To the Graduate Council:

I am submitting herewith a thesis written by Michael P. Barkdoll entitled "An Analysis of Urban Stormwater Quality and the Effects of Dustfall on Urban Stormwater Quality: East Fork of Third Creek, Knoxville, Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for Master of Science, with a major in Environmental Engineering.

Donald E. Overton

Donald E. Overton, Major Professor,

We have read this thesis
and recommend its acceptance:

Donald E. Overton

Accepted for the Council:

Hilton A. Smith

Vice Chancellor
Graduate Studies and Research

AN ANALYSIS OF URBAN STORMWATER QUALITY AND THE EFFECTS OF DUSTFALL ON URBAN STORMWATER QUALITY: EAST FORK OF THIRD CREEK, KNOXVILLE, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

Michael P. Barkdoll

March 1976

1269776

ACKNOWLEDGEMENTS

The author wishes to express sincere appreciation to Dr. Donald E. Overton for his guidance. He also gratefully acknowledges Mr. Roger Betson and his staff at The Tennessee Valley Authority for patiently explaining the data and its acquisition. The author is also grateful for the financial assistance offered by EPA Fellowship Award-Grant No. U-910367-01-0.

The assistance offered by the authors fellow graduate students is gratefully acknowledged, and especially to Mr. Terry Miller and Mr. Michael E. Meadows. Special thanks is offered to Carolyn Snow for typing the manuscript. The moral support offered by Ms. Regina Barkdoll is especially appreciated.

ABSTRACT

Urban stormwater management is becoming extremely important with respect to water quality management. This study quantifies pollutional loads during storm events in an urban watershed. It further attempts to treat the data with multivariate analysis, so that they could be used in model building. The linkage between the effects of air pollution on water quality is investigated and a first approximation model is generated. The study also makes recommendations for further investigations within this study and for future studies.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION.	1
	General Description	1
	Objective of Study.	2
II.	LITERATURE REVIEW	4
	Land Use.	4
	Contaminant Accumulation.	5
	Contaminant Removal	9
	Stormwater Characteristics.	11
	Multivariate Analysis	14
III.	METHOD AND PROCEDURE.	17
	Study Area Description.	17
	Data Acquisition.	18
	Preliminary Data Analysis	19
	Principal Components Analysis	21
	Atmospheric Dustfall and Water Quality Analysis . .	22
IV.	DISCUSSION OF RESULTS	25
	Discussion of Principal Components Analysis.	25
	Discussion of Results of Dustfall and Water Quality Analysis.	34
	Parametric Model	38
V.	CONCLUSIONS AND RECOMMENDATIONS	51
	Conclusions.	51

CHAPTER PAGE

Recommendations. 52

BIBLIOGRAPHY. 54

APPENDIX. 57

VITA. 60

LIST OF TABLES

TABLE		PAGE
I.	Z Scores for Pollutants.	20
II.	Eigenvector Matrix for 20 Water Quality Parameters	26
III.	Eigenvector Matrix for SO_4, Cl, $CaCO_3$, pH, F, Alk.	27
IV.	Eigenvector Matrix for NH_3, PO_4, NO_2-NO_3	28
V.	Eigenvector Matrix for Ca, Mg, Na, K, Mn, Pb	29
VI.	Eigenvector Matrix for SiO_2, TDS, color, SS.	30
VII.	Eigenvector Matrix for Mg, Na, SO_4, Cl, PO_4, Mn, Pb, NO_2-NO_3, and SS	31
VIII.	Equation Parameters for Difcor with Observed and Predicted Values of Runoff.	33
IX.	Mean Values of K, the Ratio of Predicted Concentrations to Observed Concentration with Correlation Coefficients. .	35
X.	Ranked Mean Values for K, the Ratio of Predicted Concentration to Measured Concentration	37
XI.	Optimized Parameters M_T and RO_c with Correlation Coefficients and Mean Dustfall Rates.	39
XII.	Mass of Pollutant Available for Removal by Runoff for Street Surface Model and for Parametric Model	45
XIII.	Ratios of M_T to D.	48
XIV.	Average, Range, and Standard Deviation of Pollutant Concentrations for 21 Storms Analysed by Knoxville Utilities Board Laboratory.	49

LIST OF FIGURES

FIGURE		PAGE
1.	Removal of Cl by Runoff.	40
2.	Removal of Lead by Runoff.	41
3.	Removal of PO_4 by Runoff	42
4.	Removal of COD by Runoff	43
5.	Removal of Suspended Solids by Runoff.	44
B1.	Map of Study Area.	57
B2.	Dustfall Sampler	58

CHAPTER I

INTRODUCTION

General Description

As science exposes more and more of the mechanisms that control humankind's environment, it becomes apparent that we must view our surroundings in toto. People significantly influence their environmental conditions which in turn influence people's lives. This process is a cyclical, synergestic phenomenon that dictates that we must react with our circumstance as a totality. Urbanization and its inherent problems point to this fact, for nowhere has humankind created a more complex and at times unwieldy circumstance than modern urban living. Although this is a rather specific, technical paper, it is hoped that the reader will keep it in the proper perspective of the total urban environment.

Water pollution control is by no means exclusively a new concept, however is is a multifaceted problem. The first solutions dealt with easily identifiable point sources and their subsequent control. The next aspect of water pollution control is identification and control of non-point sources. Churchill (19) has suggested that non-point sources have the following characteristics: They are diffuse, intermittant, arise from extensive areas, can not be monitored at point of origin, not always traceable to any exact source, site specific, and they respond to climatic conditions.

The Water Pollution Control Act of 1965 recognized non-point source pollution as a serious problem. The 1972 amendments gave impetus to the investigation of non-point source pollution by stating, "An accelerated

effort is stressed to develop, refine, and achieve practical application of waste management methods applicable to non-point sources of pollutants to eliminate the discharge of pollutants." Non-point sources are generally listed categorically as agriculture, mining, forest, and urban. This research deals exclusively with urban non-point sources of pollution.

Urban non-point source investigations are commonly categorized as combined sewers, storm sewers, and open channels. The generation of the pollution is essentially the same in each, however the means of transport may significantly influence the total effect. This investigation deals with open channel or stream transport. Urban non-point source investigations may also be separated into base flow and storm flow. This investigation deals with storm flow. The confines of this experiment are then, stormwater runoff from an urban area that is transported by open channels.

The long range objectives of studying urban stormwater runoff are:

1. To provide inputs for water quality and quantity modeling.
2. To use these models in all phases of urban planning.
3. To provide information so that methods of control may be most effective and cost efficient.
4. To subsequently enhance water quality within urban areas and to alleviate the problems of downstream users.

Objective of Study

Certain specific objectives were defined for this study that will hopefully be germane to the realization of the long range objectives previously mentioned. The first specific objective was to merely

quantify those water quality parameters that may be expected in urban stormwater. This type of data is not extremely common so that the more we know about "typical" values, the better we may access the problem. The second objective was to statistically treat water quality parameters so as to eliminate redundant variables. This reduction would significantly decrease computational complexity and at the same time allow for regionalization so that the model could be used for predictive purposes. The third objective was to develop an empirical model that would logically link the effects of air pollution on urban stormwater and water quality. The fourth specific objective was to evaluate the present experimental setup and make recommendations to enhance the effectiveness of the study as it continues.

CHAPTER II

LITERATURE REVIEW

This chapter reviews and summarizes the current knowledge concerning the quality of urban stormwater. It is divided into six sections which detail the pertinent aspects of stormwater pollution generation and subsequent data analysis.

Land Use

Leopold (1) suggests that streams in urbanizing areas undergo a unique change commensurate with the extent of urbanization. The first step in land development is clearing and grubbing, which exposes topsoil and subsoil to weathering conditions. Erosion from unprotected construction sites may generate huge quantities of sediment which are transported to natural runoff channels. Large quantities of sediment bury much of the natural stream biota, and because of increasing turbidity predator-prey relationships and reproduction cycles are adversely effected. In most urbanizing areas, large expanses of land are converted from a pervious condition to an impervious condition. Where impervious conditions are created, i.e., streets, parking lots, and roof tops, engineering designs are usually implemented to remove water as quickly as possible for convenience. These conditions necessarily impart increased flashiness to the urbanizing watershed. Increased flows have several important ramifications. The increased magnitude of stream flow may wash out certain species of aquatic biota. Streambed scour increases turbidity and bank erosion destroys littoral zones and decreases the general

aesthetic quality of the waterway. Increased flow carries the polluted stormwater off quickly so that any residual assimilative capacity of the stream is circumvented. In essense the waterway is transformed from an aesthetically pleasing natural resource into an aesthetically displeasing, unwanted barrier. By default the urban stream becomes an open channel storm sewer.

The EPA has recognized the importance of this chain of events and has published guidelines (2) for construction practices.

Urbanization increases the accumulation of potential pollutional substances on the land surface. Urbanization also increases the amount of impervious surfaces and significantly affects the manner in which deposited pollutional substances are removed by runoff. These phenomenon will be discussed in detail in subsequent sections.

Recent studies (3) have suggested that heavy urbanization may significantly affect weather patterns, especially total rainfall and the number of rainy days. Local weather modification could significantly affect local water quality by increasing the flushing action due to increased rainfall, or by increasing the probability of local inversions which would depress the natural mechanisms affecting air pollution dilution and transport.

Contaminant Accumulation

The accumulation of contaminant material in urban areas that can be removed by runoff and hence contribute to water pollution is a complex problem. It necessarily must be investigated in several ways. Pertinent considerations are the ultimate sources, and means of transport into and

out of the area. In conjunction with the above considerations, contaminant characteristics both physical and chemical are important.

A detailed categorizing of all sources of urban contaminants constitutes a monumental task. Sartor and Boyd (4) listed seven probable sources of street surface contaminants.

