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16. Abstract

A number of permanent runoff controls were constructed along new highways in the Edwards aquifer recharge zone, with their performance monitored since the highways opened. The control systems consist of a hazardous material trap, a sedimentation basin, and a vertical sand filter. The filter, constructed as part of the wall of the basin, is held in place with filter fabric and rock gabions. Numerous problems have been documented with these systems, mostly in conjunction with the performance of the vertical sand filter.

Sedimentation was the most important pollutant removal mechanism for the runoff control systems. Modifications of runoff control systems that focus on extending the detention time of the basins may be more effective in controlling suspended solids in runoff than enhancing the filter performance. Scour and resuspension of sediments were observed in the detention basins. Sediment and suspended solids removal efficiencies can be increased and maintenance requirements reduced by the installation of rock gabions, baffles, or other devices that reduce resuspension of solids.

Laboratory bench-scale filtration columns using various media were investigated at the Center for Research in Water Resources. The performance of filtration media and adsorptive media was also evaluated. Media selected for these experiments included a well-sorted medium grain size sand, a fine aggregate, grade 5 gravel, compost, and zeolites. The data indicate that the compost is a very effective medium. It out-performed the other media for the removal of TSS, oil and grease, and metals. However, the compost decomposes and subsequent breakthrough occurs. The medium sand performed well for the removal of TSS and most of the metals. Zeolites, pea gravel, and grade 5 gravel were not effective filtration media.

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AN EVALUATION OF HIGHWAY RUNOFF FILTRATION SYSTEMS

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Research Report Number 1943-6

Research Project 7-1943
Water Quantity and Quality Impacts Assessment of Highway Construction
in the Austin, Texas, Area

conducted for the

Texas Department of Transportation

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IMPLEMENTATION STATEMENT

This research report identifies numerous deficiencies in the design of highway runoff control systems constructed on new highways in the Austin, Texas, area. This information can be used to develop retrofit plans to improve the performance of the existing systems. The data also can be used to improve the design and cost effectiveness of future structures, while simultaneously improving the quality of stormwater runoff. This research will help the Texas Department of Transportation (TxDOT) maintain the quality of receiving waters crossed by highways and to satisfy permit requirements of the National Pollutant Discharge Elimination System.

Prepared in cooperation with the Texas Department of Transportation.

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DISCLAIMERS

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SUMMARY

A number of permanent runoff controls were constructed along new highways in the Edwards aquifer recharge zone, with their performance monitored since the highways opened. The control systems consist of a hazardous material trap, a sedimentation basin, and a vertical sand filter. The filter, constructed as part of the wall of the basin, is held in place with filter fabric and rock gabions. Numerous problems have been documented with these systems, mostly in conjunction with the performance of the vertical sand filter.

Sedimentation was the most important pollutant removal mechanism for the runoff control systems. Modifications of runoff control systems that focus on extending the detention time of the basins may be more effective in controlling suspended solids in runoff than enhancing the filter performance. Scour and resuspension of sediments were observed in the detention basins. Sediment and suspended solids removal efficiencies can be increased and maintenance requirements reduced by the installation of rock gabions, baffles, or other devices that reduce resuspension of solids.

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1. INTRODUCTION

1.1 Objective of Research

The Texas Department of Transportation (TxDOT) constructed runoff control systems that impound and filter highway runoff on new highways over the Edwards aquifer recharge zone. These systems were installed in 1993 and 1994 along State Highway (SH) 45 and the southern extension of MoPac in southwest Travis County. This research is concerned with the performance of filtration media used in these runoff control systems. The objectives of this research were twofold: 1) evaluation of the performance of the full-scale filtration systems in the field and 2) determination of the pollutant removal efficiencies of several filtration media in bench-scale laboratory experiments.

The field monitoring study focused on the hydraulic behavior of several vertical filters. In addition, the capacity of one system to improve water quality was evaluated. The drainage rate of six runoff control structures was monitored between May and October of 1994. The change in water level in the detention basin was measured after runoff events. Water quality samples were collected at one control structure from May 1994 through May 1995. The hydraulic performance of the system was extremely poor (slow drainage rate) prior to modifications in the Fall 1994, so useful water quality data were not collected until the replacement of the media. Therefore, only the data collected from January 1995 through May 1995 are presented in this thesis.

The runoff controls installed by TxDOT remove constituents via sedimentation and filtration. The effectiveness of the filter alone is not measured easily in the field because it is difficult to separate removal within the detention basin from removal in the filter. However, filtration was successfully evaluated in bench-scale laboratory columns.

Various granular media were selected and removal efficiencies were compared for different sized media with a range of hydraulic conductivities. The granular media tested included sand used by TxDOT in existing facilities or media identified by TxDOT as potential replacements for the sand in these filters. Alternative media which have adsorptive capacity for organic compounds and/or ion exchange capabilities were also studied. Sand was compared directly with compost and zeolites in this study.

1.2 Background

The use of sand filters for the treatment of highway runoff is not widespread. Common practices used elsewhere for storm water control include wet ponds, dry ponds (with or without extended detention), infiltration trenches, vegetative filter strips and constructed wetlands. None of these technologies was installed in the study area. Low annual rainfall in the region and the lack of available land in the highway right-of-way precluded the effective use of wetlands and wet ponds. Dry ponds could be used at the site; however, low removal efficiencies have been reported for these systems (City of Austin, 1990). Finally, infiltration trenches and vegetative filter strips were not used because of concern over groundwater contamination within the recharge zone.

Sand filters have been used widely in Austin, Texas, where over 1,000 sand filters have been constructed during the last 10 years. High removal efficiencies have been achieved in many of these systems for constituents commonly found in highway runoff; therefore, the sand filter was deemed the best management practice (BMP) for treating highway runoff in the Austin area. The filter geometry in the systems constructed by TxDOT differs from that used by the City of Austin. TxDOT installed vertical sand filters in which the water flows horizontally through the filter, while the typical system in this area has a horizontal filter, where the water flows downward through a filter bed .

The vertical filters were selected in order to reduce the area of the control system and to minimize clogging due to sedimentation occurring on the surface of the filter. Minimizing the area of the system was an objective because of the limited extent of the highway right-of-way. Maintenance requirements for vertical filters were estimated to be less than for horizontal filters because sediment would not accumulate on the vertical filter face.

Between 1993 and 1995, TxDOT spent approximately 10% of its Travis County construction budget on water quality controls. A large fraction of this money has been spent on vertical filtration systems. Evaluation of the performance of this unique filter design was the major objective of the research. The evaluations performed during this study provide TxDOT with data related to the design and operation of existing systems and will identify areas of improvement for future designs.

2. LITERATURE REVIEW

A review of the literature pertaining to the treatment of storm water runoff with sand filters was undertaken. Techniques reported in the literature for enhancing pollutant removal with alternative media also were evaluated. No information was available in the literature describing the use of vertical sand filters. A detailed literature review dealing with the generation of highway runoff and environmental impacts and treatment methods is provided in "A Review and Evaluation of Literature Pertaining to the Quantity and Control of Pollution from Highway Runoff and Construction" (Barrett et al., 1994).

2.1 Sand Filters

A general description of the use and applicability of sand filters for storm water treatment was provided by Schueler et al. (1991). Pollutant removal is achieved in the filter primarily through straining of the sediments within and sedimentation of pollutants on the filter bed. Removal rates of total suspended solids (TSS) and trace metals are high; however, biochemical oxygen demand (BOD), nutrients and fecal coliform are removed to a lesser extent. Sand filters are used frequently in areas with thin soils, soils with low infiltration rates and areas of high evapotranspiration rates because other storm water measures may be ineffective in these areas. Sand filters also pose little threat to groundwater quality and occupy a small area.

Disadvantages of sand filters include high capital costs, frequent maintenance requirements and little or no flood control benefits. The construction costs of sand filters range from $100 to $350 per cubic meter of runoff treated (Schueler et al., 1991). Filter costs are about 2 to 3 times the cost of similarly sized infiltration trenches. The high costs of filters are the result of construction with structural concrete. Quarterly maintenance is required, consisting primarily of raking, leaf removal, trash and debris removal, and surface sediment removal and disposal. Surface sediments from sand filters installed in Austin have been analyzed and can be safely landfilled. Most maintenance is performed manually; therefore, the sand filter should be designed for easy access. Maintenance costs are estimated to be 5% of construction costs per year.

A comprehensive evaluation of several storm water treatment devices was conducted by the City of Austin (City of Austin, 1990). Three of the systems evaluated were sand filters. In the first system, the filter is a part of the detention structure that was designed to treat up to 12.7 mm of runoff. The detention basin was lined with Saint Augustine grass, which was placed over a 10-cm bed of coarse sand (> 0.10 cm diameter) overlaying clay soil. Filtration mainly occurs in a trench located 24 meters from the influent to the basin. The filtration media in the trench is (from top to bottom) 8 cm of sod, 10 cm of sand, and 20 cm of gravel. The second filter studied also included the filter as the bottom of the detention basin. The top layer of the filter is 46 cm of fine sand (0.05 to 0.10 cm diameter); the middle layer is 30 cm of a coarse sand (>0.10 cm); and the bottom layer is 15 cm of pea gravel. In the third filter system, the filter is not part of the detention basin. The basin has the capacity to capture the first 12.7 mm of runoff. The filter is composed of 30 cm of the fine sand (0.05 to 0.10 cm) on top of pea gravel. The sand and the gravel are separated by a filter fabric.

The structures were monitored for five years, and a total of 143 storms were sampled. Average drainage times of 20 to 26 hours were reported. The measured removal efficiencies for the three filters are shown in Table 2.1. The off-line system performed best; however, each of the sand filters performed well. Adequate drainage rates through the filters were maintained by the regular removal of sediments deposited on top of the filters. Drainage times reached several days when accumulated sediments were not removed.

Table 2.1 Removal Efficiencies (%) of Sand Filter Systems

Filtration System	TSS	BOD	COD	TOC	NO_2+NO_3	TN	TP	Metals
On-line 1	83	15	34	44	-26	18	3	19 - 65
On-line 2	70	26	40	38	-37	32	50	20 - 85
Off-line	87	51	67	61	-82	31	61	60 - 86

(Modified from City of Austin, 1990)

Welborn and Veenhuis (1987) evaluated a sand filter in Austin, Texas. The structure was an on-line system that treated runoff from 32.4 hectares, of which about half was impervious parking lots and roads. The sand bed consists of a 46 cm fine sand top layer, followed by a 30 cm coarse sand intermediate layer, followed by a 15 cm pea gravel layer with 15 cm perforated pipe underdrains. The pond bottom is lined with a 61 cm clay liner. The maximum pond depth is 4.2 m, and the storage capacity is 4,317 m^3. A total of 22 storm events were monitored over a 2 year period, with total rainfall ranging from 3.6 to 73 mm. All inflow to the device was filtered through the sand beds, except for three large storms which crested over the emergency spillway. Peak outflow from the filter was measured at 88 L/s. Average discharge rates tended to decrease during the duration of the study, as the sand bed became clogged. The filter was cleaned twice during the study, which caused peak and average discharge rates to improve, but not to the levels measured when the filter was new. Peak and average discharges also decreased noticeably after larger storms, most likely due to the larger sediment loads associated with the storms.

The sand filter system was efficient in removing bacteria, suspended solids, BOD, total phosphorus, total organic carbon (TOC), chemical oxygen demand (COD), and dissolved zinc. Average removals ranged between 60% and 80%. The average total dissolved solids (TDS) load was approximately 13% greater in the outflow than in the inflow. Possible explanations for the increase were the dissolution of previous deposits left on the filter, leaching from the pond bed and sand filter, and mineralization of the organic material deposited on the pond bed. Organic nitrogen and ammonia nitrogen concentrations in the inflow were substantially larger than that in the outflow. Total nitrate plus nitrite levels in the outflow were about 110% larger than the inflow concentrations. These measurements indicate that nitrification occurs in the pond.

An extended-detention/filtration system was evaluated for total phosphorus and orthophosphorus removal (Holler, 1990). The system was designed so that runoff was captured in a detention basin and discharged through the filter over a 48-hour period. The storage capacity of the detention pond was 1800 m^3 which is equal to 12.7 mm of rainfall over the contributing watershed. The area drained was urban/commercial. The filtration media was a combination of limestone, sand and native fill, with a 15-cm PVC underdrain connected to a drop box. Excess runoff bypasses the filter through an emergency spillway which discharges into a separate drainage channel.

Six storms were monitored during a 1-year period. The water level in the basin receded slowly with head losses of about 3.4 cm/day. This observation indicates that the media may have been clogged with fine sediment or that the head required to operate the system properly was insufficient. A statistical analysis was performed to determine removal in the detention pond and through the filter. Significant treatment for both total phosphorus and total orthophosphorus occurred in the extended-detention pond; however, there was not a statistically significant difference in pre- and post-filter concentrations. An average removal of total phosphorus and total orthophosphorus was 77%. This removal was attributed to the extended-detention pond only.

The filters evaluated in the current study are oriented vertically; therefore, the performance evaluations discussed above cannot be used to estimate performance. Nonetheless, the performance summaries present a background and reference point for evaluating the performance of vertical filtration systems. In vertical systems, no sedimentation of solids occurs on top of the filter and distribution of flow and solids loadings through the filter are not uniform. The results of the present study show the extent to which these differences affect the performance of the filter.

2.2 Alternative Media for Enhanced Pollutant Removal

Zeolites and compost were evaluated as alternative media during this study. Zeolites have been used in the water treatment industry since the late 1800's as an ion exchange medium (Montgomery, 1985) and were tested for their potential in removing heavy metals and oil and grease. High removal of metals in a sand and zeolite bench-scale column for the treatment of a runoff "cocktail" was reported by Heathman (1994). Edwards and Benjamin (1989) described the use of a coated sand for enhanced metals removal. These filtration experiments demonstrated that an iron-hydroxide-coated sand outperformed uncoated sand in removing particulate metals, as well as uncomplexed and ammonia-complexed soluble metals. Removed metals were effectively recovered from the coated media during back washing and acid regeneration.

The most widely used alternative media are complex organic media used for the adsorption and removal of oil and grease. An enhanced sand filter design which incorporates peat into the filter material was described by Galli (1990). Peat is primarily composed of cellulose and humic and fulvic acids. The structure of peat ranges from open and porous to granular and colloidal. Porous peats tend to have a high water-holding capacity. Measured hydraulic conductivities of peat range from 0.025 cm/hr to 140 cm/hr. Peat also exhibits high adsorptive and cation exchange capacities. The carbon:nitrogen:phosphorus composition ratio of peat is around 100:10:1, which provides substrate for microbial growth. Peat typically contains large populations of nitrifying and denitrifying organisms. Phosphorus assimilation in peat has been reported; however, phosphorus detention in peat appears to be more closely linked to the calcium, aluminum, iron, and ash content of the peat. These qualities make peat a useful additive for sand filters.

Galli (1990) points to the effectiveness of peat for sewage treatment. Removals of nutrients, BOD, and pathogenic bacteria were high (i.e., greater than 80%). Peat also has been used effectively to treat electroplating wastewater and to clean up oil spills. The peat-sand filter tested in the early 1970's, consisted of a 10- to 30-cm peat layer on top of a 75- to 90-cm layer of fine sand. Grass was planted on top of the peat. Removals achieved were greater than 90% for phosphorus, 98% for BOD, and 99% for fecal coliforms. Improvements have resulted in a multi-layered design. The top layer is 30 to 46 cm of peat mixed with calcitic limestone to enhance phosphorus removal. The middle layer is 10 cm of a 50% peat/50% sand mixture. This layer provides a uniform flow through the bed and increases the peat-water contact time. The bottom layer is a 16 cm gravel layer with a perforated PVC pipe underdrain.

A peat-sand filter was constructed in Maryland where an existing off-line infiltration basin failed. The contributing watershed area was 57 hectares. Estimated removal efficiencies for TSS, total phosphorous (TP), total nitrogen (TN), BOD, trace metals, and bacteria were 90%, 70%, 50%, 90%, 80%, and greater than 90%, respectively. The peat-sand filter performed best during the warmer months. A wet pond that precedes the filter provides limited treatment during the winter when the peat-sand filter is bypassed. Suspended solids (sediments) also are removed in the pond.

Design requirements for sizing peat-sand filters for treating runoff are not rigid. Generally, an increase in the pollutant and hydraulic loadings requires an increased area of peat surface. A general rule of thumb is 0.5 hectares of peat surface for each 100 hectares of contributing watershed area. Galli (1990) stresses the importance of analyzing peat for hydraulic conductivity, cation exchange capacity, iron, aluminum, calcium carbonate, ash, and nutrient content prior to bulk purchase. Negative nutrient removal also was experienced during filter start-up as some nutrients wash from the peat.

The amount of sediment which can be deposited on peat before filter efficiency is diminished has not been established. The effects of different hydraulic conductivities of the peat on overall removal efficiencies also are unknown. The sizing relationships for designing peat-sand filters also must be defined. The effect of peat mixture and thickness on performance and longevity also must be established.

The adsorptive properties of granular activated carbon (GAC) often are used to capture organic compounds in industrial air and wastewater streams. The trihalomethane-forming potential (THMFP) of the organic constituents associated with highway runoff was a concern in areas where runoff was discharged directly to underground drainage wells in Florida (Wanielista et al., 1991). About 400 drainage wells were constructed in Florida from 1905 until 1970 in an attempt to reduce some runoff flooding problems. The practice was halted in 1970 amidst increasing concern about the potential for groundwater contamination.

Wells were retrofitted with a GAC filter bed prior to the drainage well discharge at one site. The THMFP of the water was assessed before and after carbon treatment. Removal of TOC was 6.3 mg/g per gram of activated carbon. However, the GAC treatment for the removal of THMFP precursors was calculated as $316,000, or $1.16/1000 L after detention and before injection. The rapid breakthrough experienced in the GAC beds indicated that replacement of the carbon would be required after every 2.5-cm storm event.

3. EVALUATION OF STORM WATER FILTRATION SYSTEMS

3.0 Introduction

The performance of the highway runoff detention and filtration systems constructed by TxDOT in southwest Travis County was evaluated. In this chapter, the filtration systems are described; the measurements, observations and calculations made to establish the hydraulic performance of the vertical filters are presented; and, finally, the efficiency in removing constituents from highway runoff for one control system is presented.

3.1 Description of the Runoff Retention and Filtration Systems

Each filtration system installed along SH 45 and the extension of MoPac in southwest Travis county includes a hazardous materials trap (HMT), a sedimentation basin and a vertical filter. Approximately 41 of these systems were constructed within the Edwards aquifer recharge zone. A typical runoff control system is shown in Figure 3.1. The small concrete basin in the foreground is the HMT, the sedimentation basin is just beyond the HMT, and the vertical filter is located at the far right-hand side of the sedimentation basin.

3.1.1 Hazardous Materials Trap

The hazardous materials trap is a small detention basin located at the upstream end of the control structures. The HMT is designed as a temporary storage basin for capturing any liquid hazardous materials (e.g., gasoline, oil or chemicals) spilled on the highway. Spilled materials are captured and retained in the HMT until the materials can be collected and disposed of off-site. The HMT is positioned upstream of the detention basin. However, during a rainfall event the runoff first enters and fills the HMT before entering the sedimentation basin. Whenever the HMT is filled with runoff, this basin cannot function as a hazardous materials collection tank. Siphon pipes were installed in each HMT to drain the collected runoff after each storm event. The siphon is enabled when the depth in the HMT reaches the level of the siphon (Figure 3.2).

3.1.2 Sedimentation Basin

The sedimentation basins are large concrete structures designed to capture the runoff generated by a 12.7 mm rainfall event. Runoff begins flowing into the basin after

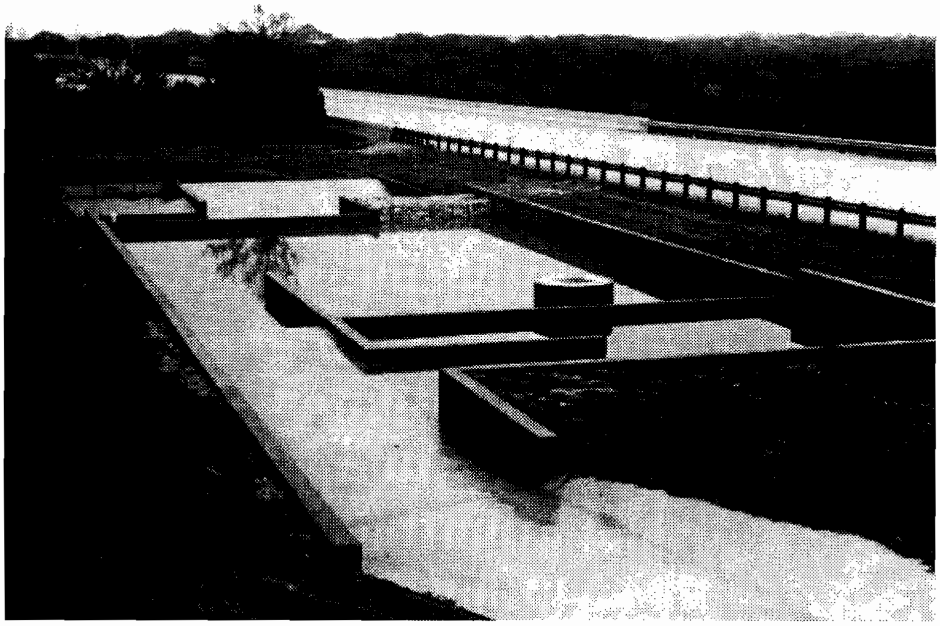

Figure 3.1 Typical Filtration System.

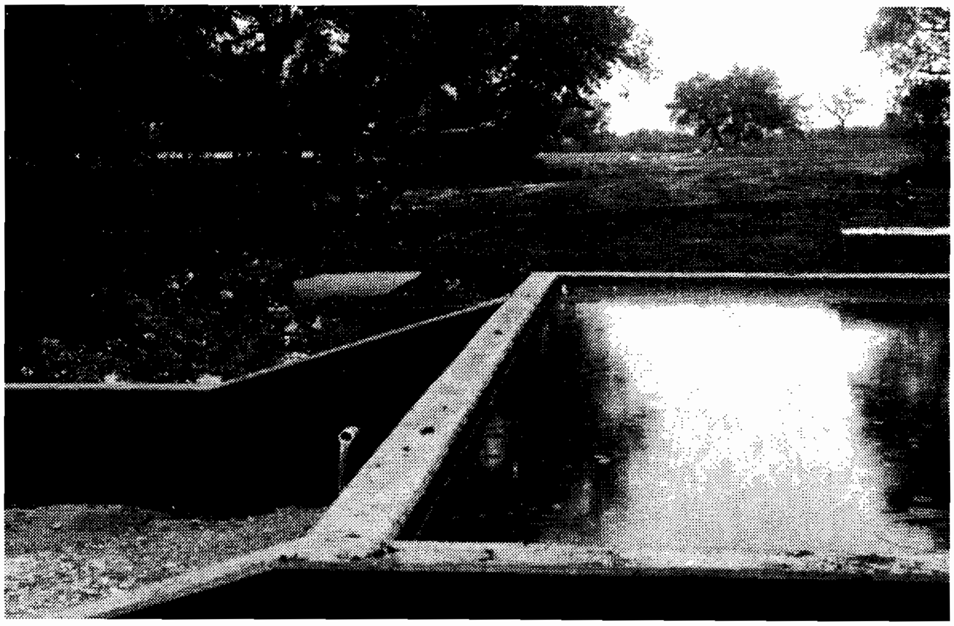

Figure 3.2 Runoff Draining From the HMT Through the Siphon.

the HMT is filled. The runoff leaves the basin through the vertical filter. The stormwater system is off-line, meaning that runoff will bypass the detention basin whenever the basin is full. The bypass is discharged untreated into the receiving water. Runoff entering a detention basin through the main runoff transmission pipe is shown in Figure 3.3.

3.1.3 Vertical Filter

Vertical filters are located at the downstream end of the structures. The filter is the drainage control for the sedimentation basin. The control structures constructed by TxDOT include vertical filters while filtration systems used elsewhere contain horizontal filters to treat runoff. The filter is a porous wall at the end of the sedimentation basin in which the medium is supported by rock gabions on each side of the filter. Geotextile fabric is used to contain the filtration medium between the rock gabions. The filtration medium originally installed in the vertical filters was a medium sized sand (0.5 to 1 mm diameter). Rock gabions contain rock (8 to 30 cm in diameter) held in place by a wire cage. A typical vertical filter with the rock gabions installed is shown in Figure 3.4. The filters were designed (sized) to allow for drainage of the sedimentation basins within 24 to 48 hours.

3.2 Evaluation of the Hydraulic Performance

3.2.1 Materials and Methods

Six structures were considered for this evaluation. The devices are located along SH 45 and the extension of MoPac in southwest Travis County, where highway runoff infiltrates directly into the Edwards aquifer recharge zone. Controls designated N, M, K and L are located along SH 45, and controls A and B are located along MoPac. The lettering scheme coincides with the designation used by TxDOT. Each control is sited within the median of the highway. The dimensions of each of the controls are presented in Table 3.1. The filter width is the dimension of the filter perpendicular to the direction of flow and the thickness of the filter is the dimension of the filter parallel to the direction of runoff flow. The dimensions were obtained either by direct measurement or from TxDOT engineering drawings of the structures.

The structures used in this evaluation were selected from among approximately 20 such structures in the study area. Each unit selected is accessible from the roadside, facilitating access for measuring water level. The six selected structures vary in size and shape and were built by different contractors. Differences in construction or installation

Figure 3.3 Retention Basin Filling with Highway Runoff.

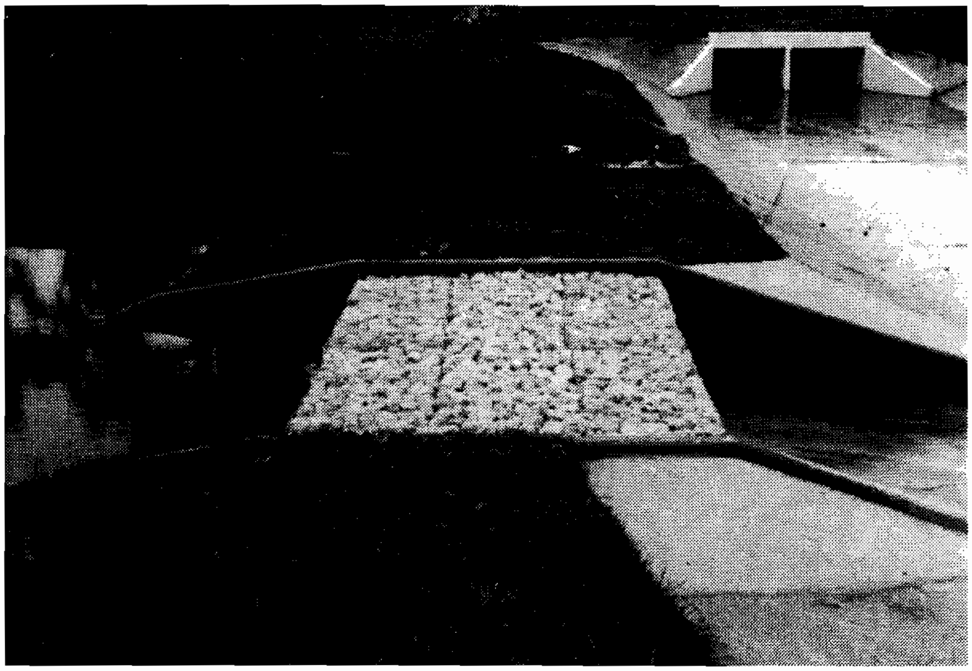

Figure 3.4 Typical Vertical Sand Filter Supported by Rock Gabions.

Table 3.1 **Basin and Filter Dimensions for the Six Control Structures**

Control	Basin Dimensions (m)			Filter Dimensions (m)	
	Length	Width	Bottom Slope	Width	Thickness
N	34	9	0.0073	5.5	0.9
M	21	13	0.0053	2.8	0.9
L	21	13	0.0040	9.1	0.9
K	10	10	0.0051	1.8	0.9
A	26	15	0.0062	5.5	0.9
B	22	8	0.0056	9.1	0.9

of the vertical filters by the contractors may have altered the drainage characteristics of the sedimentation basins which are designed to drain in 24 to 48 hours.

The method described for predicting drainage rates through the filters is the same as that used by TxDOT to design the filters. The drainage of the six runoff detention basins was estimated using the Dupuit equation for unconfined flow through a porous medium. The Dupuit equation is based on the assumptions that 1) a uniform hydraulic gradient equal to the slope of the phreatic surface exists and 2) the flow is horizontal. These assumptions lead to the following equation:

$$Q_x = -Kwh(x)\cdot\frac{dh}{dx} \qquad (3.2.1)$$

where:

Q_x = flow in the x direction (m^3/s)
K = hydraulic conductivity of the porous media (cm/s)
w = width of the cross section (m)
h(x) = height of the saturated zone (m)
x = distance in the direction of flow (cm)

Solution of this equation for the water quality enhancement structures constructed by TxDOT within the study area yields the following equation:

$$Q = K\cdot\frac{wh^2}{21} \qquad (3.2.2)$$

where:

l = thickness of the filter (cm)
w = width of filter (m)
h = water level within the detention basin next to the filter (m)

Equation 3.2.2 assumes steady-state flow or that changes in $H(t)$ are slow enough that the discharge across the filter is always adjusted to equilibrium conditions. A time step of thirty minutes was used to solve Equation 3.2.2. The detention basin was assumed to be full at time equal to zero and it was assumed that no flow entered into the detention basin. The hydraulic conductivity reported by TxDOT for the Brady sand ($K = 0.15$ cm/s) and the dimensions listed in Table 3.2 were used to develop drainage curves for each of the control structures. Calculations for the drainage of control "N" are provided in Appendix A.

The actual drainage of the six control structures was obtained by measuring the depth of water in each basin for up to one week after a runoff event. Measurements were recorded after storms on 5/16/94, 5/30/94, 8/9/94, and 10/18/94. The actual water depths are tabulated in Appendix A. The depths were converted into estimated volumes to determine the drainage rates. Two equations were used to calculate the basin volume depending on whether or not the water level (h), was greater than the change in bottom elevation of the basin due to the slope of the basin (H^*). For the water level greater than H^* the volume (V_b) was calculated as follows:

$$V_b = w \cdot l \cdot (h - \frac{1}{2}H) \tag{3.2.3}$$

otherwise, for $h < H^*$:

$$V_b = w \cdot (\frac{h^2}{2 \cdot m}) \tag{3.2.4}$$

where:

H^* = Change in bottom elevation in the detention basin due to the slope of the bottom (m)
w = width of the detention basin (m)
l = length of the detention basin (m)
m = bottom slope of the detention basin

The percent of runoff remaining in the detention basin was calculated from the following equation:

$$R_i = 100\% \cdot (1 - \frac{(V_B)_i}{V_{max}}) \tag{3.2.5}$$

where:

R_i = Percent remaining in the detention basin at time i

$(V_b)_i$ = Volume of runoff in the detention basin measured at time i (m^3)

V_{max} = Maximum volume of runoff for the detention basin (m^3)

3.2.2 Results

A comparison of the actual drainage rates of the six controls is shown in Figures 3.5a to 3.5d, in which the percent runoff remaining in the detention basin with time is plotted for the events occurring on 5/16/94, 5/30/94, 8/9/94 and 10/18/94, respectively. A wide variability in the hydraulic performance of the controls was measured with the fastest controls draining in under 50 hours and the slowest controls remaining over 50 percent full several days after the runoff event. Most of the basins did not drain within the design time of 24 to 48 hours.

Controls "N" and "K" show dramatic improvement for the storm on 10/18/94. This improvement is the result of modifications made to the filters. Control "N" was modified by replacing the original sand (0.05 to 0.10 cm diameter) with a grade 5 gravel (0.1 to 0.5 cm), which has a very high hydraulic conductivity. Control "K" was modified by replacing the sand with a narrow filter cartridge which was a 10-cm wide metal container lined with filter fabric filled with Brady sand. The cartridge system allowed easy removal and replacement of the medium after the filter clogged. The cartridge is much narrower than the 91-cm filter originally in place and allowed rapid drainage of the detention basin. During field inspection, the runoff was observed to be draining around the filter through gaps between the cartridge and the filter or the cartridge and the concrete wall. The system did not appear to perform properly and was not installed in other structures.

