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CHEMICAL TREATMENT OF URBAN STORMWATER
RUNOFF BY SETTLING COLUMN STUDIES

BY

PAUL ROBERT MOORE
B.S.E., Florida Technological University, 1977

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Engineering
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ABSTRACT

Lake Eola, in downtown Orlando, was the subject of extensive research to determine the impact of stormwater runoff to the lake and possible management alternatives. The focus of this research was stormwater treatment by chemical coagulation followed by detention.

Phosphorus was the main parameter targeted for removal. Various chemical parameters were also evaluated included: TSS, VSS, NVSS, COD, TKN, NH_3 , TOC, TP, Ca, As, Cd, Cu, Cr, Ni, Mg, Zn, Fe, and Pb. The chemical coagulants used for this research included: alum, ferric chloride, and lime. The study involved settling column tests for the various treatment methods to determine stormwater settling characteristics and pollutant removal rates by depth and time.

Detention of the runoff in the column for 120 minutes resulted in average removal rates of 55% for TSS and 30% for TP. Both alum and ferric chloride coagulation followed by 60 minutes of settling resulted in average removal rates of over 90% for both TSS and TP. Lime coagulation followed by 60 minutes of settling resulted in over 50% removal for both TSS and TP.

Regression analysis was used to develop equations relating pollutant removal with time and settling velocity. Isoconcentration lines were also developed to predict pollutant removal rates for specific parameters.

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I would like to express my sincere appreciation to the faculty members of the University of Central Florida who have contributed greatly to my growth and education. Special thanks is extended to the members of my graduate committee: Dr. J.S. Taylor, Dr. M.P. Wanielista, Dr. Y.A. Yousef and Dr. W.M. McLellon for their guidance and encouragement during this research.

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CHAPTER I

INTRODUCTION

In recent years, major water quality considerations have been directed toward nonpoint sources of pollution (Wanielista 1976, Bradford 1977). Extensive research has been conducted in an effort to determine the extent and effect of urban stormwater runoff on receiving water bodies (Pitt and Field, 1977).

Legislative actions have begun to specifically address nonpoint sources of water pollution. The 1972 amendments to the Federal Water Pollution Control Act required that nonpoint sources of water pollution be considered when developing water quality management plans for both state and areawide planning (Amy 1974). Areal planning agencies have investigated stormwater runoff as a major source of pollution and have initiated steps to control and abate its effect on receiving waters (ECFRPC 1978).

The water pollution potential of stormwater runoff was not fully appreciated until major research studies concluded that in many regions urban runoff can be a more serious source of water pollution than municipal wastewater effluents (Amy 1974). Flow rate variability of stormwater runoff makes it much more difficult to control and treat than the more conventional point sources of water pollution

such as wastewater treatment plant effluents. Urban runoff is an intermittent source of large flows whereas municipal wastewater is typically a continuous discharge at a relatively constant flow rate (Colston 1974).

The quantity of flow from urban stormwater is characterized by the amount, frequency, intensity, and duration of the storm event. The quality of stormwater runoff is influenced by many factors including meteorological, hydrological, and geological conditions. The ever changing land use patterns in a high growth region such as central Florida also affects runoff quality (Turner 1973).

Nonpoint sources of water pollution have been identified as potential major contributors to lake degradation in the State of Florida (Wanielista 1976). Major pollutants found in urban runoff included suspended solids, BOD₅, nitrogen, and phosphorus. Phosphorus has been found to be the limiting nutrient in many Florida lakes (Dye et al. 1975)

Once urban stormwater runoff has been determined to cause degradation to a receiving water body, the next step would be to initiate control practices which would lessen its impact. Because of urban stormwater's varying flow rate it is not conducive to effective biological treatment. It would appear that a physical/chemical treatment process would offer an effective management practice for controlling urban runoff.

Physical/ chemical treatment of stormwater runoff has been investigated in various research studies (Colston 1974). Most efforts have dealt with combined sewer overflows (both municipal wastewater and stormwater runoff). Very little research has been conducted which attempted to determine pollutant removal efficiency rates from chemically coagulated processes involving stormwater runoff.

Objectives

The objectives of this research are to determine the water quality characteristics of the urban runoff from the test site, evaluate various chemical coagulants and detention times on various chemical parameter removal rates, and to use this data to develop optimal design strategies. The primary coagulants investigated were aluminum sulfate (alum), ferric chloride, and lime.

Lake Eola in downtown Orlando was used as the test site. From previous studies this lake was determined to be highly eutrophic with phosphorus found to be the limiting nutrient (Harper 1979). Optimal coagulant dosages and pH will be determined as a function of phosphorus removal in a series of column studies. A computer program will also be utilized to effectively correlate pollutant removal rates with various parameters.

CHAPTER II

URBAN STORMWATER RUNOFF CHARACTERISTICS

The concern of urban stormwater runoff as a pollution source has come into focus in recent years. Weibel (1964) was perhaps one of the first to call attention to the potential pollutant nature of stormwater runoff from both the chemical and sediment aspects. He noted that concentrations of various chemical parameters of urban runoff were on the average comparable to typical secondary sewage treatment plant effluents and that concentrations of suspended solids in stormwater runoff were on the average comparable to concentrations found in raw sewage. Table 1 compares typical raw domestic sewage constituents to that of urban runoff loads.

An urban storm event can be described in a qualitative manner. The first step is the accumulation of materials on the land surface. This is a function of land uses, dustfall, street sweeping frequency, antecedent rainfall characteristics, and many other factors. When a storm event occurs, contaminants from street surfaces, rooftops, and other sources are dislodged and enter the flow system. The runoff transports the pollutant materials across urban areas and into street gutters and storm sewer systems. Eventually,

TABLE 1

COMPARISON OF RAW DOMESTIC SEWAGE
TO URBAN STORMWATER RUNOFF

Constituents	Raw Domestic Sewage		Urban Runoff Loads as Percentage of Sewage Loads	
	(lb/day/acre)	(lb/yr/acre)	During Runoff	Annually
Suspended Solids	1.5	540	2400	160
COD	2.6	960	520	33
BOD ₅	1.5	540	110	7
Total PO ₄	0.19	68	70	5
Total N	0.23	82	200	14

SOURCE: G. Amy, et al., Water Quality Management Planning for Urban Runoff.
(Washington, D.C.: U.S. Environmental Protection Agency, 1974), p. V-4.

urban runoff discharges into receiving water bodies where the accumulated materials cause degradation (Amy 1974).

The pollutant concentration is greatest at the beginning of the storm event and as rainfall continues the runoff becomes less contaminated. This initial high pollutant concentration is known as the "first flush" effect (Wanielista 1878).

The primary effects of urban stormwater runoff on receiving waters include siltation and increased concentrations of organic matter, nutrients, and pathogenic organisms. The organic materials cause an oxygen demand on water bodies which endanger fish populations and in extreme conditions cause anaerobic conditions, producing odor problems. Nutrients cause increased rates of eutrophication with sustained plankton and algae blooms. Chemical contaminants such as pesticides, can cause harmful effects to aquatic life (Crane 1973, Weibel 1966).

John Lager, et al. (1977) listed principal sources of urban runoff pollutants which included:

1. Street pavement. The components of road surface degradation can become part of the urban runoff loading. The aggregate material is the largest contributor and additional quantities will come from binders, fillers, and any other substances applied to the surface. The amount of pollutants will depend on the age and type of surface, the climate, and the quantity and type of traffic.

2. Motor vehicles. Vehicles can contribute a wide variety of materials to the street surface runoff. Fuels and lubricants spill or leak, particles are worn from tires or brake linings, exhaust emissions collect on the road surface, and corrosion products or broken parts fall from vehicles. While the quantity of material deposited by motor vehicles is expected to be relatively small, the pollution potential is important. Vehicles are the principal nonpoint source of asbestos and some heavy metals including lead.
3. Atmospheric fallout. Air pollutants include dust, contaminants, and particles from industrial stacks and vents, from automobiles and planes, and from exposed land. The airborne matter will settle on the land surface and washoff as contaminated runoff.
4. Vegetation. Leaves, grass, clippings, and other plant materials that fall or are deposited on land surfaces will become part of the runoff problem. Quantities will depend on the geographic location, season, landscaping practices, and disposal methods.
5. Land surface. The type of ground cover found in a drainage basin and the amount of vehicular and pedestrian traffic is a function of land use and will affect the quality of storm runoff.

6. Litter. Litter consists of various kinds of discarded refuse items, packaging material, and animal wastes. Although the quantities are small and not significant sources of pollution, the debris is highly visible in a receiving water and can be a focal point for citizen complaints.

7. Spills. These obvious surface contaminants can include almost any substance hauled over city streets. Dirt, sand, and gravel are the more common examples. Industrial and chemical spills are potentially the most serious.

8. Various agricultural chemicals. A variety of chemicals may be used as fertilizers, pesticides, and herbicides. These materials may become part of the urban runoff and present a major pollutinal problem.

9. Construction sites. Soil erosion from land surfaces disturbed by construction activities is a highly visible source of solids in storm runoff. Important urban sites will include large scale projects such as highway construction and urban renewal. The construction methods and control measures will influence quantities.

10. Collection network. Storm sewer networks using natural or improved earthen channels will be subject to erosion of the banks. Collection networks also tend to accumulate deposits of material that will be dislodged and transported by storm flows.

The quality of urban stormwater runoff has been determined in various studies throughout the United States. Table 2 summarizes pollutant concentrations in stormwater runoff from various cities.

This table depicts the wide range of pollutant concentrations found at different localities. On the average, high suspended solids concentrations are encountered with considerable nitrogen and phosphorus contributions. Fecal coliform counts were also found to be of significant importance in this data.

Recent studies have been conducted in Florida concerning stormwater quality. A study performed in the central Florida area of Eustis identified the magnitude of nonpoint sources as being significant. The quality of the nonpoint source runoff was found to vary, depending upon the rainfall intensity antecedent dry period, and amount of rainfall (Wanielista 1976).

A study done in Miami, Florida, reported on nonpoint source effects and related them to land use conditions. This study concluded that large amounts of nutrients and bacteria are being discharged in the Coral Gables Waterway during the the rainy season (Wanielista 1976).

Stormwater runoff characteristics at various urban sites were measured as part of the Orlando Metropolitan 208 Program (ECFRPC 1978). Various water quality parameters for this area are listed in Table 3.

TABLE 2

SUMMARY OF POLLUTANT CONCENTRATIONS
IN STORMWATER RUNOFF

mg/l → µg/l
mg × 1000 µg
mg
µ

City	Average pollutant concentrations, mg/L									
	TSS	VSS	BOD	COD	Kjeldahl nitrogen	Total nitrogen	Phos- phorus	OP ₄ -P	Lead	Fecal coliforms ^a
Atlanta, Georgia [10]	287	...	9	48	0.57	0.82	0.33	....	0.15	6 300
Des Moines, Iowa [11]	419	104	56	...	2.09	3.19	0.56	0.15	....	.....
Durham, North Carolina [12]	1 223	122	..	170	0.96	....	0.82	....	0.46	230
Knoxville, Tennessee [13]	440	...	7	98	1.9	2.5	0.63	0.30	0.17	20 300
Oklahoma City, Oklahoma	147	...	22	116	2.08	3.22	1.00	1.00	0.24	40 000
Tulsa, Oklahoma [14]	367	...	12	86	0.85	....	....	0.38	....	420
Santa Clara, California	284	70	20	147	....	5.8	0.23	....	0.75	.....
Pullach, Germany [3]	158	53	11	125	....	...	....	....	....	.....
Average (not weighted)	415	88	20	113	1.41	3.11	0.62	0.46	0.35	13 500
Range	147-1 223	53-122	7-56	48-170	0.57-2.09	0.82-5.8	0.33-1.00	0.15-1.00	0.15-0.75	230-40 000

^a. Organisms/100 mL.

SOURCE: J.A. Lager, et al., Urban Stormwater Management and Technology - Update and User's Guide (Cincinnati, Ohio: U.S. Environmental Protection Agency, 1977), p. 96.

TABLE 3

STORMWATER CHARACTERISTICS AT URBAN
LAND USE SITES IN THE ORLANDO AREA

Site	# of Samples	Statistic	Parameter					
			BOD5	Suspended Solids	Total Nitrogen	Total Phosphorus	Lead	Sulphate
Altamonte Springs Mall	60	Mean	13.8	38.9	1.36	0.163	0.20	12.0
		SD	12.7	48.3	1.17	0.089	0.22	13.9
		Range	1.0 to 48.0	2.0 to 222	0.2 to 3.5	0.004 to 0.410	0.04 to 0.97	1.4 to 37.6
Clermont	54	Mean	23.3	153.9	3.78	1.020	-	-
		SD	30.2	292.8	4.80	1.214	-	-
		Range	2.6 to 100.0	1 to 1,937	0.4 to 20.3	0.13 to 6.67	-	-
Lake Sylvan	50	Mean	35.4	69.6	6.63	1.602	-	-
		SD	24.3	92.5	8.22	1.683	-	-
		Range	4.1 to 70.0	1.0 to 496	0.6 to 48.6	0.24 to 6.4	-	-
Sanford	59	Mean	11.6	88.0	2.23	0.667	0.22	14.6
		SD	13.0	89.6	0.88	0.241	0.28	8.2
		Range	1.3 to 48.0	1.0 to 348	0.9 to 4.2	0.38 to 1.37	0.02 to 1.07	2.1 to 36.0

Note: All values in mg/l.

SOURCE: East Central Florida Regional Planning Council, Orlando Metropolitan
Areawide Water Quality Management Plan (Orlando: ECFRPC, 1978), p. VI-21.

An analysis of this Orlando area data showed various trends including (ECFRPC 1978):

1. Suspended solids transported from a particular watershed are greater during the initial part of the storm. The water quality parameters: BOD₅, nitrogen, and phosphorus show a lag period during transport over the watershed.
2. For most Florida-type rainfall events (short, intense rainfalls) on small watersheds, over ninety percent (90%) of the suspended solids loads and in excess of eighty percent (80%) of the BOD₅ and total nitrogen and phosphorus loadings are transported from the watershed in the first ten minutes of runoff.

The nature and extent of urban stormwater runoff are important factors that must be determined before a control practice can be effectively initiated. In dealing with chemical treatment of stormwater runoff all aspects of the pollutant source must be realized. Once it is established that urban runoff should be treated in a given area, the next step is evaluation of the unit process pollutant removal efficiency of the chosen treatment method. Only by determining the most efficient and economical treatment method will the public be assured of the maximum return on its investment (Colston 1974).

CHAPTER III

LAKE EOLA: TEST SITE

Lake Eola, located in downtown Orlando, was the subject of this extensive research effort sponsored by the U.S. Environmental Protection Agency, the City of Orlando, and the University of Central Florida. The Lake was chosen as the test site mainly due to past water quality information on the Lake, it is a landlocked lake with no point source discharges, and the watershed and pollution sources were well-defined. Probably, the most important factor in choosing Lake Eola as the test site was that it is of major concern to the local community which is interested in improving the aesthetic appeal of the Lake (Wanielista 1973).

Lake Eola is located in a highly urbanized area. It is a small landlocked lake with a surface area of 28.75 acres and a volume of approximately 100 million gallons. A fountain in the Lake is a local attraction for residents and tourists. The Lake is restricted with no swimming, fishing, or motor boating allowed (Wanielista 1973).

The Lake receives stormwater runoff via an extensive stormsewer system from commercial and residential areas. Figure 1 depicts the drainage basin and various land uses

within the basin. The drainage basin consists of approximately 350 acres with 180 acres located in the northern portion of the basin drained by drainage wells. The remaining acreage drains directly into Lake Eola and consists of: Lake Eola (28.75 acres), impervious surfaces (85 acres), and pervious surfaces (56 acres). This corresponds to a contributing watershed which is sixty (60) percent impervious (Wanielista 1976).

The main sources of pollution to Lake Eola are the various stormsewer outfalls which drain the surrounding urban areas. Presently, there are twelve active street drains discharging to the Lake and are illustrated in Figure 2. The Lake has no surface outfall with the exception of two drainage wells. These wells are primarily for lake level control and drain into an artesian aquifer. The level of the Lake is held between 87.0 and 88.5 feet above mean sea level (MSL). The piezometric surface is at approximately 57.0 feet above MSL which allows natural flow down the drainage wells. Lake Eola has a maximum water depth of approximately 22 feet near the center and decreases in depth to about 2 feet near the shore (Wanielista 1978).

Lake Eola underwent a restoration program in the Spring of 1972. The project was performed due to poor water quality conditions and for aesthetic purposes. The Lake was drawn down about 10 feet exposing approximately

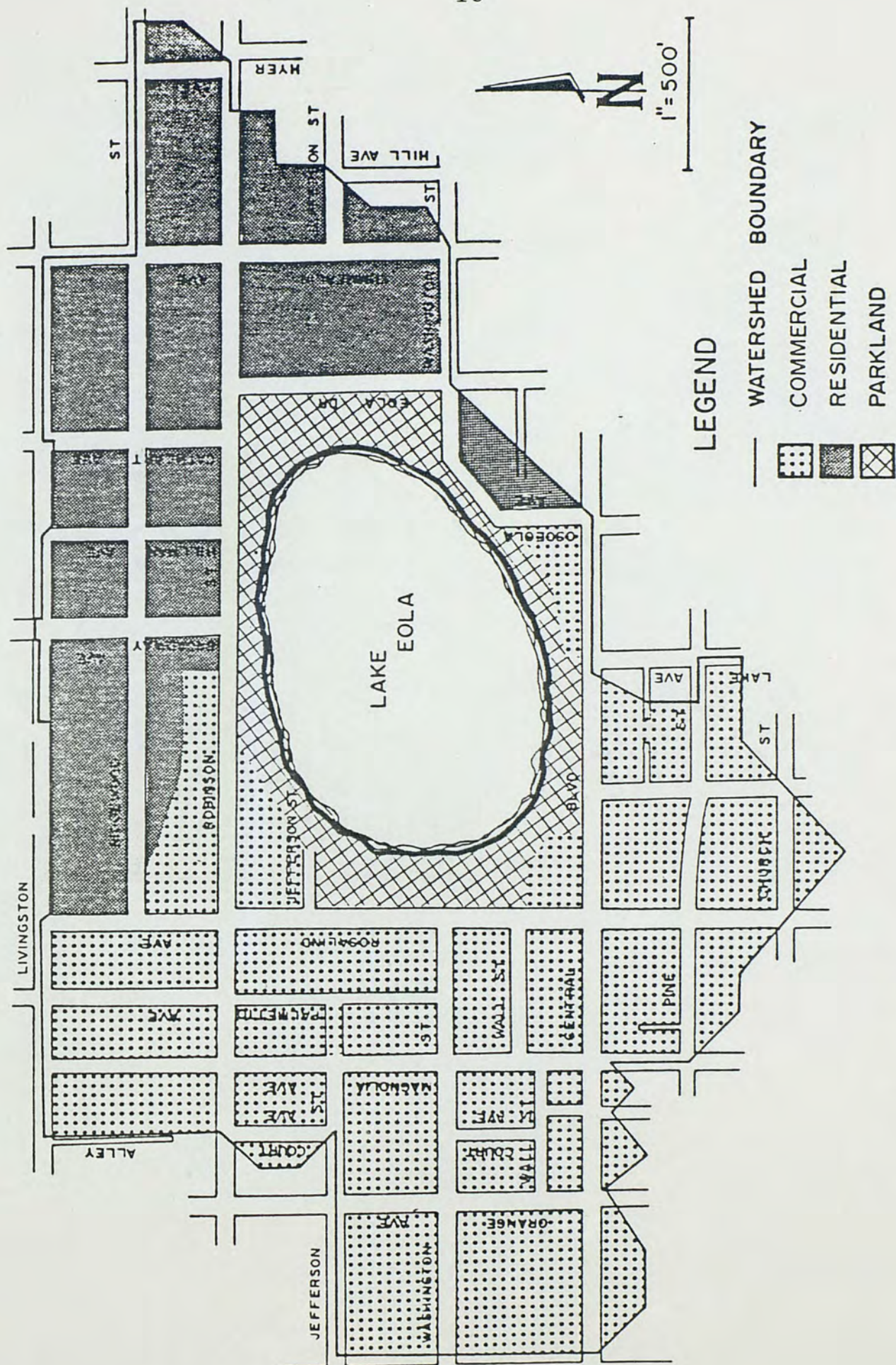


Fig. 1. Lake Eola drainage basin with various land uses.

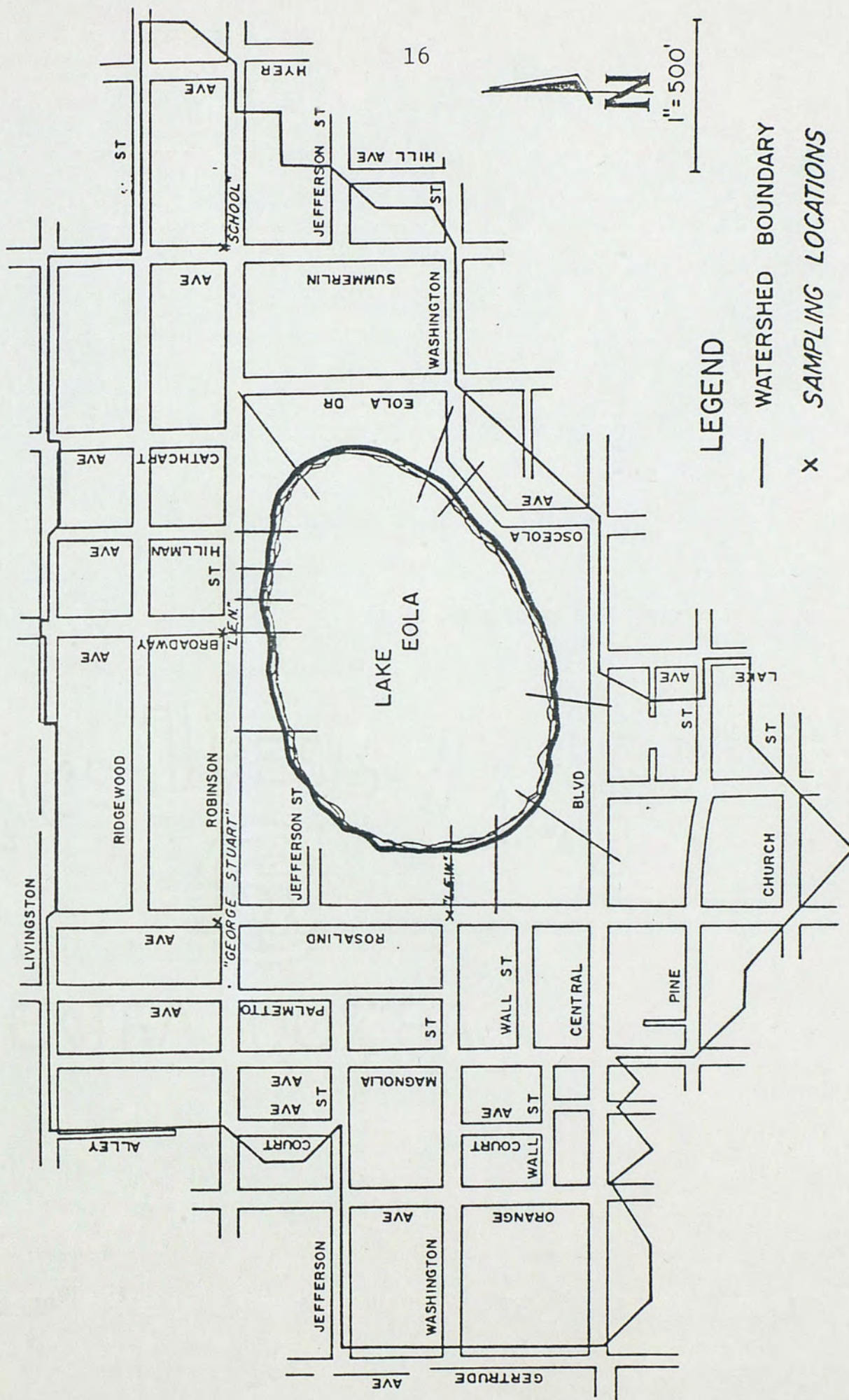


Fig. 2. Stormsewer outfalls to Lake Eola.

forty (40) percent of the bottom muds. About four feet of muck was removed, sand was replaced on the bottom, and the stormwater outfalls were extended into the Lake to reduce the siltation problem. The Lake was refilled using the drainage wells. However, nutrients, metals, and organic materials from stormwater runoff inputs were not effectively reduced. Lake Eola regressed into an unappealing water body with excessive algae growth and fish kills (Wanielista 1973).

Previous studies have been conducted on Lake Eola to determine the impact of stormwater runoff on the Lake. Wanielista (1976) sampled two sites in the watershed of Lake Eola which were representative of commercial and residential land uses. Table 4 lists the various water quality characteristics from these two sampling sites.

The data in Table 4 is intended to provide general background conditions of nonpoint sources entering Lake Eola. Phosphorus appeared to be the limiting nutrient in Lake Eola and will be carefully considered when investigating chemical treatment of the urban runoff.

TABLE 4

CHANGES IN WATER QUALITY CHARACTERISTICS
DUE TO NONPOINT SOURCES ON LAKE EOLA

Parameter	Range at LE1		Range at LE2
	Dry Period	Wet Period*	Wet Period
Flow, cfs	0.276	0.276-14.7	Not Recorded
pH	8.09-8.39	8.47-7.02	7.72-6.52
SPCOND ($\mu\text{mho/cm}$)	340-360	395-77	208-51
Turb, JTU	0.9-2.8	0.3-34	0.9-24
SS, mg/l		1-372	1-36
TDS, mg/l		786-76	122-59
Alkalinity mg/l as CaCO_3	144.5-155.5	158.2-25	77.7-27
Hardness mg/l as CaCO_3	152-172	178.8-34.6	81-19
BOD, mg/l	4.5-5.9	3.2-37.2	1.8-11
COD, mg/l		7.5-284.5	15-78.2
TOC, mg/l	2.1-8.3	0.8-146	2.9-31
IC, mg/l	20.8-28	32.7-4.1	12.5-2.9
TKN, mg/l-N	0.14-0.95	0.07-3.87	0.02-1.03
NO_3 , mg/l-N	0.17-0.27	0.11-1.33	0.03-0.53
OP, mg/l-P	0.37-0.68	0.47-0.12	0.01-0.2
TP, mg/l-P	0.62-1.08	1.0-0.17	0.12-0.94

* Values in second column reflect high flow conditions

NOTE: Dry period occurred during April, 1975.

Wet period occurred during May and June, 1975

SOURCE: M.P. Wanielista, et al., Nonpoint Source Effects (Orlando, Florida: Florida Technological University, 1976), p. IV-6.

CHAPTER IV

CHEMICAL/SEDIMENTATION TREATMENT THEORY

Introduction

Contaminants in stormwater runoff can be classified as either colloidal (suspended) or particulate. These classifications are based on the size of the particles in question. The large particles found in urban runoff can be removed solely by sedimentation. However, a large portion of the particles are too small for gravitational settling alone and require other removal mechanisms.

One physical/chemical treatment method which may be effective for stormwater runoff treatment is coagulation. Coagulation is the process in which colloidal particles in solution are agglomerated by one or a combination of processes into a particle of such weight and size that it will settle out of the flow.

Particle size of the contaminants is an important factor to consider when discussing stormwater runoff. A study done by Sartor and Boyd (1972) determined the particle size distribution of street surface contaminants from various cities. Table 5 lists this data which was found by summing values obtained by dry sieving, wet sieving, and sedimentation pipette analyses. General classifications of sand, silt, and

TABLE 5
 PARTICLE SIZE DISTRIBUTION OF SOLIDS
 FROM SELECTED CITY COMPOSITES

SIZE RANGES	MILWAUKEE	BUCYRUS	BALTIMORE	ATLANTA	TULSA
> 4,800 μ	12.0%	- %	17.4%	- %	- %
2,000-4,800 μ	12.1	10.1	4.6	14.8	37.1
840-2,000 μ	40.8	7.3	6.0	6.6	9.4
246-840 μ	20.4	20.9	22.3	30.9	16.7
104-246 μ	5.5	15.5	20.3	29.5	17.1
43-104 μ	1.3	20.3	11.5	10.1	12.0
30-43 μ	4.2	13.3	10.1	5.1	3.7
14-30 μ	2.0	7.9	4.4	1.8	3.0
4-14 μ	1.2	4.7	2.6	0.9	0.9
< 4 μ	0.5	-	0.9	0.3	0.1
Sand %, 43-4,800 μ	92.1	74.1	82.1	91.9	92.3
Silt %, 4-43 μ	7.4	25.9	17.1	7.8	7.6
Clay %, < 4 μ	0.5	-	0.9	0.3	0.1
Lb Sand/curb mi	2,480	1,020	845	394	300
Lb Silt/curb mi	200	356	176	33.5	30
Lb Clay/curb mi	13.5	-	9.3	1.3	0.3

Note: μ = microns.

SOURCE: J.D. Sartor and G.B. Boyd, Water Pollution Aspects of Street Surface Contaminants (Washington, D.C.: U.S. Environmental Protection Agency, 1972), p. 48.

clay are also included in this Table to help describe the nature of the contaminants. These classifications also correspond roughly to the behavior these materials will exhibit in water. Sand will generally settle out at low flow velocities, clay will remain suspended, and silt will be intermediate (Sartor and Boyd 1972).

From Table 5, clay-like materials account for less than one percent of the total solids and silt accounts for less than 25 percent of the total solids. This indicates that a small percentage of solids will remain suspended in stormwater runoff. It should also be remembered that concentrations of pollutants are in most instances much higher in suspended solids than in the waters with which these solids are associated (Sanks 1979).

Sedimentation of urban stormwater runoff is probably the most common treatment method in use today. Table 6 lists the removal rates of heavy metals, nitrogen, phosphorus, and other constituents by sedimentation. From this Table heavy metals show an average removal rate of less than 40 percent, nitrogen removal less than 50 percent and phosphorus removal less than 23 percent. This would suggest that sedimentation alone will improve the quality of urban stormwater runoff, but only to a certain degree.

Theory of Chemical Coagulation

Chemical treatment of stormwater runoff may be utilized for greater pollutant removal rates. Coagulation, the

TABLE 6

POLLUTANT REMOVAL FOR VARIOUS
CONSTITUENTS BY SEDIMENTATION

Pollutant	Average removal, %
Heavy metals ^a	
Copper	24.1
Chromium	32.3
Nickel	26.6
Zinc	27.2
Lead	30.6
Iron	16.6
Cadmium	38.8
Calcium	19.2
Magnesium	23.5
Sodium	18.5
Potassium	23.5
Mercury	8.4
Nitrogen ^b	
Ammonia	22.1
Organic	50.5
Total Kjeldahl	38.4
Nitrate	15.4
Nitrite	0
Phosphorus ^b	
Total	22.2
Ortho	6.7
Other constituents ^b	
COD	34.4
TOC	21.3
Oil and grease ^c	11.9

a. Average of 10 samples.

b. Average of 2 to 3 samples.

c. Average of 6 samples.

SOURCE: J.A. Lager, et al., Urban Stormwater Management and Technology - Update and User's Guide (Cincinnati, Ohio: U.S. Environmental Protection Agency, 1977), p. 194.

aggregation of colloidal particles in the chemical treatment process, can be considered as having two separate and distinct components. The first step involves particle destabilization which permits attachment when the particles are brought into contact. This is accomplished by the addition of chemicals. The second step involves bringing the particles into contact so that aggregation can occur. This is done by gentle stirring or flocculation of the water (Weber 1972).

When discussing the coagulation process it is advantageous to first identify forces which cause particle stability. Colloidal particles in water carry an electric charge. These particles can develop an electric charge in various ways. Most colloidal particles in water develop a negative primary charge. The charge is affected by pH and ionic content of the water sample (Weber 1972).

When a colloidal particle exists in a solid and liquid phase together, the charge on the particle must be balanced by an equivalent opposite charge in the liquid phase. Because of this, a double layer exists at each solid-liquid interface. This double layer consists of a charged particle and an equivalent ion of opposite charge which accumulate near the water surface. The concentration of opposite charged ions is greatest near the surface of a particle and gradually decreases with distance from the solid-liquid interface. The electric double layer occupies a small volume and does not extend far into a solution (Weber 1972).

