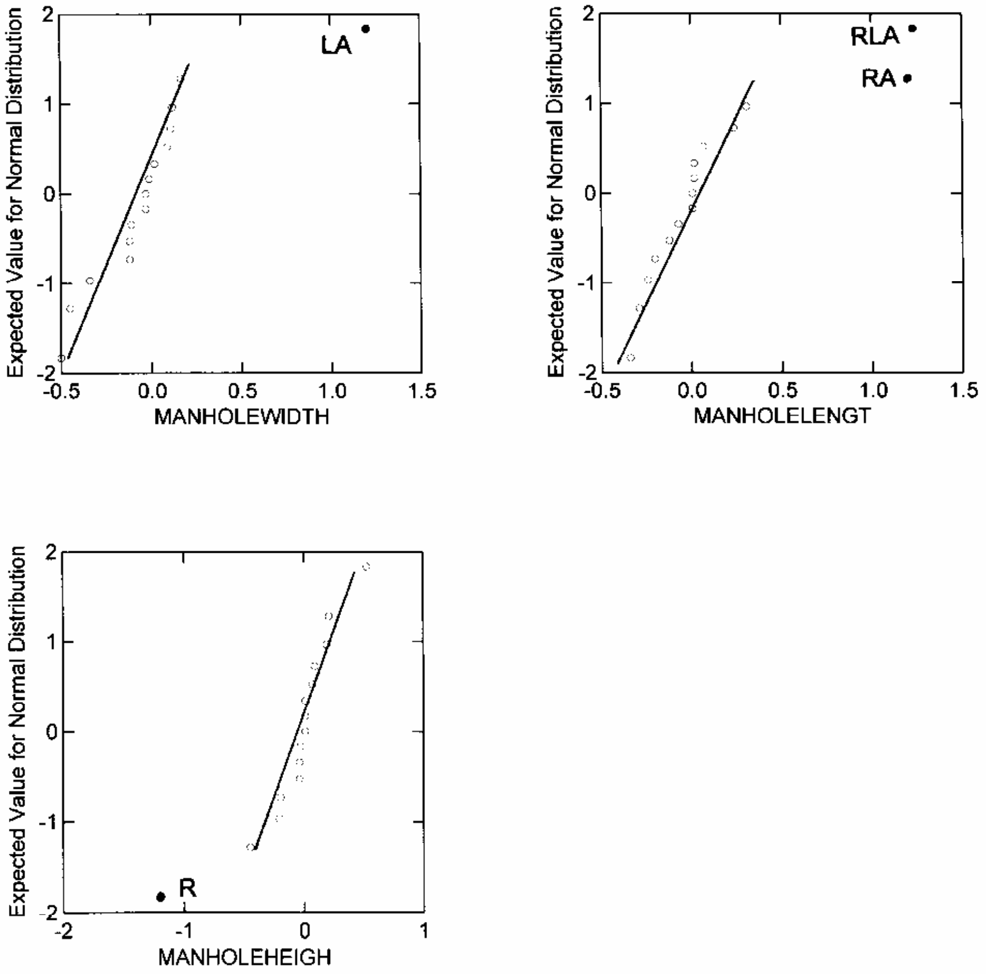


Figure E-10. Significant main and interacting factors for manhole size characteristics.