1. Pavement
2. Vehicles
   - (i) leakage, fuel, lubricants, etc.
   - (ii) tire, clutch, and brake wear
   - (iii) exhaust
   - (iv) dirt, rust and decomposing coatings from bodies
   - (v) broken vehicle components
3. Atmospheric
4. Vegetation
5. Litter
6. Spills
7. Anti-skid compounds

The means by which these contaminants are transported into and out of the urban area are also very complex. Influent contaminants may be moved by humankind's activities or the wind. Wind transported material is commonly called dustfall. Dustfall includes sedimentation, coagulation with subsequent sedimentation, and impaction. Dustfall is normally associated with samples collected excluding rainfall and snowfall. If rainout and washout are included, one has a measure of total atmospheric fallout. Rasool (16) defines rainout as those particles which are removed by condensation processes in clouds and washout as the

removal affected by falling hydrometeors. In a Chicago study, Heaney and Sullivan (17) estimated that approximately 70% of the material found on street surfaces could be attributed to dustfall.

Rassano and Johnson (18) investigated dustfall in Seattle as a source of water quality impairment. Their investigation was conducted to calculate the impact of the dust that fell directly into water supply reservoirs. They found that no constituents were of a magnitude to adversely affect water quality except for lead for certain times of the year. Their dustfall collection network showed that greater accumulations for all constituents except lead and phosphate occurred near highly industrialized areas. Lead accumulations were found to correlate well with traffic flow. Phosphates were greatest in residential and suburban areas. Dustfall was found to have a pronounced seasonal variation with maximum values occurring in March, April, and May with values remaining essentially constant throughout the remainder of the year.

Effluent transport of contaminants from an urban area may be attributed to resuspension by air masses, sanitary practices such as street cleaning, urban runoff, and physical entrapment within the area such as soil absorption. In a study by Andren, Lindberg, and Bate, (22) trace elements were studied in a rural watershed at Oak Ridge, Tennessee. A material balance was done to determine the cycling of trace elements through the watershed. Input consisted of wet deposition (rainout and washout) and dry deposition (impaction). Output was speciated as to dissolved and particulate forms in the main drainage channel. They found that dry deposition was 4.5, 20.6, 2.3, 20.0, 16.5, 33.1 and 9.2%

of total deposition for Cd, Cr, Cu, Hg, Mn, Pb, and Zn respectively. They also found that the watershed efficiently retained Pb (97-98% of the input), Cd (94-95%), Cu (82-84%), Cr (59%), Mn (57%), Zn (73-75%) and Hg (69-75%).

The accumulation of any contaminant is then a combination of source strength, transport in minus transport out of the area. Sartor and Boyd investigated accumulation rate and found that it was constant for approximately one to two days after the street had been cleaned either by street cleaning or rain, and then the rate decreased and approached an asymtote. Different solids rates for different land uses were observed with industrial areas being 60 lb/curb mile/day, residential areas 28 lb/curb mile/day, and commercial areas 10 lb/curb mile/day. They also found that asphalt streets had loadings 80% heavier than concrete streets. Street surface conditions rated fair to poor were loaded approximately 2-1/2 times as heavy as street surfaces rates good to excellent.

The physical and chemical characteristics of street surface contaminants are well documented in references (4) and (5). Some of the most important points are that from 40 to 90% of contaminants occur as particles less than 246 microns. Particle size is important because it determines how the contaminants may be influenced by wind, water, and sanitary practices, and it dictates possible effects on receiving waters. Particle size is also germane to design criteria if urban stormwater is to be treated by municiple wastewater treatment plants. Since no data is available concerning accumulation and removal of contaminants from previous surfaces, small particles observed on street surfaces may

render area wide estimates conservative. For example, a particle with a diameter of 246 microns could be resuspended by air masses with velocities of less than five miles per hour, therefore particles on a street surface could be displaced by the turbulence created by vehicular traffic, and redeposited on adjacent surfaces thereby decreasing the apparent contaminant loading on the street surfaces, but increasing the loading on adjacent areas. Particle size is also pertinent, because municipal street cleaning practices are rather ineffective for smaller particles.

Contaminant Removal

Once the contaminants have been deposited and accumulate with time, they are removed by either natural cleaning, rain and runoff or by sanitary practices, street cleaning, etc. Sartor and Boyd (4) simulated rainfall on street surfaces and studied the transport of contaminants. Their experiments show that with constant rainfall intensity, the amount of material washed off follows an exponential relationship presented in Equation II-1.

$$N_c = N_o(1-e^{-krt}) \qquad \text{(II-1)}$$

Where N_c is the amount of material of a given particle size which has been removed during time interval t by a rainfall of intensity r. N_o is the initial loading intensity of that material of that particle size which could ever be washed from the street by rain of intensity r (even as t approaches infinity). The proportionality constant k, is dependent on street surface characteristics. An important conclusion of this

study is that, "the amount of material (N_o) which is capable of being removed from a street varies with the rainfall intensity r." They also found that removal rate was virtually independent of particle size for particle sizes between 10 and 1000 microns.

Sartor and Boyd (4) also demonstrated that both the rate of removal and the total amount removed were highly related to the type of street surface and the conditions of the street. They found that removal was best on old asphalt, worst on new asphalt and intermediate on concrete. One shortcoming of this study was that the total initial amount of contaminants was never measured, so that percent removals could not be calculated.

A subsequent study by EPA (5) addressed itself to this particular problem. They found that percent removal was a function of total runoff and not runoff intensity. These experiments were conducted for runoff rates between 0.1 and 1.0 times/hour, inclusive, and runoff durations of 0.25 to 6.0 hours, inclusive. Ninety percent removal was produced by 0.5 total inches of runoff. Their removal equation was of the form

$$\% \text{ Removal} = (1-e^{-P/.217}) \times 100 \qquad \text{(II-2)}$$

where P = total inches of runoff. Again this relationship holds for street surfaces only, therefore, for other surfaces the value of .217 would be different. The numerical value 0.217 represents the "easiest removal case" so that for semi-pervious and pervious areas the numerical value would increase. Simply stated this says that for surfaces more complex than street surfaces, it takes more water (runoff) to remove the same amount of material. Because removal and runoff are linked

exponentially, one must incorporate this with dilution to adequately describe predicted concentrations. It is important whether one is interested in pollutional load or average pollutant concentrations. For example, "a storm event which produces a large volume of runoff will contribute a greater pollutant load to a receiving water than a storm event which produces a smaller volume of runoff. However, runoff from the latter will contain a greater average pollutant concentration (5)."

Stormwater Characteristics

Urban stormwater characteristics are commonly investigated under two temporal regimes; within storm variation and between storm variation. Within storm variation concerns pollutional concentration or pollutional loading versus time. Colston (6) found that the concentration of most water contaminants within a storm was a function of flow and time from the beginning of a storm. He represented the phenomenon by a pollutograph which shows concentration versus time. Most pollutographs depict high concentrations at the beginning of a storm, with decreasing concentration as the storm progresses. This phenomenon has been called the "first flush effect," and it seems to validate the conclusion drawn from contaminant removal studies presented previously in this chapter. Wilbur's results (7) also follow this same general trend for a small urban watershed in New Jersey. Wilbur's studies were on heavy metals for a storm sewered watershed, whereas Colston's were for metals, nutrients, solids and inorganics for a non-storm sewered watershed in Durham, North Carolina. Another means of presenting within storm variation is by using a loadograph. A loadograph plots total load

versus time. Colston, Wilbur and others (5) have validated that loading increases rather linearly for some time and then asymtotically approaches a constant. Of course both the pollutograph and the loadograph are somewhat dependent upon the shape of the runoff hydrograph. Wilbur further studied the variation of concentration of settleable and non-settleable solids during a storm. He found that settleable solids dominated during the rising limb of the hydrograph and non-settleable solids dominated during the falling limb. He concluded that settleable solids were flushed early because of high flows which provided enough kinetic energy for the scour of larger particles.

Colston also postulated that for urban streams, critical conditions as they apply to aquatic biota, are probably created under low flow conditions concurrent with a small storm.

Stormwater characteristics may be categorized as heavy metals, nutrients, inorganics, solids, pestisides, and solids. Wilbur found that lead and zinc accounted for approximately 85% of the total heavy metal load. He also found that the older storm sewers may appreciably contribute to heavy metal concentrations. Bryan (8) also studied lead concentrations in urban stormwater in Durham, North Carolina. By studying several different watersheds with different land uses, he found that lead concentrations were roughly proportional to paved area. Concentrations ranged from less than 0.1 m./l to 12.6 mg/l with a mean value of .59 mg/l. Wilbur reported a mean value of .9 mg/l for lead. Other investigators have reported similar results.

Colston and Bryan both had difficulty in obtaining reliable BOD values. Both authors speculated that there was some contaminant that

was having inhibitory effects. The most probable contaminants were thought to be one of the heavy metals, because in many samples the concentration of one or more heavy metals was greater than or equal to known inhibitory concentrations. Colston further pursued the problem and determined that approximately 44% of COD was biodegradeable. He also postulated that the BOD of urban stormwater might be exerted in a receiving body of water if the runoff were diluted enough to suppress the inhibitory effects.

While most studies to date have focused on variations within a storm, little or no work has been done in analyzing between storm variations. It is generally conceded among researchers in this field that the important parameters governing between storm variations are:

1. intensity and duration of runoff
2. antecedent dry period
3. waste removal from streets
4. land use

The importance of intensity and duration of runoff have been discussed previously. The antecedent dry period limits the amount of material that may accumulate within an urban watershed and which will subsequently be removed by runoff. For urban areas with some pervious areas, the antecedent dry period has some influence on the amount of rainfall that is not absorbed by the soil. Other important aspects of the antecedent dry period and waste removal from streets have been discussed previously.

Some of the primary aspects of land use were enumerated in earlier sections. One of the problems with this parameter is that it is

difficult to quantify. An urbanization index would necessarily contain many parameters. A recent EPA study (5) lists the following parameters:

1. population density
2. street types
3. street condition
4. fraction of the area as road surface
5. type of landscaping in the area beyond the sidewalk
6. average daily traffic
7. method of street cleaning
8. median income
9. age of homes
10. single or multiple housing units
11. percent commercial
12. percent industrial
13. type of industry

Multivariate Analysis

Cooley and Lohnes (9) define multivariate analysis as, "the branch of statistics concerned with analyzing multiple measurements that have been made on one or several samples of individuals." Kendall (10) further explains multivariate analysis by saying, "the variates are dependent among themselves so that we cannot split off one or more from the others and consider it by itself. The variates must be considered together."