Attractive and repulsive forces exist between all types of colloidal particles. Attractive forces, termed Van der Waals forces, tend to draw particles together while the electrostatic repulsive forces tend to keep them apart. Van der Waals attractive forces vary inversely as the square of the distance between the particles. The electrostatic forces decrease exponentially with distance. Only if the kinetic energy of the relative particles is strong enough to overcome the repulsive forces, where Van der Waals attractive forces predominate, will the particles become unstable and coagulate (Fair et al. 1971).

The stability of colloidal systems are caused by:

1. Mutual repulsion due to high zeta potential.
2. By adsorbing on the colloid a relatively small hydrophilic (water liking) colloids.
3. By adsorbing on the colloid a non-ionic polyelectrolyte.

Destabilization of colloidal particles to bring about coagulation can be accomplished by various processes which include:

1. Compression of the double-layer (diffuse layer).
2. Adsorption to produce charge neutralization.
3. Enmeshment in a precipitate.
4. Adsorption to permit interparticle bridging.

The compression of the diffuse layer to cause coagulation is based on electrostatic forces. Ions of similar charge to that of the colloid will repel, while counter ions

are attracted. Coagulants which act in this manner are called indifferent electrolytes. Destabilization brought about by indifferent electrolytes are due to ions of opposite charge to that of the colloid (counter-ions). This is accomplished by compressing the diffuse layer surrounding the colloidal particle. The effectiveness of coagulants to compress this layer increases with charge on the particle. A coagulant such as Al^{3+} would be a more effective coagulant than Na^{+} (Weber 1972).

Coagulation in water treatment processes undergo various interactions in addition to electrostatic attraction and repulsion. Coagulants which act as indifferent electrolytes, as in the diffuse layer compression method, are not generally applicable to common water systems. It is necessary to discuss the other modes of particle destabilization to understand most coagulation processes.

The adsorption and charge neutralization method of particle destabilization relies on coagulant-colloid, coagulant-solvent, and colloid-solvent interactions. Neutralization of the negatively charged colloids occurs by increasing the amount of positively charged cations found in the coagulant (Colston 1974).

Destabilization of colloids can also be accomplished by enmeshment in a precipitate. Certain coagulants, $Al_2(SO_4)_3$ or $FeCl_3$, cause rapid precipitation of metal hydroxide when used in high concentrations. During the process, colloidal

particles can be enmeshed in the precipitates and subsequently removed. The precipitation effectiveness depends on the degree of oversaturation of the solution, the presence of anions, and the concentration of colloidal particles. The term sweep coagulation is used to describe the process by which colloids are entrapped in the precipitating hydroxide. This destabilization method is one of the predominant mechanisms for coagulation (Weber 1972).

Adsorption and interparticle bridging is the last major particle destabilization method discussed. This method mainly is associated with the use of polymers as destabilizing agents in water treatment. To be effective, the polymers must contain chemical groups which can interact with sites on the surface of colloidal particles. Anionic polymers are effective in coagulation, even though the particles in water are negatively charged (Weber 1972).

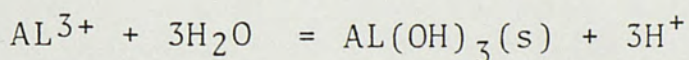
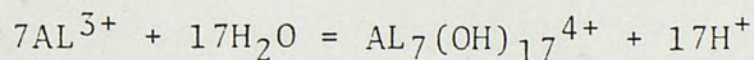
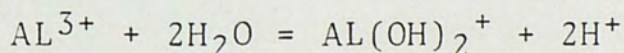
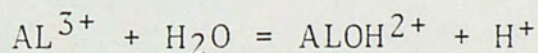
Interparticle contact occurs due to perikinetic and/or orthokinetic flocculation. Perikinetic flocculation is when the surface charge of the colloids is reduced by ions of opposite charge to levels below those of Van de Waals attractive forces and thus will coagulate. Orthokinetic flocculation is when the colloidal particle becomes trapped on, enmeshed in, or adsorbed by precipitate formed by metal hydroxides. The particles are caught by the large settling mass of the precipitates and are removed (Colston 1974).

Coagulation in water treatment occurs predominantly by two mechanisms mentioned previously: adsorption of the soluble species on the colloid and by sweep coagulation (Amirtharajah 1979). Figure 3 depicts these two major methods of chemical coagulation.

Destabilization by Aluminum

Destabilization of colloidal particles can be brought about with the addition of aluminum to a water sample. The coagulation ability of aluminum ions is dependent on its valence number. Al^{3+} is a more effective coagulant than Ca^{2+} , but this specie does not exist in a natural water environment. The effect of Al^{3+} as a coagulant is determined by its hydrolysis product (Fair, et al. 1971).

When aluminum ions are added to water they react with it, or hydrolyze. The aluminum ion becomes completely surrounded by six water molecules and has a net charge of +3. The ion is represented as $Al(H_2O)_6^{3+}$ or simply Al^{3+} . Due to the pH conditions in the water treatment process the tri-valent aluminum ion reacts immediately to form various species such as (O'Melia 1979):



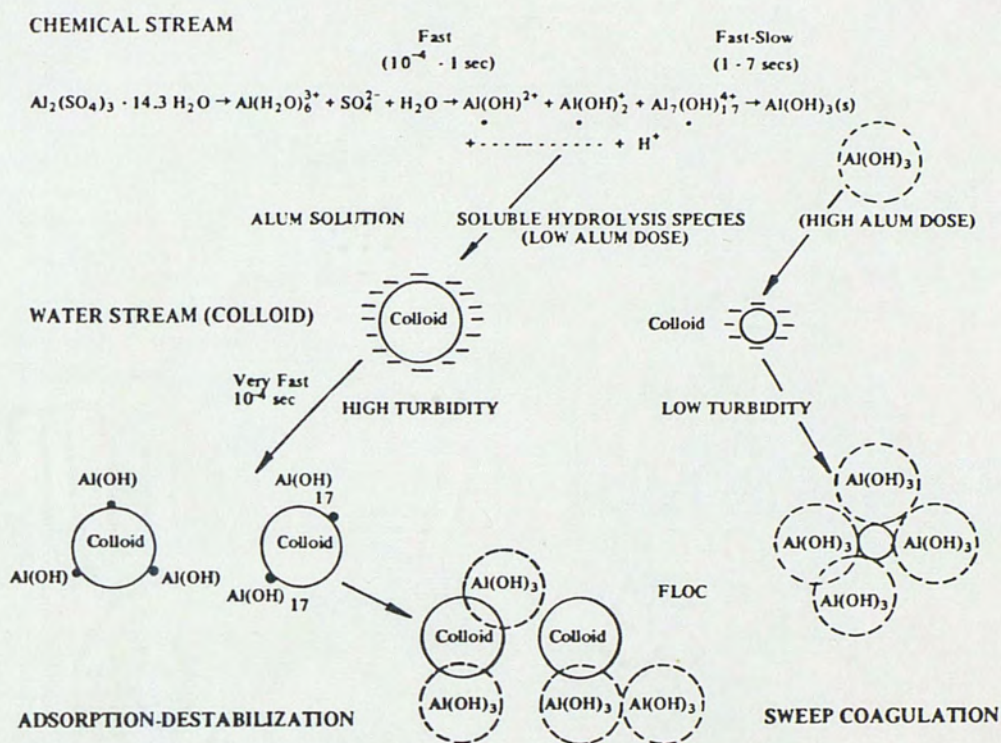


Fig. 3. Reaction schematics of coagulation.

SOURCE: A. Amirtharajah, "Design of Rapid Mix Units," in Water Treatment Plant Design for the Practicing Engineer, ed. Robert L. Sanks (Ann Arbor: Ann Arbor Science Publishers, Inc., 1979), p. 132.

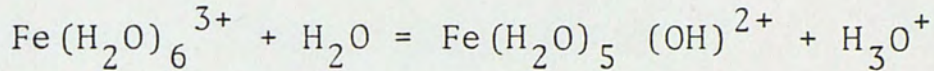
The ions AlOH^{2+} and $\text{Al}(\text{OH})_2^+$, shown in the above reactions contain only one aluminum atom. Their charge is less than +3 but they are a more effective coagulant for negative colloids because they are readily adsorbed on the surface of many solids. The aluminum species $\text{Al}_7(\text{OH})_{17}^{4+}$, from the above equations, resembles a polymer and is also a good coagulant. The type of aluminum specie formed is dependent on the amount of the coagulant added and the pH of the water treated (O'Melia 1979).

There are two main methods which an aluminum material, such as alum, can act as a coagulant. Sweep coagulation and adsorption to produce charge neutralization are the two methods which have been discussed previously. Sweep coagulation is used in coagulating waters having a low turbidity and produces large quantities of aluminum hydroxide precipitate to accomplish this sweep removal. The second major mechanism of coagulation can only be used for high turbidity waters (O'Melia 1979).

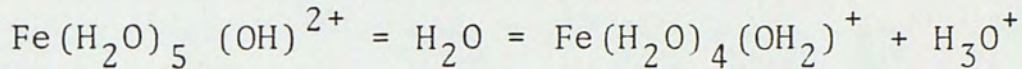
Destabilization by Ferric Iron

Ferric iron (Fe^{3+}) is also a common element used for coagulation in water treatment. Fe^{3+} does not exist in natural water environments. It is similar to Al^{3+} in that its effectiveness as a coagulant is caused by its hydrolysis process (Fair, et al. 1971).

The reaction of ferric iron in water can be shown in the following equations:



an additional proton transfer results in:



When ferric iron is added to water a series of hydrolytic reactions occur, from the formation of hydroxo-complexes ($\text{Fe}(\text{OH})_2^+$), through the formation of colloidal hydroxometal polymers, eventually to the formation of a metal hydroxide precipitate. The addition of ferric iron to water results in a decrease in pH and alkalinity. The dosage of ferric iron required for destabilization of colloids is always sufficient to exceed the solubility of the metal hydroxide (Weber 1972).

These reactions remove colloidal particles by the previously mentioned methods, similar to that discussed for aluminum coagulants. Sweep coagulation may occur due to the precipitation of large quantities of ferric hydroxide and adsorption to produce a charge neutralization may also occur.

Theory of Phosphorus Removal by Chemical Treatment

Phosphorus was determined to be the major limiting nutrient in Lake Eola (Harper 1979). Because of this, phosphorus removal was investigated. Various coagulants were of interest, namely aluminum, iron, and calcium compounds.

Sources of phosphorus in urban runoff consists of fertilizers from lawns, pet wastes, rainfall, soils, and plant matter (Porcella, et al. 1974). Weibel (1966) noticed that phosphorus concentrations of 0.36 mg/l were found in stormwater runoff and that rainfall concentrations averaged about 0.08 mg/l. This demonstrates that a high phosphorus input occurs from urban activities.

A study done on the Lake Wingra watershed in Madison, Wisconsin, investigated nutrient loading sources. It was concluded that more than eighty (80) percent of the influent phosphorus comes from stormwater runoff (Lager, et al. 1977).

Phosphorus is found in stormwater runoff in three basic forms: orthophosphate, polyphosphate, and organic phosphorus.

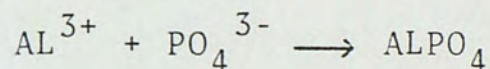
Orthophosphates are defined as those phosphorus containing compounds which are derived from orthophosphoric acid, H_3PO_4 . In solution, the protons will dissociate from the compound and the concentration of the various ionic forms which exist are determined by the pH of the water (Porcella, et al. 1974).

Orthophosphates are by far the dominant form in typical wastewaters. A study done in Oklahoma City, Oklahoma, and Santa Clara County, California, concluded that orthophosphorus was the major form of phosphorus present in stormwater runoff. Orthophosphorus accounted for almost 100 percent of the total phosphorus concentrations measured (Lager, et al. 1977).

Polyphosphates can be looked on as polymers of phosphoric acid from which water has been removed. Complete hydrolysis results in formation of orthophosphate. The polyphosphates which may be present in stormwater gradually hydrolyze in the aqueous solution and reverts to the ortho form. Organic phosphorus is complicated in nature and is not of great concern due to its limited concentrations. The decomposition of organic phosphorus also leads to orthophosphate (U.S. EPA 1976).

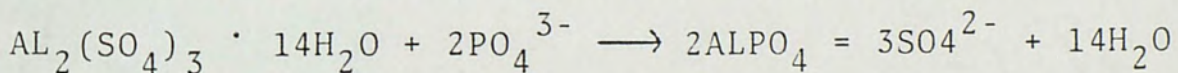
Aluminum as a Coagulant for Phosphorus Removal

Phosphorus can combine with aluminum ions as shown in the following equation:



This indicates that the mole ratio of AL to PO_4 is 1:1. On a weight basis this means that 27 pounds of AL will react with 95 pounds of PO_4 to form 122 pounds of ALPO_4 . PO_4 contains 31 pounds of P, so that on a weight ratio $\frac{\text{AL}}{\text{P}} = \frac{27}{31}$ or 0.87:1 (U.S. EPA 1976).

The removal of phosphorus by the addition of aluminum sulfate (alum) can be expressed in the following equation:



The molecular weight of alum ($\text{AL}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$) is 594. This indicates, from the above equation, that 594 pounds of alum will react with 190 pounds of PO_4^{3-} , which contains 62 pounds of phosphorus, to form 244 pounds of ALPO_4 . The

theoretical weight ratio of alum to phosphorus is

$$\frac{\text{molecular weight of alum}}{\text{molecular weight of phosphorus removed}} = \frac{594}{62} = 9.6:1$$

Typical alum averages about 17 percent soluble aluminum as Al_2O_3 or about 9.1 percent as AL (U.S. EPA 1976).

The solubility of AlPO_4 in water is pH dependent as shown below (U.S. EPA 1976).

<u>pH</u>	<u>Approximate Solubility (mg/l)</u>
5	0.03
6	0.01 (minimum solubility)
7	0.3

Optimal pH values for phosphorus removal using alum have been found to be in the range of 5.5 to 6.0 (Ferguson and King 1977).

The addition of alum to a water will lower the pH, which should be considered if discharging to ~~nature~~^{al} waters occurs. Also the hardness of the water influences alum additions. It was found that calcium hardness tends to decrease the amount of alum required for an equivalent alum dosage (Francisco, et al. 1976).

Overall, alum appears to be an excellent coagulant for the removal of phosphorus from stormwater runoff. Costs and availability also influence the use of alum as a coagulant.

Iron as a Coagulant for Phosphorus Removal

Ferric and ferrous ions can be used to precipitated phosphorus in a similar manner as that with aluminum. The

mole ratio of Fe to PO_4 is 1:1. Fe:P ratios of 1.5 to 3.0 have been found to result in phosphate reduction of 75 to 95 percent (Porcella, et al. 1974).

Other studies have found that increasing the Fe^{3+} /total phosphorus mole ratio significantly enhances total soluble and total phosphorus removal (Kavanaugh, et al. 1978).

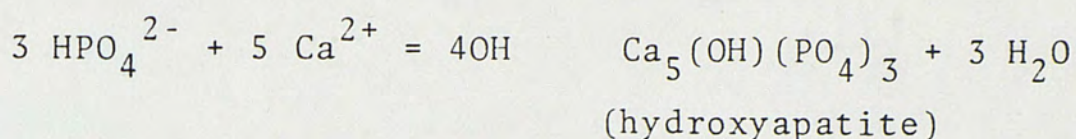
The situation involving ferrous (Fe^{2+}) ion precipitation of phosphorus is more complicated. Theoretically, the mole ratio of $\text{Fe}:\text{PO}_4$ for ferrous ions should be 3:2. But experimental results have found that when Fe^{2+} is used, the mole ratio Fe:P will be the same as when Fe^{3+} is used (U.S. EPA 1976).

The optimum pH range for Fe^{2+} is approximately eight, with good phosphorus removal between pH seven and eight. For Fe^{3+} optimal pH range was found to be between 4.5 and 5 (U.S. EPA 1976).

A study done by Colston (1974) on the chemical treatment of urban runoff found an optimum pH range of 9 - 12 for ferric chloride. He also found the optimum pH range using ferrous chloride to be between 6.8 to 11.

Lime as a Coagulant for Phosphorus Removal

Calcium ion reacts with phosphate ion in the presence of hydroxyl ion to form hydroxyapatite. This material is of a variable composition, but an approximate equation is shown below (U.S. EPA 1976).



Lime is a common chemical used for the removal of phosphorus even though its removal efficiency at a given pH falls below that predicted by solubility equilibria calculations. Reasons for this difference include (Fair, et al. 1971):

1. Precipitation of hydroxyapatite is slow, and the solubility equilibrium is not reached in normal detention times,
2. Particles of precipitated hydroxylapatite may behave as colloids and not settle out,
3. Certain polymer phosphates are capable of forming soluble polyphosphate - calcium complexes, and
4. Within certain pH ranges, some of the Ca^{2+} in the water is used up in the CaCO_3 precipitation.

Experiments have shown that lime can produce significant phosphorus removals in secondary wastewater effluents. Lime ($\text{Ca}(\text{OH})_2$) dosages for efficient removal ranges from 200 to 400 mg/l with an optimal pH range of 10.5 to 11.5 (King, et al. 1979)

CHAPTER V

EXPERIMENTAL PROCEDURE

Runoff Sample Collection

There were four sites utilized for sample collection from the Lake Eola drainage area. These sites are depicted in Figure 4 and throughout the study are referred to as the George Stuart site, School site, Lake Eola North site, and Lake Eola West site. The drainage areas which contribute runoff to these sampling sites are 0.42, 5.72, 1.10, and 0.56 acres in size respectively.

The samples were collected manually from each site. Each site was sampled on two separate storm events except for the Lake Eola West site which was only sampled once. Approximately 240 liters of stormwater runoff were collected during each sampling period. All samples collected were done by a team of two or more research assistants which were at the site prior to a rainfall event. The sites would be visited during days which had high rainfall probability until the required number of storm events were collected.

All runoff samples were collected in five gallon plastic industrial buckets with removable lids. During any storm event sampled the average number of buckets filled would be 20 with the least number collected being 12 and the maximum collected was 25. Figure 5 depicts several sampling buckets

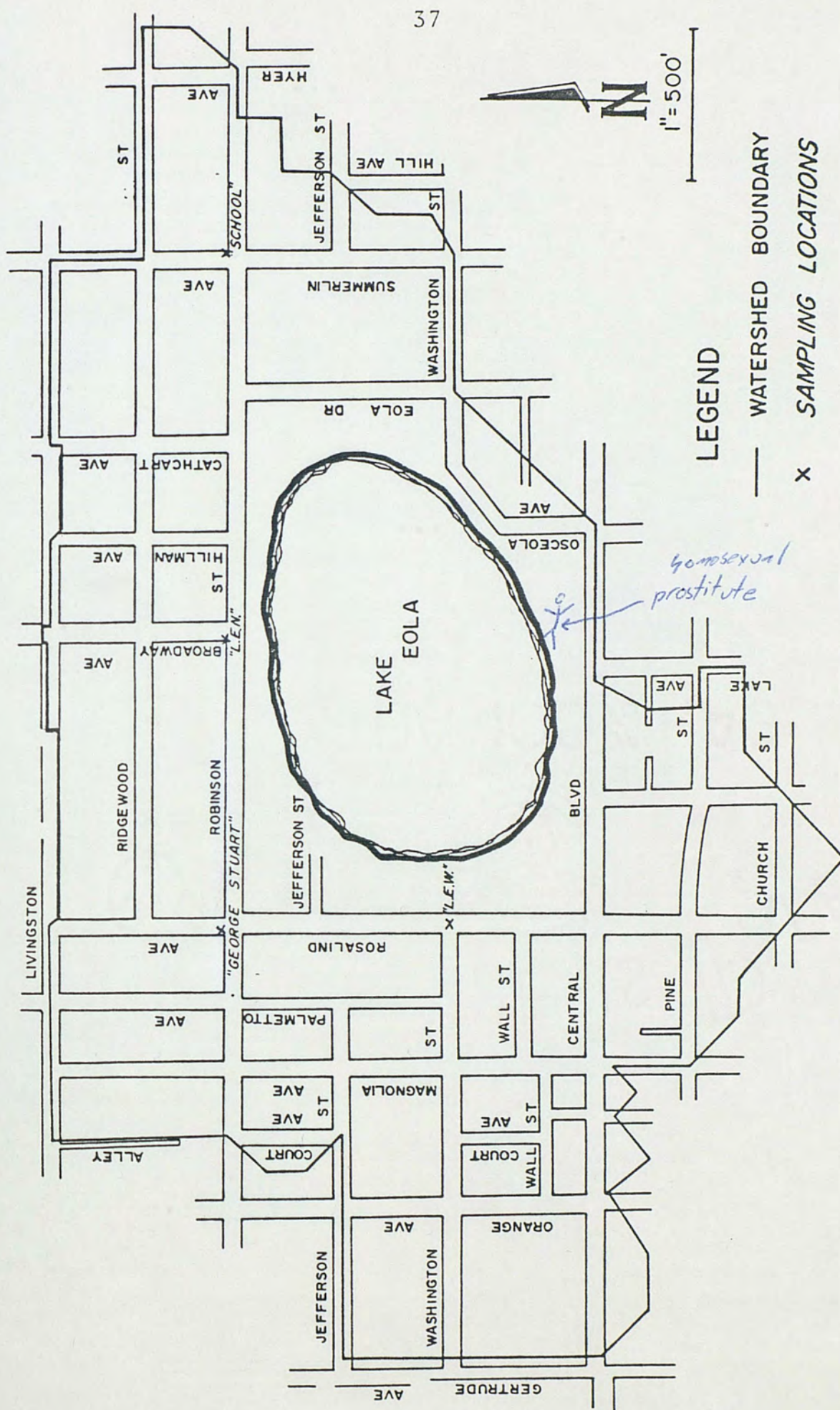


Fig. 4. Lake Eola sampling site locations.

that have been filled and transported to the laboratory for column testing.

The collection technique utilized to obtain representative stormwater runoff samples was to lower a sampling bucket into the catchbasin and have the runoff free fall into the container. One person is required to be in the catchbasin to collect the sample, while the other person would record the time it would take to fill the bucket and also the elapsed time from the start of the storm event. This sampling technique insured that no solids were lost from the stormwater runoff and provided all necessary information to develop the rainfall hydrograph.

Once the samples were collected and brought to the laboratory the next step was the column study. This procedure will be discussed next.

Column Study Procedure

The objective of the column study was to evaluate detention as a means of improving the quality of stormwater runoff that would enter a water body. The actual column settling test was patterned after the procedure described by Zamoni and Blomquist (1975). Due to the amount of pollutants in the dissolved form which were not removed by detention alone it was necessary to investigate the use of chemical coagulation as a method of pollutant removal. Jar tests were performed on the first stormwater sample collected with the procedure and results to be discussed in later sections.

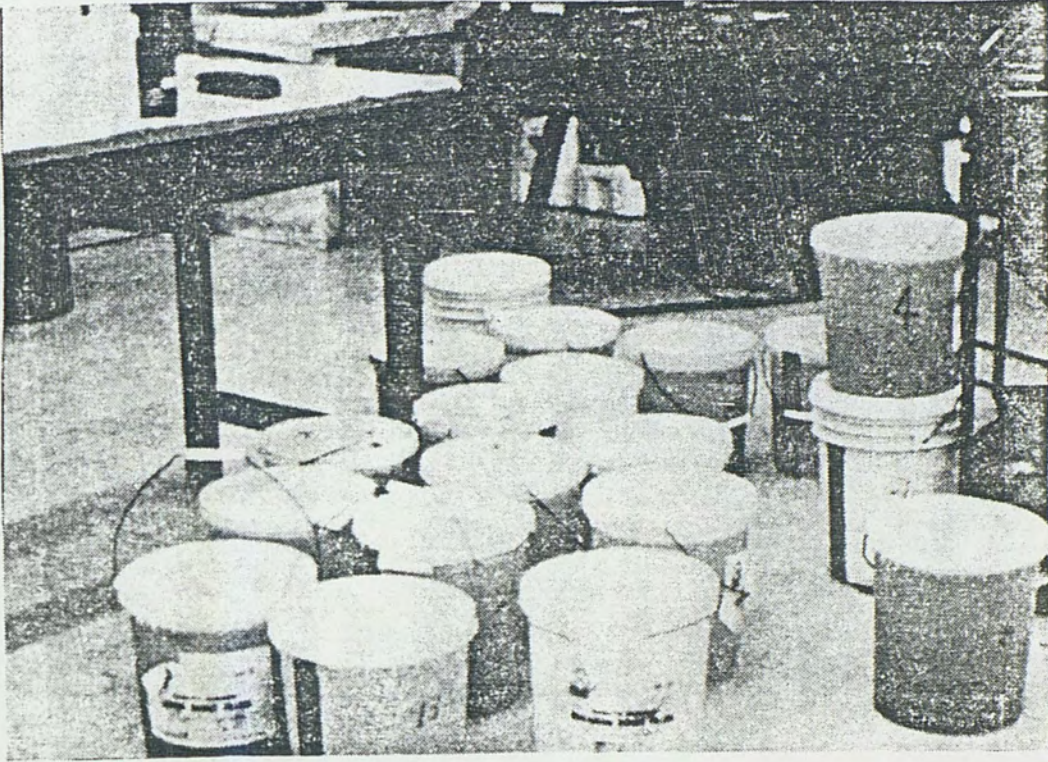


Fig. 5. Sampling buckets used in the column study.

The first column study was used to evaluate detention only, while the second study evaluated coagulation and detention on the same storm. A composite sample was utilized for the actual column study and was prepared by taking a weighted fraction of each collected sample of stormwater runoff. This weighted fraction was determined from the hydrograph with samples added to the column in their weighted proportion.

The actual column is depicted in Figure 6. The column is six foot in length and has a diameter of 12 inches. Total volume of the column is approximately 120 liters. The column is suspended on a sawhorse-like structure that is capable of rotating on both vertical and horizontal axes. Column rotation is depicted in Figure 7. Rotational speed can be controlled with the control box located on the side column support. Three ports are located on each side of the column, but for this study only three ports were used. These ports are located 1.1, 3.0, and 4.5 feet below the initial height of the filled column. Although the column is six feet in height, the filled depth was only 5.5 feet due to the sealer cap which requires 0.5 feet of column to properly seal it.

After the composite sample is placed in the column, chemicals required for coagulation are added next. The chemicals are added in a concentrated solution and mixed with a hand-held laboratory mixer. The sealer cap is then

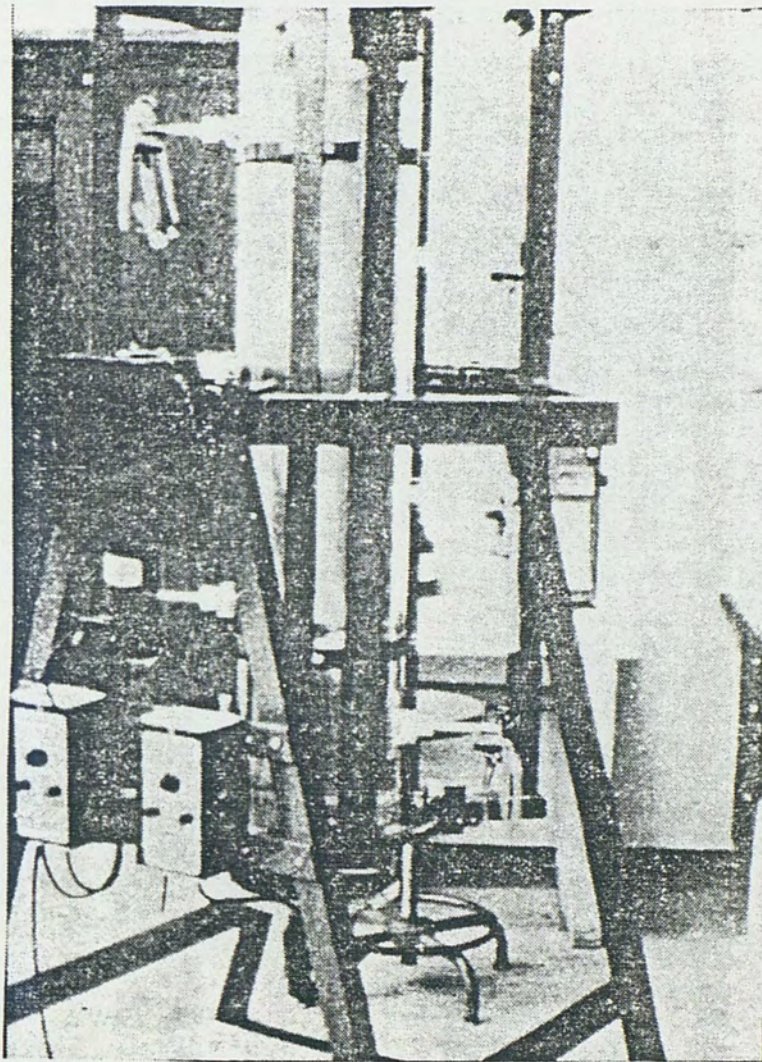


Fig. 6. Settling column.

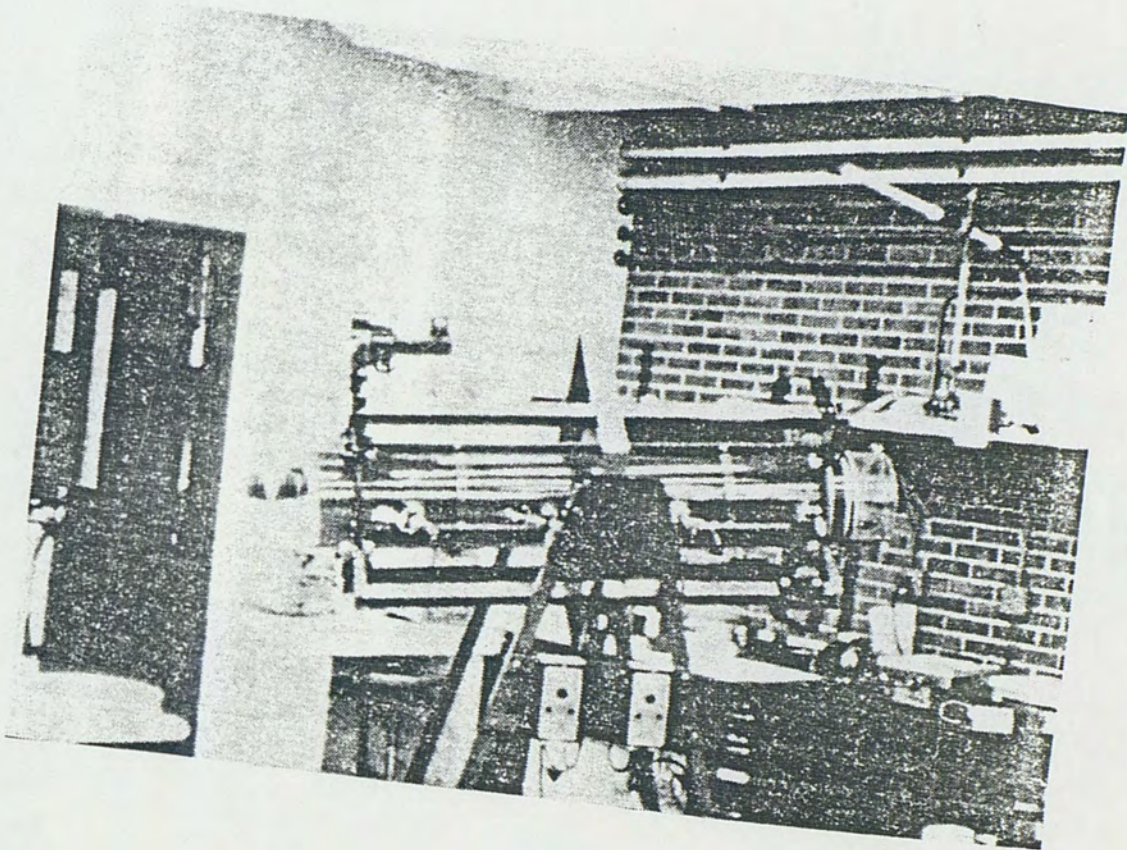


Fig. 7. Settling column rotation.

placed on the column. A small amount of air is left in the column to promote mixing and floc formation. The column was then rotated on both axes at 10 - 15 rpm for 15 minutes. After rotation the column was righted and locked in position for sample withdrawal.

Samples were withdrawn simultaneously from the three ports after elapsed times of 0, 5, 10, 15, 30, 60 and 120 minutes from the time the column was locked in place. It required three people to adequately take the samples. The size of each sample collected ranged from approximately 500 to 600 milliliters. Erlenmeyer flasks were used for collection with each flask identified by storm date, sample treatment, time of sample, and port taken from.