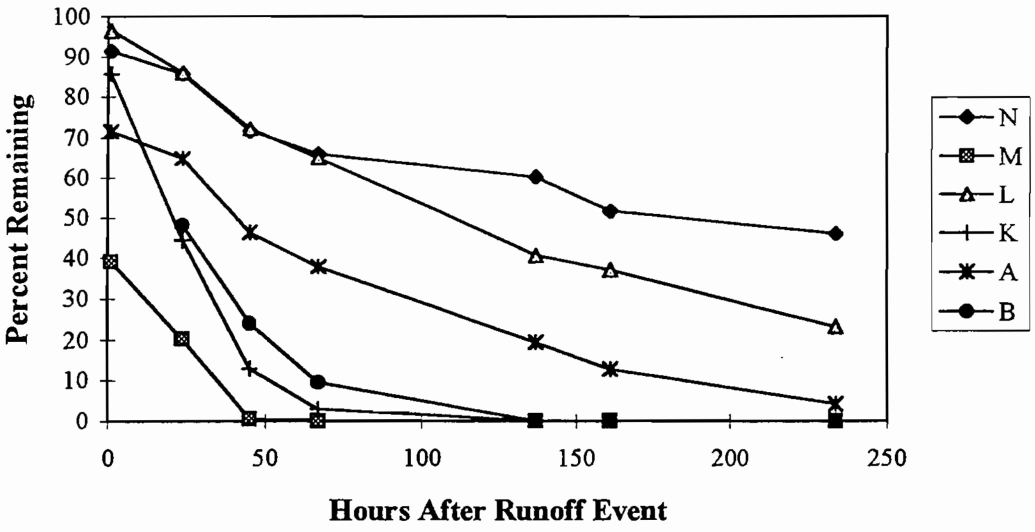

Figure 3.5a Drainage of Six Runoff Controls after Storm on 5/16/94.

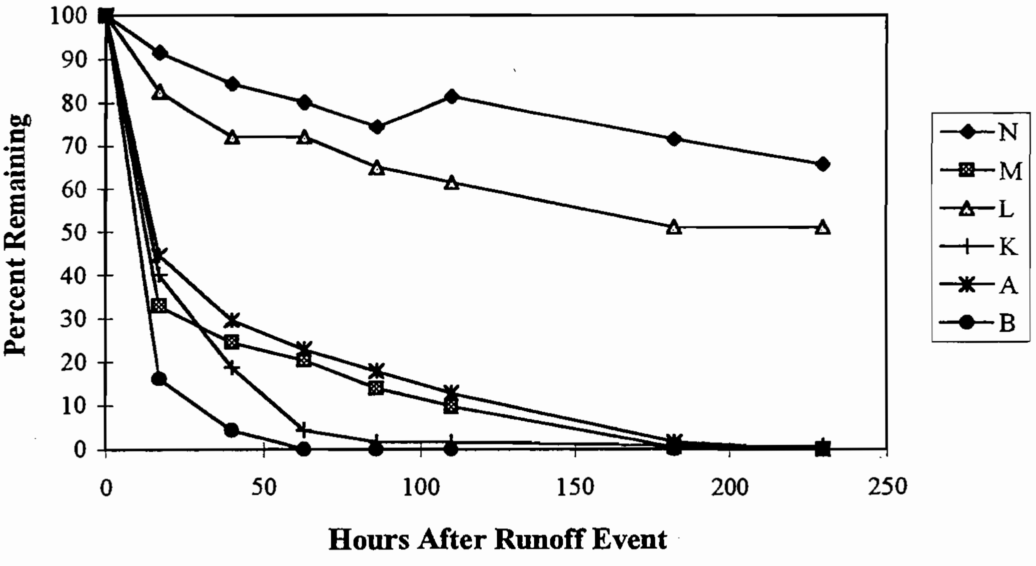

Figure 3.5b Drainage of Six Runoff Controls after Storm on 5/30/94.

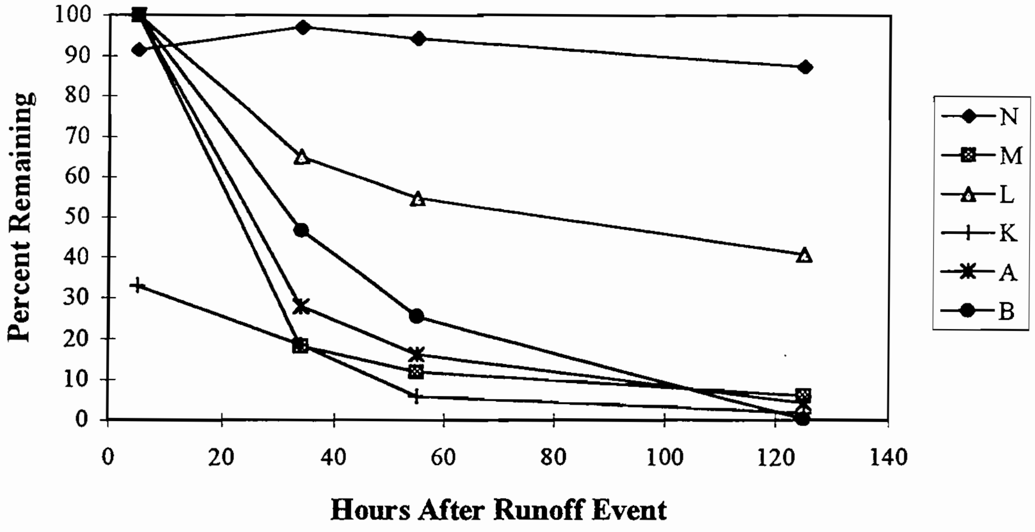

Figure 3.5c Drainage of Six Runoff Controls after Storm on 8/9/94.

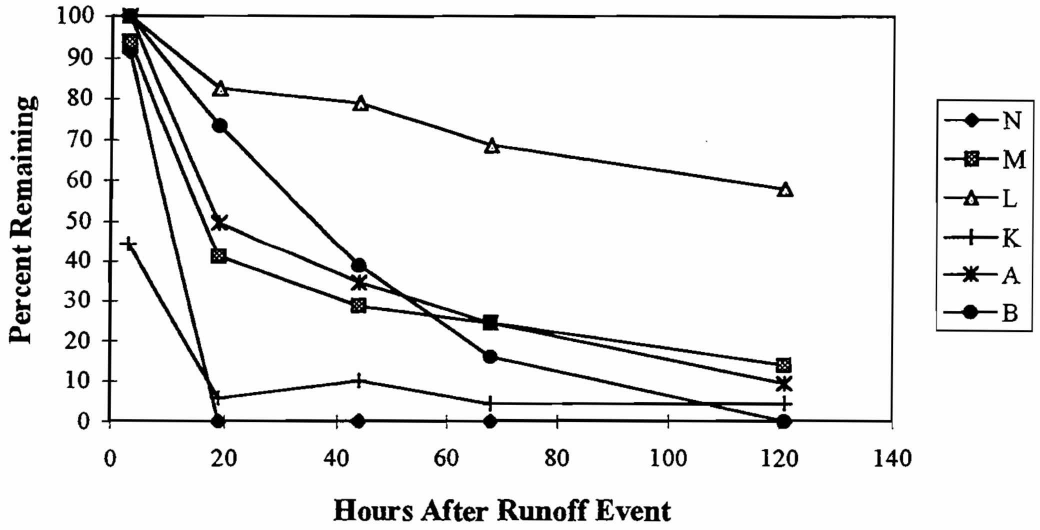

Figure 3.5d Drainage of Six Runoff Controls after Storm on 10/18/94.

Predicted Drainage of the Six Controls

Predicted drainage curves which are presented in Figure 3.6 indicate the variability in the predicted drainage of these detention basins. This variability is attributable to the differences in the basin and filter dimensions of the controls. The magnitude of this difference is much less than that of the actual drainage times of the basins. The predicted drainage times which are shown in Figure 3.6 are greater than the design specifications.

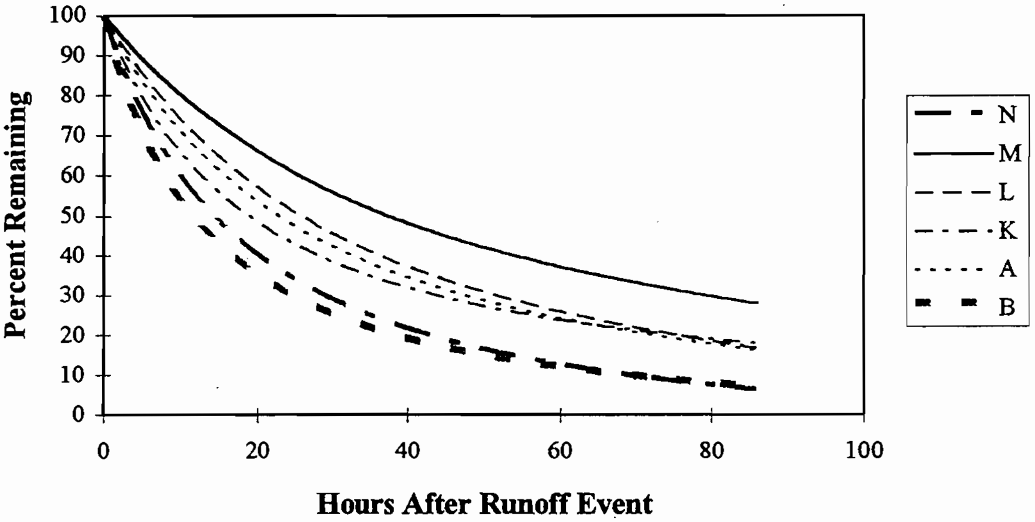

Figure 3.6 Comparison of Predicted Drainage for Six Runoff Controls.

3.2.3 <u>Discussion</u>

The results of this monitoring show that there is a problem with the hydraulic performance of the vertical filters. Many of the filters drained poorly. Without adequate drainage the filtration systems are ineffective because runoff from a preceding storm may reduce the capture capacity of the detention basin. The overall efficiency of the system is reduced whenever the full capacity of the system is not available. The basins also can provide a breeding area for mosquitos if water stands for long periods. Furthermore, many of the detention basins drained differently, and the reason for this poor and variable performance is not clear.

Several controls, including "N" and "L" evaluated in this performance assessment failed immediately. These controls, which represent approximately one third of the total number of controls installed in the study area, clogged during the first runoff event after they were brought on line. Most of the detention basins associated with these controls never drained completely. The drainage is controlled by the flow through the filters.

Three factors which may control the drainage rate through vertical sand filters wrapped in filter fabric are: 1) the filtration media alone controls the drainage; 2) the filter fabric affects flow and the combination of the sand and filter fabric controls drainage and 3) the filter fabric impedes flow to such an extent that the fabric alone controls the drainage.

The design of the filtration systems by TxDOT assumed that the drainage rate was controlled by sand alone; however, observed data do not bear out this assumption. A comparison of the predicted and measured drainage of control "N" is shown in Figure 3.7. The measured drainage rates were observed for the first two runoff events after the filter was brought on line. The predicted drainage curve was developed assuming that the sand alone controlled flow through the filter.

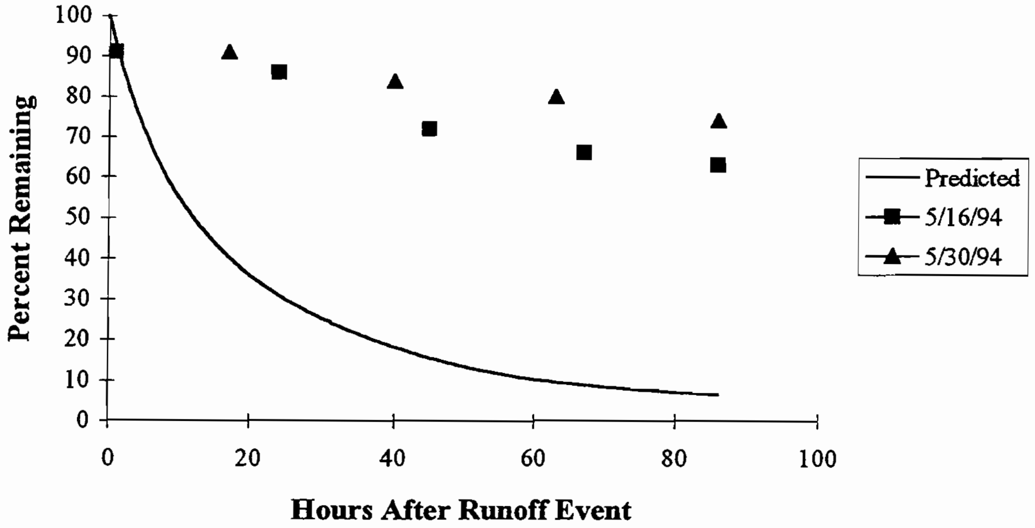

Figure 3.7 Measured and Predicted Drainage at Control "N".

The difference between predicted and measured rates can be explained by clogging of the sand. However, the same sand used in these runoff controls was used elsewhere successfully as filtration media for storm water. The City of Austin has operated storm water filters using the same sand for over ten years and has not experienced similar clogging problems. The City filters are horizontally bedded and do not have a sand/filter fabric interface. Even though differences between the performance of horizontal filters and to vertical filters are expected, it is unlikely that the sand used effectively in horizontal filters would clog immediately in a vertical filter. A vertical filter would be expected to clog at a different rate than a horizontal filter; however, this effect would not be evident until after several runoff events. Furthermore, the runoff entering the filtration systems was not laden heavily with solids, so clogging should not have been so dramatic. The discrepancy between the predicted and measured drainage times shown in this case indicates that something other than the sand controlled the drainage rate.

The hydraulic behavior can be explained by the effect of the filter fabric alone. The filter fabric is a one dimensional sheet which contains openings small enough to retain the sand yet large enough to allow the runoff to pass. During installation of the filter, the sand partially fills the small openings in the fabric creating a sand and filter fabric interface which may reduce the drainage rate. The interface may be clogged because the size of the openings in the fabric is reduced by the sand. Therefore, the size of the opening through which the runoff can pass is decreased and the rate of clogging by smaller-sized particles increases. The placement of the fabric on the outside of the sand filter increases its exposure to runoff with high TSS concentrations which can accelerate the clogging process. The City of Austin uses the filter fabric effectively as an underdrain for the sand filters; therefore, the fabric remains permeable for long periods because it is exposed to low suspended solids loadings.

Installation of alternative granular media which can be held in place by materials other than the geotextile fabrics may improve the drainage. In September 1994 TxDOT replaced the sand in control "N" with a grade 5 gravel with a high hydraulic conductivity (approximately three times greater than the sand). The performance of control "N" was improved by installing the gravel media. However, the runoff in the detention basin drained in 10 hours which is much less than the 24 to 48-hour design drainage time.

Several of the control structures drained much more rapidly than controls "N" and "K". These rapidly draining controls appear to be operating nearly as designed with at least a majority of the flow passing through the filter within the first 50 hours after the runoff event. For example, for the storm on 5/16/94 75%, 85%, and 100% of the runoff drained through controls "B", "K" and "M", respectively, in the first 50 hours. The drastic difference in drainage rate for these systems compared to controls "N" and "L" indicates that the mechanism controlling the drainage of these systems is different. If the mechanism controlling the drainage were the same, all of the detention basins would drain poorly.

One factor which introduces variability into the drainage rates is the different size and shape of the filters and detention basins. However, each control receives a proportional amount of runoff; therefore, only a small portion of the variability in drainage rates can be attributed to size and shape. Traffic pattern and land usage within the study site were the same, so the sediment loads on the controls per area of highway should be the same. Thus, variations in sediment loadings are not a significant factor. The filters with faster drainage rates actually receive higher sediment loads because there is less time for sediment removal via sedimentation; therefore, the concentration of suspended solids in the runoff which passes through the filter would be higher than in a slowly draining system.

The variability in performance may be attributed to improper installation resulting in rapid draining caused by channeling around the filters. Proper installation requires the filter medium to be completely wrapped in the geotextile fabric, which is installed flush with the concrete channel on all sides, with no exposure of sand directly to the runoff. When the filter is not properly installed, passages may exist around the sand and filter fabric and runoff flows through channels without passing through the filter fabric/sand interface.

Other evidence, such as wash out of sand, suggests improper installation of the sand filters. In many cases, but never for controls "N" or "L", sand was washed from the filter indicating that the filter fabric did not completely contain the sand. The runoff passed through the sand without also passing through the filter fabric or the water formed channels around the filter. Basins "M", "K" and "B" drained somewhat faster than the predicted drainage rate. The drainage of basin "K" for several storms is presented in Figure 3.8. The increased drainage rate of the filter may be the result of an installation where the fabric and sand were not flush to the concrete walls and channels formed through which water flowed at a rate greater than the rate of flow through the sand. Field observations at control "M" support this assumption. Runoff drained from the detention basin through the filter predominantly along one side of the effluent channel.

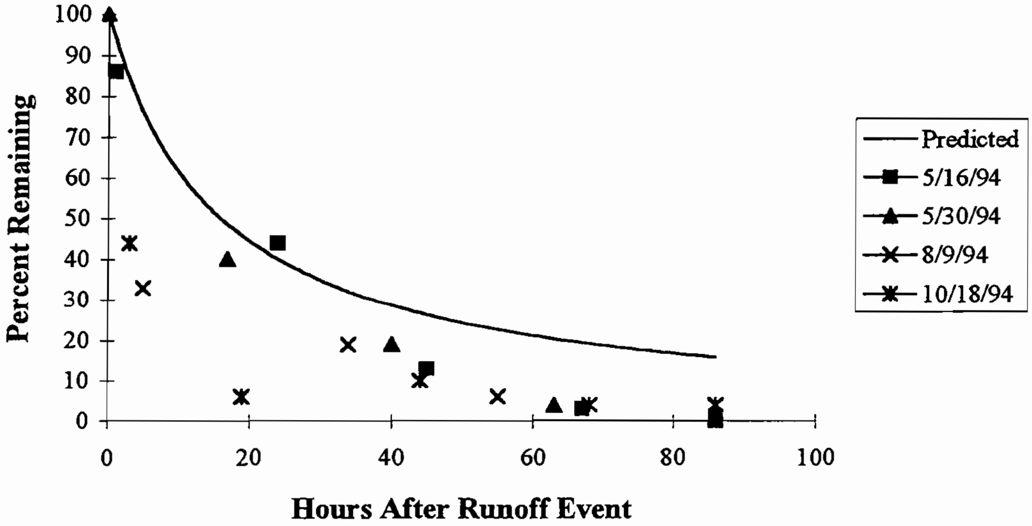

Figure 3.8 Measured and Predicted Drainage of Control "K".

The clogging pattern of vertical sand filters can result in increased maintenance problems. Most of the runoff passes through the bottom portion of vertical filters and little runoff passes through the upper layers. In effect the bottom of the filter is fully utilized and upper portions are not. An estimate of the extent to which different vertical sections of the filter will be utilized is shown in Figure 3.9. The average amount of runoff passing through each section of the filter (with the bottom at 0 meters and the top at 1 meter) for a storm that fills the basin is illustrated. The calculation is based on the predicted flow through control "N" as shown in Figure 3.6. This analysis illustrates that most of the flow occurs through the lower portion of the filter. This pattern is exacerbated in real systems because many of the storms are small and the basin does not fill completely. During these events no runoff passes through the upper portion of the filter and all of the runoff passes through the lower portions of the filter. This means that clogging of a vertical filter occurs at the face and at the bottom of the filter. Therefore, each time the filter clogs the whole filter must be replaced. However, in a horizontally bedded filter clogging occurs at the top of the bed and the top layer can be removed without removal of all of the filtration medium. Replacing all of the filter medium each time clogging occurs is an inefficient use of the filtration medium.

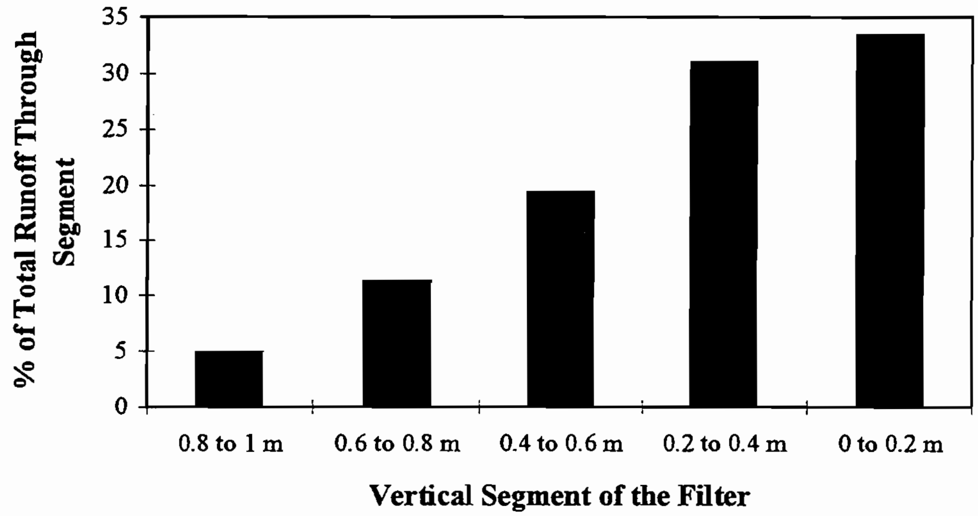

Figure 3.9 Percent of Runoff Passing Through Segments of a Vertical Filter.

3.3 Pollutant Removal Efficiency

3.3.1 Materials and Methods

The control structure "N" is located along SH45 in southwest Travis County near Danz Creek (Figure 3.10). Runoff is captured from the eastbound and westbound segments of SH45 as well as from a small road connecting the two roadways. The runoff is transmitted to manhole 1 (MH1) via transmission lines T1 and T2. The total drainage area which contributes flow into control "N" is $2.11 * 10^4$ m^2 (2.11 hectares). The runoff is discharged from the facility into Danz Creek.

Control "N" (Figure 3.10) includes an HMT, a detention pond, and a vertical filter. The area of the HMT is 51 m^2. Runoff enters the HMT through a 45.7-cm pipe and exits through a 10-cm effluent siphon pipe, which discharges directly into the detention pond. The siphon is enabled when the water depth in the HMT exceeds 0.6 meters. However, the water depth in the HMT can reach 1.1 meters during a runoff event. At that height the total HMT volume is 56 m^3. The volume of the detention pond is 270 m^3. The basin has a bottom slope of 0.007 m/m. The majority of runoff that enters the detention pond enters through transmission line T3, which is a 61-cm pipe connecting manhole 1 (MH1) and manhole 2 (MH2). The vertical filter is located at the downstream end of the detention basin. The vertical filter is 5.5-m wide (transverse to flow) and 0.9 meters thick (in the direction of flow). The water depth in the pond can reach 1 meter at the face of the filter when the pond is full.

The filtration medium installed in control "N" during this experiment was the grade 5 gravel described in Section 3.2.2 and Section 4.1. Control "N" drained poorly with sand wrapped in filter fabric as the filtration media. Consequently, the grade 5 gravel was selected as a replacement medium because of its high hydraulic conductivity. The gravel was wrapped with a wire mesh similar in size and texture to window screen and placed between the rock gabions.

Sampling stations were established at the influent and effluent of control "N" to measure flow rates into and out of the structure and to collect water quality samples. Each station consisted of an ISCO 3230 flowmeter, an ISCO 3700 automatic sampler and a power supply. All measurements of flow and depth were recorded at five minute intervals.

An estimation of the volume of runoff entering and leaving the system is required to perform a system mass balance. Provided in this section is a description of the measurements, calculations and assumptions used to obtain this information. The basic

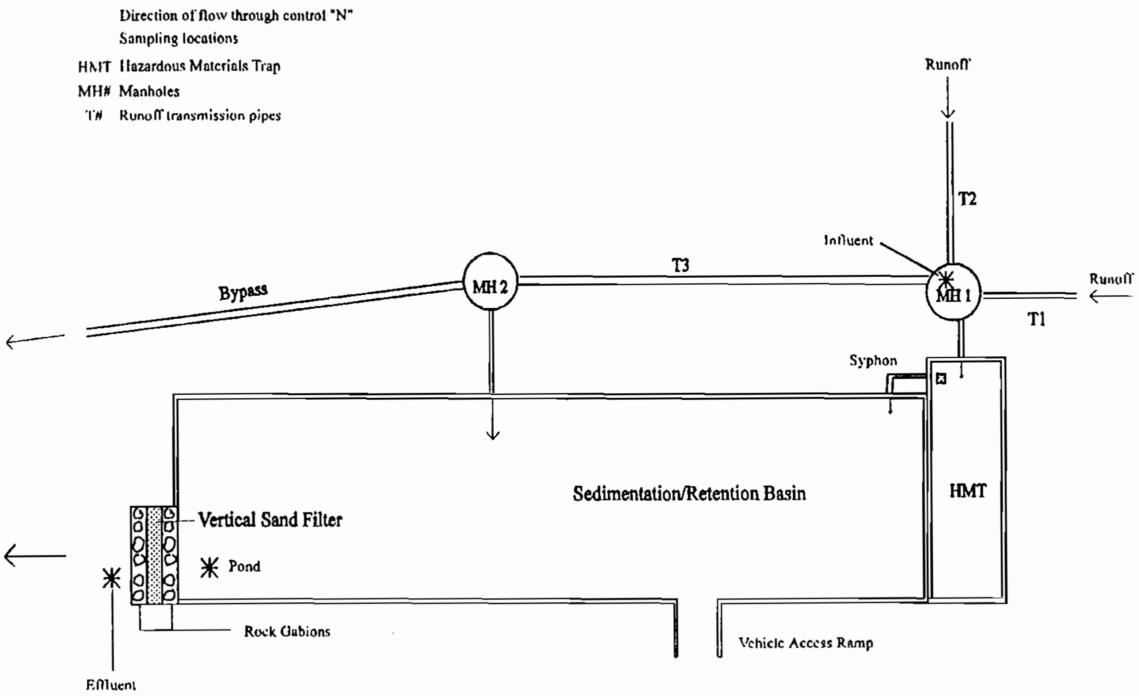

Figure 3.10 - Control "N" site layout and sampling locations.

equation for estimating flow through the system was obtained by performing a flow balance on the detention basin. The continuity equation is:

$$\frac{\Delta V}{\Delta t} = (Q_{inf})_{T3} + Q_{HMT} - Q_{eff} \tag{3.3.1}$$

where:

$\Delta V/\Delta t$ = rate of change in detention basin volume (L/s)
$(Q_{inf})_{T3}$ = influent flow rate (L/s) through pipe T3
Q_{HMT} = flow rate through HMT (L/s)
Q_{eff} = effluent flow rate through vertical filter (L/s)

Rate of Change in Detention Basin Volume

The rate of change in volume was calculated by measuring the change in depth in the detention pond and calculating the volume. The basin volume was calculated using Equation 3.2.3 and 3.2.4. Depth was recorded at five-minute intervals. The rate of change in storage reported at a specific time, t_i, refers to the average rate of change of the volume of the basin for the five-minute interval prior to that time. The difference between the basin volume at the beginning of the interval, $(V_B)_i$, with that at the end of the interval, $(V_B)_{i+1}$, was divided by the five minutes expressed as seconds as follows:

$$\left(\frac{\Delta V}{\Delta t}\right)_i = \frac{(V_B)_i - (V_B)_{i+1}}{300\text{sec}} \tag{3.3.2}$$

Influent Flow rate Measurement and Calculation

Measurement of the flow into control "N" is difficult because a portion of the flow enters through the HMT and the rest enters through pipe T3. Highway runoff is transmitted to MH1 through T1 and T2 as shown in Figure 3.10, and the runoff either enters the HMT or flows into pipe T3. Only the flow through pipe T3 was measured; therefore, a model was developed to estimate flow through the HMT.

The model is presented graphically in Figure 3.11, which shows the anticipated water depth within the HMT for a typical runoff event. Flow through the HMT was divided into three segments ending at times t_1, t_2, and t_3, respectively. At time t_0 the runoff event begins, and the water depth in the HMT increases. No flow leaves the HMT or enters pipe T3 during this interval. The pipes are configured such that no flow enters T3 until the HMT fills.

At time t_1 the water reaches a maximum in the HMT and the siphon is engaged. Flow through T3 occurs only during this interval and a portion of the runoff flows into the HMT at a rate equal to the discharge rate through the siphon, maintaining the HMT full. The remaining runoff flows through T3. In most cases the flow through T3 greatly exceeded the flow into the HMT during this interval. This flow distribution continues until time t_2 when the runoff ceases and the water depth in the HMT begins to decrease. The length of the second interval was determined by selecting, from the influent hydrograph, the time frame during which the flow through T3 exceeded 1 L/s. During the third interval there is no runoff, and the HMT drains completely by the end of this interval.

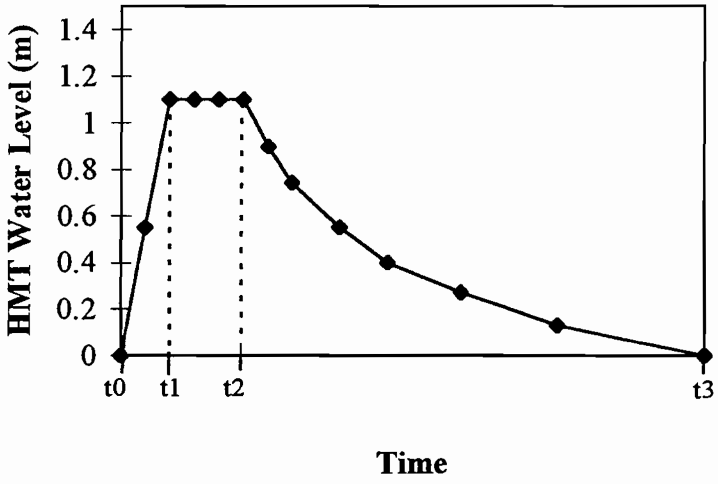

Figure 3.11 Model Of Water Level In HMT for a Typical Runoff Event.

A number of field measurements were taken to calculate flow through the HMT. The HMT drains completely in three hours after the runoff event; therefore, the average flow rate, based on this drainage time was 5.4 L/s ($56\text{m}^3/3$ hr) for the third interval. The average flow rate was assigned for this interval since the actual flow rate was not measured. This flow rate is used in the calculation of the effluent flow rate. Also, the measured flow rate through the siphon was approximately 10 L/s when the HMT was full. Based on these observations the influent flow through the HMT was calculated using the following equation:

$$(Q_{\inf})_{HMT} = Volume_{HMT} + (Q_{HMT})_{full} \cdot (t_2 - t_1) \cdot 0.06 \qquad (3.3.3)$$

where:

$(Q_{inf})_{HMT}$ = Total inflow from the HMT (m^3)
$(Vol)_{HMT}$ = Total volume of the HMT = $56 m^3$
$(Q_{HMT})_{full}$ = The full HMT flow rate through the siphon = 10 L/s
$t_2 - t_1$ = Duration of the second time interval (min)
0.06 = Unit conversion factor

The main component of the influent was the flow in T3, which was the only measured portion of the influent. A 90° V-notch weir was installed in the upstream end of pipe T3 to measure flow through that pipe. The weir had a maximum capacity of 45 L/s. The flow through pipe T3 exceeded the rated capacity of the weir during part of the runoff event for seven of the nine storms. In these cases the unmeasured part of the flow was estimated based on the measured change in detention basin volume and assumed values of the effluent and HMT flow rates. When the flow rate through T3 was greater than 45 L/s, the flow rate was estimated by rearranging and solving Equation 3.3.4 as follows:

$$(Q_{T3})_i = \frac{(\frac{\Delta V}{t})_i + (\frac{\Delta V}{t})_{i+1}}{2} + (Q_e)_{i+1} + Q_{HMT} \tag{3.3.4}$$

where:

$(Q_{T3})_i$ = Flow rate through pipe T3 (L/s) at time i
$(\Delta V/t)_i$ = Average rate of change in ret. basin volume (L/s) between times i and i-1
$(Q_e)_{i+1}$ = Estimated effluent flow rate (L/s) at time i+1
Q_{HMT} = Estimated flow through the HMT (L/s)

Since the HMT remains full during the runoff event, the full HMT flow rate of 10 L/s was used in these calculations.

Selection of an effluent flow rate for solving Equation 3.3.4 was not a straightforward process because the calculated effluent flow rate is based on the influent flow rate. Fortunately, the effluent flow rate was much less than the influent flow rate during these events; therefore, an exact measure of the effluent flow rate was not necessary to estimate the influent flow rate. For example, the effluent flow rate usually was between 1 and 10 L/s when the influent flow rate exceeded the capacity of weir. Frequently, the influent flow rate was greater than 100 L/s during these intervals. The flow rate through the vertical filter is a direct function of the water depth in the detention pond; therefore, the effluent flow rate was estimated by relating the water depth in the detention basin at the time(s) of excessive inflow to the effluent flow rate at that time.

The effluent flow estimates used to calculate the influent flow rate through T3 were obtained in two ways. The effluent drainage curve for the detention basin was used when possible. The water level in the detention basin was rising at the times that the influent flow rates were desired. When the water depth in the pond was falling and the influent flow rate was known, an effluent flow estimate was calculated directly from the influent flow rate and the rate of change in the volume of the detention basin.

On the other hand, if the pond depth for which the effluent flow rate was desired did not occur at a time when the influent flow rate was known, the effluent flow rate was not obtained directly. Instead, the effluent flow rate was estimated by using the drainage curve from a different storm and selecting the effluent flow rate at the desired depth in the basin. The drainage characteristics of control "N" did not vary over the course of the monitoring program; therefore, the use of the drainage curve from one storm to estimate the effluent flow rate from another was reasonable. The drainage curve from the preceding or following storm was used whenever possible to minimize the error introduced by variations in the drainage behavior of the filter from storm to storm.

