Technical Report

CRWR 263

CHARACTERIZATION OF HIGHWAY RUNOFF IN THE AUSTIN, TEXAS AREA

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1. INTRODUCTION

Nonpoint pollution resulting from storm water runoff has recently been recognized as one of the leading causes of the degradation of the quality of receiving waters in the United States. The area southwest of Austin is part of the recharge zone of the Barton Springs portion of the Edwards aquifer. This is a karst aquifer, which is characterized by numerous caves, sinkholes, and other solution features. Recharge enters the aquifer directly through fractures and other openings a the surface, so very little filtration of the runoff occurs before entering the aquifer. The aquifer provides the sole source of drinking water for approximately 35,000 residents of Hays and Travis counties. Construction of new highways in the recharge area of the aquifer led to the concern that nonpoint source pollution from highway runoff could pose a serious threat to the quality of the groundwater and the health of area residents.

Accurate knowledge of the quantity and quality of runoff is required to assess the impacts of runoff on the environment and to develop appropriate mitigation technologies. A comprehensive study of the effects of runoff from highway construction and operation was undertaken by the Center for Research in Water Resources to help develop this information. The primary objective of this portion of the research study was the development and execution of a program to characterize the quantity and quality of runoff from existing highways in the Austin, Texas area.

This portion of the research study focused on the characterization of the quantity and quality of runoff from existing sections of the MoPac expressway and estimation of the pollutant loads resulting from runoff from existing and newly completed sections of highway under different vehicle use patterns. The effects of drainage system type, traffic volume, and surrounding land use on highway storm water runoff characteristics were investigated. In addition to the average quality of runoff, the temporal variation in quality was also studied. A “first flush” effect (i.e., higher concentrations of pollutants at the beginning of runoff events) has been reported in several studies and is often used as the justification for the design standards which require capture and treatment of the first 1/2 inch (or other arbitrary volume) of storm water runoff. The information developed in this study should result in improvement in the design of drainage and treatment systems for highway storm water runoff. Better designs will act to reduce the impact of highway derived nonpoint source pollution on the environment.

2. MATERIALS AND METHODS

2.1 Site Descriptions

Three sites along the MoPac Expressway in the Austin, Texas area were selected for monitoring runoff from highways. The locations were identified as MoPac at West 35th Street, MoPac at Convict Hill Road and MoPac at Walnut Creek. The sites differed in daily traffic flow, surrounding land use, and drainage area. Accessibility for runoff sampling also was a consideration in site selection. Runoff samples were collected during the time period of September 1993 though May 1995. The physical characteristics of the sites are discussed below.

2.1.1 MoPac at West 35th Street

MoPac at West 35th Street is a high traffic site located in central Austin (Figure 2.1). The land use of the area is mixed residential and commercial. Samples were collected from a storm drain inlet located along the gutter of a curbed section of the three southbound lanes. The catchment covers an area of 5,341 m^2 which is 100% asphalt. The average daily volume of traffic at this site was approximately 60,000 vehicles per day, ranging from a maximum of 6,000 vehicles per hour to a minimum of about 100 vehicles per hour. Induction coils installed in each lane of traffic recorded traffic counts during each rainfall event.

Figure 2.1 Photograph of MoPac at West 35th Street

2.1.2 MoPac at Convict Hill Road

MoPac at Convict Hill Road is a low traffic site located on the southwestern edge of Austin (Figure 2.2). The land around Convict Hill Road is mostly residential and rural property. Runoff was collected from the down spout of the northbound lanes of the MoPac overpass over Convict Hill Road. This outfall drains 526 m^2 of bridge deck, which is 100% asphalt paved and has two lanes of traffic and wide shoulders. One meter high concrete barriers are located along each side of the roadway. The average traffic count in April 1995 was approximately 8780 vehicles per day, ranging from less than 10 vehicles per hour to nearly 1400 vehicles per hour.

Figure 2.2 Photograph of MoPac at Convict Hill Road

2.1.3 MoPac at Walnut Creek

The Walnut Creek site is located in north Austin and consists of a combination of paved highway and grassy shoulder and median (Figure 2.3). The land use classification of the area is mostly commercial and high density residential. Water was collected from a 10.46 ha (104,600 m^2) area. Approximately 37.6% of the drainage area is paved with asphalt and consists exclusively of the six north- and south-bound lanes of MoPac. No curb or gutter was installed and the highway runoff drains into a large grassy median. Runoff from the median enters a 1.22 m diameter storm sewer system through drop inlets. In April 1995, approximately 47,000 vehicles per day were recorded for this section of MoPac. The hourly traffic counts ranged from about 100 to 3600 vehicles.