Each sample taken was analyzed for the general water quality parameters: COD, TOC, TSS, TNVSS, TP, TKN, and $\text{NH}_3\text{-N}$. The samples were also analyzed for the metals: Zn, Cd, Ni, Cu, Mg, Fe, Pb, Ci, and Ca. Approximately 100 milliliters of the total sample taken were used for metal analysis. Two milliliters of concentrated NH_4OH were added to these samples then sealed and stored on a shelf at room temperature. The remaining samples, used for general water quality determinations, had 10 drops of saturated mercuric chloride solution added to them, sealed, and stored at 4°C . The various chemical and metal analyses methods for the Lake Eola Column Study are listed in Table 7.

TABLE 7

CHEMICAL ANALYSIS METHODS FOR THE LAKE EOLA COLUMN STUDY

Parameter	Method	Reference
1. Residue Total suspended solids Non-volatile suspended solids Volatile suspended solids	Dry at 105°C and weigh Ignition at 550°C Difference	Standard Methods - 14th Ed. APHA 1975
2. Chemical oxygen demand	Dichromate digestion followed by spectrophotometric determination of chromic ion	Oceanography Interna- tional Corp., 1977
3. TKN	Acid digestion followed by dis- tillation and acidimetric filtra- tion of ammonia	Standard Methods - 14th Ed. APHA 1975
4. NH_3	Filtration followed by phenate determination of ammonia	Standard Methods - 14th Ed. APHA 1975
5. NO_3^-	Ion-specific electrode	Standard Methods - 14th Ed. APHA 1975
6. Total Phosphorus	Persulfate digestion - ascorbic acid reduction of phosphomolyb- dic acid - absorbance measured at 880 nm	Standard Methods - 14th Ed. APHA 1975
7. Soluble reactive phosphorus	Filtration, ascorbic acid reduc- tion of phosphomolybdic acid - absorb- ance measured at 880 nm	Standard Methods - 14th Ed. APHA 1975
8. Metals	Plasma emission spectrophotometry	SMI, 1978

Jar Test Procedure for Phosphorus Removal

The jar test consists of placing several samples of stormwater runoff in a series of containers, and stirring in a manner simulating that of the proposed treatment unit. Varing dosages of coagulants and other chemicals used are added to each container. After an appropriate period of mixing and coagulation, stirring is stopped and the floc formed is allowed to settle for a specified time. The water is then analyzed to determine optimal chemical dosages (Tekippe and Harn 1970).

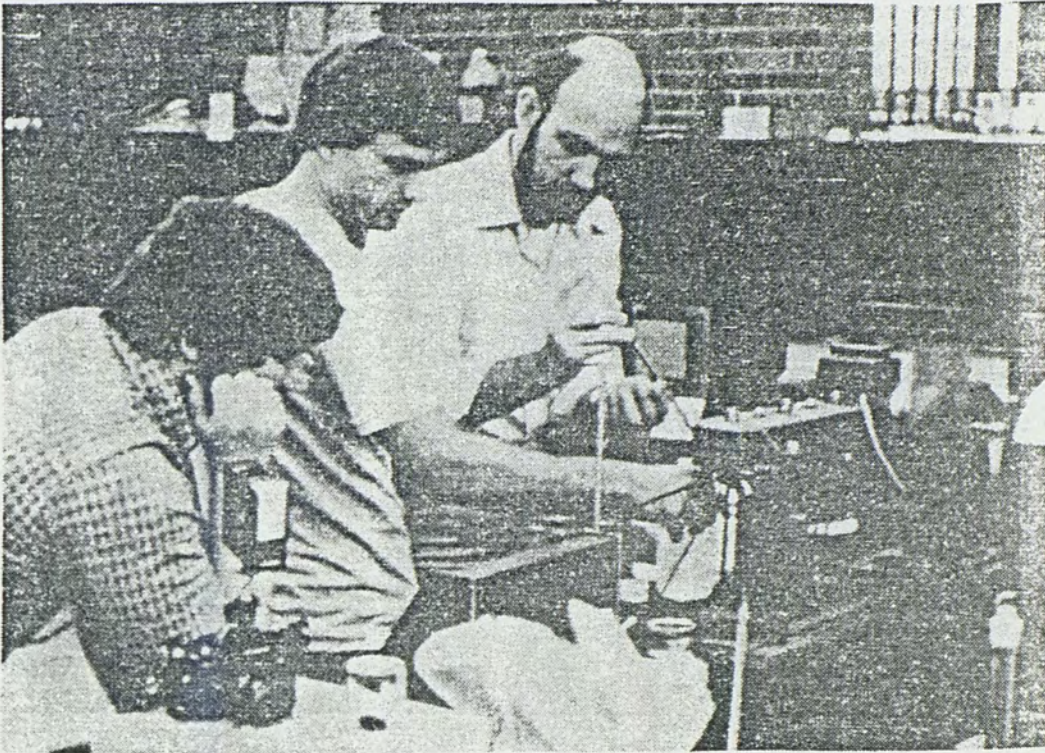
The step by step procedure used in conducting this research is as follows:

1. All glassware to be used is washed with chromic acid and rinsed with distilled water.
2. The parameters tested for this initial laboratory phase include: pH, orthophosphate, total phosphorus, total organic carbon and total inorganic carbon.
3. The orthophosphate test used was the ascorbic acid method described in Standard Methods. A combined reagent consisting of 50 ml of 5N H_2SO_4 , 5 ml of antimony potassium tartrate solution, 15 ml of ammonium molybdate solution, and 30 ml of 0.1 M ascorbic acid solution was used to form ammonium phosphomolybdate in the stormwater samples to be tested. The ammonium phosphomolybdate produces a visible blue solution that is directly propor-

tional to the phosphate present. A standard curve was derived with known concentrations of phosphorus versus absorbence. This curve was later used in the determination of the phosphorus content in the samples.

4. The first jar test involved finding the optimal concentration of alum to remove orthophosphorus from the stormwater samples. Six jars (1 liter beakers) were set in the jar test apparatus (6 - paddle Phipps and Bird) and filled with 1 liter of composite stormwater runoff. The stormwater samples were taken from a site which drains into Lake Eola, in downtown Orlando. The composite sample consisted of proportionally weighted stormwater samples which were to represent an input hydrograph to the catchbasin in study. The first set of jars contained amounts of alum weighing 0, 10, 20, 30, 40, 50 milligrams and placed in 1 liter jars to form solutions ranging in concentration from 0 - 50 mg/l. The second jar test had concentrations of alum ranging from 100 - 200 mg/l, while the third set had concentrations of alum ranging from 220 to 320 mg/l. The jar test procedure is depicted in Figure 8.
5. The measurement of pH of each sample was taken initially and held constant at 5.5 (the original pH of the stormwater samples).

Dr Thomas



Engineers at work

Fig. 8. ~~Jar Test procedure.~~

6. The optimal dosage of alum for orthophosphorus removal was now determined. The jar test apparatus was set at maximum speed for three minutes while the alum was added. One jar was held constant for control purposes.
7. After the three minutes of rapid mix, the speed was reduced to 30 rpm's and flocculated for an additional 30 minutes.
8. After the flocculation phase the samples were allowed to settle for 30 minutes.
9. The samples were then analyzed for orthophosphorus concentrations. Percent removals were calculated and the optimum alum dosage was found.
10. Optimum pH for orthophosphorus removal was now required. The jar test was repeated using the optimal alum dosage with pH adjusted to 5, 5.5, 6, 6.5, 7 and 8. Sodium hydroxide and sulfuric acid were used to adjust the pH prior to adding the alum coagulant and the various pH values were maintained throughout the experiment.
11. The same jar test procedure used in steps 6 - 9 was used to find the optimal pH range.
12. An additional step is required in performing jar tests once the optimal dosage and pH are found. This step

involves using the optimal pH value found and performing the test again for optimal coagulant dosage.

A similar jar test procedure was followed for determining optimal dosages and pH for ferric chloride and lime coagulants.

References for the above procedure are from Standard Methods (14th Edition), Water Chemistry Laboratory Manual (1972) by the American Association of Professors in Sanitary Engineering and by H.E. Hudson (1974).

CHAPTER VI

RESULTS AND DISCUSSION FROM THE LAKE EOLA

COLUMN STUDY

Introduction

The column study consisted of stormwater samples from seven storm events. Seven column tests were conducted for detention alone, four column tests for alum coagulation and detention, one column test for ferric chloride coagulation and detention, and one column study for lime coagulation and detention. A total of 13 column studies were performed on representative samples from the seven storm events.

The average chemical characteristics of each storm event and also physical characteristics of each urban sampling site are presented in Table 8. The chemical values were determined by averaging the initial samples taken from each port during the column study. In a few instances, the maximum value for any one parameter will exceed the average value listed for a particular storm. This is due to the averaging of the three values from the ports for each storm while the maximum and minimum results are singular values.

Water quality data for each of the 13 column studies are listed in Appendix A. From this data it appears that the highest organic and metal loading occurred during the first storm event on 4/5/79. This storm was preceded by

TABLE 8

STORM CHARACTERISTICS AND STORM WATER QUALITY FOR ALL
STORMS UTILIZED IN THE LAKE EOLA COLUMN STUDY

Storm Date	Average Data for Individual Storms (1979)							Data for All Storms		
	4/05	4/25	5/24	6/22	6/27	7/08	7/12	Mean	Max	Min
Location	School	G.S.	LEW	LEN	School	LEN	G.S.			
Drainage Area (acres)	5.12	.42	.56	1.10	5.12	1.10	.42			
Duration (min)	184.0	103.0	121.1	29.4	59.5	21.5	131.9	92.9	184.0	21.5
Runoff Volume (gal)	8595	420.4	1593.8	1030.6	1965	1223.3	3236.7	2580.7	8595	420.4
Precipitation (in.)	10.16	0.06	0.42	0.07	0.10	0.11	0.33			
Peak Flow (gpm)	114.3	16.0	33.3	100.0	86.2	71.4	57.1	68.3	114.3	16.0
Sample Percent	.41	7.7	2.0	3.1	1.6	2.6	1.0	2.63	7.7	.38
Water Quality Parameters - Mean Values										
TSS (mg/l)	138.6	71.2	53.0	76.7	260.3	360.0	61.3	145.9	524.0	19.0
VSS (mg/l)	123.3	44.0	20.3	49.3	129.7	240.0	22.7	89.9	348.0	3.0
NSS (mg/l)	15.3	27.2	32.7	27.3	130.7	120.0	38.7	56.0	176.0	12.0
COD (mg/l)	--	226.0	57.1	128.0	255.7	270.0	76.9	168.9	335.0	54.5
TKN (mg/l)	17.6	1.4	1.2	3.0	1.0	4.4	0.9	4.2	17.9	0.8
NH3 (mg/l)	2.1	--	0.3	0.9	0.1	0.2	0.2	0.5	2.8	0.0
TOC (mg/l)	520.0	61.0	19.9	29.5	29.0	--	--	139.9	540.0	16.8
TP (mg/l)	3.2	0.3	0.1	1.0	1.5	0.9	0.2	1.0	3.3	0.1
Metals - Mean Values										
Ca (mg/l)	83.6	62.0	26.7	34.0	67.0	21.0	31.3	46.5	125.0	5.0
As (ppb)	124	195	98	44	1135.0	34	68	256	1226	0
Cd (ppb)	18	14	52	44	28	74	11	34	154	4
Cu (ppb)	190	97	56	60	65	39	126	90	196	21
Cr (ppb)	51	64	21	25	31	15	29	33	66	14
Ni (ppb)	109	59	22	27	33	15	20	38	138	12
Mg (ppb)	6325	--	406	899	2742	551	715	1391	6325	97
Zn (ppb)	940	455	303	801	672	467	407	559	1050	81
Fe (ppb)	3328	1580	795	836	1597	1162	884	1455	3650	211
Pb (ppb)	1913	747	316	278	625	345	386	659	2240	29

approximately 32 days of dry weather. The highest solids loading rate occurred during the fifth and sixth storm event, July 27 and June 8 respectively. This may be due to construction activities near these sampling sites during this period.

The first storm event, 4-5-79, also provided the highest concentrations of several pollutant parameters including: TKN, NH_3 , TOC, Ca, Ni, Mg, Zn, Fe, and Pb. No unusual activity occurred at this sampling site for the first storm event. The high concentrations may probably be attributed to the high runoff volume encountered and the long antecedent dry period.

High COD and Cd concentrations were observed from the runoff during the 7-8-79 storm event which were sampled from the Lake Eola North site. These high concentrations may be due to construction activities in this part of the watershed. Very high arsenic concentrations occurred from the 6-27-79 storm collected from the school site. No explanation can be found for these unusually high arsenic concentrations except possible laboratory errors or some unknown activity at the sampling site.

The water quality characteristics of urban stormwater runoff within a drainage basin are variable in nature. As listed in Table 8, the various water quality parameters for the storms tested show wide ranges.

Urban stormwater runoff characteristics from several sites throughout the country and one site in Germany are

listed in Table 2 from Chapter II. Comparisons of this table with the results from the Lake Eola Study listed in Table 8 show good correlation with many of the water quality parameters. Total suspended solids (TSS) from the Lake Eola Study are on the low side of the range listed in Table 2, but the volatile suspended solids show almost identical mean values for both tables.

The parameters COD and Pb from the Lake Eola Study are on the high side of the range listed in Table 2. The nutrient parameters, TKN and phosphorus, are also on the high side of the range listed, with mean TKN values almost three times higher than the mean value listed in Table 2. On the average the results from the Lake Eola Study are in the range reported by other studies.

Comparisons can also be made between the column study stormwater runoff results obtained in 1979 and previous Lake Eola sampling in 1975. Table 9 lists the data from 1975 Lake Eola Study. The parameters TOC, TKN, and TP from the column study data (Table 8) are mostly in the given range of Table 9. Only one storm event (4-5-79) generated pollutants of high magnitude that were consistently out of the given range. These comparisons indicate that the results obtained from the column study are typical of urban stormwater runoff.

TABLE 9

SELECTED STORMWATER DATA FOR THE
LAKE EOLA DRAINAGE BASIN

Parameter	Commercial Area - 28 AC		Residential Area-16.1 AC (Wet Period*)
	Dry Period	Wet Period*	
Flow-cfs	0.276	0.276-14.7	Not Recorded
pH	8.09-8.39	8.47-7.02	7.72-6.52
Alkalinity (mg/l as CaCO ₃)	144-155	158-25	77-27
Conductivity (µmho/cm)	340-360	395-77	208-51
Turbidity (S.U.)	0.9-2.8	0.3-34	0.9-24
BOD (mg/l)	4.5-5.9	3.2-37.2	1.8-11.0
TOC (mg/l)	2.1-8.3	0.8-146	2.9-31
TKN (mg/l-N)	0.14-0.95	0.07-3.87	0.02-1.03
NO ₃ (mg/l-N)	0.17-0.27	0.11-1.33	0.03-0.53
OP (mg/l-P)	0.37-0.68	0.47-0.12	0.01-0.20
TP (mg/l-P)	0.62-1.08	1.00-0.17	0.12-0.94

SOURCE: M.P. Wanielista, et al., Nonpoint Source Effects (Orlando, Florida: Florida Technological University, 1976), p. IV-6.

Treatment of Stormwater Runoff

Introduction -

As discussed previously, the treatment methods employed for the Lake Eola stormwater study included: settling, alum coagulation and settling, ferric chloride coagulation and settling and lime coagulation and settling. Graphical representations of generalized water quality changes for various parameters investigated in the Lake Eola Column Study due to the four treatment methods are depicted in Figures 9, 10, 11 and 12. These graphs are general trends found in the study and are not of considerable detail. More specific, detailed representations of selected water quality parameters are depicted on other graphs. The discussion of the results obtained for each treatment method will be divided by port (1, 3, and 5) with a short summary at the end of each treatment section.

Settled Stormwater Runoff Treatment -

Figure 9 depicts generalized removal rates of pollutants from settled stormwater runoff with no chemical treatment. After mixing in the column, the stormwater sample was allowed to settle for two hours. Samples were withdrawn periodically to determine the effect of settling on the various water quality parameters.

The majority of graphs from this figure depict a consistent trend in pollutant removal rates. This basic trend is a gradual increase in parameter removal rates, tapering off to a more linear representation, usually after thirty to sixty

minutes of settling time. The graphs depicting total suspended solids (TSS), volatile suspended solids (VSS), chemical oxygen demand (COD), ammonia nitrogen (NH_3), total organic carbon (TOC), total phosphorus (TP) and cadmium (Cd) follow this type of removal pattern. From Figure 9, the order or position the various port curves are on the graphs varies with each parameter, but the three ports do follow similar removal trends.

The majority of the metals; zinc (Zn), arsenic (As), nickel (Ni), copper (Cu), iron (Fe), lead (Pb), and chromium (Cr) follow a slightly different removal pattern. The first port and occasionally the third port follow the removal pattern of the other parameters discussed previously (gradual increase in removal then tapering off). The fifth port usually shows a decrease in removal rates then approaches a linear representation after 60 minutes of settling time. This fifth port curve represents basically no removal of pollutants.

More detailed removal curves for total phosphorus and total suspended solids for settled stormwater runoff are depicted in Figures 13 and 14, respectively. Also listed on these figures are the wide range of removal rates encountered for each port during all settled stormwater column tests. The average total phosphorus removed after 120 minutes of settling was approximately 30 percent. The average total suspended solids removed was about 55 percent after 120 minutes.

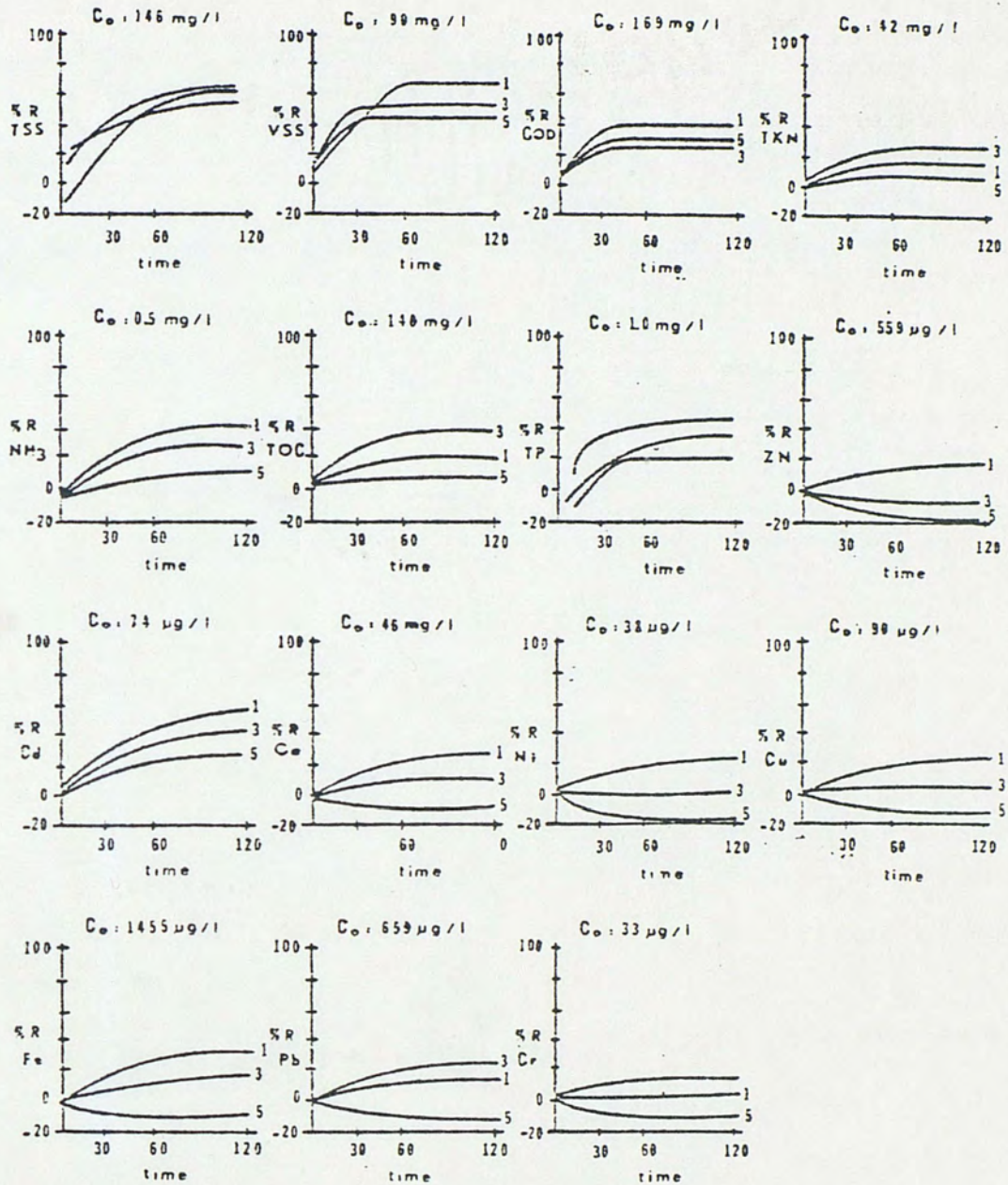


Fig. 9. Generalized representation of water quality changes for all parameters studied in Lake Eola column study involving settled stormwater runoff. (Dotted lines indicate negative values).

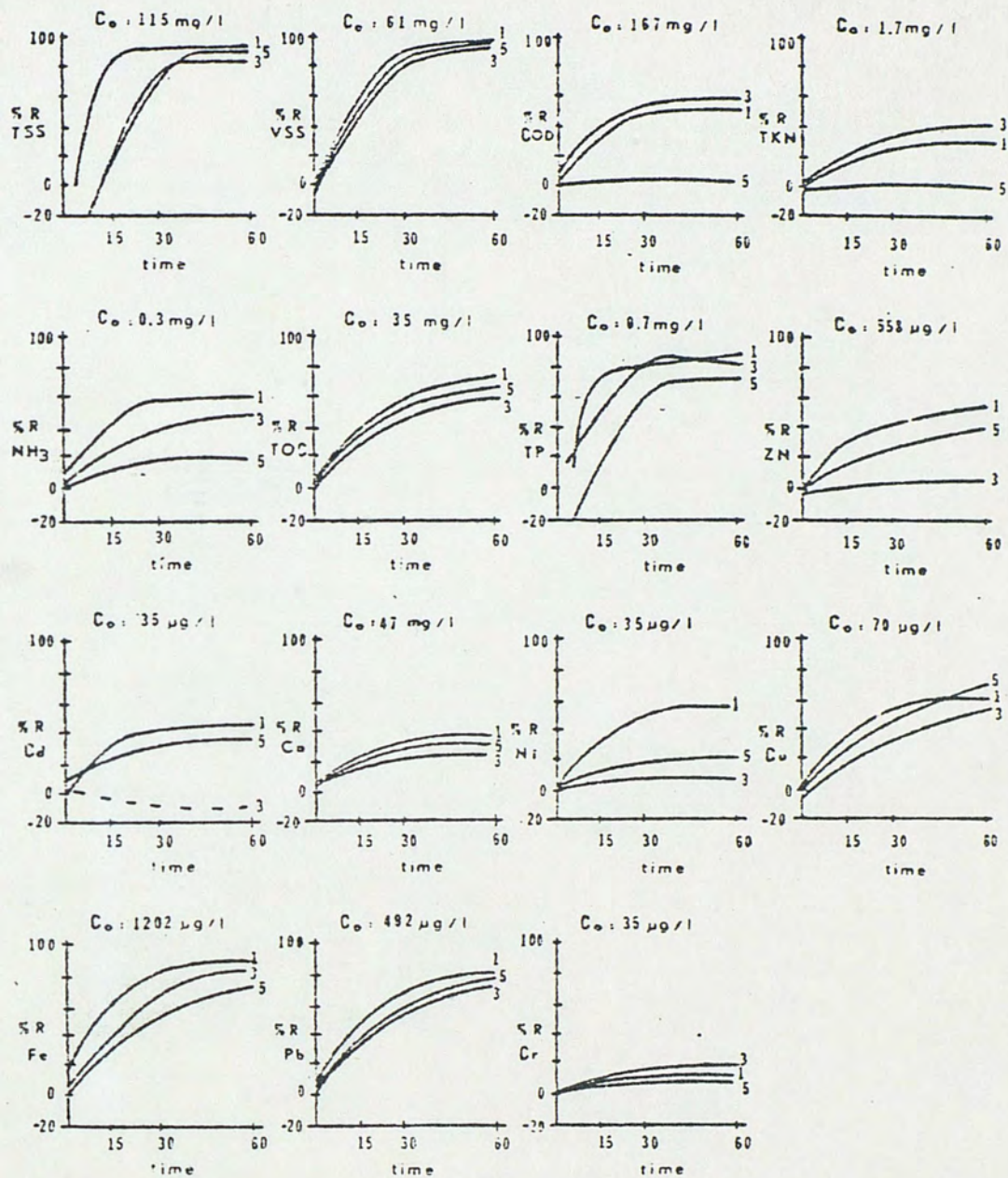


Fig. 10. Generalized representation of water quality changes for all parameters studied in Lake Eola column study involving alum coagulated and settled stormwater runoff. (Dotted lines indicate negative values).

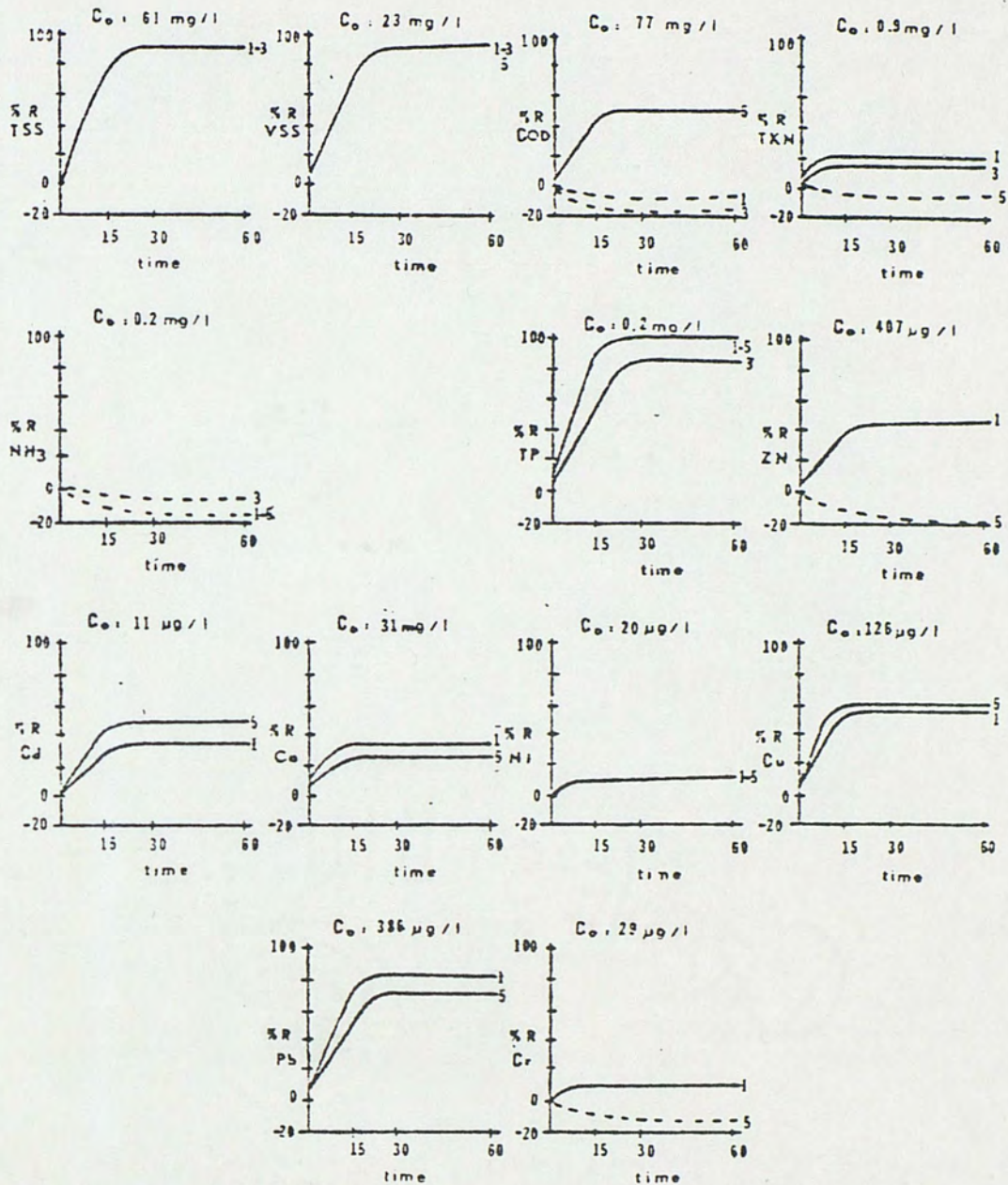


Fig. 11. Generalized representation of water quality changes for all parameters studied in Lake Eola column study involving settled and ferric coagulated stormwater runoff. (Dotted lines indicate negative values).

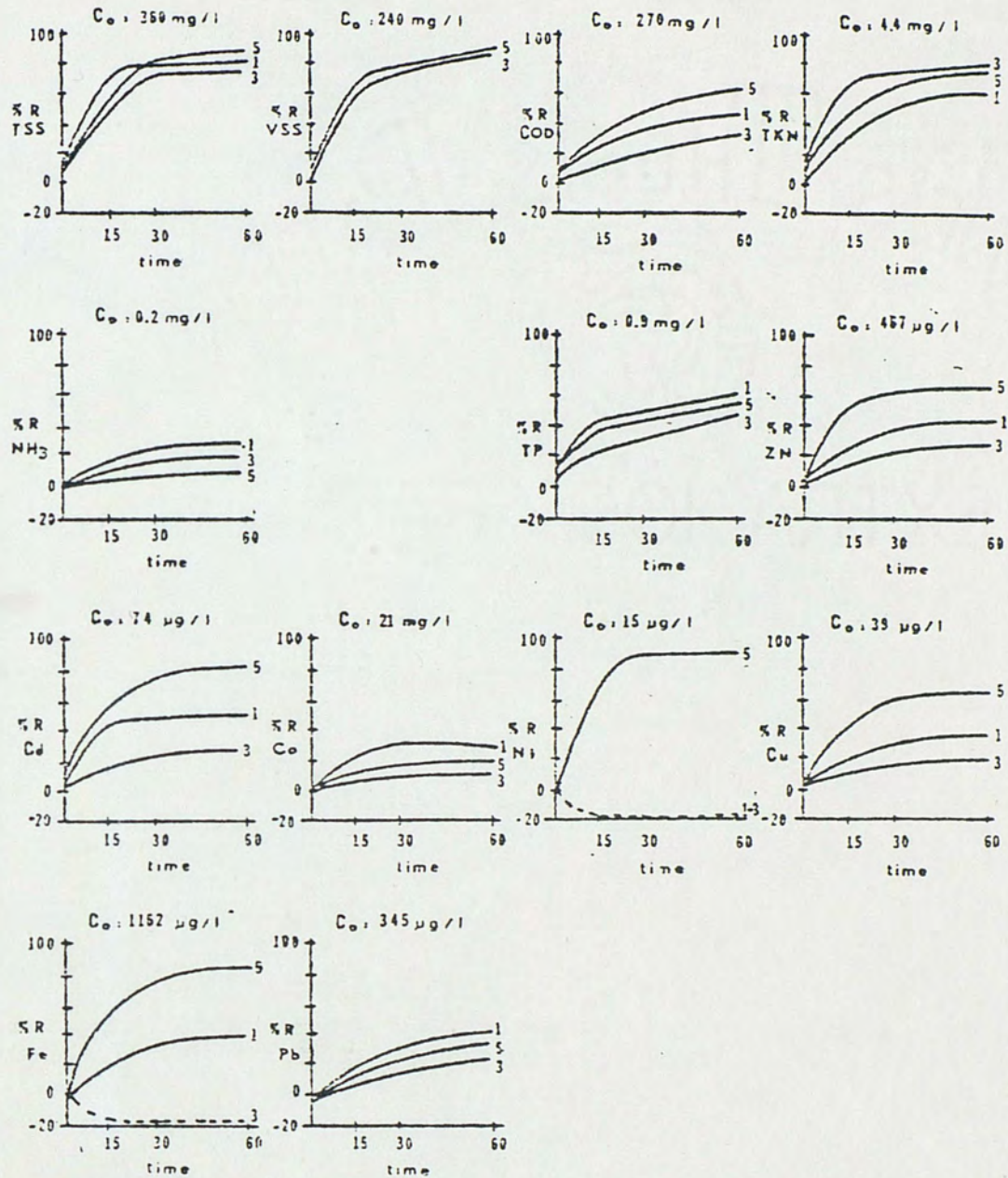


Fig. 12. Generalized representation of water quality changes for all parameters studied in Lake Eola column study involving lime coagulated and settled stormwater runoff. (Dotted lines indicate negative values).

