

TREATMENT OF URBAN STORMWATER RUNOFF
BY SEDIMENTATION

by

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I. INTRODUCTION

Urbanization promotes the delivery of contaminants to the aquatic environment by the overland passage of stormwater through the surrounding watershed. Sources of these contaminants include industry, automobiles, litter, animal wastes, dust, and deicing compounds. The increase of impervious surface area through land development leads to an increase in stormwater flow rates and volume. As a result, adverse impacts may include flooding, erosion, siltation, low recharge of groundwater, accumulation of debris, turbidity of streams, damage to aquatic life, and other impairments to water quality (1). With approximately 80 percent of the U. S. population living in urban areas and those areas increasing an estimated 1,500 square miles annually, the problem will continue to grow (2). However, proper management can lessen the impact of urban runoff.

As a response to the requirements of section 208 of Public Law 92-500 for developing regional water quality management plans, control and abatement projects are being implemented to minimize the impacts of nonpoint source pollution. One such management technique now used in urban regions is the construction of detention or sedimentation basins to control stormwater runoff. These basins serve to restrict the amount of sediment and other pollutants that enter urban water-courses. Prevention of the rapid runoff from the impermeable surfaces encountered in business and residential areas also reduces waste treatment plant bypass and overflow in localities with combined sewer systems.

Because of variances in stormwater flow rates and contaminant con-

centrations with time, the design of pollutant control devices is difficult (3). Detention basin designs are generally aimed at restricting both peak flows and sediment loads (4). The determination of basin efficiency for pollution control would assist in developing the most cost-effective stormwater management policies for a given area.

In recent years, many investigations have been performed on basin efficiency and the available literature is extremely variable in methods and results. Research has been conducted using computer models, laboratory simulations, and basins in actual operation. Variations were encountered as a result of differences in characteristics of sampling locations such as land use, soil type, climate, vegetative cover, among others. Most investigations have dealt only with sediment removal. Consequently, the existing information on detention basin removal of the broad range of pollutants associated with urban runoff is scant.

The objective of this research project was to characterize the degree of treatment that could be achieved by gravity sedimentation of stormwater from highly impermeable areas. A laboratory scale model was used to simulate a detention basin. Thirty-three water quality parameters were examined at subsequent water column depths and time intervals to evaluate settling efficiency. Three commercial areas (shopping centers) were selected as sampling sites due to their large impermeable surface areas and because they were representative of locations where basins would be constructed. Because stormwater runoff can conceivably contain any pollutant found in the surrounding watershed and removal capabilities are dependent upon pollutant characteristics, this study should be helpful in determining the potential effectiveness of local detention basin use.

II. LITERATURE REVIEW

The Urban Stormwater Problem

Urban runoff is a nonpoint source of pollution that has received much attention since the 1972 Amendments to the Federal Water Pollution Control Act (Public Law 92-500). Previously, water quality management had dealt mainly with the control of point source pollution such as industrial and sewage treatment plant effluents. With about one-half of the stream lengths in the United States having limited water quality and an estimated 30 percent of these streams contaminated with urban runoff, it has become obvious that secondary treatment of point sources is not enough to maintain receiving water quality (5).

The runoff process begins with precipitation dissolving and removing materials from the air such as particulates, carbon monoxide, sulfur oxides, and nitrogen oxides (6). As precipitation reaches urban surfaces, additional pollutants are collected from places such as buildings, streets, undeveloped land, industrial areas, and parking lots. Increasing volume and flow velocities intensify the ability of runoff to mobilize pollutants through solution, scour, and suspension (7). As a result, sediment, organic material, nutrients, heavy metals, and pathogenic bacteria are transported to nearby watercourses or collection systems.

Stormwater has been proven to be a significant pollutant source and has been shown to cause three types of problems: combined sewer system overflows, surface runoff with or without storm sewer collection, and sewage treatment plant overflows (8). Table I compares the general quality of these wastewaters with that of municipal sewage (8).

TABLE I. COMPARISON OF GENERAL WATER QUALITIES* (8)

Type	BOD ₅ mg/L	Suspended solids mg/L	Total coliforms MPN/100 ml	Total nitrogen mg/L-N	Total phosphorus mg/L-P
Untreated municipal	200	200	5×10^7	40	10
Treated municipal					
Primary effluent	135	80	1×10^7	35	8
Secondary effluent	25	15	1×10^3	30	5
Combined sewage	115	410	5×10^6	11	4
Surface runoff	30	630	4×10^5	3	1

* Flow weighted means used to base values

Concentrations of degradable organic matter, measured by the 5-day biochemical oxygen demand, (BOD_5) in combined sewer systems are about one-half those of untreated municipal sewage. In surface runoff, organic concentrations are greater than that typically found in secondary-treated municipal effluent. The accuracy of biochemical oxygen demand measurements on runoff is questionable, however, because stormwater can contain significant amounts of toxic materials, such as heavy metals, that interfere with the microbial utilization of organics.

Stormwater runoff may contain solids concentrations greater than or equal to untreated sewage, and bacterial contamination in levels considered unsafe for water contact (8,9). Colston (10), in a study of urban runoff in Durham, North Carolina, found municipal waste had greater concentrations of organic material, but urban runoff contained higher suspended solids and metals concentrations.

Randall et al. (11) attributed approximately 85 and 89 percent of the nitrogen and phosphorus going into the Occoquan Reservoir in Virginia, to stormwater runoff. They concluded that eutrophication control could not be accomplished with the elimination of point source discharges only. Furthermore, the greatest pollutant loads were from the urban section of the study area even though the agricultural section was almost twice as large.

The disruption of drainage patterns within a watershed by urban development increases the velocity and amount of stormwater runoff. As velocities increase, the sediment concentrations in runoff increase (12). Sediment impairs water quality by causing conditions such as turbidity, blanketing of aquatic habitats, and interference in channels,

conduits, and navigable waterways (7). High sediment loads are of further importance because other types of pollutants are associated with sediment (7,12). For example, sediment transports and stores adsorbed phosphorus and nitrogen (13). This phenomenon will be discussed in a later section.

Ragan and Dietemann (14) reported on a survey of sediment loadings in the Anacostia River in Maryland. For a 10 cubic foot per second/square mile flood flow, the river was described as having a sediment load of 15 tons/square mile. After the start of urban development, that load increased to 45 tons/square mile. Accordingly, one of the tributaries discharging into the Anacostia increased from an average of 9 feet in width to an average of 37 feet. This is an excellent example of the physical alteration of a stream that occurs as a result of urban development and the need for control of runoff rates to prevent erosion. In the same study, a marked increase was found in the recurrence of 1, 2, 5, 10, and 20-year floods which Ragan and Dietemann (14) described as "representative of the behavior of urban streams."

Increased velocities also transport larger size particles, but large particles are not an indication of a higher pollutant concentrations (12). Sartor et al. (15) in a study on street surface contaminants, found the major portion of pollutants to be inorganic material similar to silt and sand. The quality of pollutants present depended upon the length of time that had passed since a street had been cleaned by either rain or street cleaning. More importantly, the greatest levels of pollutants were associated with the finer portion of street contaminants. The very fine particles that were less than

43 microns in size made up only 5.9 percent of the total solids, but contained 33 to 50 percent of the algal nutrients, 25 percent of the oxygen demand, and 50 percent of the heavy metals. This is of significance because conventional street-sweeping practices have been shown to leave 85 percent of the particles less than 43 microns on the street surface. Therefore, such practices are not always effective in reducing contaminant concentrations (12, 15, 16).

Pitt (16) compared the concentration of pollutants in runoff with that of samples of street dirt. Results indicated that street activities contributed the greatest portion of heavy metals, while erosion and runoff during a storm contributed nutrients and organic materials. Typical heavy metals encountered in runoff include zinc, maganese, iron, cadmium, copper, nickel, lead, and chromium (6).

Christensen and Guinn (17) established a quantitative relationship between the concentrations of lead and zinc in runoff and the amount of lead found in gasoline and zinc in automobile tires. Measurements of lead and zinc in runoff from the study area reasonably agreed with their calculated street deposition values of 0.0030 grams zinc/vehicle kilometer and 0.0049 grams lead/vehicle kilometer. They mentioned that other sources of heavy metals may include building and fence corrosion or industrial activities.

Wilber and Hunter (18); in a study of metals in stormwater in Lodi, New Jersey; most frequently encountered lead, zinc, and, occassionally, copper. These three metals made up 90 to 98 percent of the total quantity of metals found. In addition, when compared to precipitation and secondary treatment plant effluent annual metals yields, stormwater contributed 86 percent of the total annual load of heavy metals.

Stormwater Management

The purpose of stormwater management is to prevent or reduce the adverse impacts created by runoff such as flooding, erosion, and impairments to water quality. In early stormwater management, sewer systems were used for quick removal. This practice addressed only flooding and resulted in a relocation of the problem downstream while further increasing stream flow rates. Current management techniques have turned towards the maintenance of the natural flows by enhancing infiltration or the use of physical controls (1). Management of flow rates is intended to restrict the peak rate after land development to that which occurred before (19).

Wildrick et al. (6) discussed various management techniques for urban runoff source control that included improving stormwater drainage, on-site detention, erosion control, public works practices, and legal remedies. Improving stormwater drainage involves restoring natural drainage patterns, where appropriate, by the elimination of curbs and gutters, disconnecting drain spouts that empty into sewer systems, the use of porous pavement, aerating vegetative strips to increase infiltrations, and storage in stream channels. On-site detention collects excess runoff and stores it in parking lots, detention ponds, holding tanks, and on rooftops. Control of erosion may be brought about by predevelopment planning and by selecting the correct vegetative cover. Mulching, surface roughening, and filters (crushed stone, straw, or sandbags) are used to trap the coarser sediment. Public works practices prevent pollution by street cleaning, catch basin cleaning, refuse collection, control of deicing salts, sewer cleaning, and using separate sewers for stormwater.

Legal remedies involve enacting legislation to prevent and control activities causing runoff pollution.

The ineffectiveness of conventional street sweeping in removing the large pollutant levels associated with fine particle sizes has been mentioned previously. In addition, according to Pitt (16), street cleaning equipment removes large particles that are associated with aesthetics more effectively than finer particles that typically have greater pollutant strengths. Field (5), however, stated that fine materials could be removed more effectively with vacuum and air-blast street cleaners. Therefore, the contribution of street cleaning practices towards the elimination of potential water pollution should not be underestimated.

Storage Basins

Experience has shown that sedimentation control during construction activities in urban regions can be effectively accomplished with the use of basins below the site (4). Detention basins store runoff temporarily and control water release rates while draining. Retention basins or ponds maintain a permanent body of water while receiving and releasing runoff (20). Return period, storm duration, and land use affect the inflow volume, so all must be taken into consideration in basin design (21).

A detention basin is designed to limit the peak release rate after development to that of the design storm prior to development. They may be natural or man-made, and accumulations of sediment on the basin bottom, which could affect pollutant removal efficiency, are removed when needed (22). Dual-purpose detention basins provide local flood

control and reductions of particulate contaminants (23). Storm duration is an important consideration in detention facility design because if designs are based upon short duration events, long duration storms may bring about flooding (24).

It has been suggested that detention and retention basins may be used for recreational as well as management purposes (22, 25, 26), thus increasing the advantages to a locality. Nightingale (27), however, discussed the accumulation of lead, zinc, and copper in soils found in retention basins used for flood control, recreation, and groundwater recharge in Fresno, California. Large concentrations of lead, zinc, and sometimes copper were found in the first 5 centimeters of soil and decreased in amount down to 15 centimeters. He concluded that lead concentrations could accumulate to the point of becoming a health hazard if basins are also used for recreation purposes.

As previously mentioned, the design of a detention basin is generally based upon the control of peak flows and the removal of sediment. A study undertaken by Davis et al. (4) on detention basin efficiency concluded that design criteria for pollutant control is different from that of stormwater flow-rate control. Riser characteristics are important for flow-rate restrictions while flow length and retention time influence pollution control.

Sediment deposition depends upon soil properties, detention time, basin depth, and sediment concentrations. Detention time and depth are related to design. Sediment concentrations in the inflow are a function of rain intensity, vegetative cover, soil properties and permeability, and distances and slope during transport through the watershed (28).

Sediment-Pollutant Relationships

In runoff, a state of equilibrium among dissolution rates, atmospheric exchange, and removal to solid forms may be reached for pollutants. This state involves continuous changes in rates and direction and may not even be reached for any significant length of time (29). Pollutants can be found dissolved in water, in solid form, or adsorbed to particles of soil (30).

The colloidal fraction of the sediment load is generally associated with pollutant transport. As the size and weight of particles decrease, the transportability of adsorbed pollutants increases per unit weight of soil (30). Adsorption can be described as a physicochemical process in which particles of soil immobilize ions or molecules (31).

Lead and cadmium in solution may be a result of being part of organic or inorganic complexes, in hydrated cation form, or adsorbed to suspended material such as silica, clays, and organic matter (32, 33). Willis (33) cited Bunzel et al. (34) on the adsorption and desorption of Pb^{2+} , Cd^{2+} , Cu^{2+} , Zn^{2+} , and Ca^{2+} on peat. Adsorption was found to occur in the selective order of $Pb^{2+} > Cu^{2+} > Cd^{2+} \cong Zn^{2+} > Ca^{2+}$ in a pH range of 3.5 to 4.5. Adsorption seemed to be an ion exchange process where two H_3O^+ ions were exchanged for each cation adsorbed.

To compare the adsorption of various nutrients, an adsorption partition coefficient (K_s) may be used (30):

$$K_s = \frac{\text{concentration of substances adsorbed to soil particles (ppm; mg/L)}}{\text{concentration of substance in solution (ppm; mg/L)}}$$

Table II lists typical partition coefficient groupings for selected nutrients (30). Phosphorus is a strongly adsorbed nutrient (30). However, nitrate is not adsorbed by soil particles (30, 35). It is for this

TABLE II. NUTRIENTS GROUPED ACCORDING TO
ABSORPTION PARTITION COEFFICIENTS (30)

Group I $K_s \sim 1000$	Group II $K_s \sim 5$	Group III $K_s \sim 0-0.5$
Organic Nitrogen	Soluble Inorganic Phosphorus	Nitrate
Ammonium		
Solid Phase Phosphorus		

Group I.	Strongly absorbed and solid phase pollutants
Group II.	Moderately absorbed pollutants
Group III	Nonabsorbed or soluble pollutants

reason that nitrate is often a major portion of the total nitrogen concentration found in urban runoff where proper management has limited erosion (36).

Collins and Ridgway (12) studied the relationships between sediment and various pollutants. Using a computer model, they found total organic nitrogen, ammonia, total phosphorus, biochemical oxygen demand, total iron, and total lead concentrations were dependent upon the amount of solids present. However, parameters such as soluble orthophosphate, nitrate, chloride, fecal coliform bacteria, total dissolved solids, and oil and grease correlated with the quantity of runoff.

Sedimentation Theory

Detention basins are often irregularly shaped and poorly defined as hydraulic structures. They are usually small in size, however, and the function of a detention basin can resemble that of a sedimentation tank in a water treatment plant (37). Therefore, the same settling theories applied to the design of treatment plants have been used to describe detention basin sedimentation (25).

Sedimentation basin design normally centers upon the theory of the ideal basin as depicted in Figure 1 (38). Flow is assumed to be horizontal in the settling region and all particles are distributed uniformly in the entrance zone (39). When entering the ideal basin, a discrete particle will have a vertical settling velocity, v_s , that is the same as its terminal settling velocity when described by Newton's or Stokes' Law:

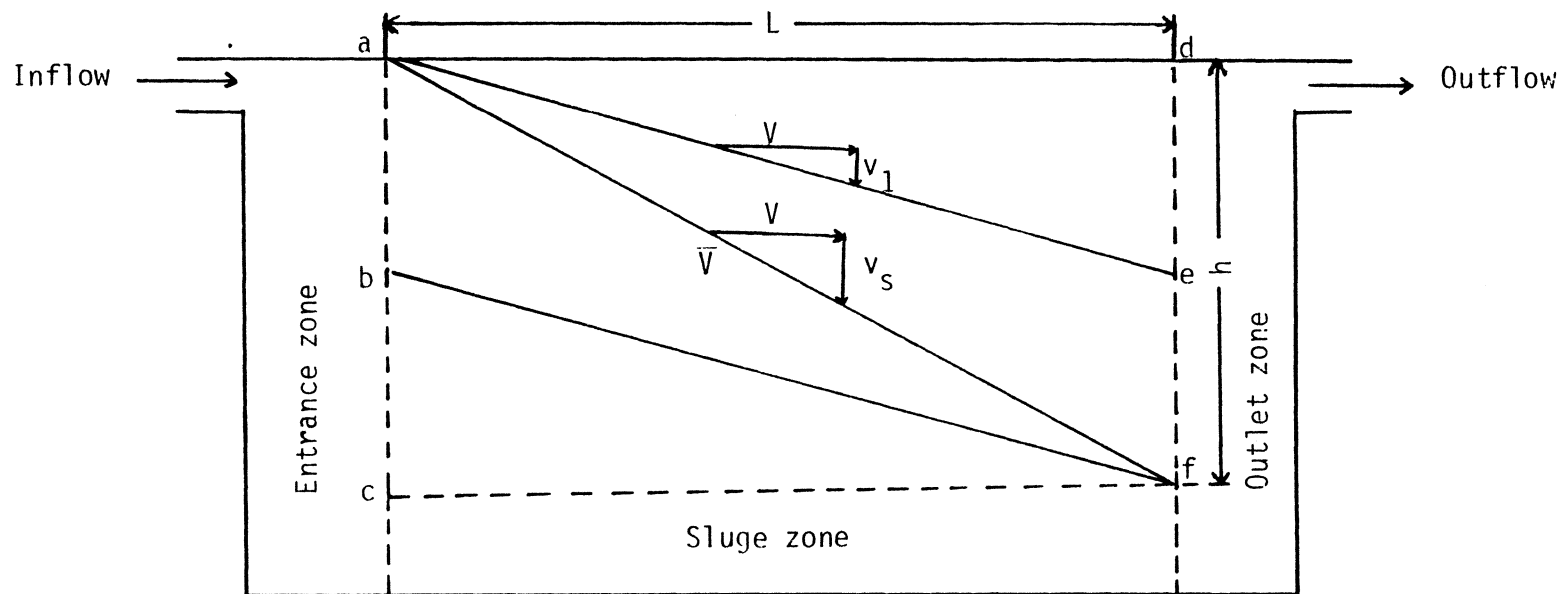


FIGURE 1. IDEAL SEDIMENTATION BASIN (38)

$$\text{Newton's Law} \quad v = \left[\frac{4g(\rho_s - \rho) d}{3C_D \rho} \right]^{\frac{1}{2}} \quad [1]$$

$$\text{Stokes' Law} \quad v = \frac{g}{18\mu} (\rho_s - \rho) d^2 \quad [2]$$

where v = terminal settling velocity
 ρ_s = particle mass density
 ρ = fluid mass density
 g = acceleration due to gravity
 d = particle diameter
 C_D = dimensionless drag coefficient
 μ = fluid absolute viscosity

The dimensionless drag coefficient is expressed as:

$$C_D = \frac{24}{N_R} + \frac{3}{\sqrt{N_R}} + 0.34 \quad [3]$$

where N_R = Reynolds number, $\frac{vd\rho}{\mu}$

This equation applies for Reynolds numbers as great as 1000. However, when the Reynolds number is less than 0.5, part of the equation is neglected and becomes:

$$C_D = \frac{24}{N_R} = \frac{24\mu}{vd\rho} \quad [4]$$

which, after substitution into Newton's Law, forms Stokes' Law (38).

The particle will also have a horizontal settling velocity, V , that will be equal to the basin fluid velocity:

$$V = Q/A = Q/w \cdot h \quad [5]$$

in which Q is the rate of flow and A is the area of the basin. In order for a particle to be removed, the terminal settling velocity and

the horizontal settling velocity must result in a factor, $\bar{V}$, that will deposit it on the basin bottom before reaching the outlet. A surface overflow rate may be used to represent the velocity of the slowest particle that is completely removed by settling. The surface overflow rate numerically equals the flow rate divided by the basin plan area (38). It is commonly expressed in gallons/day/ft² or meters/day, and may be obtained from settling velocities by a conversion in the units of expression as shown in Table III.

The overflow rate may be defined by:

$$\begin{aligned} v_s/V &= h/L, \text{ or} \\ v_s &= Vh/L = h/L \cdot Q/w \cdot h = Q/wh \end{aligned} \quad [6]$$

All particles having settling velocities greater than or equal to the overflow rate will be completely removed. Particles with settling velocities less than the overflow rate will undergo removal in direct proportion to the ratio of their settling velocity to the surface overflow rate. In Figure 1 (38), a particle that enters the basin at point a and has a velocity of v_1 will exit the basin through the outflow. The same particle entering at point b with an equal velocity will be completely removed. The number of particles, X_r , with velocity v_1 that will be removed can be related to the vertical dimensions of b-c and a-c in Figure 1 (38)

$$X_r = \frac{b-c}{a-c} = \frac{v_1/V \cdot L}{v_s/V \cdot L} = \frac{v_1}{v_s} \quad [7]$$

The prediction of basin efficiency for suspended particles with a wide assortment of densities and sizes can be accomplished by the determination of the particle size distribution or by the use of a settling column analysis (38). In laboratory settling column, the

TABLE III. CONVERSION OF SETTLING VELOCITIES TO OVERFLOW RATES

Settling Velocities ^a	Overflow Rates
63 millimeters/second ^b	1.3×10^4 gallons/day/ft ²
1000 millimeters/second ^c	2.1×10^6 gallons/day/ft ²
0.025 millimeters/second ^d	53.06 gallons/day/ft ²

a. Settling velocities from reference (40)

b. Velocity for sands

c. Velocity for gravels

d. Velocity for fine silt

overflow rate can be determined by dividing the effective depth of the column by the amount of time needed for a given percent of solids to settle through that depth (41). When wastewater is known to contain particles that settle discretely by maintaining their individuality during settlement, one sample port along the column depth is used for analysis. If wastewater contains mostly suspended organic matter, there is a tendency for materials to aggregate. Hence, flocculant settling occurs. In a wide particle size distribution, large and small particles combine, and the new larger particles formed will settle faster than the originals. Laboratory settling column tests differ in that more sampling ports are used (39). Figure 2 represents such a column (41).

Sedimentation Efficiency

Because of the expense and necessity of storage basins, it is important to determine the factors influencing efficiency and the degree of treatment possible. From a study of the treatment of stormwater discharges and combined sewer overflows in an Environmental Protection Agency (EPA) publication, the effectiveness of stormwater sedimentation in removing suspended solids was between 20 to 60 percent and 30 percent for 5-day biochemical oxygen demand (42). Table IV lists average sedimentation removal values for various constituents from combined sewer overflow storage facilities (42, 43). Unfortunately, settling times were not provided.

The particle size distribution has a very important effect on sediment trap efficiency. As the portion of larger particles increases, the total amount of solids that settle increases (24). Detention basins

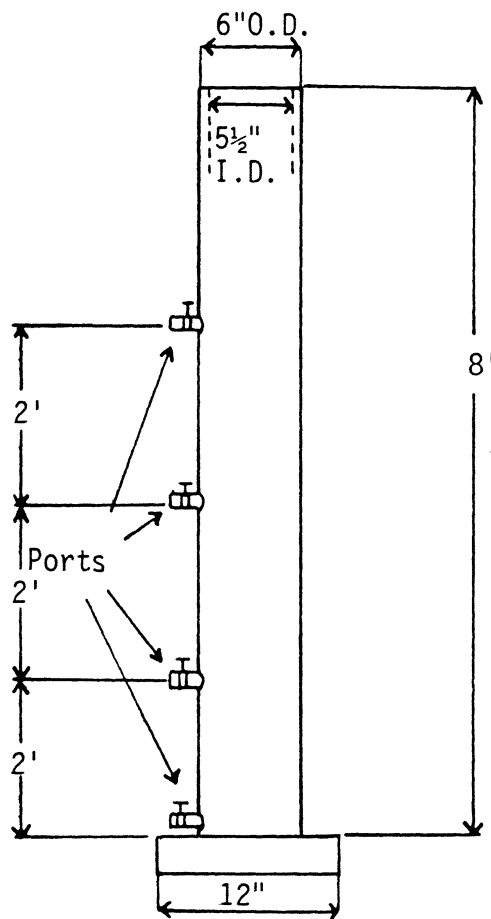


FIGURE 2. LABORATORY SETTLING COLUMN (41)

TABLE IV. AVERAGE SEDIMENTATION REMOVAL VALUES FROM COMBINED SEWER OVERFLOW AS CITED BY THE EPA (42) FROM THE CITY OF NEW YORK ENVIRONMENTAL PROTECTION ADMINISTRATION (43)

Pollutant	Average Percent 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	0.0
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

normally remove settleable solids which have diameters of 10 microns or greater. Solids from 1 to 10 microns in diameter are considered non-settling. At 10°C, settling velocities for settleable solids vary between 63 to 1000 millimeters per second for sands and gravel and less than 0.025 millimeters per second for fine silt. Because of the association of small diameter solids with the major portion of the contaminant load, basin design must focus on the removal of these particles (40).

Kamedulski and McCuen (21) evaluated stormwater management policies with a mathematical model. The model predicted the efficiency of detention basins with flow and sediment data. Results indicated trap efficiency to be dependent upon the sediment in the inflow and the basin storage volume. Trap efficiency ranged between 85 and 95 percent, the high values being attributed to the watershed soil's large particle sizes. This investigation involved four different basin design policies, and adjustments to the basin surface area and riser diameter and height were made to obtain the optimum design.

Ward et al. (28) developed a mathematical model to predict sedimentation in detention basins. Results of particle size and trap efficiency relationships indicated that particle sizes below 20 microns were most significant in determining basin efficiency. This model offers the advantage of not being limited by the geometry or outlet structure of a particular basin.

Curtis and McCuen (37) also developed a mathematical model to study detention basin efficiency. They found that detention basin location, particle size distribution, depth, and orifice diameter

influenced efficiency. The model was capable of simulating many different design conditions that would be beneficial to management concerns over design criteria and performance. This model, as well as the former models, provide information only on sediment trap efficiencies. Because of the need to remove other pollutants found in runoff, the effect of detention on these pollutants must also be studied.

McCuen (19) examined trap efficiencies for eleven, water-quality parameters from a stormwater basin in Maryland and found that most pollutants were removed at least 60 percent. He was able to determine trap efficiencies for various return periods and storm duration but was limited to the design characteristics of the particular basin site used.

Oliver and Grigoropoulos (44) performed a study on the detention of stormwater using a small lake and found this practice to be effective in improving water quality. An average decline of 89 percent was observed for total suspended solids, 65 percent for total phosphorus, 52 percent for chemical oxygen demand, and 31 percent for organic nitrogen. Ammonia increased by 13 percent. The authors stated that the lake was being used for recreational purposes but did not assess the effects of stormwater addition on recreation. The addition of nutrients, heavy metals, organic matter, and pathogenic bacteria; all of which are commonly found in stormwater; may produce aesthetic or health concerns.

Ferrara and Witkowski (45) described influent and effluent pollutant concentrations in a stormwater detention basin sampling project. Total phosphorus, total Kjeldahl nitrogen, chemical oxygen demand, and solids concentrations were determined for three particle

size ranges. The particle size ranges were separated by filtration using 1 micron glass fiber filters, 105 micron polypropylene filters, and unfiltered portions of samples. The greatest concentrations of all four parameters tested were found to occur in the range of less than one micron. For the three storm events used in this study, total solids concentrations were reduced 36.2, 14.7, and 46.7 percent in the basin effluent. Solids concentrations in the effluent were relatively the same throughout the study. Percent reductions of total chemical oxygen demand were 11.4, 9.7, and 20.7. In two of the storm events, the basin exhibited increases in the effluent of about 20 percent in total Kjeldahl nitrogen. Only one storm event displayed significant total phosphorus reduction, which was greater than 40 percent. The authors attributed pollutant removal in the basin to equalization and sedimentation processes.

Characklis et al. (46) discussed a monitoring study of urban development in a planned community in Texas involving stormwater source controls. The project thoroughly examined water quality and hydrologic data to assess management plans. With the use of a man-made lake, a reduction of 81 percent was observed in the sediment load from seven storms. Orthophosphate-phosphorus, ammonia, and nitrites and nitrates increased in the lake outflow which was attributed to unmonitored runoff and rainfall entering the lake, and the water quality of the lake itself.

To effectively reduce pollutant concentrations, an adequate detention time must be established. Whipple and Hunter (47) investigated the removal of urban runoff pollutants by sedimentation in a laboratory settling column and found substantial reductions in pollutant

concentrations after thirty-two hours. Suspended solids, lead, and hydrocarbons were reduced approximately 70, 60, and 65 percent, respectively. Zinc removals were between 17 and 36 percent, and copper, nickel, and biochemical oxygen demand reductions ranged from 20 to 50 percent.

Bennett et al. (48) evaluated pollutant reductions from snowmelt and rainfall flows by treatment methods that included sedimentation, chemical clarification, and filtration in a laboratory-scale treatment system. The results showed sedimentation alone was not as effective for snowmelt runoff as it was for rainfall runoff. This was due to the colloidal nature of the particulates found in snowmelt. Because rainfall runoff has been the center of most research studies, this project was beneficial in characterizing both precipitation varieties.

Many other physical-chemical treatment studies have been conducted to determine the feasibility of application on urban runoff. Samar et al. (49) used jar tests in a physical-chemical treatment involving alum coagulation, flocculation, sedimentation, and powered activated carbon adsorption. With this method, average values of turbidity, chemical oxygen demand, and lead were reduced 97, 85 and 100 percent. However, with sedimentation alone, average removals of 63, 64, and 82 percent were obtained for turbidity, chemical oxygen demand, and lead.

Mische and Dharamadhikars (50) used jar tests to observe the response of urban runoff to treatment. With the use of sedimentation alone, the chemical oxygen demand was reduced by 60 to 70 percent. After alum addition, removal was greater than 85 percent. Alexander (51) used jar tests on stormwater from the same Manassas Mall site used

in the current project and obtained chemical oxygen demand reductions of 30 percent by sedimentation and 50 percent with the use of chemical coagulation. Nitrogen and phosphorus concentrations were mainly composed of soluble forms, so they were not reduced efficiently with sedimentation alone. Colston (10) obtained values of 60, 77, and 50 percent for chemical oxygen demand, suspended solids, and turbidity after fifteen minutes of quiescent settling in jar tests. With the addition of alum, removals of 84, 99, and 94 percent were obtained for chemical oxygen demand, suspended solids, and turbidity. He stated that significant oxygen concentration improvements downstream could be obtained from the use of sedimentation storage impoundments.

Summary

The degree of contamination found in stormwater from urban regions is by no means minor. Urban runoff is considered a significant non-point source of pollution and control measures have been devised to minimize adverse effects. Storage basins have become one answer for the control of pollution as well as flooding. The available literature on research involving detention or sedimentation basin effectiveness has provided many factors responsible for pollutant entrapment efficiency. The information is somewhat fragmentary. Nonetheless, it appears that runoff detention can reduce contaminant concentrations significantly.

III. METHODS AND MATERIALS

Sampling Site Descriptions

Three commercial areas were chosen as sampling locations: Fair Oaks Mall in Fairfax, Virginia, and Manassas Mall and Manassas Shopping Center in Manassas, Virginia. These sites were selected because of their large, impermeable surface areas. They were also typical of locations in urban regions where basins are used to control runoff.

Fair Oaks Mall was a relatively new shopping center. Samples were collected from a 60-inch culvert that drains directly into a retention pond currently in use. The drainage area was 54.66 acres, and the pond discharged into Difficult Run, which flowed into the Potomac River.

At the Manassas Mall site, samples were taken from a 42-inch storm sewer that received drainage from a commercial area of about 23 acres. The storm sewer system emptied into Bull Run, which discharged into the Occoquan Reservoir.