Water quality analyses usually encompass P measures on N samples, where P and N may be quite large. For an analysis where P constituents

were analysed, there would be P means, P standard deviations and $(P^2-P)/2$ correlation coefficients. If P equals 20 then a total of 230 parameters would have to be analysed. Mahloch (11) suggests that, "the advantage of using multivariate techniques lies in the fact that the number of statistical parameters subject to interpretation is reduced significantly with the concomitant reduction of large data bases to a manageable level for the purpose of analysis." Water quality analysis presents a special problem because the variables are not independent, but may be highly interrelated. A form of factor analysis known as principal components analysis is well suited to this type of data. In short, principle components analysis is a procedure whereby the matrix of interdependent variables is mathematically transformed into a new set of mutually independent variables or components. The new variables are merely linear combinations of the original variables and are by definition independent. The mathematical transformation is performed on the matrix of the correlation coefficients so that scaling effects are circumvented. Each component explains some portion of the total variance of the original variables and the component which explains the greatest percentage is calculated first with subsequent components explaining some portion of the remaining variance. Hopefully a small number of components will explain a large percentage of the variance so that subsequent computations will be minimized. The mechanics of principle components analysis may be found in any standard multivariate analysis textbook (9,10,12,13).

After principle components analysis has been performed and components selected, other forms of multivariate analysis may be used. Snyder (14)

demonstrated the need for principle components analysis prior to multiple regression analysis concerning hydrologic data with known interrelationships. Other authors (12,13,15) have shown the necessity of principle components analysis before using additional types of multivariate analysis such as cluster analysis, discriminant analysis, canonical analysis and multiple regression.

Mahloch (11) performed a series of multivariate tests on water quality data from the Pascagoula River basin in Mississippi. Principle components analysis with Varimax rotation was performed on 17 water quality parameters, and six principle components were extracted which accounted for 76% of the total variance of the original data. Mahloch's components had physical significance, that is to say that the original variables which made up each component had logical groupings. For example, component II was formed from BOD, total coliform and fecal coliform. This component could be taken to represent the degree of pollution resulting from domestic sources. Mahloch went on to show that other multivariate techniques in conjunction with factor analysis could be used in assessing water quality data.

CHAPTER III

METHOD AND PROCEDURE

Study Area Description

The watershed used in this study was a 1.6 square mile area located in the Lonsdale section of Knoxville, Tennessee. A map of the study area appears in Appendix A. It is an older urban area with 14% of the land area developed to industrial activities. The major industry in the watershed is a scrap yard and foundry that is located adjacent to the main channel for approximately 1500 feet. Other industries are two trucking firms, a lumber yard, a porcelain plant, a linen service, a building materials supply, and a wood veneer plant. Most of the industry is located adjacent to either the main channel or one of the minor channels. Approximately 71% of the area is residential. Most houses are older, single dwelling units. The general economic status of the area is low income. One housing project is located in the area consisting of multiple dwelling units. Approximately 1% of the land is used for commercial purposes. The remaining 14% is undeveloped. The undeveloped areas are primarily steep ridges that are forested. The majority of the undeveloped land is located on Sharp Ridge which is the head water area of the East Fork of Third Creek. The length of the main channel which drains the area is 8,800 feet, with 6,400 feet of other contributing channels. The average slope of the main channel is 2.3% and the maximum elevation drop in the watershed is approximately 300 feet.

While Knoxville in general is located in a karst region, no sinkholes are found in the Londsdale area. The study area is primarily underlain by shale formations, although some sections have sandstone and limestone (20).

There are a total of 22.4 miles of roads located in the study area. The population density of the area is approximately 12 persons per acre. Very little construction activity took place during the study so that land use has remained relatively constant. There is one major traffic artery within the area with a length of 7000 feet. The study area is located in the fork of two major interstate highways, so that three sides are in a relatively close proximity to these interstate highways which are very heavily travelled. There are also 2.2 miles of railroads located within the area. These tracks are not heavily used.

Data Acquisition

All data used in this study were collected by the Water Management Division of the Tennessee Valley Authority (21). Rainfall data collection was begun in October 1971, and was recorded by a continuous recorder located at the Patent Button Company on Proctor Street. Runoff data were recorded by a Stephens Continuous Streamflow Recorder, which was located at the same place. Runoff data were first collected in August 1971 and like rainfall data have been collected to the present.

Water quality data were collected at the same site. A proportional flow collection system was utilized and was calibrated so that only flows greater than 2 cfs were sampled. A maximum of 56 one half liter samples were collected between servicings. Each batch of samples was composited and then analysed. Values obtained were then averaged

concentrations over the sampling period. Prior to May 26, 1973, samples were analysed by TVA laboratories. This analysis covered 27 water quality parameters. After May 26, 1973 samples were analysed by the Knoxville Utilities Board laboratory and organic nitrogen specific conductance mercury, arsenic and COD were not analysed. Analytical methods outlined in Standard Methods were used.

Water quality samples were not collected for every storm because of equipment failures and because logistics made it impossible. Data were collected more or less continuously from October 1971 until the present.

Dust fall data were collected by utilizing one dust fall jar located near the intersection of McPherson Street and Ohio Avenue, approximately 5200 feet from the water sampling stations. The dust fall jar used was 7.7 inches in diameter and was positioned four feet off the ground. It was equipped with a bird ring. A drawing of the dustfall jar appears in Appendix A. Samples were analysed for the same constituents as water quality and by the same laboratories. Dust fall samples were not screened to remove insects and other extranneous material.

Preliminary Data Analysis

In selecting data to be used for this study, certain elimination guidelines were used. Seventy three storms were sampled for water quality data during the period of October 1971 to October 1974. The hydrographs for each storm were studied and 47 storms were selected for preliminary investigations. Storms deleted were those in which (1) several storms occurred during the sampling period, (2) the sampling period did not

encompass the entire hydrologic event, (3) non-flow weighted samples or grab samples, and (4) samples that were removed a considerable time after the storm occurred. Although some of the remaining storms were not single events, it was felt that these storms were representative of very wet periods entailing complex storms which occur in this area during the late winter and early spring. BOD was dropped from the data matrix because of the problems encountered by other researchers which were alluded to in the literature review section. Water quality parameters not analysed by both laboratories were not included so that the data matrix consisted of 47 storm events analysed for 20 water parameters plus average flow during the storm. A dichatomy apparently existed for certain water quality parameters. The dichatomy may have been caused by different sample preparations procedures or analytical procedures used by the two different laboratories. This was checked statistically. Events were selected in pairs by average flow.

A Z score was calculated for each water quality parameter and flow and is shown in Table I. $CaCO_3$ is hardness expressed as $CaCO_3$.

TABLE I

Z Scores for Pollutants

Pollutant	Z	Pollutant	Z	Pollutant	Z	Pollutant	Z
Flow	.075	K	4.17	$CaCO_3$	.578	NO_2NO_3	1.10
SiO_2	-.57	SO_4	1.07	pH	2.96	SS	2.44
Fe	5.62	Cl	-1.50	Color	3.36	Alk	1.89
Ca	.71	NH_3	3.92	Mn	1.33		
Mg	1.10	PO_4	1.80	F	1.72		
Na	-.76	TDS	3.25	Pb	1.05		

The Z score is the test for comparing the mean values of two populations and is computed by

$$Z = \frac{\bar{X}_1 - \bar{X}_2}{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}} \qquad \text{(III-1)}$$

Where

$\bar{X}_1$ = mean pop. 1

$\bar{X}_2$ = mean pop. 2

S_1^2 = variance pop. 1

S_2^2 = variance pop. 2

N_1 = number obs. pop. 1

N_2 = number obs. pop. 2

The null hypothesis is that the two subsamples are from the same populations. By comparing the Z score to values listed in standard statistical tables it can be shown that for scores greater than 1.96 or less than -1.96, the null hypothesis may be rejected at a significance of .05. For values greater than 2.57 or less than -2.57 the null hypothesis may be rejected at a significance level of .01.

Principal Components Analysis

Principal components analyses was used on the entire data matrix and two subsets of the matrix. The first subset, consisted of four categories. Since it is advantageous in modeling if the derived parameters have physical significance, and since no such occurrence happened in analyzing the entire data matrix, it was thought that possibly the water quality variables could be classified and analyzed

categorically. Four subsets were chosen and contained the following variables:

a. Metals	b. Physical	c. Nutrients	d. Others
1. Fe	1. S.S.	1. NO_2-NO_3	1. SO_4
2. Ca	2. T.D.S.	2. NH_3	2. Cl
3. Mg	3. SiO_2	3. PO_4	3. $CaCO_3$
4. Na	4. Color		4. F
5. K			5. Alk
6. Pb			6. pH
7. Mn			

The second subset of data analyzed consisted of those water quality variables that showed a consistency in analysis performed by the two laboratories. This list included SiO_2, Mg, Na, Cl, PO_4, $CaCO_3$, Mn, F, Pb, alk, and NO_2-NO_3. The results of these three trails are presented and discussed in Chapter IV.

Atmospheric Dustfall and Water Quality Analysis

Two models were tested to investigate the effects of dustfall on urban stormwater quality, where dustfall in this study is meant to represent total atmospheric fallout, which includes material removed by precipitation. The first being a deterministic model of the form

$$C = \frac{D \times N}{Vol} \qquad \text{(III-2)}$$

Where

C = average concentration of constituent within a storm hydrograph.

D = dustfall rate-weight/unit time

N = time since last storm, i.e., antecendent dry period

Vol = runoff volume.

This model necessarily contains several simplifying assumptions.

(i) Removal of contaminants by runoff is 100% efficient

(ii) There is no carry over from storm to storm, i.e., each is an isolated event

(iii) All dustfall becomes a water contaminant

(iv) Dustfall is the only source of water quality impairment

(v) Dustfall jars are a true measure of dustfall.

Although the model is very simplistic and has severe limitations, it was thought that the results could be quite instructive as to helping to determine the magnitude of the effect of dustfall on urban stormwater quality. Eleven storms were selected which represented singular hydrologic events and which had dustfall data and water quality data coincident. For each event, the dustfall rate was multiplied by the antecedent dry period and divided by the volume of the runoff. This predicted concentration could then be compared to the concentration that was actually measured for that storm.