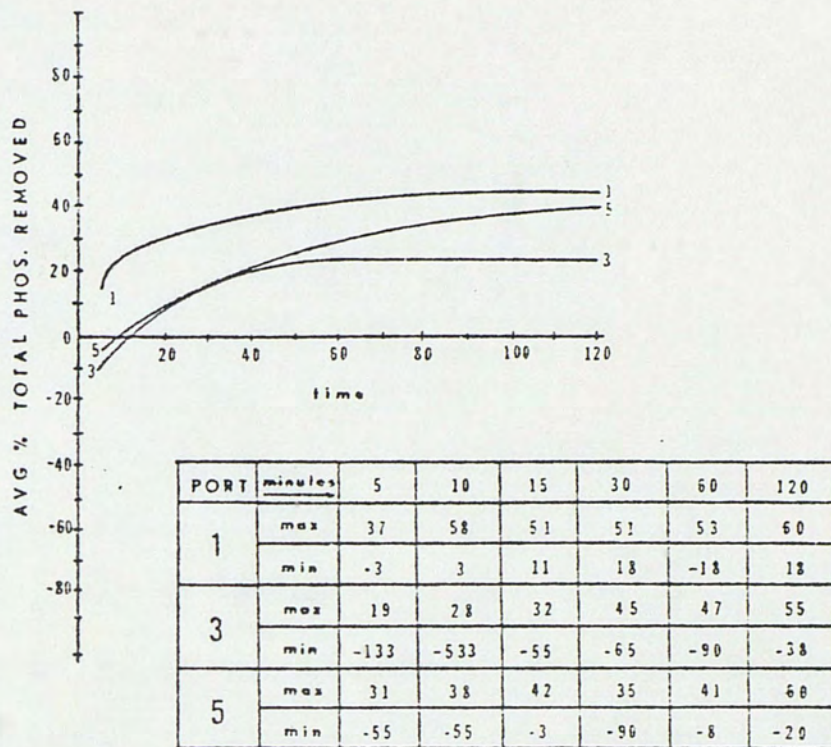


FIGURE 13. AVERAGE PERCENT TOTAL PHOSPHORUS REMOVED VERSUS TIME FOR SETTLED STORMWATER RUNOFF.

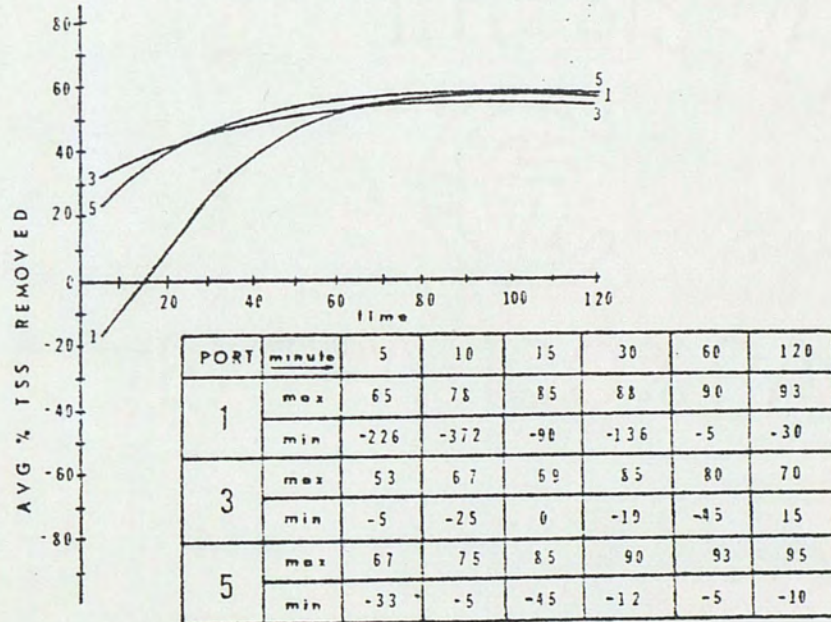


FIGURE 14. AVERAGE PERCENT TOTAL SUSPENDED SOLIDS REMOVED VERSUS TIME.

Alum Treated and Settled Stormwater -

Generalized representations of water quality changes for various parameters due to alum coagulated and settled stormwater are depicted in Figure 10. Extensive jar tests involving $\text{Al}_2 (\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O}$ (alum) for the removal of phosphorus determined that optimal doses occurred at 240 mg/l with a pH equal to 5.5. Results of the alum jar tests are listed in Appendix B.

The analysis of the water quality data contained in Figure 10 for the first part of the column study indicate several parameters that were reduced substantially in concentration. Total suspended solids continued to decrease in concentration throughout the 60 minutes of sedimentation. Total suspended solids (TSS) removals reached 90 percent after approximately 30 minutes of settling and approached 97 percent removal after 60 minutes. Volatile suspended solids (VSS) decreased in concentration in a similar manner as TSS and reached 90 percent removal after approximately 30 minutes of sedimentation. Non-volatile suspended solids (NVSS) also decreased in the same manner, reaching 90 percent removal after approximately 60 minutes.

Chemical oxygen demand (COD) removal rates were variable in nature. The removals approached 50 percent after approximately 30 minutes. Ammonia nitrogen ($\text{NH}_3\text{-N}$) removal rates were rather consistent throughout the sedimentation period. From 5 - 60 minutes of settling time the percent

removal rate was 40 to 60, respectively. Total organic carbon (TOC) removal rates were also fairly constant, with 45 to 60 percent reduction between 10 and 60 minutes.

Total phosphorus removals in the first port were excellent using alum coagulation. Total phosphorus (TP) removals approached 90 percent after approximately 30 minutes of settling time and reached 99 percent removal after 60 minutes of sedimentation.

Analysis of the heavy metal data from the first port indicate copper (Cu), iron (Fe), and lead (Pb) removal after 60 minutes of settling. Total kjeldahl nitrogen (TKN), cadmium (Cd), magnesium (Mg), and chromium (Cr) removals by alum treatment and sedimentation were inconsistent, thus making removal trend observations difficult.

A review of the data from port 3 indicates a similar removal pattern of many water quality parameters which occurred at port 1. Total suspended solids, volatile suspended solids, and non-volatile suspended solids all showed similar removal trends and continue to decrease in concentration through the 60 minutes of settling. All three parameters approached 90 percent removal after 30 minutes of sedimentation.

Chemical oxygen demand (COD) removal rates are fairly consistent from 5 to 60 minutes with a removal range of 45 to 60 percent. Total kjeldahl nitrogen (TKN) removal rates at port 3 were variable with no conclusion being drawn.

Total organic carbon and copper both approached 50 percent removal after 30 minutes of settling and increased slightly after 60 minutes. Total phosphorus removal approached 90 percent after 30 minutes and increased to 96 percent after 60 minutes of sedimentation.

From the heavy metal data, Fe and Pb neared 70 percent and 60 percent removal respectively after 30 minutes of settling. No basic change occurred for the parameters zinc (Zn), cadmium (Cd), nickel (Ni), magnesium (Mg), and chromium (Cr) at port 3.

Port 5, the lowest port tested, showed consistent patterns for solids and phosphorus removals as occurred at ports 1 and 3. TSS, VSS, and NVSS took longer to show any significant removals compared with ports 1 and 3, but all approached 90 percent removal after 60 minutes of settling. Total phosphorus removals increased consistently throughout the 60 minute period and approached 90 percent removal after 30 minutes. Maximum total phosphorus removals occurred after 60 minutes and reached 95 percent reduction.

Ammonia-nitrogen, cadmium, and total organic carbon all showed variable removal rates. No pattern could be distinguished from the available data.

From the heavy metal data at port 5 Cu, As, Fe, and Pb approached 40, 50, 50, and 60% removal respectively after 30 minutes of settling. All of these metals increased

approximately an additional 10 percent in removal after 60 minutes of sedimentation. Very little change occurred for COD, Ni, Mg, Cr, TKN, and NH_3 throughout the course of the column study at port 5.

In summary for alum treatment of stormwater runoff, various water quality parameters showed considerable removal rates during this column study. The parameters which encountered 90 percent or greater removal rates include: TSS, VSS, NVSS, and TP. More detailed removal curves for TSS and TP are depicted in Figures 15 and 16, respectively. Iron and lead were also reduced substantially during the study (70 to 90 percent reduction) while COD, NH_3 , TOC, Zn, Cd, As, and Cu were reduced 50 to 60 percent.

From a lake management standpoint, the 90 percent reduction in phosphorus, which is the limiting nutrient in many urban lakes (Vollenweider 1968, Shannon and Brezonik 1972), using alum coagulation and sedimentation is a significant achievement. Another important parameter which has a positive effect on algae reduction in lakes is copper sulfate (Fair, et al. 1971). Using alum coagulation, copper was reduced a maximum of 60 percent which may cause an increase in algae productivity.

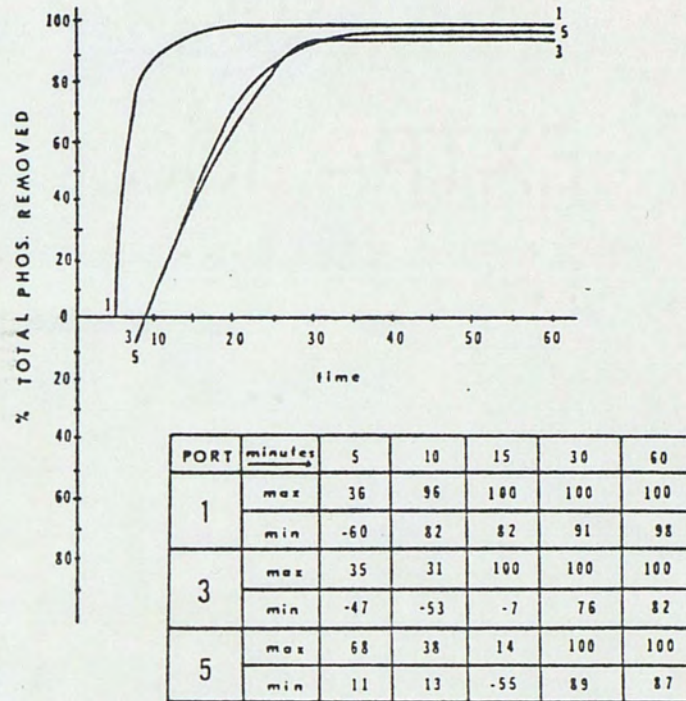


FIGURE 15. AVERAGE % TOTAL PHOSPHORUS REMOVED VERSUS TIME FOR ALUM COAGULATED AND SETTLED STORMWATER RUNOFF.

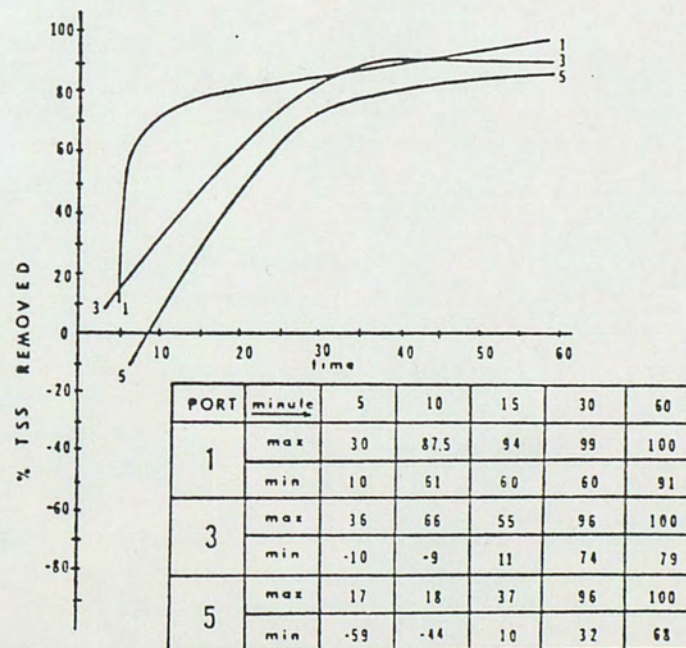


FIGURE 16. AVERAGE % SUSPENDED SOLIDS REMOVED VERSUS TIME FOR ALUM COAGULATED AND SETTLED STORMWATER RUNOFF.

Ferric Chloride Treated and Settled Stormwater -

Generalized representations of water quality changes for various parameters due to ferric chloride coagulated and settled stormwater are depicted in Figure 11. Limited jar tests involving ferric chloride (FeCl_3) for the removal of phosphorus indicated that the optimal dose occurred at 80 mg/l with a pH of 5.0. Results of the ferric chloride jar test are listed in Appendix B.

The analysis of the data in Figure 11 at port 1 showed good removal rates for many of the water quality parameters tested. Total suspended solids (TSS) and volatile suspended solids (VSS) were removed consistently throughout the settling period. Solids removal approached 90 percent after 20 minutes of settling.

Total phosphorus removal rates were found to be very good using ferric chloride. Total phosphorus was basically 100 percent removed after 30 minutes of settling.

Zinc removal rates were consistent throughout the settling period. Removal rates for zinc ranged from 30 percent to 40 percent between 15 and 60 minutes. No data were available on any of the heavy metals at 5 minutes from port 1.

Arsenic had very poor removal rates from port 1. Both nickel and chromium showed consistently low removal rates during the entire study. Lead and copper had relatively constant removal rates of approximately 80 and 50 percent, respectively. Variable removal rates were found for COD, TKN, NH_3 and Cd. No observable removal patterns could be

detected for these parameters.

No data were available on the parameter T.O.C. or any of the heavy metals for port 3. From the data presented in Figure 11, total suspended solids and volatile suspended solids showed good removal rates similar to port 1. Both parameters were very consistent in removal rates, ranging from 67 percent at 5 minutes settling time to 94 percent after 60 minutes of settling.

The removal of total phosphorus also appears good for port 3, but was more variable than at port 1. Total phosphorous removal rates ranged from 5 to 100 percent between 10 and 15 minutes of settling time then decreased to approximately 80 percent between 30 and 60 minutes.

Ammonia concentrations showed very little removal throughout the study period. Variable removal rates occurred for the parameters COD and TKN.

Many water quality parameters showed similar removal rates at port 5. From the data, total suspended solids and volatile suspended solids had removal rates of approximately 40 percent after 5 minutes of sedimentation and approached 95 percent after 60 minutes.

The parameters COD, Cd, Ni, and Cu showed very consistent removal rates. The removal rates for COD, Cd, Ni and Cu were approximately 50, 50, 10, and 55 percent respectively.

Total phosphorus removals at port 5 were very good. Removal rates ranged from 10 percent at 5 minutes to 100

percent after 60 minutes of settling time. Total phosphorus was almost completely removed using ferric chloride after 15 minutes of settling.

Lead also showed good removal at port 5. Removal rates increased from 10 to 75 percent in 60 minutes of settling. Very little to no removal was observed for the parameters TKN, Zn, Ci, and Mg. Variable removal rates were found for NH_3 and As with no conclusions able to be made.

Lime Treated Stormwater Runoff -

Lime was used as a coagulant in stormwater runoff in only one of the column studies. From a literature research it was found that optimal phosphorus removal occurred at approximately a pH of 11.5 (King 1979, Cavagnaro 1978). It has been postulated that at this high pH level magnesium hydroxide precipitates and serves as a coagulant aid in removing the remaining phosphorus solids from suspension (Cavagnare 1978)

The storm event of 7-8-79 was treated with $\text{Ca}(\text{OH})_2$ (lime). It required 205 milligrams per liter of $\text{Ca}(\text{OH})_2$ to reach a pH value of 11.5. The data from this column study are listed in Appendix A with jar test results listed in Appendix B. Generalized removal rates of various water quality parameters using lime coagulation are depicted in Figure 12.

The results from the lime treated column study were not as impressive as those encountered using alum and ferric chloride as a coagulant. It was found from the first port of the column that total suspended solids removal increased throughout the 60 minute settling period and reached maximum removal of 84 percent.

The data for TKN from the first port indicate that removals were very consistent at 60 to 80 percent reduction from 10 to 60 minutes of settling. Basically, TKN removals were complete after 30 minutes of settling. Ammonia (NH_3) removals were low after 60 minutes and reached approximately 20 percent reduction.

Total phosphorus removals continued to increase in removal throughout the column study. Total phosphorus was reduced approximately 30 to 60 percent between 10 and 60 minutes of settling. Cadmium removal rates were very consistent throughout the study with approximately a 40 to 50 percent reduction at port one. Copper removals were also consistent during the study with a 20 to 30 percent reduction in concentration at port 1.

The parameters Mg, Fe, and Pb were very similar in percent removals during the study period at port 1. All four parameters managed 20 to 40 percent reduction in concentration after 60 minutes of settling.

The parameters which showed variable reduction amounts were COD, Zn, As, and Ni. No removal pattern could be observed from the data concerning these parameters.

The data from port 3 for the lime column study showed very similar removal patterns as those from port 1. Total suspended solids and volatile suspended solids all increased in removal during the 60 minute settling period. The concentration were reduced 20 to 80 percent during the 10 to 60 minute interval.

TKN removal rates increased consistently throughout the column study at port 3. Removal rates went from 40 to 80 percent reduction during the 60 minute period. Total phosphorus also increased removal rates, from 0 to 60 percent reduction during the settling period.

Cadmium and magnesium showed steady removals during the entire study. A 20 to 30 percent reduction respectively for cadmium and magnesium were observed at the end of the settling time.

Variable removal rates were found for COD, NH_3 , Zn, Ni, and As. These results patterned those found from analysis of port 1 data.

Port 5, the deepest port at approximately 4.5 feet, showed similar results for the solids reduction as in ports 1 and 3. Total suspended solids and volatile suspended solids reached approximately 90 percent reduction after the 60 minutes settling period.

Several parameters showed greater removal rates in port 5 than in any of the other ports. Zinc was reduced approximately 60 percent, cadmium approximately 80 percent, nickel about 90 percent, copper about 60 percent, and iron about 80 percent in port 5. All of the reduction rates were much higher than found in ports 1 and 3.

Total phosphorus reduction was found to be similar to the other ports and reached 60 percent at the end of 60 minutes. Low removal rates were shown for lead and ammonia.

CHAPTER VII

DATA ANALYSIS

Introduction

The data generated from the several Lake Eola column studies performed were analyzed by two basic methods. The first method involved regression analysis of the data to determine the "best" statistical curve fit available. The regression analysis procedure was used to develop equations that would aid in describing the removal of various water quality parameters by the various treatment methods. The computer program S.A.S. (Statistical Analysis System) was employed to determine and manage the numerous equations that were used in the analysis.

The second method utilized for the data evaluation involved the development of isoconcentration lines or sometimes referred to as "iso-percentage" removal lines. The sedimentation characteristics of the stormwater were determined by withdrawing samples from the column at three depths and various time intervals. The fraction of the water quality parameter removed at each depth is used to construct lines depicting percent removal rates. Isoconcentration lines were developed for total suspended solids and total phosphorus removals for each of the stormwater treatment methods.

Regression Analysis -

Regression analysis was performed on the data obtained from the column studies in order to make predictions of parameter removal rates by means of mathematical equations. The equations chosen for use in this analysis procedure were:

1. $\% \text{ removal } x = m t + b$
2. $\% \text{ removal } x = m sv + b$
3. $\% \text{ removal } x = m \ln t + b$
4. $\% \text{ removal } x = m \ln sv + b$
5. $(\% \text{ removal } x)^{-1} = m sv + b$

Where

x = any variable (chemical parameter)

t = time

sv = settling velocity

m = slope

b = intercept

Regression analysis was performed at each port (1, 3 and 5) for percent removal of the various parameters versus time. Analysis was also performed for percent removal of the various parameters versus settling velocity and the natural log of the settling velocity. Since settling velocities are determined by depth versus time, regression analysis equations involving settling velocities are applicable to all ports.

Regression analysis results for the various treatment alternatives are listed in Tables 10 through 15. The data

are presented in tabular form relating the slope (m), intercept (b), correlation coefficient (r), alpha (a), and the number of observations (n) to the regression variables. The alpha value (a) relates the confidence level placed on the results. The lower the alpha value, the more probable a direct relationship exists that the slope is correct. The correlation coefficient (r) indicates the amount of variation that can be expected from the developed equation. The correlation coefficient approaches plus (+) or minus (-) one. Perfect correlation exists when the coefficient (r) equals +1 or -1. Inverse correlation is a negative value of (r) and results when the variables are inversely related to one another.

The treatment methods analyzed included detention only, alum treatment and detention, and ferric chloride treatment and detention. Lime treatment was not considered for statistical analysis due to the poor removal levels experienced for the various chemical parameters.

The components of the regression equations developed for detention treated stormwater runoff are listed in Tables 10 and 11. Table 10 lists the results for percent removals versus time for the three ports, settling velocity, and \ln of the settling velocity. Table 11 differs in that the percent removals were compared to the \ln of time for each port and the inverse of the percent removals were compared to the settling velocity.

TABLE 10
REGRESSION EQUATION RESULTS FOR
SETTLED STORMWATER RUNOFF

	RTSS	RVSS	IRISS	RCOD	RTKN	RIIH	RTDC	RTP	RZh	RCd	RNI	RCU	RMg	RFe	RPb	RCr	RCa
Port 1	m	0.61	0.93	0.20	0.33	0.09	0.17	0.18	-0.29	-0.18	0.46	0.15	0.07	0.27	0.11	0.08	0.20
% R vs. r	b	-3.27	-25.42	22.16	25.37	26.76	4.50	22.30	11.68	30.18	-43.67	4.76	-4.65	0.82	-5.91	1.87	1.88
Time	a	.285	.284	.359	-.230	.251	.414	.505	-.123	-.032	.083	.148	.074	.492	.081	.132	.211
n	n	.050	.050	.020	.116	.109	.028	.000	.414	.828	.586	.316	.678	.000	.584	.429	.150
		48	48	42	48	42	28	49	46	48	45	48	34	48	48	38	48
Port 3	m	0.11	0.14	-0.03	0.08	0.11	0.17	0.42	0.53	-0.25	0.33	0.07	0.23	0.14	0.12	0.18	0.08
% R vs. r	b	34.74	38.35	14.05	9.15	6.17	17.02	-22.17	-47.15	48.55	-66.92	-5.92	-14.31	-0.61	12.95	-9.82	-39.75
Time	a	.258	.296	-.002	.147	.216	.416	.166	.100	-.069	.036	.062	.147	.179	.324	.141	-.009
n	n	.074	.039	.987	.314	.169	.014	.260	.527	.638	.839	.672	.392	.218	.023	.373	.954
		49	49	42	49	42	34	48	42	49	35	49	36	49	49	42	49
Port 5	m	0.28	0.16	0.39	0.09	0.26	0.30	0.32	0.54	0.17	0.42	-0.04	-0.28	0.41	0.15	0.06	-1.28
% R vs. r	b	29.92	33.13	24.84	3.41	-11.22	-16.31	3.21	-109.07	-44.35	-94.85	-45.11	-85.28	-75.03	-221.99	-0.04	20.83
Time	a	.402	.300	.459	.142	.223	.363	.475	.049	.010	.027	-.082	-.098	.050	-.041	.199	-.316
n	n	.004	.038	.001	.336	.156	.023	.001	.737	.948	.858	.574	.587	.733	.779	.252	.027
		49	48	48	48	42	35	49	49	49	47	49	33	49	49	35	49
All Ports	m	-25.42	-20.55	-18.85	-16.94	-47.17	-35.32	-55.39	-175.67	-77.65	-07.26	-44.08	-129.65	-90.33	-155.27	-32.00	-4.20
% R vs. r	b	38.85	35.55	32.44	14.18	23.35	17.68	25.28	-2.34	24.11	-34.86	-4.09	-6.30	4.80	-34.69	7.96	-18.29
S.V.	a	-.102	-.062	-.067	-.105	-.308	-.325	-.223	-.274	-.170	-.136	-.152	-.204	-.218	-.106	-.232	-.006
n	n	.256	.494	.458	.246	.001	.003	.012	.003	.058	.162	.091	.058	.015	.239	.022	.947
		125	124	124	124	108	83	125	.117	125	108	125	87	125	125	.97	125
All Ports	m	-7.64	-8.97	-4.51	-0.62	-9.91	-8.17	-12.93	-28.09	-9.26	-21.70	-9.79	-17.52	-18.06	-32.04	-5.54	-0.02
% R vs. r	b	16.88	11.73	18.64	9.29	-8.25	-7.54	-14.71	100.90	-12.50	-100.71	-34.83	-72.21	-53.82	-137.63	-10.82	-19.21
in S.V.	a	-.156	-.137	-.032	-.020	-.332	-.374	-.268	-.221	-.104	-.167	-.173	-.141	-.223	-.112	-.210	-.000
n	n	.082	.128	.366	.828	.000	.001	.002	.016	.247	.084	.054	.191	.012	.212	.039	.999
		125	124	124	124	108	83	125	117	125	108	125	87	125	125	.97	125

TABLE 11
REGRESSION EQUATION RESULTS FOR
SETTLED STORMWATER RUNOFF

	RTSS	RVSS	RNSS	RCOD	RTKN	RNH	RTDC	RTP	RZn	RCd	RNI	RCu	RMg	RFe	RPb	RCr	RCa
Port 1	14.74	19.29	9.99	9.24	-1.92	6.27	4.95	8.46	-0.89	2.69	4.52	3.56	0.76	6.09	1.78	2.95	5.33
b	-22.08	-42.64	-5.34	0.79	15.55	9.23	-3.81	2.48	2.59	12.27	-34.27	-0.53	-3.65	-6.56	-6.17	-3.65	-5.95
r	.269	.249	.217	.466	.066	.332	.426	.639	.017	.040	.050	.122	.040	.415	.062	.182	.205
ln Time	.064	.088	.138	.002	.645	.032	.024	.000	.911	.787	.743	.408	.823	.003	.678	.275	.163
n	47	47	47	41	47	41	27	48	45	47	44	47	33	47	47	37	47
Port 3	9.43	11.09	1.93	2.03	4.76	4.45	7.51	6.54	8.28	4.48	0.73	1.51	4.29	3.55	5.25	3.64	-3.74
b	8.10	7.65	12.36	4.21	-2.13	-2.80	0.09	-22.05	-44.47	21.09	-47.85	-6.89	-15.48	-5.26	0.91	-11.85	-21.28
r	.416	.478	.041	.072	.232	.269	.523	.115	.080	.122	.008	.074	.133	.171	.406	.140	.027
ln Time	.003	.001	.781	.651	.109	.084	.002	.436	.613	.405	.965	.615	.438	.241	.004	.375	.055
n	48	48	48	41	48	41	33	47	41	48	34	48	35	48	48	41	48
Port 5	12.41	10.38	13.85	7.92	2.75	4.39	3.70	8.35	-2.56	0.30	-11.80	-9.75	-14.99	-2.57	-34.56	.159	-23.93
b	1.58	5.84	-2.68	-9.05	-1.29	-12.59	-13.79	-8.70	-67.99	-33.12	-35.36	-13.80	-41.93	-43.22	-91.85	-2.23	38.82
r	.506	.449	.509	.361	.140	.163	.215	.445	.023	.004	.116	.164	.100	.027	.098	.195	.243
ln Time	.000	.001	.000	.020	.341	.301	.214	.001	.875	.979	.439	.260	.580	.856	.503	.262	.106
n	48	47	47	40	47	41	34	48	48	40	46	48	32	48	48	34	48
All Ports	.079	-2.52	-1.30	11.99	14.43	9.88	-5.17	-0.04	0.16	-3.28	9.86	-1.27	0.07	0.29	-1.86	0.27	-2.19
b	.781	1.36	3.52	0.43	10.69	17.40	3.58	0.04	-0.08	3.09	2.56	1.90	0.06	0.76	1.24	-0.02	3.63
r	.002	.066	.017	.170	.098	.058	.081	.109	.051	.044	.112	.024	.037	.008	.049	.222	.029
(%R) ⁻¹	.982	.466	.849	.080	.279	.549	.469	.226	.588	.629	.248	.794	.735	.932	.588	.029	.748
vs.																	
S.V.	124	123	123	106	123	107	82	124	116	124	107	124	86	124	124	96	124

TABLE 12

REGRESSION EQUATION RESULTS FOR ALUM
COAGULATED AND SETTLED STORMWATER RUNOFF

	RTSS	RVSS	RNSS	RCOD	RTKN	RHI	RDC	RTIP	RZn	RCd	RH	RCu	RMg	Pie	RPb	RCr	RCa	
Port 1 % R vs Time	m b r a n	0.96 47.75 .731 .000 24	0.76 61.42 .663 .000 24	1.08 39.99 .726 .000 24	-0.11 43.36 .176 .422 23	-0.65 37.03 -.208 .340 23	0.25 16.58 .293 .238 10	0.60 31.15 .663 .000 24	1.04 51.56 .618 .001 24	0.57 22.92 .382 .065 24	-0.63 43.69 -.091 .672 24	0.26 33.93 .199 .351 24	0.41 36.60 .414 .044 24	0.05 14.61 .284 .324 14	0.59 54.68 .609 .002 24	0.56 48.01 .560 .004 24	-0.03 8.31 .070 .829 12	1.23 26.16 .284 .189 23
Port 2 % R vs Time	m b r a n	1.45 16.33 .819 .000 24	1.48 20.02 .765 .000 24	1.46 14.62 .835 .000 24	0.40 36.01 .525 .010 23	-0.52 44.67 -.068 .757 23	-0.14 37.65 .067 .835 12	0.85 1.09 .795 .000 24	1.97 -4.47 .771 .000 24	0.84 -28.13 .163 .458 23	1.98 -137.85 .056 .800 23	0.40 -11.33 .156 .477 23	1.88 -50.92 .420 .046 23	0.29 -4.59 .895 .016 6	1.69 -6.59 .850 .000 23	1.69 -16.86 .780 .000 23	0.43 -4.11 .411 .064 21	0.44 -0.28 .294 .174 23
Port 5 % R vs Time	m b r a n	1.90 -12.40 .829 .000 24	2.48 -30.39 .645 .001 24	1.77 -12.00 .772 .000 24	1.07 -57.68 .188 .403 22	-0.11 -9.52 -.075 .728 24	-0.50 32.08 -.175 .587 12	1.37 -12.02 .639 .001 24	1.57 11.44 .767 .000 23	0.20 23.83 .292 .273 16	1.06 -19.48 .427 .054 21	0.51 -6.81 .306 .249 16	0.96 6.02 .789 .000 21	0.25 -3.62 .421 .173 12	1.42 -13.96 .734 .000 21	1.37 -1.69 .887 .000 21	0.15 0.36 .310 .261 15	0.45 10.07 .393 .078 21
All Ports % R vs S.V.	m b r a n	-133.34 84.61 -774 .000 60	-162.11 94.67 -690 .000 60	-122.89 79.00 -702 .000 60	-95.83 44.13 -.394 .003 56	-9.98 15.98 -.046 .733 58	-23.20 43.32 -.118 .499 35	-89.65 53.15 -.630 .000 60	-123.51 86.78 -.609 .000 59	-44.32 27.66 -.164 .246 52	-129.14 10.86 -.167 .218 56	-58.64 29.20 -.251 .073 52	-83.23 42.24 -.353 .008 56	-27.98 14.47 -.513 .009 25	-126.75 71.51 -.721 .000 56	-111.44 65.29 -.663 .000 56	-22.53 11.66 -.344 .032 39	-28.32 17.92 -.117 .393 55
All Ports % R vs ln S.V.	m b r a n	-33.22 -10.53 -.827 .000 60	-38.78 -17.97 -.708 .000 60	-31.97 -11.21 -.784 .000 60	-20.30 -17.84 -.357 .007 56	-0.12 13.25 -.002 .986 58	-6.53 25.13 -.151 .387 35	-23.28 -12.50 -.701 .000 60	-34.42 -8.44 -.725 .000 59	-15.21 -12.00 -.262 .060 52	-31.21 -79.04 -.179 .187 56	-16.21 -15.59 -.324 .020 52	-24.61 -24.36 -.463 .000 56	-7.82 -6.36 -.570 .003 25	-31.58 -18.54 -.796 .000 56	-28.60 -15.50 -.754 .000 56	-5.10 -3.42 -.315 .051 39	-11.11 -9.86 -.211 .122 55