The final site involved sample collection from 42-inch culvert under Portner Avenue in Manassas. This culvert collected runoff from the Manassas Shopping Center, which was a 30 acre commercial area, and discharged into a concrete channel that ran through a residential area. The channel eventually flowed into Bull Run, which discharged into the Occoquan Reservoir.

Parking and road areas at Manassas Mall and Fair Oaks Mall were cleaned daily. Manassas Shopping Center was cleaned five days a week. Cleaning practices at all three sites involved vacuum trucks and sweeping by hand. Table V lists the sampling sites and the dates on which samples were collected.

TABLE V. SAMPLING SITE AND DATES OF COLLECTION

Sampling Site	Collection Date
Fair Oaks Mall	6/20/81
	7/4/81
	10/23/81
Manassas Mall	7/5/81
	7/26/81
	8/11/81
Manassas Shopping Center	9/15/81

Sample Collection

Stormwater was collected by taking grab samples from the storm drainage systems during a storm event. Five 5½-gallon polyethylene carboys were used for collection. The samples were then taken to the Occoquan Watershed Monitoring Laboratory in Manassas, Virginia.

At the laboratory, 4 liters (1.06 gallons) from each of the five carboys were placed in a sixth carboy to obtain composite samples. Because of the variations in pollutant concentrations with time and flow, compositing was done to minimize any difference in pollutant concentrations between the carboys. Composited samples were then placed in four Plexiglas columns. The columns were five feet in depth, six inches in diameter, and a quarter-inch thick. Each column contained approximately 20 liters (5.28 gallons) of sample. Three ports on each column were used to withdraw sample at one-foot intervals, and at designated times.

Stormwater collected on June 30 from Fair Oaks Mall was used as a preliminary sample. This was treated differently from all others in that only one column was used and only solids, nutrients, and heavy metals determinations were made. Sampling depths were at one, two, and three feet. Sampling times were at zero, two, six, and twenty-four hours. The preliminary stormwater sample was taken for preparation for the following analytical procedures and sampling techniques.

After filling the columns, samples were withdrawn at consecutive intervals of either one, two, and three-foot depths or one, two, and four feet. The sampling times began initially following sample addition and after two, six, twelve, twenty-four, and forty-eight hours. Samples

were collected at the one-foot depth at time zero from each column to determine if any major variations existed in pollutant concentrations between the columns. This comparison was performed for five storms. Table VI lists the amount of sample taken from each column and the time.

Sample Analysis

Each sample was analyzed for total suspended solids, volatile suspended solids, particle size distribution, lead, zinc, copper, nickel, chromium, cadmium, nitrate and nitrite, total and soluble Kjeldahl nitrogen, ammonia, total and soluble phosphorus, and orthophosphate. Total and fecal coliform bacteria and 5-day biochemical oxygen demand were also determined but with less frequency, at zero, two, and twenty-four hours. Chemical oxygen demand analyses were made at time zero and at two, twenty-four, and forty-eight hours. Total and soluble organic carbon determinations were made at zero, two, twelve, twenty-four, and forty-eight hours. Dissolved oxygen was measured in two stormwater samples at all sampling time and depth intervals.

Total and volatile suspended solids were analyzed according to Section 209 D, Total Nonfiltrable Residue Dried at 103-105 C, and Section 209 G, Volatile and Fixed Matter in Nonfiltrable Residue and in Solid and Semisolid Samples, in Standard Methods for the Examination of Water and Wastewater (52).

Heavy metals were analyzed by the use of a Perkin-Elmer (Norwalk, Connecticut) Model 403 Atomic Absorption Spectrophotometer according to Perkin-Elmer (53). Filtered and non-filtered samples were used, with the filtered sample being obtained by passing a portion of sample through

TABLE VI. SAMPLE VOLUMES AND TIMES OF SAMPLING

Column No.	Time, (hr)	Sample Volume (ml)	No. of Samples Taken	Total Volume Removed (ml)
1	0	800	3	4200
	6	600	3	
2	0	750	1	3750
	2	1000	3	
3	0	600	1	4200
	12	600	3	
	48	600	3	
4	0	750	1	3750
	24	1000	3	

a Whatman 934AH glass, microfiber filter. Samples from four storms were sent to Virginia Tech in Blacksburg, Virginia, for lead determinations by a Perkin-Elmer (Norwalk, Connecticut) Model 703 Atomic Absorption Spectrophotometer according to Fernandez et al. (54) and EPA Methods for Chemical Analysis of Water and Wastes (55). Table VII lists the instrument detection limit for the heavy metals analyzed.

Nutrients were analyzed by the Technicon (Tarrytown, New York) Auto Analyzer II. Two triple-channel autoanalyzers were used to determine nutrient concentrations according to the EPA Methods for Chemical Analysis of Water and Wastes (55) and Technicon Industrial Methods (56). Soluble nutrients were from filtered aliquots collected during total suspended solids analyses. An ascorbic acid method (Technicon Method 94-70W) and a phenate method (Technicon Method 98-70W), both as modified by Farmer (57), were used for measurements of ortho-phosphate and ammonia, respectively. Total and soluble Kjeldahl nitrogen were analyzed by a phenate method (Technicon Method 324-74W), and total and soluble phosphorus were determined using an ascorbic acid method (Technicon Method 327-74W). Total and soluble Kjeldahl nitrogen and phosphorus samples were digested before analysis (58). Nitrates and nitrites were determined together by a cadmium reduction method (Technicon Method 100-70W).

Chemical oxygen demand was analyzed according to Section 508 A, Dichromate Reflux Method, in Standard Methods for the Examination of Wastewater (52). Total and soluble organic carbon were analyzed by an IONICS (Watertown, Massachusetts) Analyzer Model 1258, according to IONICS (59). Soluble organic carbon was determined in samples filtered

TABLE VII. INSTRUMENT DETECTION LIMITS FOR HEAVY METALS ANALYSES

Instrument	Heavy Metal	Detection Limit ($\mu\text{g/l}$)
Perkin Elmer Model 403	Lead	100
	Zinc	20
	Copper	20
	Cadmium	20
	Chromium	20
	Nickel	20
Perkin Elmer Model 703	Lead	1

through Whatman 934 AH glass microfiber filters. Five-day biochemical oxygen demand measurements were obtained with a HACH BOD manometer apparatus according to the HACH laboratory manual (60).

Total and fecal coliform bacteria were analyzed according to Section 908A, Standard Total Coliform MPN Tests, and Section 908 C, Fecal Coliform MPN Procedure, in Standard Methods for the Examination of Water and Wastewater (52). Particle-size distributions were determined by a HIAC (Menlo Park, California) Particle Size Analyzer Model PC-320 at Virginia Tech in Blacksburg, Virginia according to Knocke (61). Dissolved oxygen measurements were made with a Yellow Springs Instruments (Yellow Springs, Ohio) Model #57 meter.

Data Analysis

The data obtained from the laboratory analysis were manipulated to obtain additional information as listed in Table VIII. All mathematical and statistical computations were performed by the use of the Statistical Analysis System (SAS) according to Saunders (62) and SAS User's Guide (63).

During the initial sampling interval, some pollutant settling may have occurred within the minutes it took for the samples to be withdrawn from the column. To compensate for this and provide the most accurate estimate of initial pollutant concentrations, data from the three initial samples were averaged together following laboratory analysis.

TABLE VIII. PARAMETERS DERIVED FROM THE MANIPULATION OF LABORATORY DATA

Total Nitrogen	=	Total Kjeldahl Nitrogen + Nitrites and Nitrates
Organic Nitrogen	=	Total Kjeldahl Nitrogen - Ammonia-Nitrogen
Suspended Kjeldahl Nitrogen	=	Total Kjeldahl Nitrogen - Soluble Kjeldahl Nitrogen
Suspended Zinc	=	Total Zinc - Soluble Zinc
Suspended Lead	=	Total Lead - Soluble Lead
Suspended Organic Carbon	=	Total Organic Carbon - Soluble Organic Carbon
Suspended Phosphorus	=	Total Phosphorus - Soluble Phosphorus

IV. RESULTS

The following is a description of the results obtained by sedimentation of stormwater from seven storm events. Appendix Tables A-1, A-2, and A-3 contain lists of data obtained from the sample analyses. Sedimentation results were analyzed graphically by the approach commonly used for flocculant suspended solids.

Solids

Total suspended solids (TSS) initial concentrations varied from 15 to 721 milligrams per liter (mg/L) for the seven samples collected. Figures 3 through 9 show TSS settling profiles of percent reduction with time and depth. The lowest TSS concentrations of 15 mg/L occurred in the July 4 sample from Fair Oaks Mall. This sample displayed a slow TSS reduction until the second day, as seen in Figure 3, when TSS removal increased from about 25 percent at 24 hours to an average of nearly 80 percent after 48 hours.

The July 5 sample from Manassas Mall had an initial TSS concentration of 35 mg/L, and after 24 hours of settling, was reduced by 60 percent as shown in Figure 4. The preliminary sample collected on June 20 at Fair Oaks contained a similar initial TSS concentration of 38 mg/L. Settling results differed, however, in that TSS was reduced by 60 percent before 12 hours of settling had occurred. Figure 5 shows the settling profile of the June 20 sample.

Figure 6 shows the settling results from the October 23 Fair Oaks sample, which contained an initial TSS concentration of 100 mg/L. In this sample, a larger percent reduction occurred in a shorter period.

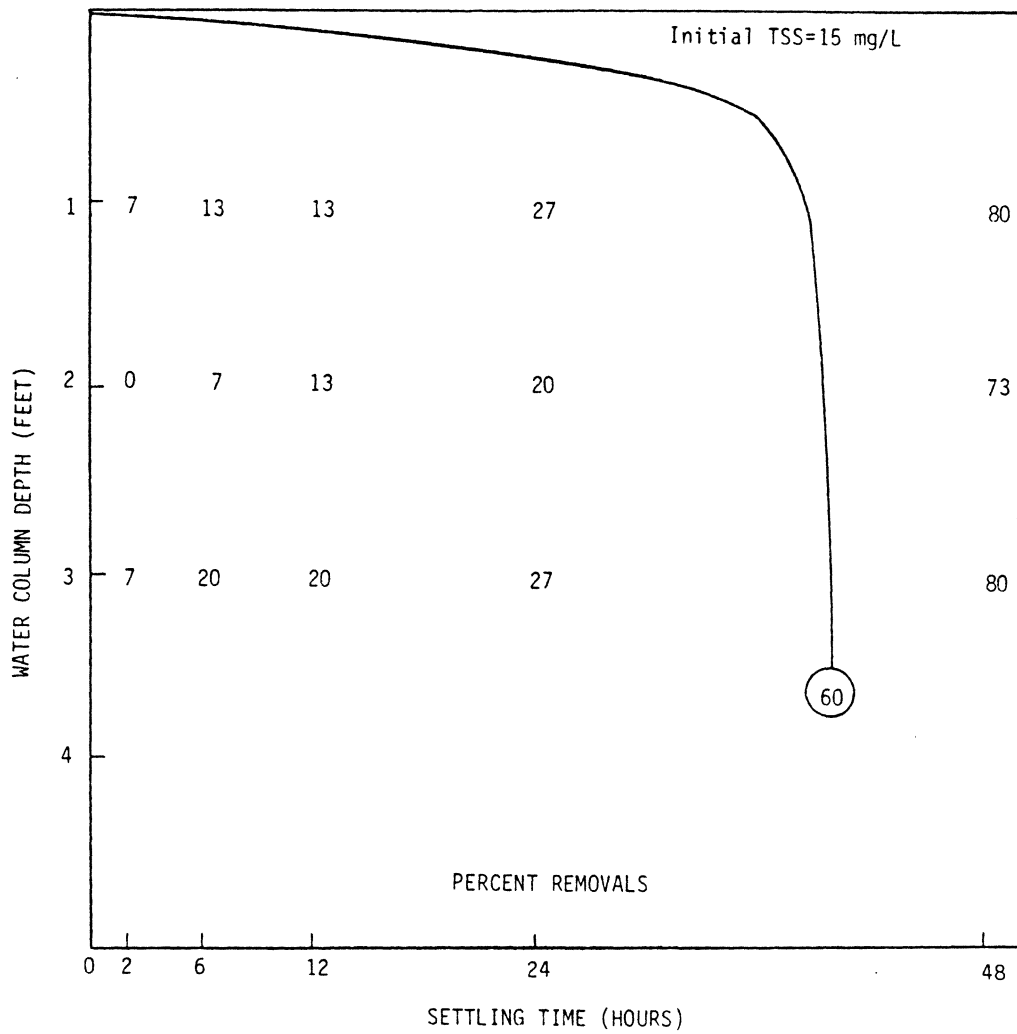


FIGURE 3. SEDIMENTATION REMOVAL OF TSS FROM FAIR OAKS MALL STORMWATER - JULY 4, 1981 SAMPLE

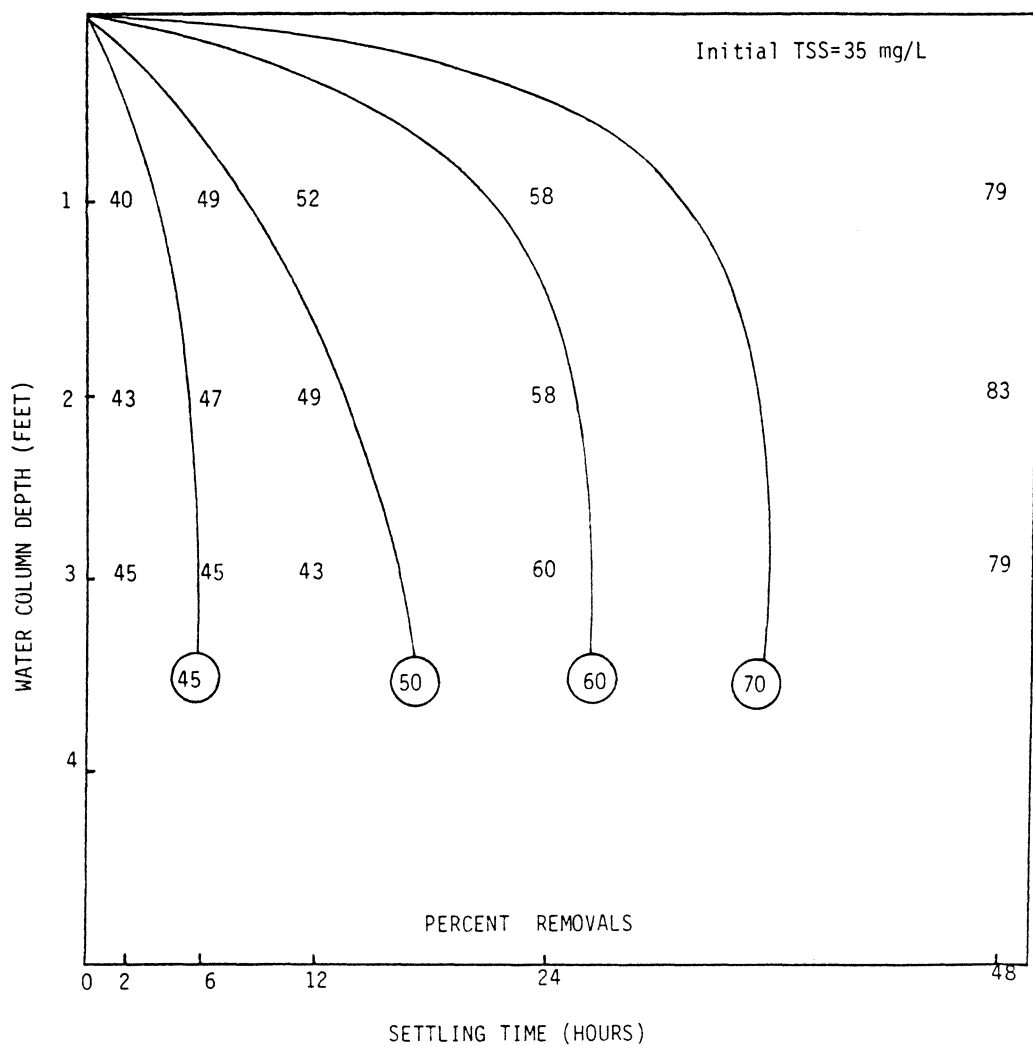


FIGURE 4. SEDIMENTATION REMOVAL OF TSS FROM MANASSAS MALL STORMWATER - JULY 5, 1981 SAMPLE

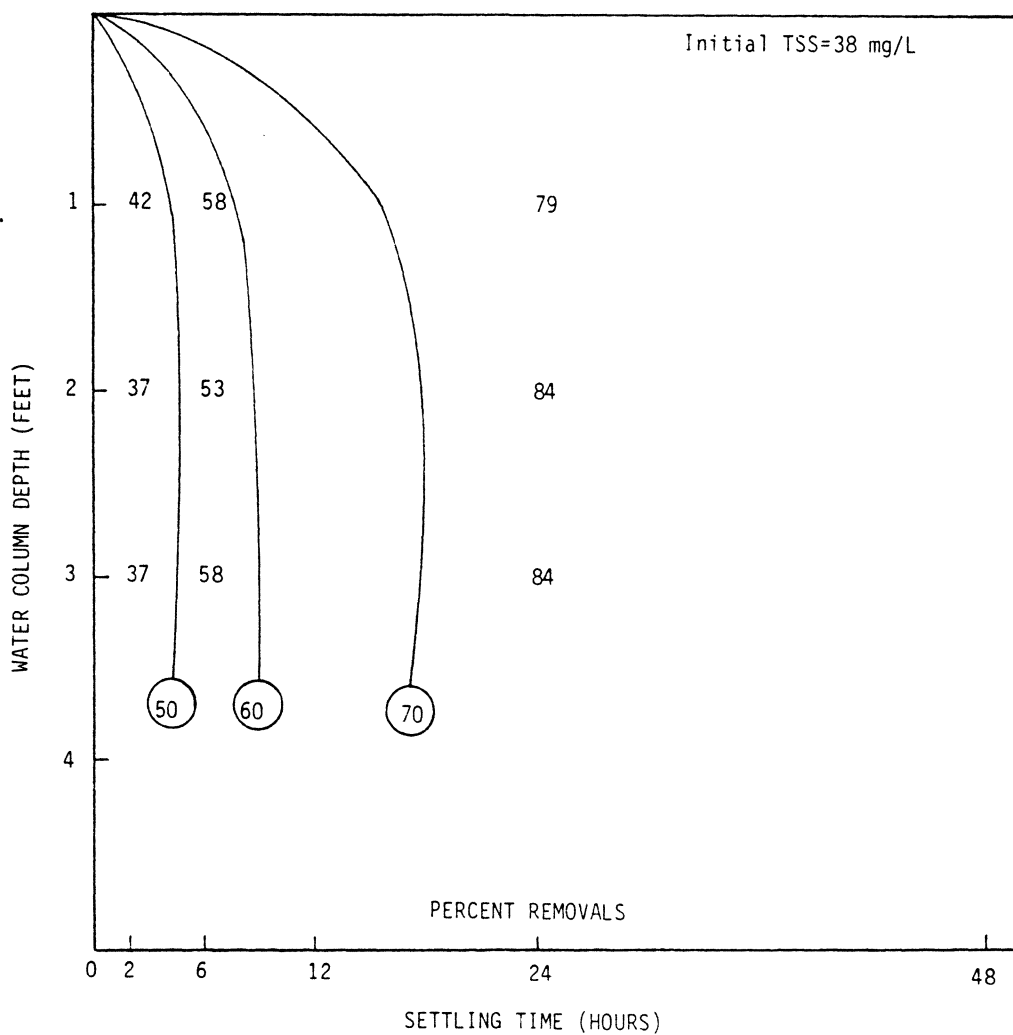


FIGURE 5. SEDIMENTATION REMOVAL OF TSS FROM FAIR OAKS MALL STORMWATER - JUNE 20, 1981 SAMPLE

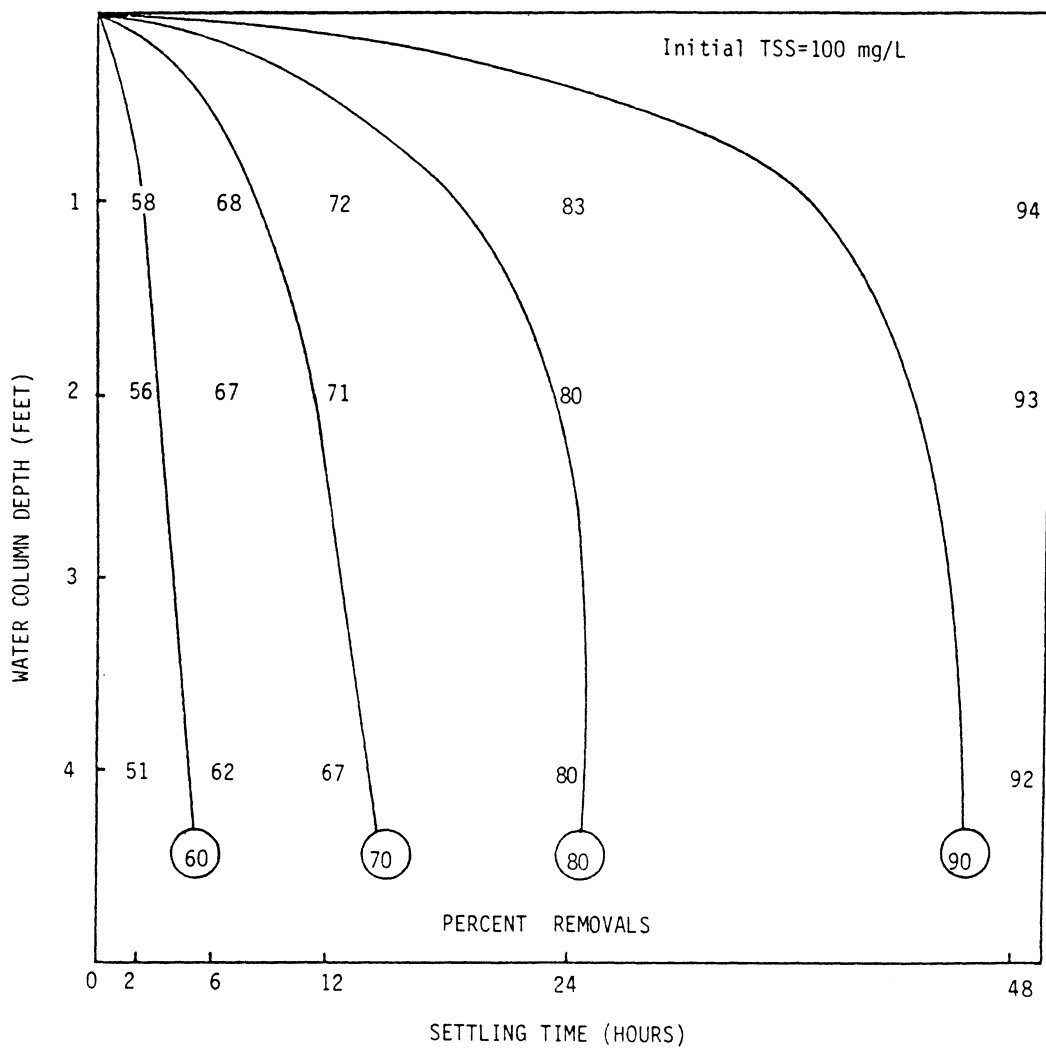


FIGURE 6. SEDIMENTATION REMOVAL OF TSS FROM FAIR OAKS MALL STORMWATER - OCTOBER 23, 1981 SAMPLE

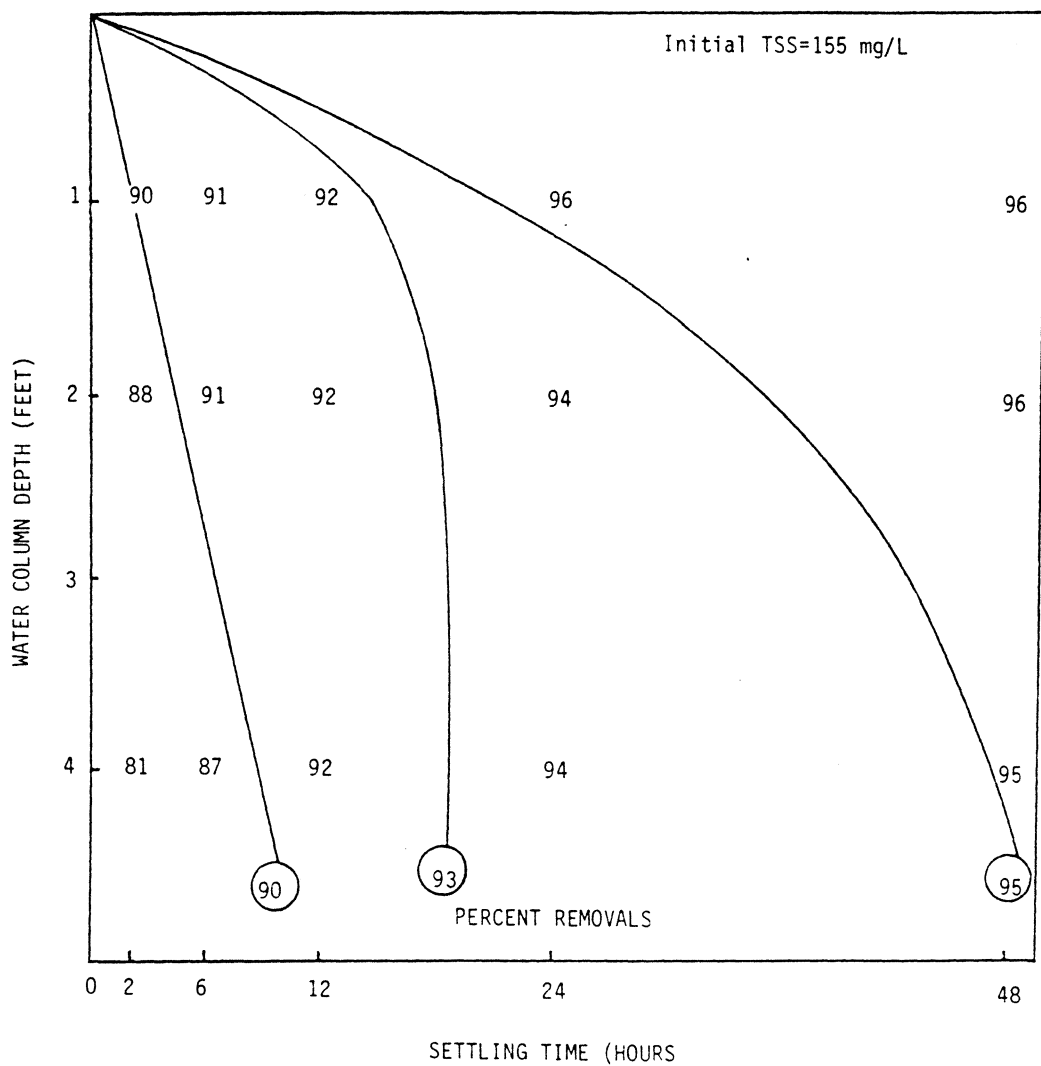


FIGURE 7. SEDIMENTATION REMOVAL OF TSS FROM MANASSAS MALL STORMWATER - July 26, 1981 SAMPLE

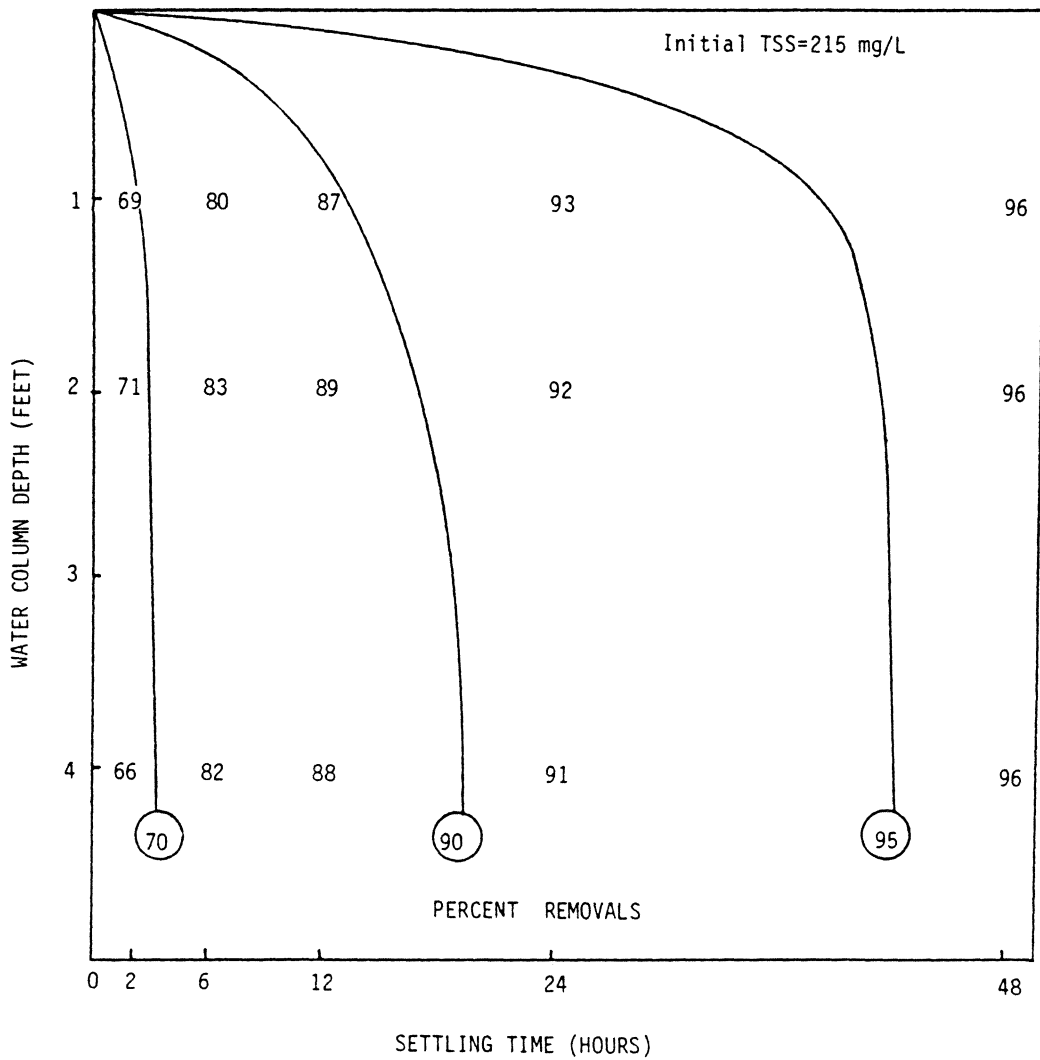


FIGURE 8. SEDIMENTATION REMOVAL OF TSS FROM MANASSAS MALL STORMWATER - August 11, 1981 SAMPLE

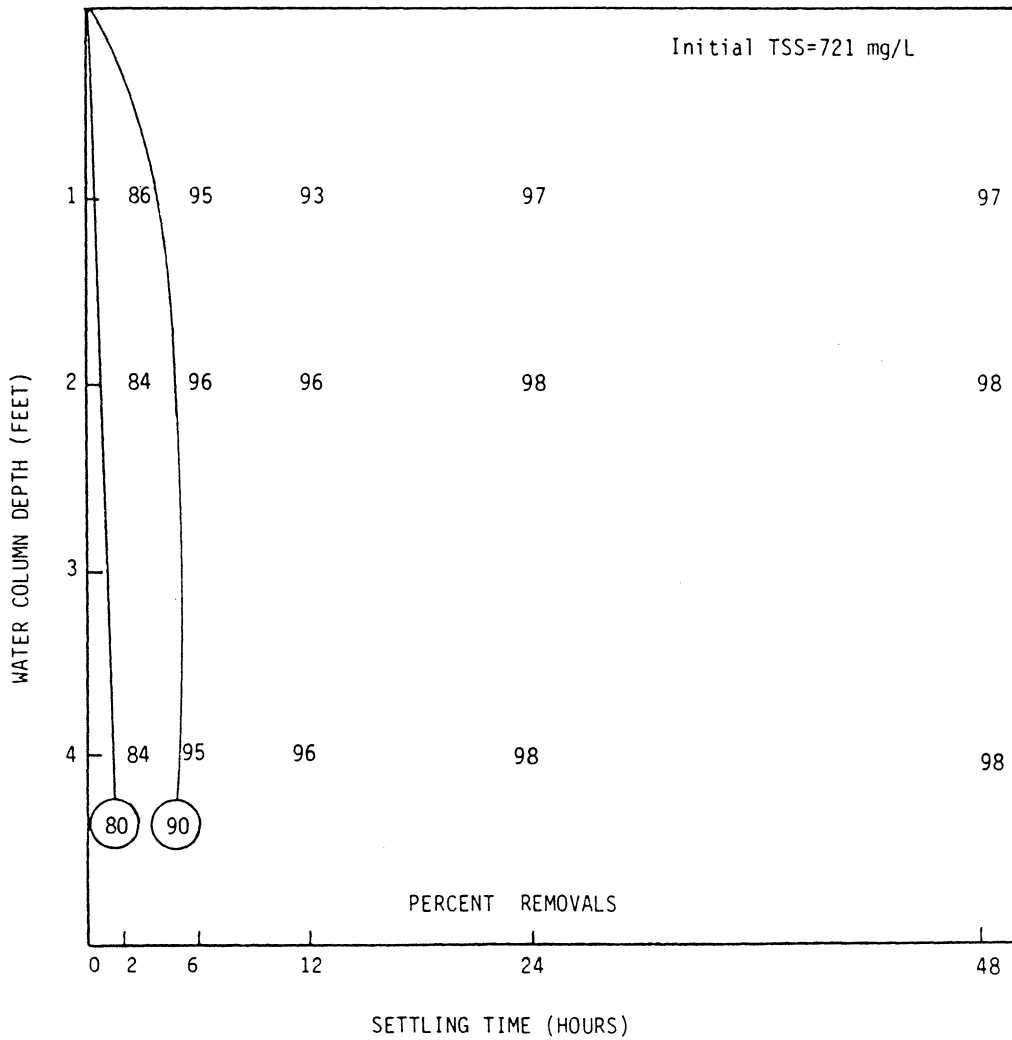


FIGURE 9. SEDIMENTATION REMOVAL OF TSS FROM MANASSAS SHOPPING CENTER
STORMWATER - SEPTEMBER 15, 1981 SAMPLE

of time than in previous samples with lower TSS concentrations. Between 24 and 48 hours, the TSS concentrations was reduced to 80 to 90 percent.