The second model tested was a parametric model which was a contaminant removal model similar to the one developed for street surface contaminants by Sartor and Boyd (4). It is of the form,

$$C = \frac{M_T}{RO}\left(1-e^{-RO/RO_C}\right) \qquad \text{(III-3)}$$

Where

C = average concentration of pollutant during stormwater runoff

M_T = the total mass of contaminant material within a watershed that could be removed by runoff

RO = volume of runoff

RO_c = that amount of runoff which produces 63.2% removal of accumulated contaminants

e = 2.718.

This model was transformed slightly for computational efficiency to

$$C \times RO = M_T (1-e^{-RO/RO_c}) \qquad \text{(III-4)}$$

where C x RO now represents mass loadings for a given storm. A non-linear least squares computer program was used to evaluate the two parameters M_T and RO_c.

CHAPTER IV

DISCUSSION OF RESULTS

A. DISCUSSION OF PRINCIPAL COMPONENTS ANALYSIS

The results of principle components analysis on the entire data matrix are presented in Table II. Although the dimensionality of the problem is apparently reduced, i.e., 10 components explain 90% of the original variance, it still requires all 20 original variables to describe 10 components. This illustrates the fact that although the water quality parameters are interrelated, they are not strongly or consistently interrelated. Some of the apparent non-homogeneity of this matrix may be attributed to the apparent dichatomy that was mentioned previously. Principal components analysis deals with relative measure so that incongruencies in analysis produced erroneous results. A second detriment is that of the 47 storms analysed, some were multiple storms and some samples included several storms sampled over several days.

The results of the analysis of the four subsets of the original data matrix are presented in Tables III-VI. The results are similar to those of the entire matrix. Since these subsets were organized subjectively, any interpretation must be cautious at best. The objective in devising the subsets was to see if physical significance had statistical significance. For stormwater there is apparently no such relationship.

The results of a fifth subset are presented in Table VII. This matrix consisted of 20 storms which were single hydrologic events and

TABLE II

Eigenvector Matrix for 20 Water Quality Parameters

Pollutant	Components							
	1	2	3	4	5	6	7	8
SiO_2	-.11	-.19	-.15	-.47	-.31	-.37	.16	.18
Fe	.31	-.33	.01	-.03	.07	.04	-.17	-.16
Ca	-.22	-.39	-.19	-.04	.13	-.07	.06	-.09
Mg	-.28	-.33	.02	.18	.03	.09	.25	.08
Na	-.07	.06	.19	-.14	.57	-.27	-.40	.46
K	.25	-.36	-.07	.14	.04	.07	-.29	-.29
SO_4	-.15	-.11	-.46	.13	.08	-.04	-.26	-.08
Cl	-.28	-.07	.13	-.25	.05	.28	.08	-.39
NH_3	-.12	.01	.21	.52	-.37	-.05	-.29	.10
PO_4	-.01	-.22	.46	.22	.12	.00	.06	-.05
TDS	-.18	.04	.10	.05	-.45	-.48	-.13	-.20
$CaCO_3$	-.27	-.30	.00	.11	-.03	.23	-.04	.26
pH	-.13	.09	.28	.07	.35	-.37	.29	-.45
Color	.18	.11	-.39	.02	.06	.10	.13	-.10
Mn	.28	-.28	.13	-.13	-.17	-.08	.08	.13
F	-.23	-.05	.11	-.42	-.05	.05	-.45	-.14
Pb	.25	-.22	.15	-.07	-.03	-.03	.32	.29
Alk	-.33	-.16	.12	-.12	-.05	.25	.04	.08
NO_2-NO_3	-.16	-.22	-.31	.24	.18	-.40	.11	.05
SS	.31	-.28	.12	-.11	-.01	-.15	-.16	-.17

8 components explain 85% of variation in 20 variables

TABLE III

Eigenvector Matrix for SO_4, Cl, $CaCO_3$, pH, F, Alk

Pollutant	Components			
	1	2	3	4
SO_4	.18	.66	.66	.20
Cl	.49	-.17	-.04	.07
$CaCO_3$	.48	.30	-.04	-.47
pH	.16	-.66	.70	-.16
F	.44	-.12	-.14	.78
AlK	.53	-.04	-.23	-.31

4 components explain 89% of variation in 6 variables

TABLE IV

Eigenvector Matrix for NH_3, PO_4, NO_2-NO_3

Pollutants	Components		
	1	2	3
NH_3	-.66	-.32	-.67
PO_4	-.70	-.07	.71
NO_2-NO_3	.27	-.95	.17

TABLE V

Eigenvector Matrix for Ca, Mg, Na, K, Mn, Pb

Pollutant	Components			
	1	2	3	4
Ca	-.21	-.68	-.05	-.14
Mg	-.27	-.63	-.03	.34
Na	-.20	.10	-.95	-.18
K	.48	-.32	-.01	.64
Mn	.59	-.15	-.10	.00
Pb	.52	-.10	-.27	.65

4 components explain 93% of variation of 6 variables

TABLE VI

Eigenvector Matrix for SiO_2, TDS, color, SS

Pollutants	Components		
	1	2	3
SiO_2	-.35	-.78	-.34
TDS	-.66	-.06	-.03
Color	.53	-.12	-.73
SS	.41	-.61	.59

TABLE VII

Eigenvector Matrix for Mg, Na, SO_4, Cl, PO_4, Mn, Pb, NO_2-NO_3, and SS

Pollutants	Components					
	1	2	3	4	5	6
Mg	.35	-.10	-.06	-.03	-.50	.35
Na	.34	-.33	-.21	-.11	-.16	.14
SO_4	.33	-.21	-.36	.05	.68	-.24
Cl	.34	-.32	-.20	-.06	-.24	-.14
PO_4	.34	.14	.38	-.15	-.24	-.78
Mn	.32	.48	.09	-.70	.23	.30
Pb	.31	.67	-.26	.57	-.10	.02
NO_2-NO_3	.32	-.19	.74	.35	.25	.30
SS	.35	-.06	-.08	.11	.09	.06

6 Components explain 99.4% of variation in 9 variables

and had concise sampling periods. The results show that although six components explain 99% of the variation of the original nine variables, the dimensionality is not really reduced because all of the original variables are equally weighted across the first component. Since the weightings range from .31 to .35, the first component does not explain much of the original variation of any one of the original variates.

A multiple regression was done on the components using a differential corrections method. The results of this analysis are presented in Table VIII. The form of the regression equation is

$$Q_p = a_1X_1+a_2X_2+a_3X_3+\ldots a_nX_n \qquad \text{(IV-1)}$$

Where

Q_p = predicted runoff

$a_1 \ldots a_n$ = optimized parameters

$X_1 \ldots X_n$ = concentrations of water variables.

The correlation coefficient for this model was 0.50. Thus, the coefficient of determination is only 0.25 which is not nearly high enough to make any firm conclusions. Other forms of equations were tried using non-linear forms such as

$$Q_p = X_1^{a_1} + X_2^{a_2} \ldots X_n^{a_n}. \qquad \text{(IV-2)}$$

All non-linear forms had correlation coefficients of less than 0.20.

It may be concluded that none of the attempts for reducing the data matrix by utilizing principle component analysis were successful for this data.

TABLE VIII

Equation Parameters for Difcor with Observed

and Predicted Values of Runoff

Parameters[a]								
1	2	3	4	5	6	7	8	9
105.1	-56.4	-10.6	-46.7	-469.4	-396.8	73635.5	83382.2	0.9

Observed (1000 gallons)	Predicted (1000 gallons)	Error[b] (1000 gallons)
2230	1605	625
2200	1957	243
837	1187	-350
763	1588	-825
657	522	135
207	1534	133
4675	1652	3113
1074	2006	-932
545	-59	604
231	-209	440
798	-11	809
943	1250	307
1250	1707	457
2090	1194	896
346	968	-622
468	462	6
476	1306	-830
127	7	120
234	275	-41
152	671	-519

a - Equation form is Runoff = parameter 1 x Mg + parameter 2 x Na + parameter 3 x SO_4 + parameter 4 x Cl + parameter 5 x PO_4 + parameter 6 x Pb + parameter 8 x NO_2-NO_3 + parameter 9 x SS.

b - Correlation coefficient is .50

B. DISCUSSION OF RESULTS OF DUSTFALL AND WATER QUALITY ANALYSIS

The results of utilizing the equation

$$C = \frac{DxN}{VoT} \qquad \text{(IV-3)}$$

compared to the measured results are shown in Table IX. Note that the mean K value is the mean value of the predicted concentration divided by the observed concentration. The correlation coefficient is for the correlation between observed and predicted concentrations. These results must be viewed with discretion as they are highly dependent upon the dustfall data which has limitations because only one dustfall jar was used for sampling, and site selection may have been less than optimum. However, it is still instructive to note the apparent relative magnitudes dictated by the mean K values. K values may be investigated categorically. For example,

Case 1 $K < 0.8$

Case 2 $0.8 \leq K \leq 1.2$

Case 3 $K > 1.2$

These classifications are subjective but instructive. Case 1 represents underprediction by the model. This suggests that a) there are other sources, i.e., scour, leaching, etc., and b) dustfall is not the only mode of transport of contaminant into the watershed. Case 2 represents the situation where dustfall nearly approximates measured stormwater concentrations. Case 3 dictates that the model overpredicts.

TABLE IX

Mean Values of K, the Ratio of Predicted Concentrations to Observed Concentration with Correlation Coefficients

Pollutant	Number of Observations	K	Correlation Coefficient
Fe	10	0.12	.57
Mn	10	0.27	.27
SS	11	0.27	.76
Mg	11	0.39	-.27
Na	11	0.52	-.16
$CaCO_3$	10	0.75	-.31
Pb	10	0.83	.53
As	6	1.14	.48
K	11	1.52	.51
SiO_2	8	1.73	-.10
TDS	11	2.19	-.61
SO_4	11	2.23	.04
COD	7	2.88	.39
F	8	4.01	-.14
PO_4	11	4.28	.35
Cl	11	4.63	-.32
Hg	7	5.84	-.13
NO_2-NO_3	11	18.21	.01
NH_3	11	152.11	-.48

This may be caused by a) environmental sinks for dustfall contaminants b) less than 100% removal by runoff.