TABLE 13

REGRESSION EQUATION RESULTS FOR ALUM
COAGULATED AND SETTLED STORMWATER RUNOFF

Port 1 % R vs. Int	m	b	r	n	RTSS	RVSS	RVSS	RVSS	RCOD	RTKN	RIHI	RTDC	RTP	RZN	RCd	RIHI	RCu	RMd	PIR	RPh	RCr	RCd
					25.91	26.64	25.68	25.68	10.38	14.67	14.50	16.78	29.47	13.35	1.68	12.48	14.28	5.13	21.63	19.73	1.77	15.21
					-1.68	3.80	-5.40	-5.40	.418	.054	.438	-1.58	-5.58	-0.81	19.51	4.13	5.15	0.05	6.37	4.07	2.26	-32.59
					.908	.907	.859	.859	.047	.808	.069	.849	.811	.436	.041	.301	.540	.491	.927	.752	.188	.282
					.000	.000	.000	.000	.000	.000	.000	.000	.000	.033	.850	.154	.006	.075	.000	.000	.560	.192
					23	23	23	23	22	22	17	23	23	23	23	23	23	13	23	23	11	22
Port 3 % R vs. Int	m	b	r	n	24.29	26.10	23.56	23.56	13.72	4.64	5.32	14.95	27.31	2.99	-1.38	1.16	11.30	3.01	20.62	18.23	4.94	4.54
					-14.46	-15.10	-14.02	-14.02	5.27	15.96	16.09	-12.75	-28.60	-14.75	-74.49	-4.65	-33.47	-5.14	-21.56	-24.49	-6.49	-2.52
					.814	.789	.809	.809	.663	.126	.133	.707	.709	.057	.007	.412	.229	.698	.738	.632	.364	.209
					.000	.000	.000	.000	.001	.567	.670	.000	.000	.796	.974	.852	.294	.123	.000	.001	.105	.339
					23	23	23	23	22	22	11	23	23	22	22	22	22	5	22	22	20	22
Port 5 % R vs. Int	m	b	r	n	23.96	27.94	21.85	21.85	3.61	-4.11	1.46	16.59	23.73	7.47	7.91	5.63	13.73	1.77	15.99	18.07	2.46	8.95
					-20.62	-41.54	-25.91	-25.91	-20.85	-0.49	13.35	-21.63	-14.22	5.66	-11.62	-0.03	-7.17	-2.50	-18.86	-14.89	-2.30	-3.58
					.716	.526	.654	.654	.070	.106	.751	.541	.710	.345	.253	.254	.705	.303	.604	.782	.329	.431
					.000	.008	.001	.001	.758	.622	.828	.006	.000	.191	.269	.343	.000	.338	.004	.000	.231	.051
					23	23	23	23	21	23	11	23	22	15	20	15	20	11	20	20	14	20
All Ports (% R)-1 vs SV	m	b	r	n	-0.01	0.02	1.10	1.10	-2.73	2.00	18.51	17.14	-0.02	-0.31	25.67	21.17	-0.06	0.09	0.15	0.04	-2.27	-7.32
					0.01	0.01	3.08	3.08	7.81	1.24	7.28	-0.85	0.02	0.13	-0.55	-0.85	0.03	0.20	-0.03	-0.05	3.30	3.50
					.018	.077	.015	.015	.026	.037	.133	.228	.076	.135	.258	.235	.123	.034	.127	.016	.036	.125
					.892	.557	.911	.911	.851	.783	.445	.079	.568	.341	.055	.093	.366	.872	.353	.907	.830	.363
					59	59	59	59	55	57	34	59	58	51	55	51	55	24	55	55	38	54

TABLE 14

REGRESSION EQUATION RESULTS FOR FERRIC
CHLORIDE COAGULATED AND SETTLED STORMWATER RUNOFF

	RTSS	RVSS	RHSS	RCOD	RTKN	RNIH	RTDC	RTP	RZn	RCd	RNi	RCu	RMq	RFe	RPb	RCr	RCa
Port 1 m	0.19	0.17	0.19	-0.53	-0.67	-0.94		0.52	-0.10	-0.06	-0.18	0.07	-0.03		0.05	-0.01	0.23
% R vs. r	83.63	82.77	84.19	8.37	17.08	5.36		75.22	37.20	68.60	12.99	49.65	20.57		77.96	6.01	32.35
Time a	.525	.521	.528	-.516	-.304	-.875		.646	.612	-.126	-.172	.602	.494		.573	.458	.249
n	.284	.289	.282	.295	.558	.023	0	.166	.272	.840	.782	.283	.397	0	.312	.438	.687
	6	6	6	6	6	6		6	5	5	5	5	5		5	5	5
Port 2 m	0.30	0.31	0.29	0.49	0.34	-0.31		0.19									
% R vs. r	78.04	78.32	79.35	-54.70	-24.16	5.52		68.13									
Time a	.573	.581	.569	.022	.395	-.643		.403									
n	.234	.227	.238	.967	.438	.168	0	.331	0	0	0	0	0	0	0	0	0
	6	6	6	6	6	6		6									
Port 5 m	0.59	0.55	0.61	-0.10	0.04	-0.94		1.05	-1.60	-0.13	-0.04	0.72	-0.20		0.79	-0.34	0.13
% R vs. r	67.96	69.17	67.18	44.49	-10.91	5.36		51.49	6.51	53.51	9.00	21.30	9.36		36.43	3.48	12.61
Time a	.636	.619	.646	.279	-.100	-.875		.696	-.912	.352	.221	.746	-.484		.724	-.948	.506
n	.175	.190	.165	.593	.850	.023	0	.124	.031	.562	.721	.148	.409	0	.167	.014	.385
	6	6	6	6	6	6		6	5	5	5	5	5		5	5	5
All Ports m	-52.16	-50.30	-53.53	56.39	-22.35	39.15		-26.21	-36.23	13.05	1.40	-57.86	-12.68		-75.69	-0.53	-23.76
% R vs. a	98.18	97.36	98.84	-15.57	1.16	-21.72		100.25	10.67	43.87	7.53	59.33	14.27		85.75	0.22	26.81
S.V. n	-.879	-.860	-.886	.311	-.170	.474	0	-.832	-.220	.280	.111	-.915	-.412		-.951	-.019	-.701
	.000	.000	.000	.258	.544	.074		.000	.601	.501	.794	.001	.311	0	.000	.964	.053
	15	15	15	15	15	15		15	8	8	8	8	8		8	8	8
All Ports m	-9.07	-8.53	-9.43	8.97	-3.80	11.73		-16.17	-13.86	6.94	1.20	-10.91	-3.57		-14.97	-1.00	-4.49
% R vs. a	68.34	68.98	67.98	15.12	-11.47	9.92		48.71	-27.29	61.71	10.41	22.69	4.32		36.34	-2.04	11.75
In S.V. n	-.655	-.626	-.669	.212	-.124	.609	0	-.669	-.342	.606	.386	-.702	-.471		-.765	-.149	-.539
	.008	.013	.006	.447	.659	.016		.006	.407	.111	.345	.052	.239	0	.027	.726	.168
	15	15	15	15	15	15		15	8	8	8	8	8		8	8	8

TABLE 15

REGRESSION EQUATION RESULTS FOR FERRIC
CHLORIDE COAGULATED AND SETTLED STORMWATER RUNOFF

	RTSS	RVSS	RNSS	RCOD	RTKN	RNH	RTOC	RTP	RZn	RCd	RNi	RCu	RMg	RFe	Rph	RCr	RCa
Port 1 m	22.06	21.56	22.39	-4.68	-3.26	-11.34		25.24	11.20	6.49	0.91	13.83	4.96		20.82	1.36	6.21
b	21.42	21.60	21.31	-7.45	8.50	12.33		13.71	4.02	18.77	3.98	6.84	3.38		11.44	1.10	5.85
% R vs r	.871	.866	.874	.342	.121	.719		.934	.931	.388	.242	.927	.872		.912	.829	.707
ln time a	.024	.026	.023	.507	.819	.108		.006	.022	.518	.695	.024	.054		.031	.082	.182
n	5	5	5	5	5	5		5	4	4	4	4	4		4	4	4
Port 3 m	22.83	22.94	22.88	-8.80	5.40	-2.15		19.73									
b	18.00	17.59	18.20	-15.14	-16.03	3.54		14.11									
% R vs. a	.901	.908	.898	.302	.216	.344		.833									
ln Time	.014	.012	.015	.561	.682	.504		.039									
n	5	5	5	5	5	5		5									
Port 5 m	25.40	25.24	25.51	7.65	-3.00	-11.34		29.31	-18.59	10.47	1.59	16.38	-0.19		21.20	-3.67	5.49
b	8.57	9.21	8.16	17.15	-1.28	12.33		-4.97	14.22	16.11	2.69	-5.16	3.79		-2.52	4.02	0.26
% R vs. a	.921	.912	.926	.519	.383	.719		.900	.715	.723	.635	.764	.052		.896	.730	.758
ln Time	.009	.011	.008	.292	.453	.108		.014	.175	.168	.250	.053	.933		.040	.162	.137
n	5	5	5	5	5	5		5	4	4	4	4	4		4	4	4
All m	0.01	0.01	0.01	42.94	-34.25	49.33		0.07	-0.11	-0.01	-0.08	-1.25	0.27		0.10	0.83	0.15
b	0.01	0.01	0.01	2.77	21.71	7.85		0.00	0.01	0.03	0.17	0.16	-0.00		0.00	-0.11	0.03
Ports -1 r	.847	.838	.852	.302	.241	.295		.791	.677	.319	.317	.894	.655		.904	.419	.910
(% R) a	.000	.000	.000	.274	.388	.286		.000	.065	.442	.444	.003	.078		.002	.302	.002
vs. SV n	14	14	14	14	14	14		14	7	7	7	7	7		7	7	7

No outstanding correlations were achieved for detention treatment only. Trends were seen in the removal of total phosphorus, total suspended solids and total organic carbon. The highest (r) value encountered for all parameters was 0.639 found for total phosphorus removal versus \ln time at port 1. Correlations were poor for this same parameter versus \ln time at port 5.

The "best" regression equations were selected on the basis of the alpha value being less than 0.05 and the highest correlation coefficient. Percent removal as a function of \ln time was the "best" regression equation for solids, COD, TOC, and TP removals. $\text{NH}_3\text{-N}$ removal was most predictable as a function of settling velocity (sv). No correlation could be made for the parameters: Ni, Ca, TKN, Zn, Cd, Cu, and Mg.

The regression analysis results for alum treated and detained stormwater are listed in Tables 12 and 13. Correlation coefficients are much higher in these tables compared to detention treatment alone.

The highest correlation coefficient encountered was 0.908 for the percent TSS removed as a function of \ln time with an alpha value of 0.000. Many of the parameters experienced very low alpha values, less than 0.05. For solids removal the "best" regression equation probably involved \ln of the settling velocity, but very good correlations also occurred for time, \ln time and settling velocity.

Total phosphorus was another important parameter which showed very good correlations to nearly all variables. Best correlations probably occur for percent removal versus \ln of time.

Good correlations were found for almost all parameters evaluated for at least one of the variables. Poor correlations were found for the parameters TKN, Zn, Cd, and Ci which would indicate poor or variable removal rates using alum.

All regression equations for alum appear to be somewhat predictive of the various water quality parameter removal conditions except for the equations involving the inverse of the percent removal versus settling velocity.

The regression analysis results for the ferric chloride treated and settled stormwater are listed in Tables 14 and 15. The results from these tables are similar to those found for alum. Solids reduction can best be described by the equation involving percent removal versus \ln of time, although good correlations also existed for settling velocity. The highest correlation coefficient for solids was 0.926 with an alpha value of 0.008 which occurred at the percent removal versus \ln time at port 5.

Good phosphorus correlations occurred at all variables with the "best" fit being percent removal versus \ln of time. The parameters TKN and $\text{NH}_3\text{-N}$ showed the lowest correlations. The lack of data limited the statistical analysis for the ferric chloride treated column study.

A comparison involving detention treatment only with alum treated and detained stormwater runoff on the mass loadings to Lake Eola are listed in Table 16. It was estimated that 1.4×10^8 gallons of stormwater runoff reaches Lake Eola each year based on estimates for rainfall, contributing surface areas, land uses, and percent impervious surfaces (Taylor 1980).

The "best" fit regression analysis equation based on a 3.0 foot basin at 60 minutes of settling time for both treatment methods was used to determine removal efficiencies and are also listed in Table 16. From these equations, percent removal rates can be calculated and the overall mass loadings can be found.

Detention of stormwater alone produces good reductions in several parameter loadings including TSS, COD, TOC and Pb compared to the untreated mass loadings. Total phosphorus is only reduced 137 pounds per year by detaining stormwater runoff in a 4.5 foot basin for 60 minutes.

Alum treatment reduces the mass loadings of many parameters substantially. All parameters except TKN, NH_3 , Cd, Ni, and Ca were reduced. Total phosphorus was reduced from 598 pounds per year to 32 pounds per year which corresponds to a 95 percent reduction.

TABLE 16

COMPARISON OF DETENTION ONLY AND ALUM COAGULATION
AND DETENTION FOR THE IMPROVEMENT OF LAKE EOLA STORMWATER

Stormwater Variable	Average Initial Concentration	Detention Only		Alum Coagulation and Detention		% Re	Δ % Re	Δ Conc.: Re	Untreated Mass Loading lbs/yr	Detention Mass Loading lbs/yr	Alum Coagulation and Detention Mass Loading lbs/yr
		Best Regression Equation % Removal	% Re	Best Regression Equation	% Re						
TSS	80 mg/l	12.41 lnt + 1.58	52.4	-33.22 lnsv - 10.53	89.0	36.6	53.4 mg/l	93,160	72,292	10,247	
VSS	46 mg/l	10.38 lnt + 5.04	48.3	-38.78 lnsv - 17.97	98.4	49.9	44.9 mg/l	53,584	28,643	4,152	
WVSS	34 mg/l	13.85 lnt - 2.68	62.6	-31.97 lnsv - 11.21	84.6	22.0	42.3 mg/l	39,576	14,801	6,095	
COD	74 mg/l	7.92 lnt - 9.05	23.4	13.72 lnt + 5.27	61.4	38.0	64.2 mg/l	86,224	66,048	33,282	
TK11-H	3.3 mg/l							3,876	3,876	3,876	
NH ₃ -H	0.43 mg/l	-9.91 lnsv - 0.25	21.4					503	396	503	
TOC-C	99 mg/l	7.51 lnt - 0.09	30.7	-23.23 lnsv - 12.50	57.1	26.4	36.9 mg/l	114,920	79,634	4,930	
TP-P	0.50 mg/l	0.32 t + 3.21	22.4	-34.42 lnsv - 8.44	94.7	72.3	0.7 mg/l	598	461	32	
Zn	0.33 g/l			-15.21 lnsv - 12.00	33.6	33.6	188 g/l	449	449	298	
Cd	0.03 g/l							34	34	34	
Hf	.03 g/l			-16.21 lnsv - 15.59	33.0	33.0	13 g/l	34	34	23	
Cu	.07 g/l			-24.61 lnsv - 24.36	49.4	49.4	44 g/l	83	43	27	
Hg	1.03 g/l			- 7.32 lnsv - 6.36	15.6	15.6	217 g/l	1,197	1,197	1,010	
Fe	0.99 g/l	-10.06 lnsv - 53.02	0.40	-31.58 lnsv - 18.54	76.2	75.8	1103 g/l	1,156	694	275	
Pb	0.44 g/l	0.12 t + 12.95	20.15	-28.60 lnsv - 15.50	70.2	50.1	463 g/l	517	413	155	
Cr	0.03 g/l	-32.00 sv + 7.96	6.36	-22.53 sv - 11.66	55.0	49.6	16 g/l	30	29	14	
Ca	32.1 mg/l							37,400	37,400	37,400	

Isoconcentration Lines -

Isoconcentration lines were developed for total suspended solids and total phosphorus removal for all four treatment methods. The method for constructing these lines is outlined by W. Weber in his book Physicochemical Processes for Water Quality Control (1972).

Due to variations in type, nature, and concentration of solids involved, no one theory can be used to describe all water and wastewater settling. Interaction between particles and their possible agglomeration all effect settling characteristics. Most settling in water and wastewater is of the flocculant type (Zanoni 1975).

It is not possible to predict the performance of sedimentation basins for wastewater applications from theoretical relationships. The fact that interparticle contact occurs during the settling of flocculant suspensions makes it necessary to perform a settling test to determine the performance of a settling basin (Zanani 1975).

The general formula for the development of isoconcentration lines is given by:

$$R = R_o + \frac{h_1}{h_o} \Delta R_1 + \frac{h_2}{h_o} \Delta R_2 + \frac{h_3}{h_o} \Delta R_3 + \dots$$

Where

R = total % removal

R_o = % removal given by the isocentration line intersecting height " h_o ", which is the depth of the basin

h_1, h_2, h_3 , etc. are the average heights between the isoconcentration lines directly above ideal basin detention time.

$\Delta R_1, \Delta R_2, \Delta R_3$, etc. are the differences between the values of the isoconcentration line above and below h_1, h_2, h_3 , etc.

Isoconcentration lines developed for the four treatment methods are listed in Tables 17 through 24. The scales of all the graphs are equal except for the TSS and TP removals by sedimentation which uses 120 minutes compared to 60 minutes of settling time for the remaining curves.

Figures 17 and 18 depict TSS and TP removals respectively for settled stormwater runoff. Removal of TSS approaches 60 percent after 120 minutes of settling at the 5 foot depth. Total phosphorus removals are slightly less, reaching 40 percent removal after 120 minutes at the 5 foot depth.

Figures 19 and 20 depict TSS and TP removals for alum coagulated and settled stormwater. Removal efficiencies are substantially increased over sedimentation alone. Removals for TSS approach 90 percent after 60 minutes of settling at the 5 foot depth with TP removals reaching 90 percent after only 30 minutes of settling at the 5 foot depth.

Ferric chloride treatment results for TSS and TP removals are depicted in Figures 21 and 22, respectively. Ferric chloride showed the highest TSS removals of all the treatment

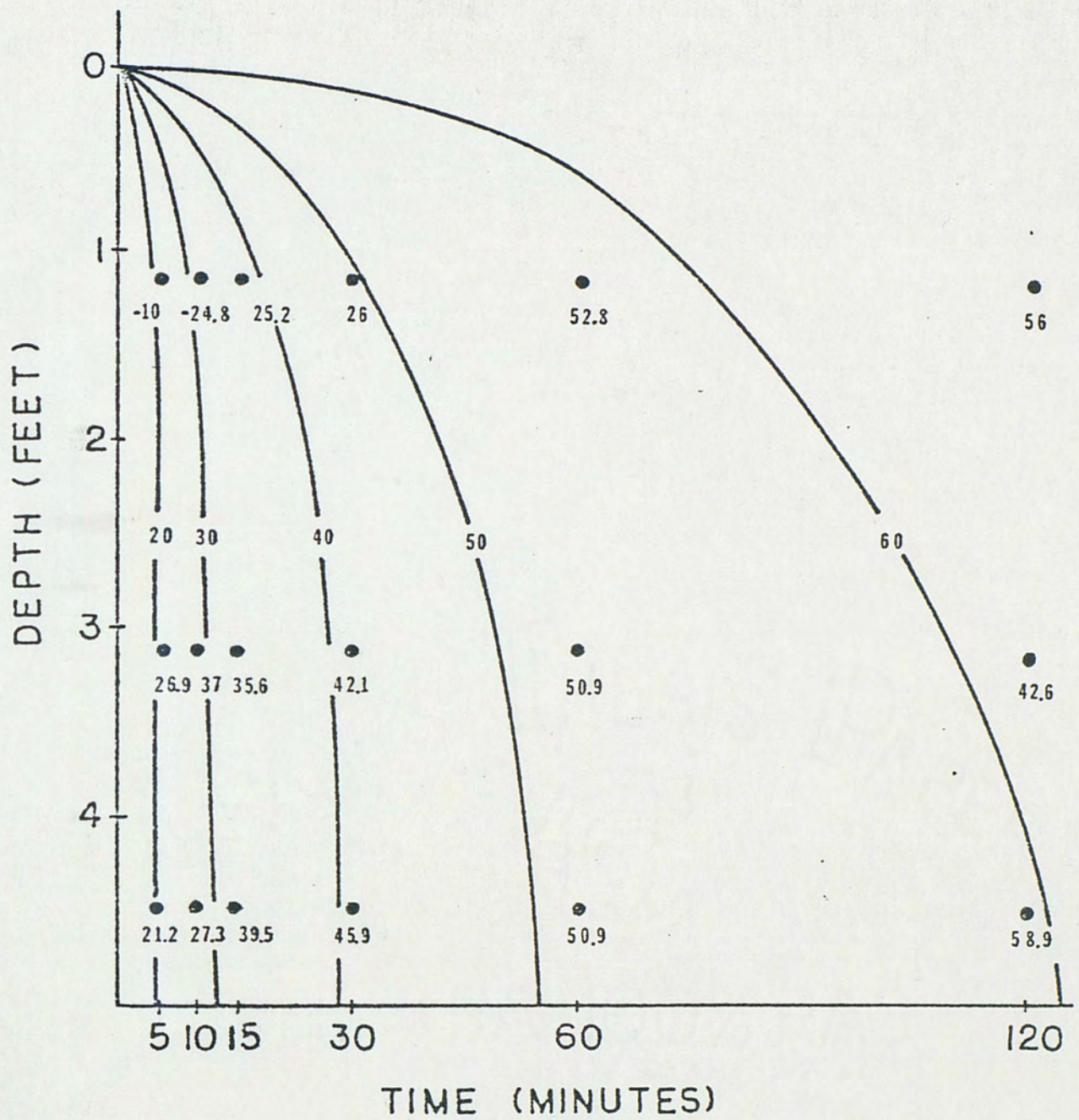


Fig. 17. Isoconcentration lines for suspended solids removal for settled stormwater runoff.

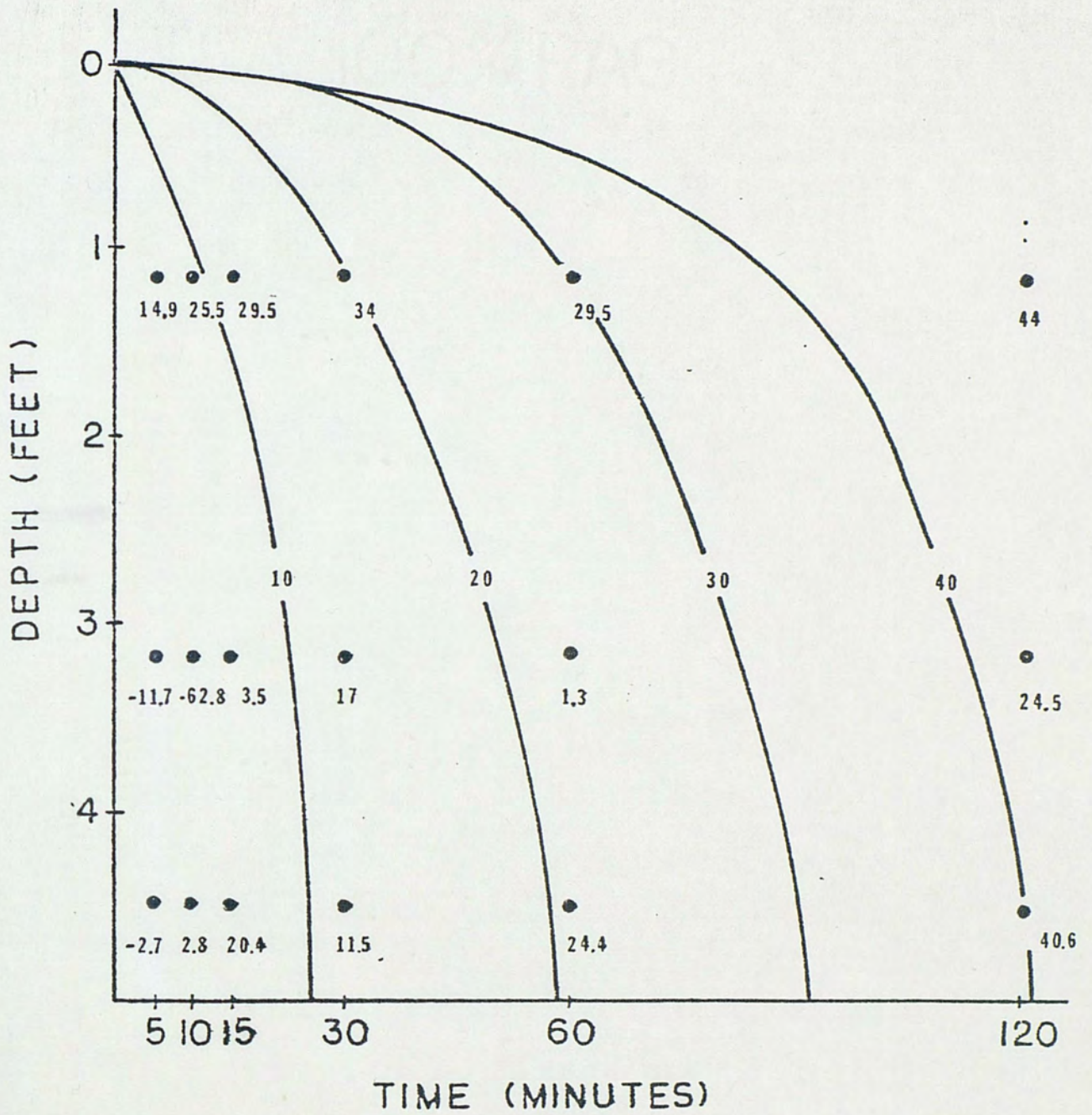


Fig. 18. Isoconcentration lines for total phosphorus removal from settled stormwater runoff.

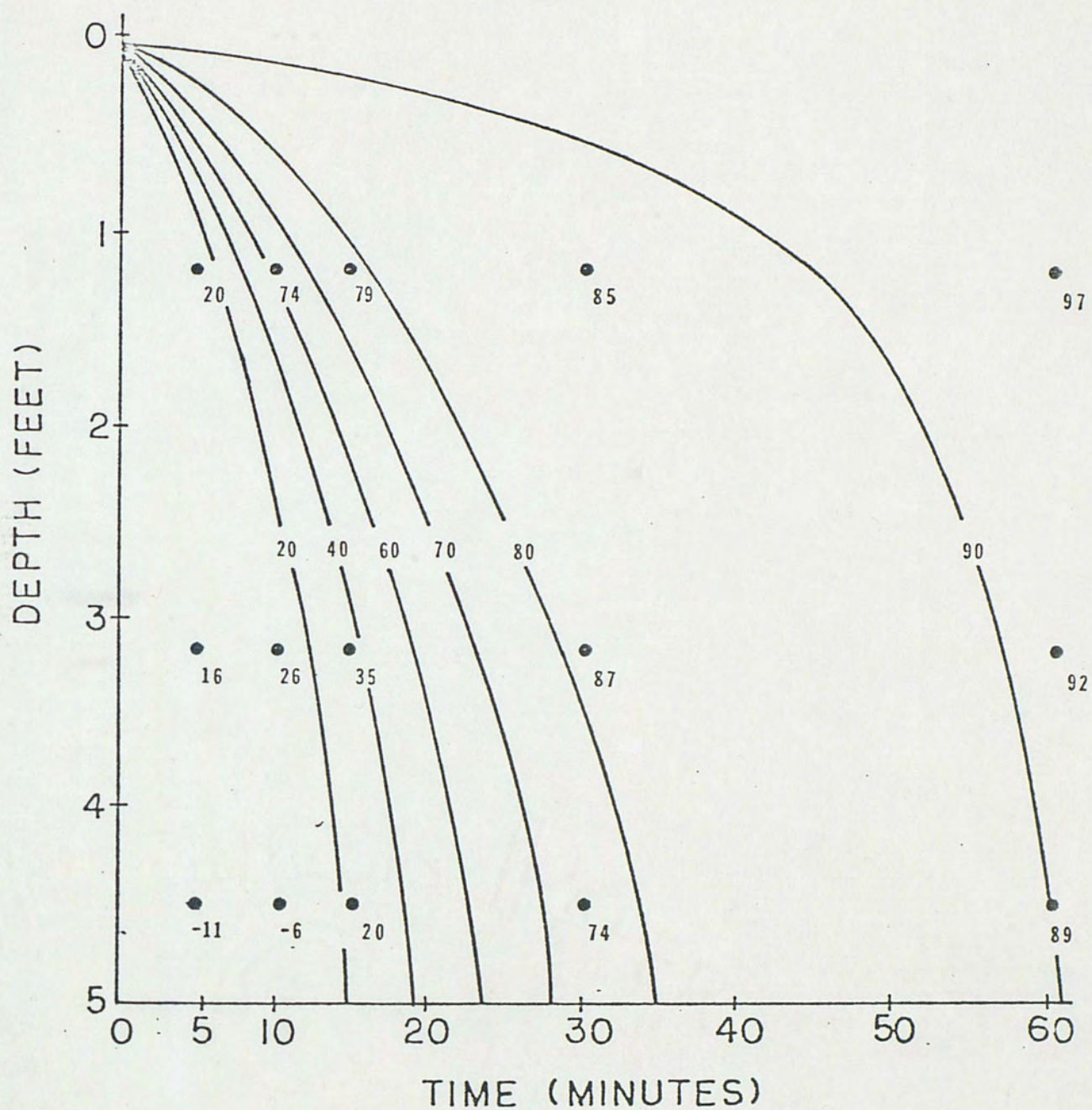


Fig. 19. Isoconcentration lines for total suspended solids for alum coagulated and settled stormwater runoff.

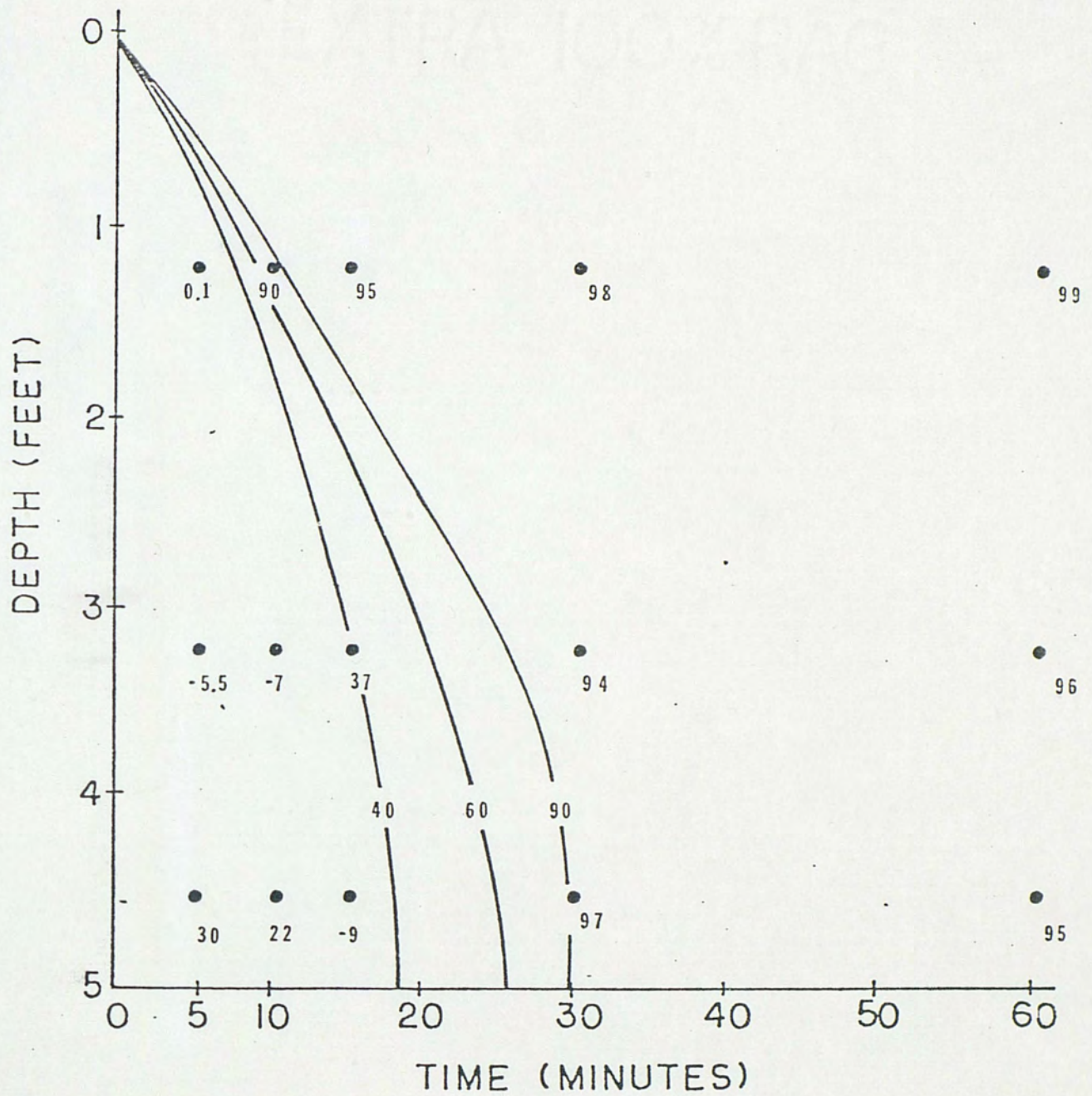


Fig. 20. Isoconcentration lines for total phosphorus removal for alum coagulated and settled stormwater runoff.