The initial TSS concentration of the July 26 sample from Manassas Mall was 155 mg/L. Before 12 hours of settling occurred, 90 percent of this concentration had been removed as seen in Figure 7. Figure 8 shows the settling profile for the sample collected on August 11 from the same site. Although the August 11 sample contained a greater initial TSS concentration than the July 26 sample, settling removal was not as fast. As seen in the settling profile, 90 percent of the TSS concentration was removed between 12 and 24 hours. The August 11 sample contained an initial TSS concentration of 215 mg/L.

The highest TSS concentration in the seven samples occurred in the September 15 sample from Manassas Shopping Center. An initial concentration of 721 mg/L was reduced by 90 percent in only 2 to 6 hours. Figure 9 shows the settling profile of this sample.

Figures 10 through 16 show settling profiles of variations in TSS concentrations with time and depth rather than as percent reductions. After two days, TSS concentrations were reduced to less than 10 mg/L. The only exception was the September 15 sample in Figure 16 in which final TSS concentrations were reduced to slightly less than 20 mg/L from an initial concentration of 721 mg/L.

In Figure 10, depicting results from treatment of the July 4 sample from Fair Oaks Mall, TSS was reduced from 15 mg/L to 10 mg/L after 24 hours of settling. In the June 20 sample from Fair Oaks Mall and the July 26 sample from Manassas Mall in Figures 12 and 14, TSS concentrations were reduced to 10 mg/L before 24 hours of settling had occurred. The initial TSS concentrations in these samples were 35 mg/L and 155 mg/L.

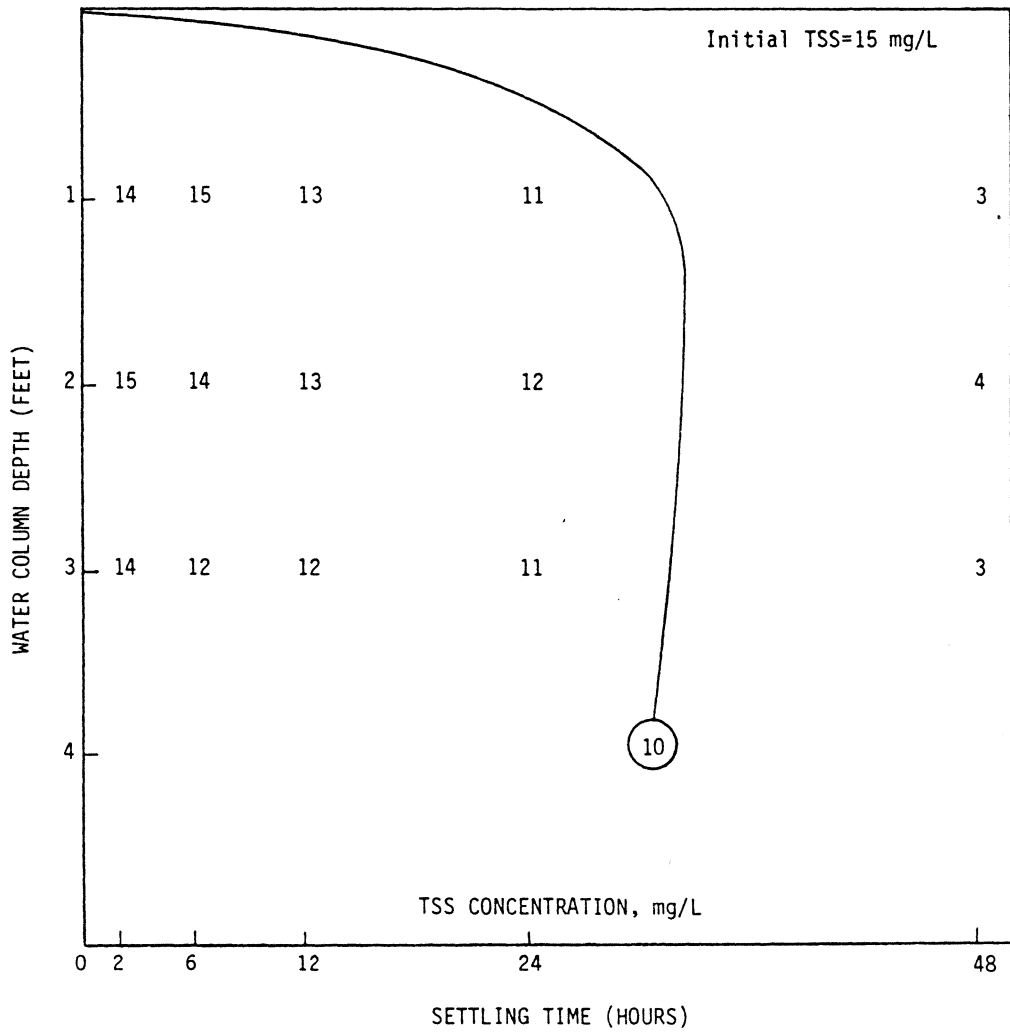


FIGURE 10. CHANGES IN SUSPENDED SOLIDS CONCENTRATIONS WITH SETTLING TIME FOR THE FAIR OAKS MALL SAMPLE OF JULY 4, 1981

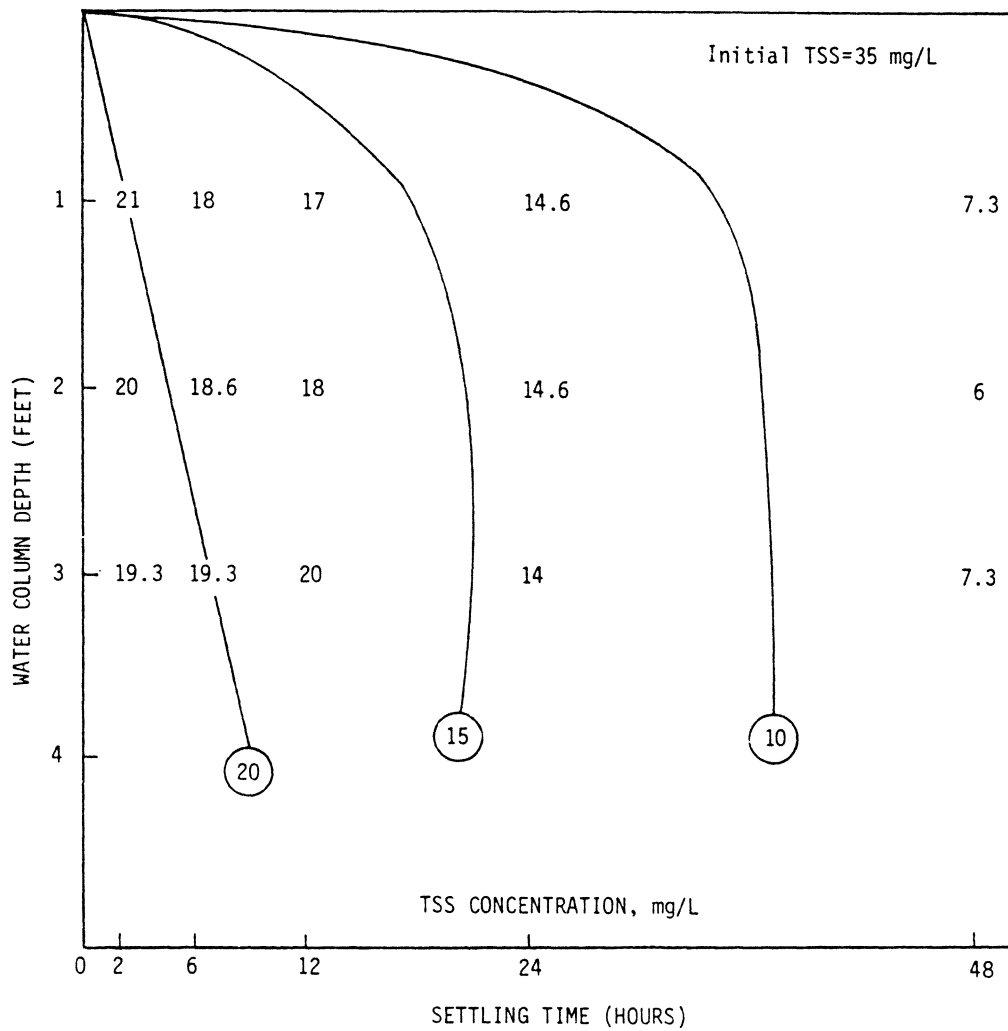


FIGURE 11. CHANGES IN SUSPENDED SOLIDS CONCENTRATIONS WITH SETTLING TIME FOR THE MANASSAS MALL SAMPLE OF JULY 5, 1981

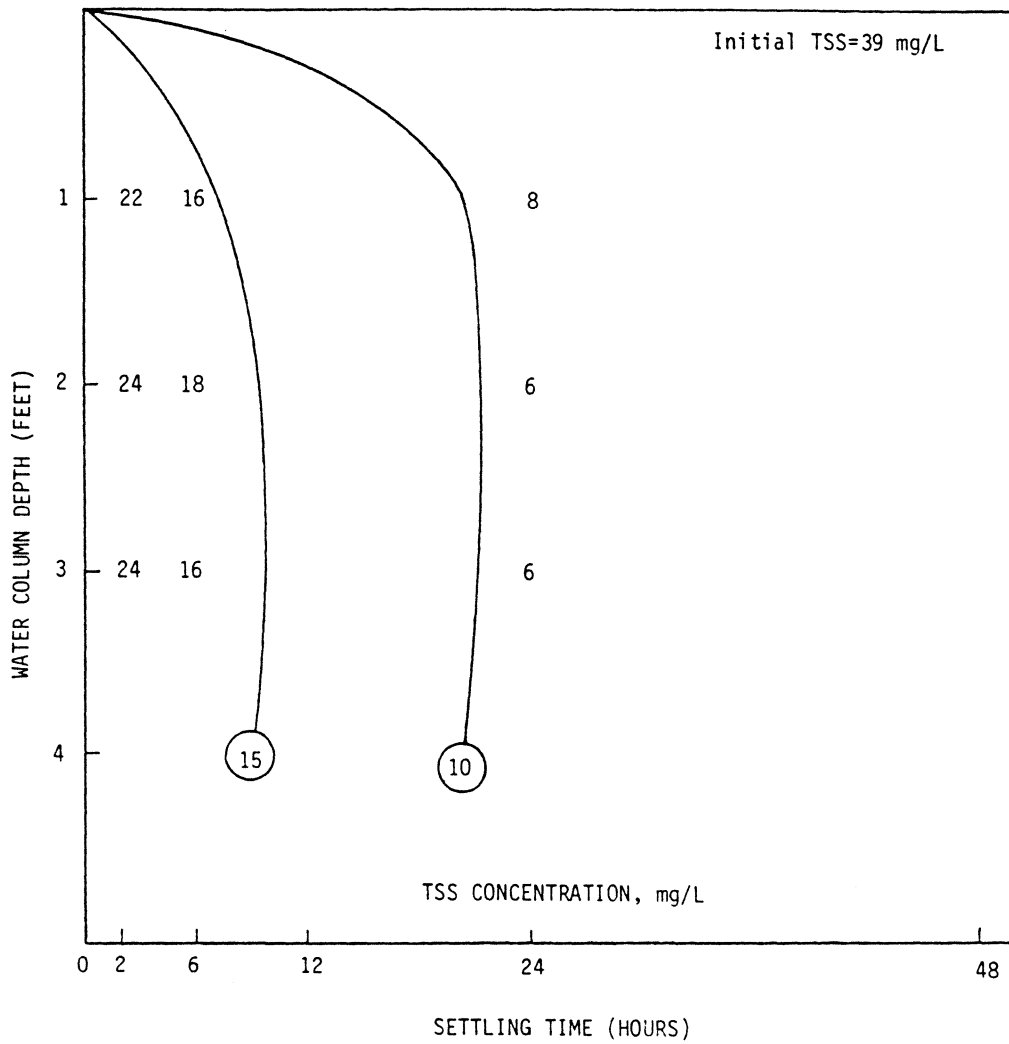


FIGURE 12. CHANGES IN SUSPENDED SOLIDS CONCENTRATION WITH SETTLING TIME FOR THE FAIR OAKS MALL SAMPLE OF JUNE 20, 1981

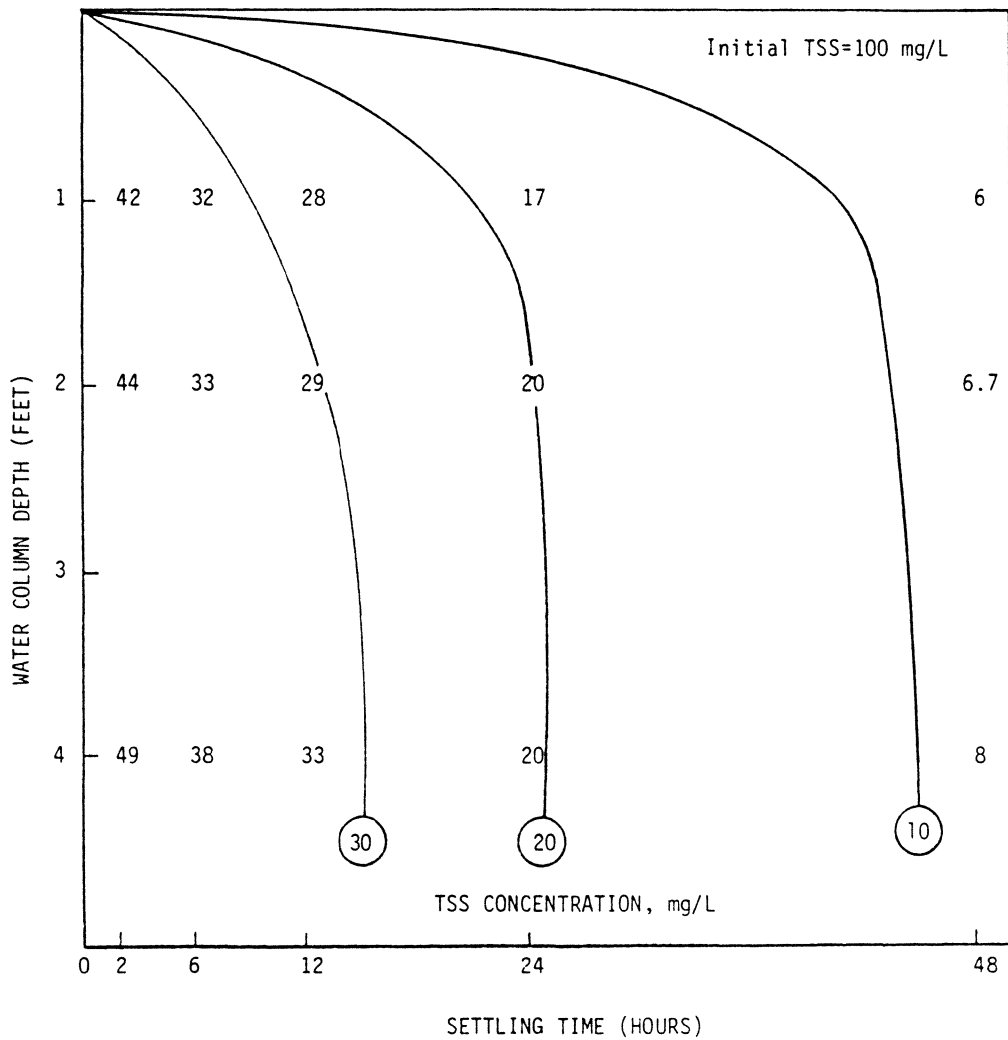


FIGURE 13. CHANGES IN SUSPENDED SOLIDS CONCENTRATIONS WITH SETTLING TIME FOR THE FAIR OAKS MALL SAMPLE OF OCTOBER 23, 1981

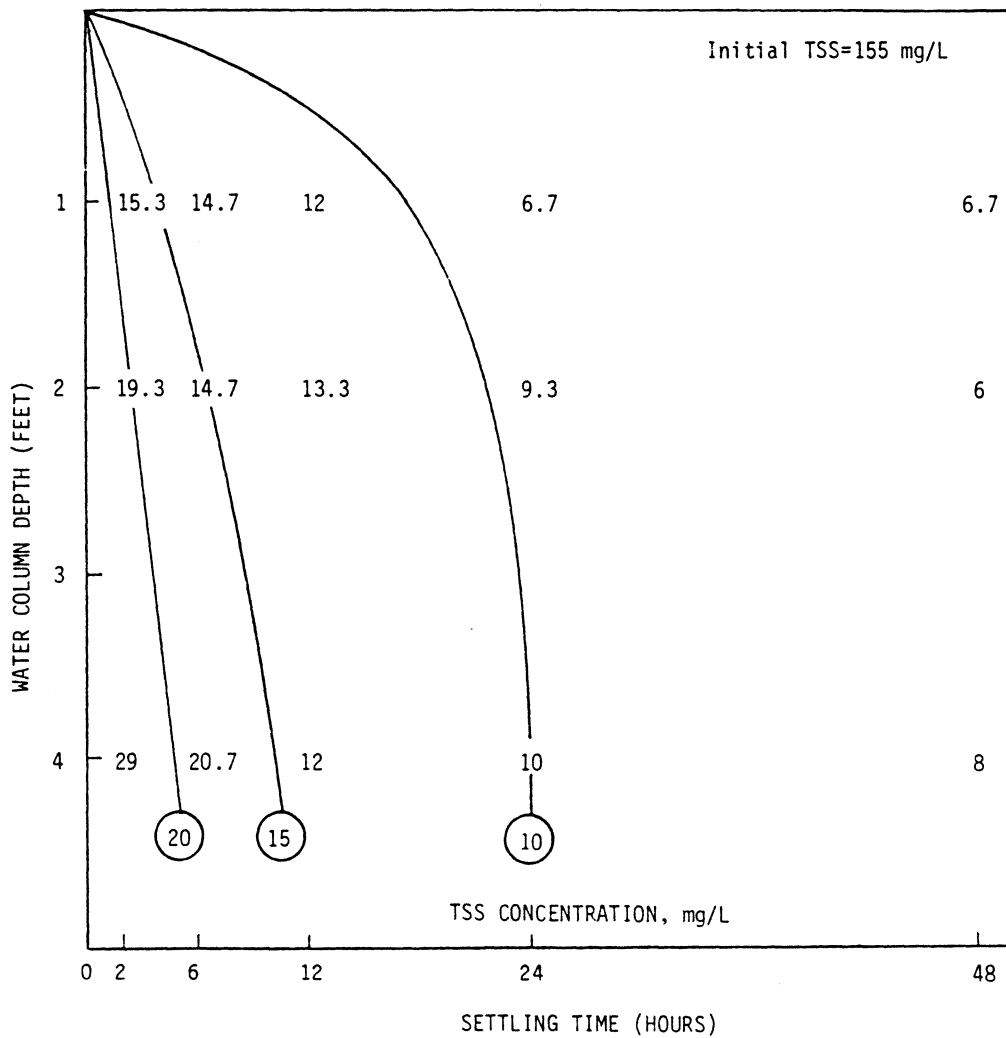


FIGURE 14. CHANGES IN SUSPENDED SOLIDS CONCENTRATIONS WITH SETTLING TIME FOR THE MANASSAS MALL SAMPLE OF JULY 26, 1981

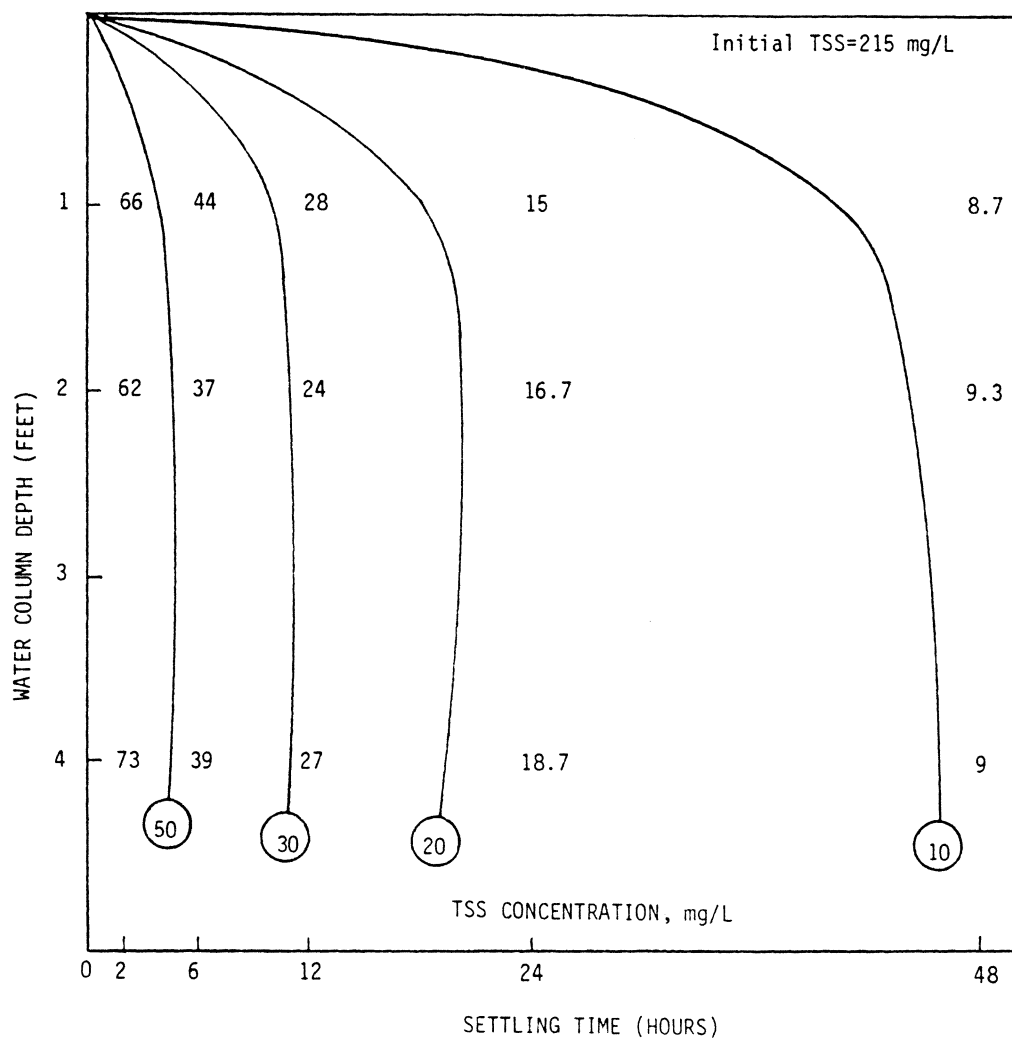


FIGURE 15. CHANGES IN SUSPENDED SOLIDS CONCENTRATIONS WITH SETTLING TIME FOR THE MANASSAS MALL SAMPLE OF AUGUST 11, 1981

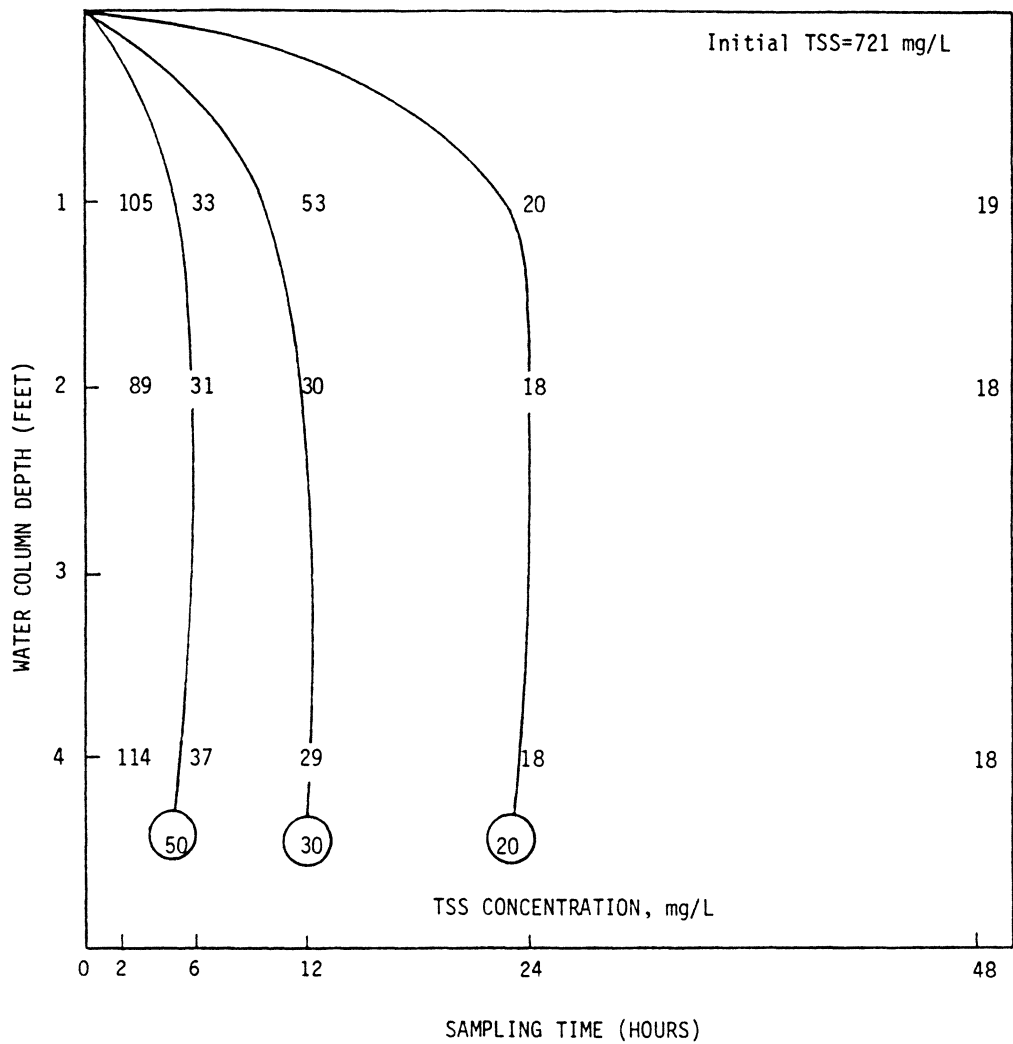


FIGURE 16. CHANGES IN SUSPENDED SOLIDS CONCENTRATIONS WITH SETTLING TIME FOR THE MANASSAS SHOPPING CENTER SAMPLE OF SEPTEMBER 15, 1981

Settling of TSS concentration was slower in the remaining samples. TSS concentrations were reduced to 10 mg/L between 24 and 48 hours of settling in the sample collected on October 23 from Fair Oaks Mall in Figure 13. The samples collected on July 5 and August 11 from Manassas Mall were also reduced to 10 mg/L within the same time period as seen in Figures 11 and 15. Although these three samples were reduced to approximately the same concentration within the same time period, their initial concentrations varied greatly.

After 48 hours of settlement, TSS concentrations from all seven stormwater samples were reduced to a range of 3 to 19 mg/L. The large reduction in TSS concentrations was not exclusive to the 48-hour time interval. The initial TSS concentration affected the rate of removal. This is observed in the sample presented in Figure 17 where initial TSS concentration are compared to the number of hours of settlement in which 60 percent of the TSS was removed. The time values used in Figure 17 were approximated from the percent reduction profiles in Figures 3 through 9. As indicated in Figure 17, the least number of hours required to remove 60 percent of the TSS concentration occurred in the samples with the highest initial TSS concentrations.

There was a larger variation between the samples in the percent volatile matter that composed total suspended solids concentrations. Volatile suspended solids (VSS) initial concentrations ranged from 9 to 264 mg/L for the seven stormwater samples.