A comparison of the total runoff and total rainfall measured at the site for each storm are presented in Table 3.2. The total runoff is the sum of the influent flow through

Table 3.2 Measured Rainfall and Runoff at Control "N"

Date	Rainfall (mm)	Rainfall (m^3)	Runoff (m^3)	Runoff Coefficient
1/12/95	5.6	118	104	0.88
2/24/95	28.4	601	551	0.92
2/25/95	14.0	295	259	0.88
3/7/95	12.4	263	237	0.90
3/13/95	38.1	805	796	0.99
4/4/95	21.1	445	436	0.98
4/18/95	8.4	177	140	0.79
4/19/95	16.0	338	310	0.92
4/22/95	7.1	150	144	0.96
5/18/95	13.7	290	254	0.88
			Average	0.91

pipe T3 and the flow from the HMT. The results indicate that the runoff calculated by the procedure described above is reasonable. The total measured runoff compares favorably with the volume of rainfall measured. The satisfactory estimate of the influent flow may be the result of: 1) a small effluent flow rate and HMT flow rate compared to the influent flow rate during the time(s) when the influent exceeded the capacity of the weir, and 2) the measured change in depth in the detention basin reflected high influent flow rates.

Calculation of the Effluent Flow

Estimated effluent flow was based on the calculated and measured flow rates through pipe T3, an assumed HMT flow rate, and the measured change in the volume of the detention basin. Rearranging Equation 3.3.1 gives the basic equation for calculating the effluent flow:

$$(Q_{eff})_i = -(\frac{\Delta V}{\Delta t})_i + (Q_{T3})_{i-1} + (Q_{HMT})_i \qquad (3.3.5)$$

The influent flow rate at time i-1 was used in Equation 3.3.5 to calculate the effluent flow at time i to account for the time of travel of the runoff through pipe T3. The flow rate through the HMT was determined using the convention presented earlier with no flow during the filling of the HMT, a flow rate of 10 L/s whenever the flow rate exceeded 1 L/s through T3, and a flow rate of 5.4 L/s during the drainage of the detention basin for three hours after the runoff event. Equation 3.3.5 was applicable whenever there was no bypass of the detention basin.

Estimation of Bypass

Runoff can bypass the detention basin during large storms. Bypass flow rates were not taken. Therefore, the bypass flow was estimated. The system is designed so that bypass does not occur until the detention pond is full, after which time the bypass flow rate equals the influent flow rate minus the maximum effluent flow rate. The maximum effluent flow rate is equal to the flow rate through the filter when the water depth within the detention pond is 1 m. This calculated flow rate is approximately 50 L/s (Equation 3.3.5). On occasion bypass would occur even when the detention pond was not full, because the capacity of the pipe leading into control "N" from manhole #2 was exceeded. In such cases the bypass flow rates could not be estimated, and it was assumed that the bypass was insignificant compared to the total runoff through pipe T3. The detention basin depth exceeded 1 m only during the event on 2/24/95; therefore, the bypass was calculated for only one runoff event using this procedure.

Samples were collected with ISCO 3700 automatic samplers containing 24 350-mL bottles. Two liters of runoff were required to perform all of the laboratory analyses; therefore, each sampler was divided into four sets of 6 bottles with a capacity of 2.1 liters. The samplers were programmed to collect composite samples in order to collect samples for a wide size range of storms. Each sample set consisted of a series of smaller samples collected at specified intervals.

Influent samples of 175 mL were collected at 40 m^3 flow intervals. Each sample set consisted of two of these samples. The sampler was programmed to collect the first sample once runoff began flowing through pipe T3. A 175-mL aliquot of runoff was placed into each of the first six bottles. Additional 175-mL aliquots of runoff were placed consecutively in the four bottle sets for each 40 m^3 of runoff. This type of sampling scheme is referred to in the ISCO literature as multiplexed sampling, which means one sample is placed in several bottles and each sample set consists of more than one sample. A maximum of eight samples–or four sample sets–could be collected, although for most of the storms less than four sets were collected.

Effluent samples were collected at timed intervals. Since the effluent flow rate and the rate of change of constituent concentration in the detention basin are at a maximum right after the runoff event and taper off thereafter, a timed sampling scheme was used to collect samples at frequent time intervals during and right after the runoff event followed by less frequent sampling later. Samples were collected at 20 minute intervals for the first 1.5 hours of the sampling interval and at 30 minute intervals thereafter. Each of the four sample sets was divided into four 85-mL aliquots for a total of 16 effluent samples. Once the effluent sampler was initiated, samples were collected for the specific time period. The effluent sampler was initiated once the water depth in the detention pond reached 0.4 meters.

On two occasions (2/25/95 and 4/4/95) the samplers did not function properly and composite samples were not collected. In both cases discrete samples were collected instead of composite samples, and the mass balance calculations were adjusted to account for the different sampling procedure.

Discrete samples also were collected within the detention pond for several storms. These samples were collected manually next to the rock gabions. The samples were collected for up to three hours after the runoff event ended so that the change in constituent concentration with time within the detention pond could be measured. On several occasions discrete effluent samples were collected at the same time as the detention pond samples which allowed for direct comparison of constituent concentrations upstream and downstream of the filter. These pairs of discrete pond and effluent samples are referred to as coupled samples.

The parameters measured are listed in Table 3.3. The analytical method used and the holding times for the samples also are included in this table. All samples were retrieved within 24 hours and most were retrieved within 12 hours after the runoff event. In some cases the samples were not recovered in the required time to allow for the analysis of all constituents. For example, many samples were not retrieved within the six hours required for performing bacteriological analysis.

Table 3.3 Summary of Sample Analysis Methods and Holding Times

Constituent	Method Description	Method Number	Holding Time
TSS	TSS Dried at 103 - 105 _C	SM[1] 2540(D)	7 days
VSS	Solids Ignited at 500 _C	SM 2540(E)	7 days
COD	Closed Reflux, Colorimetric Method	SM 5220(D)	28 days
BOD	5-Day Test	SM 5210(B)	2 days
Nitrate	Nitrate Electrode Method	SM 4500-NO_3^-	7 days
Oil and Grease	Spectrophotometric, Infrared	EPA[2] 413.2	6 months
Total Carbon	Combustion In-frared	SM 5310(B)	28 days
Metals	Inductively Coupled Plasma Method	SM 3500	6 months
Bacteriological	Membrane Filter Techniques	SM 9222	6 hours

1 - "SM" refers to *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992).
2 - "EPA" refers to *Methods for Chemical Analysis of Water and Wastes* (USEPA, 1979).

A mass balance was performed on control "N" to determine removal efficiencies of constituents in highway runoff. This effort involved calculating the influent and effluent loads for each of the constituents for the ten runoff events which were monitored. The basic equation used for calculating mass loadings in the influent is:

$$W_T = \sum_{i=1}^{n} (V_{HMT} + V_{T3})_i C_i \qquad (3.3.6)$$

where:

W_T = Total load of a given constituent (g)
C_i = Constituent concentration for sample i (mg/L)
$(V_{T3})_i$ = Flow through T3 associated with sample i (m^3)

$(V_{HMT})_i$ = Flow through the HMT associated with sample i (m^3)

n = Number of samples collected

The flow associated with each sample included the flow through the HMT plus the flow through pipe T3, which was obtained by using the runoff hydrographs. The area under the curve associated with the time when a sample set was collected was calculated. A sample hydrograph is presented in Figure 3.12, which shows the influent hydrograph and the time corresponding to each sample set for the storm on 2/25/95. The HMT flow was obtained by multiplying the full HMT flow rate (10 L/s) by the length of time over which the sample was collected.

The equation for calculating the effluent load, W_{eff}, is:

$$W_{eff} = \sum_{i=1}^{n}(V_i C_i)_{eff} + W_B \tag{3.3.7}$$

The first term in Equation 3.3.7 is the effluent load that passed through the vertical filter. The flow through the filter, Q_i, associated with each sample, C_i, was calculated similarly to the calculation of the influent flow by integrating the basin drainage curve over the time that the sample was collected. The second term, W_B, corresponds to the load which bypasses the system completely, and is the product of the influent concentration at the time of bypass and the volume of bypass.

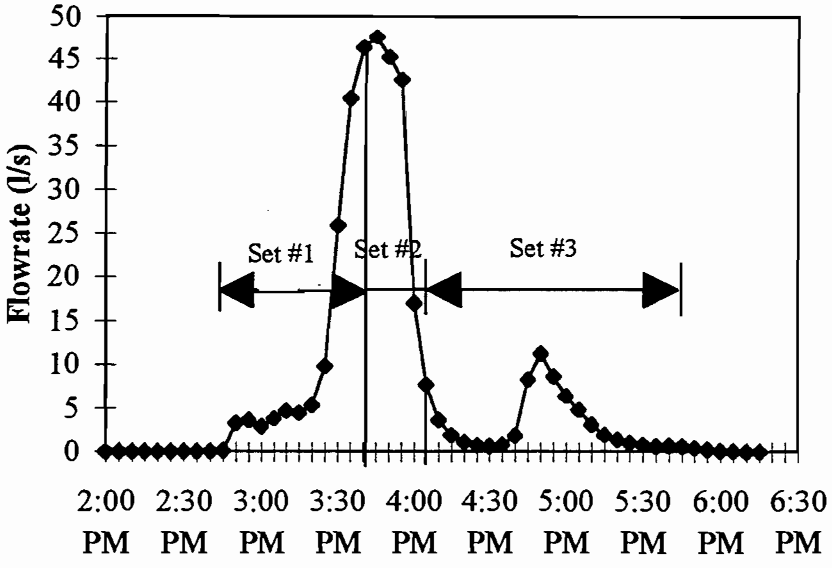

Figure 3.12 Influent Runoff Hydrograph with Sample Collection Intervals.

Another mass balance calculation was performed to compare the mass removed by filtration to the mass removed by sedimentation. The mass removed by sedimentation in the detention basin was estimated based on the concentrations in the samples collected in the basin. Samples were collected for three storm events. The samples were collected only during a portion of the drainage period of the detention pond; therefore, mass balance calculations were made for only that portion of the time. The mass removed by sedimentation was obtained by subtracting from the total mass in the detention basin at the beginning of the interval the mass that exited the basin through the filter and the mass remaining at the end of the interval. The equation is:

$$W_{sed} = (C_R)_1 V_1 - \sum_{i=1}^{n} (C_R)_i V_i - (C_R)_n V_n \qquad (3.3.8)$$

where:

W_{sed} = The mass of a given constituent settled out (g)

$(C_R)_i$ = Constituent concentration within the detention basin at time i (mg/L)

V_i = Volume of runoff in the detention basin at time i (m^3)

Q_i = Flow from the detention basin between time i and i-1

$(C_R)_n V_n$ = Mass remaining in the basin at the time of the last sample

The calculation was performed over each five minute interval between the first and last basin sample (collected at time n). The concentration within the detention basin for each of these intervals was obtained by linear extrapolation between the measured samples. For a given storm only four or five discrete samples were collected. The flow from the detention basin was obtained from the effluent flow calculations described earlier.

The mass filtered during the same interval was calculated by subtracting the effluent load through the filter from the mass that exited the basin. The effluent load was obtained by solving Equation 3.3.5 for the time interval over which the basin samples were collected, and the mass that exited the basin was obtained from Equation 3.3.8.

3.3.2 Results

Analysis of the influent and effluent loads of control “N” shows the overall ability of the system to reduce loads of constituents from the highway runoff. Summary information for each of the ten storms sampled between 1/12/95 and 4/22/95 are provided in Table 3.4. The table includes the calculated volume of runoff at the influent and effluent of control “N”. The influent runoff is the sum of the flow through the HMT and pipe T3 and the effluent runoff is that discharged through the vertical filter plus any bypass flow. In most cases the calculated influent and effluent flows were nearly the same. Differences in influent and effluent flow measurements can be attributed to errors associated with measuring the depth collected in the detention pond and at the influent weir as well as errors associated with assumptions about the HMT flow rate, bypass flow and the effluent flow rate.

Mass loadings are shown for several constituents. Some of the constituents were not measured for many of the storms or were usually below the detection limit; therefore, those constituents were not listed. For example, nickel, cadmium, and chromium were less than the detection limit for all but a handful of the samples. Oil and grease concentrations were usually less than 2.0 mg/L. Mass loadings for oil and grease are provided only for the events on 3/13/95 and 5/18/95. Blanks listed in the table indicate that loads were not calculated for that constituent and that event. The loadings are reported for the main components of the influent and effluent and as total loads. The percent reduction listed in the table is the total reduction in load between the influent runoff and the runoff discharged into Danz Creek. In many cases a negative value is reported for the percent reduction, indicating that an increase in the constituent was measured between the influent to and effluent from the system.

The results for the ten individual storms were combined to give the overall performance of control "N". The sum of the influent and effluent loads to the control during the monitoring period is shown in Table 3.5. The loads are presented as mass of constituent per drainage area of highway. When evaluating the effectiveness of the structure as a water quality enhancement device, the overall, long-term performance is important; therefore, the results presented in the table more accurately define the effectiveness of the structure than do the results observed for individual storms. However, the individual storm data provide information about the operation of the system and the important processes involved.

Discrete samples were collected at the same time in the detention basin and from the effluent of the filter during three of the storms. These samples allow a direct comparison between constituent concentrations just prior to and just after passing through the filter and they indicate the effectiveness of the filter as a pollutant removal device. The coupled samples, including the date and time collected and the concentration of several constituents, are listed in Table 3.6. Little or no change in concentration between

Table 3.4 Mass Balance Results for Control "N" for Each of the Ten Storms

1/12/95
Measured Influent Runoff : 104 m^3
Measured Effluent Flow : 102 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent Reduction
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	
TSS	2016	1728	2668	NA	3744	2668	29
VSS				NA			
COD				NA			
Total Carbon	974	835	2447	NA	1809	2447	-35
Diss. T Carbon				NA			
Nitrate	14.6	12.5	42	NA	27.1	42	-55
T. Phosphorus				NA			
Oil & Grease				NA			
Zinc	12.8	15	2.8	NA	27.8	2.8	90
Lead				NA			
Iron	65	56	91	NA	121	91	25
Copper	0.22	0.19	0.24	NA	0.41	0.24	41
Total Metals	78	71	94	NA	149	94	37

2/24/95
Measured Influent Runoff : 554 m^3
Measured Effluent Flow : 557 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent Reduction
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	
TSS	17496	72367	22593	1836	89863	24429	73
VSS	992	6943	2778	184	7935	2962	63
COD	3140	8966	10182	826	12106	11008	9
Total Carbon	1562	4106	7608	344	5668	7952	-40
Diss. T Carbon	158	616	984	124	774	1108	-43
Nitrate	53	155	294	28	208	322	-55
T. Phosphorus							
Oil & Grease							
Zinc	3.1	11.2	8.6	0.7	14.3	9.3	35
Lead							
Iron	405	1695	1390	109	2100	1499	29
Copper	1.01	4.4	4.18	0.23	5.41	4.41	18
Total Metals	409	1711	1403	0.23	2120	1513	29

Table 3.4 (Continued)

2/25/95
Measured Influent Runoff : 257 m^3
Measured Effluent Flow : 239 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	Reduction
TSS	10776	6426	4778	NA	17202	4778	72
VSS	1320	940	395	NA	2260	395	83
COD	1698	1301	2542	NA	2999	2542	15
Total Carbon	874	584	2065	NA	1458	2065	-42
Diss. T Carbon	228	214	601	NA	442	601	-36
Nitrate	40.9	30.4	54.3	NA	71.3	54.3	24
T. Phosphorus				NA			
Oil & Grease				NA			
Zinc	2.41	1.83	4.33	NA	4.24	4.33	-2
Lead	2.75	2.19	4.02	NA	4.94	4.02	19
Iron	178	127	273	NA	305	273	10
Copper	1.96	1.59	1.35	NA	3.55	1.35	62
Total Metals	185	133	283	NA	318	283	11

3/7/95
Measured Influent Runoff : 237 m^3
Measured Effluent Flow : 242 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	Reduction
TSS	5252	7061	14162	NA	12313	14162	-15
VSS	1616	2173	6258	NA	3789	6258	-65
COD	1919	2581	4637	NA	4500	4637	-3
Total Carbon	404	543	3097	NA	947	3097	-227
Diss. T Carbon	465	625	968	NA	1090	968	11
Nitrate				NA			
T. Phosphorus				NA			
Oil & Grease				NA			
Zinc	1.41	1.9	3.58	NA	3.31	3.58	-8
Lead	1.41	1.9	4.4	NA	3.31	4.4	-33
Iron	171	229	406	NA	400	406	-1
Copper	1.4	1.9	3.28	NA	3.3	3.28	1
Total Metals	175	235	417	NA	410	417	-2

Table 3.4 (Continued)

3/13/95
Measured Influent Runoff : 796 m^3
Measured Effluent Flow : 802 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	Reduction
TSS	27612	102334	42831	NA	129946	42831	67
VSS	1704	6336	8288	NA	8040	8288	-3
COD	1611	6604	10133	NA	8215	10133	-23
Total Carbon	395	1553	4346	NA	1948	4346	-123
Diss. T Carbon	153	643	2591	NA	796	2591	-226
Nitrate	17.4	74.6	125.8	NA			
T. Phosphorus				NA			
Oil & Grease	1016	109	1148	NA	1125	1148	-2
Zinc	1.42	6.71	7.91	NA	8.13	7.91	3
Lead				NA			
Iron	130	603	985	NA	733	985	-34
Copper	1.24	4.61	2.58	NA	5.85	2.58	56
Total Metals	133	614	995	NA	747	995	-33

4/4/95
Measured Influent Runoff : 436 m^3
Measured Effluent Flow : 458 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	Reduction
TSS	3004	7194	16933	NA	10198	16933	-66
VSS	2696	6509	1043	NA	9205	1043	89
COD	398	970	5658	NA	1368	5658	-314
Total Carbon	310	779	2861	NA	1089	2861	-163
Diss. T Carbon	122	314	1023	NA	436	1023	-135
Nitrate	7	16	50	NA	23	50	-117
T. Phosphorus	3	6.6	27	NA	9.6	27	-181
Oil & Grease				NA			
Zinc				NA			
Lead				NA			
Iron	60	148	392	NA	208	392	-88
Copper	0.7	1.9	1.1	NA	2.6	1.1	58
Total Metals	61	150	393	NA	211	393	-87

Table 3.4 (Continued)

4/18/95

Measured Influent Runoff : 143 m^3
Measured Effluent Flow : 166 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	Reduction
TSS	3312	1723	1691	NA	5035	1691	66
VSS	1472	766	780	NA	2238	780	65
COD	3312	1723	4428	NA	5035	4428	12
Total Carbon	957	498	2208	NA	1455	2208	-52
Diss. T Carbon	92	48	893	NA	140	893	-538
Nitrate	32.2	16.8	81.4	NA	49	81.4	-66
T. Phosphorus	12.9	6.7	19.3	NA	19.6	19.3	2
Oil & Grease				NA			
Zinc	0.034	0.067	0.886	NA	0.101	0.886	-777
Lead				NA			
Iron	33	65	53	NA	98	53	46
Copper				NA			
Total Metals	33	65	54	NA	98	54	45

4/19/95

Measured Influent Runoff : 311 m^3
Measured Effluent Flow : 347 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	Reduction
TSS	5456	13203	12002	NA	18659	12002	36
VSS	2040	4927	5447	NA	6967	5447	22
COD	2924	7118	8825	NA	10042	8825	12
Total Carbon	988	2460	3711	NA	3448	3711	-8
Diss. T Carbon	257	222	1684	NA	479	1684	-252
Nitrate	9.8	24.4	60.1	NA	34.2	60.1	-76
T. Phosphorus	10.3	25.1	24.9	NA	35.4	24.9	30
Oil & Grease				NA			
Zinc	1.28	3.08	0.69	NA	4.36	0.69	84
Lead				NA			
Iron	122	308	153	NA	430	153	64
Copper	0.34	0.84	0.85	NA	1.18	0.85	28
Total Metals	124	312	155	NA	436	155	65

Table 3.4 (Continued)

4/22/95
Measured Influent Runoff : 144 m^3
Measured Effluent Flow : 148 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent Reduction
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	
TSS	8624	7539	4118	NA	16163	4118	75
VSS	1848	1615	2036	NA	3463	2036	41
COD	3311	2894	5350	NA	6205	5350	14
Total Carbon	1247	1090	2684	NA	2337	2684	-15
Diss. T Carbon	77	67	1064	NA	144	1064	-639
Nitrate	81	71	155	NA	152	155	-2
T. Phosphorus			10	NA		10	
Oil & Grease				NA			
Zinc	1.46	1.28	0.41	NA	2.74	0.41	85
Lead				NA			
Iron	148	130	126	NA	278	126	55
Copper	0.23	0.2	0.29	NA	0.43	0.29	33
Total Metals	150	131	127	NA	281	127	55

5/18/95
Measured Influent Runoff : 254 m^3
Measured Effluent Flow : 286 m^3

Constituent	Influent Loads (g)		Effluent Loads (g)		Total Loads (g)		Percent Reduction
	HMT	Pipe T3	Filter	Bypass	Influent	Effluent	
TSS	23612	10880	10646	NA	34492	10646	69
VSS	3472	1600	2036	NA	5072	2036	60
COD	8334	3840	9243	NA	12174	9243	24
Total Carbon	2309	1064	3441	NA	3373	3441	-2
Diss. T Carbon	1319	608	2639	NA	1927	2639	-37
Nitrate							
T. Phosphorus							
Oil & Grease	380	120	257	NA	500	257	49
Zinc							
Lead							
Iron							
Copper							
Total Metals							

Table 3.5 Overall Performance of Control "N" for Ten Storms

Constituent	Units	Mass Loads[1] Influent Runoff	Effluent Discharge	Percent Mass Reduction
TSS	g/m^2	16.0	6.4	60
VSS	g/m^2	2.32	1.4	39
BOD[2]	g/m^2	0.048	0.038	26
COD	g/m^2	2.96	2.9	1
Total Carbon	g/m^2	1.11	1.65	-48
Diss. T Carbon	g/m^2	0.29	0.59	-101
Nitrate	mg/m^2	31.2	42.4	-36
Oil and Grease[2]	mg/m^2	47	39	17.7
Chromium[2]	mg/m^2	0.10	0.13	-28
Zinc	mg/m^2	2.70	1.01	63
Iron	mg/m^2	183	140	23
Copper	mg/m^2	0.81	0.57	32

1 - results based on 151 mm rainfall.

2 - based on a subset of the data.

Table 3.6 Summary of Coupled Basin and Effluent Samples Collected at Control "N"

Sample Number	Date	Time	Constituent Concentration (mg/L) TSS	COD	Nitrate	Total Carbon	Dissolved Total Carbon	Total Phosphorus	Iron	Copper	Zinc
1: Basin	2/24/95	14:45	68	19	0.62	7.5	2		2.84	0.006	0.02
Effluent			52	22	0.53	26.8	2.7		3.691	0.01	0.019
2: Basin	2/24/95	15:15	48	17	0.63	4.1	1.3		2.224	0.007	0.019
Effluent			48	16	0.62	5.4	1		2.206	0.003	0.014
3: Basin	2/24/95	15:45	40	12	0.62	4.7	1		2.228	0.006	0.019
Effluent			40	18	0.6	7.5	2.7		2.373	0.005	0.016
4: Basin	2/24/95	16:30	32	10	0.66	5.4	1.3		1.804	0.009	0.026
Effluent			36	16	0.65	6.8	1		1.803	0.017	0.017
5: Basin	2/24/95		24	19	0.66	4.1	2.7		1.605	0.006	0.022
Effluent				25	0.6	3.4	1		1.436	0.006	0.015
6: Basin	4/19/95	12:00	96	26	0.21	7.9	4.1	0.08			
Effluent			36	19	0.19	8.5	2.2	0.08			
7: Basin	4/19/95	12:50	36	22	0.19	7.9	2.8	0.07	0.746	0.002	0.009
Effluent			0	23	0.17	13	4.7	0.07	0.672	0.003	0.002
8: Basin	4/19/95	13:50	28	24	0.17	9.8	5.3	0.07			
Effluent			12	27	0.17	7.2	5.3	0.06			
9: Basin	4/19/95	18:30	16	21	0.19	7.9	5.3	0.08	0.439	<0.002	<0.0007
Effluent			12	17	0.17	7.9	6.5	0.04	0.502	<0.002	<0.0007
10: Basin	4/22/95	17:30	32								
Effluent			28								

many of the basin and effluent samples was observed. These data indicate that little removal of these constituents occurred during filtration. However, there was a noticeable reduction in concentration for some of coupled samples. For example, the basin TSS for the 6th coupled sample was 96 mg/L whereas the effluent for the same sample was 36 mg/L, which corresponds to a 63% reduction in TSS concentration. The concentration of nutrients and metals were also similar between the coupled samples.

Several samples were collected from the detention basin after the events on 2/24/95, 4/4/95 and 4/19/95. These samples were collected to measure the change in concentration of constituents in runoff with time in the basin. An example of the change in TSS concentration within the detention basin is shown in Figure 3.13, which is a plot of the measured TSS versus time for the storm on 2/24/95. The TSS concentration within the detention basin dropped nearly 65% during the three-hour time span shown in the figure. This removal was due to sedimentation of solids within the basin. An estimate of the mass settled within the detention pond versus that removed by filtration was made for these events, and the results are summarized in Table 3.7. These results are based only on the time over which detention basin samples were collected and they do not represent the total mass loads for the events. However, these data provide a convenient comparison of the extent to which filtration and sedimentation play a role in solids removal. In each case the removal by sedimentation was greater than the removal by filtration, indicating that sedimentation is the more important solids removal mechanism.

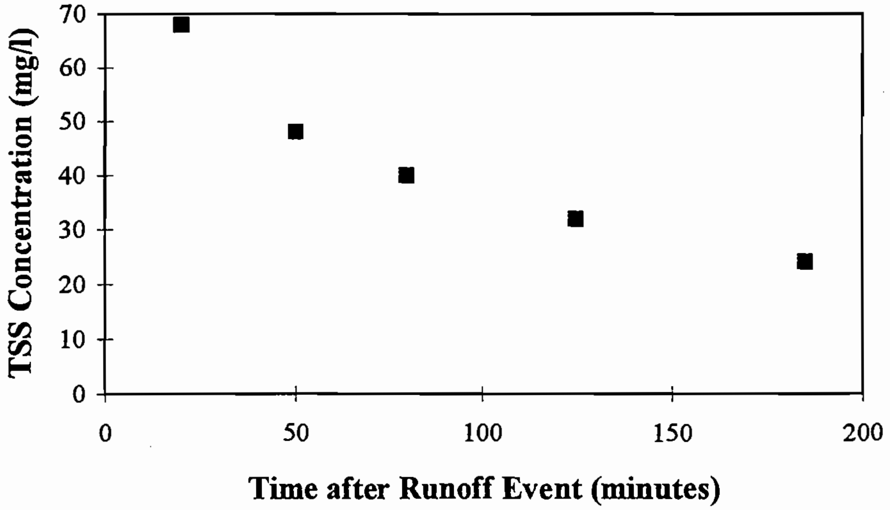

Figure 3.13 Changes in TSS Concentration Within the Retention Basin.

Table 3.7 **Comparison of Filtered and Settled TSS for Three Storms**

Date	Initial TSS in the Basin (kg)	Final TSS in the Basin (kg)	TSS Load to Filter (kg)	Effluent TSS from Filter (kg)		TSS Filtered (kg)	TSS Settled (kg)
2/24/95	14.4	0.4	11.8	11.3		0.4	2.3
4/4/95	14.4	0.2	8.2	4.4		3.8	6
4/19/95	24	0.6	14.1	10		4	9.3
					Total:	8.2	17.6

3.3.3 Discussion

The purpose of the control structures evaluated in this study is the reduction of the load of constituents in highway runoff into receiving waters. The effectiveness of one of these structures, control "N", was monitored in detail. Removal efficiencies for control "N" were quantified Control "N" was modified prior to this monitoring program and is unlike most of the other controls; therefore, the results obtained for this system cannot be used directly to demonstrate the effectiveness of the other control structures. However, much that was learned observing the performance of control "N" is applicable to the other controls and to runoff filtration systems in general.

The removal efficiencies reported for control "N" are typical for storm water treatment facilities. A wide range of removal efficiencies are reported in the literature for several kinds of controls. In general, control "N" did not perform as well as sand filtration systems and performed as well as dry detention ponds. The removal efficiency for TSS of 59% is below values reported for other sand filters. The City of Austin has reported removal efficiencies of 70 to 87% for sand filters (City of Austin, 1990). The use of gravel instead of sand as a filtration medium reduces the effectiveness of the filter and reduces the time in the detention structure which acts as a sedimentation basin; therefore, the gravel filtration system would not be expected to perform as well as a properly operated sand filter. A wide range of TSS removal efficiences are reported for dry detention ponds. The city of Austin reports a TSS removal efficiency of 16% for one dry detention pond, and Schueler et al. (1991) report a range of TSS removal efficiencies between 30% and 70% for dry detention ponds. The performance of control "N" falls within this reported range.

Control "N" was less effective for other constituents. No removal of COD, an increase in nitrate and a small reduction in metals were observed. The performance of control "N" for these constituents was within the range of performance reported for dry ponds and below the performance level reported for sand filters. The City of Austin has reported removal efficiencies of 34 to 61%, -82 to -26%, and 19 to 86%, for COD, nitrate and trace metals, respectively for sand filters. Reported results for a dry pond were 8%, 43% and -64 to 19% for COD, nitrate and trace metals, respectively. Schueler reported removal efficiencies of 15 - 40% for COD and low or negative removal of nitrate for dry ponds. Removal of metals between 28% and 40% was reported for a scale model of a typical detention basin (Cole and Yonge, 1993). The increase in nitrate, which commonly is reported for storm water treatment structures, is the result of the conversion of organic and ammonia nitrogen into nitrate during the nitrification process. Although total nitrogen was not measured during this experiment, decreased total nitrogen usually was reported in systems where nitrate levels increased.

Negative removal efficiencies were measured for total carbon and dissolved total carbon at control "N". Reported removal efficiencies for total organic carbon are 87% and 18% for filtration systems and dry detention systems, respectively (City of Austin, 1990). The negative removal at control "N" likely was caused by the dense vegetation in the receiving waters downstream of the filter and large quantities of leaves and other organic debris collected in the detention basin. High carbon concentrations at these locations could have been caused by decaying plants and/or algal growth.

Control "N" and dry ponds act as stormwater detention structures which provide removal by sedimentation prior to discharge. The difference is that control "N" has a gravel filter as an effluent control structure instead of a weir or orifice common to dry detention ponds. Some removal was observed for the gravel filter. Whatever removal occurred in the filter could have easily been matched in a dry detention pond with a longer detention time than control "N".

The inferior performance of control "N" compared to sand filters was caused by two factors. First, filtration through a sand filter is more effective than filtration through a grade 5 gravel filter. In many instances, gravel would not be considered as a filtration medium; however, control "N" drained poorly so the gravel was deemed a viable alternative to sand. The second factor for the inferior performance was that the sand filters operated by the City of Austin typically drain in 24 to 48 hours. At these detention times sedimentation of a large fraction of the sediment load occurs in the detention basin.

The replacement of sand with grade 5 gravel resulted in an improvement in the performance of Control "N", although the efficiency was less than that reported for sand filters. Control "N" experienced very slow drainage through the originally installed vertical sand filter. The control structure was essentially non-functional because between 50% and 100% of the detention basin was occupied by accumulated runoff.

Consequently, most runoff bypassed the control system and was discharged directly into Danz creek. After the installation of grade 5 gravel as the filtration media the runoff in the control drained with most of the runoff passing through the system in less than five hours. This performance also is poor because the drainage time was much less than the designed drainage time of 24 to 48 hours specified in the design criteria. However, the results of this monitoring study showed that some removal of constituents of runoff was achieved even with the short detention time. Essentially, with the grade 5 gravel medium a large portion of the runoff was captured and received moderate treatment. Other environmental problems such as the generation of odors and mosquito infestation associated with a stagnant body of water were eliminated once the grade 5 gravel was installed.

The results of this study demonstrated the importance of sedimentation as a removal mechanism for control systems constructed by TxDOT. A large portion of many of the constituents found in runoff are present in the particulate form; therefore, sedimentation can be used as an effective removal mechanism for most constituents. The effectiveness of sedimentation is dependent on the residence time of runoff in the detention basin. Removal efficiencies increase as the runoff is retained for longer periods of time. A large portion of the TSS settled out even in control "N", which drains in less than 10 hours. The effectiveness of sedimentation in this type of system is limited by the dynamics of flow through the filter. The flow through the filter is highest when the basin is full. Unfortunately, the solids concentration is also highest because the time for sedimentation in the basin is short. A large fraction, and in some cases a majority, of the TSS load is discharged during the early stages of the drainage of the basin. This problem is compounded in a system such as control "N" which has a high effluent flow rate. A large reduction in TSS load can be anticipated, if the drainage time of the system is extended to reduce the high initial load discharged from the system.