Figure 2.3 Photograph of MoPac at Walnut Creek

A summary of the physical characteristics of the three sites is presented in Table 2.1. Drainage area and average daily traffic also are included in this table. The traffic count at the low traffic volume site (Convict Hill Road) was only 20 percent of the traffic count at the site which had the highest traffic volume (35th Street). The size of the catchment at Convict Hill Road was only 10 percent of the highway surface drained at 35th Street. The traffic mix, and prevailing weather conditions were similar at all sites.

2.2 Climatic Conditions

The National Weather Service data indicate that annual rainfall in Austin, Texas is 82.6 cm; however, during the 12 month period July 1993 - July 1994, the total rainfall was only 44.4 cm. The National Weather Service data indicate that average storm event is 1.4 cm at storm intensities of about 0.18 cm/hr and storm duration of 11.8 hrs. However, storm characteristics vary greatly. Coefficients of variations associated with the data reported for average rainfalls were 1.63 for total volume of rainfall, 1.47 for rainfall intensity, and 1.9 for storm duration.

The National Weather Service data indicate that the wettest seasons occurred during the Spring and Fall. Dry conditions prevailed in the summer months. The rainfall intensity of events that occurred during the late fall and winter months was usually light and occurred over long duration (several hours to over a day). Rainfall events that occurred during the early fall and spring months ranged from drizzle to heavy down pours. Midsummer rainfall events are rare in Austin and tend to be heavy downpours resulting from electrical storms. Dry conditions were prevalent in Austin from June to August of 1994 with less than 0.25 mm of rain at any of the three sites for a period of 40 days.

Table 2.1 Summary of Characteristics of Three Highway Runoff Sampling Sites

	Convict Hill Road	Walnut Creek	West 35th Street
Drainage area	526 m^2	104,600 m^2	5,341 m^2
Pavement	100% asphalt	37% asphalt	100 % asphalt
Lanes of Traffic	2 (3.66 m)	6 (3.66 m each)	3 (3.66 m)
Shoulders	2.44 m and 6.71 m	2.4 m	2.4 m and 3.3 m
Curb/Guardrail	1 m retainer	none	15 cm curb
Average Daily Traffic	8,780	47,240	58,150
Speed Limit	88 km/hr	88 km/hr	88 km/hr
Land Use	rural/residential	commercial/ high density residential	commercial/ residential

2.3 Water Quantity Measurements

Automatic flow measuring and sampling systems were installed and operated at three (3) sites: MoPac at West 35th Street, MoPac at Convict Hill Road, and MoPac at Walnut Creek. The monitoring system installed at MoPac at 35th Street was in operation from October 1993 through July 1995, and the units at the other two sites were in operation April 1994 through July 1995. Water levels at each site were measured using bubble flow meters (ISCO 3230). The water levels were converted into a flow rate based on rating curves developed for each site. The information recorded at the automatic sampling station included rainfall volume, runoff flow rate, and the sampling times. These data were downloaded from the flow meters to a laptop computer, and were converted to text format and exported to Microsoft Excel.

Each sampling station included a 12 volt battery to power the flow meter, sampler, and recorder. A solar panel (Solarex Megamodule MSX60) recharged the battery. The flow meter, sampler, and battery were housed in a large steel enclosure. A rain gauge (ISCO 674) also was placed at each site to measure rainfall. Because of the relatively small size of each of the contributing watersheds, a single gauge at each site was determined to be sufficient for accurately measuring rainfall volume and intensity.

2.3.1 Flow Measurement at West 35th Street

Water level was read from a bubbler tube located at the bottom of the curbing system before the water entered the catchment inlet. A rating curve was developed for this location by discharging water from a fire hydrant approximately 100 meters upstream of the level measuring location. The water was discharged at metered flow rates to construct the rating curve. The water elevation recorded at different flow rates by the flow meter allowed the development of an accurate relationship between water level and flow rate. The flow meter was active at this site for more than one year. Monitoring flow rates of numerous storms produced an average runoff coefficient of about 0.90 which is consistent with values commonly reported in the literature for 100% impervious surfaces. The runoff coefficient calculations are shown in Figure 2.4.