Table IX lists the changes in percent volatile suspended solids that occurred during sedimentation. Samples that contained low TSS concentrations had the greatest percent of initial volatile solids. The

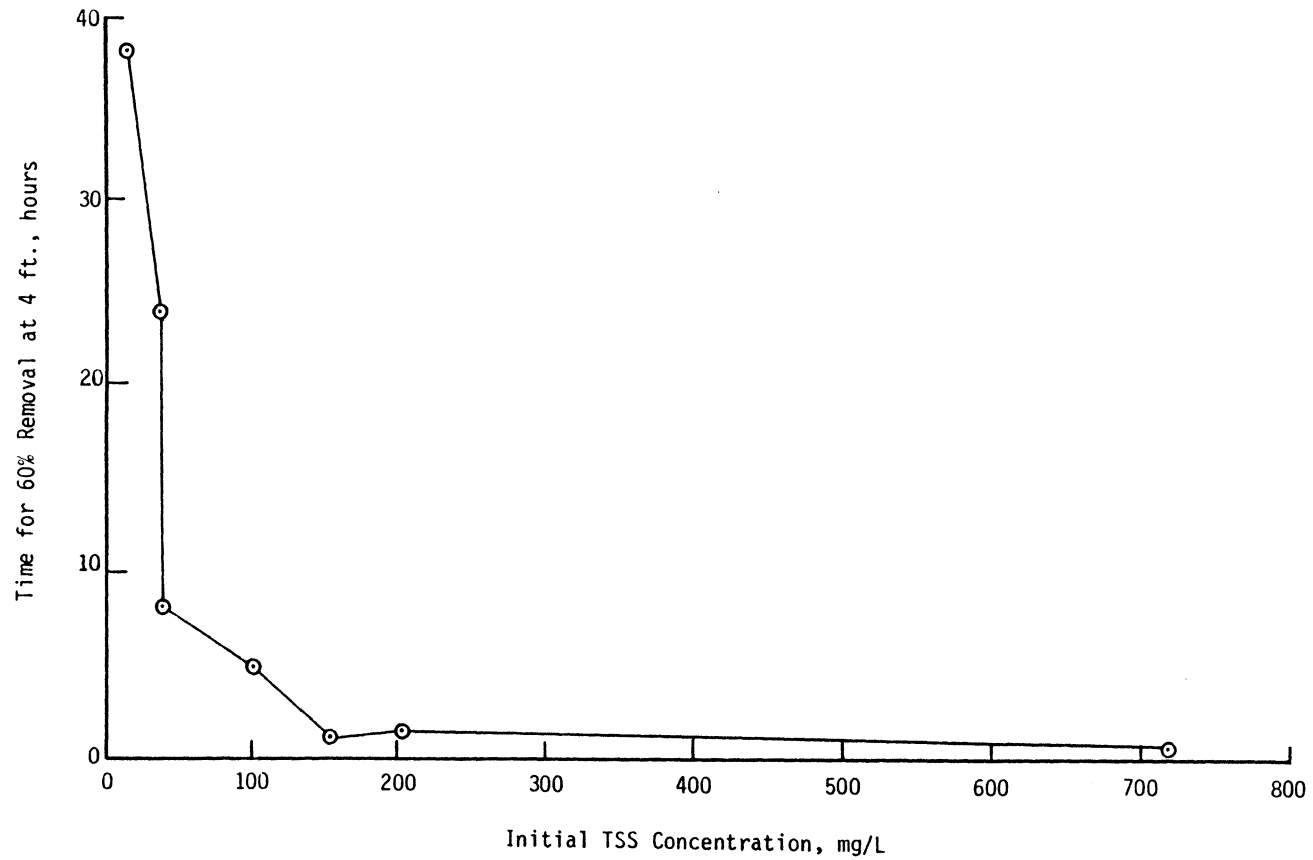


FIGURE 17. THE EFFECT OF INITIAL TSS CONCENTRATIONS ON REMOVAL RATES

TABLE IX CHANGES IN PERCENT VOLATILE SUSPENDED SOLIDS DURING SEDIMENTATION

Sample Date	Sample Location	Initial Percent of TSS	Total Average	24 and 48 Hour Average	Percent Change	Initial TSS mg/L
6/20/81	Fair Oaks Mall	54	64.3	69.7	+5.4	38
7/4/81	Fair Oaks Mall	60	57.7*	94.2	+36.5	15
7/5/81	Manassas Mall	47	57.3	54.0	-3.3	35
7/26/81	Manassas Mall	23	26.1	38.0	+11.9	155
8/11/81	Manassas Mall	27	25.7*	52.2	+26.5	215
9/15/81	Manassas Shopping Ctr.	37	33.8	42.7	+8.9	721
10/23/81	Fair Oaks Mall	41	38.1*	15.2	-22.9	100

*Average value taken during first 12 hours only.

September 15 sample, which contained the highest TSS concentration, was an exception to this trend. This may have been because of variability between sampling sites.

In four of the samples, the changes in percent volatile matter during sedimentation were insignificant. For three samples, however, there were large differences in suspended solids composition between those removed during the first 12 hours and the solids that remained in suspension after 12 hours. These three samples are indicated by asterisks in Table IX. The total average percent values in Table V for these three samples are from averaging the percentage removals during the first twelve hours of settling. Two of the samples (July 4 and August 11) had large increases in percent volatile solids after 12 hours. The third sample (October 23) displayed a decrease in percent volatile solids after 12 hours. With the exception of the October 23 sample, the solids that settled the slowest were more organic in composition, based on the percentages of volatile matter.

Particle Size Distribution

Particle counts for eleven size ranges were determined for all seven stormwater samples. Appendix Table A-2 lists particle counts for each sample and size range. The greatest number of particles occurred in the smallest particle size range of 5 to 15 microns in diameter, and then decreased in number up to the largest size range of 105 to 115 microns. This distribution continued throughout the duration of the sedimentation period. The trend of increasing particle sizes along with decreasing particle counts is easily observed in Table A-2.

There were no significant differences in the reduction of the

number of particles between each size range. Overall, particle numbers in each size range were reduced significantly with time. The July 4 sample was an exception and actually increased in the number of particles in each range. However, after 48 hours of settling, particle numbers in ranges less than 65-75 microns were reduced.

Nutrients

Table X lists percent reductions for all nutrient concentrations obtained from laboratory analysis as well as those obtained from the manipulation of the laboratory data. Total Kjeldahl nitrogen (TKN) concentrations were composed largely of soluble forms as seen in the soluble Kjeldahl nitrogen (SKN) concentrations in Table A-1. The September 15 sample was an exception and initially contained 4.40 mg/L of TKN and 0.76 mg/L of SKN. Thus, the suspended Kjeldahl nitrogen (Susp. KN) concentration was 3.64 mg/L. Consequently, this stormwater sample obtained the highest TKN reductions of 75, 73, and 73 percent at one, two, and four feet after 48 hours. Total nitrogen (TN) also reflected the high percent reductions with values of 74, 73, and 72 percent at one, two, and four feet, respectively.

The reduction of TN concentrations corresponded closely with that of TKN as seen in Table X. TN reductions were equal to or slightly less than TKN reductions for all seven stormwater samples. The greatest reductions in TN, TKN, suspended KN, and organic nitrogen occurred after 2 hours of settlement in most of the samples. In the June 20 and July 5 samples, however, the greatest reduction occurred after 24 hours of settlement. The reduction of these forms of nitrogen in the July 4

TABLE X. PERCENT REDUCTIONS FOR NUTRIENT CONCENTRATIONS

Sample Date	Time (Hours)	Depth (Feet)	Percent Reduction										
			TN	TKN	SKN	SUSP. KN	NH ₃ -N	NO ₂ +NO ₃	Organic -N	TP	TSP	SUSP. P	OP
6/20/81	0	1,2,3	0	0	0	0	0	0	0	0	0	0	-
	2	1	2	-2	-1	-5	6	8	-11	7	17	0	-
		2	0	-2	5	-33	7	1	-13	14	17	12	-
		3	-1	-3	-3	0	-2	1	-4	14	0	25	-
	6	1	7	6	4	14	6	8	6	28	33	25	-
		2	1	2	0	10	5	-1	-2	36	33	38	-
		3	3	5	7	-5	6	1	4	28	33	25	-
	24	1	14	13	6	47	5	14	24	43	33	50	-
		2	10	11	2	53	6	9	18	43	33	50	-
		3	11	13	4	57	5	7	24	43	33	50	-
7/4/81	0	1,2,3	0	0	0	0	0	0	0	0	0	0	0
	2	1	-1	-1	6	-36	5	0	-1	1	1	0	2
		2	-4	-5	8	-75	15	33	-7	6	14	-45	4
		3	12	11	12	6	5	33	12	7	8	0	2
	6	1	-2	-1	8	-50	5	-67	-1	0	7	-45	6
		2	7	7	15	-36	15	0	6	1	12	-73	6
		3	2	2	12	-50	15	0	1	-1	7	-54	4
	12	1	7	7	1	39	5	0	7	6	0	45	4
		2	-5	-4	-1	-19	15	-33	-6	-6	3	-63	4

TABLE X. CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Percent Reduction										
			TN	TKN	SKN	SUSP. KN	NH ₃ -N	NO ₂ +NO ₃	Organic -N	TP	TSP	SUSP. P	OP
7/4/81	12	3	14	15	20	-14	25	-33	14	31	30	36	4
	24	1	8	7	24	-80	-35	33	11	39	36	54	10
		2	9	9	34	-122	-35	33	13	31	39	-18	14
		3	9	8	15	-31	-35	33	12	35	38	18	12
	48	1	5	5	25	-97	-25	0	8	46	42	73	18
		2	-72	-73	25	-592	-35	-33	-77	-	42	-	18
		3	28	28	30	14	-25	33	33	41	43	27	20
7/5/81	0	1,2,3	0	0	0	0	0	0	0	0	0	0	0
	2	1	6	6	-10	27	-28	6	8	21	17	23	0
		2	5	6	-25	45	-43	5	5	16	-50	46	0
		3	2	12	-15	45	-42	-8	12	5	-17	15	0
	6	1	7	11	-7	32	-43	4	13	21	0	31	0
		2	2	10	-2	25	-28	-5	11	47	0	69	0
		3	6	7	-9	28	-528	5	9	21	-17	23	0
	12	1	11	15	-7	42	-71	6	18	31	17	38	-33
		2	8	13	-9	41	-100	2	17	32	0	46	-66
		3	10	7	-6	23	-528	14	24	32	-17	54	-
24	1	21	22	-14	65	-528	21	39	42	-17	69	-133	
	2	12	18	-17	61	-185	5	24	42	-16	69	-33	

TABLE X. CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Percent Reduction										
			TN	TKN	SKN	SUSP. KN	NH ₃ -N	NO ₂ +NO ₃	Organic -N	TP	TSP	SUSP. P	OP
7/5/81	24	3	6	16	-4	40	-185	-3	22	42	0	62	0
	48	1	24	25	-11	68	-186	23	32	52	-33	92	-33
		2	20	27	-23	88	28	13	27	53	17	69	33
		3	17	18	-21	65	-214	15	25	47	-17	77	-
7/26/81	0	1,2,4	0	0	0	0	0	0	0	0	0	0	0
	2	1	38	53	28	77	13	0	56	52	0	87	11
		2	35	53	31	74	28	5	55	52	0	87	11
		4	32	48	28	68	0	5	51	48	0	80	11
	6	1	38	53	23	82	0	10	56	56	0	93	0
		2	34	52	15	86	0	5	55	56	0	93	11
		4	35	52	21	80	-28	8	56	52	10	80	0
	12	1	37	50	25	72	-28	13	55	52	-10	93	0
		2	31	48	21	74	-28	2	52	52	0	87	11
		4	33	52	21	80	0	2	55	52	0	87	-11
	24	1	36	45	5	84	-86	13	53	52	0	86	11
		2	28	42	-6	88	-57	5	48	52	-10	93	0
		4	21	28	-3	58	-57	8	34	32	-40	80	0
	48	1	33	54	21	84	28	18	55	44	-10	80	11
		2	32	44	24	62	28	13	44	44	-10	80	11

TABLE X. CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Percent Reduction										OP
			TN	TKN	SKN	SUSP. KN	NH ₃ -N	NO ₂ +NO ₃	Organic -N	TP	TSP	SUSP. P	
7/26/81	48	4	37	48	34	62	0	18	51	40	-10	73	11
8/11/81	0	1,2,4	0	0	0	0	0	0	0	0	0	0	0
	2	1	31	37	-10	64	-35	12	47	31	0	56	-25
		2	30	38	-7	67	-21	4	46	33	10	52	-12
		4	23	28	-37	65	-50	7	53	33	0	59	0
	6	1	36	44	-1	69	-14	12	52	46	19	67	0
		2	39	50	7	77	-14	4	60	46	19	67	-12
		4	35	46	-1	74	0	1	53	46	19	67	0
	12	1	40	49	15	68	-	12	-	79	86	74	75
		2	26	35	-4	60	-	-1	-	77	48	106	25
		4	34	46	38	50	-	-1	-	81	81	81	62
	24	1	45	52	35	62	43	23	54	54	33	70	12
		2	42	51	35	64	64	12	53	52	33	67	0
		4	43	55	38	65	57	7	54	44	38	48	12
	48	1	50	52	20	71	0	44	60	85	90	81	88
		2	46	50	12	73	0	36	59	85	90	81	88
		4	39	52	1	81	7	-1	58	85	90	81	88
9/15/81	0	1,2,4	0	0	0	0	0	0	0	0	0	0	0
	2	1	60	61	0	73	0	0	63	30	10	42	5

TABLE X. CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Percent Reduction										
			TN	TKN	SKN	SUSP. KN	NH ₃ -N	NO ₂ +NO ₃	Organic -N	TP	TSP	SUSP. P	OP
9/15/81	2	2	63	64	-3	78	0	-10	67	21	3	31	5
		4	60	61	5	73	0	0	64	24	10	33	0
	6	1	73	74	-3	90	-10	0	77	51	3	79	10
		2	73	73	3	88	0	0	76	51	17	71	10
		4	70	71	-8	87	0	0	74	50	10	73	10
	12	1	70	71	8	85	10	-50	74	51	40	58	42
		2	73	74	10	87	21	0	76	62	40	75	37
		4	73	74	21	85	21	0	76	65	47	75	37
	24	1	77	77	12	91	21	0	80	71	40	88	5
		2	81	82	10	97	21	0	84	76	40	96	37
		4	73	74	4	88	21	0	76	66	33	85	26
	48	1	74	75	1	90	-63	0	81	68	33	88	10
		2	73	73	3	88	-74	0	80	66	33	85	26
		4	72	73	-7	89	-158	0	83	65	37	81	5
10/23/81	0	1,2,4	0	0	0	0	0	0	0	0	0	0	0
	2	1	35	47	4	85	0	-1	56	31	8	57	9
		2	25	35	8	59	0	-6	42	29	-4	67	4
		4	23	32	-4	64	5	-6	38	22	-17	67	4
	6	1	32	40	-2	77	5	9	46	33	4	67	14

TABLE X. CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Percent Reduction										TP	TSP	SUSP. P	OP
			TN	TKN	SKN	SUSP. KN	NH ₃ -N	NO ₂ +NO ₃	Organic -N							
10/23/81	6	2	27	34	0	64	5	4	40	33	4	67	14			
		4	-16	-23	0	-43	0	4	-27	36	8	67	14			
	12	1	32	42	4	77	5	-1	49	31	0	67	14			
		2	23	31	-1	59	5	-1	35	18	0	38	14			
		4	20	28	-7	60	-10	-6	36	31	8	57	9			
	24	1	29	40	-19	93	-26	-6	53	42	8	81	0			
		2	21	33	-12	72	-21	-14	43	31	8	57	0			
		4	21	32	-17	76	-21	-12	42	38	4	76	0			
	48	1	17	19	-31	64	-105	12	43	42	-8	100	9			
		2	32	42	-15	94	-10	1	52	42	8	80	14			
		4	30	40	-7	82	-5	1	49	42	8	81	14			

sample was unusual in that nitrogen concentrations increased and decreased throughout the settlement period, and no trend in settling was observed.

There was no apparent relationship between sampling sites and the reduction of TN, TKN, suspended KN, and organic nitrogen. Initial nitrogen concentrations did not seem to have an effect on settling efficiency. The July 4 sample from Fair Oaks contained an initial suspended KN concentration that was much lower than the other samples. The larger fraction of SKN in this sample may account for the erratic percent reduction values of TN and TKN.

Nitrate and nitrite ($\text{NO}_2 + \text{NO}_3$) concentrations displayed erratic increases and decreases during the settlement period for all seven stormwater samples as seen in Table X. Ammonia-nitrogen concentrations ($\text{NH}_3\text{-N}$) were also unresponsive to settlement. Generally $\text{NH}_3\text{-N}$ values were found to increase after 48 hours of settlement. In Table X few exceptions are seen in this trend. The exceptions were the June 30, July 26, and August 11 samples, in which $\text{NH}_3\text{-N}$ concentrations increased slightly or remained unchanged after 48 hours. Overall, $\text{NH}_3\text{-N}$ displayed the same erratic increases and decreases as did $\text{NO}_2 + \text{NO}_3$.

Total phosphorus (TP) initial concentrations were mostly composed of suspended forms with the exception of the July 4 and October 23 samples in which total soluble phosphorus (TSP) was more than one-half of the TP concentration. Table XI lists TP concentrations along the percentage of soluble and suspended phosphorus for initial values and final values after 48 hours of settlement at the one-foot column depth. This column depth interval was chosen because it represented TP concen-

TABLE XI. CHANGES IN THE PERCENTAGE OF SOLUBLE AND SUSPENDED PHOSPHORUS AFTER 48 HOURS OF SETTLEMENT

Sample Date	Sample Location	Initial Values			Final Values After 48 Hours at 1 ft.		
		TP (mg/L)	% Soluble	% Suspended	TP (mg/L)	% Soluble	% Suspended
6/20/81	Fair Oaks	0.14	43	57	0.08*	50*	50*
7/4/81	Fair Oaks	0.83	87	13	0.45	93	7
7/5/81	Manassas Mall	0.19	32	68	0.09	89	11
7/26/81	Manassas Mall	0.25	40	60	0.14	79	21
8/11/81	Manassas Mall	0.48	44	56	0.07	29	71
9/15/81	Manassas Shopping Center	0.82	37	63	0.26	77	23
10/23/81	Fair Oaks	0.45	53	47	0.26	100	0

*From 24 hours of settlement.

trations that were typical of the other depth intervals. As seen in Table XI, after two days of settling, TP concentrations were mostly composed of soluble forms, with the exception of the August 11 sample. This sample had the largest percent reductions in TP and TSP concentrations in Table X, which were 85 and 90 percent, respectively.

The August 11 sample also exhibited the largest reduction in the concentration of orthophosphate-phosphorus (OP), which was reduced by 88 percent after 48 hours. Percent reductions of OP concentrations were not as great in the remaining samples. In all seven samples, OP concentrations presented drastic increases and decreases between settling times and depths. This is evident in Table X where OP percent reductions are presented.

Heavy Metals

Results from metals analysis revealed that all seven stormwater samples contained nickel, chromium, and cadmium concentrations less than the instrument detection limit of 20 micrograms per liter ($\mu\text{g/L}$). Thus, no data were obtained for the settling of these metals. Only one sample, September 15, contained copper concentrations greater than the 20 $\mu\text{g/L}$ detection limit. Initially, the total copper (TCu) concentrations was 58 $\mu\text{g/L}$. After only two hours of settling, copper concentrations decreased below the detection limit with the exception of the two hour one-foot depth TCu sample, which contained a concentration of 25 $\mu\text{g/L}$. Therefore, no copper data were available for further settling analysis.

Lead concentrations in the June 20, July 4 and July 5 samples

samples were analyzed by the use of a different instrument with a much lower detection limit. Appendix Table A-3 lists the results obtained from sample analysis for lead, zinc, and copper. Appendix Table A-4 lists suspended lead and zinc concentrations along with other information derived from laboratory data. Zero values in these tables are not absolute because they reflect only the instrument detection limit.

The concentration of total lead (TPb) in the September 15 sample from Manassas Shopping Center was the largest of the samples analyzed. An initial TPb concentration of 913 $\mu\text{g/L}$ was reduced by 92, 88, and 89 percent at one, two, and four feet after 48 hours. The soluble lead (SPb) concentration was initially 813 $\mu\text{g/L}$, and was reduced by 91, 85 and 88 percent during the same time period. The suspended lead (susp. Pb) concentration was initially 100 $\mu\text{g/L}$, and after 48 hours was reduced by 100, 90, and 100 percent. This sample also contained the largest total zinc (TZn) concentration, which was 692 $\mu\text{g/L}$. TZn was reduced by 81 percent at all three depths after 48 hours. Soluble zinc (SZn) was reduced by 68 percent from an initial 630 $\mu\text{g/L}$, and suspended zinc (susp. Zn) was reduced by 100 percent from an initial 62 $\mu\text{g/L}$ after 48 hours. Percent reduction values for lead and zinc are listed in Table XII.

The suspended lead concentration of 327 $\mu\text{g/L}$ in the sample collected on August 11 was greater than that found in the September 15 sample even though the TSS concentration in the September 15 sample was over 500 mg/L greater. Although the initial concentrations differed between the two samples, percent reductions were as great in each.

TABLE XII. PERCENT REDUCTIONS FOR LEAD AND ZINC CONCENTRATIONS

Sample Date	Time (hours)	Depth (feet)	Percent Reduction					
			TZn	SZn	Susp. Zn	TPb	SPb	Susp. Pb
6/20/81	0	1,2,3	0	0	0	-	-	-
	2	1	10	22	-36	-	-	-
		2	19	26	-10	-	-	-
		3	12	22	-27	-	-	-
	6	1	6	-13	83	-	-	-
		2	1	1	-2	-	-	-
		3	-21	-13	-52	-	-	-
	24	1	29	22	58	-	-	-
		2	7	9	-2	-	-	-
		3	24	16	58	-	-	-
7/5/81	0	1,2,3	0	0	0	-	-	-
	2	1	5	-3	42	-	-	-
		2	2	-8	19	-	-	-
		3	5	5	-16	-	-	-
	6	1	5	5	-16	-	-	-
		2	5	-2	42	-	-	-
		3	5	-3	53	-	-	-
	12	1	5	5	-16	-	-	-
		2	5	-3	42	-	-	-
		3	5	-3	42	-	-	-
	24	1	4	-5	42	-	-	-
		2	5	-3	42	-	-	-
		3	5	-3	42	-	-	-
	48	1	12	5	77	-	-	-
		2	12	5	77	-	-	-
		3	12	5	88	-	-	-

TABLE XII. CONTINUED

Sample Date	Time (hours)	Depth (feet)	Percent Reduction					
			TZn	SZn	Susp. Zn	TPb	SPb	Susp. Pb
7/26/81	0	1,2,4	0	0	0	0	0	0
	2	1	69	11	91	85	50	88
		2	69	50	71	83	50	85
		4	62	0	87	78	62	80
	6	1	72	22	91	83	88	83
		2	75	30	95	86	75	87
		4	69	33	83	80	75	80
	12	1	72	33	87	85	75	86
		2	72	20	95	85	50	87
		4	69	33	83	87	75	88
	24	1	75	11	100	88	25	91
		2	72	30	91	91	62	93
		4	56	22	87	78	62	79
	48	1	72	0	100	92	75	93
		2	72	30	91	94	75	95
		4	75	33	91	97	75	98
8/11/81	0	1,2,4	0	0	0	0	0	0
	2	1	4	1	31	67	2	76
		2	13	5	100	69	7	76
		4	13	2	66	65	32	78
	6	1	13	6	48	65	19	71
		2	30	26	48	69	30	82
		4	30	26	48	62	14	83
	12	1	24	16	66	76	28	89
		2	30	23	66	74	9	84
		4	30	23	66	82	28	97

TABLE XII. CONTINUED

Sample Date	Time (hours)	Depth (feet)	Percent Reduction					
			TZn	SZn	Susp. Zn	TPb	SPb	Susp. Pb
8/11/81	24	1	19	9	66	68	29	73
		2	24	13	83	80	2	90
		4	7	-5	66	82	23	90
	48	1	27	12	100	85	-5	97
		2	22	6	100	85	-7	97
		4	16	9	48	82	16	91
9/15/81	0	1,2,4	0	0	0	0	0	0
	2	1	58	60	44	70	73	50
		2	62	63	52	74	75	60
		4	60	61	52	70	70	70
	6	1	74	72	92	86	86	80
		2	73	71	92	87	85	100
		4	70	68	84	85	83	100
	12	1	69	67	92	87	85	100
		2	73	70	100	88	90	70
		4	74	73	84	86	84	100
	24	1	70	70	84	88	89	80
		2	70	68	92	88	90	70
		4	84	81	100	91	90	100
	48	1	81	68	100	92	91	100
		2	81	68	100	88	85	90
		4	81	68	100	89	88	100
10/23/81	0	1,2,4	0	0	0	0	0	0
	2	1	33	11	48	45	-25	52
		2	29	11	40	13	0	15
		4	24	11	40	13	0	15

TABLE XII. CONTINUED

Sample Date	Time (hours)	Depth (feet)	Percent Reduction					
			TZn	SZn	Susp. Zn	TPb	SPb	Susp. Pb
10/23/81	6	1	29	11	40	56	17	60
		2	29	11	40	52	25	55
		4	29	11	40	46	41	56
	12	1	46	11	70	49	58	60
		2	38	11	55	44	50	54
		4	33	11	56	50	42	59
	24	1	51	11	78	72	25	82
		2	46	11	70	71	33	82
		4	46	11	70	63	58	76
	48	1	51	11	93	76	25	86
		2	51	11	93	81	25	92
		4	51	11	93	77	33	89

The largest concentration of suspended zinc occurred in the July 26 sample. The initial concentration of 115 $\mu\text{g/L}$ was reduced by 100, 91, and 91 percent at the one, two, and four-foot depths after 48 hours. The October 23 sample also underwent large percent reductions of suspended zinc (93 percent at all three depths). Total zinc concentrations in these two samples were mainly composed of suspended forms. The samples collected on June 20 and July 5, September 15, and August 11 contained total zinc concentrations composed mostly of soluble forms. With the exception of the June 20 sample, percent reductions of suspended zinc in these samples were as great as those samples with total zinc concentrations mainly composed of suspended forms.

The distribution of suspended and soluble forms of zinc had an effect on the percent reduction of total zinc concentrations, with the exception of the September 15 sample. For example, in the July 26 sample, which contained mostly suspended zinc, the total zinc concentration was reduced by 82, 72, and 75 percent after 48 hours of settling. However, in the August 11 sample, which contained mostly soluble forms, total zinc was reduced by only 27, 22, and 16 percent during the same time period.

Organic Matter

The degradable organic matter of three stormwater samples; August 11, September 15, and October 23, was measured by the 5-day biochemical oxygen demand (BOD_5) test. The August 11 sample contained an initial BOD_5 of 35 mg/L . After 24 hours, this concentration decreased to 10 mg/L , 10 mg/L , and 20 mg/L at one, two, and four feet, respec-

tively. The BOD_5 of the September 15 sample was initially 210 mg/L and after 24 hours was reduced by 62, 81, and 62 percent to 80 mg/L, 40 mg/L, and 80 mg/L at one, two, and four feet, respectively. The October 23 sample exhibited a reduction from 30 mg/L to 10 mg/L at one, two, and four feet, respectively, after 24 hours of sedimentation.

The chemical oxygen demand (COD) was used to measure organic matter in all stormwater samples except the preliminary sample collected on June 20. The COD of the September 15 sample was the highest of all samples analyzed. Initially, the concentration was 908 mg/L, and after 48 hours was reduced to 416 mg/L, 424 mg/L, and 436 mg/L at one, two, and four feet, respectively. These concentrations represent reductions of 54, 47, and 52 percent, respectively.

The COD of the sample collected on July 4 was 6.8 mg/L initially. After 24 hours, this concentration was reduced to 4.8 mg/L, 4.8 mg/L, and 5.2 mg/L at one, two, and three feet, respectively. The October 23 sample, which was from the same sampling location as the July 4 sample, contained an initial COD concentration of 87 mg/L. After 48 hours, the COD was reduced to 52 mg/L, 44 mg/L, and 41 mg/L at one, two, and four feet.

After 48 hours, the COD of the July 5 sample was reduced from 83 mg/L to 68 mg/L, 68 mg/L, and 64 mg/L at one, two, and three feet, respectively. The July 26 sample contained an initial COD of 50 mg/L, and was reduced to 22.3 mg/L, 19.1 mg/L, and 20.1 mg/L at one, two, and four feet, respectively. The initial COD of the August 11 sample was reduced from 138 mg/L to 48 mg/L, 47 mg/L, and 47 mg/L after 48 hours.

Total and soluble organic carbon determinations were performed for five samples, and organic carbon was found to occur mostly in the soluble

state. The total organic carbon (TOC) concentration of the July 26 sample was the lowest of the samples analyzed and decreased from 9 mg/L to 4.8 mg/L, 4.5 mg/L, and 4.5 mg/L at one, two, and four feet, respectively, after 48 hours. The highest TOC concentration was in the September 15 sample, and was initially 321.8 mg/L. After 48 hours, this concentration decreased to 208.6 mg/L, 203.2 mg/L, and 197.8 mg/L at one, two, and four feet, respectively. The soluble organic concentration (SOC) decreased from 280 mg/L to 203.2 mg/L, 197.8 mg/L, and 197.8 mg/L.

The TOC concentration of the July 4 sample was initially 22 mg/L and the SOC concentration was 20.3 mg/L. After 24 hours, TOC was reduced to 18.3 mg/L and 17.8 mg/L, respectively, at the two and three-foot depths, and increased slightly to 22.8 mg/L at the one-foot depth. The SOC concentration decreased to 19.2 mg/L and 17.8 mg/L, respectively, at the one and three-foot depths. The samples collected on August 11 and October 23 had similar initial TOC and SOC concentrations and reductions after settling.

Total and Fecal Coliform Bacteria

Total and fecal coliform bacteria analyses were determined for six stormwater samples. Total and fecal coliform bacteria were greater than 2,400 per 100 milliliters (ml) in the July 4 sample throughout 24 hours of settling. The July 5, August 11, and September 15 samples contained total and fecal coliform bacteria values greater than 2,400,000 per 100 ml during 24 hours of settling. As a result, no data were available from these samples to characterize changes in bacteria numbers.

The July 26 sample initially contained 460,000 total and fecal

coliform bacteria per 100 ml. After two hours of settling, total coliform bacteria counts were 240,000, 140,000, and 240,000 per 100 ml, and after 24 hours were 460,000, 43,000, and 93,000 per 100 ml, respectively, at the one, two, and four-foot column depths. After two hours of settling, fecal coliform bacteria counts were 240,000, 43,000, and 240,000 per 100 ml, and after 24 hours were 460,000, 43,000, and 93,000 per 100 ml at one, two, and four feet, respectively.

Total and fecal coliform bacterial counts in the October 23 sample were greater than 24,000,000 per 100 ml initially. After two hours, total coliform bacteria decreased 4,600,000, 2,100,000, and 90,000 per 100 ml, and fecal coliform bacteria counts decreased 30,000, 230,000, and 90,000 per 100 ml at one, two, and four feet, respectively. After 24 hours, total coliform bacteria counts were 70,000, 43,000, and 43,000 per 100 ml. After 24 hours, fecal coliform bacteria counts decreased to 9,000, 23,000, and 7,000 per 100 ml at one, two, and four feet, respectively.

Dissolved Oxygen

To determine if any major oxygen changes took place within the laboratory columns, dissolved oxygen measurements were performed for two storms at all sampling depths and times. Table XIII lists the dissolved oxygen results from the August 11 and October 23 stormwater samples. Note the similarities in dissolved oxygen changes with time between the two samples. After 48 hours of settling, dissolved oxygen concentrations decreased from an initial range of 7.4 to 7.6 mg/L to between 3.2 to 3.9 mg/L.

TABLE XIII. DISSOLVED OXYGEN CONCENTRATION CHANGES
WITH TIME AND DEPTH

Time (hr)	Depth (ft)	Dissolved Oxygen (ppm)	
		8/11/81	10/23/81
0	1	7.6	7.4
	2	7.6	7.4
	4	7.4	7.35
2	1	7.0	7.4
	2	6.9	7.4
	4	7.4	7.4
6	1	7.0	7.0
	2	6.9	7.1
	4	6.8	7.3
12	1	6.4	6.4
	2	6.4	6.5
	4	6.2	6.6
24	1	4.5	4.6
	2	4.9	4.8
	4	4.6	4.1
48	1	3.9	3.2
	2	3.8	3.6
	4	3.8	3.6

Variations Between Columns

To determine if any major differences occurred in pollutant concentrations among the four columns used for laboratory settling, a sample was taken from each at the one-foot depth following sample addition. This comparison was performed on five samples. Data obtained from laboratory analysis are listed in Appendix Tables A-5 and A-6. Table XIV contains the statistics obtained from the computer analysis of data from each stormwater sample.

The greatest variations between the four columns occurred within the particle size ranges. This is most evident in the stormwater samples collected on August 11 and September 15 as seen in Table XIV. The September 15 sample also exhibited large variations in the concentration of other parameters as seen in the standard deviations of TSS, VSS, TPb, SPb, TZn, and SZn. A large variation occurred in TKN, TPb, and SZn concentrations in the August 11 sample, and in TPb and TZn concentrations in the sample collected on October 23.