Increases in sediment load were measured for several storms. These observations indicate that scouring of previously settled solids plays an important role in determining the fate of sediments in the runoff. Further evidence of sediment resuspension was also observed in the field. Little sediment accumulated in the detention basin in front of the influent pipe while approximately 1 cm of sediment was visible in most other parts of the basin. The lack of sediment in front of the influent pipe indicates that solids which do settle were resuspended by the influent runoff during subsequent events.

Two problems are associated with the resuspension of solids. TSS and other constituents associated with the solid matrix, may be transported through the filter leading to unnecessarily high loads discharged from the filter. Also, resuspended solids that are transported to and captured in the filter will lead to premature clogging of the filter increasing maintenance requirements and associated costs.

The capture volume of control "N" with the gravel media in place was much greater than the design storage capacity. The design capacity was calculated simply by multiplying the design storm, in this case 1.27 cm of rainfall, by the drainage area of the control. The effluent flow during the runoff event was assumed to be negligible; therefore, the volume of the detention basin was sized equal to the design storage volume. The assumption did not hold once the gravel media was installed. The effluent flow rate through the gravel was high enough that a significant portion of the total runoff passed through the gravel during the runoff event, and a much larger volume of runoff was captured than just the storage capacity of the detention basin.

The actual volume captured was the sum of the volume of the detention basin, the flow through the filter during the runoff event and the volume of the HMT. For example, if the average flow through the detention basin was 30 L/s, which is not unreasonable for a storm lasting 30 minutes, then 54 m^3 of runoff would have passed through the gravel filter during the storm. Therefore, with the volume of the HMT (56 m^3), the total capture is 110 m^3 greater than the design storage volume of the detention basin. This capture represents a 44% increase over the design storage capacity of 250 m^3. In some cases the actual volume captured and treated was over 100% greater than the design capacity of system.

The preceding example illustrated one benefit of using a filtration media such as grade 5 gravel which provides rapid drainage of the detention basin. The volume of runoff that can be treated for a given size detention basin increases as the drainage rate through the filter increases. However, with the reduced residence time in the detention basin and the reduced filtration capacity, the removal efficiency of the structure decreases with increased drainage rates. The overall effectiveness of the control structure is the product of the captured runoff volume and the removal efficiency for that captured runoff; therefore, there is a tradeoff between these variables for different drainage rates. Increasing the drainage time to between 24 and 48 hours would provide better removal of sediments than the current drainage time of 10 hours.

The overall performance of the control was presented in Table 3.5 along with the mass loadings for each of the ten storms. A high degree of variability was observed in the performance of the system as demonstrated by the removal efficiency of TSS which ranged from -66% for the storm on 4/4/95 to 75% on 4/22/95. This variability from storm to storm was expected because of the variability associated with the characteristics and flow rate of runoff entering it. The rainfall intensity, rainfall volume, concentration of constituents, and particle size distribution are factors that can vary between storms. High intensity storms can lead to the resuspension of large quantities of solids and the transport of more suspended solids to the detention basin. The amount of bypass around the system is dependent on the rainfall intensity and total volume. The constituents of the runoff and the particle size distribution will vary and affect the system performance.

3.3.4 Recommendations

The importance of sedimentation as a removal mechanism was demonstrated during this study. At the present time there is no proven method for effectively installing and operating a vertical sand filter in the structures installed by TxDOT. Efforts to modify the control structures along the southern extension of MoPac and SH 45 have focused on improving the hydraulic performance of the filters. A change in strategy may be called for which focuses on improving the performance of the systems by optimizing the sedimentation of solids within the detention basin. The first step to improve the performance would be installation of an effluent flow control device that provides consistent drainage of the detention basin of between 24 and 48 hours. Some sort of energy dissipater, e.g. baffles or rock gabions, placed within the detention basin near the influent would reduce the resuspension of solids during filling of the basin.

Attempts to optimize sedimentation and minimize resuspension of sediments should be incorporated in new designs as well. Properly designed and constructed sand filters might still be the best management practice for highway runoff treatment in the Austin area. A properly designed sedimentation/detention basin compliments the sand filter because the sediment load reduction in the basin lessens the load onto the filter which increases the life of the filter. Horizontally bedded filters have been constructed and operated effectively elsewhere and should be considered as the preferred filter configuration.

Several of the controls within the study area drained adequately with vertical sand filters installed. The reasons for the improved drainage is unknown. The filters in these controls may not function as water quality enhancement devices if channeling around the filters occurs; however, these systems may provide sufficient residence time for the sedimentation of solids and modifications of the installation may not be required.

4. BENCH-SCALE LABORATORY FILTRATION EXPERIMENTS

4.0 Introduction

Three separate and independent bench-scale filtration experiments were conducted:

1) evaluation of the removal efficiencies of constituents in highway runoff by a sand filter;
2) comparison of the effectiveness in removing runoff constituents by several granular media i.e., Brady sand, concrete aggregate sand. and pea gravel; and
3) evaluation of the filtration capacity of four media; i.e., Brady sand, compost, zeolites, and grade 5 gravel.

4.1 Materials and Methods

The experimental apparatus and procedure were similar and in some cases identical for the three experiments. Any part of the description which pertains to only one or two of the experiments is identified as such.

4.1.1 Experimental Apparatus

The experiments were performed in bench-scale columns. Each column was constructed of acrylic cylinders attached to an acrylic base with silicon glue. A small circular orifice was drilled into the side of the column near the bottom to allow drainage. A tube was attached to the orifice. A flexible hose was connected to the tube to facilitate the collection of effluent samples. Each filter was constructed with a bottom drainage layer, the filtration medium on top of the drainage layer and a top layer of gravel. The top layer of gravel distributed the runoff evenly over the column without mixing of the filtration medium during the application of runoff. Each of the columns were 1.2 meters tall. A 30-cm diameter column was used for the first experiment while 10 cm columns were used in experiments two and three. A schematic of a typical column used in experiments two and three is presented in Figure 4.1.

4.1.2 Runoff

Runoff was collected along MoPac near 35th Street, which is a high traffic highway site located in central Austin, Texas. A description of the site, including an extensive runoff characterization, is available in "An Evaluation of the Factors Affecting

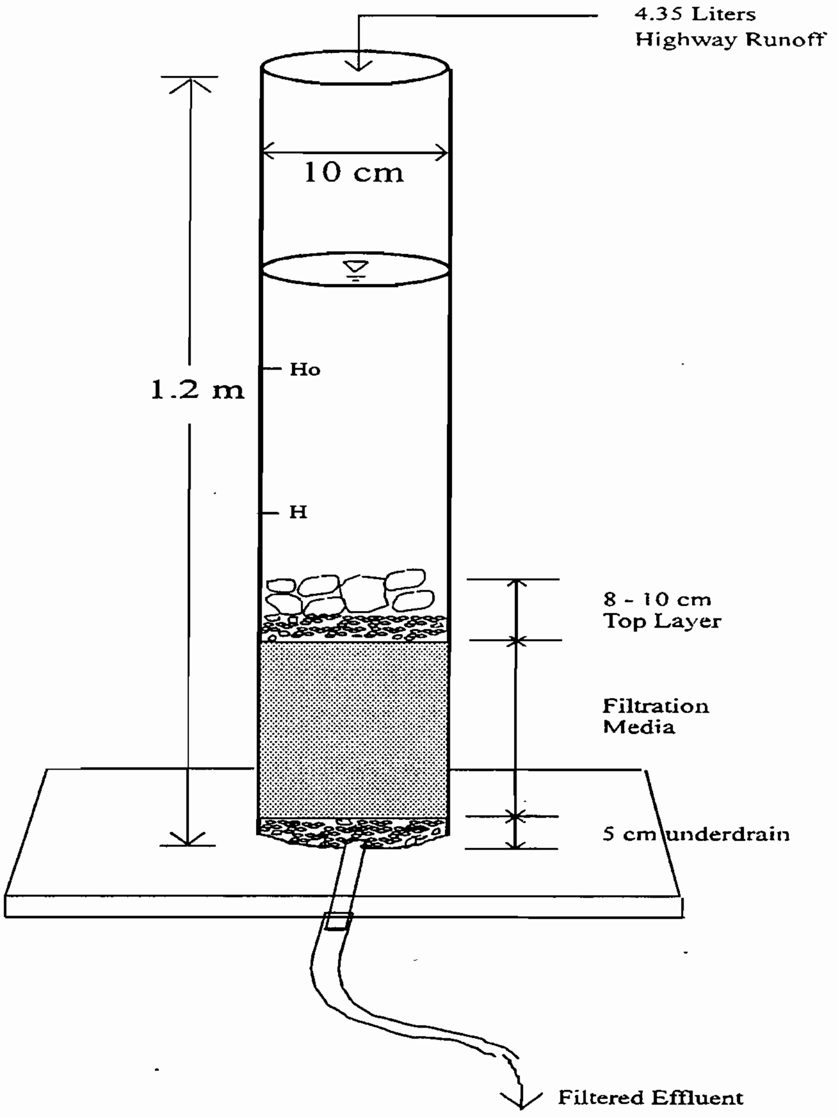

Figure 4.1 Schematic of Column Setup for Filtration Experiments.

the Quality of Highway Runoff in the Austin, Texas Area" (Irish et al., 1995). Runoff was collected during simulated rain events for the first two experiments and during natural rainfall events for the third experiment. A comparison of the median concentration of the runoff used in these experiments with the annual event mean concentrations (EMC's) at the same MoPac site and with values reported in the literature is provided for several constituents in Table 4.1. The runoff used for experiments two and three falls within the range of concentration expected in highway runoff; however, the runoff used in experiment three is somewhat atypical with a very high TSS EMC (>1,000 mg/L).

Table 4.1 Comparison of Median Concentration

Constituent	Experiment Median EMC (mg/L)			MoPac Median EMC (mg/L)	Driscoll et al 1990 Median EMC (mg/L)
	#1	#2	#3		
TSS	1064	104	160	131	142
COD	124	72	165	126	114
Nitrate	0.60	0.28	0.80	1.03	0.76
TOC	28	18	65	55	25
Zinc	0.49	0.14	0.20	0.208	0.329
Lead	0.07	0.15	0.02	0.050	0.4
Iron	6.5	1.7	3.6	2.6	

4.1.3 Granular Media

Several granular media were tested. These include the Brady sand originally installed by TxDOT in the filters along SH 45 and MoPac, a concrete aggregate, pea gravel and grade 5 gravel. The Brady sand is a uniform, medium sized sand with a specification that 80 to 100% of the sand is between 0.05 and 0.10 cm in diameter. The concrete aggregate is a well graded sand with a significant portion of the sand particles outside of the range specified for the Brady sand. This sand is also readily available and inexpensive. The pea gravel media was a large-sized granular media, which typically would be used to support filtration media such as sand. The grade 5 gravel is smaller than pea gravel, but it too was tested because of its high hydraulic conductivity and because it was used by TxDOT as a replacement media in several filters which exhibited poor drainage. A sieve analysis for each of the granular media used in experiments two and three is provided in Appendix C. A sieve analysis was not performed for the sand used in experiment one; however, that sand is similar to the concrete aggregate used in experiment two.

4.1.4 Alternative Media

Two alternative media, those with adsorptive or ion exchange capacity, were tested in the third experiment. Compost, manufactured by CSF Treatment Systems, Inc. in Portland, Oregon was obtained for testing. This material is a low nitrogen, yard debris compost which has been used successfully elsewhere for the treatment of storm water runoff. The compost was washed and wetted prior to installation in the column. The second media tested was zeolites which are naturally occurring clay minerals. Zeolites have been used in water and wastewater applications as adsorptive and cation exchange media. The zeolites were tested alone and in combination with the Brady sand. The zeolites were obtained from Geo-Environmental Services, Inc. in Austin, Texas. The zeolites used in this experiment were a uniform sized granular media with a size range between the Brady sand and the grade 5 gravel.

4.1.5 Procedure

Highway runoff was collected at the MoPac site in 20L containers. The runoff was stored in a cold room in the laboratory at 5° - 10° C for up to one week. The experimental procedure consisted of the following steps:

1) Mix the runoff by pouring into empty container.

2) Collect an initial sample of the mixed runoff.

3) Experiment #1: Fill the column to a predetermined depth, which corresponded to the application of 22 liters of runoff.

   Experiments #2 and #3: Split the remainder of the runoff into 4.35-L aliquots and dose the columns by pouring one aliquot of runoff into each column.

4) Collect the filtered runoff from each column and reserve a portion of the effluent samples for analyses.

5) Record the time for the water level in the column to drop from H_0 to H.

6) Prepare the influent and effluent samples for analysis.

This procedure is referred to as an experimental run. Each of these experiments consisted of several experimental runs. In most cases the samples were analyzed for total suspended and volatile suspended solids, metals, nutrients, COD and organic carbon content. However, on a few occasions only suspended solids measurements were performed. The analytical techniques used in these experiments were summarized in Table 3.3.

A summary of the three experiments, including the media used, runoff source and number of dosages applied to each column, is provided in Table 4.2. Only one column was used in experiment one, while three and five columns were used in experiments two and three, respectively. During experiment two all three columns were dosed each time

Table 4.2 Summary of Methods and Materials for the Three Experiments

Column	Filtration Media	Underdrain Media	Runoff Source	Number of Dosages Applied to Column
Experiment #1				
1	28 cm concrete sand	5 cm pea gravel	simulated	29
Experiment #2				
1	17 cm Brady sand	5 cm pea gravel	simulated	15
2	18 cm concrete agg.	5 cm pea gravel	simulated	15
3	18 cm pea gravel	none	simulated	15
Experiment #3				
1	20 cm Brady sand	5 cm pea gravel	actual	31
2	20 cm compost	5 cm grade 5 gravel	actual	30
3	10 cm sand on top of 10 cm zeolites	5 cm pea gravel	actual	16
4	20 cm zeolites	5 cm pea gravel	actual	4
5	20 cm grade 5 gravel	none	actual	11

that runoff was collected; however, for a number of reasons the columns were dosed sporadically during the third experiment and only the Brady sand was dosed during each experimental run. For example, the column containing only zeolites performed so poorly initially that the testing was terminated.

4.1.6 Calculating Constituent Removal Efficiencies

The procedure for calculating the removal efficiency of the various constituents was the same for each of the experiments. The mass load of the constituents into and out of each of the columns was calculated for each experimental run by multiplying the measured concentration by the volume of runoff applied to the column. The mass loads for each experimental run were added to give the overall mass in the influent and effluent to the columns. The removal efficiencies were calculated from the cumulative mass loads as follows:

$$R = \left(1 - \frac{\sum_{i=1}^{n} (C_{eff})_i V_i}{\sum_{i=1}^{n} (C_{in})_i V_i}\right) \cdot 100 \tag{4.1}$$

where:

R = Overall percent removal
$(C_{eff/inf})_i$ = Measured effluent and influent concentrations for experimental run i (mg/L)
V_i = Volume of runoff applied during experimental run i (L)
n = Total number of experimental runs for that column

Oil and grease data were not obtained for each experimental run in experiment number three; therefore, an adjusted procedure was used to determine the mass loading of oil and grease. If enough runoff volume was collected from MoPac to provide for at least two experimental runs, oil and grease samples were collected for only one of those experimental runs. The data obtained for the one experimental run was then applied to all of the experimental runs performed with that runoff sample. It was assumed that the oil and grease concentration did not vary significantly for the runoff collected at the same site and at the same time and that the behavior of the filter with respect to oil and grease did not vary significantly between consecutive experimental runs.

4.1.7 Calculating the Hydraulic Conductivity

The hydraulic conductivity of the filtration media, K, also was calculated during the experiments. The measured drop in head above the filtration media was used in the equation for a falling head permeameter test (Bear, 1972) as follows:

$$K = \frac{al}{At} \cdot \ln(\frac{H_0}{H}) \tag{4.2}$$

where:

a = Area through which the water falls (cm^2)
A = Area of the filtration media (cm^2)
l = Length of the filtration media (cm)
t = Time for the water level to fall from H_0 to H (sec)

The area through which the water falls and the area of the porous media are equivalent in these experiments. The water levels, H_0 and H, were measured from the bottom of the filtration medium.

4.2 Results

4.2.1 Experiment Number One

The mass balance results for experiment one are summarized in Table 4.3 which includes the average influent concentration, influent load, effluent load and percent removal for several constituents. A total of 22 dosages of runoff were applied to the column; however, only TSS measurements were collected for each application. The other data were collected every 4th or 5th dosage of the column. The mass loadings shown in the table represent the sum of the influent and effluent mass for only the dosages that the given constituent was measured; therefore, the total loads applied to and captured within this column are not known for most of the constituents. The sand performed exceptionally well as a filtration media for the simulated runoff. The concentration data collected during this experiment as well as experiments two and three are presented in Appendix C.

Table 4.3 Mass Balance Results for Experiment One

Constituent	Avg. Influent Conc., mg/l	Influent Load, g	Effluent Load, g	Percent Removal
TSS	1366	649	17	97
VSS	163	77	3	96
BOD	24	5.7	0.8	87
COD	198	38.6	6.0	84
TOC	44	5.7	5.1	11
Nitrate	0.95	0.1	0.7	-379
Total Phos.	0.89	0.2	0.0	86
Oil and Grease	4.79	0.8	0.1	92
Cadmium	0.077	0.003	0.004	-21
Chromium	0.113	0.005	0.003	36
Copper	0.069	0.010	0.003	67
Iron	8.52	1.29	0.08	94
Lead	0.426	0.018	0.017	8
Nickel	0.078	0.002	0.001	54
Zinc	0.788	0.119	0.004	96

The hydraulic conductivity of the sand medium was measured for many of the experimental runs. The results are presented in Figure 4.2. The low values may be attributed to the high loading of TSS into the column which likely caused immediate clogging of the sand, thereby reducing the hydraulic conductivity. The data used for

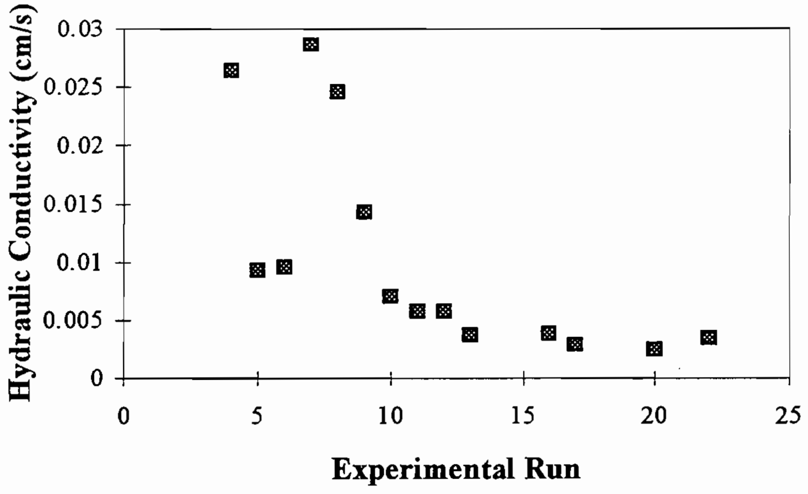

Figure 4.2 Measured Hydraulic Conductivity in Experiment One.

these calculations as well as the calculations themselves are provided in Appendix C for each of the three experiments.

4.2.2 Experiment Number Two

The mass balance results for experiment two are presented in Table 4.4. Each column was dosed during each experimental run; therefore, the same influent mass was applied to each column. All constituents, except nitrate and TOC, were measured for all 15 runs. Nitrate measurements and TOC measurements were collected for only the first five and the first ten experimental runs, respectively. The results indicate that the Brady sand and concrete aggregate sand are comparable filtration media with similar removal efficiencies for all of the constituents. The pea gravel performed very poorly as a filtration medium with negative or near zero removal rates for all constituents.

The measured hydraulic conductivity is shown in Figure 4.3 for the 15 experimental runs. As expected the pea gravel has a much higher hydraulic conductivity than either of the sands, while the concrete aggregate has a higher hydraulic conductivity than the Brady sand throughout the experiment. After decreasing initially, the hydraulic conductivity of the Brady sand and concrete aggregate tended to stabilize during the last 11 experimental runs.

Table 4.4 Mass Balance Results for Experiment Two

	Influent Load, g	Effluent Loads, g			Percent Removal		
		Brady Sand	Concrete Aggregate	Pea Gravel	Brady Sand	Concrete Aggregate	Pea Gravel
TSS	7.8	2.8	3.5	7.1	64	55	9
VSS	1.1	0.4	0.5	0.9	65	56	22
COD	4.2	3.2	3.2	4.3	23	23	-3
TOC	0.8	0.8	0.8	0.8	-7	-4	-5
Nitrate	8.7	8.8	8.8	8.7	-1	-1	0
O&G	0.19	0.12	0.10	0.18	37	44	6
Cd	0.00023	0.00010	0.00011	0.00022	55	53	6
Cr	0.00068	0.00058	0.00042	0.00065	15	39	4
Cu	0.00045	0.00029	0.00019	0.00043	35	59	6
Fe	0.13	0.06	0.06	0.13	56	53	0
Ni	Na	Na	Na	Na			
Pb	0.0029	0.0028	0.0018	0.0027	4	39	6
Zn	0.0091	0.0054	0.0058	0.0094	40	37	-3

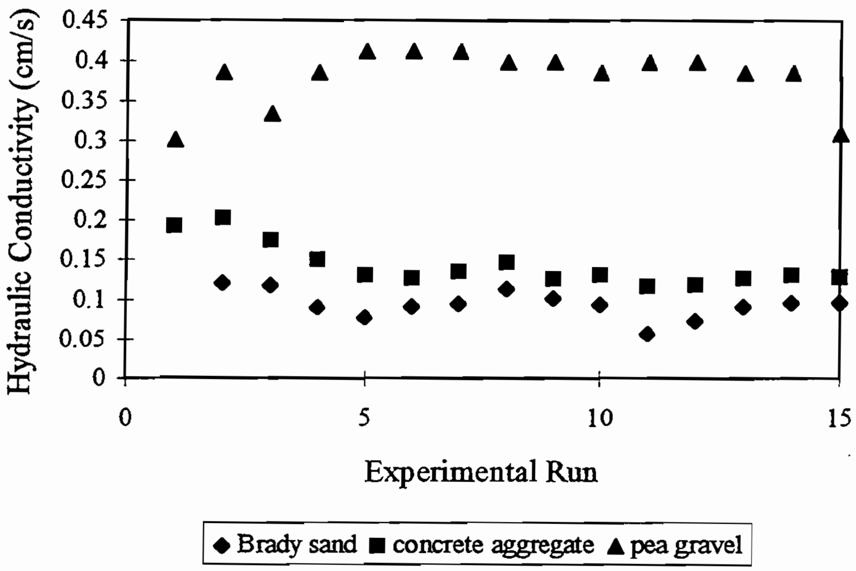

Figure 4.3 Measured Hydraulic Conductivity for Experiment Two.

4.2.3 Experiment Number Three

The mass balance results for the 31 experimental runs performed during experiment number three are presented in Table 4.5. These tables include the influent and effluent mass loads and the percent removal of several constituents for each of the columns. The number of dosages applied to the columns also is included. The Brady sand was dosed during each run. Suspended solids measurements were obtained for all 31 experimental runs; however, measurements for the other constituents were collected only through the 25th run. Furthermore, measurement of total phosphorus and nitrate were collected for only the first 17 runs and the 12th through the 17th runs, respectively. The mass balance results presented in the table are based only on the experimental runs for which data were collected. For example, the mass loads shown for nitrate are the mass loads into and out of the column for the 12th through the 17th experimental runs only. The results presented in the table show that the compost provided the highest constituent removal rates and that zeolites alone and grade 5 gravel provide little filtration.

The results presented in Table 4.5 may be used to compare the performance of the Brady sand and the compost directly; however, only a subset of the data presented in that table can be used to compare the Brady sand with the Brady sand in combination with zeolites. . These two media can be compared by looking at the experimental results only through experimental run 17 which is the last run during which the sand and zeolites were dosed. A summary of the removal efficiencies for the two columns through run 17 is presented in Table 4.6. Not all of the constituents are shown. The data presented in the table were selected because these parameters are most indicative of the performance of the media. The Brady sand alone was generally more effective than the Brady sand in combination with zeolites for the removal of all constituents.

The initial hydraulic conductivity, measured during the first dosage of runoff, for each column is shown in Table 4.7. A much higher hydraulic conductivity was observed for the grade 5 gravel than for the sand, sand in combination with zeolites and the compost. The hydraulic conductivity of the zeolites nearly equals that of the grade 5 gravel. The compost media initially had a hydraulic conductivity which was an order of magnitude less than the Brady sand, indicating that the use of compost as a filtration medium will require a larger filter area.

The hydraulic conductivity was calculated for each experimental run for the Brady sand, the compost and the Brady sand in combination with zeolites, and the results of

Table 4.5 Mass Balance Results for Experiment Three

	Brady Sand 31 Dosages of Runoff			Compost 30 Dosages of Runoff			Brady Sand and Zeolites 16 Dosages of Runoff		
Constituent	Influent Load, g	Effluent Load, g	Percent Removal	Influent Load, g	Effluent Load, g	Percent Removal	Influent Load, g	Effluent Load, g	Percent Removal
TSS	22.7	5.9	74	21.13	3.7	82	7.2	3.9	46
VSS	3.5	1.4	60	3	0.6	80	2.2	0.8	64
COD	20.5	15.6	24	19.0	13.1	31	8.6	5.6	35
Total Carbon	6.3	4.8	24	5.7	5.0	12	3.9	2.8	27
Diss. Tot Carbon	3.2	3.2	0	2.9	4.2	-47	2.1	2.0	1
Nitrate-N	14.2	23.6	-66	14.2	58.9	-314	14.2	52.6	-270
Tot. Phosphorus	18.1	12.0	34	15.3	40	-162	16.4	12.1	26
Oil and Grease	0.55	0.33	40	0.52	0.25	52	0.24	0.19	21
Chromium	0.0006	0.0004	31	0.0005	0.0003	53	0.0003	0.0002	29
Copper	0.0035	0.0023	34	0.0032	0.0014	55	0.0014	0.0013	13
Iron	0.360	0.200	44	0.32	0.10	69	0.15	0.1	33
Lead	0.0021	0.0017	18	0.0018	0.0013	26	0.0012	0.0008	33
Zinc	0.021	0.013	40	0.019	0.005	75	0.0081	0.0039	51
Total Metals	0.387	0.217	44	0.344	0.108	69	0.161	0.106	34

Table 4.5 (Continued)
Mass Balance Results for Experiment Three

Constituent	Grade 5 Gravel 11 Dosages of Runoff Influent Load, g	 Effluent Load, g	 Percent Removal	Zeolites 4 Dosages of Runoff Influent Load, g	 Effluent Load, g	 Percent Removal
TSS	4.4	7.5	-70	3.0	5.1	-70
VSS	1.3	0.8	35	0.9	0.8	13
COD	5.4	4.6	15	3.1	2.4	22
Total Carbon	2.6	2.2	15	1.3	1.1	15
Diss. Tot Carbon	1.4	1.1	17	0.59	0.59	0
Nitrate-N	9.6	11.2	-17	NA	NA	NA
Tot. Phosphorus	7.5	6.4	15	6.1	5.8	5
Oil and Grease	NA	NA	NA	0.07	0.08	-14
Chromium	0.0002	0.0003	-30	0.0001	0.0001	27
Copper	0.0008	0.0009	-18	0.0006	0.0005	16
Iron	0.08	0.1	-25	0.07	0.08	-14
Lead	0.0007	0.0006	25	0.0005	0.0003	41
Zinc	0.0043	0.0058	-36	0.0039	0.0026	32
Total Metals	0.086	0.107	-25	0.075	0.083	-11

Table 4.6 Comparison of Brady Sand and Brady Sand in Combination with Zeolites

Constituent	Percent Mass Removal	
	Brady Sand	Brady Sand with Zeolites
TSS	75	46
COD	38	35
Oil and Grease	26	21
Nitrate	- 66	-269
Iron	48	34
Zinc	57	60
Copper	39	13

Table 4.7 Initial Hydraulic Conductivity for Each Column

Media	Hydraulic Conductivity (cm/s)
Brady Sand	0.077
Compost	0.0077
Sand and Zeolites	0.081
Zeolites	0.335
Grade 5 Gravel	0.346

these calculations are shown in Figure 4.4, which is a plot of hydraulic conductivity versus experimental run for the three columns. The downward trend in hydraulic conductivity for the Brady sand was expected because of clogging of the medium; however, the increase shown for compost was surprising. The increase in hydraulic conductivity toward the end of the experiment may have been the result of decomposition of the compost. The sand/zeolites combination media had a higher hydraulic conductivity than either the Brady sand or the compost for each of the experimental runs in which it was involved.

A filter can fail by two mechanisms. Filters may clog as a result of high sediment load, thereby rendering the filter ineffective. Filters may also experience breakthrough; i.e., the effluent loading begins to increase as previously trapped materials are released. An organic medium such as the compost also may decompose, accelerating breakthrough.

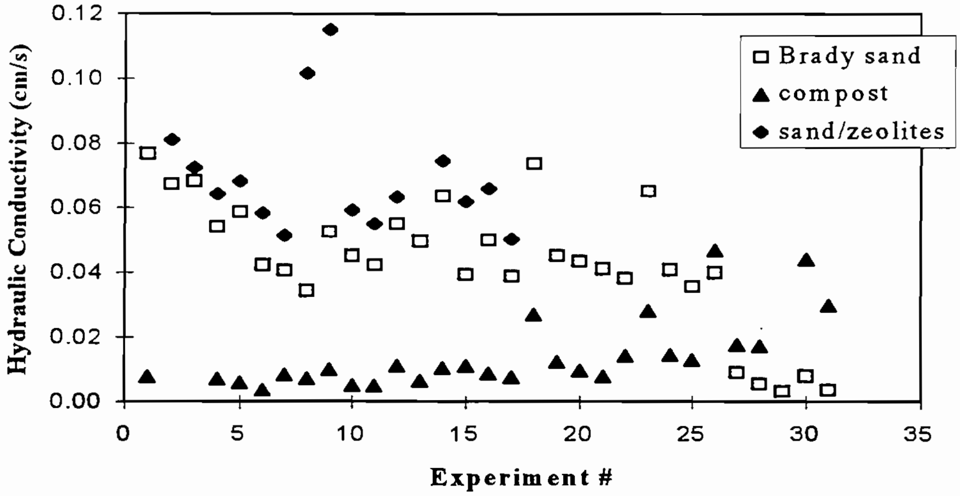

Figure 4.4 Hydraulic Conductivity for Experiment Three.

In this experiment the Brady sand began to clog with no sign of breakthrough, whereas the compost began to experience breakthrough with no sign of clogging The increase in hydraulic conductivity illustrated in Figure 4.4 for the compost indicated that the compost may have been decomposing towards the end of the experiment.

The change in the overall mass reduction for TSS is shown in Figure 4.5 for the 31 experimental runs. The data indicate a downward trend in the overall reduction in TSS for the Brady sand through experimental run 25, and an increase thereafter. The increased removal realized in the Brady sand column could have been caused by clogging of the filter. A decrease in compost performance occurred after the 20th experimental run. The compost had performed consistently well prior to the 20th run with removal efficiencies exceeding 90%; however, a steady decrease in the overall removal of TSS was observed in subsequent runs. The trends in overall TSS load reduction closely resemble the trends in hydraulic conductivity for both media, indicating that the clogging and breakthrough did occur.

4.3 Discussion

4.3.1 The Effectiveness of the Granular Filtration Media

The effectiveness of several granular filtration media was evaluated in three experiments. The results indicate moderate to excellent removal efficiencies can be achieved in sand columns for the removal of suspended solids, metals and oil and grease.

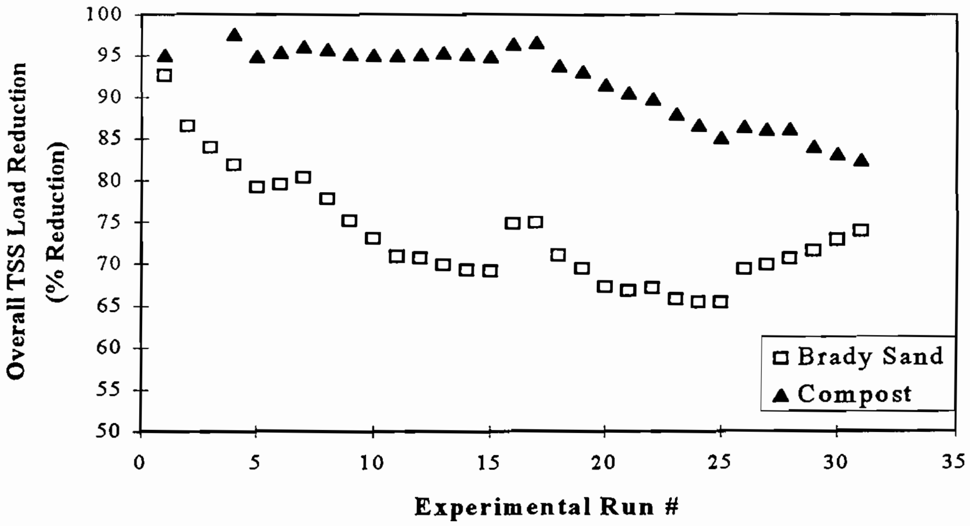

Figure 4.5 Overall Mass Reduction of TSS for Brady Sand and Compost.