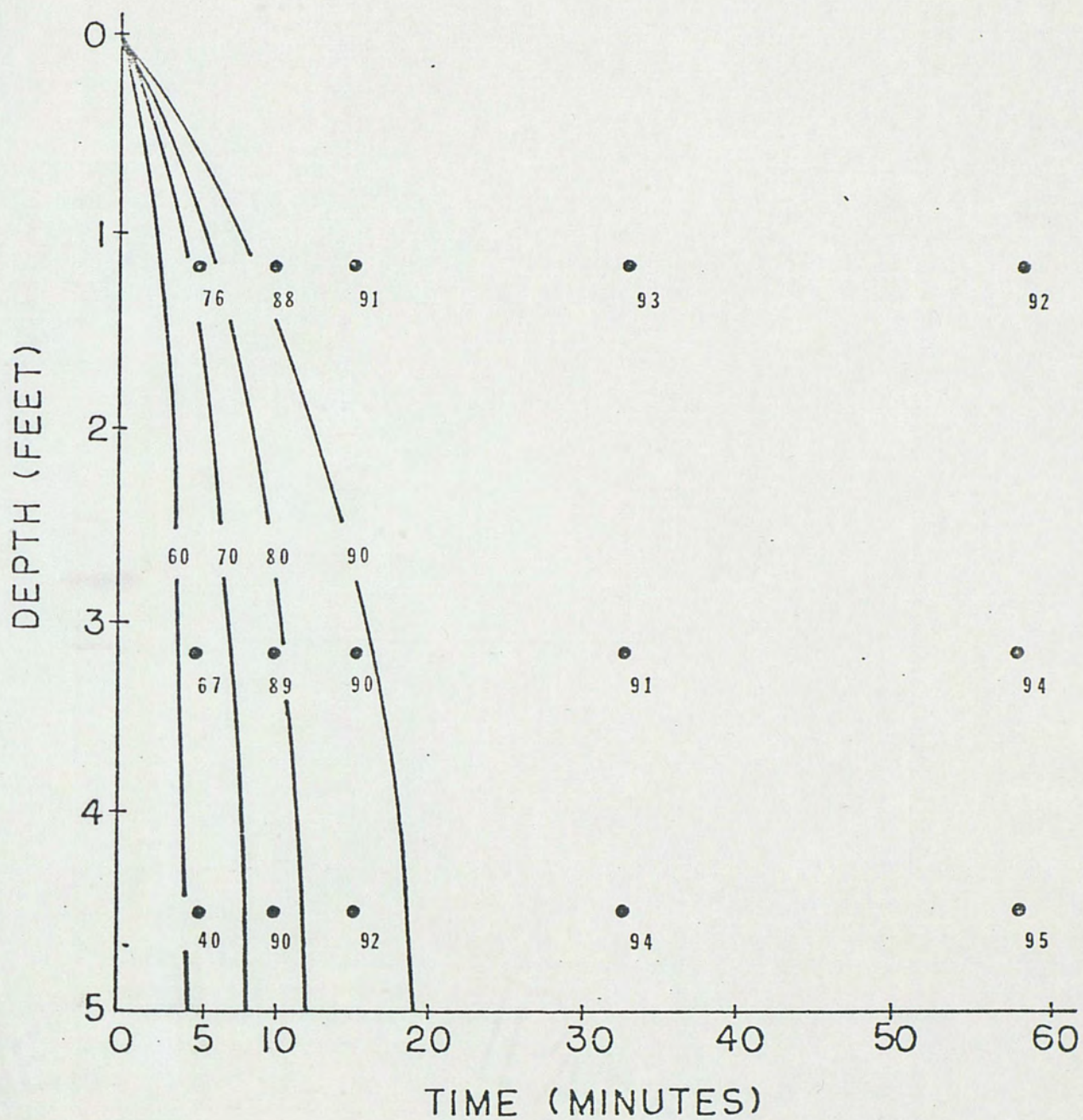


Fig. 21. Isoconcentration lines for total suspended solids removal for ferric chloride coagulated and settled stormwater runoff.

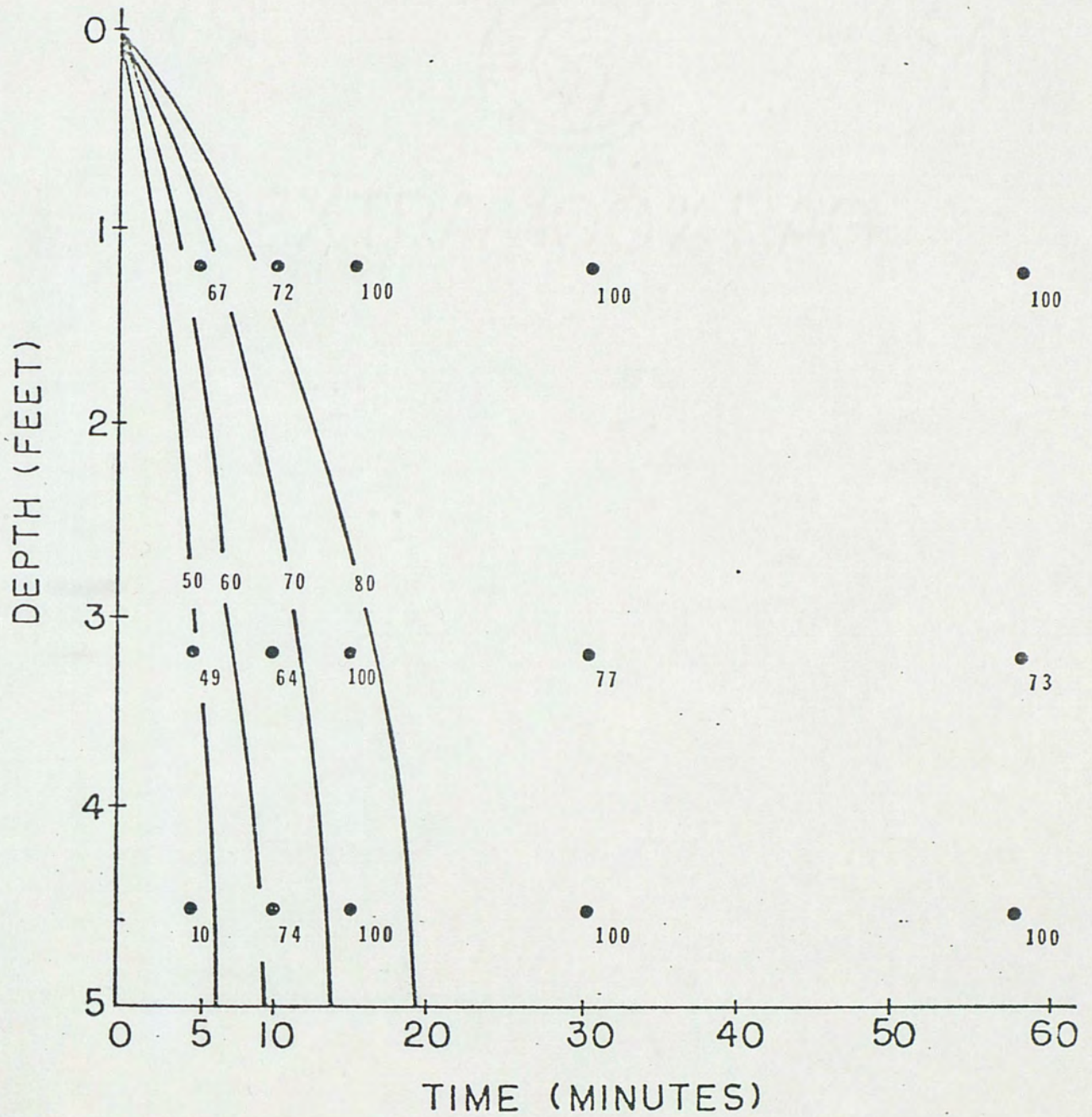


Fig. 22. Isoconcentration lines for total phosphorus removal for ferric chloride coagulated and settled stormwater runoff.

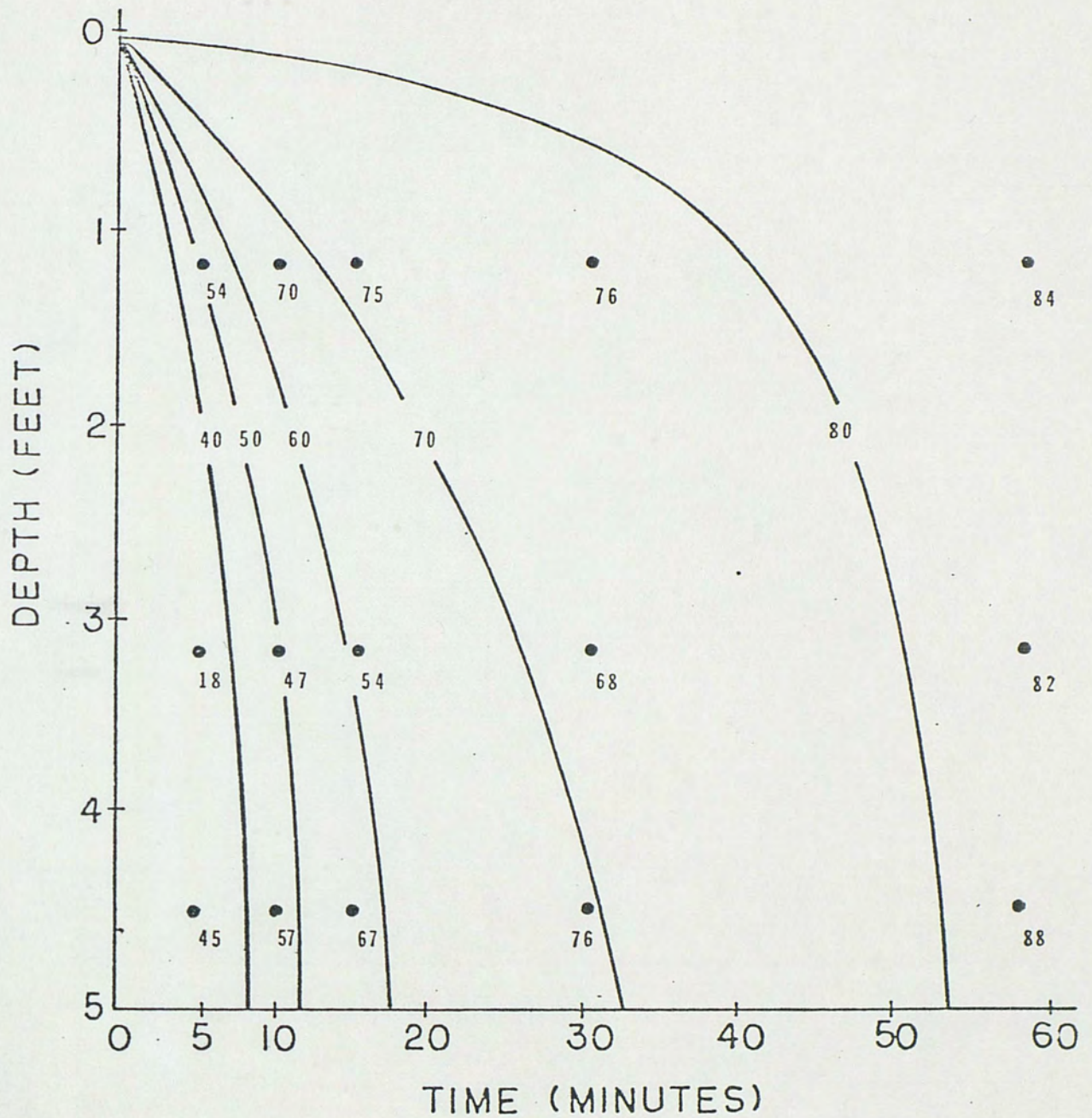


Fig. 23. Isoconcentration lines for total suspended solids removal for lime coagulation and settled stormwater runoff.

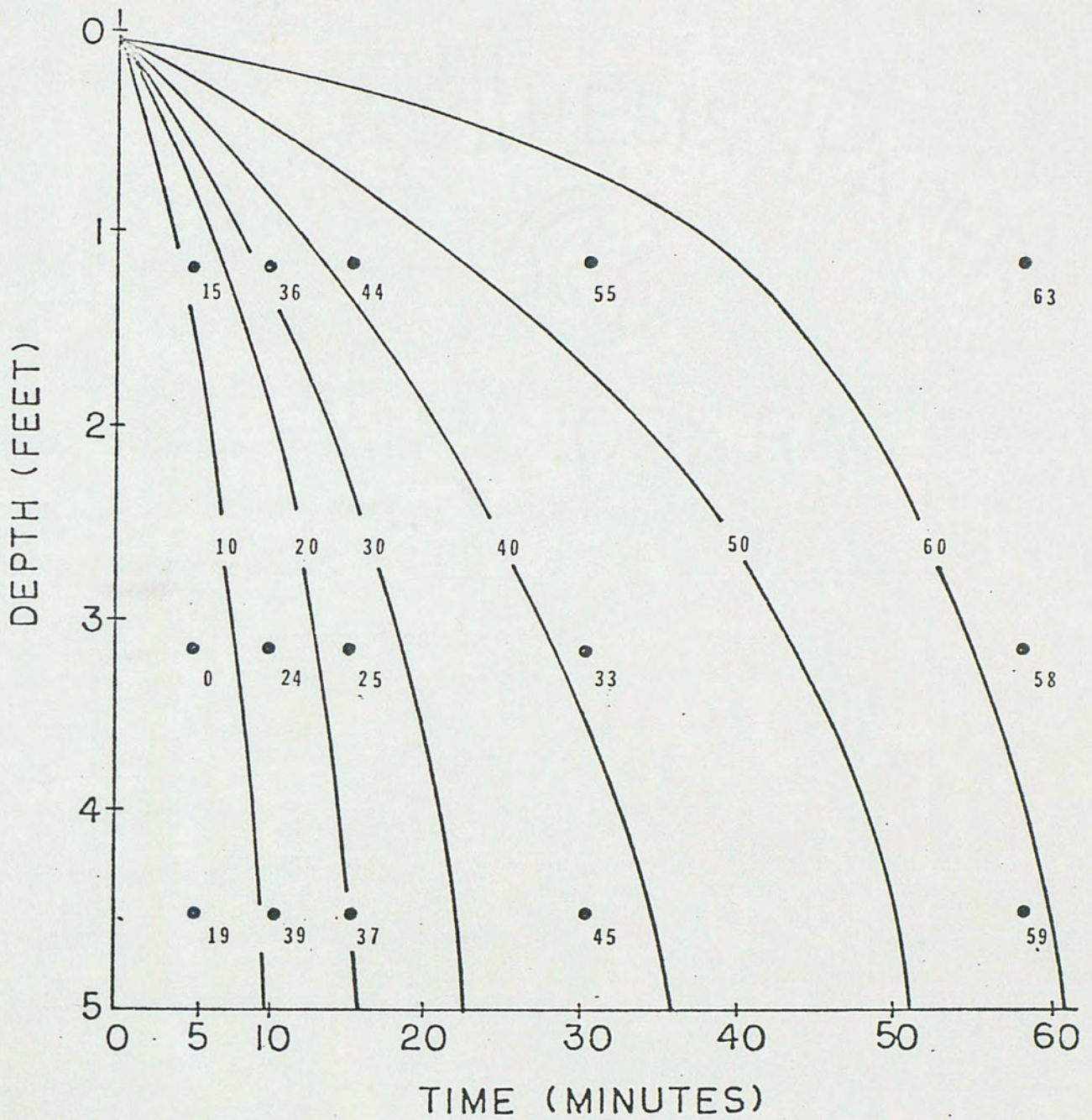


Fig. 24. Isoconcentration lines for total phosphorus removal for lime coagulated and settled stormwater runoff.

methods. TSS removals approached 90 percent after 20 minutes of settling at the 5 foot depth. Total phosphorus removal rates were also very good with variable percent removals occurring at port 3. TP removals were approximately 80 percent after 20 minutes of settling at the 5 foot depth.

Lime treatment of TSS and TP are depicted in Figures 23 and 24, respectively. These removal rates were much less than alum or ferric chlorided treated stormwater but are greater than sedimentation alone. TSS reductions approached 80 percent after about 55 minutes of settling at the 5 foot depth.

A comparison of the two analysis methods are listed in Table 17. This table lists the removal efficiencies for total suspended solids and total phosphorus predicted by the isoconcentration lines and by regression analysis. The comparison involves the data for the alum coagulated and detained stormwater runoff.

The regression equations utilized for the two water quality parameters are listed in Table 16. The results for the isoconcentration line method are from Appendix C which calculates an example problem using the generated data for a 4.5 foot deep basin.

From Table 16, the isoconcentration line method predicts slightly higher removal rates for TSS and much high removal rates for short settling times involving TP than the regression analysis method. The accuracy of the isoconcentration line

TABLE 17

COMPARISON OF TSS AND TP REMOVAL BY REGRESSION
ANALYSIS AND ISOCONCENTRATION LINES INVOLVING
ALUM TREATED AND SETTLED STORMWATER RUNOFF

Settling Time (min)	Settling* Velocity (Ft/min)	% TSS REMOVAL		% TP REMOVAL	
		Isoconcentration lines	Regression Analysis	Isoconcentration lines	Regression Analysis
10	0.45	26	16	40	19
15	0.30	42	30	60	33
20	0.225	68	39	80	43
30	0.15	85	53	90	57
40	0.1125	88	62	90 +	67
60	0.075	90	76	90 +	81

97

* Based on a 4.5 feet basin

- NOTE: 1. Regression analysis results were taken from the equations listed on Table 16
2. Isoconcentration results were found from an example problem listed in Appendix C.

method to predict overall removal rates at a specific time is dependent on the number of lines constructed on the graph. More isoconcentration lines are needed for the total phosphorus removal figure to improve its accuracy.

The regression analysis equations are more accurate due to the greater number of data points and the various equations tested. These equations tend to be conservative when compared to the isoconcentration line method which may be more useful in design considerations.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The purpose of the column studies was to examine the changes in urban stormwater runoff quality due to various treatment alternatives. Detention of stormwater runoff in a man-made column was evaluated along with chemical treatment involving the addition of alum, ferric chloride, and lime to determine their effectiveness in reducing various water quality parameters. The main emphasis of the research involved removal of phosphorus from urban runoff. From the results obtained from the column studies the following conclusions were reached:

1. The quality of stormwater runoff samples collected for this project appear to be consistent with values found nationally and also from previous Lake Eola studies.
2. Detention of stormwater runoff in the column for 120 minutes resulted in the average total suspended solids (TSS) removal of approximately 55 percent and average total phosphorus (TP) removals of approximately 30 percent.
3. Detention of stormwater runoff was not found to be effective in removing significant concentrations of heavy metals.

4. The addition of 240 mg/l of alum at a pH of 5.5 to the column along with 60 minutes of settling resulted in the removal of approximately 94 percent total suspended solids (TSS) and 92 percent total phosphorus (TP).
5. Alum treatment of urban stormwater runoff removed to some degree all heavy metal concentrations encountered.
6. The addition of 80 mg/l of ferric chloride at a pH of 5.0 to the column with 60 minutes of settling time would result in total suspended solids (TSS) removals of about 95 percent and total phosphorus (TP) removals of about 92 percent.
7. Ferric chloride treatment was effective in reducing the majority of heavy metals encountered in urban runoff.
8. Lime treatment of urban runoff with 60 minutes of settling showed similar total suspended solids (TSS) removals as that found for detention treatment alone for 120 minutes of settling.
9. Lime treatment with detention of urban runoff at a pH of 11.5 resulted in total phosphorus removals of approximately 55 percent.
10. Lime treatment with detention showed no significant removals for heavy metals.

11. Regression analysis is a useful method in predicting water quality parameter removal rates as a function of settling velocity and time.
12. Good correlations were found for the regression equations involving alum and ferric chloride treated stormwater for nearly all water quality parameters tested.

In terms of phosphorus removal, it is found that phosphorus binds readily with common coagulants such as calcium, iron, and aluminum to form relatively insoluble compounds. Calcium compounds are of limited use in lake environments because of its ineffectiveness below pH 9. Anoxic conditions in the hypolimnion of eutrophic lakes would reduce iron compounds to the soluble state if added directly to a lake. This addition might then aggravate rather than alleviate the problem of phosphorus concentrations (Funk 1979).

It appears that aluminum compounds, namely alum, are a widely used and effective treatment method for phosphorus removal and inactivation. Various treatment method designs could be used to effectively reduce many water quality parameters from urban stormwater runoff before discharge to Lake Eola.

APPENDIX A

LAKE EOLA COLUMN STUDY RESULTS

LAKE EOLA COLUMN STUDY # 1

STORM DATE: 4/5/79
 SAMPLE LOCATION: School
 TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted										all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NI ₃ -N	TOC-C	TP-P			Zn	Cd	As	Ni	Cu	Mn	Fe	Pb	Ca	Cr
1.17	0	-	154	136	18		17.6	2.8	515	3.3			945	12	110	138	196	X	2730	1580	53.0	80
3.17	0	-	142	126	16		17.9	1.7	505	3.3				19			187	6325	3650	2240	49.2	73
4.50	0	-	120	108	12		17.4	1.7	540	2.9			935	23	137	79	188	X	3605	1920	53.0	98
1.17	5	0.23	112	102	10		18.2	1.4	524	2.1				15	88		149	4970	1830	1555	40.6	59
3.17	5	0.63	110	98	12		19.0	1.7	514	2.8			835	11	37	54	144	X	2910	1770	53.0	48
4.50	5	0.90	160	138	22		18.8	1.4	496	3.3			975	15	89	72	175	X	3555	2040	52.5	67
1.17	10	0.12	728	716	12		24.6	1.7	496	2.8			750	3	240	67	168	X	2675	1780	60.1	64
3.17	10	0.32	176	152	20		19.9	0.9	511	2.8			745	9	118	59	134	X	2320	1480	49.8	53
4.50	10	0.45	124	112	12		---	1.7	469	1.8			785	9	45	63	156	X	2195	1440	51.0	60
1.17	15	0.08	106	102	4		18.8	0.9	596	1.9			780	11	106	83	128	6300	2030	1400	48.7	63
3.17	15	0.21	142	124	18		21.0	1.4	564	2.2				10			178	6250	2365	1715	46.2	59
4.50	15	0.30	172	158	14		17.6	1.1	446	2.2			820	6	44	75	182	X	3410	2835	60.1	66
1.17	30	0.04	136	119	17		14.5	1.4	412	2.0			700	4	12	68	154	X	2085	1510	56.6	67
3.17	30	0.11	168	104	52		16.5	1.7	419	2.1			685	3	0	55	161	X	2270	1605	58.1	48
4.50	30	0.15	132	120	12		17.9	0.6	392	2.1			725	11	17	54	130	5200	2100	1370	48.6	57
1.17	60	0.02	76	82	0		17.9	1.7	408	1.9			750	13	29	53	140	5150	1525	1150	47.6	51
3.17	60	0.05	208	176	32		16.5	1.7	488	1.9			720	8	111	635	141	X	4715	1530	58.1	850
4.50	60	0.08	128	110	18		16.8	2.0	450	2.2			755	16	59	61	222	5250	2100	1460	48.8	58
1.17	120	0.01	114	96	18		19.9	0.9	362	1.9				17			147	4940	1700	1500	39.7	53
3.17	120	0.03	144	116	28		19.3	1.4	391	2.5			785	11	0	64	163	X	2700	1815	58.6	62
4.50	120	0.04	132	128	4		17.4	1.1	405	1.2			795	19	74	63	137	5200	1865	1345	48.3	53

(1) Ca # is in mg/l

LAKE EOLA COLUMN STUDY # 2

STORM DATE: 4/25/79
 SAMPLE LOCATION: George Stuart
 TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS										
			all general water quality reported in mg/l as noted										all metals reported as the element in µg/l										
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	Li	Ca	Cr		
1.17	0	-	67.5	46	21.5	212	1.68	0	53	.26	387	8	175	61	111		1520	655	61.0	61			
3.17	0	-	77	47	30.0	263	1.40	0	77	.33	540	24	163	56	94	X	1840	870	66.0	67			
4.50	0	-	69	39	30.0	203	0.98	0	53	.32	439	10	247	60	87	X	1380	715		58			
1.17	5	0.23	68	38	30.0	235	1.54	0	46	.27	460	5	175	92	97	X	1520	765	64.0	64			
3.17	5	0.63	81	49	32.0	278	1.12	0	60	.34	333	46	705	63	164	2858	1853	932		38			
4.50	5	0.90	68	36	32	334	1.26	0	72	.38	586	41	748	70	180	2930	2212	1010		54			
1.17	10	0.12	60	36	24	226	0.98	0	46	.25	303	48	799	86	171	2882	1634	789		39			
3.17	10	0.32	66	40	26	263	1.54	0	64	.30	418	34	639	67	178	2900	3750	900		68			
4.50	10	0.45	72	36	36	305	0.98	0	76	.35	434	43	635	73	184	3055	2175	1020		54			
1.17	15	0.08	63	33	30	259	1.26	0	66	.23	363	110	1222	145	346	2965	2379	1119		136			
3.17	15	0.21	57	35	22	268	0.84	0	69	.30	366	39	587	60	156	2765	1495	786		36			
4.50	15	0.30	63	35	28	251	0.98	0	66	.31	338	32	432	56	159	2825	1905	810		36			
1.17	30	0.04	45	25	20	188	---	0	51	.19	232	28	560	56	148	2775	1195	665		40			
3.17	30	0.11	55	29	26	249	0.42	0	67	.18	355	26	284	58	144	2905	1545	815		39			
4.50	30	0.15	63	33	30	221	1.96	0	53	.21	334	24	376	76	163	2985	1540	770		39			
1.17	60	0.02	42	22	20	203	1.96	0	47	.20	332	2	236	46	90	X	954	547	63.2	67			
3.17	60	0.05	51	26	25	179	0.98	0	43	.25	197	48	820	65	147	2465	1270	640		32			
4.50	60	0.08	50	30	20	249	1.12	0	38	.22	358	36	520	63	161	2870	1200	680		37			
1.17	120	0.01	84	28	60	146	1.26	0	41	.21	157	24	426	45	123	2546	781	471		24			
3.17	120	0.03	49	27	22	287	1.40	0	77	.23	237	43	740	55	145	2625	1205	670		34			
4.50	120	0.04	45	25	20	249	0.84	0	60	.25	263	26	400	55	144	2840	1230	675		41			

(1) Ca# is in mg/l

LAKE EOLA COLUMN STUDY # 3

STORM DATE: 4/25/79

SAMPLE LOCATION: George Stuart

TREATMENT: Alum Coagulation

Dose = 240 mg/l as $Al_2(SO_4)_3 \cdot 18 H_2O$

pH = 5.5 NaOH adjusted

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted										all metals reported as the element in $\mu g/l$									
			TSS	VSS	WVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P			Zn	Cd	As	Ni	Cu	Mg	Fe	Pb(1)	Ca	Cr
1.17	0	-	171	110	60	260	1.57	0	62	.44			2149	193	1158	340	567	3701	10175	6930	X	133
3.17	0	-	152	84	68	200	1.4	0	56	.17			580	8	203	62	103		1980	680	91.7	75
4.50	0	-	170	96	74	100	1.06	0	50	.37			520	53	530	62	186	2845	1775	940	X	47
1.17	5	0.23	154	86	68	240	1.34	0	56	.28			457	3	179	48	97		1409	742	68.6	
3.17	5	0.63	167	97	70	180	0.28	0	50	.25			339	58	650	63	176	2800	1445	820	X	40
4.50	5	0.90	270	162	108	370	0.00	0	90	.12			Insufficient	Sample								
1.17	10	0.12	66	38	28	110	1.12	0	34	.08			265	72	786	88	224	2706	888	601	X	43
3.17	10	0.32	165	97	68	210	1.40	0	57	.26			497	93	1494	120	334	2854	1944	1146	X	90
4.50	10	0.45	164	100	64	260	1.12	0	71	.23			Insufficient	Sample								
1.17	15	0.08	50	28	22	100	0.28	0	31	.08			212	44	542	85	237	2604	5396	512	X	53
3.17	15	0.21	136	68	68	200	0.00	0	55	.10			2167	0	47	114	248		1530	777	72.7	117
4.50	15	0.30	153	81	72	210	1.82	0	39	---			295	51	745	55	166	2590	1250	700	X	35
1.17	30	0.04	30	14	16	70	0.45	0	26	.04			344	17	140	53	57	X	378	366	63.9	52
3.17	30	0.11	39	21	18	70	0.62	0	25	.04			344	14	267	37	51	X	382	365	58.0	51
4.50	30	0.15	30	20	10	70	0.28	0	23	.04			316	6	30	52	60	X	467	323	57.0	50
1.17	60	0.02	16	10	6	60	1.51	0	23	.01			230	59	550	54	122	2460	351	359	X	24
3.17	60	0.05	14	14	0	80	0.98	0	25	.03			Insufficient	Sample								
4.50	60	0.08	18	10	8	80	2.41	0	24	.03			289	3	74	30	50	X	332	277	56.5	41
1.17	120	0.01	---	---	---	---	---	-	---	---			---	---	---	---	---	---	---	---	---	---
3.17	120	0.03	---	---	---	---	---	-	---	---			---	---	---	---	---	---	---	---	---	---
4.50	120	0.04	---	---	---	---	---	-	---	---			---	---	---	---	---	---	---	---	---	---

(1) Ca # is in mg/l

LAKE EOLA COLUMN STUDY # 4

STORM DATE: 5/24/79

SAMPLE LOCATION: Lake Eola West

TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted										all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb(1)	Ca	Cr		
1.17	0	-	19	3	16	58.4	1.12	0.34	---	0.17	415	123	75	31	66	470	915	219	X	29		
3.17	0	-	61	43	18	54.5	1.12	0.22	19.8	0.12	414	30			80	650	1260	700	20.9	46		
4.50	0	-	79	15	64	58.4	1.46	0.22	20.0	0.13	81	4	120	12	21	97	211	29	X	5		
1.17	5	0.23	62	12	50	87.6	0.78	0.00	14.0	0.16												
3.17	5	0.63	47	33	14	48.6	1.12	0.34	19.2	0.28	137	15	24	57	69	405	705	162	X	22		
4.50	5	0.90	69	9	60	38.9	1.34	0.52	16.6	0.20	585	20	135	74	56	885	1315	408	24.6	63		
1.17	10	0.12	16	16	0	58.4	1.23	0.34	7.6	0.07	257	32	985	276	66	610	930	625	16.5	47		
3.17	10	0.32	23	23	0	48.6	0.90	0.22	---	0.26	408	12	66	37	43	795	1130	840	21.5	50		
4.50	10	0.45	72	10	62	54.5	1.46	0.45	16.0	0.20	494	16			63	705	1100	640	19.3	63		
1.17	15	0.08	36	10	26	40.9	1.01	0.34	14.4	0.14	351	17	37	33	42	730	860	279	19.2	33		
3.17	15	0.21	55	9	46	48.6	0.22	0.22	10.5	0.13	595	13	76	38	45	745	925	335	19.9	45		
4.50	15	0.30	12	10	2	99.2	1.34	0.45	17.6	0.11	600	6	184	41	52	X	1245	451	27.8	56		
1.17	30	0.04	45	3	42	48.6	0.90	0.34	12.5	0.14	184	67	1005	63	130	815	1145	435		31		
3.17	30	0.11	50	10	40	58.4	0.90	0.34	11.2	----	402	7	0	35	61	X	1040	369	24.2	44		
4.50	30	0.15	45	5	40	38.9	1.12	0.34	18.8	0.25	394	4	11	39	52	X	1070	436	24.9	61		
1.17	60	0.02	20	0	20	38.9	0.56	0.11	11.6	0.20	366	15	9	35	42	675	595	223	15.8	34		
3.17	60	0.05	21	21	0	48.6	0.39	0.00	11.7	0.23	385	17	125	34	49	750	825	288	19.0	41		
4.50	60	0.08	55	5	50	48.6	1.68	0.22	20.7	0.14	157	54	715	78	123	775	945	451		28		
1.17	120	0.01	1	1	0	29.2	2.02	0.22	10.4	0.07	272	23			75	695	855	565	15.1	43		
3.17	120	0.03	51	1	50	38.9	1.34	0.22	11.0	0.05	285	16	20	50	42	715	765	283	17.9	48		
4.50	120	0.04	15	13	2	48.6	1.01	0.34	10.1	0.05	241	13			64	710	955	510	15.7	53		