TABLE XIV. STATISTICS DERIVED FROM DATA FOR COLUMN COMPARISON

Sample Date	Variable	Minimum Value	Maximum Value	Range	Mean	Standard Deviation
7/4/81	TSS (mg/L)	12	13	1	12.25	0.50
	VSS	7	8	1	7.50	0.58
	NO ₂	0.04	0.06	0.02	0.04	0.01
	NH ₃	0.15	0.19	0.04	0.17	0.02
	OP	0.49	0.15	0.02	0.50	0.01
	TKN	2.24	2.37	0.13	2.31	0.07
	SKN	1.40	1.92	0.52	1.71	0.24
	TP	9.80	0.87	0.07	0.84	0.03
	TSP	0.64	0.71	0.07	0.68	0.03
	Particle Counts:					
	5-15 (microns)	9767	58605	48838	23769	23350
	15-25	3322	11090	7768	5533	3717
	25-35	1175	2730	1555	1675	715
	35-45	626	740	114	674	53
	45-55	336	397	61	367	26
	55-65	175	250	75	208	31
	65-75	60	160	100	115	41
	75-85	50	118	68	88	29
	85-95	25	60	35	50	17
	95-105	35	41	6	39	3
	105-115	5	28	23	21	11
7/5/81	TSS (mg/L)	35	28	3	36.5	1.29
	VSS	17	18	1	17.2	0.50
	NO ₂	2.11	2.45	0.34	2.28	0.17
	NH ₃	0.05	0.07	0.02	0.06	0.01
	OP	0.03	0.03	0.00	0.03	0.00
	TKN	2.14	2.38	0.24	2.26	0.10
	SKN	1.26	1.39	0.13	1.32	0.06
	TP	0.18	0.21	0.03	0.19	0.01
	TSP	0.05	0.05	0.00	0.05	0.00
	Particle Counts:					
	5-15 (microns)	28895	45630	16735	39515	9232
	15-25	11760	20115	8355	17005	4568
	25-35	5805	11965	6160	9303	3164
	35-45	3365	6240	2875	5047	1498
	45-55	1965	3480	1515	2880	805
	55-65	1235	2160	925	1745	470
	65-75	820	1165	345	997	173
	75-85	820	985	165	882	90
	85-95	565	605	40	588	21
	95-105	355	475	120	430	65
	105-115	295	350	55	322	28

TABLE XIV. CONTINUED

Sample Date	Variable	Minimum Value	Maximum Value	Range	Mean	Standard Deviation
8/11/81	TSS (mg/L)	175	205	30	187	13.14
	VSS	40	50	10	45	4.27
	TPb ($\mu\text{g/L}$)	251	343	92	283	41.09
	SPb	45	59	14	51	6.06
	TZn	155	170	15	159	7.50
	SZn	135	170	35	149	17.02
	NO ₂ 3 (mg/L)	0.69	0.75	0.06	0.73	0.03
	NH ₃	0.28	0.42	0.14	0.35	0.06
	OP	0.03	0.11	0.08	0.08	0.03
	TKN	1.84	2.95	1.11	2.25	0.48
	SKN	0.86	0.94	0.08	0.90	0.03
	TP	0.32	0.48	0.16	0.40	0.08
	TSP	0.08	0.22	0.14	0.17	0.06
	Particle Counts:					
	5-15 (microns)	76495	459650	383155	243828	187274
	15-25	32940	153900	120960	88207	55579
	25-35	17470	54350	36880	37817	16804
	35-45	9510	20100	10590	16422	4740
	45-55	4645	8990	4345	7146	1840
	55-65	2220	4665	2445	3371	1098
	65-75	1020	2330	1310	1575	556
	75-85	400	1520	1220	1005	513
	85-95	350	940	590	549	268
	95-105	150	670	520	405	268
	105-115	100	315	215	219	106
9/15/81	TSS (mg/L)	600	681	81	633	39.75
	VSS	180	258	78	212	33.08
	TPb ($\mu\text{g/L}$)	920	1650	730	1195	331.71
	SPb	820	1280	460	982	210.14
	TZn	690	870	180	750	81.65
	SZn	610	670	60	646	25.62
	NO ₂ 3 (mg/L)	0.01	0.04	0.03	0.03	0.02
	NH ₃	0.15	0.19	0.04	0.17	0.02
	OP	0.06	0.19	0.13	0.13	0.05
	TKN	4.89	5.41	0.52	5.22	0.29
	SKN	0.72	0.76	0.04	0.75	0.02
	TP	0.80	0.90	0.10	0.86	0.05
	TSP	0.00	0.31	0.31	0.20	0.14
	Particle Counts:					
	5-15 (microns)	1358550	1460950	102400	1386817	49534
	15-25	614750	650000	35250	629783	14850
	25-35	18277	196150	177873	141644	82919
	35-45	43850	54950	11100	47750	5097

TABLE XIV. CONTINUED

Sample Date	Variable	Minimum Value	Maximum Value	Range	Mean	Standard Deviation
9/15/81	Particle Counts:					
	45-55 (microns)	10850	15850	5000	12917	2131
	55-65	4250	5800	1550	4869	662
	65-75	1450	2550	1100	1933	459
	75-85	550	1400	850	1100	389
	85-95	150	650	500	350	216
	95-105	150	450	300	300	122
	105-115	150	300	150	238	63
10/23/81	TSS (mg/L)	75	90	15	83.5	7.23
	VSS	41	45	4	43	2.31
	TPb (ug/L)	110	220	110	147	51.86
	SPb	12	25	13	18.5	6.45
	TZn	100	150	50	116	22.87
	SZn	35	50	15	41	6.29
	NO23 (mg/L)	0.71	0.81	0.10	0.76	0.05
	NH3	0.34	0.38	0.04	0.36	0.02
	OP	0.22	0.24	0.02	0.23	0.01
	TKN	1.82	2.11	0.29	1.92	0.13
	SKN	1.02	1.07	0.05	1.04	0.03
	TP	0.36	0.44	0.08	0.39	0.04
	TSP	0.24	0.26	0.02	0.25	0.01
	Particle Counts:					
	5-15 (microns)	78140	127070	48930	100662	23968
	15-25	33070	51940	18870	42852	8422
	25-35	17180	23660	6480	20662	3478
	35-45	6710	13690	6980	10466	2933
	45-55	3840	7110	3270	5902	1455
	55-65	2100	3670	1570	3135	706
	65-75	1390	2250	860	1971	395
	75-85	920	1990	1070	1580	462
	85-95	560	1090	530	898	238
	95-105	510	830	320	679	162
	105-115	370	730	360	522	159

V. DISCUSSION

Because of the variations in pollutant concentrations that existed among the seven stormwater samples, the project was able to characterize sedimentation under a wide range of initial conditions. The following is a discussion of the degree of treatment achieved by sedimentation, and the potential utilization of settling results in basin design.

The Efficiency of Stormwater Sedimentation

Although soluble stormwater runoff pollutant concentrations were not as readily removed, sedimentation reduced the concentration of insoluble forms significantly. Total suspended solids concentrations were greatly reduced in all seven stormwater samples after two days. However, the rate at which the reductions occurred was dependent upon the initial TSS concentration. Samples with high initial TSS concentrations were reduced at a faster rate than those samples with low concentrations. TSS concentrations in all seven stormwater samples were reduced to 19 mg/L or less after two days. Most of these final concentrations were lower than the 15 mg/L suspended solids concentration of treated secondary effluent shown in Table I (8).

The particle-size distributions from the seven stormwater samples were composed mainly of small-diameter particles. The greatest number of particles occurred in the 5 to 15 and 15 to 25 micron size ranges. Street-cleaning particles at all three sampling sites could explain this majority of small-diameter particles because normally the larger particles are removed most effectively.

The reduction of nutrient concentrations by sedimentation was

hampered by the fact that for most samples, nutrient concentrations contained a large fraction of soluble forms. This was also true for heavy metals and organic carbon concentrations. Nevertheless, these pollutants were reduced, with the exception of ammonia, which actually increased.

The negative percent reduction values of ammonia were probably the result of microbial activity. Ammonia was generally found to increase with time, while other forms of nitrogen decreased. The large reduction in dissolved oxygen concentrations in the columns during the settling period supports the hypothesis of the existence of microbial activity. Therefore, an assumption may be made that while undergoing settling, organic nitrogen was converted to ammonia by bacteria.

Dissolved oxygen concentrations decreased by approximately 4 mg/L after 48 hours of settling. However, the current project was under quiescent conditions. In an actual detention basin, wind currents could provide circulation to help replenish oxygen concentrations, although at the greater depths that would be used, mixing might not occur in the lower part of the basin and similar decreases in dissolved oxygen could occur. If dissolved oxygen concentrations are sufficiently depleted in the lower depths and cause anoxic conditions, the bottom sediments could release pollutants such as phosphorus and ammonia-nitrogen into the water.

After settling, total phosphorus concentrations in three of the stormwater samples (June 20, July 5, and August 11) were below the recommended concentration of 0.10 mg/L for flowing waters. To control eutrophication within a lake or reservoir, the recommended total phosphorus concentration that should not be surpassed is 0.025 mg/L (64).

Although total phosphorus concentrations were greatly reduced, final concentrations after 48 hours exceeded this critical concentration.

For domestic water supplies, the EPA criterion for lead is 50 $\mu\text{g/L}$ and for zinc is 5 mg/L (64). Of the four samples with initial total lead concentrations greater than this critical value, only two contained total lead concentrations less than 50 $\mu\text{g/L}$ after 48 hours of settling. None of the samples collected contained initial total zinc concentrations greater than the 5 mg/L critical value.

Organic matter, as measured by BOD_5 and COD, was considerably reduced by settling. As previously mentioned, TOC concentrations did not respond to settling well because there was a large soluble fraction. The BOD_5 in the September 15 sample was the highest of the three samples analyzed. The initial concentration of 210 mg/L was as high as that of untreated municipal sewage, as listed in Table I (8). After 24 hours of settlement, this concentration was reduced to 40 mg/L at the two-foot depth, and 80 mg/L at the one and four-foot depths. These final concentrations were much higher than those in the other two samples. After 24 hours of settling, the BOD_5 of the samples collected on August 11 and October 23 was reduced to 20 mg/L or less, which is lower than the BOD_5 of treated secondary effluent given in Table I (8).

Total and fecal coliform bacteria counts were not noticeably reduced in the majority of stormwater samples. There were no discernible trends between these counts at the settling time intervals, and values varied greatly between depth intervals. In addition, bacteria numbers, in some instances were greater than the limit of the dilution procedure used. The sample collected on October 23 was the only sample to show a

marked decrease in the number of bacteria. In this sample, total and fecal bacteria counts were greater than 2.4×10^7 initially and were reduced to as low as 7.0×10^4 and 7.0×10^3 , respectively.

Table XV lists the average percent reductions from the seven stormwater samples analyzed. Because the three-foot column-depth interval was used for only three samples and data were not available for all parameters, the values in Table XV are the result of averaging different numbers of percent reductions. The three stormwater samples (June 20, July 4, and July 5) that involved the use of the three-foot column-depth sampling interval contained initial pollutant concentrations that were generally lower than those that were sampled at the four-foot depth. Consequently, percent reductions were greater in those samples that involved sampling from the four-foot column-depth.

To compare the percent reductions from the current project with that from the literature, values from all three sampling depths were averaged together. In Table XVI, percent reductions from the literature are shown in comparison with the 48-hour average percent reductions. This time interval was chosen because it represented all stormwater samples, excluding the preliminary sample of June 20, and 48 hours was the duration of the project settling period. Overall, the percent reduction values of the current project compared well with the values from the literature in Table XVI, and values obtained in the current project in some cases were greater.

Initial pollutant concentrations varied between the seven stormwater samples because of differences in flow volumes and pollutant concentrations during sample collection. Samples collected at the same

TABLE XV. PERCENT REDUCTION VALUES AVERAGED TOGETHER FROM THE SEVEN STORMWATER SAMPLES ANALYZED

Parameter	After 24 Hours				After 48 Hours			
	1 ft. ^a	2 ft. ^a	3 ft. ^b	4 ft. ^c	1 ft. ^d	2 ft. ^d	3 ft. ^e	4 ft. ^c
TSS	76	75	57	91	90	90	80	95
VSS	67	68	42	91	88	86	74	94
COD	41 ^d	38 ^d	20 ^e	48	46 ^f	49 ^f	22 ^g	58
BOD	61 ^b	73 ^b	-	24	-	-	-	-
TOC	30 ^f	24 ^f	19 ^g	36	38 ^c	40 ^c	-	39
SOC	12 ^c	11 ^b	12 ^g	13 ^e	14 ^b	9 ^b	-	7 ^e
Susp. OC	47 ^c	80 ^b	100 ^g	79 ^e	95 ^b	96 ^b	-	80 ^e
NH3	-86	-30	-72	0	-48	-10	-120	-39
NO23	13	10	12	1	12	5	24	4
TKN	36	35	12	47	34	20	23	53
SKN	7	6	5	3	4	4	4	5
Susp. KN	52	45	22	72	47	-31	40	78
Organic-N	45	40	19	52	46	31	29	60
TN	33	29	9	40	34	22	31	44
OP	-16	3	6	12	17	32	20	30
TP	50	47	40	45	56	58	44	58
TSP	19	18	24	9	19	30	13	31
Susp. P	71	67	43	72	86	79	52	79
TZn	41 ^d	37 ^d	14 ^e	46	49 ^f	48 ^f	12 ^g	56

TABLE XV. CONTINUED

Parameter	After 24 Hours				After 48 Hours			
	1 ft. ^a	2 ft. ^a	3 ft. ^b	4 ft. ^c	1 ft. ^d	2 ft. ^d	3 ft. ^e	4 ft. ^c
SZn	20 ^d	21 ^d	13 ^e	16	15 ^f	16 ^f	5 ^g	25
Susp. Zn	71 ^d	63 ^d	50 ^e	81 ^f	94 ^f	92 ^g	88	83
TPb	79 ^c	82 ^c	-	78	86 ^c	87 ^c	-	86
SPb	30 ^c	30 ^c	-	29	34 ^c	32 ^c	-	36
Susp. Pb	82 ^c	84 ^c	-	86	94 ^c	94 ^c	-	94

a. From 7 samples

b. From 3 samples

c. From 4 samples

d. From 6 samples

e. From 2 samples

f. From 5 samples

g. From 1 sample

TABLE XVI. COMPARISON OF PERCENT REDUCTION VALUES FROM THE CURRENT PROJECT WITH THOSE FROM THE LITERATURE

Study	Parameter Percent Reduction											
	TSS	COD	BOD	TOC	NH ₃	TKN	ORGANIC N	TP	OP	NO ₂ +NO ₃	TZN	TPb
EPA (42)	20-60	-	30	-	-	-	-	-	-	-	-	-
New York City (43) ^a	-	34.4	-	21.3	22.1	38.4	50.5	22.2	6.7	15.4	27.2	30.6
Oliver and Grigoropoulos (44)	89	52	-	-	13	-	31	65	-	-	-	-
Whipple and Hunter (47)	70	-	20-50	-	-	-	-	-	-	-	17-36	60
Samar <u>et al.</u> (49)	-	85	-	-	-	-	-	-	-	-	-	100
Colston (10)	77	60	-	-	-	-	-	-	-	-	-	-
Mische and Dharmadhikare (50)	-	60-70	-	-	-	-	-	-	-	-	-	-
Alexander (51)	68	30	24	-	6	26	-	26	-	1	-	24
Ferrar and Witkowski (45)	15-47	8-21	-	-	-	20	-	-	-	-	-	-
Current Study	90	49	53 ^b	39	-45	36	42	46	24	11	48	86

a. From combined sewer overflow.

b. From 24-hour intervals.

sites were not even similar. Figures 18 through 32 show box plots of percent reductions with time for TSS, suspended P, suspended Pb, and TKN. Box plots were used in order to show the 25th percentile, 50th percentile (median), 75th percentile, and minimum and maximum values. All depths were combined for each time interval. To demonstrate the wide range of percent reductions that occurred among the seven samples, the samples were combined together and also in three groups according to initial TSS concentrations. The first group consisted of those samples with extremely low initial concentrations of 15, 35, and 38 mg/L (July 5, July 4, and June 20). The second group consisted of higher initial concentrations of 100, 155, and 215 mg/L (October 23, July 26, and August 11). The third group consisted of only one sample (September 15) which was separated because it contained a TSS concentration of 721 mg/L and did not closely relate to any other sample.

Figure 18 shows the reduction of TSS from those samples that contained low initial concentrations of 15, 35, and 38 mg/L. Settling in these samples was slow until the 48-hour sampling interval. In samples that contained higher TSS concentrations of 100, 155, and 215 mg/L, TSS settling was considerably faster, as indicated by Figure 19. In Figure 20, the sample with an initial TSS concentration of 721 mg/L displayed a faster rate of removal from all samples grouped together. In Figure 21, there is shown a somewhat gradual increase in the median values of percent reductions with time. In grouping all samples together, the effects of initial TSS concentrations on removal rates were not noticeable as they were in the preceding figures.

Figure 22 presents the range of percent reduction of suspended P

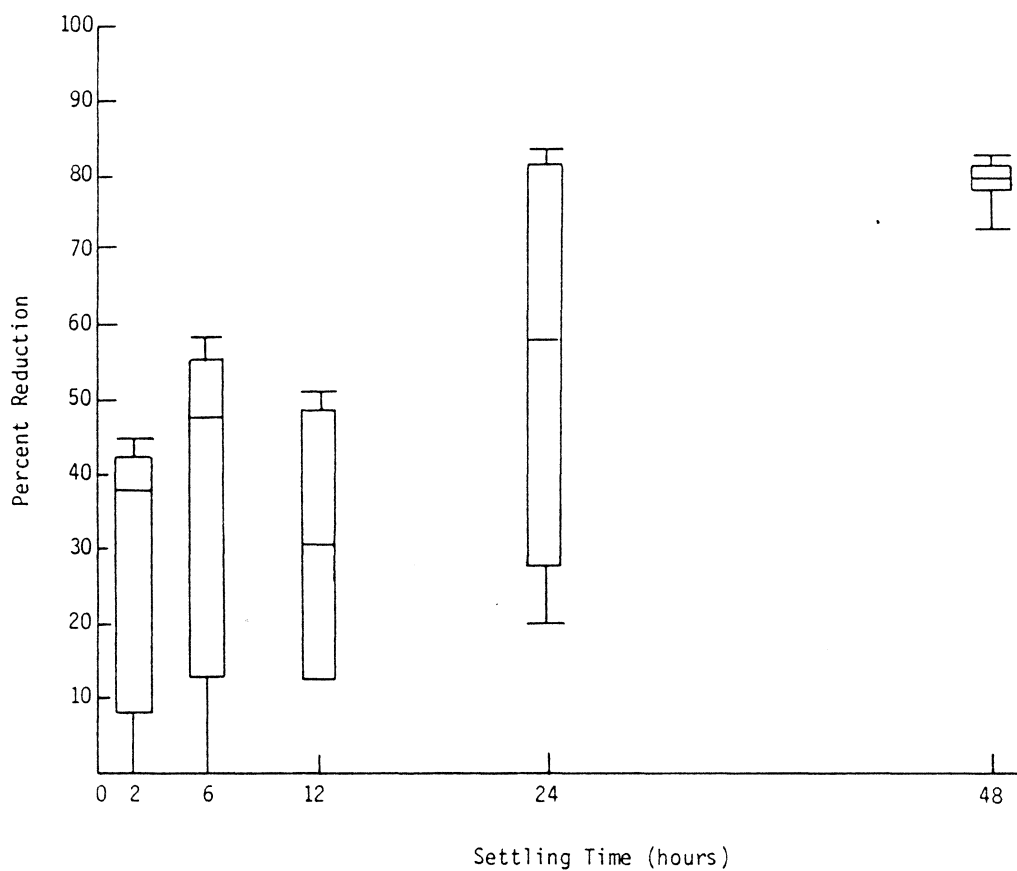


FIGURE 18. PERCENT REDUCTION OF TSS WITH SETTLING TIME IN SAMPLES WITH LOW INITIAL CONCENTRATIONS OF 15, 35, AND 38 mg/L (JULY 4, JULY 5, AND JUNE 20)

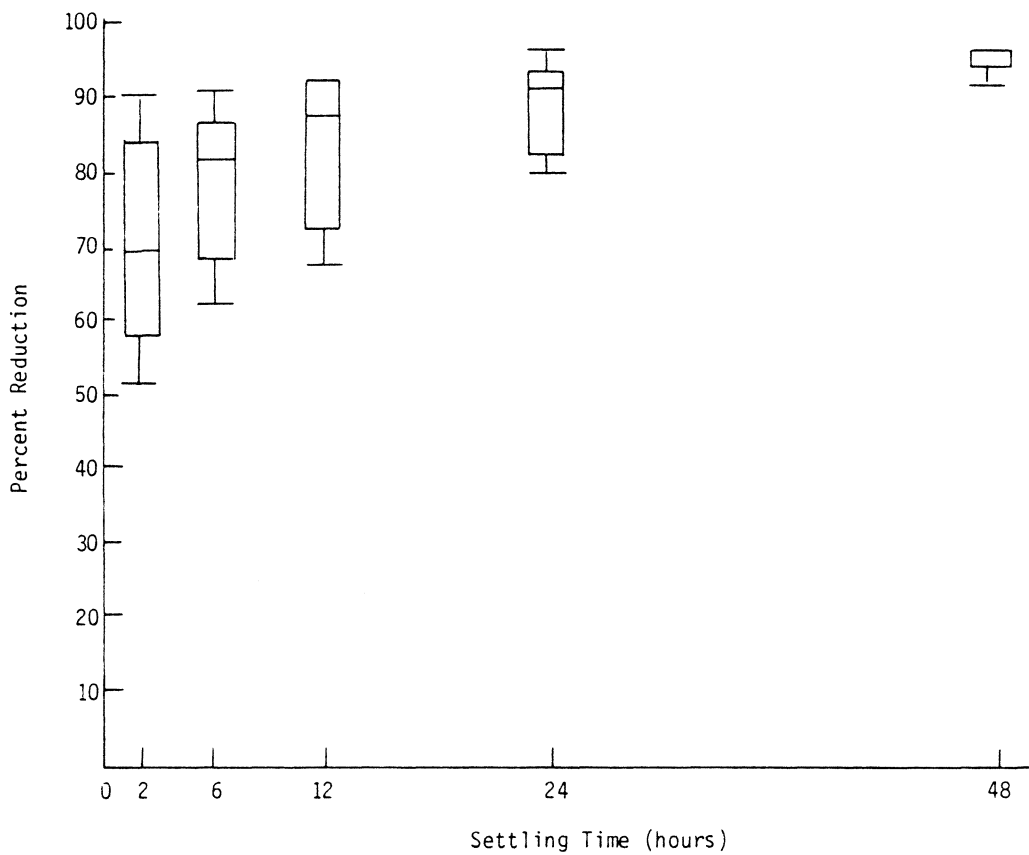


FIGURE 19. PERCENT REDUCTION OF TSS WITH SETTLING TIME IN SAMPLES WITH INITIAL TSS CONCENTRATIONS OF 100, 155, AND 215 mg/L (OCTOBER 23, JULY 26, AND AUGUST 11)

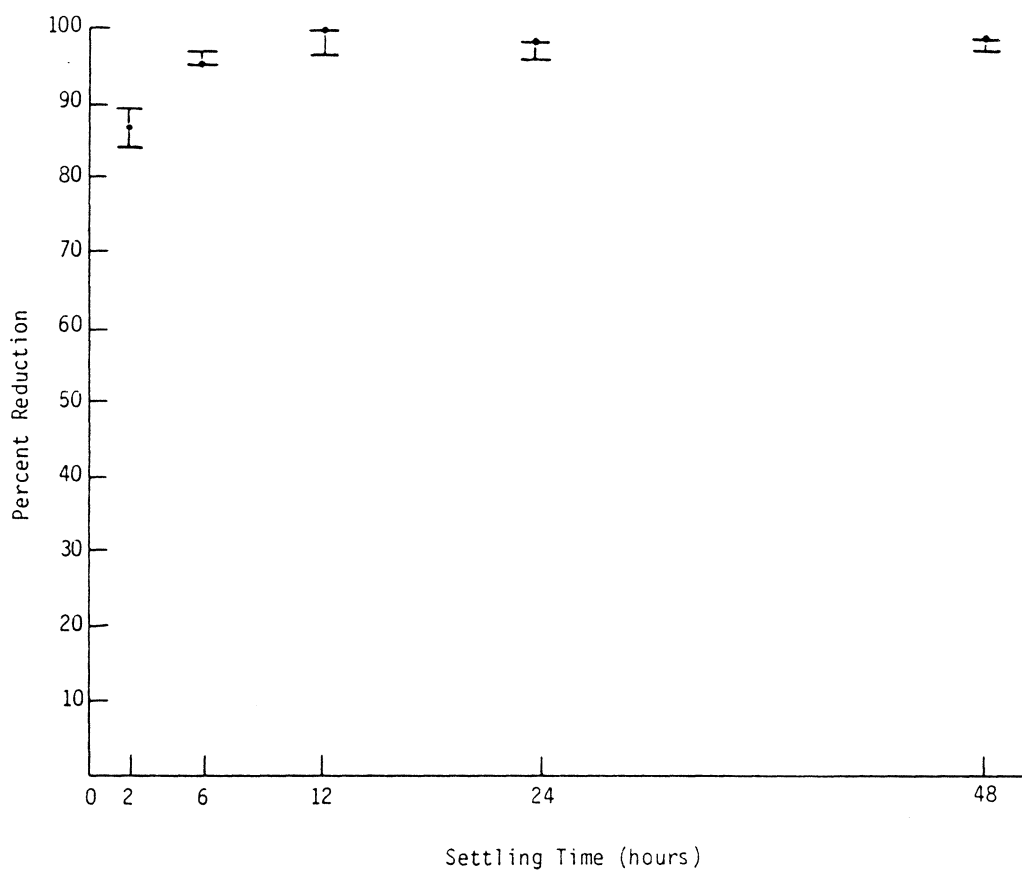


FIGURE 20. PERCENT REDUCTION OF TSS WITH SETTLING TIME IN THE SAMPLE WITH AN INITIAL TSS CONCENTRATION OF 721 mg/L (SEPTEMBER 15)

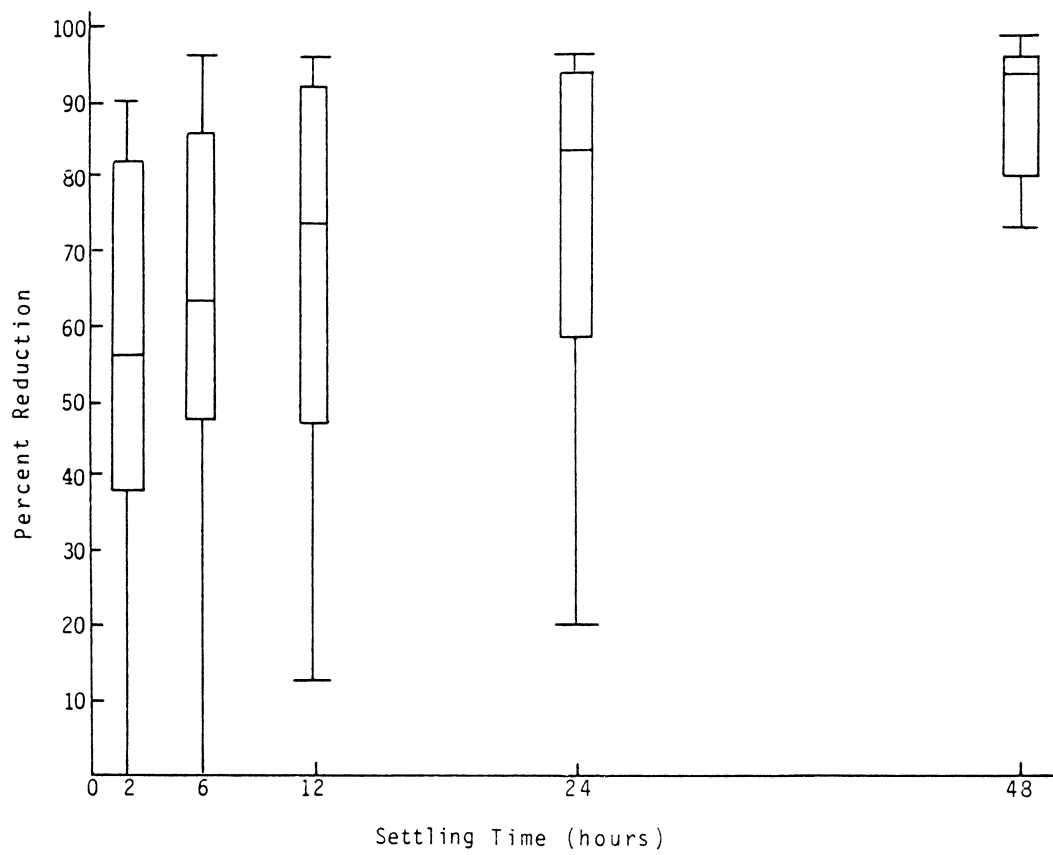


FIGURE 21. PERCENT REDUCTION OF TSS WITH SETTLING TIME IN COMBINED RESULTS

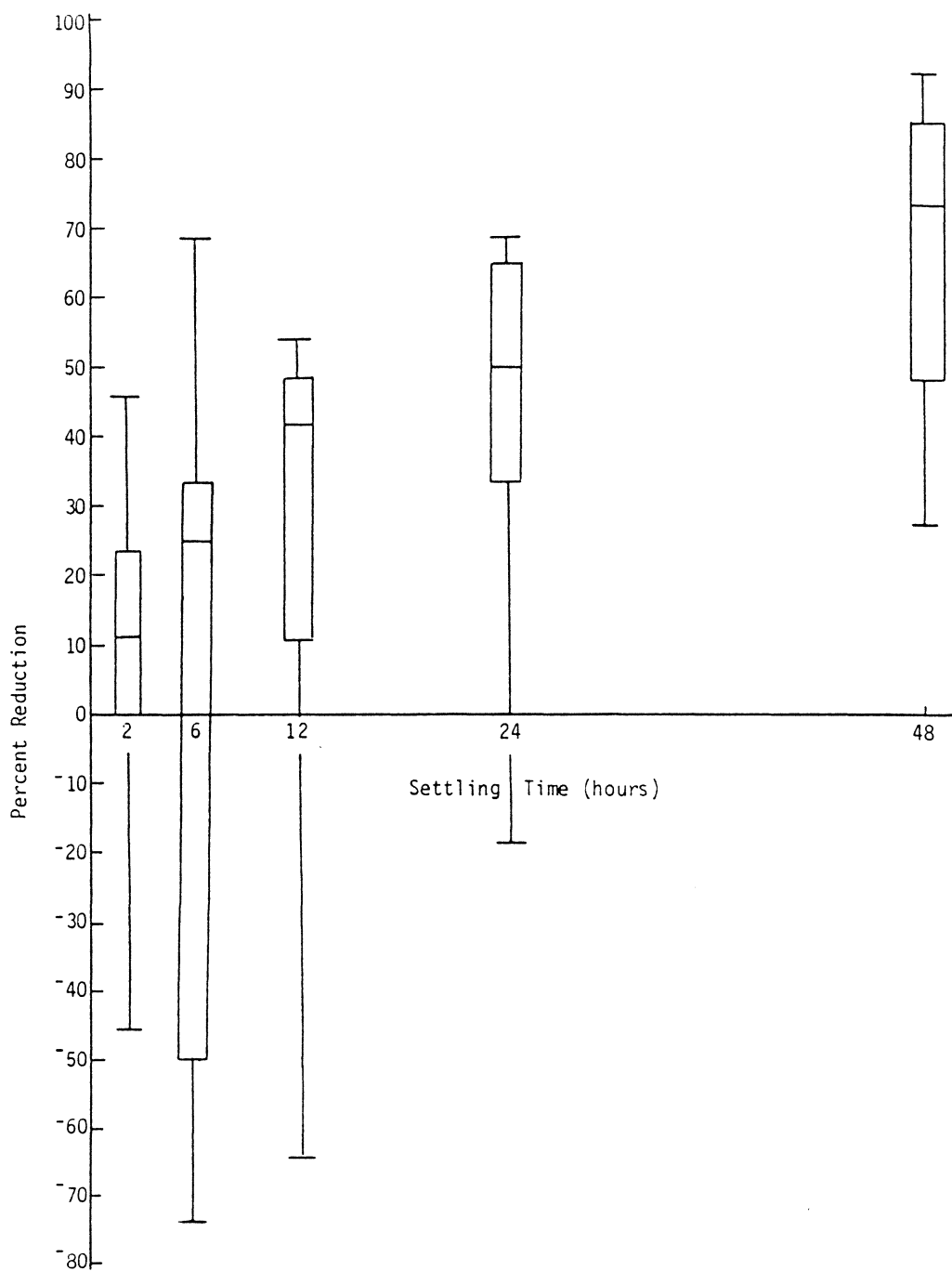


FIGURE 22. PERCENT REDUCTION OF SUSPENDED PHOSPHORUS WITH SETTLING TIME IN SAMPLES WITH INITIAL TSS CONCENTRATIONS OF 15, 35, AND 38 mg/L (JULY 4, JULY 5, AND JUNE 20)