The actual removal depends on the runoff application rate as well as the medium used. High removal rates were reported in the first experiment for the sand treating simulated runoff. The runoff used in that experiment was collected during the beginning of the simulated runoff events and contained high suspended solids concentrations which likely caused clogging of the media and led to the high removals. A dark layer developed on top and within the first few centimeters of the sand indicating that straining occurred there. This layer of sediment and sand probably formed an effective filtration layer.

The excellent performance of sand in experiment one was not duplicated in the other two experiments . The smaller filters used in experiments two and three and the lower suspended solids load in the runoff contribute to the lower performance. The results observed in experiments two or three are more realistic because the characteristics of the runoff used in those experiments more closely resembles typical runoff (refer to Table 4.1).

The performance of sand is a function of the hydraulic conductivity. The TSS load reduction versus the average hydraulic conductivity for four sands are presented in Figure 4.6. These data highlight the tradeoff between the drainage rate and the effectiveness of the filter. As the hydraulic conductivity increases the drainage rate through the filter also increases but the filtration efficiency decreases. These phenomena have important implications for the design of control systems which include filtration. An attempt to improve the hydraulic performance of a filter by increasing the drainage

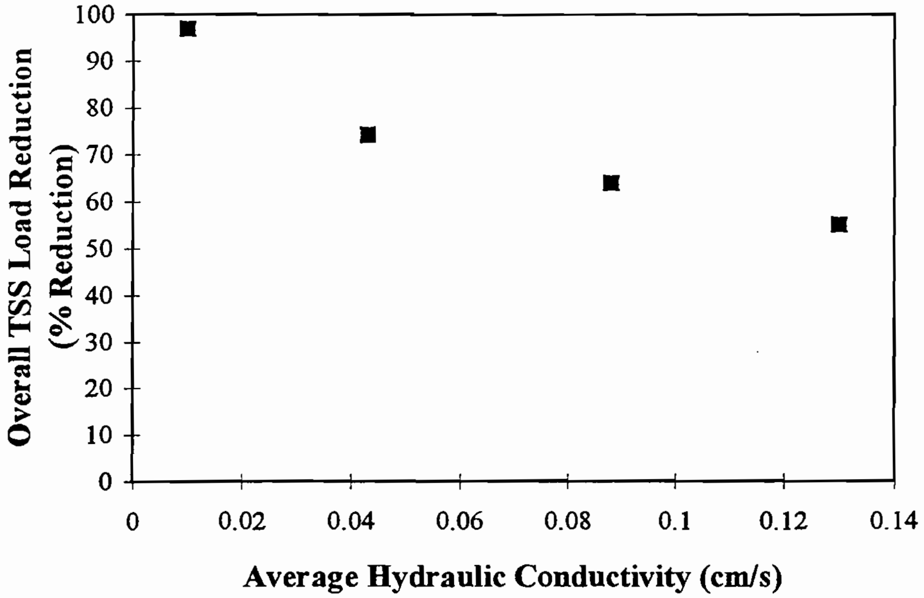

Figure 4.6 TSS Reduction and Hydraulic Conductivity.

rate, as was done by TxDOT to several filtration systems, can result in a corresponding decrease in the water quality of the filtered effluent. This tradeoff is compounded when gravel media are considered. TSS load reductions of 9 and -70 percent were recorded for pea gravel and grade 5 gravel, respectively. The grade 5 gravel was used as a replacement medium in several filters installed by TxDOT, even though the gravel appears to provide no benefit as a filter. The grade 5 gravel when used in the vertical filters can be expected to act only as the hydraulic control for the drainage of the detention basin.

Another aspect of the performance of sand that was determined during the experiments was that runoff with a high TSS concentration does drain through sand. Although the flow through the columns was vertical, it is reasonable to expect the runoff to pass horizontally through sand in the vertical filters in the field. This observation gives further evidence that the flow through the vertical filters is not controlled by the sand and, instead, is controlled by a combination of the filter fabric/sand interface caused by wrapping the sand with geotextile fabric.

4.3.2 Comparison of Brady Sand with Alternative Media

An attempt was made to identify alternative media which could provide enhanced removal of constituents in highway runoff, especially metals and oil and grease. Two alternative media, compost and zeolites, were evaluated during the third experiment. The compost has been used effectively before as a storm water filtration medium and provides removal by adsorption to the organic carbon matrix. Zeolites also were tested because of the reported adsorption and ion exchange capabilities.

The results of the third experiment indicate that the compost outperformed the Brady sand for the removal of solids, metals, and oil and grease and is a viable alternative. The higher removal efficiencies of the compost do not necessarily make compost the preferred medium. Issues related to the construction and operation of a structure utilizing compost were not addressed in this research. For example, the effects of decomposition of compost and associated constituent breakthrough were not determined nor were the maintenance requirements to replace a clogged sand filter. In horizontally bedded sand filters the filters are easily rejuvenated after clogging by removing or replacing the top layer of the filter medium after clogging is observed. The same may not be true for a compost filter. No information is available which can be related directly to the behavior of compost in a vertical filter. Structural or hydraulic problems may be associated with using compost in a vertical configuration.

The compost was a source of nitrate, total phosphorus and dissolved total carbon throughout the experiment. Depending on the type of receiving water and the water quality objectives, the generation of these constituents might be undesirable. Although sand filters also contribute nitrate and remove only a small fraction of the total phosphorus and dissolved total carbon, they perform better than compost for these constituents.

Zeolites were tested alone and in combination with the Brady sand. In neither case did the zeolites show promise as a filtration media for highway runoff. Only four dosages were applied to the column containing zeolites alone because the performance was so poor. The zeolites in combination with Brady sand were tested more extensively since some removal occurred. However, sand alone consistently outperformed the combination of sand and zeolites in the removal of all constituents. Therefore, it is recommended that zeolites not be used as an alternative filtration medium.

5. SUMMARY AND CONCLUSIONS

5.1 Field Performance of Vertical Sand Filter Systems

A number of permanent runoff controls were constructed along the new highways in the Edwards aquifer recharge zone and their performance has been monitored since the highways opened. The control systems consist of a hazardous material trap, a sedimentation basin, and a vertical sand filter. The filter is constructed as part of the wall of the basin and held in place with filter fabric and rock gabions.

Numerous problems have been documented with these systems, mostly in conjunction with the performance of the vertical sand filter. Drainage rates observed for the control systems varied from 30 to 50 hours for the faster draining systems to several days for the systems that drained slowly. Channeling of the runoff through the filter may wash out the sand, resulting in inadequate detention times and no filtration. In other systems, the filters clogged almost immediately creating permanent storage in the sedimentation basin so that all subsequent runoff bypasses the control. Because of these hydraulic problems, it has not been possible to accurately determine the pollutant removal effectiveness of these systems.

The use of sand and geotextile fabrics in the vertical sand filters makes it difficult to predict the drainage rate of these runoff control systems. Drainage of the contents of the runoff control system through the vertical filters is not controlled solely by the sand but also is affected by the geotextile fabric that is used to support the sand between the rock gabions. Therefore, control systems designed based only on the hydraulic behavior of the sand may not drain in 24 hours as called for in the design.

The hazardous material trap (HMT) retains the first flush of runoff during a rainfall event. Therefore, the HMT cannot function as a hazardous materials collection basin during runoff events when the roads are wet and the chance for an accident is higher.

Sedimentation is the most important pollutant removal mechanism for the runoff control systems. Removal of solids as a result of sedimentation was high in control "N" which provided minimal detention time. Modifications of runoff control systems which focus on extending the detention time of the basins may be more effective in controlling suspended solids in runoff than enhancing the filter performance. Scour and resuspension of sediments was observed in the detention basins. This phenomenon causes increased suspended solids loadings on the filters resulting in discharge of higher concentrations of suspended solids in the filter effluent and in clogging of the sand filter. Sediment and suspended solids removal efficiencies can be increased and maintenance requirements reduced by the installation of rock gabions, baffles or another device which reduces resuspension of solids.

5.2 Laboratory Filtration Experiments

Laboratory, bench-scale filtration columns using various media were investigated at the Center for Research in Water Resources. The performance of filtration media and adsorptive media was evaluated. The bench-scale, horizontally-bedded, vertical-flow filtration systems were dosed with stormwater runoff collected from an area highway.

Media selected for these experiments include a well-sorted medium grain size sand, a fine aggregate, grade 5 gravel, compost, and zeolites. The well sorted sand is typical of that used in sand filtration systems in the Austin area. The compost was obtained from a company in Oregon which has used it successfully in runoff controls. The zeolites were obtained locally and were tested because of their adsorption capability. The zeolites were tested in combination with the fine sand. In the latter case the column was constructed with four inches of sand on top of four inches of zeolites.

The results of laboratory studies indicate that high removal efficiencies for constituents in highway runoff can be achieved in horizontal (vertical flow) sand filter columns. The data indicate that the compost is a very effective medium. It out performed the other media for the removal of TSS, oil and grease, and metals. However, the compost decomposes and subsequent breakthrough occurs. The medium sand performed well for the removal of TSS and most of the metals. Clogging of the 20-cm column of sand occured prior to breakthrough; therefore, clogging is expected to precede breakthrough in the field, where the filters are 90 cm across. The column with the medium sand media outperformed the column with the fine sand plus zeolites, showing that the zeolites are not a promising medium for enhancing removal via adsorption. Negative removals were obtained for nitrate in all of the columns, the result of nitrification occurring in the columns.

Similar removal efficiencies were measured using concrete aggregate sand and the Brady sand. Pea gravel and grade 5 gravel are not effective filtration media. The gravel medium contained a significant fine portion which continued to wash out of the column for the duration of the experiment, resulting in negative removal for TSS and associated metals. Grade 5 gravel installed in runoff controls serves only as a hydraulic control device and not as a filtration media.

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APPENDIX A

Numerical Solution for Predicting the Drainage of Retention Basin

Filter "N"				
Initial Depth (m)	1.01	Bottom Slope	0.007	
Basin Area (m^2)	307	Basin Length (m)	34	
Hydraulic Cond (cm/s)	0.15	Elev. Change (m)	0.2446	
Filter Thickness (m)	0.91			
Filter Width (m)	5.5			6.27
Time Step (hours)	0.5			

Time Step	Basin Depth	Time (hrs)	Incremental Discharge (m^3)	Basin Volume (m^3)	Delta h	Flowrate (l/s)	% Remaining
0	1.01	0		272.53			100
1	0.98	1	8.32	264.21	0.0271	4.62E+00	97
2	0.96	1	7.88	256.33	0.0257	4.38E+00	94
3	0.93	2	7.48	248.85	0.0244	4.15E+00	91
4	0.91	2	7.10	241.75	0.0231	3.94E+00	89
5	0.89	3	6.75	235.00	0.0220	3.75E+00	86
6	0.87	3	6.43	228.57	0.0209	3.57E+00	84
7	0.85	4	6.13	222.44	0.0200	3.41E+00	82
8	0.83	4	5.85	216.58	0.0191	3.25E+00	79
9	0.81	5	5.59	210.99	0.0182	3.11E+00	77
10	0.79	5	5.35	205.65	0.0174	2.97E+00	75
11	0.78	6	5.12	200.53	0.0167	2.84E+00	74
12	0.76	6	4.91	195.62	0.0160	2.73E+00	72
13	0.74	7	4.71	190.91	0.0153	2.61E+00	70
14	0.73	7	4.52	186.40	0.0147	2.51E+00	68
15	0.72	8	4.34	182.05	0.0141	2.41E+00	67
16	0.70	8	4.17	177.88	0.0136	2.32E+00	65
17	0.69	9	4.02	173.86	0.0131	2.23E+00	64
18	0.68	9	3.87	169.99	0.0126	2.15E+00	62
19	0.66	10	3.73	166.26	0.0121	2.07E+00	61
20	0.65	10	3.60	162.67	0.0117	2.00E+00	60
21	0.64	11	3.47	159.20	0.0113	1.93E+00	58
22	0.63	11	3.35	155.85	0.0109	1.86E+00	57
23	0.62	12	3.24	152.61	0.0105	1.80E+00	56
24	0.61	12	3.13	149.48	0.0102	1.74E+00	55
25	0.60	13	3.03	146.45	0.0099	1.68E+00	54
26	0.59	13	2.93	143.52	0.0095	1.63E+00	53
27	0.58	14	2.84	140.68	0.0092	1.58E+00	52
28	0.57	14	2.75	137.93	0.0090	1.53E+00	51
29	0.56	15	2.67	135.27	0.0087	1.48E+00	50
30	0.55	15	2.59	132.68	0.0084	1.44E+00	49
31	0.55	16	2.51	130.17	0.0082	1.39E+00	48
32	0.54	16	2.44	127.74	0.0079	1.35E+00	47
33	0.53	17	2.36	125.37	0.0077	1.31E+00	46
34	0.52	17	2.30	123.08	0.0075	1.28E+00	45
35	0.52	18	2.23	120.84	0.0073	1.24E+00	44
36	0.51	18	2.17	118.67	0.0071	1.21E+00	44
37	0.50	19	2.11	116.56	0.0069	1.17E+00	43
38	0.50	19	2.06	114.50	0.0067	1.14E+00	42
39	0.49	20	2.00	112.50	0.0065	1.11E+00	41
40	0.48	20	1.95	110.55	0.0063	1.08E+00	41
41	0.48	21	1.90	108.65	0.0062	1.05E+00	40
42	0.47	21	1.85	106.80	0.0060	1.03E+00	39
43	0.46	22	1.80	105.00	0.0059	1.00E+00	39
44	0.46	22	1.76	103.24	0.0057	9.77E-01	38
45	0.45	23	1.72	101.53	0.0056	9.53E-01	37
46	0.45	23	1.67	99.85	0.0055	9.30E-01	37
47	0.44	24	1.63	98.22	0.0053	9.08E-01	36
48	0.44	24	1.60	96.62	0.0052	8.86E-01	35
49	0.43	25	1.56	95.06	0.0051	8.66E-01	35
50	0.43	25	1.52	93.54	0.0050	8.46E-01	34
51	0.42	26	1.49	92.05	0.0048	8.26E-01	34
52	0.42	26	1.45	90.60	0.0047	8.08E-01	33
53	0.41	27	1.42	89.18	0.0046	7.90E-01	33
54	0.41	27	1.39	87.79	0.0045	7.72E-01	32
55	0.40	28	1.36	86.43	0.0044	7.55E-01	32
56	0.40	28	1.33	85.10	0.0043	7.39E-01	31
57	0.40	29	1.30	83.80	0.0042	7.23E-01	31
58	0.39	29	1.27	82.52	0.0042	7.08E-01	30
59	0.39	30	1.25	81.27	0.0041	6.93E-01	30

60	0.38	30	1.22	80.05	0.0040	6.79E-01	29
61	0.38	31	1.20	78.86	0.0039	6.65E-01	29
62	0.38	31	1.17	77.68	0.0038	6.52E-01	29
63	0.37	32	1.15	76.53	0.0037	6.39E-01	28
64	0.37	32	1.13	75.41	0.0037	6.26E-01	28
65	0.36	33	1.10	74.30	0.0036	6.14E-01	27
66	0.36	33	1.08	73.22	0.0035	6.02E-01	27
67	0.36	34	1.06	72.16	0.0035	5.90E-01	26
68	0.35	34	1.04	71.12	0.0034	5.79E-01	26
69	0.35	35	1.02	70.09	0.0033	5.68E-01	26
70	0.35	35	1.00	69.09	0.0033	5.57E-01	25
71	0.34	36	0.98	68.11	0.0032	5.47E-01	25
72	0.34	36	0.97	67.14	0.0031	5.37E-01	25
73	0.34	37	0.95	66.19	0.0031	5.27E-01	24
74	0.33	37	0.93	65.26	0.0030	5.18E-01	24
75	0.33	38	0.91	64.34	0.0030	5.08E-01	24
76	0.33	38	0.90	63.45	0.0029	4.99E-01	23
77	0.33	39	0.88	62.56	0.0029	4.90E-01	23
78	0.32	39	0.87	61.70	0.0028	4.82E-01	23
79	0.32	40	0.85	60.84	0.0028	4.74E-01	22
80	0.32	40	0.84	60.01	0.0027	4.66E-01	22
81	0.32	41	0.82	59.18	0.0027	4.58E-01	22
82	0.31	41	0.81	58.37	0.0026	4.50E-01	21
83	0.31	42	0.80	57.58	0.0026	4.42E-01	21
84	0.31	42	0.78	56.79	0.0026	4.35E-01	21
85	0.30	43	0.77	56.02	0.0025	4.28E-01	21
86	0.30	43	0.76	55.26	0.0025	4.21E-01	20
87	0.30	44	0.75	54.52	0.0024	4.14E-01	20
88	0.30	44	0.73	53.78	0.0024	4.08E-01	20
89	0.30	45	0.72	53.06	0.0024	4.01E-01	19
90	0.29	45	0.71	52.35	0.0023	3.95E-01	19
91	0.29	46	0.70	51.65	0.0023	3.89E-01	19
92	0.29	46	0.69	50.96	0.0022	3.83E-01	19
93	0.29	47	0.68	50.29	0.0022	3.77E-01	18
94	0.28	47	0.67	49.62	0.0022	3.71E-01	18
95	0.28	48	0.66	48.96	0.0021	3.65E-01	18
96	0.28	48	0.65	48.31	0.0021	3.60E-01	18
97	0.28	49	0.64	47.67	0.0021	3.54E-01	17
98	0.28	49	0.63	47.05	0.0020	3.49E-01	17
99	0.27	50	0.62	46.43	0.0020	3.44E-01	17
100	0.27	50	0.61	45.82	0.0020	3.39E-01	17
101	0.27	51	0.60	45.21	0.0020	3.34E-01	17
102	0.27	51	0.59	44.62	0.0019	3.29E-01	16
103	0.27	52	0.58	44.04	0.0019	3.25E-01	16
104	0.26	52	0.58	43.46	0.0019	3.20E-01	16
105	0.26	53	0.57	42.89	0.0019	3.16E-01	16
106	0.26	53	0.56	42.33	0.0018	3.11E-01	16
107	0.26	54	0.55	41.78	0.0018	3.07E-01	15
108	0.26	54	0.54	41.24	0.0018	3.03E-01	15
109	0.25	55	0.54	40.70	0.0017	2.98E-01	15
110	0.25	55	0.53	40.17	0.0017	2.94E-01	15
111	0.25	56	0.52	39.65	0.0017	2.90E-01	15
112	0.25	56	0.52	39.13	0.0017	2.87E-01	14
113	0.25	57	0.51	38.62	0.0017	2.83E-01	14
114	0.25	57	0.50	38.12	0.0016	2.79E-01	14
115	0.24	58	0.50	37.62	0.0016	2.75E-01	14
116	0.24	58	0.49	37.14	0.0016	2.72E-01	14
117	0.24	59	0.48	36.65	0.0016	2.68E-01	13
118	0.24	59	0.48	36.18	0.0016	2.65E-01	13
119	0.24	60	0.47	35.71	0.0015	2.61E-01	13
120	0.24	60	0.46	35.24	0.0015	2.58E-01	13
121	0.24	61	0.46	34.78	0.0015	2.55E-01	13
122	0.23	61	0.45	34.33	0.0015	2.51E-01	13
123	0.23	62	0.45	33.89	0.0015	2.48E-01	12
124	0.23	62	0.44	33.44	0.0014	2.45E-01	12
125	0.23	63	0.43	33.01	0.0014	2.42E-01	12
126	0.23	63	0.43	32.58	0.0014	2.38E-01	12
127	0.23	64	0.42	32.16	0.0014	2.35E-01	12
128	0.22	64	0.42	31.74	0.0014	2.32E-01	12
129	0.22	65	0.41	31.33	0.0013	2.29E-01	11
130	0.22	65	0.41	30.92	0.0013	2.26E-01	11
131	0.22	66	0.40	30.52	0.0013	2.23E-01	11
132	0.22	66	0.40	30.12	0.0013	2.20E-01	11
133	0.22	67	0.39	29.73	0.0013	2.18E-01	11
134	0.22	67	0.39	29.34	0.0013	2.15E-01	11
135	0.21	68	0.38	28.96	0.0012	2.12E-01	11
136	0.21	68	0.38	28.58	0.0012	2.09E-01	10

137	0.21	69	0.37	28.21	0.0012	2.06E-01	10
138	0.21	69	0.37	27.85	0.0012	2.04E-01	10
139	0.21	70	0.36	27.48	0.0012	2.01E-01	10
140	0.21	70	0.36	27.13	0.0012	1.98E-01	10
141	0.21	71	0.35	26.77	0.0011	1.96E-01	10
142	0.21	71	0.35	26.43	0.0011	1.93E-01	10
143	0.20	72	0.34	26.08	0.0011	1.91E-01	10
144	0.20	72	0.34	25.74	0.0011	1.88E-01	9
145	0.20	73	0.33	25.41	0.0011	1.86E-01	9
146	0.20	73	0.33	25.08	0.0011	1.84E-01	9
147	0.20	74	0.33	24.75	0.0011	1.81E-01	9
148	0.20	74	0.32	24.43	0.0010	1.79E-01	9
149	0.20	75	0.32	24.11	0.0010	1.76E-01	9
150	0.19	75	0.31	23.80	0.0010	1.74E-01	9
151	0.19	76	0.31	23.49	0.0010	1.72E-01	9
152	0.19	76	0.31	23.19	0.0010	1.70E-01	9
153	0.19	77	0.30	22.88	0.0010	1.67E-01	8
154	0.19	77	0.30	22.59	0.0010	1.65E-01	8
155	0.19	78	0.29	22.29	0.0010	1.63E-01	8
156	0.19	78	0.29	22.00	0.0009	1.61E-01	8
157	0.19	79	0.29	21.72	0.0009	1.59E-01	8
158	0.18	79	0.28	21.43	0.0009	1.57E-01	8
159	0.18	80	0.28	21.16	0.0009	1.55E-01	8
160	0.18	80	0.28	20.88	0.0009	1.53E-01	8
161	0.18	81	0.27	20.61	0.0009	1.51E-01	8
162	0.18	81	0.27	20.34	0.0009	1.49E-01	7
163	0.18	82	0.26	20.08	0.0009	1.47E-01	7
164	0.18	82	0.26	19.82	0.0009	1.45E-01	7
165	0.18	83	0.26	19.56	0.0008	1.43E-01	7
166	0.18	83	0.25	19.30	0.0008	1.41E-01	7
167	0.17	84	0.25	19.05	0.0008	1.39E-01	7
168	0.17	84	0.25	18.81	0.0008	1.38E-01	7
169	0.17	85	0.24	18.56	0.0008	1.36E-01	7
170	0.17	85	0.24	18.32	0.0008	1.34E-01	7
171	0.17	86	0.24	18.08	0.0008	1.32E-01	7
172	0.17	86	0.24	17.85	0.0008	1.31E-01	7

APPENDIX B

Summary of Water Level Measurements Collected for Six Controls During Evaluation of the Hydraulic Performance of the Controls

Date of Runoff Event 5/16/94

	Measured Depth within Retention Basin (cm)						
Date	16-May	17-May	18-May	19-May	22-May	23-May	26-May
Elapsed Time (hrs)	1	24	45	67	137	161	234
N	94	89	76	71	66	58	53
M	29	18	3	0	0	0	0
L	39	36	30	28	19	18	13
K	79	42	14	5	0	0	0
A	62	57	43	37	23	18	10
B	47	52	29	15	0	0	0

Date of Runoff Event 5/30/94

	Measured Depth within Retention Basin (cm)						
Date	30-May	31-May	1-Jun	2-Jun	3-Jun	6-Jun	8-Jun
Elapsed Time (hrs)	17	40	63	86	110	182	230
N	94	88	84	79	85	76	71
M	25	20	18	14	11	3	0
L	34	30	30	28	27	23	23
K	38	19	6	4	4	3	3
A	42	30	25	22	18	6	0
B	22	10	0	0	0	0	0

Date of Runoff Event 8/9/94

	Measured Depth within Retention Basin (cm)			
Date	9-Aug	10-Aug	11-Aug	14-Aug
Elapsed Time (hrs)	5	34	55	125
N	94	99	97	90
M	66	17	13	9
L	41	28	24	19
K	32	19	8	4
A	84	29	20	10
B	102	51	30	3

Date of Runoff Event 10/18/94

	Measured Depth within Retention Basin (cm)			
Date	18-Oct	19-Oct	20-Oct	21-Oct
Elapsed Time (hrs)	3	19	44	68
N	94	0	0	0
M	62	30	23	20
L	41	34	33	29
K	42	8	11	6
A	84	46	34	27
B	102	76	43	22

Summary of Flow Rate Measurements and Calculations

Date 1/12/95

Influent Flow Rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flow Rate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
6:55 PM	0.000	0.0	0.0				
7:00 PM	0.171	16.6	2.5				
7:05 PM	0.246	41.3	11.2				
7:10 PM	0.241	39.5	23.3				
7:15 PM	0.206	26.7	33.2				
7:20 PM	0.171	16.7	39.7				
7:25 PM	0.140	10.2	43.8				
7:30 PM	0.112	5.9	46.2				
7:35 PM	0.087	3.1	47.5				
7:40 PM	0.064	1.4	48.2				
7:45 PM	0.040	0.4	48.5				
7:50 PM	0.014	0.0	48.6				
7:55 PM	0.000	0.0	48.6				

Effluent Flow Rate Calculation

Measurement of effluent flow

There was an error in the measurement of runoff level within the detention basin for this storm. The maximum level measured by the flowmeter was 0.184 m, but the maximum level that I measured

was 0.29 m. The flow rate was estimated in3 stages. During stage 1 the pond level increased from 0 to 0.18 meters; during stage two the measured level remained between 0.18 and 0.2 meters; and during stage three the level decreases.

For stage 1 the inflow from the HMT is unknown so the effluent flow was estimated by gaging the pond level, using pond level vs. outflow data from other storms.

For stage 3 it is assumed that the HMT has finished draining, so the outflow was calculated directly from the change in level in the detention pond. For stage 2 I assumed that the effluent Flow rate was constant and that the total was the difference between the inflow and the effluent flow for stages one and three.

Flow Distribution (m^3)

	Stage 1	Stage 2	Stage 3	Total
Sample 1	0	40.0382509		40.03825
Sample 2		11.4395003	0	11.4395
Sample 3			0	0
Sample 4			0	0

Stage 1 Effluent Flow

Time	Measured Level (m)	3/7/95 Flow Rate (L/s)	2/24/95 Flow Rate (L/s)	2/25/95 Flow Rate (L/s)	Average Flow Rate (L/s)
19:00	0.05	0.2	0.3	0.2	0.233333
19:05	0.106	1.2	1.3	1	1.166667
19:10	0.215	2.5	2.5	6	3.666667
19:15	0.245	3	3	7	4.333333
19:20	0.281	4.1	4.1	9	5.733333

Summary of Flow Rate Measurements and Calculations (Cont.)

Stage 3 Effluent Flow

Time	Det. Basin Volume (m^3)	Effluent Flow (m^3)	Cumulative Flow (m^3)
21:50	50.523249		
21:55	50.216669	0.306580032	0.30658003
22:00	49.603509	0.613160064	0.9197401
22:05	48.377189	1.226320128	2.14606022
22:10	48.070609	0.306580032	2.45264026
22:15	46.844288	1.226320128	3.67896038
22:20	46.231128	0.613160064	4.29212045
22:25	45.004808	1.226320128	5.51844058
22:30	43.778488	1.226320128	6.7447607
22:35	42.245588	1.53290016	8.27766086
22:40	40.712688	1.53290016	9.81056102
22:45	39.792948	0.919740096	10.7303011
22:50	38.566628	1.226320128	11.9566212
22:55	36.7284	1.838227548	13.7948488
23:00	35.519318	1.209082158	15.003931
23:05	34.330471	1.188846473	16.1927774
23:10	32.87287	1.45760166	17.6503791
23:15	31.729554	1.143316183	18.7936953
23:20	30.606473	1.123080498	19.9167758
23:25	30.052521	0.553951867	20.4707276
23:30	28.421019	1.631502075	22.1022297
23:35	27.358646	1.062373444	23.1646032
23:40	26.575145	0.783500415	23.9481036
23:45	25.294606	1.280539419	25.228643
23:50	20.488631	4.805975104	30.0346181
23:55	14.228216	6.260414938	36.295033
0:00	7.6516183	6.57659751	42.8716305
0:05	5.1221577	2.529460581	45.4010911
0:10	4.0471369	1.075020747	46.4761119
0:15	3.0985892	0.948547718	47.4246596
0:20	2.3530307	0.745558506	48.1702181
0:25	2.1272763	0.225754357	48.3959724
0:30	1.6447817	0.482494606	48.8784671
0:35	1.3968946	0.247887137	49.1263542
0:40	1.2805394	0.116355187	49.2427094
0:45	1.0630058	0.21753361	49.460243
0:50	0.8657079	0.197297925	49.6575409
0:55	0.6886456	0.177062241	49.8346032
1:00	0.4957743	0.192871369	50.0274745
1:05	0.3952282	0.100546058	50.1280206
1:10	0.2282838	0.166944398	50.294965
1:15	0.1827535	0.04553029	50.3404953
1:20	0.1068697	0.075883817	50.4163791
1:25	0.0910606	0.015809129	50.4321882
1:30	0.1239436	-0.032882988	50.3993052
1:35	0.1422822	-0.018338589	50.3809666
1:40	0.1068697	0.035412448	50.4163791
1:45	0.1068697	0	50.4163791
1:50	0.1068697	0	50.4163791
1:55	0.1068697	0	50.4163791
2:00	0.0910606	0.015809129	50.4321882

Summary of Flow Rate Measurements and Calculations (Cont.)