(1) Ca # is in mg/l

LAKE EOLA COLUMN STUDY # 5

STORM DATE: 5/24/79

SAMPLE LOCATION: Lake Eola West

TREATMENT: Alum Coagulation

Dose = 240 mg/l $Al_2(SO_4)_3$ 18 H₂O

pH = 5.5 NaOH adjusted

pH = 5.5 NaOH adjusted																				
GENERAL WATER QUALITY										METALS										
Port (ft)	Time (min)	Vel (ft/min)	all general water quality reported in mg/l as noted										all metals reported as the element in µg/l							
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb(II)	Ca	Cr
1.17	0	-	106	26	80	97.3	1.23	0.34	20.6	0.25	348	94		64	142	855	1470	625		34
3.17	0	-	152	40	112	155.6	1.68	0.11	18.4	0.26	740	20	52	55	65	X	1460	575	31.2	63
4.50	0	-	72	24	48	48.6	1.01	0.34	19.2	0.31		33			133	745	1315	710	20.5	54
1.17	5	0.23	88	12	76	48.6	0.67	0.00	13.5	0.4	472	21	91	31	51	X	1015	411	27.9	54
3.17	5	0.63	109	31	78	48.6	0.90	0.00	12.6	0.17	630	11	0	39	70	X	1670	625	32.6	66
4.50	5	0.90	60	22	38	38.9	2.24	0.34	7.5	0.23	605	19	8	42	68	820	1415	520	26.0	46
1.17	10	0.12	41	0	41	54.5	0.78	0.22	8.7	0.01	515	25	54	35	31	670	384	300	17.9	39
3.17	10	0.32	52	6	46	54.5	0.00	0.00	21.5	0.18	515	9	0	29	88	X	1470	515	32.4	38
4.50	10	0.45	104	78	76	68.1	1.12	0.00	19.2	0.24										
1.17	15	0.08	42	0	42	38.9	1.68	0.11	7.0	0.00	325	22	0	35	24	605	273	555	17.2	42
3.17	15	0.21	68	4	64	58.4	0.00	0.00	9.1	0.00	365	9	160	36	75	X	655	297	25.6	45
4.50	15	0.30	56	16	40	42.8	1.57	0.22	7.7	0.48	344	63	880	59	144	880	1555	640		32
1.17	30	0.04	42	0	42	29.2	0.90	0.00	8.5	0.00	347	35	16	25	22	620	191	103	18.9	35
3.17	30	0.11	24	0	24	68.1	0.56	0.11	8.0	0.00	363	19	8	30	22	625	241	123	19.0	30
4.50	30	0.15	49	0	49	38.9	1.68	0.34	6.4	0.00	229	57	865	56	108	665	349	285		21
1.17	60	0.02	0	0	0	58.4	1.34	0.11	4.0	0.00	304	10	0	39	26	X	166	151	21.2	37
3.17	60	0.05	32	0	32	48.6	0.22	0.00	5.9	0.00	296	14	93	35	24	580	162	123	17.1	34
4.50	60	0.08	23	0	23	48.6	0.78	0.34	3.1	0.04	386	6	0	42	24	X	203	152	22.6	49
1.17	120	0.01	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3.17	120	0.03	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4.50	120	0.04	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

(1) Ca # is in mg/l

LAKE EOLA COLUMN STUDY # 6

STORM DATE: 6/22/79
 SAMPLE LOCATION: Lake Eola West
 TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted					all metals reported as the element in ug/l														
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb (l)	Ca	Cr		
1.17	0	-	50	36	14	128	3.92	0.99	22.5	0.99	818	73	83	39	68	915	899	280	24.9	37		
3.17	0	-	102	64	38	138	2.38	0.76	44.4	0.92	1050	39	50	23	58	949	853	292	26.7	34		
4.50	0	-	78	48	30	118	2.58	0.82	21.5	1.01	536	19	0	20	55	832	755	261	22.0	31		
1.17	5	0.23	46	28	18	118	2.69	0.87	25.6	0.82	324	19	37	20	64	822	794	267	21.8	28		
3.17	5	0.63	68	38	30	130	2.46	0.67	23.7	0.84	460	11	48	20	53	789	743	252	21.4	26		
4.50	5	0.90	48	32	16	132	2.80	0.70	23.8	0.71	718	10	0	19	53	817	749	258	22.5	33		
1.17	10	0.12	38	28	10	118	2.35	0.67	27.8	0.71	467	16	74	27	72	846	810	273	22.5	29		
3.17	10	0.32	42	26	16	118	2.58	0.67	21.7	0.84	768	13	2	59	72	850	967	300	24.5	35		
4.50	10	0.45	38	30	8	89	2.58	0.70	20.9	0.94	367	10	83	20	48	800	820	272	21.6	36		
1.17	15	0.08	36	20	12	108	1.68	0.67	19.8	0.76	599	19	0	44	76	875	874	280	22.8	34		
3.17	15	0.21	38	26	12	108	1.90	0.70	24.5	0.78	590	10	31	20	49	831	878	273	22.6	34		
4.50	15	0.30	40	22	18	93	2.24	0.73	26.6	0.59	1080	13	55	28	59	1110	1040	314	30.0	42		
1.17	30	0.04	24	16	8	89	2.69	0.93	21.8	0.79	819	18	13	31	77	923	764	259	24.2	35		
3.17	30	0.11	34	26	8	118	2.69	0.65	23.8	0.83	1130	13	18	19	56	1040	887	282	29.0	34		
4.50	30	0.15	24	18	6	79	2.46	0.76	27.7	0.81	434	12	0	33	53	857	931	269	22.4	41		
1.17	60	0.02	20	16	4	89	2.02	0.67	17.3	0.84	1060	15	0	18	46	844	694	237	23.5	25		
3.17	60	0.05	26	18	8	99	1.79	0.62	21.3	0.86	884	11	64	19	54	826	770	262	22.6	33		
4.50	60	0.08	23	15	8	69	2.53	0.56	24.3	0.82	481	11	104	25	48	836	852	257	22.2	35		
1.17	120	0.01	12	8	4	73	2.24	0.53	25.0	0.70	344	15	22	15	48	746	566	194	19.4	24		
3.17	120	0.03	26	20	6	85	2.24	0.67	21.3	0.86	371	10	88	19	56	802	700	245	21.4	31		
4.50	120	0.04	23	15	8	63	2.53	0.67	20.6	0.81	477	11	29	34	52	805	844	236	21.1	37		

) Ca # is in mg/l

LAKE EOLA COLUMN STUDY # 7

STORM DATE: 6/22/79
 SAMPLE LOCATION: Lake Eola West
 TREATMENT: 240 mg/l $Al_2(SO_4)_3 \cdot 18H_2O$

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted										all metals reported as the element in $\mu g/l$									
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr		
1.17	0	-	144	68	76	108	2.58	0.56	31.2	0.75	730	22	74	87	64	860	1060	328	26.0	37		
3.17	0	-	179	91	88	108	2.46	0.53	32.4	0.82	468	17	111	18	65	911	1220	336	26.9	36		
4.50	0	-	109	53	56	59	2.46	0.65	28.7	1.02	498	17	112	22	74	918	1210	328	28.5	49		
1.17	5	0.23	96	54	42	59	2.24	0.60	35.1	0.72	770	32	90	20	59	932	1100	329	28.8	36		
3.17	5	0.63	115	63	52	49	2.02	0.60	32.4	0.88	478	18	78	18	58	953	1270	342	25.1	35		
4.50	5	0.90	112	62	50	45	2.35	0.54	26.2	0.86	433	18	173	23	59	885	1200	326	27.5	40		
1.17	10	0.12	18	8	10	69	1.68	0.61	18.9	0.08	753	31	85	28	52	829	520	163	25.9	38		
3.17	10	0.32	88	41	47	79	2.35	0.63	32.6	0.93	593	16	61	18	57	939	1120	319	27.4	34		
4.50	10	0.45	89	44	45	59	2.58	0.61	38.2	0.86	401	17	142	17	63	910	1120	315	27.7	35		
1.17	15	0.08	9	4	5	59	1.46	0.53	15.5	<0.05	541	27	149	18	51	791	481	146	25.1	28		
3.17	15	0.21	91	41	50	45	2.35	0.56	36.0	0.88	434	13	98	29	69	908	1360	330	26.9	55		
4.50	15	0.30	96	45	51	---	2.58	0.51	33.5	0.88	621	16	129	14	66	905	1090	308	26.6	28		
1.17	30	0.04	5	2	3	49	1.46	0.54	16.8	<0.05	314	43	81	13	45	815	361	135	25.9	18		
3.17	30	0.11	9	3	6	65	1.23	0.56	14.4	<0.05	560	19	112	21	51	837	483	144	24.8	29		
4.50	30	0.15	15	6	9	69	2.01	0.56	14.7	<0.05	677	16	97	12	43	836	470	156	27.5	18		
1.17	60	0.02	1	1	0	49	2.24	0.53	19.5	<0.05	442	52	68	14	49	882	353	130	27.1	23		
3.17	60	0.05	2	1	1	43	2.24	0.60	14.6	<0.05	372	51	111	15	54	812	309	122	24.2	21		
4.50	60	0.08	2	0	2	39	2.35	0.60	19.5	<0.05	461	17	78	12	46	852	361	111	24.7	15		
1.17	120	0.01																				
3.17	120	0.03																				
4.50	120	0.04																				

) Ca # is in mg/l

LAKE EOLA COLUMN STUDY # 8

STORM DATE: 6/27/79
 SAMPLE LOCATION: School
 TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted					all metals reported as the element in µg/l														
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb (l)	Ca	Cr			
1.17	0	-	160	88	72	335	0.78	0.13	39.3	1.42	758	53	1226	64	117	2874	2060	615	29.4	125		
3.17	0	-	319	155	164	216	1.01	0.13	31.0	1.70	770	23	1143	19	39	2764	1440	632	30.7	44		
4.50	0	-	302	146	156	216	1.12	0.16	16.8	1.44	487	7	1035	17	38	2588	1290	628	32.0	32		
1.17	5	0.23	118	60	58	151	1.01	0.10	31.0	1.33	294	15	1101	20	36	2335	1370	596	29.0	40		
3.17	5	0.63	147	71	76	162	1.46	0.15	30.9	1.37	339	11	1101	23	58	2599	1860	621	30.1	45		
4.50	5	0.90	174	90	84	171	1.23	0.16	23.4	1.48	1064	9	1572	34	61	3590	1910	848	42.1	46		
1.17	10	0.12	110	54	56	149	0.78	0.12	27.6	1.11	791	14	1090	108	52	2588	2500	586	31.6	161		
3.17	10	0.32	142	74	68	151	1.01	0.13	33.0	1.30	433	10	1016	20	42	1707	1060	570	28.9	31		
4.50	10	0.45	133	67	66	195	1.01	0.16	27.4	1.38	756	12	1132	59	63	2313	1420	596	29.8	41		
1.17	15	0.08	55	25	30	140	1.12	0.12	29.3	0.90	1654	15	1111	47	34	2170	1530	586	32.9	71		
3.17	15	0.21	144	70	74	184	1.46	0.13	34.5	1.42	463	11	1258	29	39	2225	1220	581	28.9	46		
4.50	15	0.30	99	47	52	151	1.12	0.13	26.3	1.48	399	9	1258	39	52	1949	1030	580	28.4	44		
1.17	30	0.04	43	23	20	129	1.23	0.12	28.3	0.82	276	10	745	23	45	2519	1412	582	27.3	53		
3.17	30	0.11	53	27	26	149	1.34	0.12	21.8	0.99	2162	7	985	30	42	2720	1462	603	32.4	49		
4.50	30	0.15	51	23	28	141	1.34	0.15	22.9	0.96	689	7	765	26	43	2106	1242	597	29.0	50		
1.17	60	0.02	43	27	16	128	1.23	0.13	24.1	0.79	1562	7	615	30	64	2476	1322	529	30.4	46		
3.17	60	0.05	46	24	22	169	1.23	0.12	20.8	0.88	1962	7	835	77	37	2550	1752	608	37.0	86		
4.50	60	0.08	53	27	26	140	1.23	0.13	20.0	0.92	426	5	645	25	67	2360	1182	570	27.5	43		
1.17	120	0.01	---	---	---	216	1.46	0.18	24.3	0.78	2732	77	745	37	51	1767	941	505	42.7	42		
3.17	120	0.03	46	38	8	173	1.23	0.10	17.4	0.86	1522	7	755	46	38	2074	1502	547	33.7	70		
4.50	120	0.04	56	28	28	130	1.34	0.13	11.6	0.95	1422	13	775	34	50	2296	1162	562	33.1	60		

Ca # is in mg/l

LAKE EOLA COLUMN STUDY # 9

STORM DATE: 6/27/79

SAMPLE LOCATION: School

TREATMENT: 240 mg/l Al₂ (SO₄)₃ .18 H₂O

pH = 5.5, NaOH adjusted

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS											
			all general water quality reported in mg/l as noted										all metals reported as the element in µg/l											
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P		Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	Ca	Cr			
1.17	0	-	148	74	74	54	1.59	0.10	25.5	0.99		1282	17	905	51	63	X	2732	708	37.1	63			
3.17	0	-	156	80	76	76	1.68	0	29.9	0.88		729	8	985	56	70	X	1392	689	29.3	61			
4.50	0	-	142	72	70	54	1.68	0	29.2	0.93		915	11	1025	55	68	X	1272	686	33.7	54			
1.17	5	0.23	119	55	64	---	1.79	0.06	23.1	0.79		730	15	1030	123	70	X	1720	644	32.7	249			
3.17	5	0.63	141	69	72	---	1.79	0.02	26.7	0.90		1620	9	1340	50	77	X	1610	741	36.2	51			
4.50	5	0.90	139	63	76	43	1.46	0.02	31.7	0.83		474	11	1330	61	78	X	1520	693	29.9	56			
1.17	10	0.12	24	14	10	54	0.22	0	15.6	0.08		389	7	345	60	62	7030	579	230	22.7	33			
3.17	10	0.32	165	95	70	61	1.57	0.02	29.8	0.81		631	11	1330	57	76	X	1570	738	30.6	63			
4.50	10	0.45	144	68	76	39	1.34	0	32.1	0.81		448	14	1510	72	57	X	1580	750	31.3	70			
1.17	15	0.08	14	2	12	39	1.90	0	11.5	<0.05		836	10	348	57	66	3020	414	217	33.1	43			
3.17	15	0.21	116	48	68	22	2.10	0	28.4	0.77		1030	9	1170	64	76	X	1250	699	37.9	58			
4.50	15	0.30	90	50	40	---	2.66	0.02	31.4	0.81		370	13	1450	88	52	X	1560	737	31.3	79			
1.17	30	0.04	1	1	0	43	---	0.02	9.5	<0.05		925	14	405	68	38	1720	571	204	34.6	47			
3.17	30	0.11	7	3	4	39	---	0.02	12.5	<0.05		761	10	588	66	32	3480	696	251	30.2	66			
4.50	30	0.15	6	0	6	65	1.57	0	11.2	<0.05		515	8	468	51	42	3170	1390	197	30.1	29			
1.17	60	0.02	0	0	0	82	2.46	0	10.3	<0.05		264	16	597	67	36	1123	447	215	29.8	63			
3.17	60	0.05	0	0	0	43	3.58	0	13.8	<0.05		901	11	609	65	32	1165	286	223	32.4	68			
4.50	60	0.08	0	0	0	76	1.34	0	10.2	<0.05		244	9	381	78	29	844	1060	166	26.9	39			
1.17	120	0.01																						
3.17	120	0.03																						
4.50	120	0.04																						

) Ca # is in mg/l

LAKE EOLA COLUMN STUDY # 10

STORM DATE: 7/8/79
 SAMPLE LOCATION: George Stuart
 TREATMENT: Untreated

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted										all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P			Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	11a	Cr
1.17	0	-	318	214	104	290	5.250	.16		.800			613	46	28	15	42	568	1066	351	15.8	24
3.17	0	-	238	158	80	260	3.240	.15		.836			409	154	0	17	39	535	1269	320	14.7	17
4.50	0	-	524	348	176	260	4.620	.15		1.015			380	21	75	14	36	550	1151	365	14.3	22
1.17	5	0.23	112	70	42	98	2.590	.15		.747			2710	26	18	41	43	1046	1318	277	34.1	50
3.17	5	0.63	134	90	44	150	2.730	.16		.783			4030	15	10	150	60	1893	2725	354	50.3	188
4.50	5	0.90	172	102	70	230	2.870	.13		.926			554	8	77	15	34	470	1029	233	13.0	15
1.17	10	0.12	64	38	26	120	1.890	.11		.664			285	11	32	11	36	345	1180	223	10.3	12
3.17	10	0.32	80	46	34	80	2.660	.13		.765			213	13	32	12	33	409	1107	265	11.3	13
4.50	10	0.45	128	88	40	110	2.17	.15		.789			389	6	65	14	32	441	1080	242	12.0	18
1.17	15	0.08	48	26	22	50	1.75	.15		.604			222	13	0	12	35	436	1091	248	12.3	13
3.17	15	0.21	74	44	30	90	1.82	.15		.729			243	14	0	14	43	483	988	272	12.4	14
4.50	15	0.30	117	49	68	---	1.47	.16		.717			338	8	67	24	35	464	1191	218	12.2	22
1.17	30	0.04	35	19	16	100	1.05	.13		.473			383	18	0	19	36	460	1429	254	12.4	16
3.17	30	0.11	48	22	26	50	.77	.15		.568			239	14	4	33	38	458	1661	265	12.0	13
4.50	30	0.15	56	32	24	60	1.12	.15		.676			466	15	13	111	28	503	977	247	13.6	19
1.17	60	0.02	26	14	12	100	.63	.15		.425			353	14	0	16	33	430	1155	208	11.2	18
3.17	60	0.05	37	19	18	50	.84	.11		.556			377	11	0	22	36	498	1967	242	12.3	19
4.50	60	0.08	36	---	---	54	.91	.16		.598			197	11	65	16	32	460	779	220	11.7	18
1.17	120	0.01	22	10	12	60	.84	.10		.372			331	12	46	13	36	433	1035	204	11.2	14
3.17	120	0.03	27	17	10	44	.84	.16		.491			213	16	0	20	42	444	1065	194	10.7	14
4.50	120	0.04	40	22	18	60	.70	.15		.568			265	10	49	11	24	402	537	148	10.7	15

(1) Ca is in mg/l

LAKE EOLA COLUMN STUDY # 11

STORM DATE: 7/8/79
 SAMPLE LOCATION: George Stuart
 TREATMENT: 205 mg/l Ca(OH)₂
 pH = 11.6
 Mixing Time = 15 min.

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted										all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P			Zn	Cd	As	Ni	Cu	Mg	Fe	Pb(l)	Ca	Cr
1.17	0	-	151	---	---	64	3.64	.077		.861			407	14	49	21	47	1120	1278	403		36
3.17	0	-	130	72	58	60	4.06	.094		.841			326	12	34	23	53	1090	1260	403		37
4.50	0	-	201	115	86	130	3.99	.112		1.035			773	27	32	175	76	1270	4850	486		34
1.17	5	0.23	70	32	38	50	1.54	.077		.735			453	9	126	28	43	1230	1319	417		34
3.17	5	0.63	107	57	50	130	2.52	.059		.841			367	10	2	37	45	1240	1480	462		37
4.50	5	0.90	111	55	56	60	2.31	.077		.841			487	8	22	48	37	1070	1640	372		33
1.17	10	0.12	46	20	26	50	1.12	.077		.554			475	7	0	39	32	942	1014	325		28
3.17	10	0.32	69	33	36	40	1.26	.094		.641			448	11	11	111	33	988	1600	333		31
4.50	10	0.45	87	41	46	50	1.75	.059		.634			489	8	71	38	43	1070	1900	400		40
1.17	15	0.08	38	14	24	50	.77	.077		.481			216	8	38	19	37	870	1024	302		29
3.17	15	0.21	60	26	34	54	1.26	.094		.634			306	10	91	40	63	1070	1330	399		36
4.50	15	0.30	66	30	36	50	1.89	.042		.648			388	10	58	38	47	1090	2150	417		37
1.17	30	0.04	36	14	22	40	1.68	.059		.387			383	7	80	23	33	819	784	283		28
3.17	30	0.11	42	20	22	50	1.19	.077		.561			237	9	63	34	42	847	1010	300		32
4.50	30	0.15	48	22	26	60	1.12	.094		.574			284	6	0	20	29	850	1040	324		30
1.17	60	0.02	24	12	12	70	1.40	.059		.321			381	7	24	44	29	688	875	258		27
3.17	60	0.05	24	8	16	36	.77	.059		.354			396	10	0	87	49	703	2090	262		32
4.50	60	0.08	25	12	14	50	.98	.094		.427												
1.17	120	0.01																				
3.17	120	0.03																				
4.50	120	0.04																				

(1) Ca is in mg/l

LAKE EOLA COLUMN STUDY # 12

STORM DATE: 7/12/79
 SAMPLE LOCATION: Lake Eola North
 TREATMENT: Untreated

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS									
			all general water quality reported in mg/l as noted										all metals reported as the element in µg/l									
			TSS	VSS	·NVSS	COD	TKN-N	NH ₃ -N	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb(l)	Ca	Cr			
1.17	0	-	65	21	44	90	1.05	.229	.155	531	9	72	14	132	683	848	378	30.4	24			
3.17	0	-	58	22	36	56.3	.84	.153	.151	392	12	0	21	124	750	918	376	29.5	38			
4.50	0	-	61	25	36	84.38	.77	.121	.151	298	12	131	25	122	711	886	403	26.5	32			
1.17	5	0.23	45	17	28	78.75	.7	.175	.100	555	5	128	20	112	679	792	336	26.4	25			
3.17	5	0.63	48	20	28	84.38	.7	.096	.144	497	11	0	21	129	819	987	391	30.1	40			
4.50	5	0.90	49	21	28	84.38	.84	.080	.103	1085	6	133	21	114	757	710	284	26.2	25			
1.17	10	0.12	41	15	26	93.75	.84	.128	.103	421	8	124	16	109	680	836	318	24.9	28			
3.17	10	0.32	43	18	25	84.38	.84	.112	.107	1635	6	75	15	104	1666	781	322	35.5	24			
4.50	10	0.45	48	19	29	103.13	.77	.144	.134	359	11	160	23	113	661	892	335	24.1	26			
1.17	15	0.08	33	11	22	56.25	.63	.144	.077	373	5	14	18	103	658	713	283	23.7	24			
3.17	15	0.21	43	17	26	84.38	.84	.096	.233	681	9	88	28	110	677	781	330	24.5	26			
4.50	15	0.30	41	17	24	78.75	.77	.112	.103	479	12	205	26	113	689	844	352	25.4	34			
1.17	30	0.04	26	11	15	62.63	.63	.128	.077	403	8	109	17	96	677	774	283	24.5	26			
3.17	30	0.11	37	14	23	56.25	.7	.144	.247	262	6	154	21	109	634	734	294	22.1	24			
4.50	30	0.15	38	15	23	75	.63	.144	.114	850	9	140	35	117	732	883	324	25.6	28			
1.17	60	0.02	25	13	12	71.25	.84	.049	.074	471	7	0	14	100	745	715	289	25.6	27			
3.17	60	0.05	24	11	13	84.38	.98	.071	.233	372	9	132	20	109	651	758	307	23.4	25			
4.50	60	0.08	25	12	13	71.25	.7	.058	.110	1250	9	189	27	115	887	746	316	31.7	29			
1.17	120	0.01	19	12	7	75	2.31	.049	.063	1224	9	121	50	96	756	670	276	27.9	31			
3.17	120	0.03	59	29	30	150	.35	.112	.209	661	30	161	23	154	844	902	381	26.7	30			
4.50	120	0.04	23	11	12	65.63	.77	.033	.084	865	6	141	24	129	880	831	305	27.0	28			
(1) Ca is in mg/l																						

(1) Ca is in mg/l

LAKE EOLA COLUMN STUDY # 13

STORM DATE: 7/12/79

SAMPLE LOCATION: Lake Eola North

TREATMENT: 80 mg/l FeCl₃

Coagulation pH = 5.0, NaOH Adjusted

Mixing Time = 15 min.

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY										METALS											
			all general water quality reported in mg/l as noted										all metals reported as the element in µg/l											
			TSS	VSS	NVSS	COD	TKN-N	NH ₃ -N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	Ala	Cr				
1.17	0	-	135	53	82	52.5	1.4	.144		.236	763	16	9	32	237	1040	---	---	535	35.1	29			
3.17	0	-	142	58	84	37.5	1.4	.175		.228														
4.50	0	-	200	78	122	103.13	1.4	.144		.254	835	19	98	38	236	1093	---	---	531	36.8	36			
1.17	5	0.23	32	12	20	52.5	1.61	.128		.078														
3.17	5	0.63	47	19	28	37.5	2.03	.175		.117	1187	6	0	33	146	1317	---	---	240	40.2	25			
4.50	5	0.90	121	47	74	41.25	1.47	.128		.228	959	9	4	35	238	1047	---	---	480	36.5	34			
1.17	10	0.12	16	8	8	41.25	1.4	.175		.067	518	6	140	27	120	834	7834							
3.17	10	0.32	16	8	8	65.63	.91	.175		.081	480	9	44	33	119	878	9278							
4.50	10	0.45	21	7	14	73.13	1.47	.175		.067	932	10	82	35	119	996	---	---	170	37.2	31			
1.17	15	0.08	12	5	7	65.63	.35	.159		< .05	454	7	0	30	116	829	6551							
3.17	15	0.21	14	6	8	75	1.54	.175		< .05	836	7	0	34	116	876	6985							
4.50	15	0.30	16	6	10	52.5	1.54	.159		< .05														
1.17	30	0.04	10	5	5	46.87	1.89	.159		< .05	400	10	0	30	111	830	5808							
3.17	30	0.11	13	4	8	43.13	1.96	.159		.053	1163	10	0	24	115	972	5999							
4.50	30	0.15	12	4	8	75	1.82	.159		< .05	945	8	58	34	106	999	6235							
1.17	60	0.02	11	5	6	67.5	1.68	.223		< .05	458	13	0	31	110	847	5504							
3.17	60	0.05	9	4	5	46.87	.84	.207		.061	1746	12	80	53	108	1160	5543							
4.50	60	0.08	10	5	5	56.25	1.4	.223		< .05	1685	11	105	36	101	1147	5699							
1.17	120	0.01																						
3.17	120	0.03																						
4.50	120	0.04																						

(1) Ca is in mg/l

APPENDIX B

SUMMARY OF JAR TEST RESULTS

Lake Eola Runoff Samples

Date Taken: 4-5-79

Coagulant: Alum - $\text{Al}_2(\text{SO}_4)_3$ - 18 H_2O

Rapid Mix - Max. RPM for 3 minutes

Slow Mix - 30 RPM for 30 minutes

Sedimentation - 30 minutes

Apparatus - Phipps & Bird

Initial pH = 5.5

FOR OPTIMAL DOSE -

<u>Final pH</u>	<u>Alum Dose (mg/l)</u>	<u>O-P (mg/l)</u>	<u>% Removal</u>
5.5	0 (blank or raw)	5.2	0
5.5	10	5.2	0
5.5	20	5.1	1.9
5.5	30	5.2	0
5.5	40	5.1	1.9
5.4	50	5.2	0
5.3	100	4.3	17.3
5.3	120	4.8	26.9
5.3	140	3.2	38.5
5.2	160	1.9	63.5
5.2	180	1.2	76.9
5.1	200	1.1	78.8
5.1	220	0.7	86.5
5.0	240	0.6	88.5
5.0	260	0.65	87.5
4.9	280	0.6	88.5
4.9	300	0.6	88.5
4.9	320	0.6	88.5

OPTIMAL DOSE @ 240 mg/l

Date Taken: 4-5-79

FOR OPTIMAL pH

Constant Alum Dose of 240 mg/l

<u>pH Maintained At</u>	<u>O-P (mg/l)</u>
5.0	0.5
5.5	0.4
6.0	0.95
6.5	1.1
7.0	2.6
8.0	3.7

OPTIMAL pH @ 5.5

Lake Eola Runoff Samples

Date Taken: 4-25-79

Coagulant: Alum - $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$

Rapid Mix - Max RPM for 3 minutes

Slow Mix - 30 RPM for 30 minutes

Sedimentation - 30 minutes

Apparatus - Phipps & Bird

Initial pH = 7.3

Final pH maintained @ 5.5

<u>Sample Nbr.</u>	<u>Alum Dose (mg/l)</u>	<u>T-P (mg/l)</u>	<u>Turbidity (JTU)</u>
1	Raw 0	1.1	80
2	150	0.23	12
3	180	0.34	12
4	200	0.35	8.0
5	210	0.42	12
6	220	0.44	12
7	230	0.36	43
8	240	0.42	34
9	250	0.38	11
10	260	0.33	12
11	280	0.31	7.3
12	300	0.43	5.5
13	Raw Diluted (1:1)	0.66	14
14	Raw Diluted (1:3)	0.35	10

OPTIMAL DOSE FOR T-P REMOVAL 150 mg/l

ALKALINITY = 91.75 mg/l as CaCO_3

Lake Eola Runoff Samples

Date Taken: 5-24-79

Coagulant: Alum - $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$

Rapid Mix - Max. RPM for 3 minutes

Slow Mix - 30 RPM for 30 minutes

Sedimentation - 30 minutes

Apparatus - Phipps & Bird

Initial pH = 7.7

pH Maintained @ 5.5

FOR OPTIMAL DOSE -

<u>Sample Nbr.</u>	<u>Alum Dose (mg/l)</u>	<u>T-P (mg/l)</u>	<u>Turbidity (JTU)</u>
1	0 (Blank)	0.255	6.5
2	10	0.18	4.8
3	20	0.11	4.5
4	30	0.12	4.4
5	40	0.12	4.2
6	50	0.115	4.5
7	60	0.12	4.7
8	80	0.12	4.5
9	100	0.11	3.8
10	120	0.12	5.2
11	140	0.13	4.8
12	160	0.12	4.5
13	180	0.115	4.2
14	200	0.13	5.2
15	220	0.13	6.2
16	240	0.135	5.6
17	260	0.14	6.2

OPTIMAL DOSE @ 20 mg/l for T-P Removal
 100 mg/l for Turbidity Removal

Date Taken: 5-24-79

For Optimal pH

Constant Alum Dose of 20 mg/l

<u>pH Maintained At</u>	<u>T-P (mg/l)</u>
4.0	0.19
5.0	0.15
5.5	0.17
6.0	0.20
7.0	0.32
8.0	0.35