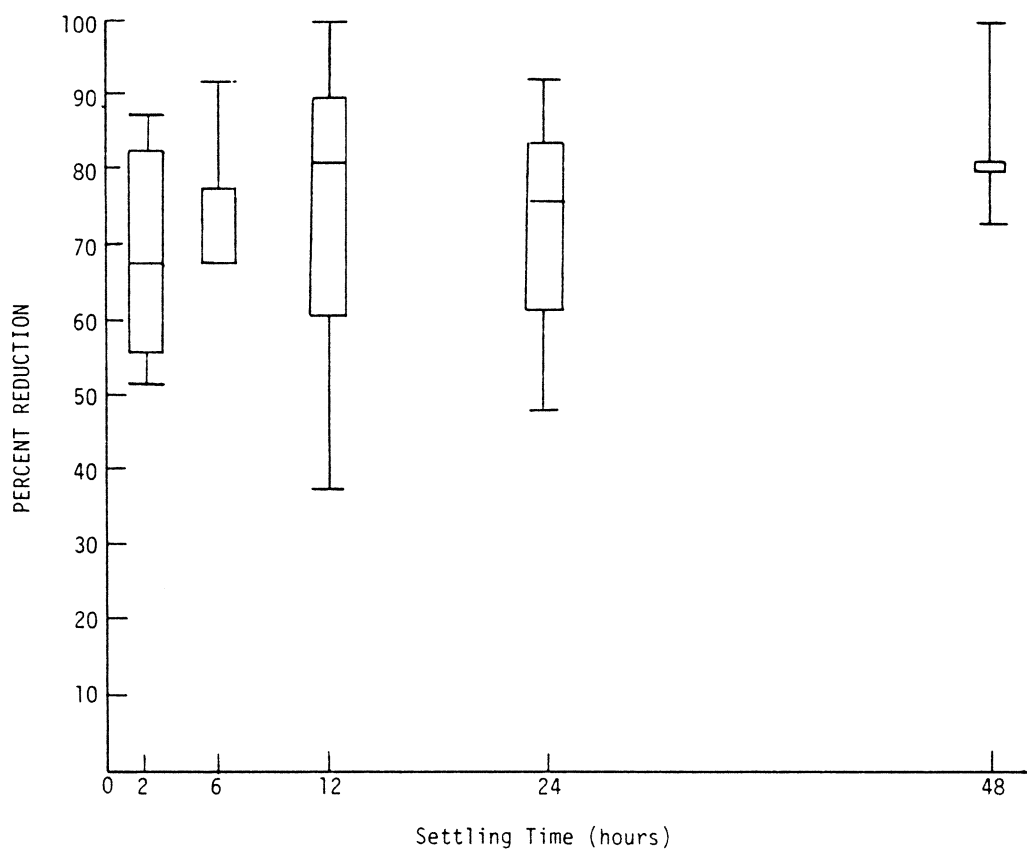


FIGURE 23. PERCENT REDUCTION OF SUSPENDED PHOSPHORUS WITH SETTLING TIME IN SAMPLES WITH INITIAL TSS CONCENTRATIONS OF 100, 155, AND 215 mg/L (OCTOBER 23, JULY 26, AND AUGUST 11)

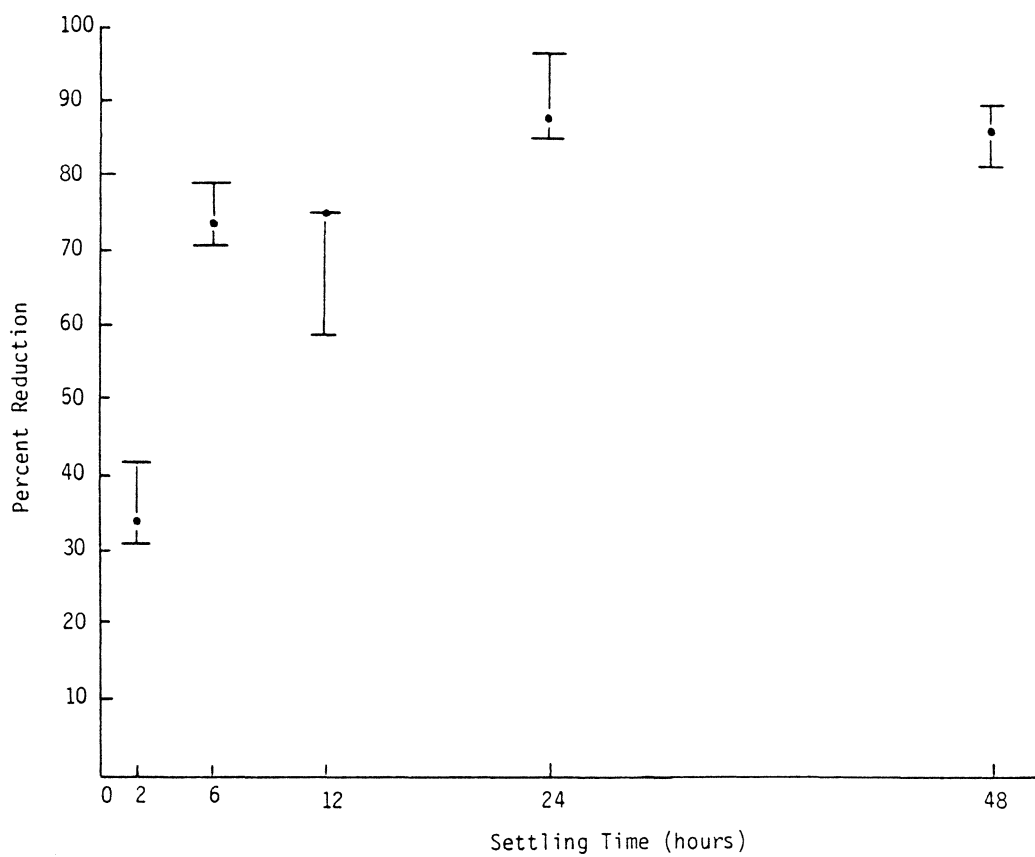


FIGURE 24. PERCENT REDUCTION OF SUSPENDED PHOSPHORUS WITH SETTLING TIME IN THE SAMPLE WITH AN INITIAL TSS CONCENTRATION OF 721 mg/L (SEPTEMBER 15)

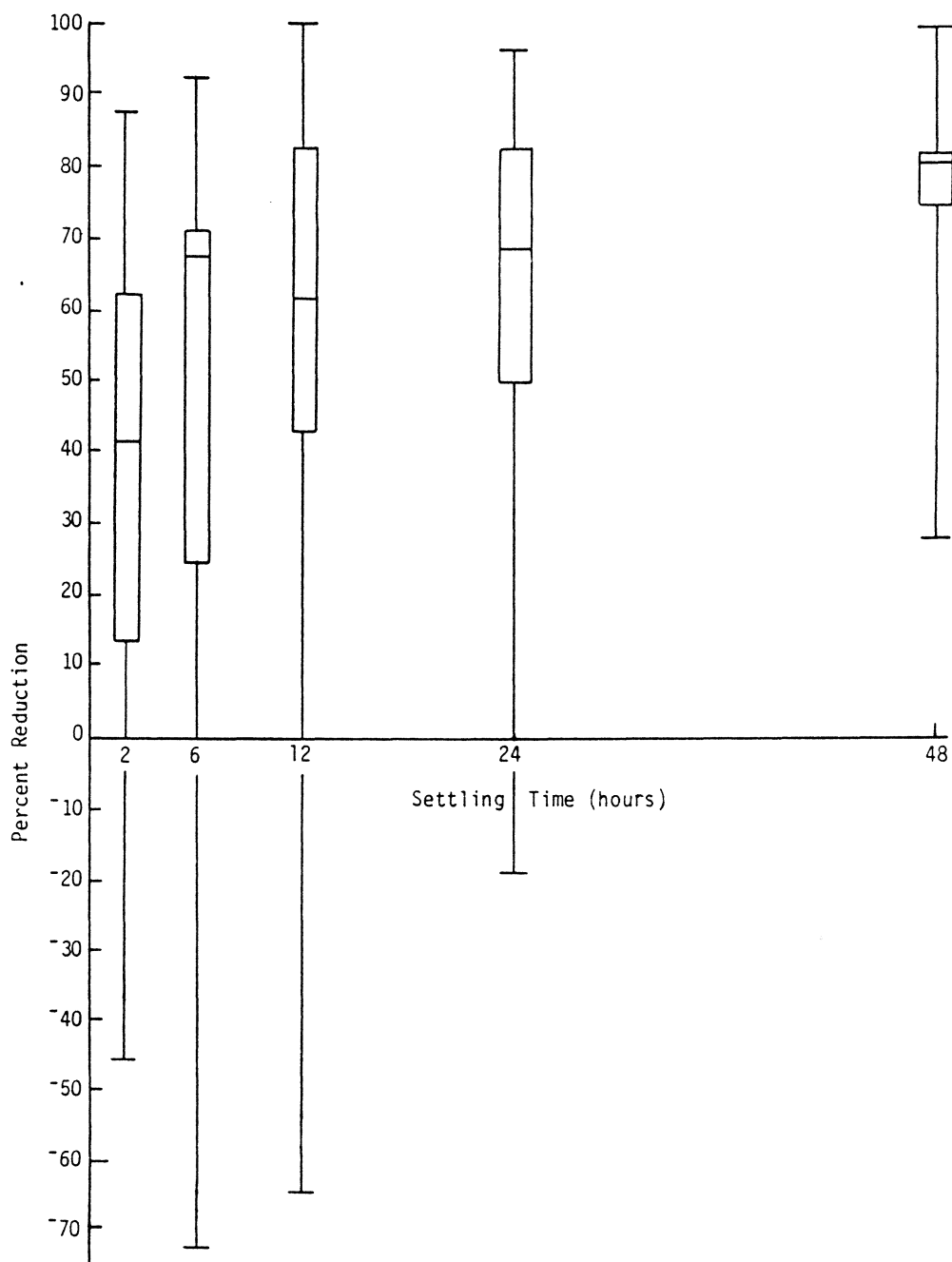


FIGURE 25. PERCENT REDUCTION OF SUSPENDED PHOSPHORUS IN COMBINED RESULTS

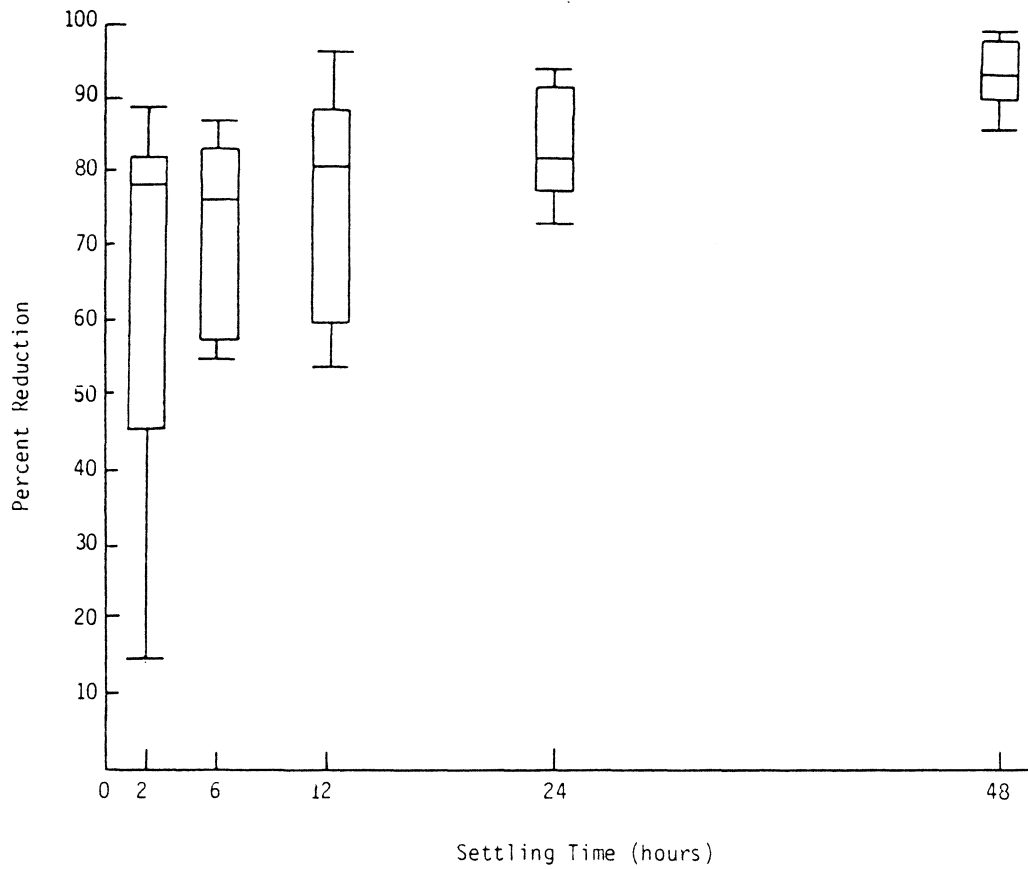


FIGURE 26. PERCENT REDUCTION OF SUSPENDED LEAD WITH SETTLING TIME IN SAMPLES WITH INITIAL TSS CONCENTRATIONS OF 100, 155, AND 215 mg/L (OCTOBER 23, JULY 26, AND AUGUST 11)

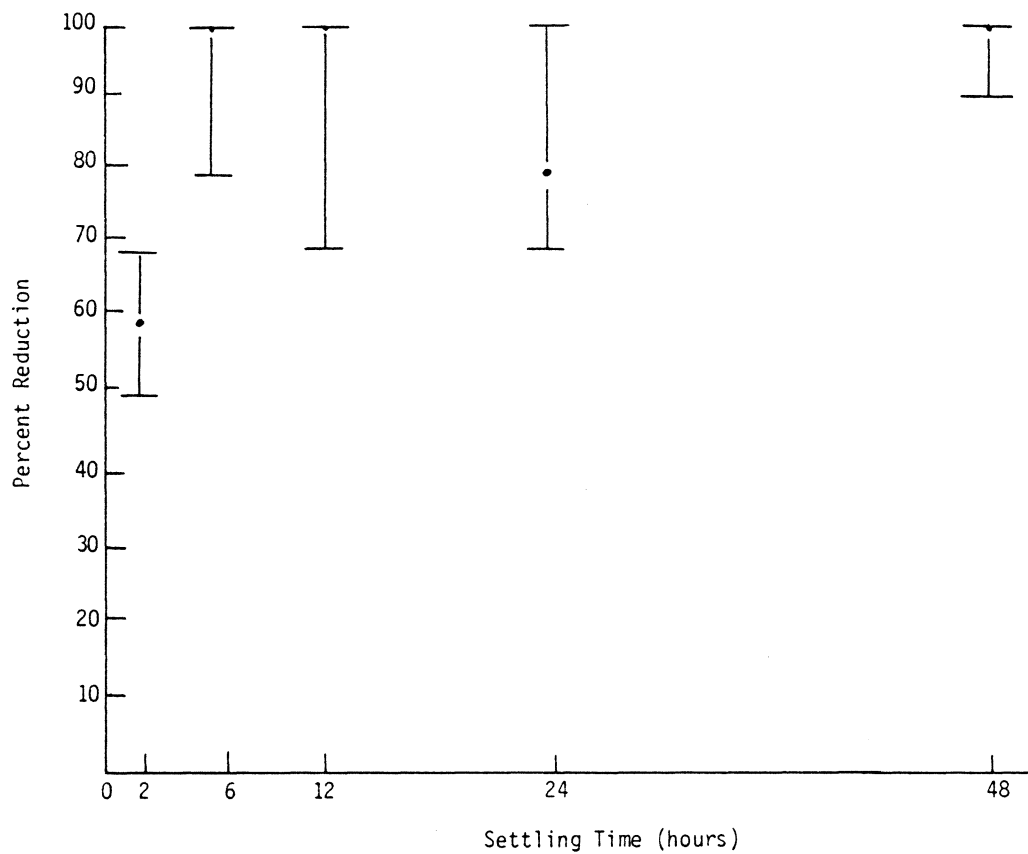


FIGURE 27. PERCENT REDUCTION OF SUSPENDED LEAD WITH SETTLING TIME IN THE SAMPLE WITH AN INITIAL TSS CONCENTRATION OF 721 mg/L (SEPTEMBER 15)

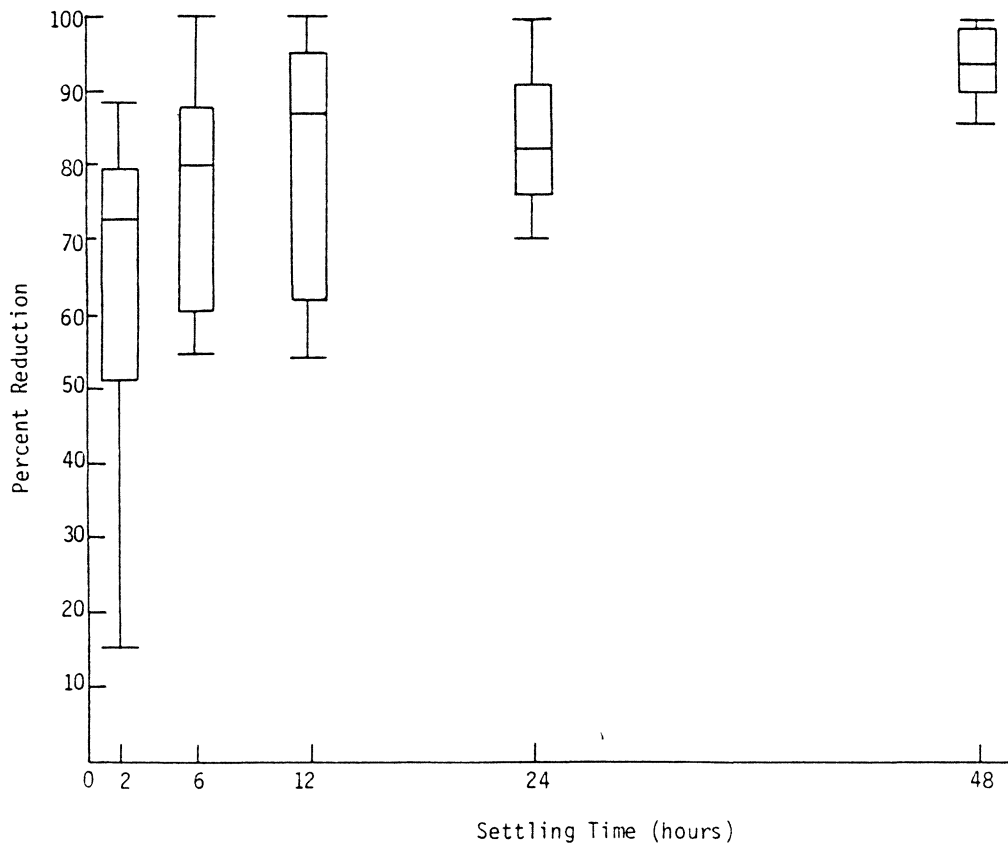


FIGURE 28. PERCENT REDUCTION OF SUSPENDED LEAD WITH SETTLING TIME IN COMBINED RESULTS

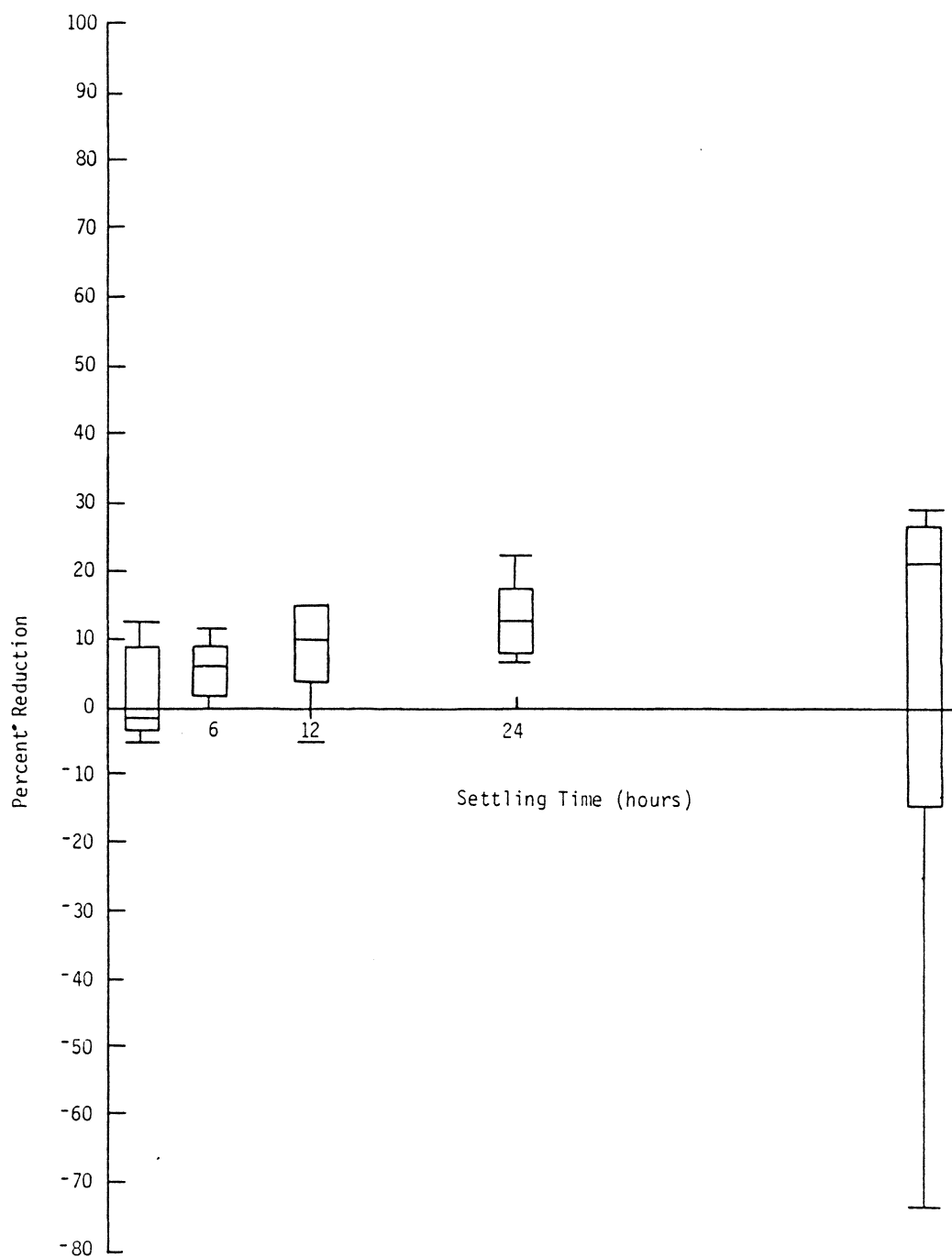


FIGURE 29. PERCENT REDUCTION OF TOTAL KJELDAHL NITROGEN WITH TIME IN SAMPLES WITH INITIAL TSS CONCENTRATIONS OF 15, 35, AND 38 mg/L (JULY 4, JULY 5, AND JUNE 20)

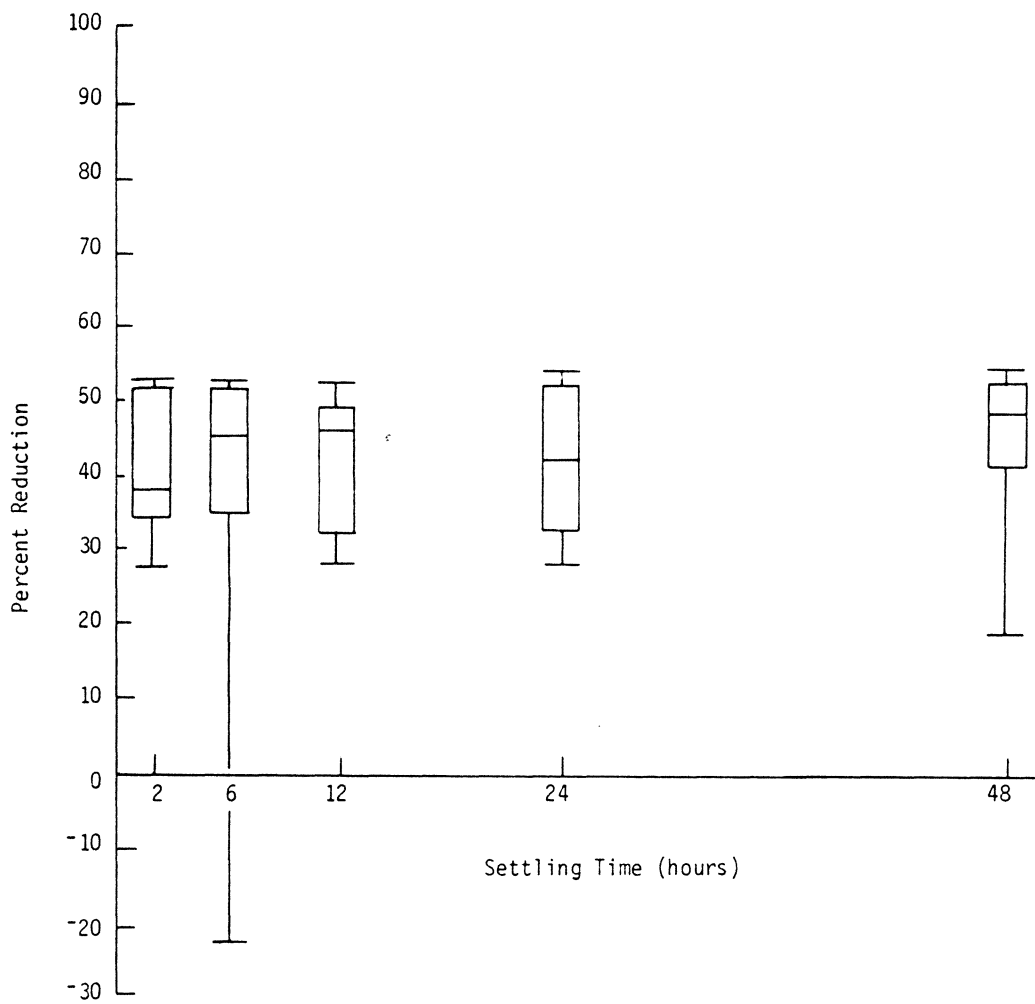


FIGURE 30. PERCENT REDUCTION OF TOTAL KJELDAHL NITROGEN WITH SETTLING TIME IN SAMPLES WITH INITIAL TSS CONCENTRATIONS OF 100, 155, AND 215 mg/L (OCTOBER 26, JULY 26, AND AUGUST 11)

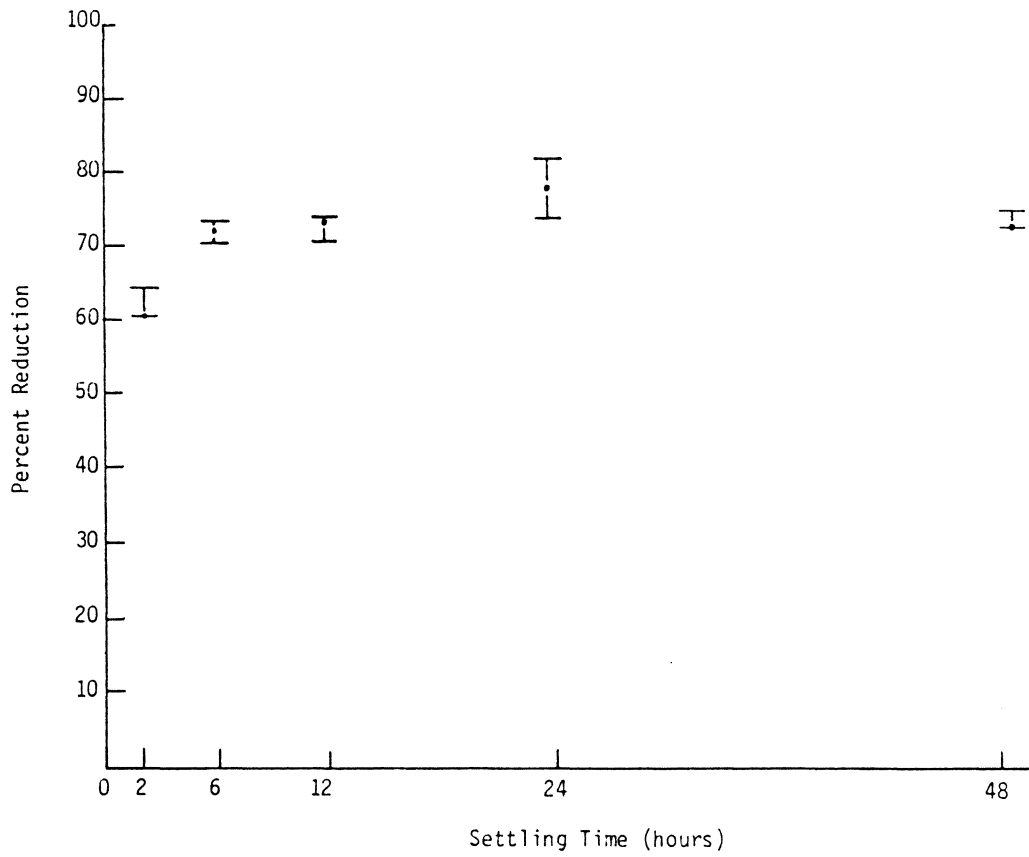


FIGURE 31. PERCENT REDUCTION OF TOTAL KJELDAHL NITROGEN WITH SETTLING TIME IN THE SAMPLE WITH AN INITIAL TSS CONCENTRATION OF 721 mg/L (SEPTEMBER 15)

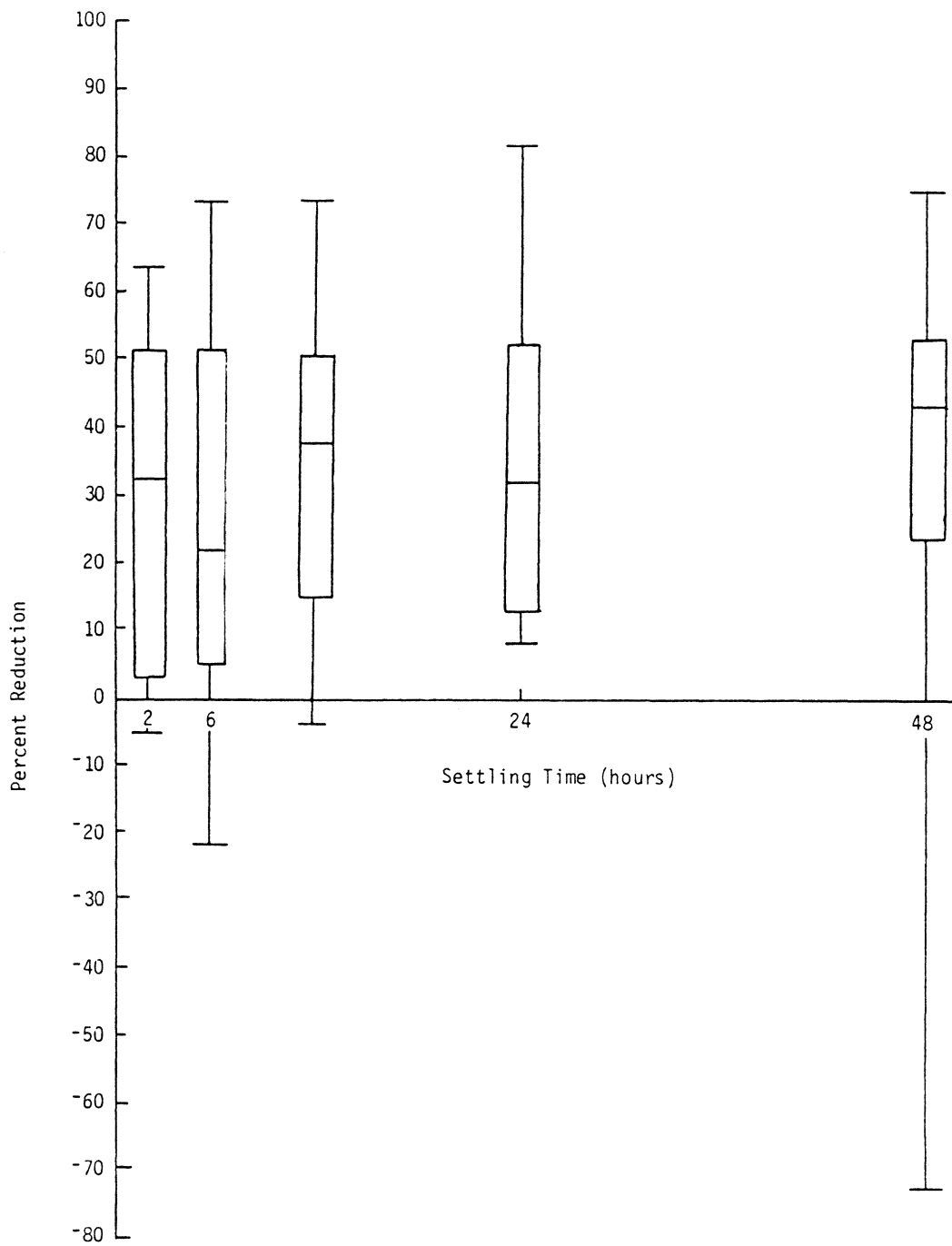


FIGURE 32. PERCENT REDUCTION OF TOTAL KJELDAHL NITROGEN WITH SETTLING TIME IN COMBINED RESULTS

with settling time from the group of samples with low initial TSS concentrations. In Figure 22, the reduction of suspended P involved negative values which indicated a small number of increases in concentration until the 48-hour settling interval. This may have been the result of differences in concentration between the four columns. In Figure 23, which shows the percent reduction of suspended phosphorus from samples with higher TSS concentrations, there were no negative extreme values, and after 48 hours of settling, the median, upper percentiles, and lower percentile of percent reduction values were in close proximity. In Figure 24 of the sample with an initial concentration of 721 mg/L, the reduction of suspended P displays the greatest change between two and six hours of settling. Figure 25 presents the reduction of suspended P from all stormwater samples combined.