Table X shows the case wise ranking for each constituent. Although some anomilies occur, it is interesting to note that the majority of the constituents in Case 1 are leachable minerals. Iron is probably in Case 1 because a foundry and scrap yard is located on the main channel but down wind from the dustfall jar. Case 2 has the single constituent of lead which agree with other researchers findings. Almost all of the lead found in urban stormwater is apparently due to internal combustion engine emissions. Although it is impossible to explain certain constituents in Case 3 it is interesting to note that PO_4, NO_2-NO_3, NH_3, and COD are in Case 3. These parameters are non-conservative such that their magnitudes can be changed from source (dustfall) to receptor (stormwater) by natural processes. Certain other constituents such as Hg and As can be modified by natural processes and/or retained on the soil surface, as was discussed in Chapter II.

The mean K values indicate the relative values of the model, while the correlation coefficient dictate a storm by storm performance. It is obvious from Table IX that as a tool for predicting concentrations for a single storm, the model is quite deficient.

Again it should be noted that this analysis was based on a single dustfall jar, and conclusions must be drawn with extreme caution. These results are valid for grounds for further research and for helping to determine the magnitude of the effect of dustfall on stormwater quality. If measures are taken to control non-point source pollution from urban areas, I also believe that dustfall data may help to determine the most

TABLE X

Ranked Mean Values for K, the Ratio of Predicted Concentration to Measured Concentration

$K < 0.8$		$0.8 \leq K \leq 1.2$		$K > 1.2$	
Fe	0.12	Pb	0.83	K	1.52
Mn	0.27	As	1.14	SiO_2	1.73
SS	0.27			TDS	2.19
Mg	0.39			SO_4	2.23
Na	0.52			COD	2.88
Ca	0.54			F	4.01
$CaCO_3$	0.75			PO_4	4.28
				Cl	4.63
				Hg	5.85
				NO_2-NO_3	18.21
				NH_3	152.11

cost effective measure of control. As in all environmental pollutional problems, one has several options for control. In non-point sources of water pollution with dustfall being a contributing factor, one may affect control (1) at the source of the air contaminants, (2) after the air contaminants have reached the surface but before they are removed by runoff, (3) or after they have entered the water system.

C. PARAMETRIC MODEL

The results for Equation III-4 are presented in Table XI, and Figures 1, 2, 3, 4, and 5. These results are significant for several reasons. Primarily they allow analysis of the magnitude of contaminants available for removal by runoff. Secondly, they allow estimates to be made as to degree of removal by runoff on a contaminant by contaminant basis. Thirdly, they allow comparisons with state-of-the-art models using only street surface contaminants. Fourthly, they allow relative comparisons with dustfall data and allow for validation of the magnitude of the effects of dustfall on urban runoff. Lastly, they provide first approximations for design criteria of pollution control measures on a probability basis because they are linked with runoff. It must be noted that both total mass of contaminants available M_T and critical runoff RO_c are site specific and may or may not be used in other urban watersheds.

Some current stormwater models utilize only street surface contaminants. Values for contaminants available for removal from streets only and from the watershed in toto are shown in Table XII. Note that while street surface contaminants are a contributing factor, they

TABLE XI

Optimized Parameters M_T and RO_c with Correlation Coefficients and Mean Dustfall Rates

Pollutant	M_T (kilograms)	RO_c	$\bar{D}$ (kilograms/day)	Correlation Coefficient
Hg	0.05	0.50	0.009	.67
As	1.28	1.46	0.064	.86
PO_4	27.5	1.44	16	.88
F	34.7	2.16	1.4	.78
Pb	43.2	1.30	0.7	.83
Mn	183	2.78	0.5	.88
N_2-NO_3	488	10.0	12	.91
SiO_2	1,062	1.64	9	.91
Mg	822	1.41	20	.81
Cl	1,067	.99	75	.89
Na	1,255	1.92	14	.89
SO4	10,136	5.71	104	.89
COD	11,677	.74	850	.85
$CaCO_3$	20,038	1.50	251	.91
Ca	65,316	21.0	61	.91
SS	520,820	15.0	1627	

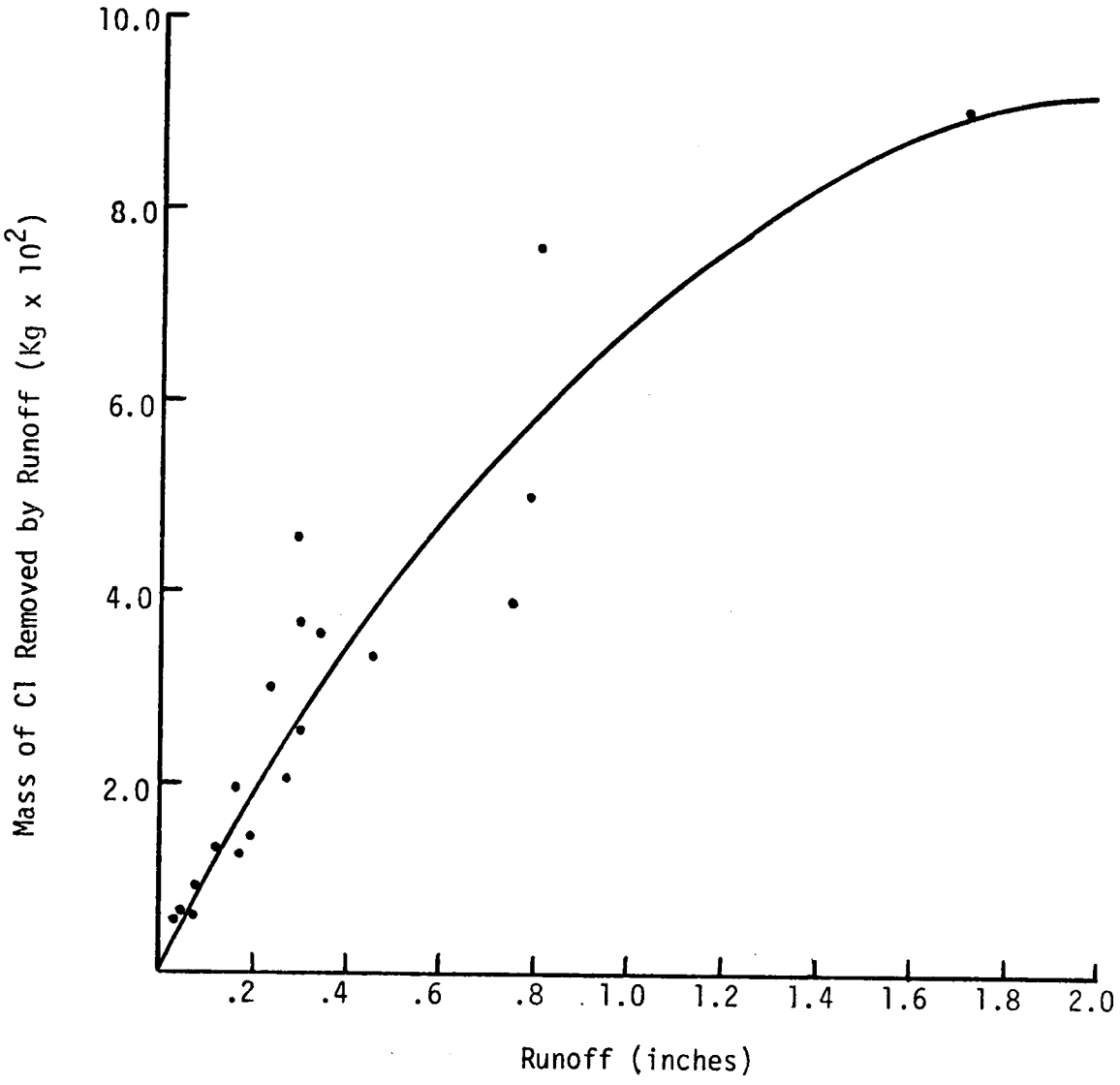


Figure 1. Removal of Cl by Runoff.

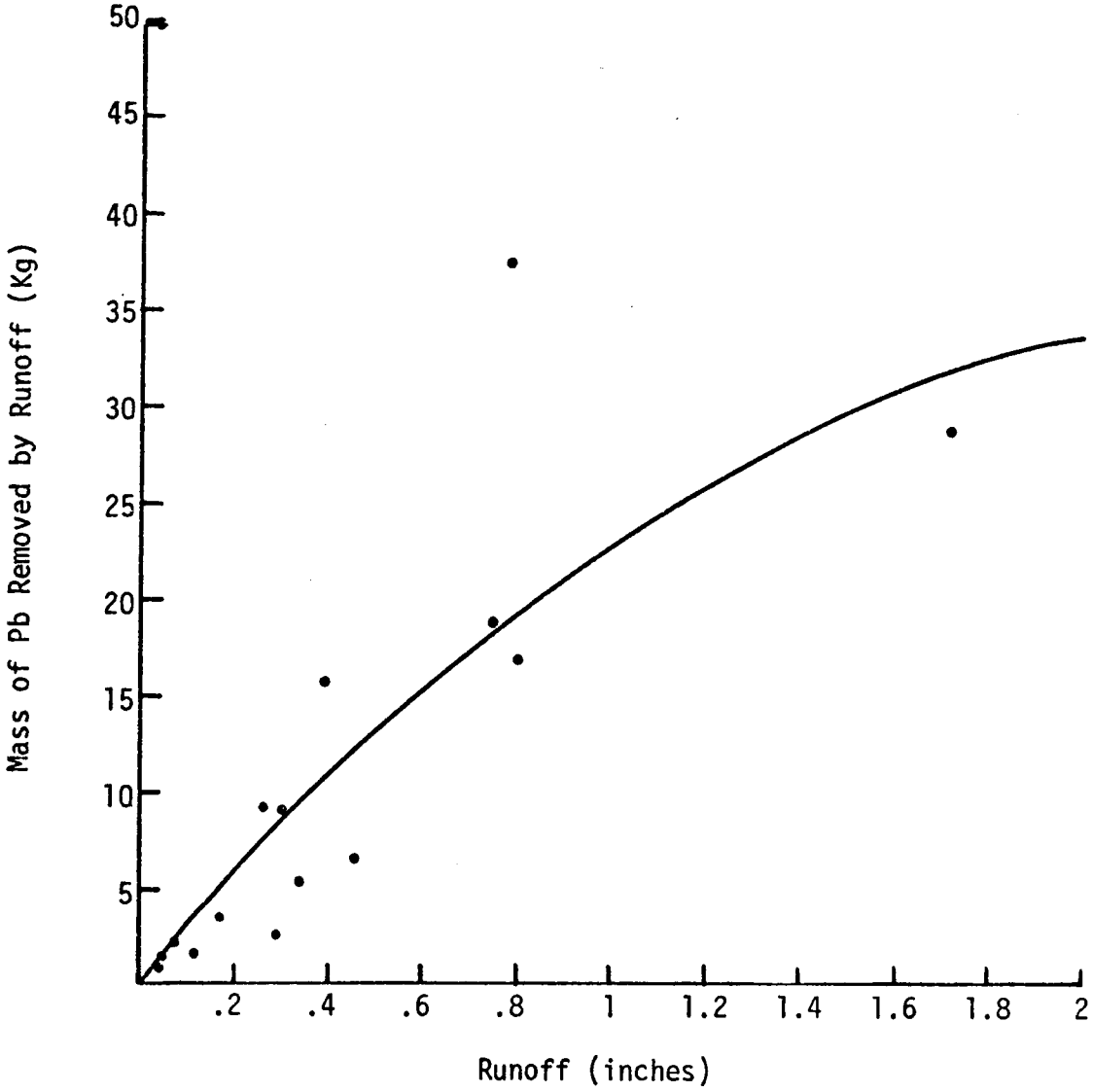


Figure 2. Removal of Lead by Runoff.