2:05	0.0910606	0	50.4321882
2:10	0.0910606	0	50.4321882
2:15	0.0765162	0.014544398	50.4467326
2:20	0.0910606	-0.014544398	50.4321882
2:25	0.1068697	-0.015809129	50.4163791
2:30	0.0910606	0.015809129	50.4321882
2:35	0.0910606	0	50.4321882
2:40	0.0765162	0.014544398	50.4467326
2:45	0.0910606	-0.014544398	50.4321882
2:50	0.0765162	0.014544398	50.4467326
2:55	0.0910606	-0.014544398	50.4321882
3:00	0.0910606	0	50.4321882
3:05	0.1068697	-0.015809129	50.4163791
3:10	0.1068697	0	50.4163791
3:15	0.1068697	0	50.4163791
3:20	0.1068697	0	50.4163791
3:25	0.1068697	0	50.4163791
3:30	0.0910606	0.015809129	50.4321882
3:35	0.0910606	0	50.4321882
3:40	0.1068697	-0.015809129	50.4163791
3:45	0.1068697	0	50.4163791
3:50	0.1068697	0	50.4163791
3:55	0.1618855	-0.055015768	50.3613633
4:00	0.2048863	-0.04300083	50.3183625
4:05	0.2282838	-0.02339751	50.294965
4:10	0.1827535	0.04553029	50.3404953
4:15	0.1422822	0.040471369	50.3809666
4:20	0.0765162	0.065765975	50.4467326
4:25	0.0512216	0.025294606	50.4720272
4:30	0.0309859	0.020235685	50.4922629
4:35	0.0006324	0.030353527	50.5226164
4:40	0.0006324	0	50.5226164
4:45	0.0006324	0	50.5226164
4:50	0.0006324	0	50.5226164
4:55	0.0025295	-0.001897095	50.5207193
5:00	0.0006324	0.001897095	50.5226164
5:05	0.0025295	-0.001897095	50.5207193
5:10	0.0025295	0	50.5207193
5:15	0.001	0.001529461	50.5222488

Stage 2 Effluent Flow

Influent Flow (m^3)	102
Effluent Flow (m^3)	
Stage 1	0
Stage 3	50.5222488
Stage 2	51.4777512

Date 2/24/95

Influent Flow rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flow rate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
1:10 PM	0	0.0	0.0				
1:15 PM	0.072	1.9	0.6				
1:20 PM	0.14	10.1	3.6				
1:25 PM	0.172	45.9	17.4				
1:30 PM	0.264	46.9	31.4	52.8	0.245	4.1	10
1:35 PM	0.289	81.0	55.7	84.8	0.328	6.2	10
1:40 PM	0.264	111.6	89.2	111.4	0.437	10.2	10
1:45 PM	0.211	85.8	114.9	81.8	0.517	14	10
1:50 PM	0.296	57.6	132.2	50.1	0.566	17.5	10
1:55 PM	0.356	72.3	153.9	62.3	0.627	20	10
2:00 PM	0.443	203.8	215.1	177.8	0.801	36	10
2:05 PM	0.473	304.4	306.4	204.4	1.001	110	10
2:10 PM	0.295	313.8	400.5	175.8	1.173	148	10
2:15 PM	0.217	65.9	420.3	-52.1	1.122	128	10
2:20 PM	0.156	13.3	424.3				
2:25 PM	0.123	7.3	426.5				
2:30 PM	0.112	5.8	428.2				
2:35 PM	0.13	8.4	430.7				
2:40 PM	0.139	9.9	433.7				
2:45 PM	0.12	6.9	435.8				
2:50 PM	0.093	3.6	436.8				
2:55 PM	0.069	1.7	437.4				
3:00 PM	0.049	0.7	437.6				
3:05 PM	0.033	0.3	437.7				
3:10 PM	0.02	0.1	437.7				
3:15 PM	0.009	0.0	437.7				

Effluent Flow rate Calculation

Time	Measured Level (meters)	Rate of Change in Basin Volume (L/s)	Influent Flow rate (L/s)	HMT Flow rate (L/s)	Effluent Flow rate (L/s)
1:00 PM	0.001	0.0	0.0		
1:05 PM	0.001	0.0	0.0		
1:10 PM	0.014	0.4	0.0		
1:15 PM	0.024	0.8	1.9	10	11.1
1:20 PM	0.098	19.0	10.1	10	1.1
1:25 PM	0.187	53.5	45.9	10	2.4
1:30 PM	0.245	52.8	46.9	10	4.1
1:35 PM	0.328	84.8	81.0	10	6.2
1:40 PM	0.437	111.4	111.6	10	10.2
1:45 PM	0.517	81.8	85.8	10	14.0
1:50 PM	0.566	50.1	57.6	10	17.5
1:55 PM	0.627	62.3	72.3	10	20.0
2:00 PM	0.801	177.8	203.8	10	36.0
2:05 PM	1.001	204.4	304.4	10	110.0
2:10 PM	1.173	175.8	313.8	10	148.0
2:15 PM	1.122	-52.1	65.9	10	128.0

2:20 PM	1.051	-72.6	13.3	10	95.8
2:25 PM	0.988	-64.4	7.3	10	81.7
2:30 PM	0.933	-56.2	5.8	10	72.0
2:35 PM	0.882	-52.1	8.4	10	70.5
2:40 PM	0.844	-38.8	9.9	10	58.8
2:45 PM	0.814	-30.7	6.9	10	47.5
2:50 PM	0.786	-28.6	3.6	10	42.3
2:55 PM	0.755	-31.7	1.7	10	43.4
3:00 PM	0.719	-36.8	0.7	5.4	42.9
3:05 PM	0.687	-32.7	0.3	5.4	38.4
3:10 PM	0.654	-33.7	0.1	5.4	39.2
3:15 PM	0.622	-32.7	0.0	5.4	38.1
3:20 PM	0.591	-31.7	0.0	5.4	37.1
3:25 PM	0.562	-29.6	0.0	5.4	35.0
3:30 PM	0.535	-27.6	0.0	5.4	33.0
3:35 PM	0.512	-23.5	0.0	5.4	28.9
3:40 PM	0.489	-23.5	0.0	5.4	28.9
3:45 PM	0.468	-21.5	0.0	5.4	26.9
3:50 PM	0.448	-20.4	0.0	5.4	25.8
3:55 PM	0.429	-19.4	0.0	5.4	24.8
4:00 PM	0.411	-18.4	0.0	5.4	23.8
4:05 PM	0.394	-17.4	0.0	5.4	22.8
4:10 PM	0.38	-14.3	0.0	5.4	19.7
4:15 PM	0.365	-15.3	0.0	5.4	20.7
4:20 PM	0.353	-12.3	0.0	5.4	17.7
4:25 PM	0.34	-13.3	0.0	5.4	18.7
4:30 PM	0.328	-12.3	0.0	5.4	17.7
4:35 PM	0.318	-10.2	0.0	5.4	15.6
4:40 PM	0.307	-11.2	0.0	5.4	16.6
4:45 PM	0.299	-8.2	0.0	5.4	13.6
4:50 PM	0.29	-9.2	0.0	5.4	14.6
4:55 PM	0.283	-7.2	0.0	5.4	12.6
5:00 PM	0.273	-10.2	0.0	5.4	15.6
5:05 PM	0.267	-6.1	0.0	5.4	11.5
5:10 PM	0.26	-7.2	0.0	5.4	12.6
5:15 PM	0.251	-9.2	0.0	5.4	14.6
5:20 PM	0.246	-5.1	0.0	5.4	10.5
5:25 PM	0.24	-6.1	0.0	5.4	11.5
5:30 PM	0.231	-8.9	0.0	5.4	14.3
5:35 PM	0.225	-5.8	0.0	5.4	11.2
5:40 PM	0.219	-5.6	0.0	5.4	11.0
5:45 PM	0.212	-6.4	0.0	5.4	11.8
5:50 PM	0.206	-5.3	0.0	5.4	10.7
5:55 PM	0.201	-4.3	0.0	5.4	9.7

Date **2/25/95**

Influent Flow Rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flowrate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
2:45 PM	0.022	0.1	0.0				
2:50 PM	0.088	3.2	1.0				
2:55 PM	0.092	3.5	2.0				
3:00 PM	0.084	2.8	2.9				
3:05 PM	0.094	3.7	4.0				
3:10 PM	0.102	4.6	5.4				
3:15 PM	0.1	4.4	6.7				
3:20 PM	0.108	5.3	8.3				
3:25 PM	0.138	9.8	11.2				
3:30 PM	0.183	25.9	19.0				
3:35 PM	0.195	40.4	31.1				
3:40 PM	0.203	46.4	45.0				
3:45 PM	0.191	47.6	59.3				
3:50 PM	0.176	45.2	72.8				
3:55 PM	0.21	42.6	85.6				
4:00 PM	0.172	16.9	90.7				
4:05 PM	0.125	7.6	93.0				
4:10 PM	0.092	3.5	94.0				
4:15 PM	0.071	1.9	94.6				
4:20 PM	0.057	1.1	94.9				
4:25 PM	0.049	0.7	95.1				
4:30 PM	0.046	0.6	95.3				
4:35 PM	0.051	0.8	95.6				
4:40 PM	0.07	1.8	96.1				
4:45 PM	0.129	8.2	98.6				
4:50 PM	0.146	11.2	101.9				
4:55 PM	0.131	8.6	104.5				
5:00 PM	0.116	6.3	106.4				
5:05 PM	0.103	4.7	107.8				
5:10 PM	0.087	3.1	108.7				
5:15 PM	0.072	1.9	109.3				
5:20 PM	0.062	1.3	109.7				
5:25 PM	0.055	1.0	110.0				
5:30 PM	0.05	0.8	110.2				
5:35 PM	0.046	0.6	110.4				
5:40 PM	0.047	0.7	110.6				
5:45 PM	0.046	0.6	110.8				
5:50 PM	0.04	0.4	110.9				
5:55 PM	0.032	0.3	111.0				
6:00 PM	0.023	0.1	111.1				
6:05 PM	0.014	0.0	111.1				
6:10 PM	0.007	0.0	111.1				
6:15 PM	0	0.0	111.1				

Effluent Flow Rate Calculation

Time	Measured Level (meters)	Rate of Change in Basin Volume (L/s)	Influent Flowrate (L/s)	HMT Flowrate (L/s)	Effluent Flowrate (L/s)
2:30 PM	0.001	0	0		
2:35 PM	0.004	0.0	0		
2:40 PM	0.016	0.5	0		
2:45 PM	0.024	0.7	0.1		2.0
2:50 PM	0.047	3.4	3.2	10	-3.3
2:55 PM	0.113	22.3	3.5	10	-9.1
3:00 PM	0.155	23.7	2.8	10	-10.2
3:05 PM	0.181	18.4	3.7	10	-5.6
3:10 PM	0.202	17.0	4.6	10	-3.2
3:15 PM	0.224	19.8	4.4	10	-5.2
3:20 PM	0.241	16.7	5.3	10	-2.3
3:25 PM	0.259	18.4	9.8	10	-3.1
3:30 PM	0.281	22.5	25.9	10	-2.7
3:35 PM	0.319	38.8	40.4	10	-3.0
3:40 PM	0.365	47.0	46.4	10	3.4
3:45 PM	0.412	48.0	47.6	10	8.4
3:50 PM	0.457	46.0	45.2	10	11.6
3:55 PM	0.49	33.7	42.6	10	21.5
4:00 PM	0.531	41.9	16.9	10	10.7
4:05 PM	0.563	32.7	7.6	10	-5.8
4:10 PM	0.573	10.2	3.5	10	7.4
4:15 PM	0.572	-1.0	1.9	10	14.6
4:20 PM	0.566	-6.1	1.1	10	18.0
4:25 PM	0.558	-8.2	0.7	5.4	19.2
4:30 PM	0.549	-9.2	0.6	5.4	15.3
4:35 PM	0.539	-10.2	0.8	5.4	16.2
4:40 PM	0.532	-7.2	1.8	5.4	13.4
4:45 PM	0.527	-5.1	8.2	5.4	12.3
4:50 PM	0.535	8.2	11.2	5.4	5.5
4:55 PM	0.552	17.4	8.6	5.4	-0.7
5:00 PM	0.565	13.3	6.3	5.4	0.7
5:05 PM	0.573	8.2	4.7	5.4	3.5
5:10 PM	0.575	2.0	3.1	5.4	8.1
5:15 PM	0.574	-1.0	1.9	5.4	9.5
5:20 PM	0.569	-5.1	1.3	5.4	12.4
5:25 PM	0.563	-6.1	1.0	5.4	12.9
5:30 PM	0.555	-8.2	0.8	5.4	14.6
5:35 PM	0.548	-7.2	0.6	5.4	13.3
5:40 PM	0.54	-8.2	0.7	5.4	14.2
5:45 PM	0.535	-5.1	0.6	5.4	11.2
5:50 PM	0.527	-8.2	0.4	5.4	14.2
5:55 PM	0.52	-7.2	0.3	5.4	13.0
6:00 PM	0.512	-8.2	0.1	5.4	13.8
6:05 PM	0.504	-8.2	0.0	5.4	13.7
6:10 PM	0.495	-9.2	0.0	5.4	14.6
6:15 PM	0.486	-9.2	0.0	5.4	14.6
6:20 PM	0.476	-10.2		5.4	15.6
6:25 PM	0.467	-9.2		5.4	14.6
6:30 PM	0.458	-9.2		5.4	14.6

6:35 PM	0.449	-9.2	5.4	14.6
6:40 PM	0.44	-9.2	5.4	14.6
6:45 PM	0.431	-9.2	5.4	14.6
6:50 PM	0.422	-9.2	5.4	14.6
6:55 PM	0.414	-8.2	5.4	13.6
7:00 PM	0.406	-8.2	5.4	13.6
7:05 PM	0.398	-8.2	5.4	13.6
7:10 PM	0.39	-8.2	5.4	13.6
7:15 PM	0.382	-8.2	5.4	13.6
7:20 PM	0.375	-7.2	5.4	12.6
7:25 PM	0.368	-7.2		12.6
7:30 PM	0.362	-6.1		6.1
7:35 PM	0.355	-7.2		7.2
7:40 PM	0.348	-7.2		7.2
7:45 PM	0.342	-6.1		6.1
7:50 PM	0.336	-6.1		6.1
7:55 PM	0.33	-6.1		6.1
8:00 PM	0.324	-6.1		6.1
8:05 PM	0.319	-5.1		5.1
8:10 PM	0.314	-5.1		5.1
8:15 PM	0.309	-5.1		5.1
8:20 PM	0.303	-6.1		6.1
8:25 PM	0.299	-4.1		4.1
8:30 PM	0.294	-5.1		5.1
8:35 PM	0.29	-4.1		4.1
8:40 PM	0.285	-5.1		5.1
8:45 PM	0.281	-4.1		4.1
8:50 PM	0.277	-4.1		4.1
8:55 PM	0.273	-4.1		4.1
9:00 PM	0.269	-4.1		4.1
9:05 PM	0.265	-4.1		4.1
9:10 PM	0.261	-4.1		4.1
9:15 PM	0.257	-4.1		4.1
9:20 PM	0.254	-3.1		3.1
9:25 PM	0.25	-4.1		4.1
9:30 PM	0.247	-3.1		3.1
9:35 PM	0.243	-4.1		4.1
9:40 PM	0.24	-3.1		3.1
9:45 PM	0.236	-4.0		4.0
9:50 PM	0.233	-3.0		3.0
9:55 PM	0.229	-3.9		3.9
10:00 PM	0.226	-2.9		2.9
10:05 PM	0.222	-3.8		3.8
10:10 PM	0.219	-2.8		2.8
10:15 PM	0.216	-2.8		2.8
10:20 PM	0.213	-2.7		2.7
10:25 PM	0.209	-3.6		3.6
10:30 PM	0.206	-2.6		2.6
10:35 PM	0.203	-2.6		2.6
10:40 PM	0.2	-2.5		2.5

Date 3/7/95

Influent Flow Rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flow Rate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
2:40 AM	0	0.0	0.0				
2:45 AM	0.359	99.7	29.9	98.0	0.223	3.8	10
2:50 AM	0.326	84.7	55.3	113.7	0.335	4.1	10
2:55 AM	0.244	40.6	67.5	67.4	0.401	6.1	10
3:00 AM	0.199	24.4	74.8				
3:05 AM	0.191	22.0	81.4				
3:10 AM	0.185	20.3	87.5				
3:15 AM	0.192	22.3	94.1				
3:20 AM	0.206	26.6	102.1				
3:25 AM	0.225	33.1	112.0				
3:30 AM	0.212	28.5	120.6				
3:35 AM	0.175	17.7	125.9				
3:40 AM	0.142	10.5	129.0				
3:45 AM	0.135	9.2	131.8				
3:50 AM	0.123	7.3	134.0				
3:55 AM	0.098	4.1	135.2				
4:00 AM	0.066	1.5	135.7				
4:05 AM	0.033	0.3	135.8				
4:10 AM	0	0.0	135.8				

Effluent Flow Rate Calculation

Time	Measured Level (meters)	Rate of Change in Basin Volume (L/s)	Influent Flow Rate (L/s)	HMT Flow Rate (L/s)	Effluent Flow Rate (L/s)
2:25 AM	0.001	0.0	0.0		0.0
2:30 AM	0.009	0.2	0.0		-0.2
2:35 AM	0.015	0.3	0.0		-0.3
2:40 AM	0.026	1.0	0.0		-1.0
2:45 AM	0.057	5.4	99.7	10	-5.4
2:50 AM	0.223	98.0	84.7	10	11.7
2:55 AM	0.335	113.7	40.6	10	-19.0
3:00 AM	0.401	67.4	24.4	10	-16.9
3:05 AM	0.438	37.8	22.0	10	-3.5
3:10 AM	0.464	26.6	20.3	10	5.4
3:15 AM	0.489	25.5	22.3	10	4.8
3:20 AM	0.513	24.5	26.6	10	7.7
3:25 AM	0.539	26.6	33.1	10	10.0
3:30 AM	0.568	29.6	28.5	10	13.5
3:35 AM	0.595	27.6	17.7	10	10.9
3:40 AM	0.608	13.3	10.5	10	14.4
3:45 AM	0.612	4.1	9.2	10	16.4
3:50 AM	0.612	0.0	7.3	10	19.2
3:55 AM	0.61	-2.0	4.1	10	19.4
4:00 AM	0.607	-3.1	1.5	10	17.2
4:05 AM	0.6	-7.2	0.3	5.4	18.7
4:10 AM	0.591	-9.2	0.0	5.4	14.9
4:15 AM	0.583	-8.2	0.0	5.4	13.6

4:20 AM	0.574	-9.2	0.0	5.4	14.6
4:25 AM	0.566	-8.2	0.0	5.4	13.6
4:30 AM	0.559	-7.2	0.0	5.4	12.6
4:35 AM	0.552	-7.2	0.0	5.4	12.6
4:40 AM	0.544	-8.2	0.0	5.4	13.6
4:45 AM	0.539	-5.1	0.0	5.4	10.5
4:50 AM	0.534	-5.1	0.0	5.4	10.5
4:55 AM	0.525	-9.2	0.0	5.4	14.6
5:00 AM	0.522	-3.1	0.0	5.4	8.5
5:05 AM	0.513	-9.2		5.4	14.6
5:10 AM	0.509	-4.1		5.4	9.5
5:15 AM	0.501	-8.2		5.4	13.6
5:20 AM	0.498	-3.1		5.4	8.5
5:25 AM	0.492	-6.1		5.4	11.5
5:30 AM	0.486	-6.1		5.4	11.5
5:35 AM	0.48	-6.1		5.4	11.5
5:40 AM	0.474	-6.1		5.4	11.5
5:45 AM	0.468	-6.1		5.4	11.5
5:50 AM	0.46	-8.2		5.4	13.6
5:55 AM	0.454	-6.1		5.4	11.5
6:00 AM	0.445	-9.2		5.4	14.6
6:05 AM	0.436	-9.2		5.4	14.6
6:10 AM	0.427	-9.2		5.4	14.6
6:15 AM	0.42	-7.2		5.4	12.6
6:20 AM	0.413	-7.2		5.4	12.6
6:25 AM	0.405	-8.2		5.4	13.6
6:30 AM	0.399	-6.1		5.4	11.5
6:35 AM	0.39	-9.2		5.4	14.6
6:40 AM	0.382	-8.2		5.4	13.6
6:45 AM	0.378	-4.1		5.4	9.5
6:50 AM	0.371	-7.2		5.4	12.6
6:55 AM	0.365	-6.1		5.4	11.5
7:00 AM	0.36	-5.1		5.4	10.5
7:05 AM	0.355	-5.1			10.5
7:10 AM	0.349	-6.1			6.1
7:15 AM	0.343	-6.1			6.1
7:20 AM	0.339	-4.1			4.1
7:25 AM	0.335	-4.1			4.1
7:30 AM	0.331	-4.1			4.1
7:35 AM	0.323	-8.2			8.2
7:40 AM	0.321	-2.0			2.0
7:45 AM	0.316	-5.1			5.1
7:50 AM	0.312	-4.1			4.1
7:55 AM	0.305	-7.2			7.2
8:00 AM	0.302	-3.1			3.1
8:05 AM	0.297	-5.1			5.1
8:10 AM	0.294	-3.1			3.1
8:15 AM	0.289	-5.1			5.1
8:20 AM	0.287	-2.0			2.0
8:25 AM	0.283	-4.1			4.1
8:30 AM	0.279	-4.1			4.1
8:35 AM	0.275	-4.1			4.1
8:40 AM	0.271	-4.1			4.1
8:45 AM	0.268	-3.1			3.1
8:50 AM	0.265	-3.1			3.1
8:55 AM	0.263	-2.0			2.0
9:00 AM	0.258	-5.1			5.1
9:05 AM	0.256	-2.0			2.0

9:10 AM	0.251	-5.1	5.1
9:15 AM	0.248	-3.1	3.1
9:20 AM	0.246	-2.0	2.0
9:25 AM	0.242	-4.1	4.1
9:30 AM	0.239	-3.0	3.0
9:35 AM	0.236	-3.0	3.0
9:40 AM	0.234	-2.0	2.0
9:45 AM	0.23	-3.9	3.9
9:50 AM	0.226	-3.8	3.8
9:55 AM	0.223	-2.8	2.8
10:00 AM	0.221	-1.9	1.9
10:05 AM	0.217	-3.7	3.7
10:10 AM	0.214	-2.7	2.7
10:15 AM	0.212	-1.8	1.8
10:20 AM	0.208	-3.5	3.5
10:25 AM	0.205	-2.6	2.6
10:30 AM	0.202	-2.6	2.6

Date 3/13/95
Influent Flow Rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flow Rate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
12:35 AM	0	0.0	0.0				
12:40 AM	0.775	386.1	115.8	376.1	0.609	20	10
12:45 AM	0.422	345.8	219.5	314.8	0.917	41	10
12:50 AM	0.297	65.7	239.3	32.7	0.949	43	10
12:55 AM	0.21	27.9	247.6				
1:00 AM	0.156	13.3	251.6				
1:05 AM	0.12	6.9	253.7				
1:10 AM	0.095	3.8	254.8				
1:15 AM	0.074	2.1	255.4				
1:20 AM	0.056	1.0	255.7				
1:25 AM	0.039	0.4	255.9				
1:30 AM	0.023	0.0	255.9				
1:35 AM	0.008	0.0	255.9				
1:40 AM	0	0.0	255.9				
1:45 AM	0	0.0	255.9				
1:50 AM	0	0.0	255.9				
1:55 AM	0	0.0	255.9				
2:00 AM	0	0.0	255.9				
2:05 AM	0	0.0	255.9				
2:10 AM	0	0.0	255.9				
2:15 AM	0.065	1.5	256.3				
2:20 AM	0.189	21.4	262.7				
2:25 AM	0.244	40.6	274.9				
2:30 AM	0.258	27.1	283.0	3.1	0.613	34	10
2:35 AM	0.249	42.7	295.8				
2:40 AM	0.253	44.4	309.1				
2:45 AM	0.316	65.5	328.8	48.0	0.7	27.5	10
2:50 AM	0.321	74.1	351.0	52.1	0.8	32	10
2:55 AM	0.368	84.2	376.3	56.2	0.8	38	10
3:00 AM	0.385	123.0	413.2	92.0	0.9	41	10
3:05 AM	0.368	81.0	437.5	48.0	1.0	43	10
3:10 AM	0.363	59.5	455.4	25.5	1.0	44	10
3:15 AM	0.306	39.1	467.1	4.1	1.0	45	10
3:20 AM	0.266	21.7	473.6	-12.3	1.0	44	10
3:25 AM	0.249	42.7	486.4				
3:30 AM	0.24	38.9	498.1				
3:35 AM	0.237	37.7	509.4				
3:40 AM	0.238	38.1	520.8				
3:45 AM	0.237	37.7	532.1				
3:50 AM	0.225	33.1	542.1				
3:55 AM	0.21	27.9	550.4				
4:00 AM	0.208	27.2	558.6				
4:05 AM	0.221	31.7	568.1				
4:10 AM	0.245	41.0	580.4				
4:15 AM	0.261	48.0	594.8				
4:20 AM	0.255	45.3	608.4				
4:25 AM	0.233	36.1	619.2				
4:30 AM	0.2	24.7	626.6				
4:35 AM	0.17	16.4	631.5				
4:40 AM	0.146	11.2	634.9				

4:45 AM	0.127	7.9	637.3
4:50 AM	0.112	5.8	639.0
4:55 AM	0.099	4.3	640.3
5:00 AM	0.088	3.2	641.2
5:05 AM	0.078	2.3	641.9
5:10 AM	0.069	1.7	642.5
5:15 AM	0.061	1.3	642.8
5:20 AM	0.053	0.9	643.1
5:25 AM	0.045	0.6	643.3
5:30 AM	0.037	0.4	643.4
5:35 AM	0.03	0.2	643.5
5:40 AM	0.021	0.0	643.5

Effluent Flow Rate Calculation

Time	Measured Level (meters)	Rate of Change in Basin Volume (L/s)	Influent Flow Rate (L/s)	HMT Flow Rate (L/s)	Effluent Flow Rate (L/s)
12:00 AM	0.203	5.1			
12:05 AM	0.208	4.3			
12:10 AM	0.212	3.5			
12:15 AM	0.215	2.7	0.0		
12:20 AM	0.218	2.7	0.0		-2.7
12:25 AM	0.221	2.8	0.0		-2.8
12:30 AM	0.223	1.9	0.0		-1.9
12:35 AM	0.227	3.8	0.0		-3.8
12:40 AM	0.241	13.8	386.1	10	-13.8
12:45 AM	0.609	376.1	345.8	10	20.0
12:50 AM	0.917	314.8	65.7	10	41.0
12:55 AM	0.949	32.7	27.9	10	43.0
1:00 AM	0.935	-14.3	13.3	10	52.2
1:05 AM	0.906	-29.6	6.9	10	52.9
1:10 AM	0.873	-33.7	3.8	10	50.6
1:15 AM	0.839	-34.7	2.1	10	48.6
1:20 AM	0.806	-33.7	1.0	10	45.8
1:25 AM	0.774	-32.7	0.4	5.4	43.7
1:30 AM	0.745	-29.6	0.0	5.4	35.5
1:35 AM	0.717	-28.6	0.0	5.4	34.0
1:40 AM	0.692	-25.5	0.0	5.4	30.9
1:45 AM	0.668	-24.5	0.0	5.4	29.9
1:50 AM	0.646	-22.5	0.0	5.4	27.9
1:55 AM	0.626	-20.4	0.0	5.4	25.8
2:00 AM	0.607	-19.4	0.0	5.4	24.8
2:05 AM	0.59	-17.4	0.0	5.4	22.8
2:10 AM	0.575	-15.3	0.0	5.4	20.7
2:15 AM	0.56	-15.3	1.5	5.4	20.7
2:20 AM	0.549	-11.2	21.4	5.4	18.1
2:25 AM	0.552	3.1	40.6	5.4	23.7
2:30 AM	0.58	28.6	27.1	5.4	17.3
2:35 AM	0.613	33.7	42.7	5.4	-1.3
2:40 AM	0.643	30.7	44.4	5.4	17.4
2:45 AM	0.673	30.7	65.5	5.4	19.1
2:50 AM	0.72	48.0	74.1	5.4	22.9
2:55 AM	0.771	52.1	84.2	5.4	27.4
3:00 AM	0.826	56.2	123.0	5.4	33.4
3:05 AM	0.916	92.0	81.0	5.4	36.4

3:10 AM	0.963	48.0	59.5	5.4	38.4
3:15 AM	0.988	25.5	39.1	5.4	39.4
3:20 AM	0.992	4.1	21.7	5.4	40.4
3:25 AM	0.98	-12.3	42.7	5.4	39.4
3:30 AM	0.968	-12.3	38.9	5.4	60.3
3:35 AM	0.958	-10.2	37.7	5.4	54.5
3:40 AM	0.948	-10.2	38.1	5.4	53.3
3:45 AM	0.945	-3.1	37.7	5.4	46.6
3:50 AM	0.938	-7.2	33.1	5.4	50.3
3:55 AM	0.933	-5.1	27.9	5.4	43.6
4:00 AM	0.921	-12.3	27.2	5.4	45.5
4:05 AM	0.91	-11.2	31.7	5.4	43.9
4:10 AM	0.904	-6.1	41.0	5.4	43.2
4:15 AM	0.905	1.0	48.0	5.4	45.3
4:20 AM	0.915	10.2	45.3	5.4	43.2
4:25 AM	0.922	7.2	36.1	5.4	43.5
4:30 AM	0.923	1.0	24.7	5.4	40.5
4:35 AM	0.913	-10.2	16.4	5.4	40.3
4:40 AM	0.896	-17.4	11.2	5.4	39.2
4:45 AM	0.873	-23.5	7.9	5.4	40.1
4:50 AM	0.849	-24.5	5.8	5.4	37.9
4:55 AM	0.826	-23.5	4.3	5.4	34.7
5:00 AM	0.801	-25.5	3.2	5.4	35.2
5:05 AM	0.778	-23.5	2.3	5.4	32.1
5:10 AM	0.756	-22.5	1.7	5.4	30.2
5:15 AM	0.734	-22.5	1.3	5.4	29.6
5:20 AM	0.715	-19.4	0.9	5.4	26.1
5:25 AM	0.694	-21.5	0.6	5.4	27.8
5:30 AM	0.677	-17.4	0.4	5.4	23.4
5:35 AM	0.66	-17.4	0.2	5.4	23.1
5:40 AM	0.643	-17.4	0.0	5.4	23.0
5:45 AM	0.627	-16.4	0.0	5.4	21.8
5:50 AM	0.613	-14.3	0.0	5.4	19.7
5:55 AM	0.599	-14.3	0.0	5.4	19.7
6:00 AM	0.586	-13.3	0.0	5.4	18.7
6:05 AM	0.574	-12.3	0.0	5.4	17.7
6:10 AM	0.563	-11.2	0.0	5.4	16.6
6:15 AM	0.552	-11.2	0.0	5.4	16.6
6:20 AM	0.541	-11.2	0.0	5.4	16.6
6:25 AM	0.532	-9.2	0.0	5.4	14.6
6:30 AM	0.523	-9.2	0.0	5.4	14.6
6:35 AM	0.514	-9.2	0.0	5.4	14.6
6:40 AM	0.506	-8.2	0.0	5.4	13.6
6:45 AM	0.498	-8.2	0.0	5.4	13.6
6:50 AM	0.491	-7.2	0.0	5.4	12.6
6:55 AM	0.485	-6.1	0.0	5.4	11.5
7:00 AM	0.478	-7.2		5.4	12.6
7:05 AM	0.471	-7.2		5.4	12.6
7:10 AM	0.466	-5.1		5.4	10.5
7:15 AM	0.46	-6.1		5.4	11.5
7:20 AM	0.455	-5.1		5.4	10.5
7:25 AM	0.45	-5.1		5.4	10.5
7:30 AM	0.445	-5.1		5.4	10.5
7:35 AM	0.441	-4.1		5.4	9.5
7:40 AM	0.436	-5.1		5.4	10.5
7:45 AM	0.432	-4.1		5.4	9.5
7:50 AM	0.428	-4.1		5.4	9.5
7:55 AM	0.424	-4.1		5.4	9.5

8:00 AM	0.42	-4.1	5.4	9.5
8:05 AM	0.417	-3.1	5.4	8.5
8:10 AM	0.413	-4.1	5.4	9.5
8:15 AM	0.41	-3.1	5.4	8.5
8:20 AM	0.406	-4.1		9.5
8:25 AM	0.403	-3.1		3.1
8:30 AM	0.4	-3.1		3.1
8:35 AM	0.397	-3.1		3.1
8:40 AM	0.394	-3.1		3.1
8:45 AM	0.391	-3.1		3.1
8:50 AM	0.388	-3.1		3.1
8:55 AM	0.385	-3.1		3.1
9:00 AM	0.382	-3.1		3.1
9:05 AM	0.379	-3.1		3.1
9:10 AM	0.377	-2.0		2.0
9:15 AM	0.374	-3.1		3.1
9:20 AM	0.371	-3.1		3.1
9:25 AM	0.369	-2.0		2.0
9:30 AM	0.367	-2.0		2.0
9:35 AM	0.364	-3.1		3.1
9:40 AM	0.361	-3.1		3.1
9:45 AM	0.359	-2.0		2.0
9:50 AM	0.356	-3.1		3.1
9:55 AM	0.354	-2.0		2.0
10:00 AM	0.352	-2.0		2.0
10:05 AM	0.349	-3.1		3.1
10:10 AM	0.347	-2.0		2.0
10:15 AM	0.346	-1.0		1.0
10:20 AM	0.342	-4.1		4.1
10:25 AM	0.34	-2.0		2.0
10:30 AM	0.339	-1.0		1.0
10:35 AM	0.334	-5.1		5.1
10:40 AM	0.333	-1.0		1.0
10:45 AM	0.332	-1.0		1.0
10:50 AM	0.327	-5.1		5.1
10:55 AM	0.326	-1.0		1.0
11:00 AM	0.323	-3.1		3.1
11:05 AM	0.317	-6.1		6.1
11:10 AM	0.313	-4.1		4.1
11:15 AM	0.31	-3.1		3.1
11:20 AM	0.304	-6.1		6.1
11:25 AM	0.301	-3.1		3.1
11:30 AM	0.298	-3.1		3.1
11:35 AM	0.293	-5.1		5.1
11:40 AM	0.29	-3.1		3.1
11:45 AM	0.287	-3.1		3.1
11:50 AM	0.282	-5.1		5.1
11:55 AM	0.279	-3.1		3.1
12:00 PM	0.277	-2.0		2.0
12:05 PM	0.271	-6.1		6.1
12:10 PM	0.269	-2.0		2.0
12:15 PM	0.266	-3.1		3.1
12:20 PM	0.263	-3.1		3.1
12:25 PM	0.26	-3.1		3.1
12:30 PM	0.257	-3.1		3.1
12:35 PM	0.252	-5.1		5.1
12:40 PM	0.249	-3.1		3.1
12:45 PM	0.246	-3.1		3.1

12:50 PM	0.243	-3.1	3.1
12:55 PM	0.24	-3.1	3.1
1:00 PM	0.237	-3.0	3.0
1:05 PM	0.234	-3.0	3.0
1:10 PM	0.231	-2.9	2.9
1:15 PM	0.228	-2.9	2.9
1:20 PM	0.226	-1.9	1.9
1:25 PM	0.223	-2.8	2.8
1:30 PM	0.219	-3.7	3.7
1:35 PM	0.217	-1.8	1.8
1:40 PM	0.215	-1.8	1.8
1:45 PM	0.211	-3.6	3.6
1:50 PM	0.208	-2.6	2.6
1:55 PM	0.206	-1.7	1.7
2:00 PM	0.202	-3.4	3.4