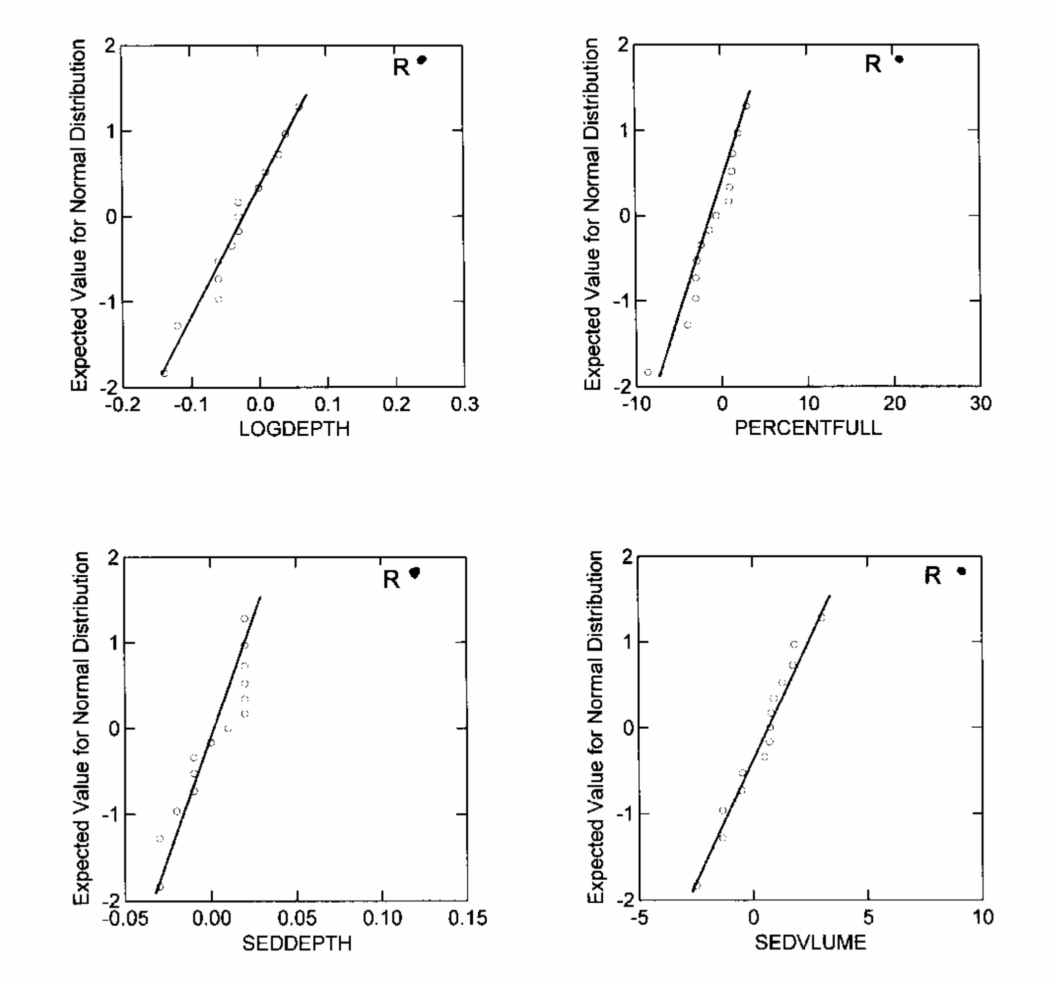


Figure E-11. Significant main and interacting factors for water and sediment quantity found in telecommunication manholes.