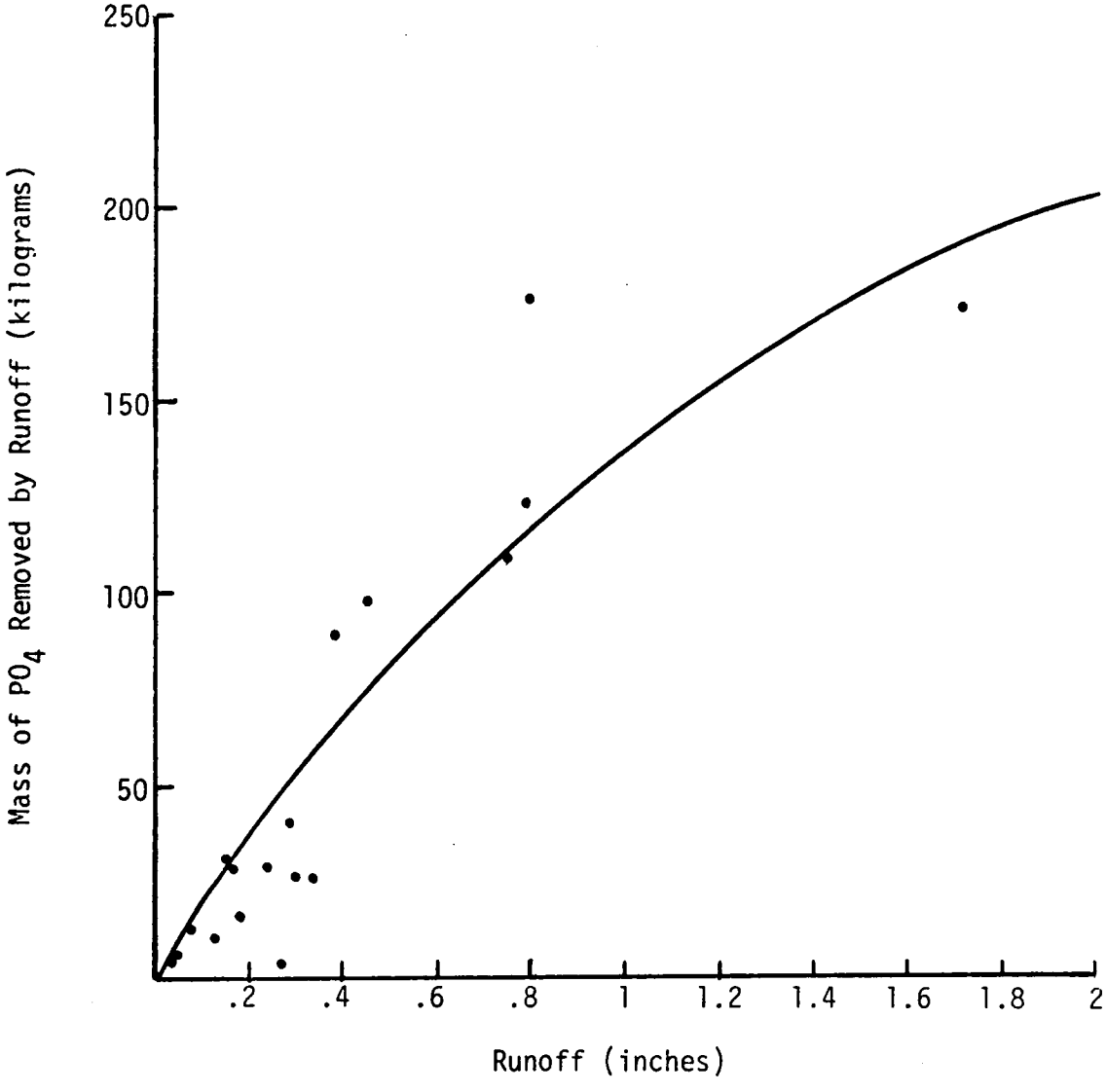


Figure 3. Removal of PO_4 by Runoff.

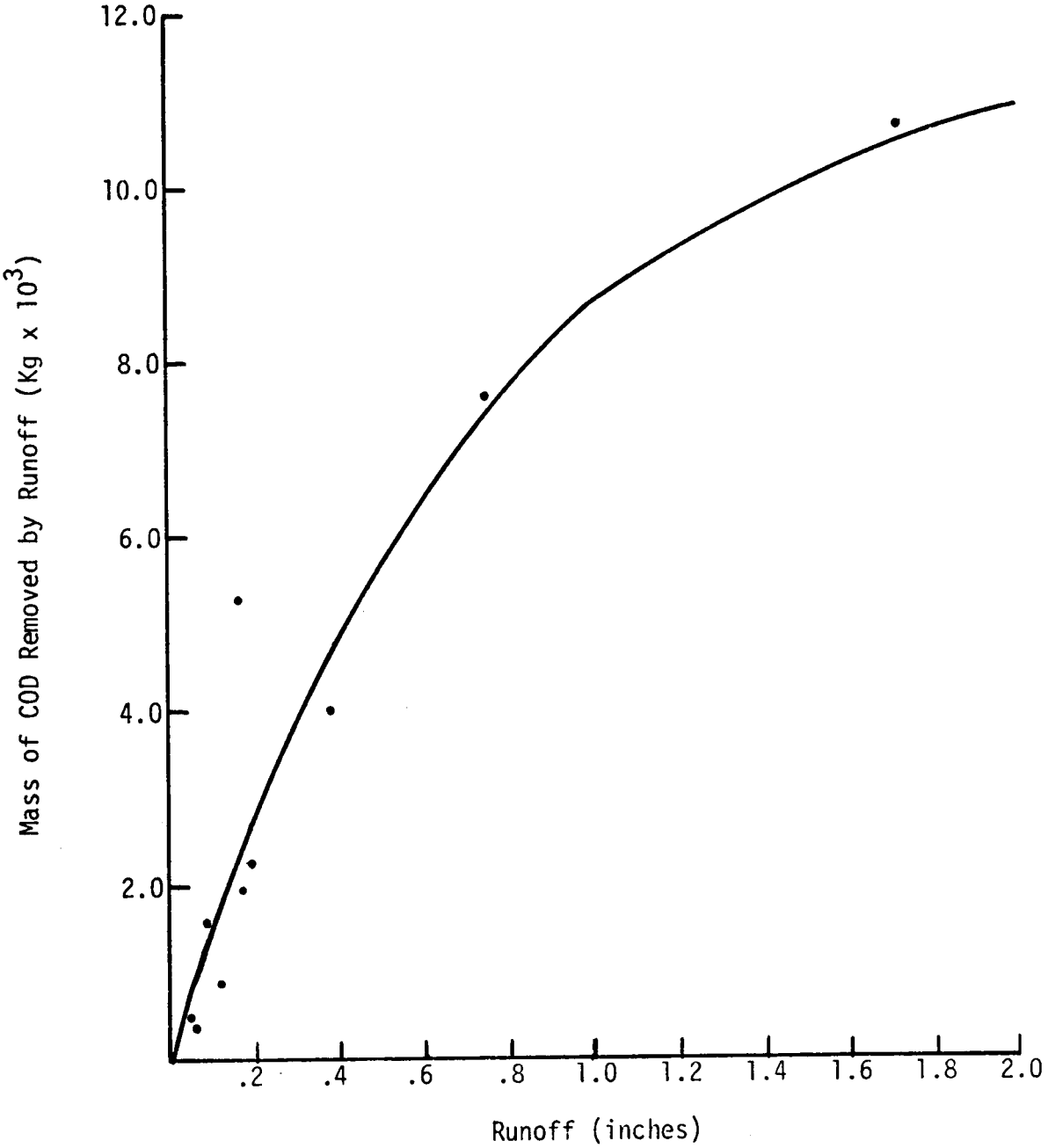


Figure 4. Removal of COD by Runoff.