Date 4/4/95

Influent Flow Rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flow Rate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
10:50 AM	0	0.0	0.0				
10:55 AM	0	14.7	4.4	21.7	0.227	3	10
11:00 AM	0.3344	91.8	31.9	93.8	0.368	8	10
11:05 AM	0.3694	132.0	71.5	127.0	0.476	15	10
11:10 AM	0.3004	92.8	99.4	85.8	0.536	17	10
11:15 AM	0.2354	37.1	110.5	51.1	0.576		
11:20 AM	0.2264	33.6	120.6				
11:25 AM	0.3014	77.4	143.8	66.4	0.706	21	10
11:30 AM	0.3414	92.1	171.5	74.1	0.772	28	10
11:35 AM	0.2884	76.1	194.3	52.1	0.808	34	10
11:40 AM	0.2554	57.2	211.4	31.2	0.833	36	10
11:45 AM	0.2494	42.8	224.3	23.0	0.853		
11:50 AM	0.2434	40.3	236.4				
11:55 AM	0.2344	36.7	247.4				
12:00 PM	0.2334	36.3	258.3				
12:05 PM	0.2394	38.7	269.9				
12:10 PM	0.2324	35.9	280.7				
12:15 PM	0.2114	28.3	289.2				
12:20 PM	0.2014	25.1	296.7				
12:25 PM	0.1984	24.2	303.9				
12:30 PM	0.1764	18.0	309.3				
12:35 PM	0.1364	9.5	312.2				
12:40 PM	0.0964	4.0	313.4				
12:45 PM	0.0584	1.1	313.7				
12:50 PM	0.0254	0.1	313.8				

Effluent Flow Rate Calculation

Time	Measured Level (meters)	Rate of Change in Basin Volume (L/s)	Influent Flow Rate (L/s)	HMT Flow Rate (L/s)	Effluent Flow Rate (L/s)
10:55 AM	0.175	-0.7	14.7	10	
11:00 AM	0.227	44.1	91.8	10	19.2
11:05 AM	0.368	143.6	132.0	10	-21.7
11:10 AM	0.476	110.4	92.8	10	12.0
11:15 AM	0.536	61.3	37.1	10	13.6
11:20 AM	0.576	40.9	33.6	10	4.5
11:25 AM	0.627	52.1	77.4	10	13.4
11:30 AM	0.706	80.7	92.1	10	14.0
11:35 AM	0.772	67.4	76.1	10	26.7
11:40 AM	0.808	36.8	57.2	10	39.9
11:45 AM	0.833	25.5	42.8	10	41.6
11:50 AM	0.853	20.4	40.3	10	32.4
11:55 AM	0.868	15.3	36.7	10	35.0
12:00 PM	0.88	12.3	36.3	10	34.4
12:05 PM	0.889	9.2	38.7	10	37.1
12:10 PM	0.899	10.2	35.9	10	38.5
12:15 PM	0.9	1.0	28.3	10	44.9

12:20 PM	0.897	-3.1	25.1	10	41.4
12:25 PM	0.895	-2.0	24.2	10	37.1
12:30 PM	0.889	-6.1	18.0	10	40.3
12:35 PM	0.876	-13.3	9.5	10	41.3
12:40 PM	0.857	-19.4	4.0	10	38.9
12:45 PM	0.831	-26.6	1.1	5.4	40.5
12:50 PM	0.812	-19.4	0.1	5.4	26.0
12:55 PM	0.787	-25.5		5.4	31.1
1:00 PM	0.766	-21.5		5.4	26.9
1:05 PM	0.744	-22.5		5.4	27.9
1:10 PM	0.727	-17.4		5.4	22.8
1:15 PM	0.713	-14.3		5.4	19.7
1:20 PM	0.693	-20.4		5.4	25.8
1:25 PM	0.677	-16.4		5.4	21.8
1:30 PM	0.663	-14.3		5.4	19.7
1:35 PM	0.649	-14.3		5.4	19.7
1:40 PM	0.633	-16.4		5.4	21.8
1:45 PM	0.618	-15.3		5.4	20.7
1:50 PM	0.607	-11.2		5.4	16.6
1:55 PM	0.593	-14.3		5.4	19.7
2:00 PM	0.581	-12.3		5.4	17.7
2:05 PM	0.569	-12.3		5.4	17.7
2:10 PM	0.556	-13.3		5.4	18.7
2:15 PM	0.544	-12.3		5.4	17.7
2:20 PM	0.532	-12.3		5.4	17.7
2:25 PM	0.516	-16.4		5.4	21.8
2:30 PM	0.502	-14.3		5.4	19.7
2:35 PM	0.486	-16.4		5.4	21.8
2:40 PM	0.472	-14.3		5.4	19.7
2:45 PM	0.46	-12.3		5.4	17.7
2:50 PM	0.449	-11.2		5.4	16.6
2:55 PM	0.436	-13.3		5.4	18.7
3:00 PM	0.426	-10.2		5.4	15.6
3:05 PM	0.416	-10.2		5.4	15.6
3:10 PM	0.405	-11.2		5.4	16.6
3:15 PM	0.395	-10.2		5.4	15.6
3:20 PM	0.387	-8.2		5.4	13.6
3:25 PM	0.378	-9.2		5.4	14.6
3:30 PM	0.37	-8.2		5.4	13.6
3:35 PM	0.362	-8.2		5.4	13.6
3:40 PM	0.354	-8.2		5.4	13.6
3:45 PM	0.347	-7.2			12.6
3:50 PM	0.34	-7.2			7.2
3:55 PM	0.333	-7.2			7.2
4:00 PM	0.326	-7.2			7.2
4:05 PM	0.319	-7.2			7.2
4:10 PM	0.314	-5.1			5.1
4:15 PM	0.308	-6.1			6.1
4:20 PM	0.302	-6.1			6.1
4:25 PM	0.296	-6.1			6.1
4:30 PM	0.291	-5.1			5.1
4:35 PM	0.286	-5.1			5.1
4:40 PM	0.281	-5.1			5.1
4:45 PM	0.276	-5.1			5.1
4:50 PM	0.272	-4.1			4.1
4:55 PM	0.267	-5.1			5.1
5:00 PM	0.263	-4.1			4.1
5:05 PM	0.258	-5.1			5.1

5:10 PM	0.254	-4.1	4.1
5:15 PM	0.25	-4.1	4.1
5:20 PM	0.246	-4.1	4.1
5:25 PM	0.241	-5.1	5.1
5:30 PM	0.237	-4.0	4.0
5:35 PM	0.233	-4.0	4.0
5:40 PM	0.23	-2.9	2.9
5:45 PM	0.225	-4.8	4.8
5:50 PM	0.222	-2.8	2.8
5:55 PM	0.218	-3.7	3.7
6:00 PM	0.214	-3.6	3.6
6:05 PM	0.211	-2.7	2.7
6:10 PM	0.207	-3.5	3.5
6:15 PM	0.204	-2.6	2.6
6:20 PM	0.2	-3.4	3.4

Date **4/18/95**

Influent Flow Rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flow Rate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
1:50 AM	0	0.0					
1:55 AM	0.038	0.1					
2:00 AM	0.091	1.2					
2:05 AM	0.099	2.4					
2:10 AM	0.09	3.5					
2:15 AM	0.074	4.1					
2:20 AM	0.119	6.1					
2:25 AM	0.204	13.8					
2:30 AM	0.203	21.6					
2:35 AM	0.212	30.2					
2:40 AM	0.204	37.9					
2:45 AM	0.169	42.8					
2:50 AM	0.131	45.4					
2:55 AM	0.105	46.8					
3:00 AM	0.08	47.6					
3:05 AM	0.052	47.8					
3:10 AM	0.019	47.9					
3:15 AM	0						

Effluent Flow Rate Calculation

Time	Measured Level (meters)	Rate of Change in Basin Volume (L/s)	Influent Flow Rate (L/s)	HMT Flow Rate (L/s)	Effluent Flow Rate (L/s)
1:20 AM	0.009	0.2	0.0		
1:25 AM	0.005	-0.1	0.0		
1:30 AM	0.084	14.8	0.0		
1:35 AM	0.114	12.5	0.0		
1:40 AM	0.137	12.2	0.0		
1:45 AM	0.154	10.4	0.0		
1:50 AM	0.168	9.5	0.0		
1:55 AM	0.183	11.1	0.4		
2:00 AM	0.196	10.4	3.5	10	1.5
2:05 AM	0.209	11.1	4.3	10	2.8
2:10 AM	0.223	12.7	3.4	10	1.1
2:15 AM	0.232	8.6	2.0	10	4.1
2:20 AM	0.241	9.0	6.7	10	5.4
2:25 AM	0.261	20.4	25.8	10	5.8
2:30 AM	0.29	29.6	25.8	10	6.2
2:35 AM	0.318	28.6	28.7	10	8.6
2:40 AM	0.347	29.6	25.9	10	7.6
2:45 AM	0.37	23.5	16.2	10	7.5
2:50 AM	0.384	14.3	8.6	10	8.1
2:55 AM	0.394	10.2	4.9	10	6.5
3:00 AM	0.399	5.1	2.5	10	8.6
3:05 AM	0.403	4.1	0.8	5.4	3.0
3:10 AM	0.407	4.1	0.1	5.4	1.8
3:15 AM	0.41	3.1	0.0	5.4	2.4

3:20 AM	0.413	3.1	0.0	5.4	2.3
3:25 AM	0.416	3.1	0.0	5.4	2.3
3:30 AM	0.418	2.0	0.0	5.4	3.4
3:35 AM	0.42	2.0	0.0	5.4	3.4
3:40 AM	0.422	2.0	0.0	5.4	3.4
3:45 AM	0.423	1.0	0.0	5.4	4.4
3:50 AM	0.424	1.0	0.0	5.4	4.4
3:55 AM	0.425	1.0	0.0	5.4	4.4
4:00 AM	0.426	1.0	0.0	5.4	4.4
4:05 AM	0.426	0.0	0.0	5.4	5.4
4:10 AM	0.426	0.0	0.0	5.4	5.4
4:15 AM	0.425	-1.0	0.0	5.4	6.4
4:20 AM	0.423	-2.0	0.0	5.4	7.4
4:25 AM	0.422	-1.0	0.0	5.4	6.4
4:30 AM	0.421	-1.0	0.0	5.4	6.4
4:35 AM	0.418	-3.1	0.0	5.4	8.5
4:40 AM	0.416	-2.0	0.0	5.4	7.4
4:45 AM	0.414	-2.0	0.0	5.4	7.4
4:50 AM	0.407	-7.2	0.0	5.4	12.6
4:55 AM	0.4	-7.2	0.0	5.4	12.6
5:00 AM	0.392	-8.2	0.0	5.4	13.6
5:05 AM	0.385	-7.2	0.0	5.4	12.6
5:10 AM	0.379	-6.1	0.0	5.4	11.5
5:15 AM	0.372	-7.2	0.0	5.4	12.6
5:20 AM	0.366	-6.1	0.0	5.4	11.5
5:25 AM	0.361	-5.1	0.0	5.4	10.5
5:30 AM	0.354	-7.2	0.0	5.4	12.6
5:35 AM	0.348	-6.1	0.0	5.4	11.5
5:40 AM	0.343	-5.1	0.0	5.4	10.5
5:45 AM	0.337	-6.1	0.0	5.4	11.5
5:50 AM	0.331	-6.1	0.0	5.4	11.5
5:55 AM	0.328	-3.1	0.0	5.4	8.5
6:00 AM	0.322	-6.1	0.0	5.4	11.5
6:05 AM	0.316	-6.1	0.0		6.1
6:10 AM	0.311	-5.1	0.0		5.1
6:15 AM	0.308	-3.1	0.0		3.1
6:20 AM	0.302	-6.1	0.0		6.1
6:25 AM	0.298	-4.1	0.0		4.1
6:30 AM	0.293	-5.1	0.0		5.1
6:35 AM	0.288	-5.1	0.0		5.1
6:40 AM	0.284	-4.1	0.0		4.1
6:45 AM	0.28	-4.1	0.0		4.1
6:50 AM	0.276	-4.1	0.0		4.1
6:55 AM	0.271	-5.1	0.0		5.1
7:00 AM	0.268	-3.1	0.0		3.1
7:05 AM	0.264	-4.1	0.0		4.1
7:10 AM	0.26	-4.1	0.0		4.1
7:15 AM	0.256	-4.1	0.0		4.1
7:20 AM	0.252	-4.1	0.0		4.1
7:25 AM	0.25	-2.0	0.0		2.0
7:30 AM	0.245	-5.1	0.0		5.1
7:35 AM	0.242	-3.1	0.0		3.1
7:40 AM	0.238	-4.0	0.0		4.0
7:45 AM	0.235	-3.0	0.0		3.0
7:50 AM	0.231	-3.9	0.0		3.9
7:55 AM	0.228	-2.9	0.0		2.9
8:00 AM	0.224	-3.8	0.0		3.8
8:05 AM	0.221	-2.8	0.0		2.8

8:10 AM	0.218	-2.8	0.0	2.8
8:15 AM	0.214	-3.6	0.0	3.6
8:20 AM	0.211	-2.7	0.0	2.7
8:25 AM	0.209	-1.8	0.0	1.8
8:30 AM	0.205	-3.5	0.0	3.5
8:35 AM	0.202	-2.6	0.0	2.6
8:40 AM	0.198	-3.4	0.0	3.4
8:45 AM	0.195	-2.5	0.0	2.5
8:50 AM	0.192	-2.4	0.0	2.4
8:55 AM	0.189	-2.4	0.0	2.4
9:00 AM	0.187	-1.6	0.0	1.6
9:05 AM	0.183	-3.1	0.0	3.1
9:10 AM	0.18	-2.3	0.0	2.3
9:15 AM	0.178	-1.5	0.0	1.5
9:20 AM	0.175	-2.2	0.0	2.2
9:25 AM	0.171	-2.9	0.0	2.9
9:30 AM	0.169	-1.4	0.0	1.4
9:35 AM	0.166	-2.1	0.0	2.1
9:40 AM	0.163	-2.1	0.0	2.1
9:45 AM	0.16	-2.0	0.0	2.0
9:50 AM	0.158	-1.3	0.0	1.3
9:55 AM	0.154	-2.6	0.0	2.6
10:00 AM	0.152	-1.3	0.0	1.3
10:05 AM	0.15	-1.3	0.0	1.3
10:10 AM	0.146	-2.5	0.0	2.5
10:15 AM	0.145	-0.6	0.0	0.6
10:20 AM	0.143	-1.2	0.0	1.2
10:25 AM	0.138	-3.0	0.0	3.0
10:30 AM	0.137	-0.6	0.0	0.6
10:35 AM	0.135	-1.1	0.0	1.1
10:40 AM	0.131	-2.2	0.0	2.2
10:45 AM	0.13	-0.6	0.0	0.6
10:50 AM	0.128	-1.1	0.0	1.1
10:55 AM	0.123	-2.6	0.0	2.6
11:00 AM	0.122	-0.5	0.0	0.5
11:05 AM	0.121	-0.5	0.0	0.5
11:10 AM	0.116	-2.5	0.0	2.5
11:15 AM	0.115	-0.5	0.0	0.5
11:20 AM	0.114	-0.5	0.0	0.5
11:25 AM	0.11	-1.9	0.0	1.9
11:30 AM	0.108	-0.9	0.0	0.9
11:35 AM	0.107	-0.5	0.0	0.5
11:40 AM	0.11	1.4	0.0	-1.4
11:45 AM	0.118	3.8	0.0	-3.8
11:50 AM	0.117	-0.5	0.0	0.5
11:55 AM	0.114	-1.5	0.0	1.5
12:00 PM	0.112	-1.0	0.0	1.0
12:05 PM	0.111	-0.5	0.0	0.5
12:10 PM	0.107	-1.8	0.0	1.8
12:15 PM	0.106	-0.4	0.0	0.4
12:20 PM	0.104	-0.9	0.0	0.9
12:25 PM	0.101	-1.3	0.0	1.3

Date **4/19/95**

Influent Flow Rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flow Rate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
10:40 AM	0	0.0	0.0				
10:45 AM	0.102	4.6	1.4				
10:50 AM	0.146	11.3	4.8				
10:55 AM	0.151	12.2	8.4				
11:00 AM	0.148	11.6	11.9				
11:05 AM	0.467	160.5	60.0	86.9	0.4	8	10
11:10 AM	0.396	202.3	120.7	238.1	0.633	11	10
11:15 AM	0.414	154.0	166.9	164.5	0.794	25	10
11:20 AM	0.355	100.6	197.1	113.4	0.905	35	10
11:25 AM	0.266	46.9	211.2	37.8	0.942	40	10
11:30 AM	0.191	21.9	217.7	-4.1	0.938		
11:35 AM	0.132	8.8	220.4				
11:40 AM	0.088	3.2	221.3				
11:45 AM	0.05	0.8	221.6				
11:50 AM	0.015	0.0	221.6				
11:55 AM	0	0.0	221.6				

Effluent Flow Rate Calculation

Time	Measured Level (meters)	Rate of Change in Basin Volume (L/s)	Influent Flow Rate (L/s)	HMT Flow Rate (L/s)	Effluent Flow Rate (L/s)
10:40 AM	0.246	5.1	0.0		
10:45 AM	0.254	8.2	4.6	10.0	
10:50 AM	0.272	18.4	11.3	10.0	-0.4
10:55 AM	0.293	21.5	12.2	10.0	0.3
11:00 AM	0.315	22.5	11.6	10	-0.6
11:05 AM	0.4	86.9	160.5	10	9.2
11:10 AM	0.633	238.1	202.3	10	-46.7
11:15 AM	0.794	164.5	154.0	10	23.6
11:20 AM	0.905	113.4	100.6	10	23.9
11:25 AM	0.942	37.8	46.9	10	45.9
11:30 AM	0.938	-4.1	21.9	10	48.5
11:35 AM	0.916	-22.5	8.8	10	47.8
11:40 AM	0.89	-26.6	3.2	10	42.5
11:45 AM	0.863	-27.6	0.8	5.4	35.0
11:50 AM	0.837	-26.6	0.0	5.4	32.4
11:55 AM	0.812	-25.5	0.0	5.4	31.0
12:00 PM	0.79	-22.5	0.0	5.4	27.9
12:05 PM	0.768	-22.5	0.0	5.4	27.9
12:10 PM	0.749	-19.4	0.0	5.4	24.8
12:15 PM	0.731	-18.4	0.0	5.4	23.8
12:20 PM	0.713	-18.4	0.0	5.4	23.8
12:25 PM	0.696	-17.4	0.0	5.4	22.8
12:30 PM	0.681	-15.3	0.0	5.4	20.7
12:35 PM	0.667	-14.3	0.0	5.4	19.7
12:40 PM	0.652	-15.3	0.0	5.4	20.7
12:45 PM	0.639	-13.3	0.0	5.4	18.7

12:50 PM	0.626	-13.3	0.0	5.4	18.7
12:55 PM	0.616	-10.2	0.0	5.4	15.6
1:00 PM	0.605	-11.2	0.0	5.4	16.6
1:05 PM	0.597	-8.2	0.0	5.4	13.6
1:10 PM	0.587	-10.2	0.0	5.4	15.6
1:15 PM	0.579	-8.2	0.0	5.4	13.6
1:20 PM	0.572	-7.2	0.0	5.4	12.6
1:25 PM	0.565	-7.2	0.0	5.4	12.6
1:30 PM	0.559	-6.1	0.0	5.4	11.5
1:35 PM	0.552	-7.2	0.0	5.4	12.6
1:40 PM	0.547	-5.1	0.0	5.4	10.5
1:45 PM	0.54	-7.2	0.0	5.4	12.6
1:50 PM	0.537	-3.1	0.0	5.4	8.5
1:55 PM	0.529	-8.2	0.0	5.4	13.6
2:00 PM	0.526	-3.1	0.0	5.4	8.5
2:05 PM	0.521	-5.1	0.0	5.4	10.5
2:10 PM	0.515	-6.1	0.0	5.4	11.5
2:15 PM	0.51	-5.1	0.0	5.4	10.5
2:20 PM	0.505	-5.1	0.0	5.4	10.5
2:25 PM	0.5	-5.1	0.0	5.4	10.5
2:30 PM	0.495	-5.1	0.0	5.4	10.5
2:35 PM	0.491	-4.1	0.0	5.4	9.5
2:40 PM	0.486	-5.1	0.0	5.4	10.5
2:45 PM	0.478	-8.2	0.0		8.2
2:50 PM	0.47	-8.2	0.0		8.2
2:55 PM	0.46	-10.2	0.0		10.2
3:00 PM	0.453	-7.2	0.0		7.2
3:05 PM	0.444	-9.2	0.0		9.2
3:10 PM	0.437	-7.2	0.0		7.2
3:15 PM	0.43	-7.2	0.0		7.2
3:20 PM	0.424	-6.1	0.0		6.1
3:25 PM	0.415	-9.2	0.0		9.2
3:30 PM	0.409	-6.1	0.0		6.1
3:35 PM	0.404	-5.1	0.0		5.1
3:40 PM	0.395	-9.2	0.0		9.2
3:45 PM	0.391	-4.1	0.0		4.1
3:50 PM	0.385	-6.1	0.0		6.1
3:55 PM	0.378	-7.2	0.0		7.2
4:00 PM	0.373	-5.1	0.0		5.1
4:05 PM	0.369	-4.1	0.0		4.1
4:10 PM	0.361	-8.2	0.0		8.2
4:15 PM	0.357	-4.1	0.0		4.1
4:20 PM	0.353	-4.1	0.0		4.1
4:25 PM	0.348	-5.1	0.0		5.1
4:30 PM	0.343	-5.1	0.0		5.1
4:35 PM	0.339	-4.1	0.0		4.1
4:40 PM	0.334	-5.1	0.0		5.1
4:45 PM	0.328	-6.1	0.0		6.1
4:50 PM	0.325	-3.1	0.0		3.1
4:55 PM	0.319	-6.1	0.0		6.1
5:00 PM	0.315	-4.1	0.0		4.1
5:05 PM	0.311	-4.1	0.0		4.1
5:10 PM	0.307	-4.1	0.0		4.1
5:15 PM	0.303	-4.1	0.0		4.1
5:20 PM	0.299	-4.1	0.0		4.1
5:25 PM	0.295	-4.1	0.0		4.1
5:30 PM	0.291	-4.1	0.0		4.1
5:35 PM	0.288	-3.1	0.0		3.1

5:40 PM	0.284	-4.1	0.0	4.1
5:45 PM	0.281	-3.1	0.0	3.1
5:50 PM	0.278	-3.1	0.0	3.1
5:55 PM	0.274	-4.1	0.0	4.1
6:00 PM	0.271	-3.1	0.0	3.1
6:05 PM	0.268	-3.1	0.0	3.1
6:10 PM	0.264	-4.1	0.0	4.1
6:15 PM	0.261	-3.1	0.0	3.1
6:20 PM	0.258	-3.1	0.0	3.1
6:25 PM	0.255	-3.1	0.0	3.1
6:30 PM	0.252	-3.1	0.0	3.1
6:35 PM	0.249	-3.1	0.0	3.1
6:40 PM	0.247	-2.0	0.0	2.0
6:45 PM	0.242	-5.1	0.0	5.1
6:50 PM	0.239	-3.0	0.0	3.0
6:55 PM	0.238	-1.0	0.0	1.0
7:00 PM	0.235	-3.0	0.0	3.0
7:05 PM	0.231	-3.9	0.0	3.9
7:10 PM	0.23	-1.0	0.0	1.0
7:15 PM	0.227	-2.9	0.0	2.9
7:20 PM	0.223	-3.8	0.0	3.8
7:25 PM	0.222	-0.9	0.0	0.9
7:30 PM	0.218	-3.7	0.0	3.7
7:35 PM	0.215	-2.7	0.0	2.7
7:40 PM	0.214	-0.9	0.0	0.9
7:45 PM	0.21	-3.6	0.0	3.6
7:50 PM	0.207	-2.6	0.0	2.6
7:55 PM	0.206	-0.9	0.0	0.9
8:00 PM	0.203	-2.6	0.0	2.6

Date **4/22/95**

Influent Flow Rate Measurement and Calculation

Time	Level at the Weir (m)	Estimated Inflow (L/s)	Cumulative Inflow (m^3)	Net Flow Rate into Basin (L/s)	Pond Level (m)	Estimated Outflow (L/s)	HMT Flow (L/s)
3:30 PM	0	0.0	0.0				
3:35 PM	0.085	2.9	0.9				
3:40 PM	0.346	94.6	29.3	91.7	0.214		
3:45 PM	0.293	77.9	52.6	105.6	0.319	6	10
3:50 PM	0.217	30.4	61.7	52.1	0.37	9	10
3:55 PM	0.153	12.6	65.5	30.4			
4:00 PM	0.102	4.6	66.9				
4:05 PM	0.061	1.2	67.3				
4:10 PM	0.019	0.1	67.3				
4:15 PM	0	0.0	67.3				

Effluent Flow Rate Calculation

Time	Measured Level (meters)	Rate of Change in Basin Volume (L/s)	Influent Flow Rate (L/s)	HMT Flow Rate (L/s)	Effluent Flow Rate (L/s)
3:30 PM	0.025	1.0	0.0		-1.0
3:35 PM	0.048	3.5	2.9	10.0	-2.1
3:40 PM	0.214	91.7	94.6	10.0	-32.9
3:45 PM	0.319	105.6	77.9	10.0	-9.4
3:50 PM	0.37	52.1	30.4	10.0	12.0
3:55 PM	0.395	25.5	12.6	10.0	6.0
4:00 PM	0.403	8.2	4.6	10.0	10.4
4:05 PM	0.402	-1.0	1.2	10.0	14.0
4:10 PM	0.402	0.0	0.1	5.4	10.7
4:15 PM	0.399	-3.1	0.0	5.4	8.5
4:20 PM	0.397	-2.0	0.0	5.4	7.4
4:25 PM	0.396	-1.0	0.0	5.4	6.4
4:30 PM	0.392	-4.1	0.0	5.4	9.5
4:35 PM	0.389	-3.1		5.4	8.5
4:40 PM	0.388	-1.0		5.4	6.4
4:45 PM	0.385	-3.1		5.4	8.5
4:50 PM	0.381	-4.1		5.4	9.5
4:55 PM	0.379	-2.0		5.4	7.4
5:00 PM	0.377	-2.0		5.4	7.4
5:05 PM	0.373	-4.1		5.4	9.5
5:10 PM	0.37	-3.1		5.4	8.5
5:15 PM	0.366	-4.1		5.4	9.5
5:20 PM	0.361	-5.1		5.4	10.5
5:25 PM	0.358	-3.1		5.4	8.5
5:30 PM	0.354	-4.1		5.4	9.5
5:35 PM	0.351	-3.1		5.4	8.5
5:40 PM	0.347	-4.1		5.4	9.5
5:45 PM	0.342	-5.1		5.4	10.5
5:50 PM	0.338	-4.1		5.4	9.5
5:55 PM	0.329	-9.2		5.4	14.6
6:00 PM	0.322	-7.2		5.4	12.6
6:05 PM	0.312	-10.2		5.4	15.6

6:10 PM	0.306	-6.1	5.4	11.5
6:15 PM	0.299	-7.2	5.4	12.6
6:20 PM	0.291	-8.2	5.4	13.6
6:25 PM	0.286	-5.1	5.4	10.5
6:30 PM	0.28	-6.1	5.4	11.5
6:35 PM	0.274	-6.1	5.4	11.5
6:40 PM	0.268	-6.1	5.4	11.5
6:45 PM	0.263	-5.1	5.4	10.5
6:50 PM	0.258	-5.1	5.4	10.5
6:55 PM	0.254	-4.1	5.4	9.5
7:00 PM	0.249	-5.1	5.4	10.5
7:05 PM	0.244	-5.1	5.4	10.5
7:10 PM	0.24	-4.1	5.4	9.5
7:15 PM	0.235	-5.0		10.4
7:20 PM	0.232	-3.0		3.0
7:25 PM	0.228	-3.9		3.9
7:30 PM	0.224	-3.8		3.8
7:35 PM	0.219	-4.7		4.7
7:40 PM	0.216	-2.8		2.8
7:45 PM	0.212	-3.6		3.6
7:50 PM	0.208	-3.5		3.5
7:55 PM	0.205	-2.6		2.6
8:00 PM	0.201	-3.4		3.4

Summary of Concentration Data

Date: **1/12/95**

Constituent	Concentration Data (mg/L)							
	Influent Composite Samples				Effluent Composite Samples			
	1	2	3	4	1	2	3	4
TSS	36				60	0	8	4
VSS	0				0	0	0	0
COD								
Total Carbon	17.4				21.3	25.1	26.4	27.7
Diss. T Carbon								
Nitrate	0.26				0.35	0.43	0.48	0.43
Oil & Grease								
Chromium	0.003				0.005	0.004	0.0023	0.0023
Zinc	0.267				0.023	0.032	0.029	0.033
Cadmium	<0.0013				<DL	<DL	<DL	<DL
Lead	<0.014				<DL	<DL	<DL	<DL
Nickel	<0.005				<DL	<DL	<DL	<DL
Iron	1.159				1.243	0.681	0.631	0.416
Copper	0.004				0.002	0.003	0.002	0.002

Date: **2/24/95**

Constituent	Concentration Data (mg/L)								
	Influent Composite Samples				Effluent Grab Samples				
	1	2	3	4	1	2	3	4	5
TSS	144	196	152	48	52	48	40	36	24
VSS	4	20	16	12	0	12	4	4	16
COD	31	26	14	11	22	16	18	16	25
Total Carbon	15.8	11.6	6.1	8.9	26.8	5.4	7.5	6.8	3.4
Diss. T Carbon	1.3	2	1	1.3	2.7	1	2.7	1	1
Nitrate	0.51	0.34	0.32	0.51	0.53	0.62	0.6	0.65	0.6
Oil & Grease					1		0.7		
Chromium	0.005	0.006	0.003	<0.0023	0.003	0.004	0.002	<0.0023	<0.0023
Zinc	0.027	0.029	0.023	0.014	0.019	0.014	0.016	0.017	0.015
Cadmium	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013
Lead	0.023	0.02	<0.014	<0.014	<0.014	<0.014	0.022	<0.014	<0.014
Nickel	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Iron	3.285	4.495	3.626	1.96	3.691	2.206	2.373	1.803	1.436
Copper	0.008	0.011	0.01	0.006	0.01	0.003	0.005	0.017	0.006

Date: **2/25/95**

Constituent	Concentration Data (mg/L)							
	Influent Composite Samples				Effluent Composite Samples			
	1	2	3	4	1	2	3	4
TSS	96	36	20		20	28	16	12
VSS	12	4	12		4	0	0	4
COD	12	11	13		12	7	9	13
Total Carbon	7.5	3.4	4.7		6.8	9.6	8.9	5.4
Diss. T Carbon	1.3	2	3.4		1	2	3.4	2
Nitrate	0.28	0.28	0.24		0.22	0.3	0.22	0
Oil & Grease			0.7		1.4		1.2	
Chromium	0.004	0.003	0.002		0.003	0.024	0.0023	0.003
Zinc	0.015	0.019	0.013		0.025	0.019	0.012	0.012
Cadmium	<0.0013	<0.0013	<0.0013		<0.0013	<0.0013	<0.0013	<0.0013
Lead	0.014	0.027	0.014		0.014	0.014	0.014	0.033
Nickel	<0.005	<0.005	<0.005		<0.005	<0.005	<0.005	<0.005
Iron	1.341	1.015	1.012		1.073	1.346	0.973	1.039
Copper	0.009	0.021	0.009		0.004	0.004	0.006	0.008

Date: **3/7/95**

Constituent	Concentration Data (mg/L)							
	Influent Composite Samples				Effluent Composite Samples			
	1	2	3	4	1	2	3	4
TSS	52				80	40		
VSS	16				28	24		
COD	19				17	21		
Total Carbon	4				17.9	8.4		
Diss. T Carbon	4.6				4	4		
Nitrate								
Oil & Grease								
Chromium	0.004				0.004	0.003		
Zinc	0.014				0.018	0.012		
Cadmium	0.0013				0.0013	0.0013		
Lead	0.014				0.023	0.014		
Nickel	0.005				0.005	0.005		
Iron	1.69				2.156	1.264		
Copper	0.014				0.013	0.014		

Date: 3/13/95

Constituent	Concentration Data (mg/l)							
	Influent Composite Samples				Effluent Composite Samples			
	1	2	3	4	1	2	3	4
TSS	268	60	204	36	132	56	36	28
VSS	12	8	24	0	12	24	4	4
COD	13	7	7	10	27	11	8	12
Total Carbon	4	1.5	1	1.5	14.1	3.4	2.7	5.9
Diss. T Carbon	1	1	1	1	6.5	1.5	1.5	5.3
Nitrate	0.11	0.15	0.11	0.11	0.36	0.17	0.1	0.1
Oil & Grease	0.8		1.7		1.8		1.3	
Chromium	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023	<0.0023
Zinc	0.01	0.033	<0.0007	0.005	0.002	0.02	0.008	0.007
Cadmium	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013	<0.0013
Lead	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014	<0.014
Nickel	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Iron	0.637	2.138	0.696	0.873	0.088	2.278	1.149	0.984
Copper	0.015	<0.002	0.002	<0.002	<0.002	0.003	0.005	<0.002

Date: 4/4/95

Constituent	Concentration Data (mg/L)							
	Influent Composite Samples				Effluent Composite Samples			
	1	2	3	4	1	2	3	4
TSS	32	12			100	20	12	24
VSS	28	12			4	0	4	4
COD	4	2			23	9	11	9
Total Carbon	2.8	2.1			12.3	5.3	4	3
Diss. T Carbon	<1.0	<1.0			4.9	<1.0	2	3
Nitrate	0.07	0.03			0.2	0.09	0.09	0.07
T. Phosphorus	0.03	0.01			0.11	0.05	0.04	0.04
Oil & Grease					2		0.09	
Chromium	<0.0023	<0.0023			<0.0023	<0.0023	<0.0023	<0.0023
Zinc	<0.0007	0.006			0.025	0.005	0.012	0.011
Cadmium	<0.0013	<0.0013			<0.0013	<0.0013	<0.0013	<0.0013
Lead	<0.014	<0.014			<0.014	<0.014	<0.014	<0.014
Nickel	<0.005	<0.005			<0.005	<0.005	<0.005	<0.005
Iron	0.571	0.350			1.539	0.716	0.60	0.74
Copper	0.002	0.011			0.004	<0.002	0.002	<0.002

Date: **4/18/95**

Constituent	Concentration Data (mg/L)							
	Influent Composite Samples				Effluent Composite Samples			
	1	2	3	4	1	2	3	4
TSS	36				28	8	8	8
VSS	16				0	8	8	4
COD	36				38	31	27	31
Total Carbon	10.4				16.2	17.4	14	14
Diss. T Carbon	2.8				9.5	11.3	11	8
Nitrate	0.35				0.62	0.55	0.64	0.55
T. Phosphorus	0.14				0.15	0.13	0.12	0.16
Oil & Grease								
Chromium	<0.0023				<0.0023	<0.0023	<0.0023	<0.0023
Zinc	<0.0007				0.014	0.006	0.004	<0.0007
Cadmium	<0.0013				<0.0013	<0.0013	<0.0013	<0.0013
Lead					0.017	<0.014	<0.014	<0.014
Nickel	<0.005				<0.005	<0.005	<0.005	<0.005
Iron	0.684				0.542	0.385	0.320	0.213
Copper	<0.002				0.002	<0.002	<0.002	<0.002

Date: **4/19/95**

Constituent	Concentration Data (mg/L)							
	Influent Composite Samples				Effluent Composite Samples			
	1	2	3	4	1	2	3	4
TSS	64	24			60	24	24	36
VSS	24	8			20	12	20	20
COD	34	17			35	27	27	20
Total Carbon	11.1	11.1			16.8	9.1	10.4	9.1
Diss. T Carbon	2.8	4.1			8.9	5.3	5.9	5.9
Nitrate	0.11	0.11			0.28	0.13	0.17	0.16
T. Phosphorus	0.12	0.06			0.11	0.07	0.06	0.06
Oil & Grease	1.6							
Chromium	<0.0023	<0.0023			0.003	<0.0023	<0.0023	<0.0023
Zinc	0.015	0.005			0.007	0.005	<0.0007	0.003
Cadmium	<0.0013	<0.0013			<0.0013	<0.0013	<0.0013	<0.0013
Lead	<0.014	<0.014			NA	<0.014	<0.014	<0.014
Nickel	<0.005	<0.005			<0.005	<0.005	<0.005	<0.005
Iron	1.339	1.812			1.19	0.840	0.754	0.597
Copper	0.004	0.002			0.003	0.006	<0.002	0.003

Date: 4/22/95

Constituent	Concentration Data (mg/L)							
	Influent Composite Samples				Effluent Composite Samples			
	1	2	3	4	1	2	3	4
TSS	112				60	28	12	12
VSS	24				24	12	12	12
COD	43				35	38	33	43
Total Carbon	16.2				16.1	19.8	19	16
Diss. T Carbon	9.6				13.6	14.8	17	10
Nitrate	1.05				1	1.1	1.1	1.05
T. Phosphorus					0.09	0.08	0.05	
Oil & Grease								
Chromium	<0.0023				<0.0023	<0.0023	<0.0023	<0.0023
Zinc	0.019				0.009	0.002	<0.0007	<0.0007
Cadmium	<0.0013				<0.0013	<0.0013	<0.0013	<0.0013
Lead	<0.014				<0.014	<0.014	<0.014	<0.014
Nickel	<0.005				<0.005	<0.005	<0.005	<0.005
Iron	1.925				1.455	0.88	0.542	0.549
Copper	0.003				<0.002	<0.002	<0.002	<0.002

APPENDIX C

Sieve Analysis for Granular Media

Brady Sand:

Sieve #	Opening Size (mm)	Percent Retained: Sample	Percent Retained: Specification*
16	1.1	0	1 - 0
20		0.9	9 - 0
30	0.6	50.9	60 - 40
40		39.4	60 - 40
50	0.3	8.2	9 - 0
80	0.2	0.6	1 - 0

Concrete Aggregate:

Sieve #	Opening Size (mm)	Percent Retained: Sample	Percent Retained: Specification*
4	4.8	0	0 - 5
8	2.4	8	0 - 20
16	1.1	27	15 - 50
30	0.6	49	35 - 75
50	0.3	77	65 - 94
100	0.17	96	90 - 100
200	0.07	99	97 - 200

Brady sand is specified per size interval.