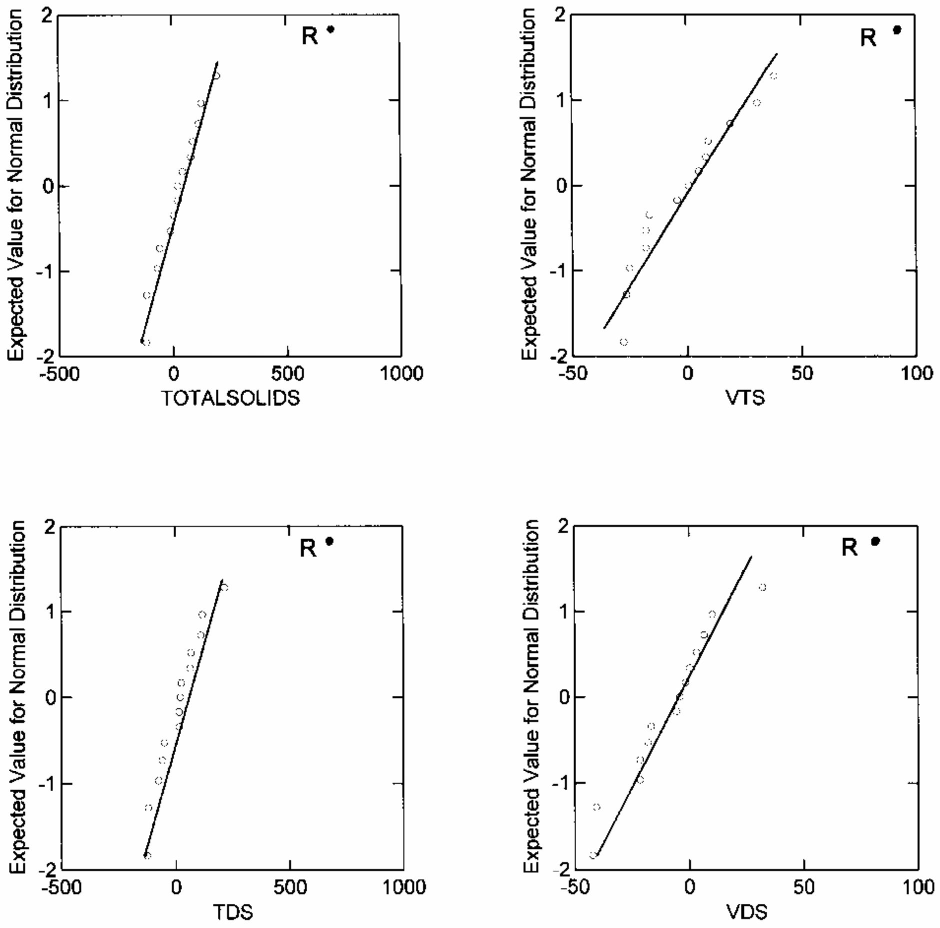


Figure E-12. Significant main and interacting factors for solids concentrations in water found in telecommunication manholes.