Figure 26 gives the percent reduction of suspended Pb with settling time in those samples with low TSS concentrations. In Figure 26, the most substantial increase in median values occurred at the forty-eight hour interval. Lead data were not available for samples with low TSS concentrations, because values were below the detection limit of 100 $\mu\text{g/L}$ of the instrument used. The reduction of suspended Pb in the sample with an initial concentration of 721 mg/L is shown in Figure 27. In this sample, the greatest increase in percent reduction values occurred between two and six hours. Figure 28 shows the percent reduction of suspended Pb from all samples combined.

Figures 20 through 32 show percent reductions of TKN with time. As in the preceding series of figures with percent reductions grouped according to TSS concentrations, the samples when grouped together

(Figure 32) do not reflect the increase in percent reductions with TSS values as observed in Figures 20, 30, and 31. However, when all samples are grouped together as shown in Figures 21, 25, 28, and 32; percent reduction values show a gradual increase in the median, and a decrease in the distance between the 25th and 75th percentile. This trend shows the overall settling efficiency for the selected pollutants from all of the stormwater samples collected. The most efficient settling time was the 48-hour interval.

The box plots demonstrate the wide differences among settling characteristics of the seven stormwater samples. One obvious disadvantage of grouping samples according to TSS concentrations was that the initial concentration of other parameters was not taken into consideration. Although nutrients and heavy metals can be associated with suspended solids, in the current project, these pollutants consisted mainly of soluble forms more often than not. For the purpose of the project, suspended forms of pollutants were of greatest concern. Therefore, the grouping of samples by TSS concentrations was used as the most practical approach for comparing settling between samples.

Overall, settling was an efficient means of treatment as seen in the substantial percent reduction values of most parameters listed in Table XV. The inconsistencies with the general trends in settling could have been the result of differences in pollutant concentrations between the columns. These differences would result in initial pollutant concentrations that were not representative and, in turn, led to percent reductions which were extremely high, low, or negative in value. The reduction in the concentration of soluble pollutants could also be the result of differences between the four columns.

The Use of Settling Data in Basin Design

From the results obtained from settling, information can be derived to aid in basin design to obtain the most efficient removal of pollutants. In Table XV, the maximum average reduction of TSS was 95 percent, which occurred at the four-foot depth interval after 48 hours of settlement. The settling velocity for this time and depth interval would be 0.083 ft/hr, and this corresponds to an overflow rate of 15 gpd/ft². Therefore, from the data provided, a basin overflow rate of 15 gpd/ft² or less should remove approximately 95 percent of the TSS concentration. TSS was reduced by 91 percent at the 24-hour four-foot interval, which would correspond to an overflow rate of 30 gpd/ft². Similarly, overflow rate velocities can be derived for other parameters for desired reductions.

Basin efficiency can also be predicted for design criteria by the use of particle size distributions. To demonstrate this technique, a representative particle diameter was derived for each of the eleven size ranges by determining the geometric mean, which is (61):

$$\text{Geometric Mean} = \sqrt{\text{largest diameter} \times \text{smallest diameter}}$$

Assuming all particles to be spherical, surface area measurements were determined by the equation (61):

$$\text{Surface Area} = \pi r^2$$

By multiplying the surface area, which had units of square microns, of each size range's mean diameter by the number of particles in each size range, the total surface area in each size range was obtained. Percent reductions were then determined for each size range for each time and depth interval. Table XVII shows the amount of total initial surface area

TABLE XVII. TOTAL INITIAL SURFACE AREA OF SUSPENDED PARTICLES AND THE PERCENT OF THE TOTAL IN EACH SIZE RANGE

Sample Date	Initial TSS (mg/L)	Initial Total Surface Area (microns) ²	Initial Percent of Total Surface Area in Each Particle Size Range (microns)										
			5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
6/20/81	38	2.5×10^7	7	14	14	13	11	10	7	9	6	5	4
7/4/81	15	2.6×10^7	12	19	16	13	10	8	6	5	5	4	3
7/5/81	35	2.3×10^8	1	7	10	9	9	18	8	10	8	9	9
7/26/81	155	3.0×10^8	9	20	22	12	12	8	5	4	3	2	2
8/11/81	215	8.3×10^8	13	22	20	15	9	7	4	3	2	2	1
9/15/81	721	2.2×10^9	18	37	14	13	6	4	2	2	1	2	1
10/23/81	100	5.9×10^8	6	14	16	16	13	10	7	7	4	4	2

of suspended solids in each sample and the percent of the total in each size range. Note that the majority of surface area was found in particles of the 15 to 35 micron size range with the exception of the July 5 sample in which the most surface area was associated with particles in the 55 to 65 size range. This distribution remained approximately the same throughout the settlement period.

By the use of the CORR procedure of SAS (63) the percent reduction of total surface area was compared to percent reductions of selected parameters to determine if a linear relationship existed. To compare differences between samples, all seven samples were grouped according to initial TSS concentration as previously separated. Correlation coefficients were obtained for twelve parameters. Table XVIII lists each parameter and the corresponding coefficient. According to these coefficients, relationships did exist between percent reductions of surface area and percent reductions of nutrients and heavy metals. The strongest relationship existed between the reduction of total surface area and the reduction of pollutants, with the exception of $\text{NO}_2 + \text{NO}_3$, in the sample with an initial TSS concentration of 721 mg/L because of the large coefficients. In samples with initial TSS concentrations of 100, 155, and 215 mg/L, the greatest coefficients were obtained in the reduction of suspended phosphorus, suspended Kjeldahl nitrogen, organic nitrogen, total lead and suspended lead. In samples with initial TSS concentrations of 15, 35, and 38 mg/L there appeared to be a much weaker relationship between the reduction of total surface area and most pollutants.

To compare the relationship between pollutant reductions and the reduction of surface area in each particle size range, the stepwise

regression procedure of SAS (63) was used. Samples were again separated by the initial TSS concentration. Table XIX lists coefficients of the parameters along with the corresponding particle size range or ranges from which surface area percent reductions were obtained. In Table XIX, the best coefficients and corresponding size ranges were listed, or the first two or three size ranges in instances where more than one range contributed to a large coefficient. The size ranges are arranged in order of importance when more than one range is listed for a coefficient. For example, the reduction of total phosphorus in the samples with initial TSS concentrations of 100, 155, and 215 mg/L was related mainly to the reduction of surface area in the 25 to 35 micron particle size range. A stronger relationship existed in the sample with an initial TSS concentration of 721 mg/L (September 15) between total phosphorus and the same particle size range, because of the larger correlation coefficient. In the September 15 sample, the reduction of total nitrogen, total zinc, and to total lead, were all related to the reduction of surface area in the size range of 35 to 45 microns. Reductions of nitrites and nitrates were not closely related to the reduction of particles as seen in the extremely low or nonexistent correlation coefficients. This was expected because these nutrients are not found associated with suspended solids.

Using the information provided by the regression analysis, a particle-size range can be chosen to be used in design criteria for the most efficient removal of pollutants. For example, the reduction of TKN in the sample with an initial TSS concentration of 721 mg/L would depend on the reduction of particles in the 35 to 45 micron size range. The design criterion for reducing TKN concentrations, therefore, would focus on the

TABLE XVIII. RELATIONSHIP BETWEEN THE PERCENT
REDUCTION OF TOTAL SURFACE AREA
AND WATER QUALITY PARAMETERS

Parameter	TSS Grouping (mg/L)	Correlation Coefficient
Suspended Lead	15,35,38 100,155,215 721	- 0.86 0.94
Suspended Kjeldahl Nitrogen	15,35,38 100,155,215 721	0.12 0.80 0.98
Suspended Organic Carbon	15,35,38 100,155,215 721	-0.20 0.57 0.96
Total Lead	15,35,38 100,155,215 721	- 0.81 0.98
Total Kjeldahl Nitrogen	15,35,38 100,155,215 721	0.18 0.76 0.98
Total Zinc	15,35,38 100,155,215 721	0.48 0.32 0.98
Suspended Zinc	15,35,38 100,155,215 721	0.97 0.46 0.97
Total Phosphorus	15,35,38 100,155,215 721	0.68 0.77 0.95
Suspended Phosphorus	15,35,38 100,155,215 721	0.64 0.84 0.95
Total Nitrogen	15,35,38 100,155,215 721	0.14 0.78 0.98
Nitrite and Nitrate	15,35,38 100,155,215 721	0.38 -0.25 -0.13
Organic Nitrogen	15,35,38 100,155,215 721	0.27 0.82 0.98

TABLE XIX. RELATIONSHIP BETWEEN REDUCTIONS IN POLLUTANT CONCENTRATION AND SURFACE AREA REDUCTIONS IN PARTICLE-SIZE RANGES OF SUSPENDED SOLIDS*

Parameter	TSS Grouping (mg/L)	Correlation Coefficient	Particle Size Range (microns)
Suspended Lead	15, 35, 38	-	-
	100,155,215	0.86	65-75, 25-35, 35-45
	721	0.87	15-25
Suspended Kjeldahl Nitrogen	15, 35, 38	0.86	105-115
	100,155,215	0.79	105-115
	721	0.99	35-45
Suspended Organic Carbon	15, 35, 38	-	-
	100,155,215	0.33	25-35
	721	0.98	15-25, 35-45, 5-16
Total Lead	15, 35, 38	-	-
	100,155,215	0.88	75-85, 35-45, 55-65
	721	0.99	35-45
Total Kjeldahl Nitrogen	15, 35, 38	0.06	55-65
	100,155,215	0.78	105-115, 25-35, 35-45
	721	0.99	35-45
Total Zinc	15, 35, 38	0.37	45-55, 15-25
	100,155,215	0.35	105,115, 95-105,75-85
	721	0.99	35-45
Suspended Zinc	15, 35, 38	0.36	105-115, 5-15
	100,155,215	0.30	105-115
	721	0.96	15-25
Total Phosphorus	15, 35, 38	0.52	25-35, 55-65, 65-75
	100,155,215	0.69	25-35, 35-45,95-105
	721	0.97	25-35

TABLE XIX. CONTINUED

Parameter	TSS Grouping (mg/L)	Correlation Coefficient	Particle Size Range (microns)
Total Nitrogen	15, 35, 38	-	-
	100,155,215	0.73	105-115, 15-25, 35-45
	721	0.99	35-45
Nitrites and Nitrates	15, 35, 38	0.25	5-15
	100,155,215	0.07	5-15
	721	-	-
Organic Nitrogen	15, 35, 38	0.11	55-65
	100,155,215	0.88	105,115, 25-35, 35-45
	721	0.99	35-45

*Particle size ranges are shown in order of importance when more than one range is listed for a coefficient.

removal of particles 35 microns or less. Using Stokes' Law, a settling velocity for a particle with a 35 micron diameter can be determined and then converted to an overflow rate. Those particles with settling velocities equal to or greater than the overflow rate settling velocity will be removed. Particles with settling velocities less than the overflow rate will be removed in direct proportion of their settling velocity to overflow rate settling velocity ratio (38).

Carrying the example further, a particle 35 microns in diameter would have an overflow rate settling velocity of 143 gpd/ft^2 according to Stokes' Law by assuming a water temperature of 20°C ($\mu = 1.0007$; $\rho = 0.998$) and a specific gravity of 1.10. This particular specific gravity was chosen to represent a small diameter particle. In Figure 33, a wide range of specific gravity values were plotted against the corresponding overflow rates from Stokes' Law using a particle diameter of 50 microns. Large specific gravity values would represent heavy particles such as sands, and the lower end of the scale would represent smaller particles such as silts. Therefore, a low specific gravity was chosen for the 35 micron particle used. An overflow rate settling velocity of 143 gpd/ft^2 would correspond to a column depth and time interval of four-foot and 5.6 hours. In Figure 9 of the September 15 stormwater sample, this would correspond to a TSS removal of approximately 90 percent. From Table X in the September 15 sample, a four-foot depth interval and settling time of 6 hours resulted in the removal of 71 percent of TKN. Therefore, the overflow settling velocity of a 35 micron particle would result in a satisfactory percent removal of TKN.

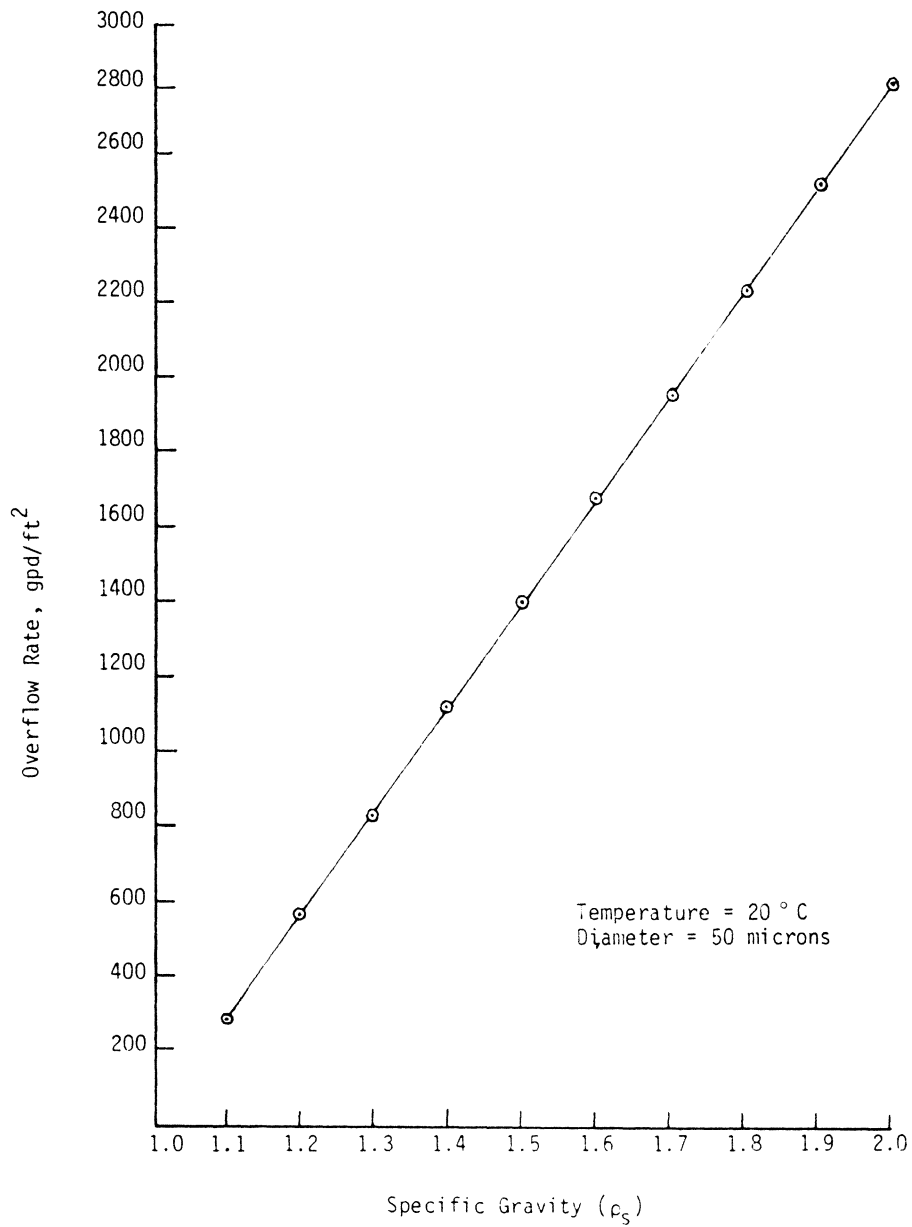


FIGURE 33. VARIOUS SPECIFIC GRAVITY VALUES AND THE CORRESPONDING OVERFLOW RATE

VI. CONCLUSIONS

From the results obtained by sedimentation of seven urban stormwater runoff samples under quiescent conditions, the following conclusions seem warranted:

1. Sedimentation is an efficient means of reducing the concentration of urban stormwater pollutants. Settling reduced the concentration of insoluble pollutants significantly, while soluble forms of pollutants were not as readily removed. The residual concentrations of TSS and BOD₅ after a 48-hour settling period tended to be in the same range as concentrations in secondary wastewater treatment plant effluents. An exception was seen in a sample with extremely high initial concentrations of BOD₅ and other pollutants still remaining after sedimentation was essentially complete.

2. The majority of the suspended solids particles in stormwater runoff from the shopping centers used as sampling sites were less than 25 mincrons in diameter, whereas most of the surface area was associated with particles between 15 to 35 microns in diameter.

3. Those pollutants with the greatest affinity for adsorption to particle surfaces were removed to the greatest extent by sedimentation. Those pollutants were lead, organic matter (BOD₅), phosphorus, and Kjeldahl and organic nitrogen.

4. Pollutants remaining in the water column after the settling period were in some instances greater in concentration than would be desired. These pollutants usually were composed of large fractions of soluble forms. Total phosphorus concentrations remaining after the sedimentation period exceeded the recommended concentration needed to

control eutrophication.

5. The results indicate that stormwater sedimentation data may be useful for basin design criteria for obtaining efficient pollutant removals. Both strong and weak linear relationships existed between percent reductions of surface area from the particle size distributions and nutrients and heavy metals percent reductions. The stronger correlations were observed in the reduction of pollutants such as total and suspended Pb, suspended TKN, suspended P, and total N. From the strong relationships between particle surface area and pollutant reduction, a representative particle size can be chosen for removal in design criteria.

6. Dissolved oxygen concentrations in the columns decreased by approximately 4 mg/L after 48 hours of settling. The decrease in dissolved oxygen and increase in ammonia-nitrogen concentrations during the sedimentation period supports the hypothesis of the existence of microbial activity within the columns. In an actual detention basin, declining dissolved oxygen concentrations in the lower depths could eventually lead to anoxic conditions and pollutants such as phosphorus and ammonia-nitrogen would be released into the water from the bottom sediments.

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APPENDIX

TABLE A-1. NUTRIENT, SOLIDS, AND ORGANIC MATTER DATA OBTAINED FROM LABORATORY ANALYSIS

Sample Date	Time (Hours)	Depth (Feet)	Parameter (mg/L)												
			TSS	VSS	COD	BOD	TOC	SOC	TP	TSP	OP	TKN	SKN	NH ₃	NO ₂ +NO ₃
6/20/81	0	1,2,3	38	20.6	-	-	-	-	0.14	0.06	-	3.33	2.75	1.92	2.14
	2	1	22.0	16.0	-	-	-	-	0.13	0.05	-	3.38	2.71	1.81	1.97
		2	24.0	14.0	-	-	-	-	0.12	0.05	-	3.38	2.61	1.79	2.11
		3	24.0	16.0	-	-	-	-	0.12	0.06	-	3.42	2.84	1.95	2.11
	6	1	16.0	10.0	-	-	-	-	0.10	0.04	-	3.13	2.63	1.81	1.97
		2	18.0	10.0	-	-	-	-	0.09	0.04	-	3.27	2.75	1.83	2.17
		3	16.0	10.0	-	-	-	-	0.10	0.04	-	3.17	2.56	1.81	2.11
	24	1	8.0	6.0	-	-	-	-	0.08	0.04	-	2.90	2.59	1.83	1.83
		2	6.0	4.0	-	-	-	-	0.08	0.04	-	2.96	2.69	1.81	1.95
		3	6.0	4.0	-	-	-	-	0.08	0.04	-	2.90	2.65	1.83	1.99
7/4/81	0	1,2,3	15.0	9.0	6.8	-	22.0	20.3	0.83	0.72	0.51	2.26	1.90	0.20	0.06
	2	1	14.0	9.0	7.2	-	19.7	19.7	0.82	0.71	0.50	2.28	1.79	0.19	0.06
		2	15.0	8.0	6.8	-	19.7	19.7	0.78	0.62	0.49	2.37	1.74	0.17	0.04
		3	14.0	8.0	6.0	-	22.5	18.6	0.77	0.66	0.50	2.01	1.67	0.19	0.04
	6	1	15.0	7.0	-	-	-	-	0.83	0.67	0.48	2.28	1.74	0.19	0.10
		2	14.0	8.0	-	-	-	-	0.82	0.63	0.48	2.10	1.61	0.17	0.06
		3	12.0	6.0	-	-	-	-	0.84	0.67	0.49	2.21	1.67	0.17	0.06
	12	1	13.0	9.0	-	-	-	-	0.78	0.72	0.49	2.10	1.88	0.19	0.06
		2	13.0	8.0	-	-	-	-	0.88	0.70	0.49	2.35	1.92	0.17	0.08
		3	12.0	7.0	-	-	-	-	0.57	0.50	0.49	1.92	1.51	0.15	0.08
	24	1	11.0	11.0	4.8	-	22.8	19.2	0.51	0.46	0.48	2.10	1.45	0.27	0.04

TABLE A-1 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Parameter (mg/L)												
			TSS	VSS	COD	BOD	TOC	SOC	TP	TSP	OP	TKN	SKN	NH ₃	NO ₂ +NO ₃
7/4/81	48	2	12.0	10.0	4.8	-	18.3	-	0.57	0.44	0.48	2.06	1.26	0.27	0.04
		3	11.0	9.0	5.2	-	17.8	17.8	0.54	0.45	0.49	2.08	1.61	0.27	0.04
		1	3.0	3.0	-	-	-	-	0.45	0.42	0.47	2.14	1.43	0.25	0.06
		2	4.0	4.0	-	-	-	-	-	0.42	0.46	3.91	1.42	0.27	0.08
		3	3.0	3.0	-	-	-	-	0.49	0.41	0.49	1.63	1.32	0.25	0.04
7/5/81	0	1,2,3	35	16.5	82	-	-	-	0.19	0.06	0.03	2.31	1.26	0.07	2.26
	2	1	21.0	12	72	-	-	-	0.15	0.05	0.03	2.16	1.39	0.09	2.13
		2	20.0	11.3	72	-	-	-	0.16	0.09	0.03	2.16	1.58	0.10	2.15
		3	19.3	13.3	74	-	-	-	0.18	0.07	0.03	2.04	1.46	0.07	2.45
	6	1	18.0	12.0	-	-	-	-	0.15	0.06	0.03	2.06	1.35	0.10	2.17
		2	18.6	12.0	-	-	-	-	0.10	0.06	0.03	2.08	1.29	0.09	2.37
		3	19.3	13.0	-	-	-	-	0.15	0.05	0.03	2.14	1.38	0.10	2.13
	12	1	17.0	10.0	-	-	-	-	0.13	0.05	0.04	1.96	1.35	0.12	2.13
		2	18.0	10.0	-	-	-	-	0.13	0.06	0.05	2.00	1.38	0.14	2.21
		3	20.0	10.0	-	-	-	-	0.13	0.07	-	2.14	1.33	0.44	1.95
	24	1	14.6	9.3	68	-	-	-	0.11	0.06	0.07	1.81	1.44	0.44	1.79
		2	14.6	9.3	70	-	-	-	0.11	0.07	0.04	1.89	1.48	0.20	2.15
		3	14.0	8.6	69	-	-	-	0.11	0.06	0.03	1.94	1.31	0.20	2.33
	48	1	7.3	3.3	68	-	-	-	0.09	0.08	0.02	1.73	1.40	0.20	1.73
		2	6.0	2.7	68	-	-	-	0.09	0.05	0.02	1.69	1.56	0.05	1.97
		3	7.3	3.3	64	-	-	-	0.10	0.07	-	1.89	1.52	0.22	1.91

TABLE A-1 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Parameter (mg/L)												
			TSS	VSS	COD	BOD	TOC	SOC	TP	TSP	OP	TKN	SKN	NH ₃	NO ₂ +NO ₃
7/26/81	0	1,2,4	155	36	50	-	9.0	-	0.25	0.10	0.09	1.26	0.61	0.07	0.77
	2	1	15.3	1.3	24	-	-	-	0.12	0.10	0.08	0.59	0.44	0.07	0.67
		2	19.3	3.3	22	-	6.8	-	0.12	0.10	0.08	0.59	0.42	0.05	0.73
		4	29	3.3	24	-	6.3	-	0.13	0.10	0.08	0.65	0.44	0.07	0.73
	6	1	14.7	2.0	-	-	-	-	0.11	0.10	0.09	0.59	0.48	0.07	0.69
		2	14.7	2.7	-	-	-	-	0.11	0.10	0.08	0.61	0.52	0.07	0.73
		4	20.7	2.6	-	-	-	-	0.12	0.09	0.09	0.61	0.48	0.09	0.71
	12	1	12.0	2.7	-	-	7.9	-	0.12	0.11	0.09	0.63	0.46	0.09	0.67
		2	13.3	4.7	-	-	6.3	-	0.12	0.10	0.08	0.65	0.48	0.09	0.75
		4	12.0	3.3	-	-	5.5	-	0.12	0.10	0.10	0.61	0.48	0.07	0.75
	24	1	6.7	2.0	23.7	-	5.3	-	0.12	0.10	0.10	0.69	0.59	0.13	0.67
		2	9.3	2.0	22.3	-	7.9	-	0.12	0.11	0.09	0.73	0.65	0.11	0.73
		4	10.0	4.7	23.2	-	5.3	-	0.17	0.14	0.09	0.90	0.63	0.11	0.71
	48	1	6.7	2.7	22.3	-	4.8	-	0.14	0.11	0.98	0.58	0.48	0.05	0.63
		2	6.0	3.3	19.1	-	4.5	-	0.14	0.11	0.08	0.71	0.46	0.05	0.67
		4	8.0	2.7	20.1	-	4.5	-	0.15	0.11	0.08	0.65	0.40	0.07	0.63
8/11/81	0	1,2,4	215	58	138	35	17.2	14.3	0.48	0.21	0.08	2.26	0.86	0.28	0.74
	2	1	66	14.6	77	25	19.2	16.6	0.33	0.21	0.10	1.42	0.90	0.38	0.65
		2	62	11.3	77	30	21.1	17.8	0.32	0.19	0.09	1.40	0.88	0.34	0.71
		4	73	16.7	77	25	15.2	15.2	0.32	0.21	0.08	1.63	1.13	0.42	0.69

TABLE A-1 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Parameter (mg/L)												
			TSS	VSS	COD	BOD	TOC	SOC	TP	TSP	OP	TKN	SKN	NH ₃	NO ₂ +NO
8/11/81	6	1	44	13.3	-	-	-	-	0.26	0.17	0.08	1.27	0.83	0.32	0.65
		2	37	10.7	-	-	-	-	0.26	0.17	0.09	1.12	0.76	0.32	0.71
		4	39	7.3	-	-	-	-	0.26	0.17	0.08	1.21	0.83	0.28	0.73
	12	1	28	8.0	-	-	13.6	13.6	0.10	0.03	0.02	1.16	0.70	-	0.65
		2	24.0	8.0	-	-	20.3	14.1	0.11	0.11	0.06	1.48	0.85	-	0.75
		4	27	7.3	-	-	15.0	14.4	0.09	0.04	0.03	1.23	0.51	-	0.75
	24	1	15.0	8.7	45	10	11.3	11.7	0.22	0.14	0.07	1.08	0.53	0.16	0.57
		2	16.7	7.3	46	10	13.4	12.4	0.23	0.14	0.08	1.10	0.53	0.10	0.65
		4	18.7	6.0	46	20	11.6	11.0	0.27	0.13	0.07	1.02	0.51	0.12	0.69
	48	1	8.7	6.0	48	-	12.5	12.5	0.07	0.02	0.01	1.08	0.66	0.28	0.41
		2	9.3	4.0	47	-	12.5	12.5	0.07	0.02	0.01	1.14	0.72	0.28	0.47
		4	9.0	6.0	47	-	13.9	13.0	0.07	0.02	0.01	1.08	0.81	0.26	0.75
9/15/81	0	1,2,4	721	264	908	210	321.8	280.0	0.82	0.30	0.19	4.40	0.76	0.19	0.04
	2	1	105	22.7	704	125	316.4	294.8	0.57	0.27	0.18	1.73	0.76	0.19	0.04
		2	89	20.7	720	72	305.6	289.5	0.65	0.29	0.18	1.59	0.78	0.21	0.04
		4	114	24.7	716	80	311.0	305.6	0.62	0.27	0.19	1.71	0.72	0.19	0.04
	6	1	33	13.3	-	-	-	-	0.40	0.29	0.17	0.16	0.78	0.21	0.04
		2	31	9.3	-	-	-	-	0.40	0.25	0.17	0.18	0.74	0.19	0.04
		4	37	11.0	-	-	-	-	0.41	0.27	0.17	1.28	0.82	0.19	0.04
	12	1	53	12.7	-	-	192.4	192.4	0.40	0.18	0.11	1.26	0.70	0.17	0.06