Concrete sand is specified as percent retained on given sieve plus larger sieves.

Grade 5 Gravel:

Sieve #	Opening Size (mm)	Percent Retained
3/8	9.5	3
4	4.8	18
6	3.4	46
8	2.4	21
% finer		12

Pea Gravel:

Sieve #	Opening Size (mm)	Percent Retained
3/8	9.5	0
4	4.8	21
8	2.4	74
% finer		5

Summary of Influent and Effluent Concentrations for 22 Experimental Runs for Experiment Number One.

Concentration Data (mg/L)

Run #:	1		2		3		4		5		6	
Constituent	influent	effluent	influent	effluent	influent	effluent	influent	effluent	influent	effluent	influent	effluent
TSS	652	112	652	0	652	0	1064	32	1064	64	2808	24
VSS	64	16	64	4	64	0	120	12	120	16	120	20
BOD	9	4	9	3	9	3						
COD	114	9	114	16	114	20						
TOC	22.43	26.45	22.43	20.81	22.43	21.21						
Nitrate	0.23	1.2	0.23	0.69	0.23	0.62						
Tot. Phos.	0.9	0.009	0.9	0.17	0.9	0.19						
O & G	3.1	0.2	3.1	0.2	3.1	0.2						
Cadmium	0.004	0.053	0.004	0.004	0.004	0.029						
Chromium	0.075	0.088	0.075	0.049	0.075	0.007						
Copper	0.043	0.031	0.043	0.021	0.043	0.017						
Iron	6.42	2.87	6.42	0.231	6.42	0.209						
Lead	0.042	0.328	0.042	0.224	0.042	0.042						
Nickel	<.015	<.015	<.015	<.015	<.015	<.015						
Zinc	0.413	0.043	0.413	0.012	0.413	0.002						

Concentration Data (mg/L)

Run #:	7		8		9		10		11	
Constituent	influent	effluent	influent	effluent	influent	effluent	influent	effluent	influent	effluent
TSS	2808	20	2808	24	2808	0	496	0	496	16
VSS	276	0	276	12	276	0	72	0	72	0
BOD	43	2					40	2		
COD	579	47					264	71		
TOC	60.68	44.32					60.48	48.49		
Nitrate	2.5	2.2					1.5	17.9		
Tot. Phos.	1.48	0.16					1.04	0.16		
O & G	3.7	0.2					4.2	0.3		
Cadmium	<0.05	<0.05					0.064	0.051		
Chromium	<0.1	<0.1					<0.1	<0.1		
Copper	0.093	0.027					0.065	0.023		
Iron	12.64	0.15					6.75	0.078		
Lead	0.347	0.1					<0.1	<0.1		
Nickel	<0.1	<0.1					<0.1	<0.1		
Zinc	0.854	0.081					0.569	0.005		

Summary of Concentration Data Collected During the Second Experiment.

Constituent **TSS**

Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	152	48	156	140
2	168	44	68	144
3	108	48	64	116
4	272	88	76	144
5	100	64	68	176
6	104	44	32	104
7	104	100	52	52
8	100	24	28	92
9	96	32	28	104
10	112	36	44	108
11	92	20	40	100
12	96	36	52	88
13	96	16	28	94
14	92	16	36	88
15	104	24	32	92

Constituent **VSS**

Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	16	0	20	16
2	24	0	4	20
3	12	0	12	12
4	32	4	8	16
5	12	4	8	20
6	4	0	8	16
7	16	8	8	0
8	16	36	12	4
9	12	12	0	12
10	20	0	4	12
11	16	0	12	12
12	16	8	4	12
13	16	0	4	16
14	16	4	4	16
15	24	12	4	12

Summary of Concentration Data Collected During the Second Experiment.
(Continued)

Exper. Run #	**Constituent** Influent Concentration (mg/L)	**COD** Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	66	46	44	65
2	50	34	32	66
3	46	29	34	55
4	***	***	***	***
5	47	40	33	65
6	72	48	52	75
7	71	67	49	52
8	68	43	48	66
9	66	52	54	67
10	72	50	53	70
11	79	65	67	71
12	78	71	72	89
13	82	62	57	80
14	78	62	66	76
15	87	73	76	93

Exper. Run #	**Constituent** Influent Concentration (mg/L)	**Zinc** Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	0.168	0.057	0.087	0.158
2	0.181	0.085	0.072	0.148
3	0.148	0.078	0.142	0.132
4	0.142		0.079	0.15
5	0.084	0.023	0.034	0.113
6	0.128	0.072	0.079	0.173
7	0.161	0.143	0.07	0.089
8	0.154	0.054	0.06	0.143
9	0.093	0.038	0.021	0.09
10	0.088	0.039	0.03	0.086
11	0.09	0.05	0.039	0.11
12	0.134	0.103	0.128	0.144
13	0.161	0.103	0.085	0.166
14	0.133	0.159	0.219	0.259
15	0.221	0.19	0.178	0.196

Summary of Concentration Date Collected During the Second Experiment.
(Continued)

	Constituent	**TOC**		
Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	19.1	20.8	19.1	19.1
2	17.3	17.3	19.1	19.1
3	17.3	17.3	17.3	17.3
4	17.3	17.3	17.3	19.1
5	17.3	20.8	19.1	20.8
6	19.2	22.2	20.7	19.2
7	17.7	22.2	19.2	19.2
8	19.2	19.2	19.2	19.2
9	17.7	19.2	19.2	17.7
10	19.2	17.7	19.2	19.2

	Constituent	**Nitrate**		
Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	0.28	0.3	0.28	0.28
2	0.26	0.3	0.28	0.28
3	0.28	0.28	0.28	0.28
4	0.59	0.56	0.59	0.57
5	0.59	0.59	0.59	0.59

	Constituent	**Oil & Grease**		
Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
6	2.9	2.3	1.6	2.9
11	3.4	1.4	1.7	2.7
15	2.2	1.6	1.5	2.4

Summary of Concentration Date Collected During the Second Experiment.
(Continued)

Constituent **Copper**

Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	0.01	0.002	0.004	0.011
2	0.015	0.007	0.002	0.009
3	0.013	0.007	0.002	0.008
4	0.011		0.005	0.011
5	0.002	0.002	0.002	0.003
6	0.003	0.01	0.005	0.013
7	0.015	0.014	0.005	0.006
8	0.012	0.007	0.004	0.01
9	0.002	0.002	0.002	0.005
10	0.005	0.002	0.002	0.003
11	0.002	0.002	0.002	0.003
12	0.002	0.002	0.002	0.003
13	0.004	0.002	0.002	0.004
14	0.003	0.002	0.002	0.004
15	0.005	0.002	0.002	0.005

Constituent **Iron**

Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	2.774	0.757	1.391	2.59
2	2.927	1.257	1.35	2.49
3	2.38	1.136	1.151	2.225
4	2.192		1.23	2.374
5	1.671	0.584	0.85	2.433
6	1.729	0.894	0.868	2.164
7	2.103	2.032	0.988	1.075
8	1.995	0.67	0.712	2.774
9	1.693	0.624	0.644	1.559
10	1.728	0.543	0.758	1.558
11	1.479	0.476	0.749	1.305
12	1.678	0.966	0.972	1.725
13	1.478	0.503	0.534	1.427
14	1.417	0.683	0.691	1.54
15	1.636	0.802	0.763	1.634

Summary of Concentration Date Collected During the Second Experiment. (Continued)

	Constituent	**Nickel**		
Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	< DL	0.008	< DL	< DL
2	< DL	0.008	< DL	< DL
3	< DL	< DL	< DL	< DL
4	< DL		< DL	< DL
5	< DL	< DL	< DL	< DL
6	< DL	< DL	< DL	< DL
7	< DL	< DL	< DL	0.007
8	0.015	0.008	0.008	< DL
9	< DL	< DL	< DL	< DL
10	< DL	< DL	< DL	< DL
11	< DL	< DL	< DL	< DL
12	< DL	< DL	< DL	< DL
13	< DL	< DL	< DL	< DL
14	< DL	< DL	< DL	< DL
15	< DL	< DL	< DL	< DL

	Constituent	**Lead**		
Exper. Run #	Influent Concentration (mg/L)	Effluent Concentrations (mg/L)		
		Brady Sand	Concrete Sand	Pea Gravel
1	0.084	0.041	0.053	0.084
2	0.112	0.094	0.032	0.086
3	0.101	0.09	0.014	0.067
4	0.106		0.039	0.078
5	0.015	0.014	0.014	0.023
6	0.014	0.09	0.055	0.08
7	0.077	0.096	0.045	0.049
8	0.063	0.067	0.05	0.061
9	0.014	0.016	0.014	0.016
10	0.014	0.014	0.014	0.014
11	0.018	0.014	0.018	0.014
12	0.014	0.014	0.014	0.016
13	0.014	0.014	0.02	0.014
14	0.014	0.014	0.014	0.016
15	0.014	0.014	0.014	0.014

Summary of Concentration Date Collected During the Third Experiment

Exper. Run #	**Constituent:** Influent Conc. (mg/l)	**TSS** Effluent Concentrations (mg/l) Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel	**Constituent:** Influent Conc. (mg/l)	**VSS** Effluent Concentrations (mg/l) Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel
1	162	12	8		176		52	8	8		32	
2	164	32		84	256		48	20		20	40	
3	196	40		96	292		56	8		20	40	
4	160	40	0	68	436		56	16	0	24	72	
5	68	32	12	52			24	12	12	12		
6	48	8	0	32			20	8	0	16		
7	76	8	0	28		204	20	4	0	0		16
8	44	32	4	44		136	12	8	4	12		24
9	128	56	9	132		260	36	8	4	12		
10	68	40	4	60		132	24	20	4	12		16
11	68	44	4	56		140	20	16	4	12		24
12	32	12	0	36		200	8	0	0	8		20
13	36	20	0	20			16	8	0	4		
14	40	20	4	72			24	12	0	8		
15	32	12	4	28			16	4	0	12		
16	376	20	0	44		468	96	0	0	4		80
17	108	24	0	36		176	20	12	0	4		8
18	128	108	48				40	36	20			
19	160	80	24				64	40	12			
20	108	80	36				36	28	24			
21	188	72	36				52	28	28			
22	188	56	34				52	20	20			
23	220	108	68									
24	220	88	64									
25	220	76	72									
26	664	76	52									
27	172	32	36									
28	188	24	24									
29	336	56	136									
30	348	36	96									
31	272	16	84									

Summary of Concentration Date Collected During the Third Experiment (continued)

Exper. Run #	**Constituent:** Influent Conc. (mg/l)	**COD** Effluent Concentrations (mg/l)					**Constituent:** Influent Conc. (mg/l)	**Oil & Grease** Effluent Concentrations (mg/l)				
		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel
1	181	98	129		134		4.1	2.8	1.6		3.9	
2	170	73		76	134							
3	196	76		89	146		3.5	2.9		5.0	5.3	
4	159	79	84	81	138							
5	105	77	92	90			3.3	2.1	1.7	2.7		
6	89	82	86	85								
7	112	83	92	80		99	2.7	2.2	0.8	2.3		
8	292	251	208	268		286						
9	160	117	108	123		167						
10	126	110	74	112		126	4.2	3.6	2.0	3.0		
11	127	106	76	107		135						
12												
13												
14	55	42	63	35								
15	52	37	35	30			2.5	1.1	1.2	1.1		
16	235	62	62	54		152						
17	87	47	47	57		95						
18	245	209	176				12.5	4.7	4.8			
19	237	209	145									
20	260	214	141									
21	242	225	246				6.1	3.5	3.4			
22	242	209	105									
23	450	382	343									
24	450	389	336				6.4	4.0	4.5			
25	450	404	362									

Summary of Concentration Date Collected During the Third Experiment (continued)

	Constituent:	**Total Carbon**					**Constituent:**	**Dissolved Total Carbon**				
Exper. Run #	Influent Conc. (mg/l)	Effluent Concentrations (mg/l) Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel	Influent Conc. (mg/l)	Effluent Concentrations (mg/l) Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel
1	90.4	46.4	71.0		62.1		42.7	39.0	66.6		42.7	
2	71.0	41.2		41.9	61.3		30.8	30.8		28.5	32.2	
3	67.3	39.7		44.2	62.1		32.2	31.5		30.0	30.8	
4	65.8	40.5	51.6	39.7	65.1		29.3	31.5	48.7	30.0	30.8	
5	44.9	36.7	52.4	40.5			30.0	30.8	56.9	28.5		
6	47.2	39.7	39.7	40.5			34.5	35.2	41.2	36.0		
7	55.9	44.0	68.5	43.3		67.7	36.6	39.6	70.0	40.3		38.1
8	111.0	96.2	84.0	90.2		99.1	87.0	83.3	77.4	84.0		86.6
9	64.8	49.2	80.3	59.6		55.9	22.6	29.2	70.0	26.3		27.5
10	52.9	44.0	38.1	44.0		48.5	26.0	28.2	37.5	27.5		27.0
11	53.7	38.1	36.6	44.8		49.5	28.2	27.5	36.8	24.6		24.6
12	40.0	37.6	75.0	37.6		54.3	22.5	24.8	60.6	24.1		22.5
13	40.8	38.4	36.8	36.8			22.5	22.5	30.4	24.1		
14	26.7	24.8	58.3	21.1			17.1	18.6	52.9	15.5		
15	23.3	20.3	24.1	17.4			15.5	15.5	23.3	15.5		
16	88.0	24.8	51.6	27.0		84.8	19.4	16.3	45.1	14.8		17.9
17	39.7	24.1	24.8	24.8		45.6	17.1	14.0	18.6	17.1		17.1
18	93.4	84.9	86.4				42.7	42.7	55.4			
19	93.4	81.4	70.9				39.9	40.6	45.5			
20	93.4	84.2	66.6				42.0	36.4	44.8			
21	94.8	81.4	65.9				42.7	42.7	44.1			
22	94.8	81.4	69.5				42.7	42.7	48.3			
23												
24												
25												

Summary of Concentration Date Collected During the Third Experiment (continued)

Exper. Run #	**Constituen** Influent Conc. (mg/l)	**NO3-N**	Effluent Concentrations (mg/l)				**Constituen** Influent Conc. (mg/l)	**TP**	Effluent Concentrations (mg/l)			
		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel
1							0.400	0.150	1.080		0.300	
2							0.320	0.140		0.200	0.330	
3							0.340	0.140		0.190	0.330	
4							0.340	0.170	0.900	0.160	0.370	
5							0.200	0.150	0.960	0.160		
6							0.370	0.270	0.830	0.290		
7							0.440	0.270	1.130	0.280		0.360
8							0.380		1.010	0.350		0.380
9							0.300	0.280	1.190	0.280		0.330
10							0.230	0.260	0.970	0.250		0.260
11							0.240	0.220	0.930	0.240		0.270
12	0.790	1.000	2.300	2.050		0.890						
13	0.800	0.920	1.000	1.000		0.830						
14	0.500	1.250	6.400	5.600			0.240	0.180		0.160		
15	0.560	0.580	0.710	0.820			0.240	0.160	0.160	0.130		
16	0.300	1.300	2.700	2.200		0.530		0.140		0.160		0.360
17	0.320	0.380	0.440	0.410		0.330	0.130	0.090	0.570	0.100		0.160
18	3.800	4.800	19.000									
19	4.000	4.000	7.400									
20	3.900	4.000	4.900									
21	4.100	4.300	4.200									
22	4.100	3.900	4.800									
23												
24												
25												

Summary of Concentration Date Collected During the Third Experiment (continued)

	Constituent:		**Copper**				**Constituent:**		**Iron**			
Exper. Run #	Influent Conc. (mg/l)	Effluent Concentrations (mg/l)					Influent Conc. (mg/l)	Effluent Concentrations (mg/l)				
		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel
1	0.030	0.015	0.012		0.024		3.633	1.055	0.487		3.407	
2	0.036	0.015		0.019	0.027		4.468	1.410		2.540	4.529	
3	0.036	0.017		0.020	0.030		4.262	1.784		2.272	4.483	
4	0.029	0.018	0.011	0.021	0.030		3.808	1.577	0.865	2.055	5.851	
5	0.019	0.017	0.011	0.017			2.281	1.424	0.529	1.601		
6	0.015	0.014	0.008	0.016			0.684	0.509	0.217	0.717		
7	0.019	0.012	0.010	0.014		0.020	1.073	0.363	0.117	0.587		1.561
8	0.029	0.010	0.012	0.030		0.030	1.706	0.418	0.354	1.516		1.990
9	0.015	0.021		0.024		0.028	1.999	2.749		3.432		3.929
10						0.024						
11	0.027	0.019	0.009	0.020		0.023	3.664	2.506	1.267	2.776		3.273
12	0.017	0.014	0.008	0.072		0.018	2.087	1.630	0.696	1.811		3.195
13	0.017	0.016	0.009	0.013		0.018	1.983	1.909	0.989	1.624		2.824
14	0.010	0.008	0.006	0.008			0.794	0.688	0.162	0.847		
15	0.009	0.007	0.005	0.006			0.758	0.501	0.150	0.448		
16	0.040	0.010	0.008			0.030	4.110	0.865	0.302			3.928
17	0.014	0.009	0.005	0.009		0.018	1.323	0.861	0.442	1.002		2.004
18	0.034	0.024	0.024				3.640	2.968	1.853			
19	0.038	0.037	0.031				2.674	3.279	1.672			
20	0.031	0.040	0.016				2.998	3.204	1.750			
21	0.098	0.029	0.023				9.255	2.977	1.584			
22	0.098	0.028	0.022				9.255	3.006	1.732			
23	0.051	0.048	0.035				5.381	3.495	2.854			
24	0.051	0.049	0.031				5.381	3.620	2.273			
25	0.051	0.057	0.036				5.381	3.712	2.421			

Summary of Concentration Date Collected During the Third Experiment (continued)

	Constituent:	**Nickel**					**Constituent:**	**Lead**				
Exper. Run #	Influent Conc. (mg/l)	Effluent Concentrations (mg/l)					Influent Conc. (mg/l)	Effluent Concentrations (mg/l)				
		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel
1	<0.005	<0.005	0.006		<0.005		0.022	0.015	0.016		0.014	
2	<0.005	<0.005		<0.005	<0.005		0.030	0.014		0.014	0.025	
3	<0.005	<0.005		<0.005	<0.005		0.029	0.014		0.014	0.014	
4	<0.005	<0.005	0.028	<0.005	<0.005		0.031	0.014	0.014	0.017	0.014	
5	<0.005	<0.005	<0.005	<0.005			0.014	0.026	0.014	0.014		
6	<0.005	<0.005	<0.005	<0.005			0.014	0.022	0.022	0.014		
7	<0.005	<0.005	<0.005	<0.005		<0.005	0.037	0.021	0.027	0.027		0.018
8	<0.005	<0.005	<0.005	0.006		<0.005	0.026	0.034	0.014	0.020		0.020
9	<0.005	<0.005		<0.005		<0.005	0.018	0.017		0.014		0.021
10						<0.005						0.024
11	<0.005	<0.005	<0.005	<0.005		<0.005	0.029	0.016	0.014	0.014		0.015
12	<0.005	<0.005	<0.005	<0.005		<0.005	0.015	0.014	0.014	0.014		0.014
13	<0.005	<0.005	<0.005	<0.005		<0.005	0.014	0.025	0.014	0.001		0.014
14	<0.005	<0.005	<0.005	<0.005			0.014	0.014	0.014	0.014		
15	<0.005	<0.005	<0.005	<0.005			0.014	0.014	0.014	0.014		
16	<0.005	<0.005	<0.005	<0.005		<0.005	na	na	na	na	na	na
17	<0.005	<0.005	<0.005	<0.005		<0.005	na	na	na	na	na	na
18	<0.005	<0.005	<0.005				0.022	0.014	0.014			
19	<0.005	<0.005	<0.005				0.020	0.014	0.014			
20	<0.005	<0.005	<0.005				0.017	0.014	0.018			
21	<0.005	<0.005	<0.005				0.015	0.024	0.014			
22	<0.005	<0.005	<0.005				0.015	0.014	0.014			
23	<0.005	<0.005	<0.005				0.025	0.014	0.018			
24	<0.005	<0.005	<0.005				0.025	0.014	0.014			
25	<0.005	<0.005	<0.005				0.025	0.019	0.020			

Summary of Concentration Date Collected During the Third Experiment (continued)

Constituent: **Zinc**

Exper. Run #	Influent Conc. (mg/l)	Effluent Concentrations (mg/l)				
		Brady Sand	Compost	Sand & Zeolites	Zeolites	Grade 5 Gravel
1	0.211	0.053	0.018		0.116	
2	0.233	0.059		0.064	0.154	
3	0.250	0.076		0.069	0.160	
4	0.190	0.061	0.026	0.064	0.170	
5	0.109	0.062	0.026	0.048		
6	0.103	0.049	0.012	0.036		
7	0.141	0.046	0.014	0.036		0.096
8	0.141	0.045	0.025	0.094		0.121
9	0.115	0.118		0.126		0.207
10						0.167
11	0.216	0.130	0.042	0.115		0.168
12	0.120	0.070	0.031	0.067		0.116
13	0.104	0.089	0.035	0.067		0.110
14	0.070	0.035	0.011	0.025		
15	0.070	0.037	0.012	0.018		
16	0.321	0.049	0.018			0.221
17	0.095	0.049	0.018	0.045		0.118
18	0.237	0.142	0.081			
19	0.218	0.184	0.090			
20	0.204	0.193	0.080			
21	0.220	0.188	0.077			
22	0.220	0.195	0.084			
23	0.392	0.295	0.123			
24	0.392	0.339	0.143			
25	0.392	0.319	0.110			

Experiment One: calculation of the hydraulic conductivity (K).

Parameters:		
	Ho, cm	58.4
	H, cm	30

Exper. Run #	delta t (min)	K (cm/s)
4	13	0.0264
5	37	0.0093
6	36	0.0095
7	12	0.0286
8	14	0.0245
9	24	0.0143
10	49	0.0070
11	60	0.0057
12	60	0.0057
13	92	0.0037
16	90	0.0038
17	120	0.0029
20	140	0.0025
22	100	0.0034
	avg	0.01053377

delta t measured as water level falls from Ho to H.

Experiment Two: calculation of the hydraulic conductivity (K).

Parameters:	filter length, cm	h1/h2
Brady Sand	16.5	2
Con. Aggregat	17.8	2
Pea Gravel	17.8	2

	Brady sand				concrete aggregate				pea gravel			
Run #	t1	t2	delta t,s	K, cm/s	t1	t2	delta t,s	K, cm/s	t1	t2	delta t,s	K, cm/s
1					9:00	7:56	64	0.1928	7:08	6:27	41	0.30093
2	18:40	17:05	95	0.12039	4:19	3:18	61	0.2023	8:34	8:02	32	0.38556
3	12:49	11:12	97	0.11791	5:26	4:15	71	0.1738	7:52	7:15	37	0.33346
4	7:45	5:38	127	0.09005	7:23	6:01	82	0.1505	7:54	7:22	32	0.38556
5	7:32	5:06	146	0.07834	13:18	11:44	94	0.1313	7:04	6:34	30	0.41127
6	6:11	4:07	125	0.0915	10:45	9:08	97	0.1272	13:43	13:13	30	0.41127
7	7:03	5:03	120	0.09531	11:10	9:39	91	0.1356	13:50	13:20	30	0.41127
8	13:51	12:10	101	0.11324	9:22	7:58	84	0.1469	6:13	5:42	31	0.398
9	57:38	55:45	113	0.10121	52:37	50:59	98	0.1259	49:05	48:34	31	0.398
10	33:35	31:33	122	0.09375	29:15	27:41	94	0.1313	26:22	25:50	32	0.38556
11	11:40	8:16	202	0.05662	6:06	4:20	106	0.1164	2:42	2:11	31	0.398
12	13:06	10:30	156	0.07331	8:09	6:25	104	0.1186	12:49	12:18	31	0.398
13	28:45	26:40	125	0.0915	22:40	21:3	97	0.1272	28:12	27:40	32	0.38556
14	9:08	7:09	119	0.09611	4:37	3:03	94	0.1313	8:52	8:20	32	0.38556
15	13:40	11:41	119	0.09611	9:10	7:34	96	0.1285	13:28	12:48	40	0.30845
			avg	0.08769				0.12977				

t1 and t2 taken when the water level was at h1 and h2 above the bottom of the filtration media, respectively.

Experiment three: calculation of the hydraulic conductivity (K).

Parameters:	filter length, cm	h1/h2*			Avg, K (cm/s)
Brady sand	20.3	1.6667	1.429	1.05	.04282
compost	20.3	1.0615	1.438	1.35	.00764
sand/zeolites	20.3	1.6667			0.0695
zeolites	20.3	1.6667			0.3719
g-5 gravel	20.3	1.6667			0.3683

* The water level was not always measured at the same location for the Brady sand and compost columns, thus different values of h1/h2 were use

	Brady sand				compost			
run #	t1	t2	delta t, s	K, cms	t1	t2	delta t, s	K, cms
1	7:34	5:19	135	.077	20:44	4:50	954	.008
2	4:10	1:36	154	.067			> 2 hrs	
3	10:05	7:33	152	.068				
4	6:24	3:12	192	.054			172	.007
5	12:15	9:18	177	.059	18:50	15:30	200	.006
6	13:04	8:58	246	.042	8:55	3:16	339	.004
7	8:56	4:39	257	.040	11:37	9:10	147	.008
8	9:34	4:30	304	.034	12:08	9:21	167	.007
9	5:09	1:51	198	.052	11:16	9:14	122	.010
10	8:33	4:42	231	.045	4:25	0:25	240	.005
11	4:15	0:08	247	.042	12:45	8:33	252	.005
12	5:45	2:36	189	.055	2:30	0:40	110	.011
13	9:40	6:10	210	.049	10:52	7:43	189	.006
14	4:30	1:47	163	.064	12:16	2:17	599	.010
15	9:12	4:47	265	.039			565	.011
16	7:36	4:08	208	.050	8:41	6:21	140	.009
17	11:17	6:49	268	.039	6:48	4:08	160	.008
18	8:17	5:56	141	.074	4:05	3:20	45	.027
19	7:12	3:22	230	.045	14:52	4:53	599	.012
20	12:51	8:51	240	.043	3:20	1:13	127	.010
21	4:15	0:02	253	.041	4:44	2:11	153	.008
22	10:54	6:21	273	.038	6:28	5:02	86	.014
23	5:06	2:27	159	.065	11:28	7:05	263	.028
24	11:30	7:15	255	.041	11:08	2:35	513	.014
25	5:20	0:28	292	.036	2:07	0:33	94	.013
26	8:49	4:28	261	.040	7:37	7:11	26	.047
27	19:06	5:40	806	.009	20:10	14:20	350	.018
28	21:50	0:13	1297	.006	9:58	8:48	70	.017
29	7:26	1:54	332	.003	9:07	8:53	14	
30	6:27	4:15	132	.008	6:20	3:32	168	.044
31	9:38	4:50	288	.004	10:10	6:02	248	.030

Experiment three: measurement of the hydraulic conductivity (cont.)

	sand/zeolites				zeolites			
run #	t1	t2	delta t, s	K, cm/s	t1	t2	delta t, s	K, cm/s
1					5:34	5:03	31	0.33
2	3:20	1:12	128	0.081	4:37	4:11	26	0.40
3	10:45	8:22	143	0.073	4:45	4:18	27	0.38
4	5:43	3:02	161	0.064	6:40	6:12	28	0.37
5	3:20	0:48	152	0.068				
6	4:37	1:39	178	0.058				
7	8:10	4:48	202	0.051				
8	3:15	1:33	102	0.102				
9	7:33	6:03	90	0.115				
10	8:30	5:35	175	0.059				
11	4:18	1:09	189	0.055				
12	5:05	2:21	164	0.063				
13								
14	5:42	3:23	139	0.075				
15	10:26	7:38	168	0.062				
16	7:29	4:52	157	0.066				
17	11:41	8:14	207	0.050				

	grade 5 gravel			
run #	t1	t2	delta t, s	K, cm/s
1				
2				
3				
4				
5				
6				
7	8:34	8:04	30	0.346
8	2:13	1:41	32	0.324
9	9:29	8:56	33	0.314
10	7:15	6:46	29	0.358
11	6:14	5:46	28	0.370
12	4:03	3:35	28	0.370
13				
14				
15				
16	6:12	5:48	24	0.432
17	10:10	9:46	24	0.432