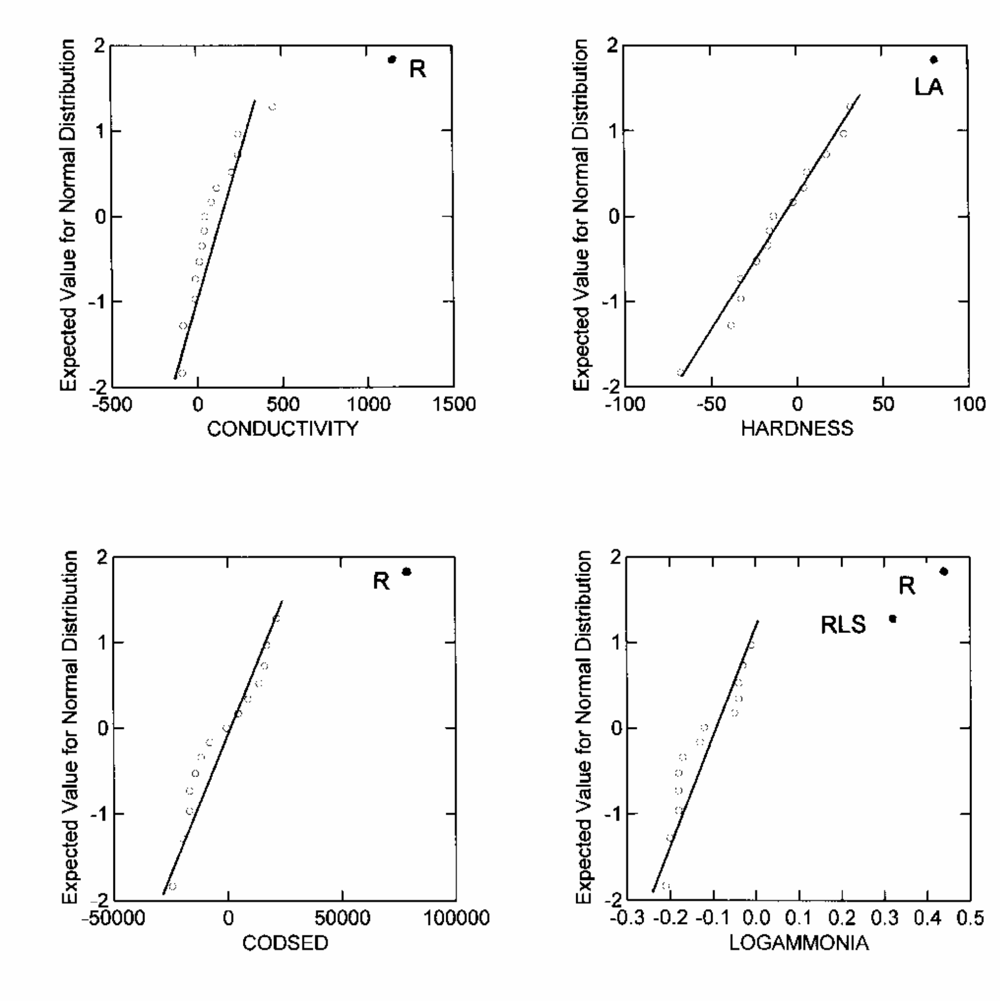


Figure E-13. Significant main and interacting factors for common constituent concentrations in water found in telecommunication manholes.

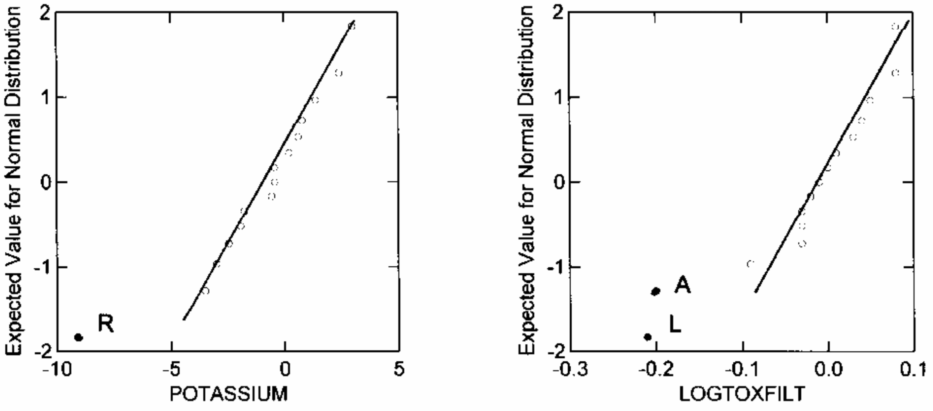


Figure E-14. Significant main and interacting factors for potassium concentrations and toxicity in water found in telecommunication manholes.