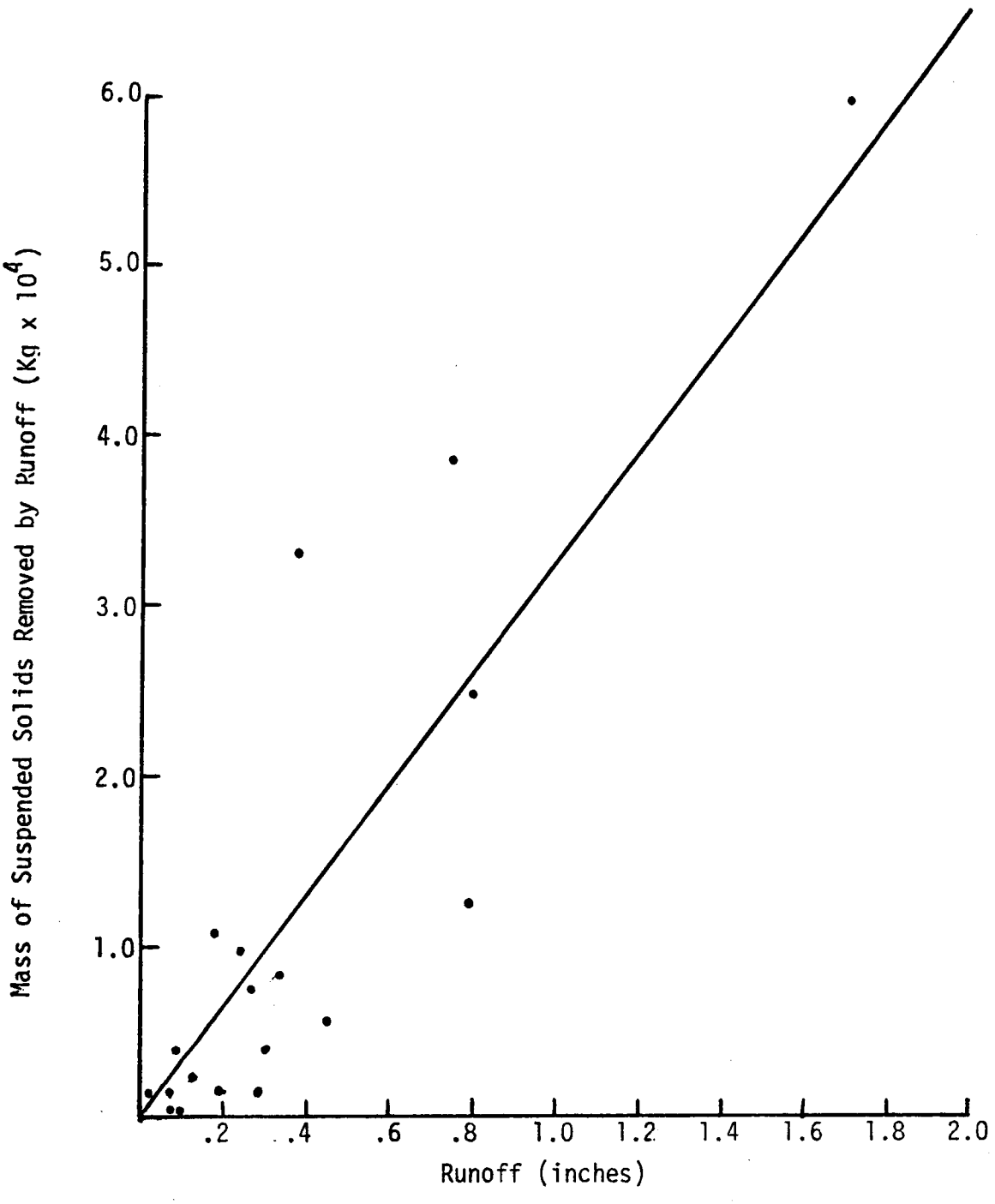


Figure 5. Removal of Suspended Solids by Runoff

TABLE XII

Mass of Pollutant Available for Removal by Runoff for Street Surface Model and for Parametric Model

Pollutant	Parametric Model (kilograms)	Street Surface Model (a) (kilograms)
SS	520,000	19,611
COD	11,677	1,354
PO_4	27.5	9.4
Pb	43.2	13.6
Hg	0.05	1.6

(a) After Sartor and Boyd (4)

grossly underestimate the total loading of the watershed. Even if street loadings are extended to all impervious areas, they still produce conservative estimates for this watershed. This leads to the obvious conclusion that semipervious and pervious areas are highly significant.

The values for removal constants RO_c are presented in Table XI. Low values of RO_c indicate easy removal by runoff and high values indicate increased difficulty in removal. Current studies indicate that for street surfaces, RO_c is 0.217. As would be expected removal constants for a total watershed are higher than for street surfaces only. Another important aspect of these findings is that there is variability in RO_c from contaminant to contaminant whereas the RO_c value for street surfaces is constant for all contaminants. The magnitudes of RO_c indicates whether the pollutants are originating from impervious or pervious areas. Small RO_c values would tend to indicate that pollutants are primarily originating from impervious areas. Large RO_c's would tend to indicate that pollutants are primarily originating from pervious areas. There are apparently significant contributions from pervious areas even for those contaminants with very low RO_c values such as H_g, COD, and Cl.

The storm that generated the 1.71 inches of runoff was a 100 year storm, therefore for constituents with RO_c values greater than 1.71, for most storms they would contribute contaminants on a linear basis, i.e., they are operating in the linear portion of the removal curve. This means that since the slope of the curve is relatively constant, concentrations are relatively constant. Variations in concentration would then be caused by secondary factors such as the antecedent dry period,

dustfall, and seasonal variations. Abnormally high concentrations could be expected for very small storms which generated runoff from impervious areas only. These data do not adequately reflect that phenomena. Very large values of RO_c, such as S.S., NO_2-O_3, SO_4 and Mn indicate that there is a very large supply of these contaminants that could ever be removed by runoff.

Direct comparisons of M_T and D are not possible because D is a rate of accumulation and M_T is a total mass. One means of comparison was accomplished by dividing M_T by D. This ratio represents the number of days it would take to accumulate M_T given the rate D. These values are presented in Table XIII. The average antecedent dry period for this study was 4.4 days, thus it can be seen that only PO_4 yields a value less than 4.4 days. It is instructive to note that generally those constituents with low M_T/D ratios also have low RO_c values. This is logical because small particles can easily be removed by runoff and easily suspended in the atmosphere by turbulence. This points up one of the incongruences of dustfall analysis. Dustfall values represent amounts of material that can be lifted to the height of the dustfall jar by air movement. Therefore, dustfall data do not truely reflect values that are only due to fallout, washout, and rainout. It is also possible that dust in an area can be suspended by local turbulence, settle, and be successively resuspended. Each time it settles it is recorded as dustfall. Although dustfall analysis suffers these limitations, it can be hypothesized that those constituents with low M_T/D ratios represent contaminants that are significantly influenced by dustfall. The M_T/D ratios also point to the fact that nutritive and

TABLE XIII

Ratios of M_T to D

Pollutant	M_T/D (days)
Ca	1070
Mn	366
SS	320
Mg	118
SO_4	97
Na	90
$CaCO_3$	80
Pb	61
SiO_2	41
NO_2-NO_3	40
F	25
As	20
Cl	14
COD	14
Hg	6
PO_4	2

heavy metal constituents are most significantly influenced by dustfall while minerals are least influenced.

Table XIV shows the average, range, and standard deviations of pollutant concentrations for 21 storms analysed by Knoxville Utilities Board Laboratory.

TABLE XIV

Average, Range, and Standard Deviation of Pollutant Concentrations for 21 Storms Analysed by Knoxville Utilities Board Laboratory

Pollutant	Mean (mg/l)	Standard Deviation	Range (mg/l) Low	High
SiO_2	5.83	4.17	1.70	20.50
Fe	1.53	1.96	.040	9.50
Ca	32.20	8.92	13.30	53.60
Mg	7.23	2.34	3.70	11.60
Na	8.21	5.71	2.70	30.50
K	4.85	1.77	2.90	9.90
SO_4	15.27	6.70	.01	29.00
Cl	10.36	3.76	5.00	20.00
NH_3	.17	.17	.03	.66
PO_4	1.68	.77	.12	3.08
TDS	256.43	114.70	137.00	565.00
$CaCO_3$	132.62	36.28	70.00	200.00
Mn	.43	.46	.01	1.92
F	.19	.16	.01	.64
Pb	.15	.15	.01	.53
Alk	106.57	35.07	57.00	210.00
NO_2- NO_3	.47	.22	.11	.98
SS	179.62	165.73	8.00	720.00

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Attempts to analyze urban stormwater quality apparently will have to utilize forms of multivariate analysis other than principle components only. The results from the parametric model show that basically there are two distinct but overlapping groups of contaminants. One group is the minerals and solids which have high RO_c values and thus have relatively constant concentrations from storm to storm and the other group is heavy metals, nutrients, and COD which have low RO_c values and thus have decreasing concentration with increasing runoff. Principle components analyses probably failed because of this dichotomy.

Conclusions concerning dustfall effects on urban stormwater quality have to be limited because of the limitations of the data. It can be said with a high degree of confidence that those constituents, such as, COD, Hg, Cl, Pb, SiO_2, PO_4, and As, with low or medium K values and with low RO_c values significantly influence stormwater quality. Contaminants with M_T/D values nearly equal to the average antecedent dry period such as COD, Hg, Cl, As, and PO_4 are primarily due to dustfall. The relative magnitude of the influence of dustfall for other constituents will have to be verified by further study.

The parametric model results indicate that for urban watersheds with pervious areas, these areas cannot be disregarded in determining pollutant yields. Models using only street surface contaminants will yield

conservative results. Removal rates are pollutant specific, so that no general model can adequately describe all pollutants. Removal is a function of total runoff and is only mildly affected by intensity of runoff. The total mass M_T available for removal is also pollutant specific. Certain pollutants such as S.S., Ca, Mg, SO_4, and $CaCO_3$ are available in extremely large quantities. These constituents probably arise from the erosion of disturbed land areas.

In summary, any study dealing with urban stormwater quality must proceed under the restraints of site and pollutant specificity. Results from this study should not be applied willy-nilly to other watersheds. Hopefully some of the fundamental concepts investigated in this study will be used in further studies of urban stormwater quality.

B. RECOMMENDATIONS

Recommendations are of two types. The initial set of recommendations are for the current study, and the second set are proposals for future study.

Since other researchers in urban stormwater quality have experienced difficulty with the BOD test, it is recommended that either attempts are made to find the cause of difficulty or to initiate other comparable tests that will allow suitable comparisons. It seems that the most promising comparative test would be the COD test which should be reinstated immediately. Since the effects of urban stormwater on receiving waters is of vital importance, it is suggested that dissolved oxygen tests should also be run. Although analysis such as the coliform bacteria tests do not specifically point to human contamination, it

would be helpful if these forms were recorded so that health hazards could be assessed, especially if control devices such as retention basins are used.

Pollutographs and loadographs would be very useful, especially in helping to determine the contributions from impervious and pervious areas. A profile of contaminant concentrations with respect to depth are vitally important because colston found that concentrations are a function of depth and the sampler for this particular study was stationary with respect to depth.