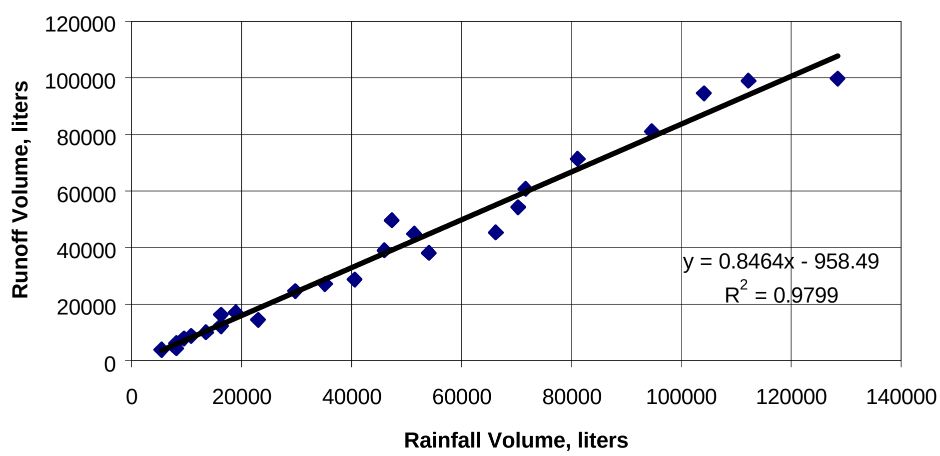

Figure 2.4 Runoff Coefficient for MoPac and West 35th Street

2.3.2 Flow Measurement at Convict Hill Road

Runoff discharge at the Convict Hill Road site was measured using a weir installed on a collection box at the base of a 6-inch diameter down spout. The weir was a compound weir, consisting of three sections: a bottom section which was 20.32 cm high with 30 degree throat, a middle portion which was 4.83 cm high with a 90 degree cross section and a top section which was a rectangular weir which had 5.33 cm sides. Depth of water in the collection box was measured and the discharge was calculated from a rating curve for each section.

$$Q = 137.7H^{2.5} \quad (30 \text{ degree})$$
$$Q = 372.9H^{2.5} \quad (90 \text{ degree})$$

where: Q = flow rate (L/s), and
H = head (m).

An identical weir was calibrated at the Center for Research in Water Resources (CRWR) laboratory. The observed discharge of the 30 degree section was almost identical to that predicted by the formulas. The recommended length and weir elevation of the collection box were limited by the height of the down spout at the base of the bridge support and the concrete pad that was located below it. However, the consistency of the results and the resulting runoff coefficient indicated that the system employed was reliable and yielded accurate flow data. The runoff coefficient calculated in this manner was about 0.94. The runoff-rainfall relationship is shown in Figure 2.5.

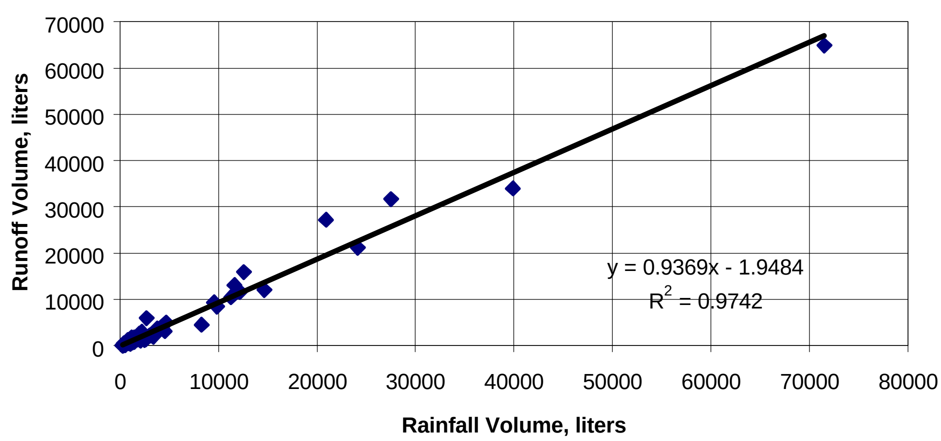

Figure 2.5 Runoff Coefficient for MoPac at Convict Hill Road

2.3.3 Flow Measurement at Walnut Creek

Samples were collected by an automatic sampler from the 1.22 m diameter outfall of the system prior to the discharge entering Walnut Creek. Flow in the storm sewer system at Walnut Creek was calculated using the Manning formula for pipe flow. The slope of the pipe (S), the roughness coefficient (n), the diameter of the pipe (D), and the depth of water in the pipe (d), were used to calculate the flow rate using:

$$Q = \frac{1000}{n} AR^{2/3} S^{1/2}$$

where: Q = flow rate (L/s),

A = cross-sectional area of flow (m^2),

R = hydraulic radius (m),

S = pipe slope, and

n = the roughness coefficient of the pipe (n = 0.013).