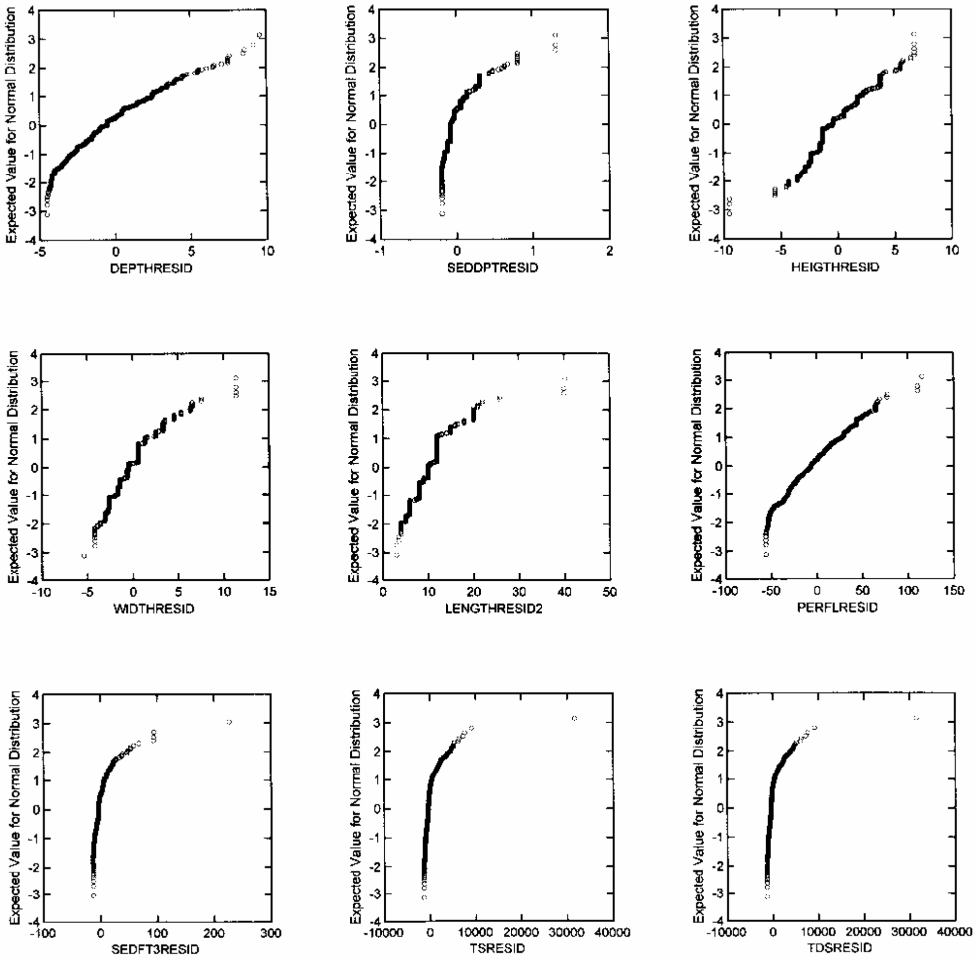


Figure E-15. Residuals for significant factorial models.

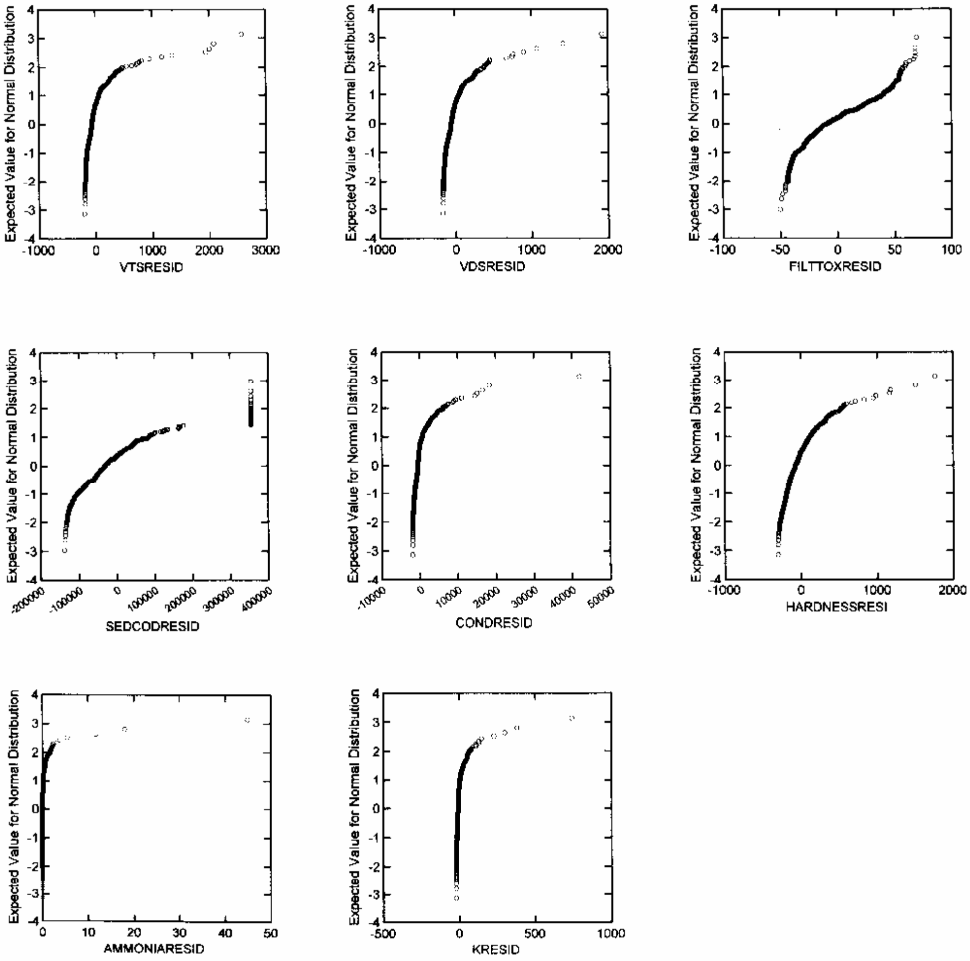


Figure E-15. Residuals for significant factorial models (cont).