It is recommended that a network of dustfall jars be placed, and in such a manner that they would effectively represent the entire watershed. These new values could be used to reevaluate those results gained from the single dustfall jar. It is also suggested that shorter sampling periods be used.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Leopold, L. B., "Hydrology for Urban Land Planning-A Guide Book on the Hydrologic Effects of Urban Land Use," Geological Survey Circular 554, U.S. Department of the Interior, Washington, D.C., 1968.

2. Environmental Protection Agencies, "Processes, Procedures, and Methods to Control Pollution Resulting from all Construction Activity," EPA-43019-73-007, 233 pp., October, 1973.

3. Changnon, Stanley A., "The LaPorte Weather Anomaly-Fact or Fiction," Man's Impact on Environment, McGraw-Hill Book Company, New York, pp. 155-166, 1971.

4. Sartor, James D., and Boyd, Gail B., "Water Pollution Aspects of Street Surface Contaminants," EPA-R2-72-081, 236 pp., November, 1972.

5. Environmental Protection Agency, "Water Quality Management Planning for Urban Runoff," EPA-440/9-75-004, 208 pp., December, 1974.

6. Colston, Newton V. Jr., "Characterization and Treatment of Urban Land Runoff," EPA-670/2-74-096, 170 pp., December, 1974.

7. Wilber, William G., and Hunter, Joseph V., "Heavy Metals in Urban Runoff," Proceedings of a Southeastern Regional Conference on Non-point Sources of Water Pollution, VPI and SU, Blacksburg, Virginia, pp. 217-238, 1975.

8. Bryan, E. H., "Concentrations of Lead in Urban Stormwater," Journal Water Pollution Control Federation, Vol. 46, No. 10, 1974.

9. Cooley, W. W., and Lohnes, P. R., Multivariate Data Analysis, John Wiley and Sons, Inc., New York, 364 pp., 1971.

10. Kendall, M. G., A Course in Multivariate Analysis, Charles Griffin, London, 185 pp., 1961.

11. Mahloch, J. L., "Multrivariate Techniques for Water Quality Analysis," J. EE Division, ASCE, Vol. 100, No. EE5, pp. 1119-1131, Ocotber, 1974.

12. Van de Geer, John P., Introduction to Multivariate Analysis for the Social Sciences, W. H. Freeman and Company, San Francisco, 293 pp., 1971.

13. Harris, Richard J., A Primer of Multivariate Statistics, Academic Press, New York, 332 pp., 1975.

14. Snyder, Willard M., "Some Possibilities for Multivariate Analysis in Hydrologic Studies," Journal of Geophysical Research, Vol. 67, No. 2, pp. 721-729, February, 1962.

15. Everitt, Brian, Cluster Analysis, John Wiley and Sons, Inc., New York, 122 pp., 1974.

16. Rasool, S. I., Chemistry of the Lower Atmosphere, Plenum Press, New York, 1973.

17. Heaney, James P. and Sullivan, Richard H., "Source Control of Urban Water Pollution," Journal of the Water Pollution Control Federation, Vol. 43, No. 4, pp. 571-579, April, 1971.

18. Johnson, Richard E., Rossano, August T. Jr., and Sylvester, Robert O., "Dustfall as a Source of Water Quality Impairment," J. SE Div., ASCE, Vol. 92, No. SA1, February, 1966.

19. Churchill, John R., "Non-point Water Pollution: Federal and State Perspectives," Proceedings of a Southeastern Regional Conference on Non-point Sources of Water Pollution, VPI and SU, Blacksburg, Virginia, pp. 279-286.

20. Cattermole, J. M., "Geology of the Knoxville Quadrangle, Tennessee," U.S. Geological Survey, Map GQ 115, Washington, D.C., 1958.

21. Betson, Roger C., unpublished data from the Tennessee Valley Authority, 1975.

22. Andren, A. W., Lindberg, S. E., and Bate, L. C., "Atmospheric Input and Geochemical Cycling of Selected Trace Elements in Walker Branch Watershed," ORNL-NSF-EATC-13, Environmental Sciences Division, Pub. No. 728, 68 pp., 1975.

APPENDIX

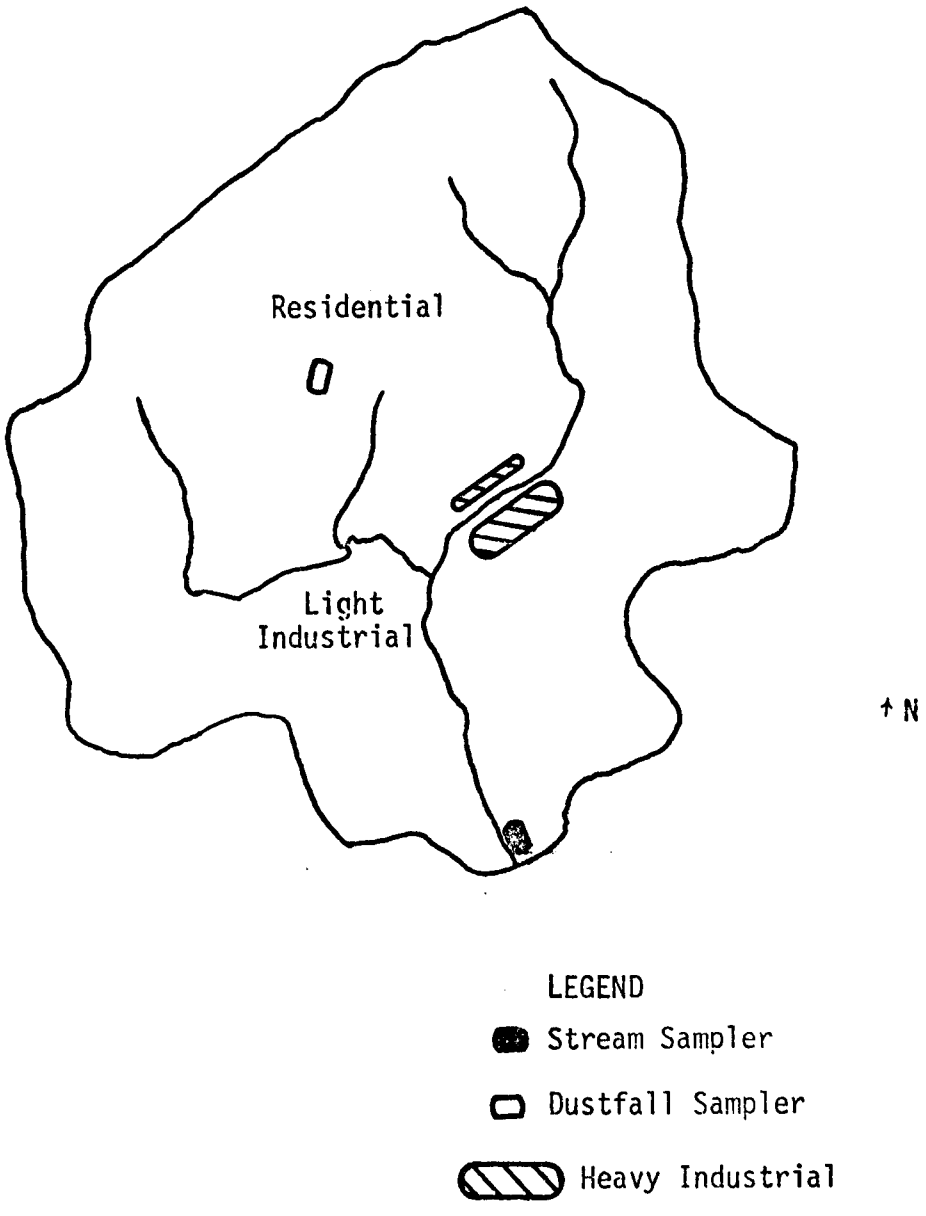
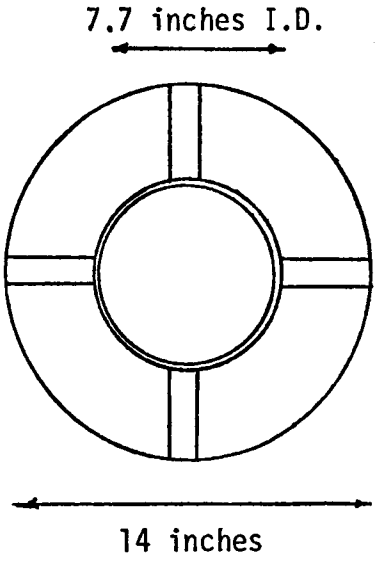


Figure B1. Map of Study Area.



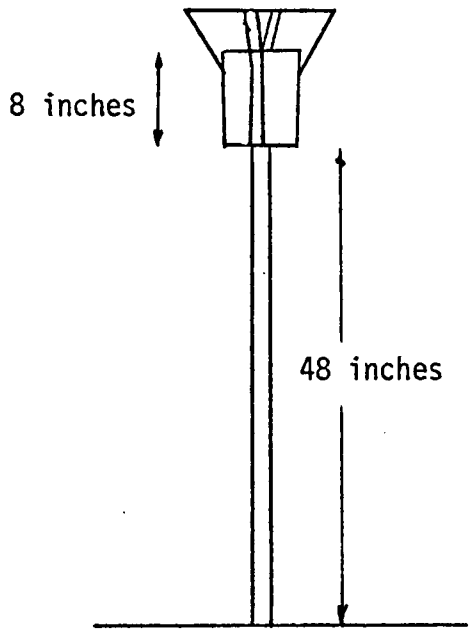


Figure B2. Dustfall Sampler.

VITA

Michael P. Barkdoll was born in Waynesboro, Pennsylvania on December 12, 1946. He attended elementary schools in Quincy, Pennsylvania and was graduated from Waynesboro Area Senior High School in 1964. The following September he entered Pennsylvania State University. He enlisted in the United States Marine Corps in September 1967 and was honorably discharged in September 1971. In June of 1972 he entered the University of Tennessee and received his Bachelor of Science degree in Engineering Science in March of 1974. The following month he began study toward a Master's degree at the University of Tennessee. He received his Master's degree in Environmental Engineering in December 1975.

He is married to the former Regina Johnson of Memphis, Tennessee.