OPTIMAL pH @ 5.0

Lake Eola Runoff Samples

Date Taken: 4-25-79

Coagulant: Ferric Chloride - FeCl_3

Rapid Mix - Max RPM for 3 minutes

Slow Mix - 30 RPM for 30 minutes

Sedimentation - 30 minutes

Apparatus - Phipps & Bird

Initial pH = 7.3

Final pH Maintained @ 4.0

<u>Sample Nbr.</u>	<u>FeCl_3 Dose (mg/l)</u>	<u>T-P (mg/l)</u>	<u>Turbidity (JTU)</u>
1	0 (Blank Diluted (1:1))	0.63	42 (Raw = 80)
2	50	0.21	6.1
3	60	0.185	4.0
4	70	0.189	4.0
5	80	0.20	5.8
6	90	0.218	4.8
7	0 (Blank Diluted (1:3))	0.37	22

OPTIMAL DOSE - TP Removal @ 60 mg/l
 Turbidity Removal @ 60 mg/l

OPTIMAL pH -

<u>pH Maintained At</u>	<u>T-P (mg/l)</u>	<u>FeCl_3 Dose (mg/l)</u>
3	0.19	60
4	0.17	60
5	0.175	60
5.5	0.18	60
6	0.21	60

OPTIMAL pH @ 4.0

ALKALINTY = 91.75 mg/l as CaCO_3

Lake Eola Runoff Samples

Date Taken: 5-24-79

Coagulant: Lime - $\text{Ca}(\text{OH})_2$

Rapid Mix - Max RPM for 3 minutes

Slow Mix - 30 RPM for 30 minutes

Sedimentation - 30 minutes

Aparatus - Phipps & Bird

Initial pH = 7.3

Final pH Maintained @ 11.5

<u>Sample Nbr.</u>	<u>Lime Dose (mg/l)</u>	<u>T-P (mg/l)</u>		<u>TP AVG.(mg/l)</u>
1	0 (Blank)	0.26	0.253	0.2565
2	80	0.162	0.091	0.1265
3	100	0.58	0.152	0.366
4	120	0.51	0.034	0.272
5	140	0.138	0.101	0.1195
6	160	0.095	0.128	0.1115
7	180	0.071	0.118	0.0945
8	200	0.004	0.138	0.071
9	250	0.071	0.041	0.056

OPTIMAL DOSE @ 250 mg/l

Lake Eola Runoff Samples

Date Taken: 7-12-79

Coagulant: Lime - CA(OH)_2

Rapid Mix - Max RPM for 3 minutes

Slow Mix - 30 RPM for 30 minutes

Sedimentation - 30 minutes

Initial pH = 6.9

Final pH Maintained @ 11.5

<u>Sampled Nbr.</u>	<u>Lime Dose (mg/l)</u>	<u>T-P (mg/l)</u>
1	0 (Blank)	0.12
2	80	0.144
3	100	0.175
4	120	0.124
5	140	0.076
6	160	0.111
7	200	0.112

OPTIMAL DOSE @ 140 mg/l

Lake Eola Runoff Samples

Date Taken: 7-12-79

Coagulant: Ferric Chloride - FeCl_3

Rapid Mix - Max RPM for 3 minutes

Slow Mix - 30 RPM for 30 minutes

Sedimentation- 30 minutes

Apparatus - Phipps & Bird

Initial pH = 6.9

pH Maintained @ 5.0

<u>Sample Nbr.</u>	<u>FeCl_3 Dose (mg/l)</u>	<u>T-P (mg/l)</u>
1	0 Blank	0.145
2	20	0.096
3	40	0.089
4	60	0.142
5	80	<0.05
6	100	<0.05
7	5	0.128
8	10	0.098

OPTIMAL DOSE @ 80 mg/l

OPTIMAL pH -

Initial pH = 6.9

<u>pH Maintained At</u>	<u>T-P (mg/l)</u>	<u>FeCl_3 Dose (mg/l)</u>
3	0.195	10
4	0.115	10
5	0.068	10
6	0.188	10
7	0.477	10

OPTIMAL pH @ 5.0

Date Taken: 7-12-79

Coagulant: FeCl_3

OPTIMAL pH -

Initial pH = 6.9

<u>pH Maintained At</u>	<u>T-P (mg/l)</u>	<u>FeCl_3 Dose (mg/l)</u>
3	0.078	80
4	0.065	80
5	0.062	80
6	0.094	80
7	0.263	80

APPENDIX C

EXAMPLE PROBLEM INVOLVING ISOCONCENTRATION LINES

Example Problem -

Settling Tank Design Problem for Coagulated and
Settled Stormwater Runoff Using Alum

The data for total suspended solids (TSS) and total phosphorus (TP) removals for alum treatment from each port at various time intervals are listed below:

Total Suspended Solids

Port \ Time (min)	% TSS REMOVED (AVERAGE)				
	5	10	15	30	60
1 (1.2ft)	20	74	79	85	97
3 (3.2ft)	16	26	35	87	92
5 (4.5ft)	-11	-6	20	74	89

Total Phosphorus

Port \ Time (min)	% TP REMOVED (AVERAGE)				
	5	10	15	30	60
1 (1.2ft)	0.14	90	95	98	99
3 (3.2ft)	-5.5	-7	37	94	96
5 (4.5ft)	30	22	-9	97	95

The data for total suspended solids and total phosphorus removals were graphed and are depicted in Figures 25 and 26 along with the developed isoconcentration lines. Using equation 3-16, p. 119, of W. Weber (1972) and the developed figures, the overall removal efficiencies for the two water quality parameters can be determined.

$$R^O = R_C + \frac{Ha}{t_2 v_0} (R_d^O - R_C^O) + \frac{Hb}{t_2 v_0} (R_e^O - R_d^O)$$

where R = removal efficiency

H = height

t = time

v = velocity

Using the developed isoconcentration lines for TSS and TP removals and assuming a 4.5 foot deep tank, Tables 18 and 19 were developed to calculate the overall removal efficiencies for the listed times. The data for TSS and TP removals were now graphed on Figures 27 and 28 respectively to develop a single overall removal efficiency line versus time. Figures 27 and 28 can be used for settling tank design calculations. A safety factor should be included in design problems using the data.

TABLE 18

DESIGN CALCULATIONS FOR A 4.5 FOOT
DEEP TANK FOR TSS REMOVAL

TIME (MIN)	% TSS RANGE	AVG. DEPTH OF RANGE (FT.)	V _s (FPM)	V _o gal/ft ² /(day)	V _s /V _o	% TSS REMOVAL
15	0-20	4.5	0.3	3231.79	1	20
	20-40	3.6	0.24		0.8	8
	40-60	2.5	0.167		0.555	5.5
	60-70	1.9	0.127		0.42	4.2
	70-80	1.3	0.087		0.29	2.9
	80-90	0.5	0.033		0.11	1.1
	Total					41.7
18	0-40	4.5	0.25	2693.2	1	40
	40-60	3.7	0.206		0.82	8.2
	60-70	2.6	0.144		0.58	5.8
	70-80	1.9	0.1055		0.21	2.1
	80-90	0.8	0.0444		0.178	1.8
	Total					57.9
22	0-60	4.5	0.205	2208	1	60
	60-70	3.9	0.177		0.86	8.6
	70-80	2.6	0.118		0.58	5.8
	80-90	1.2	0.055		0.27	2.7
	Total					77.1
27	0-70	4.5	0.167	1799	1	70
	70-80	3.6	0.133		0.8	8.0
	80-90	1.6	0.059		0.35	3.5
	Total					81.5
34	0-80	4.5	0.132	1422	1	80
	80-90	3.7	0.1088		0.818	8.2
Total					88.2	
60	0-90	4.5	0.075	808	1	90
Total					90	

TABLE 19

DESIGN CALCULATIONS FOR A 4.5 FOOT
DEEP TANK FOR TP REMOVAL

TIME (MIN)	% TP RANGE	AVG. DEPTH OF RANGE (FT.)	V_s (FPM)	V_{O_2} gal/ft ² /(day)	V_s/V_o	% TSS REMOVAL
20	0-60	4.5	0.225	2424	1	60
	60-70	3.9	0.195		0.866	8.66
	70-80	3.0	0.15		0.666	6.66
	80-90	2.2	0.11		0.488	4.88
					Total	80.20
22	0-70	4.5	0.205	2208	1	70
	70-80	3.8	0.173		0.844	8.44
	80-90	2.7	0.123		0.6	6.0
					Total	84.44
26	0-80	4.5	0.173	1864	1	80
	80-90	3.7	0.142		0.82	8.2
					Total	88.2
33	0-90	4.5	0.136	1465	Total	90

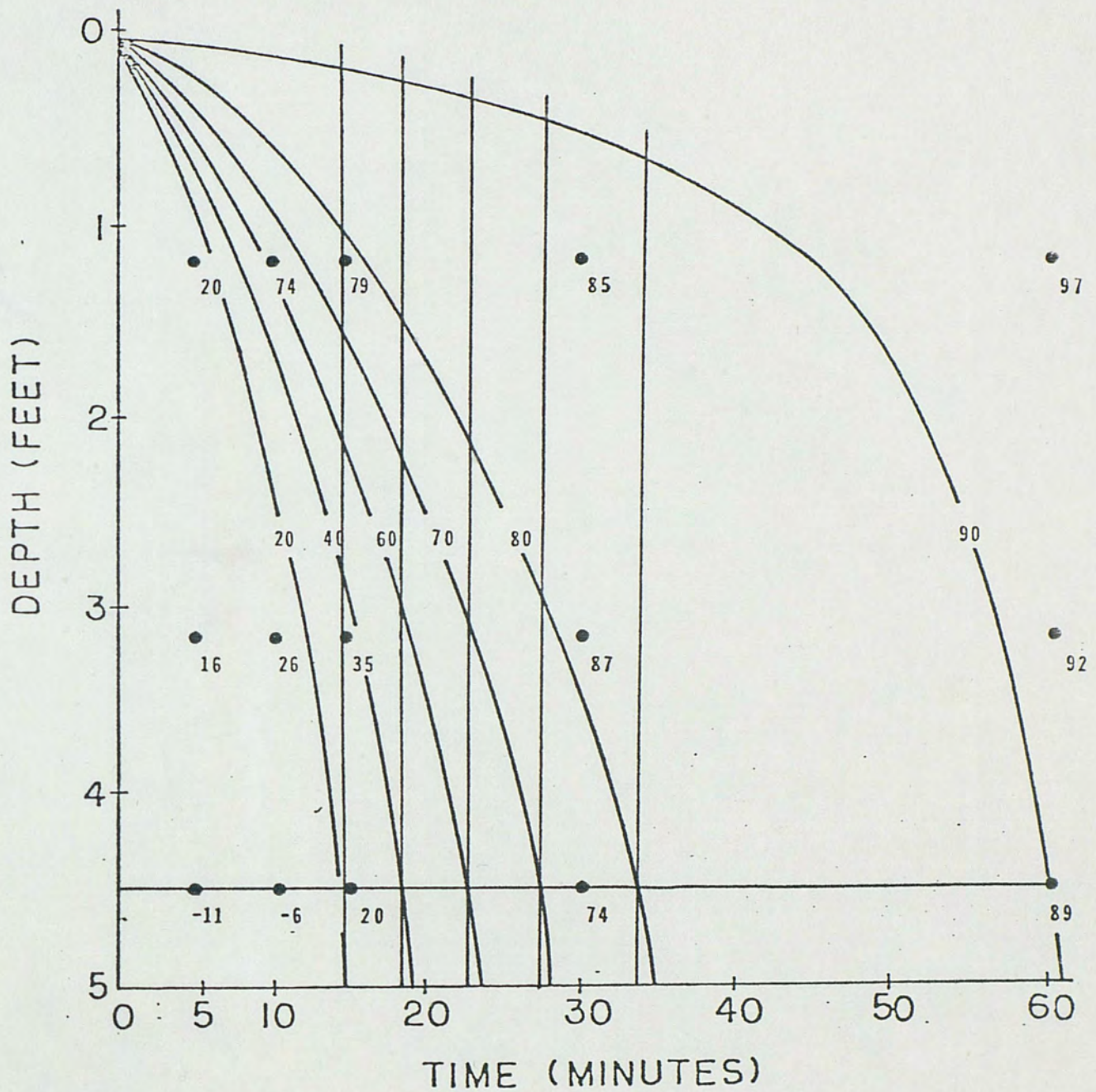


Fig. 25. Isoconcentration lines for total suspended solids for alum coagulated and settled stormwater runoff.

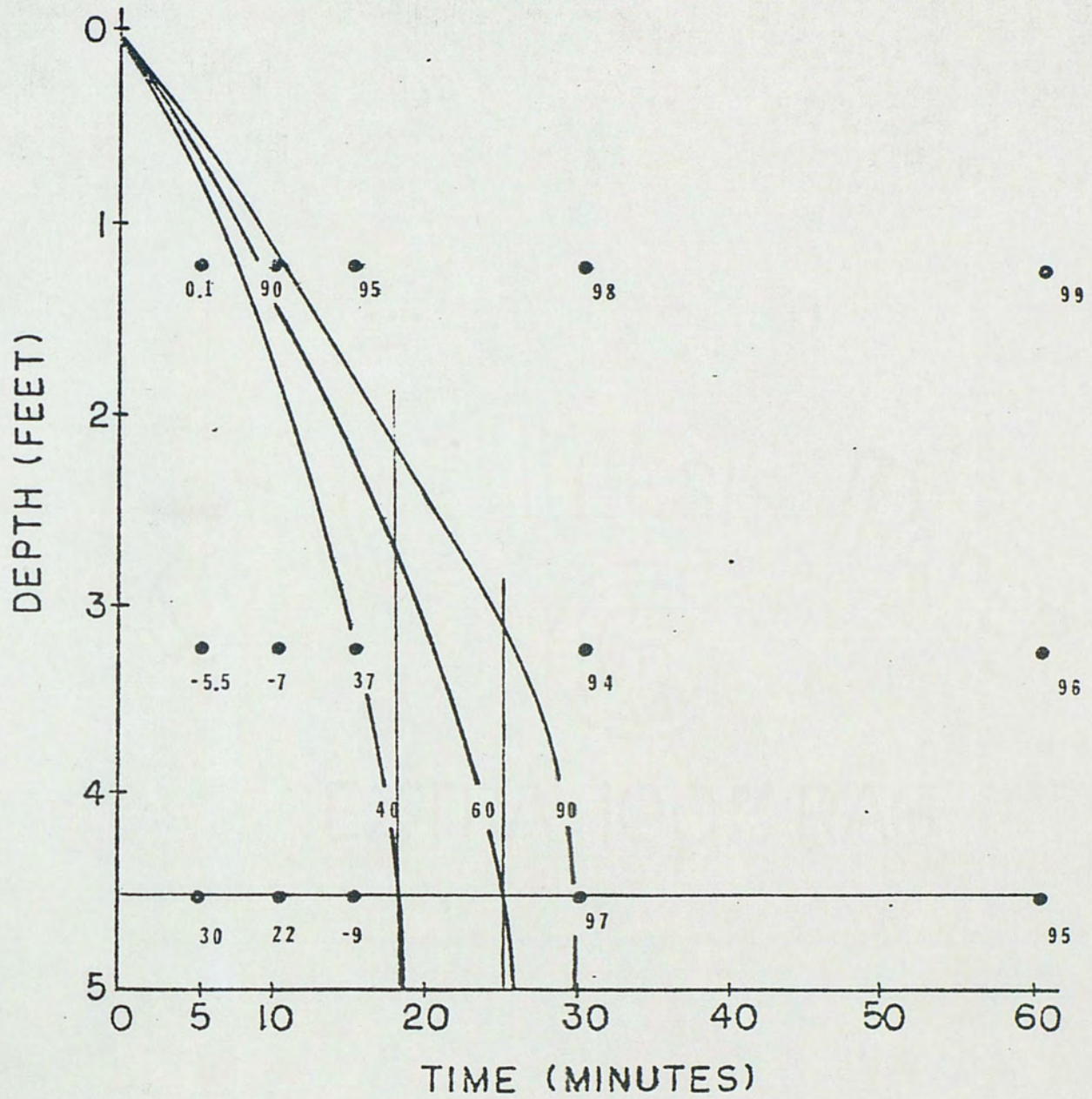


Fig. 26. Isoconcentration lines for total phosphorus removal for alum coagulated and settled stormwater runoff.

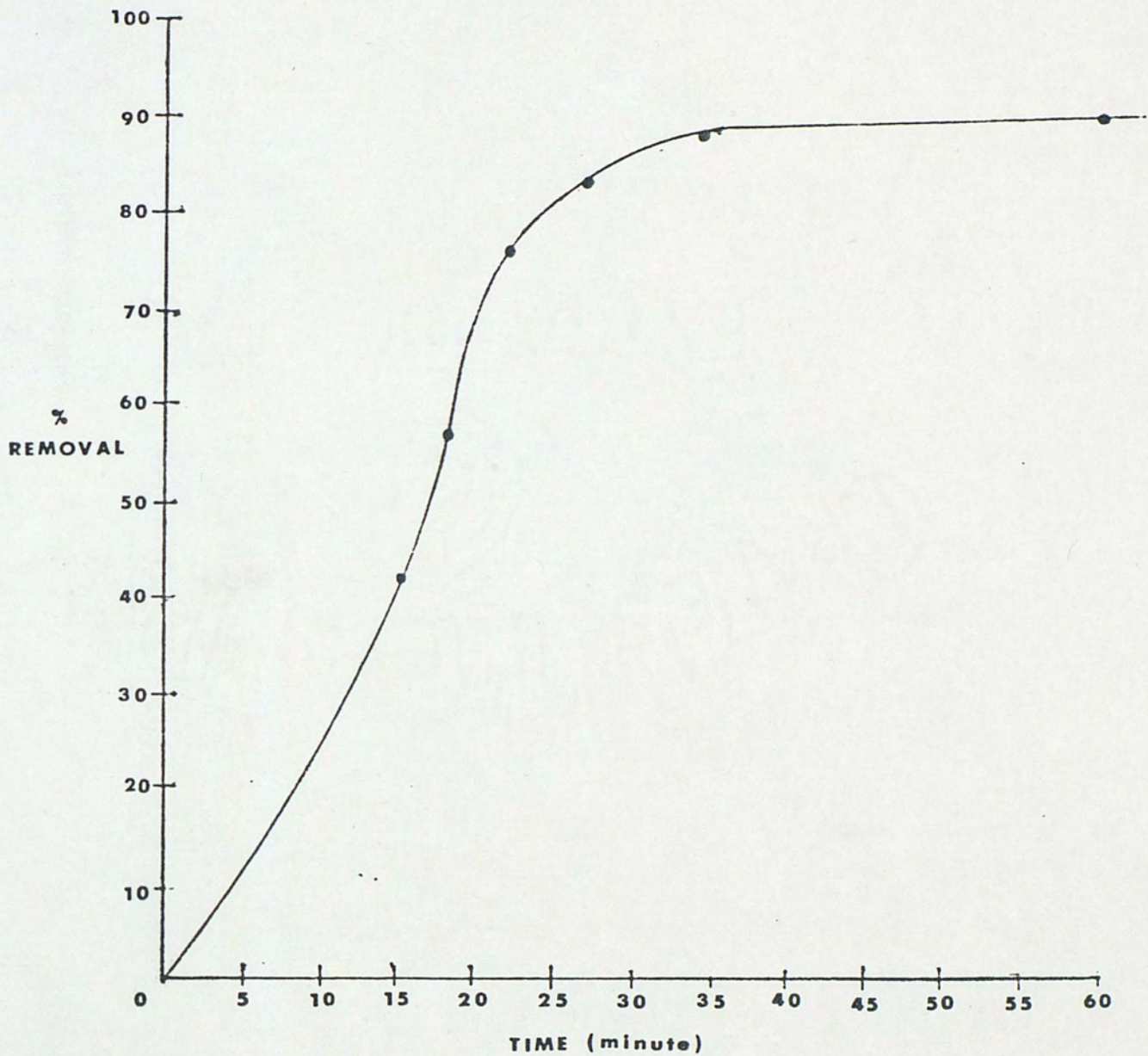


Fig. 27. Total suspended solids removal using alum for a 4.5 foot deep tank.

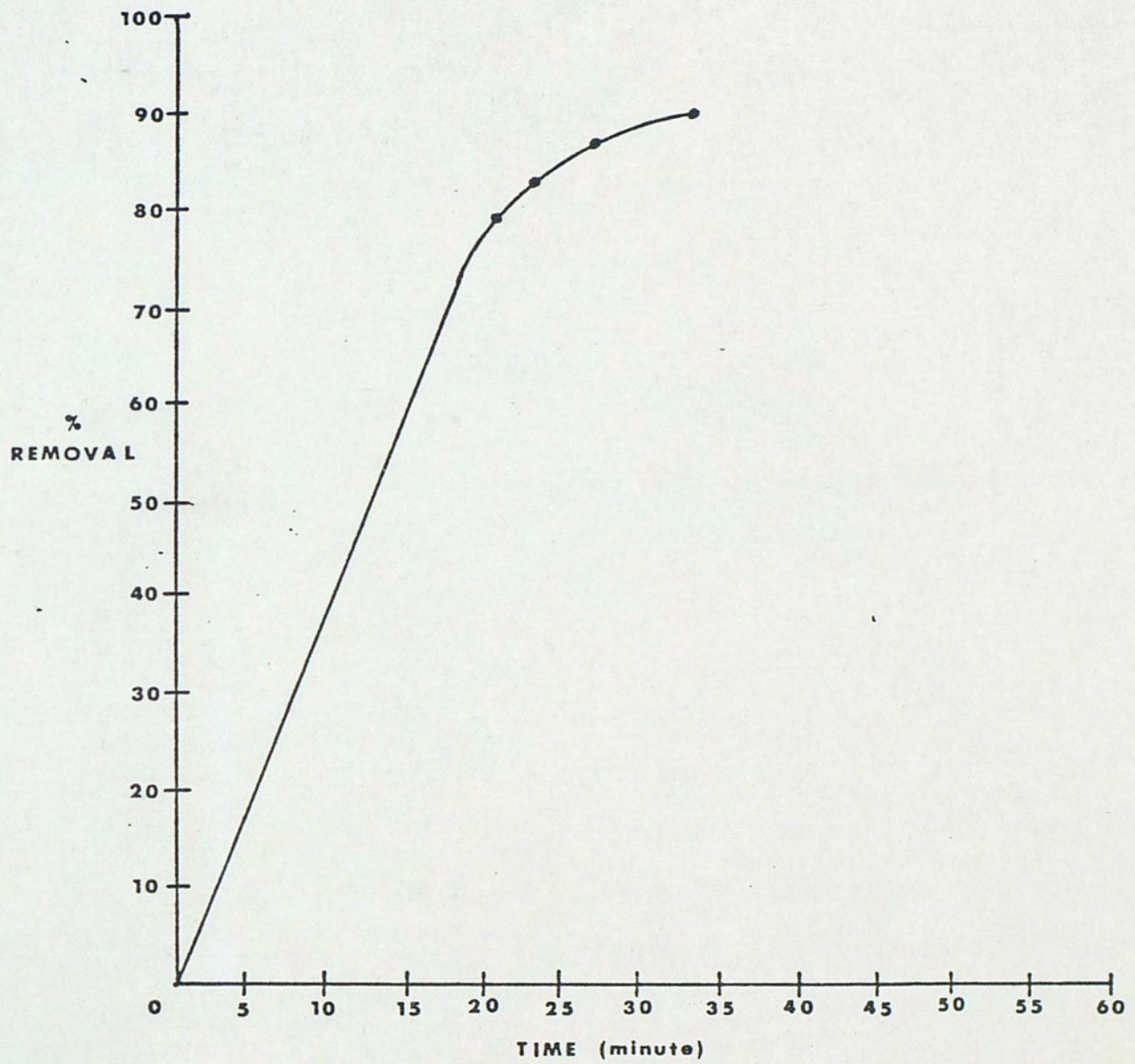


Fig. 28. Total phosphorus removal using alum for a 4.5 foot deep tank.

APPENDIX D

WEIGHT RATIOS OF VARIOUS CHEMICAL PARAMETERS
FOR ALUM, FERRIC CHLORIDE, AND LIME TREATMENT

ALUM TREATED

X_i = initial parameter concentration

X_F = final parameter concentration

TSS_i = initial TSS concentration

TSS_F = final TSS concentration

1) Port 5 (4.5 ft) at 60 minutes settling

Parameter	Initial Conc. (mg/l) (Average of all storms)	Final Conc. (mg/l) (Average of all storms)	% Removal
TSS	145.9	10.75	93
VSS	89.9	2.5	97
NVSS	56.0	8.25	85
COD	168.9	60.9	64
TKN	4.2	1.72	59
NH ₃	0.5	0.235	53
TOC	139.9	14.2	90
TP	1.0	0.0425	96

Parameter	$\frac{X_i}{TSS_i}$	$\frac{X_F}{TSS_F}$	$\frac{X_F}{TSS_i}$
TSS	1	1	0.074
VSS	0.616	0.233	0.0171
NVSS	0.384	0.767	0.057
COD	1.16	5.67	0.417
TKN	0.029	0.16	0.0118
NH ₃	0.0034	0.022	0.0016
TOC	0.959	1.32	0.0973
TP	0.0069	0.00395	0.0003

2) Port 3 (3.17 ft) at 60 minutes settling

Parameter	Initial Conc. (mg/l) (Average of all storms)	Final Conc. (mg/l) (Average of all storms)	% Removal
TSS	145.9	12	92
VSS	89.9	3.75	96
NVSS	56.0	8.25	85
COD	168.9	53.7	68
TKN	4.2	1.76	58
NH ₃	0.5	0.15	70
TOC	139.9	14.8	89
TP	1.0	0.0325	97

Parameter	$\frac{X_i}{\text{TSS}_i}$	$\frac{X_F}{\text{TSS}_F}$	$\frac{X_F}{\text{TSS}_i}$
TSS	1	1	0.082
VSS	0.616	0.3125	0.026
NVSS	0.384	0.6875	0.057
COD	1.16	4.475	0.368
TKN	0.029	0.1467	0.012
NH ₃	0.0034	0.0125	0.001
TOC	0.959	1.233	0.1
TP	0.0069	0.0027	0.0002

3) Port 1 (1.17 ft) at 60 minutes settling

Parameter	Initial Conc. (mg/l) (Average of all storms)	Final Conc. (mg/l) (Average of all storms)	% Removal
TSS	145.9	4.25	97
VSS	89.9	2.75	97
NVSS	56.0	1.5	97
COD	168.9	62.4	63
TKN	4.2	1.89	55
NH ₃	0.5	0.16	68
TOC	139.9	14.2	90
TP	1.0	0.028	97

Parameter	$\frac{X_i}{TSS_i}$	$\frac{X_F}{TSS_F}$	$\frac{X_F}{TSS_F}$
TSS	1	1	0.029
VSS	0.616	0.647	0.0189
NVSS	0.384	0.353	0.0103
COD	1.16	14.7	0.438
TKN	0.029	0.445	0.013
NH ₃	0.0034	0.038	0.0011
TOC	0.959	3.34	0.097
TP	0.0069	0.0066	0.0002

FERRIC CHLORIDE TREATED

1) Port 5 (4.5 ft) at 60 minutes settling

<u>Parameter</u>	<u>Initial Conc. (mg/l)</u> (Average of all storms)	<u>Final Conc. (mg/l)</u> (Average of all storms)	<u>%</u> <u>Removal</u>
TSS	145.9	10	93
VSS	89.9	5	94
NVSS	56.0	5	91
COD	168.9	56.25	67
TKN	4.2	1.4	67
NH ₃	0.5	0.223	55
TOC	139.9	-----	--
TP	1.0	0.05	95

<u>Parameter</u>	$\frac{X_i}{\text{TSS}_i}$	$\frac{X_F}{\text{TSS}_F}$	$\frac{X_F}{\text{TSS}_F}$
TSS	1	1	0.069
VSS	0.616	0.5	0.034
NVSS	0.384	0.5	0.034
COD	1.16	5.63	0.386
TKN	0.029	0.14	0.0096
NH ₃	0.0034	0.022	0.0015
TOC	0.959	-----	-----
TP	0.0069	0.005	0.0003

2) Port 3 (3.17 ft) at 60 minutes settling

Parameter	Initial Conc. (mg/l) (Average of all storms)	Final Conc. (mg/l) (Average of all storms)	% Removal
TSS	145.9	9	94
VSS	89.9	4	96
NVSS	56.0	5	91
COD	168.9	46.87	72
TKN	4.2	0.84	80
NH ₃	0.5	0.207	59
TOC	139.9	-----	--
TP	1.0	0.061	94

Parameter	$\frac{X_i}{\text{TSS}_i}$	$\frac{X_F}{\text{TSS}_F}$	$\frac{X_F}{\text{TSS}_F}$
TSS	1	1	0.062
VSS	0.616	0.444	0.027
NVSS	0.384	0.555	0.034
COD	1.16	5.2	0.321
TKN	0.029	0.093	0.0058
NH ₃	0.0034	0.023	0.0014
TOC	0.969	-----	-----
TP	0.0069	0.0067	0.00042

3) Port 1 (1.17 ft) at 60 minutes settling

Parameter	Initial Conc. (mg/l) (Average of all storms)	Final Conc. (mg/l) (Average of all storms)	% Removal
TSS	145.9	11	92
VSS	89.9	5	94
NVSS	56.0	6	89
COD	168.9	67.5	60
TKN	4.2	1.68	60
NH ₃	0.5	0.223	55
TOC	139.9	-----	--
TP	1.0	0.05	95

Parameter	X_i <u>TSS_i</u>	X_F <u>TSS_F</u>	X_F <u>TSS_F</u>
TSS	1	1	0.075
VSS	0.616	0.45	0.034
NVSS	0.384	0.55	0.041
COD	1.16	6.14	0.463
TKN	0.029	0.153	0.0116
NH ₃	0.0034	0.02	0.0015
TOC	0.959	-----	-----
TP	0.0069	0.005	0.0003

LIME TREATED

1) Port 5 (4.5 ft) at 60 minutes settling

Parameter	Initial Conc. (mg/l) (Average of all storms)	Final Conc. (mg/l) (Average of all storms)	% Removal
TSS	145.9	25	83
VSS	89.9	12	87
NVSS	56.0	13	77
COD	168.9	50	70
TKN	4.2	0.98	77
NH ₃	0.5	0.94	0
TOC	139.9	-----	--
TP	1.0	0.427	57

Parameter	$\frac{X_i}{TSS_i}$	$\frac{X_F}{TSS_F}$	$\frac{X_F}{TSS_F}$
TSS	1	1	0.171
VSS	0.616	0.48	0.082
NVSS	0.384	0.52	0.089
COD	1.16	2.0	0.343
TKN	0.029	0.04	0.0067
NH ₃	0.0034	0.04	0.0064
TOC	0.959	-----	-----
TP	0.0069	0.017	0.0029

2) Port 3 (3.17 ft) at 60 minutes settling

<u>Parameter</u>	<u>Initial Conc. (mg/l)</u> (Average of all storms)	<u>Final Conc. (mg/l)</u> (Average of all storms)	<u>% Removal</u>
TSS	145.9	24	84
VSS	89.9	8	91
NVSS	56.0	16	71
COD	168.9	36	79
TKN	4.2	0.77	82
NH ₃	0.5	0.059	88
TOC	139.9	-----	--
TP	1.0	0.354	65

<u>Parameter</u>	<u>TSS_i</u>	<u>TSS_F</u>	<u>TSS_F</u>
TSS	1	1	0.164
VSS	0.616	0.333	0.055
NVSS	0.384	0.666	0.11
COD	1.16	1.5	0.25
TKN	0.029	0.032	0.0053
NH ₃	0.0034	0.0025	0.0004
TOC	0.959	-----	-----
TP	----- 0.0069	0.015	0.0024

3) Port 1 (1.17 ft) at 60 minutes settling

Parameter	Initial Conc. (mg/l) (Average of all storms)	Final Conc. (mg/l) (Average of all storms)	% Removal
TSS	145.9	24	84
VSS	89.9	12	87
NVSS	56.0	12	79
COD	168.9	70	59
TKN	4.2	1.4	67
NH ₃	0.5	0.059	88
TOC	139.9	-----	--
TP	1.0	0.321	68

Parameter	$\frac{X_i}{TSS_i}$	$\frac{X_F}{TSS_F}$	$\frac{X_F}{TSS_F}$
TSS	1	1	0.164
VSS	0.616	0.5	0.082
NVSS	0.384	0.5	0.082
COD	1.16	2.9	0.48
TKN	0.029	0.06	0.0096
NH ₃	0.0034	0.0025	0.0004
TOC	0.959	-----	-----
TP	0.0069	0.0133	0.0022

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