TABLE A-1 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Parameter (mg/L)												
			TSS	VSS	COD	BOD	TOC	SOC	TP	TSP	OP	TKN	SKN	NH ₃	NO ₂ +NO
9/15/81	12	2	30	8.3	-	-	208.6	208.6	0.31	0.18	0.12	1.14	0.68	0.15	0.04
		4	29	8.0	-	-	219.3	219.3	0.29	0.16	0.12	1.15	0.60	0.15	0.04
	24	1	20.0	8.0	456	80	208.6	208.6	0.24	0.18	0.18	1.00	0.67	0.15	0.04
		2	18.0	6.0	460	40	208.6	208.6	0.20	0.18	0.13	0.81	0.69	0.15	0.04
		4	18.0	6.0	448	80	208.6	108.6	0.28	0.20	0.14	1.15	0.73	0.15	0.04
	48	1	19.0	18.7	416	-	208.6	203.2	0.26	0.20	0.12	1.10	0.75	0.31	0.04
		2	18.0	9.3	424	-	203.2	197.8	0.28	0.20	0.14	1.17	0.74	0.33	0.04
		4	18.0	10.0	436	-	197.8	197.8	0.29	0.10	0.18	1.10	0.81	0.49	0.04
10/23/81	0	1,2,4	100	41	87	30	23.1	11.1	0.45	0.24	0.22	2.35	1.11	0.38	0.76
		1	42	17.3	81	10	14.7	11.6	0.31	0.22	0.20	1.25	1.07	0.38	0.77
		2	44	16.0	71	10	16.1	11.3	0.32	0.25	0.21	1.53	1.02	0.38	0.81
		4	49	20.7	80	20	14.4	11.0	0.35	0.28	0.21	1.59	1.15	0.36	0.81
	6	1	32	12.7	-	-	-	-	0.30	0.23	0.19	1.42	1.13	0.36	0.69
		2	33	15.3	-	-	-	-	0.30	0.23	0.19	1.55	1.11	0.36	0.73
		4	38	16.0	-	-	-	-	0.29	0.22	0.19	2.89	1.11	0.38	0.73
	12	1	28	8.7	-	-	14.4	11.6	0.31	0.24	0.19	1.36	1.07	0.36	0.77
		2	29	9.3	-	-	14.4	11.6	0.37	0.24	0.19	1.63	1.12	0.36	0.77
		4	33	10.0	-	-	15.5	12.4	0.31	0.22	0.20	1.68	1.19	0.42	0.81
	24	1	17.0	1.0	62	15	12.7	12.7	0.26	0.22	0.22	1.41	1.32	0.48	0.81
		2	20.0	5.0	69	10	15.0	11.9	0.31	0.22	0.22	1.58	1.24	0.46	0.87

TABLE A-1 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Parameter (mg/L)												
			TSS	VSS	COD	BOD	TOC	SOC	TP	TSP	OP	TKN	SKN	NH ₃	NO ₂ +NO ₃
10/23/81	24	4	20.0	5.0	68	40	14.7	12.2	0.28	0.22	0.22	1.60	1.30	0.46	0.85
	48	1	6.0	0.0	52	-	12.7	12.4	0.26	0.26	0.20	1.90	1.45	0.78	0.67
		2	6.7	1.3	44	-	12.7	12.7	0.26	0.22	0.19	1.36	1.28	0.42	0.75
		4	8.0	1.3	41	-	11.9	11.3	0.26	0.22	0.19	1.41	1.19	0.40	0.75

TABLE A-2. NUMBER OF PARTICLES AND SIZE RANGES IN PARTICLE SIZE DISTRIBUTION

Sample Date	Time (hours)	Depth (feet)	Number of Particles in Particle Size Ranges (microns)										
			5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
6/20/81	0	1,2,3	6922	2968	1260	644	362	220	121	110	62	36	29
	2	1	1457	736	517	428	320	254	161	135	88	60	38
		2	7138	2474	772	298	121	90	58	52	30	38	32
		3	1212	492	192	138	87	71	44	50	32	26	23
	6	1	672	346	218	182	143	109	65	66	50	40	24
		2	1532	429	197	100	72	50	28	34	18	15	9
		3	1604	768	556	414	268	176	107	76	44	26	20
	24	1	565	145	46	24	14	6	5	2	2	2	1
		2	456	195	76	78	40	40	29	28	28	18	15
		3	584	230	90	53	16	15	6	6	4	1	1
7/4/81	0	1,2,3	9920	3265	1137	515	250	138	79	55	36	26	14
	2	1	8871	3490	1188	516	238	284	84	60	28	28	15
		2	11714	4298	1787	825	418	211	104	84	40	27	18
		3	11672	4248	1588	725	359	206	104	93	47	35	26
	6	1	59730	12525	2600	1050	410	260	80	90	40	40	45
		2	13884	5352	2036	929	469	284	170	115	65	47	25
		3	15204	4099	1020	303	113	46	26	17	6	7	4

TABLE A-2 CONTINUED

Sample Date	Time (hours)	Depth (feet)	Number of Particles in Particle Size Ranges (microns)										
			5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
7/4/81	12	1	28325	7670	2605	1320	555	260	225	100	35	40	15
		2	7416	2942	1288	758	392	217	144	128	57	51	24
		3	11729	4788	1964	981	508	308	192	133	79	69	44
	24	1	4224	1780	611	313	188	110	81	79	42	39	25
		2	11505	3662	1383	702	389	235	128	126	64	58	36
		3	6926	2222	780	406	258	152	124	117	84	66	48
	48	1	1910	535	145	58	31	22	12	14	9	8	8
		2	4912	1548	468	226	136	94	50	35	26	25	14
		3	7426	1615	428	238	156	110	79	71	42	35	24
7/5/81	0	1,2,3	34010	14525	7618	4332	2695	3595	1248	1142	745	635	518
	2	1	26220	10745	5940	3335	1995	1270	910	715	570	455	305
		2	34970	15135	8605	5085	3005	1530	795	790	455	350	480
		3	16890	6190	3350	2050	1520	1030	665	730	505	375	345
	6	1	12345	4570	2175	1265	910	810	405	580	425	330	250
		2	18890	7985	4470	2485	1695	1245	1285	675	480	395	265
		3	15055	4365	2015	1200	795	610	470	365	315	240	270
	12	1	7975	3955	2435	1845	1205	720	460	435	230	105	100

TABLE A-2 CONTINUED

Sample Date	Time (hours)	Depth (feet)	Number of Particles in Particle Size Ranges (microns)										
			5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
7/5/81	12	2	13580	5555	2920	2095	1635	1270	770	765	410	265	240
		3	24235	8110	3820	1950	1230	760	450	470	295	275	280
	24	1	13425	5010	2395	1315	720	490	310	245	185	120	110
		2	11995	4825	2645	2045	1290	775	660	495	330	285	165
		3	6465	2100	565	330	195	130	120	95	45	60	60
	48	1	15110	5220	2900	1760	1160	850	570	500	500	330	280
		2	12685	5175	2760	1745	890	555	290	230	145	45	40
		3	26245	10170	4935	2395	1530	850	440	415	310	195	115
7/26/81	0	1,2,4	109670	50980	24307	7680	4768	2233	1030	687	350	188	140
	2	1	41250	17100	8105	4090	1815	890	295	145	100	50	20
		2	49940	19745	8430	3485	1310	470	215	70	40	30	35
		4	97295	29700	8250	4390	2360	1145	545	360	165	70	40
	6	1	41400	17910	8450	4015	1680	680	295	205	50	55	0
		2	25440	10585	5305	3060	1490	695	345	195	80	60	25
		4	2356	9135	4320	2450	1220	665	300	190	95	70	15
	12	1	51785	20435	9385	4135	1945	885	340	195	65	45	20
		2	47805	17960	8405	3285	1695	565	215	85	50	20	10

TABLE A-2 CONTINUED

Sample Date	Time (hours)	Depth (feet)	Number of Particles in Particle Size Ranges (microns)										
			5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
7/26/81	12	4	36240	14805	6995	3350	1595	770	280	245	85	75	20
	24	1	61955	21515	7385	2415	750	270	75	65	35	20	5
		2	57750	18240	6310	2345	740	250	120	35	10	10	5
		4	21805	10235	5550	3595	1960	1380	670	570	360	205	125
	48	1	49050	15965	6020	1870	860	260	95	40	10	15	10
		2	18435	6920	2885	1415	510	270	70	10	5	15	5
		4	33905	16300	7070	2770	1250	570	270	125	65	25	25
8/11/81	0	1,2,4	441250	153017	61150	25017	10033	4967	2100	1450	833	683	317
	2	1	125370	52055	18665	5960	1945	830	295	245	135	60	80
		2	109215	50220	22280	9690	3785	1735	1010	690	290	125	100
		4	19230	6515	2320	1085	400	225	155	80	40	50	25
	6	1	73465	25630	10540	4550	2030	720	440	235	95	75	45
		2	83835	29630	11700	4475	1855	685	155	180	60	25	45
		4	78055	30615	14485	7435	3510	1795	825	580	355	230	120
	12	1	81100	878	14720	7280	3215	1555	750	545	260	180	170
		2	7524	1409	270	116	52	26	12	8	7	3	2
		4	9242	3112	656	440	279	168	119	90	42	28	20

TABLE A-2 CONTINUED

Sample Date	Time (hours)	Depth (feet)	Number of Particles in Particle Size Ranges (microns)										
			5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
8/11/81	24	1	8254	2448	2250	1876	1322	986	620	498	302	224	148
		2	8994	2448	1288	922	680	476	341	288	159	134	86
		4	10510	3078	1718	1106	698	428	256	216	123	86	54
	48	1	7664	2567	1602	936	406	156	58	23	10	7	6
		2	8414	1656	548	291	162	70	30	26	6	4	6
		4	7772	1574	668	348	178	76	24	20	8	8	2
9/15/81	0	1,2,4	1594984	669766	108576	58312	17708	7312	3654	2362	1050	1088	366
	2	1	780125	251175	55675	10250	2200	600	175	200	75	25	25
		2	881350	290825	58025	7650	1275	300	100	100	0	50	50
		4	1010500	347375	69400	9675	1400	450	175	225	175	25	0
	6	1	277360	100280	26490	5670	1440	370	70	50	100	50	10
		2	291400	91640	23280	5460	1260	360	180	140	80	40	0
		4	335980	104020	22360	5460	1040	320	180	100	0	0	40
	12	1	83215	38510	15700	6175	2320	1105	615	425	195	105	85
		2	65960	18410	6895	3140	1480	945	615	385	270	170	100
		4	67465	17760	6245	2860	1425	905	550	405	285	235	90
	24	1	44135	11525	3875	1635	590	330	190	85	55	10	20

TABLE A-2 CONTINUED

Sample Date	Time (hours)	Depth (feet)	Number of Particles in Particle Size Ranges (microns)										
			5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
9/15/81	24	2	60715	17095	5680	2240	840	350	110	85	45	25	10
		4	54630	13955	4065	1245	460	205	50	50	5	20	5
	48	1	69470	14110	4740	1660	590	350	120	70	70	50	10
		2	66325	23575	9200	3840	1545	660	305	255	150	95	50
		4	46235	9525	2695	105	515	325	135	55	40	40	30
10/23/81	0	1,2,4	161287	72060	34973	18757	9993	5130	2803	2090	1043	687	370
	2	1	36820	14500	6630	3695	1980	1240	760	545	370	235	205
		2	77130	25260	10090	5040	2550	1500	890	690	360	240	170
	2	4	48740	17400	6500	3810	2190	1450	760	320	470	370	220
	6	1	35740	13628	5582	2742	1318	735	408	312	150	108	75
		2	34435	11670	5845	3480	2185	1285	800	670	330	225	110
		4	31705	14030	7885	5415	3420	2375	1525	1235	825	630	520
	12	1	7968	3152	1502	820	398	210	101	72	46	24	20
		2	23548	8888	3688	1838	918	460	310	200	120	75	38
		4	42692	17482	7965	4250	2055	1125	545	438	170	105	78
	24	1	38075	11218	4352	1680	658	250	98	62	22	15	8
		2	47348	17120	6735	2610	1010	372	150	110	32	32	0

TABLE A-2 CONTINUED

Sample Date	Time (hours)	Depth (feet)	Number of Particles in Particle Size Ranges (microns)										
			5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
10/23/81	24	4	33835	14470	7110	4580	2335	1385	710	510	250	145	75
	48	1	23782	6525	2308	938	380	110	40	18	5	5	0
		2	4592	1456	467	167	67	26	15	11	4	7	7
		4	28340	8050	2735	1060	352	118	62	12	8	5	2

TABLE A-3. TOTAL AND SOLUBLE HEAVY METALS CONCENTRATIONS

Sample Date	Time (Hours)	Depth (Feet)	Heavy Metals ($\mu\text{g/l}$)					
			TPb	SPb	TZn	SZn	TCu	SCu
6/20/81	0	1,2,3	0	0	302	243	0	0
	2	1	0	0	270	190	0	0
		2	0	0	245	180	0	0
		3	0	0	265	190	0	0
	6	1	0	0	285	275	0	0
		2	0	0	300	240	0	0
		3	0	0	365	275	0	0
	24	1	0	0	215	190	0	0
		2	0	0	280	220	0	0
		3	0	0	230	205	0	0
7/4/81	0	1,2,3	0	0	0	0	0	0
	2	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
	6	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
	12	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
	24	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
	48	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
7/5/81	0	1,2,3	0	0	368	325	0	0
	2	1	0	0	350	325	0	0

TABLE A-3 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Heavy Metals ($\mu\text{g/l}$)					
			TPb	SPb	TZn	SZn	TCu	SCu
7/5/81	2	2	0	0	360	325	0	0
		3	0	0	350	300	0	0
		6	0	0	350	300	0	0
	6	1	0	0	350	300	0	0
		2	0	0	350	320	0	0
		3	0	0	350	325	0	0
	12	1	0	0	350	300	0	0
		2	0	0	350	325	0	0
		3	0	0	350	325	0	0
	24	1	0	0	355	330	0	0
		2	0	0	350	325	0	0
		3	0	0	350	325	0	0
	48	1	0	0	325	315	0	0
		2	0	0	325	315	0	0
		3	0	0	325	320	0	0
7/26/81	0	1,2,4	144	8	160	45	0	0
	2	1	21	4	50	40	0	0
		2	24	4	50	40	0	0
		4	31	3	60	45	0	0
	6	1	24	1	45	35	0	0
		2	20	2	40	35	0	0
		4	29	2	50	30	0	0
	12	1	21	2	45	30	0	0
		2	22	4	40	40	0	0
		4	19	2	50	30	0	0
	24	1	18	6	40	40	0	0
		2	13	4	45	35	0	0
		4	32	3	45	35	0	0
	48	1	12	2	45	45	0	0

TABLE A-3 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Heavy Metals ($\mu\text{g/l}$)					
			TPb	SPb	TZn	SZn	TCu	SCu
7/26/81	48	2	9	2	45	35	0	0
		4	5	2	40	30	0	0
8/11/81	0	1,2,4	370	43	172	143	0	0
	2	1	121	42	165	145	0	0
		2	116	46	150	150	0	0
		4	130	57	150	140	0	0
	6	1	130	35	150	135	0	0
		2	115	56	120	105	0	0
		4	104	49	120	105	0	0
	12	1	90	55	130	120	0	0
		2	98	47	120	110	0	0
		4	66	55	120	110	0	0
	24	1	120	31	140	130	0	0
		2	75	42	130	125	0	0
		4	65	33	160	150	0	0
	48	1	56	45	125	125	0	0
		2	56	46	135	135	0	0
		4	65	36	145	130	0	0
9/15/81	0	1,2,4	913	813	692	630	75	58
	2	1	270	220	290	255	25	0
		2	240	200	260	230	0	0
		4	270	240	275	245	0	0
	6	1	130	110	180	175	0	0
		2	120	120	190	185	0	0
		4	140	140	210	200	0	0
	12	1	120	120	215	210	0	0
		2	110	80	190	190	0	0
		4	130	130	180	170	0	0

TABLE A-3 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Heavy Metals ($\mu\text{g/l}$)					
			TPb	SPb	TZn	SZn	TCu	SCu
9/15/81	24	1	110	90	200	190	0	0
		2	110	80	205	200	0	0
		4	80	80	180	180	0	0
	48	1	70	70	200	200	0	0
		2	130	120	200	200	0	0
		4	100	100	200	200	0	0
10/23/81	0	1,2,4	127	12	112	45	0	0
		2	70	15	75	40	0	0
		1	110	12	80	40	0	0
		4	83	13	85	40	0	0
	6	1	56	10	80	40	0	0
		2	61	9	80	40	0	0
		4	68	17	80	40	0	0
	12	1	65	19	60	40	0	0
		2	71	18	70	40	0	0
		4	64	17	75	40	0	0
	24	1	36	15	55	40	0	0
		2	37	16	60	40	0	0
		4	47	19	60	40	0	0
	48	1	31	15	55	50	0	0
		2	24	15	55	50	0	0
		4	29	16	55	50	0	0

TABLE A-4. INFORMATION DERIVED FROM THE MANIPULATION OF LABORATORY DATA

Sample Date	Time (Hours)	Depth (Feet)	Total N (mg/L)	Organic N (mg/L)	Susp. KN (mg/L)	Susp. P (mg/L)	Susp. Zn (µg/L)	Susp. Pb (µg/L)	Susp. OC (mg/L)
6/20/81	0	1,2,3	5.47	1.41	0.58	0.08	59	0	--
	2	1	5.35	1.57	0.61	0.08	80	0	--
		2	5.49	1.59	0.77	0.07	65	0	--
		3	5.53	1.47	0.58	0.06	75	0	--
	6	1	5.10	1.32	0.50	0.06	10	0	--
		2	5.44	1.44	0.52	0.05	60	0	--
		3	5.28	1.36	0.61	0.06	90	0	--
	24	1	4.73	1.07	0.31	0.04	25	0	--
		2	4.91	1.15	0.27	0.04	60	0	--
		3	4.89	1.07	0.25	0.04	25	0	--
7/4/81	0	1,2,3	2.32	2.06	0.36	0.11	0	0	1.7
	2	1	2.34	2.09	0.49	0.11	0	0	0
		2	2.41	2.20	0.63	0.16	0	0	0
		3	2.05	1.82	0.34	0.11	0	0	3.9
	6	1	2.38	2.09	0.54	0.16	0	0	--
		2	2.16	1.93	0.49	0.19	0	0	--
		3	2.27	2.04	0.54	0.17	0	0	--
	12	1	2.16	1.91	0.22	0.06	0	0	--
		2	2.43	2.18	0.43	0.18	0	0	--
		3	2.00	1.77	0.41	0.07	0	0	--
	24	1	2.14	1.83	0.65	0.05	0	0	3.6
		2	2.10	1.79	0.80	0.13	0	0	--
		3	2.12	1.81	0.47	0.09	0	0	0
	48	1	2.20	1.89	0.71	0.03	0	0	--

TABLE A-4 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Total N (mg/L)	Organic N (mg/L)	Susp. KN (mg/L)	Susp. P (mg/L)	Susp. Zn (µg/L)	Susp. Pb (µg/L)	Susp. OC (mg/L)
7/4/81		2	3.99	3.64	2.49	--	0	0	--
		3	1.67	1.38	0.31	0.08	0	0	--
7/5/81	0	1,2,3	4.57	2.24	1.05	0.13	43	0	--
	2	1	4.29	2.07	0.77	0.10	25	0	--
		2	4.31	2.06	0.58	0.07	35	0	--
		3	4.49	1.97	0.58	0.11	50	0	--
	6	1	4.23	1.96	0.71	0.09	50	0	--
		2	4.45	1.99	0.79	0.04	30	0	--
		3	4.27	2.04	0.76	0.10	25	0	--
	12	1	4.09	1.84	0.61	0.08	50	0	--
		2	4.21	1.86	0.62	0.07	25	0	--
		3	4.09	1.70	0.81	0.06	25	0	--
	24	1	3.60	1.37	0.37	0.04	25	0	--
		2	4.04	1.69	0.41	0.04	25	0	--
		3	4.27	1.74	0.63	0.05	25	0	--
	48	1	3.46	1.53	0.33	0.01	10	0	--
		2	3.66	1.64	0.13	0.04	10	0	--
		3	3.80	1.67	0.37	0.03	5	0	--
7/26/81	0	1,2,4	2.07	1.19	0.65	0.15	115	139	--
	2	1	1.26	0.52	0.15	0.02	10	17	--
		2	1.23	0.54	0.17	0.02	10	20	--
		4	1.38	0.58	0.21	0.03	15	28	--
	6	1	1.28	0.52	0.11	0.01	10	24	--

TABLE A-4 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Total N (mg/L)	Organic N (mg/L)	Susp. KN (mg/L)	Susp. P (mg/L)	Susp. Zn (µg/L)	Susp. Pb (µg/L)	Susp. OC (mg/L)
7/26/81	12	2	1.34	0.54	0.09	0.01	5	18	--
		4	1.32	0.52	0.13	0.03	20	27	--
		1	1.30	0.54	0.17	0.01	15	19	--
		2	1.40	0.56	0.17	0.02	5	18	--
	24	4	1.36	0.54	0.13	0.02	20	17	--
		1	1.36	0.56	0.10	0.02	0	12	--
		2	1.46	0.62	0.08	0.01	10	9	--
		4	1.61	0.79	0.27	0.03	10	29	--
	48	1	1.21	0.53	0.10	0.03	0	10	--
		2	1.38	0.66	0.25	0.03	10	7	--
		4	1.28	0.58	0.25	0.04	10	3	--
8/11/81	0	1,2,4	3.00	1.98	1.44	0.27	29	327	2.9
		1	2.07	1.04	0.52	0.12	20	79	2.6
		2	2.11	1.06	0.52	0.13	0	70	3.3
		4	2.32	1.21	0.50	0.11	10	73	0
	6	1	1.92	0.95	0.44	0.09	15	95	--
		2	1.83	0.80	0.36	0.09	15	59	--
		4	1.94	0.93	0.38	0.09	15	55	--
	12	1	1.81	--	0.46	0.07	10	35	0
		2	2.23	--	0.63	0.00	10	51	6.2
		4	1.98	--	0.72	0.05	10	11	0.6
	24	1	1.65	0.92	0.55	0.08	10	89	0
		2	1.75	1.00	0.57	0.09	80	33	1.0

TABLE A-4 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Total N (mg/L)	Organic N (mg/L)	Susp. KN (mg/L)	Susp. P (mg/L)	Susp. Zn (µg/L)	Susp. Pb (µg/L)	Susp. OC (mg/L)
8/11/81	48	4	1.71	0.90	0.51	0.14	10	32	0.6
		1	1.49	0.80	0.42	0.05	0	11	0
		2	1.61	0.86	0.42	0.05	0	10	0
		4	1.83	0.82	0.27	0.05	5	29	0.9
9/15/81	0	1,2,4	4.44	4.21	2.64	0.52	62	100	41.8
	2	1	1.77	1.54	0.97	0.30	35	50	21.6
		2	1.63	1.28	0.81	0.36	30	40	16.1
		4	1.75	1.52	0.99	0.35	30	30	5.4
	6	1	1.20	0.95	0.38	0.11	5	20	--
		2	1.22	0.99	0.44	0.15	5	0	--
		4	1.32	1.09	0.46	0.14	10	0	--
	12	1	1.32	1.09	0.56	0.22	5	0	0.0
		2	1.18	0.99	0.46	0.13	5	30	0.0
		4	1.19	1.00	0.55	0.13	10	0	0.0
	24	1	1.04	0.85	0.33	0.06	10	20	0.0
		2	0.85	0.66	0.12	0.02	5	30	0.0
		4	1.19	1.00	0.42	0.08	10	0	0.0
	48	1	1.14	0.79	0.35	0.06	0	0	5.4
		2	1.21	0.84	0.43	0.08	0	10	5.4
		4	1.23	0.70	0.38	0.10	5	0	0.0
10/23/81	0	1,2,4	3.11	1.97	1.24	0.21	67	115	12.0
	2	1	2.02	0.87	0.18	0.09	35	55	3.1
		2	2.34	1.15	0.51	0.07	40	98	4.8

TABLE A-4 CONTINUED

Sample Date	Time (Hours)	Depth (Feet)	Total N (mg/L)	Organic N (mg/L)	Susp. KN (mg/L)	Susp. P (mg/L)	Susp. Zn (µg/L)	Susp. Pb (µg/L)	Susp. OC (mg/L)
		4	2.40	1.23	0.44	0.07	45	70	3.4
	6	1	2.11	1.06	0.29	0.07	40	46	--
		2	2.28	1.19	0.44	0.07	40	52	--
		4	3.62	2.51	1.78	0.07	40	51	--
	12	1	2.13	1.00	0.29	0.07	20	46	2.8
		2	2.40	1.27	0.51	0.13	30	53	2.8
		4	2.49	1.26	0.49	0.09	35	47	3.1
	24	1	2.22	0.93	0.09	0.04	15	21	0.0
		2	2.45	1.12	0.34	0.09	20	21	3.1
		4	2.45	1.14	0.30	0.05	20	28	2.5
	48	1	2.57	1.12	0.45	0.00	5	16	0.3
		2	2.11	0.94	0.08	0.04	5	9	0.0
		4	2.16	1.01	0.22	0.04	5	13	0.6

TABLE A-5. SOLIDS, NUTRIENTS, AND HEAVY METALS DATA FOR COLUMN COMPARISON

Sample Date	Column No.	Parameter												
		TSS (mg/L)	VSS (mg/L)	TPb (µg/L)	SPb (µg/L)	TZn (µg/L)	SZn (µg/L)	NO ₂ +NO ₃ (mg/L)	NH ₃ (mg/L)	OP (mg/L)	TKN (mg/L)	SKN (mg/L)	TP (mg/L)	TSP (mg/L)
7/4/81	1	13	7	0	0	0	0	0.06	0.19	0.51	2.26	1.88	0.85	0.71
	2	12	8	0	0	0	0	0.04	0.19	0.51	2.37	1.92	0.87	0.70
	3	12	8	0	0	0	0	0.04	0.15	0.50	2.24	1.63	0.85	0.64
	4	12	7	0	0	0	0	0.04	0.15	0.49	2.37	1.40	0.80	0.66
7/5/81	1	35	17	0	0	0	0	2.11	0.07	0.03	2.38	1.26	0.18	0.05
	2	36	17	0	0	0	0	2.17	0.07	0.03	2.14	1.34	0.19	0.05
	3	37	17	0	0	0	0	2.45	0.07	0.03	2.30	1.39	0.20	0.05
	4	38	18	0	0	0	0	2.39	0.05	0.03	2.22	1.30	0.21	0.05
8/11/81	1	188	40	343	45	170	170	0.69	0.28	0.09	1.84	0.86	0.44	0.21
	2	205	47	274	48	155	135	0.73	0.36	0.08	2.09	0.90	0.48	0.22
	3	180	50	251	52	155	135	0.75	0.42	0.03	2.95	0.94	0.35	0.08
	4	175	44	264	59	155	135	0.75	0.34	0.11	2.13	0.92	0.32	0.19
9/15/81	1	651	212	980	850	730	670	0.04	0.19	0.19	4.89	0.76	0.80	0.31
	2	600	200	920	820	690	610	0.01	0.19	0.13	5.37	0.72	0.90	0.27
	3	601	180	1650	1280	710	655	0.04	0.17	0.13	-	0.76	-	0.00
	4	681	258	1230	980	870	650	0.04	0.15	0.06	5.41	0.76	0.88	0.21
10/23/81	1	75	41	110	14	100	40	0.79	0.38	0.24	1.82	1.02	0.37	0.26
	2	90	45	110	25	110	40	0.73	0.34	0.22	1.86	1.07	0.36	0.24
	3	80	41	148	23	105	50	0.81	0.38	0.24	1.88	1.07	0.38	0.25
	4	89	45	220	12	150	35	0.71	0.34	0.22	2.11	1.02	0.44	0.24

TABLE A-6. PARTICLE SIZE DISTRIBUTION DATA FOR COLUMN COMPARISON

Sample Date	Column No.	Number of Particles in Particle Size Ranges (microns)										
		5-15	15-25	25-35	35-45	45-55	55-65	65-75	75-85	85-95	95-105	105-115
7/4/81	1	11218	4070	1482	694	358	206	119	84	59	40	24
	2	15487	3652	1172	637	397	250	160	118	60	41	28
	3	9767	3322	1312	626	336	203	121	98	58	40	26
	4	58605	11090	2730	740	380	175	60	50	25	35	5
7/5/81	1	34010	14525	7618	4332	2695	3595	1248	1142	745	635	518
	2	45630	20115	11965	6240	3480	2160	1005	820	605	355	295
	3	28895	11760	5805	3365	1965	1235	820	840	565	475	320
	4	44020	19140	10140	5535	3195	1840	1165	985	595	460	350
8/11/81	1	459650	153990	54350	20100	7850	3850	1600	400	500	600	300
	2	340950	113350	48450	18700	7100	2750	1350	1150	350	150	100
	3	76495	32940	17470	9510	4645	2220	1020	850	405	200	160
	4	98215	52640	20980	17380	8990	4665	2330	1620	940	670	315
9/15/81	1	1361217	629783	18277	47750	12917	4625	1933	1100	350	300	253
	2	1460950	614750	170350	44450	12050	4800	1800	1350	250	150	150
	3	1358550	624600	196150	54950	15850	5800	2550	1400	650	450	300
	4	1366550	650000	181800	43850	10850	4250	4250	1450	150	300	250
10/23/81	1	127070	51940	23650	13690	7110	3310	2250	1660	910	570	370
	2	82730	39060	18160	6710	3840	2100	1390	920	560	510	430
	3	114710	47340	23660	11500	6700	3670	2180	1990	1090	830	730
	4	78140	33070	17180	9965	5960	3460	2065	1750	1035	805	560

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TREATMENT OF URBAN STORMWATER RUNOFF
BY SEDIMENTATION

by

Kathy Lee Ellis

(ABSTRACT)

Laboratory-scale settling units were used to determine the degree of treatment that could be achieved by sedimentation of stormwater runoff. Seven runoff samples were collected from shopping centers, which were selected because of their large impermeable surfaces resulting in high pollutant concentrations. The sampling sites were also representative of locations where detention basins would be constructed to control runoff flows and/or sediment loads. Approximately twenty liters of stormwater runoff were placed in each of four Plexiglas columns, and samples were withdrawn from column sampling ports immediately following sample addition, and after two, six, twelve, twenty-four, and forty-eight hours. The settling of the first runoff sample collected was terminated after only twenty-four hours. Sampling depths along the column, were either at one, two, and three feet, or at one, two, and four feet. Each sample was analyzed for total and volatile suspended solids, total and soluble Kjeldahl nitrogen, total and soluble phosphorus, orthophosphate, ammonia, oxidized nitrogen forms (nitrites and nitrates), the particle-size distribution, and six heavy metals. Organic matter and total and fecal coliform bacteria were also measured but with less frequency. Dissolved oxygen measurements were made during settling of two of the seven experiments.

Sedimentation reduced the concentration of most pollutants significantly, although pollutant concentrations composed mainly of soluble forms were not readily removed. Also examined was the use of settling data for determining particle removals in basin design criteria by the relationship between the reduction of particle surface area and various pollutants. The greatest majority of surface area in the run-off samples was associated with particles that were between 15 to 35 microns in diameter.