The rainfall runoff relationship is shown in Figure 2.6. The larger scatter of the points is the result of the large percentage of the area which is grass covered and where the initial moisture content of the soil strongly influences the volume of runoff. The average runoff coefficient for this site was approximately 0.10, which is in the expected range of values for a site of these characteristics.

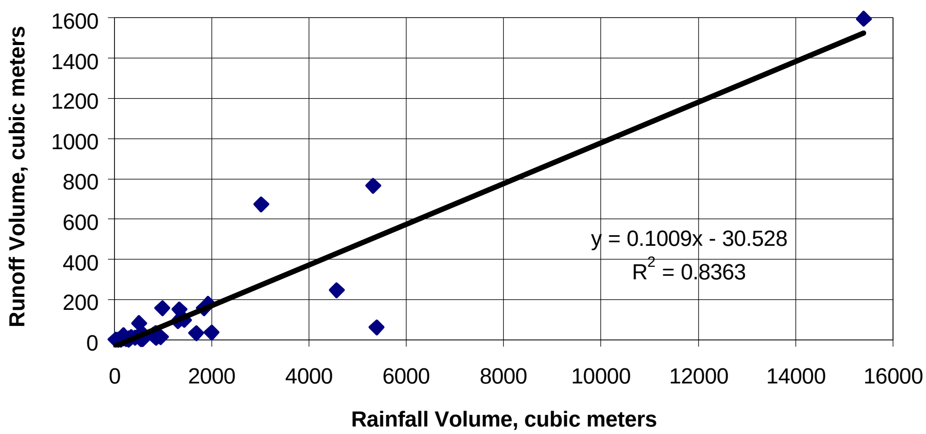

Figure 2.6 Runoff Coefficient for MoPac and Walnut Creek

The calculated runoff for the three sites are presented in Table 2.2. These runoff coefficients were determined from an analysis of volume of runoff collected and the volume of rainfall occurring in natural rainfall events.

Table 2.2 Runoff Coefficients

Sampling Site	Calculated Runoff Coefficient
MoPac at Convict Hill Road	0.94
MoPac at Walnut Creek	0.10
MoPac at West 35th Street	0.85

A second sampler installed at the Walnut Creek site collected runoff directly from the northbound lanes of MoPac. Water falling from a down spout located in the Walnut Creek overpass was collected in a 190L barrel. Flow out of an orifice at the base of the barrel was calculated using Bernoulli's formula. The formula used to measure flow was:

$$Q = C_D \cdot A_O \sqrt{2 \cdot g \cdot H}$$

where:
- Q = flow rate (L/s),
- C_D = a coefficient of discharge (0.6),
- A_o = the area of the orifice (m^2),
- g = gravity (9.81 m/s^2),
- H = the depth of water above the orifice (m).

The area drained is approximately 1,060 m^2. Only about 50% of the runoff was collected during heavier storms, because of the large distance the runoff fell before collection in the barrel. The sample collection interval was determined based on experience at the 100% paved sites at Convict Hill Road and West 35th Street.

2.4 Water Quality Sampling

Water quality samples were collected during runoff events at each site with an automatic sampler (ISCO 3700). The automatic samplers were programmed to sample based on the volume of runoff flowing past the sampling point or based on time after runoff initiated the sampling program. At Walnut Creek and Convict Hill Road the sampler was programmed to draw samples at set volumes of flow. At the 35th Street site, the sampler was initially programmed to collect samples on a timed basis, but was later converted to collect flow weighted composite samples. The sampler was initiated by the flow meter when the water level at the collection site exceeded a predetermined value. Samples were collected and analyzed according to the methodology specified by the U.S. Environmental Protection Agency (EPA).

Initially, the samplers were configured to collect samples in twenty-four 350 mL bottles. Therefore either six samples in four bottles each, or four samples in six bottles each were composited on a flow weighted basis. Later, four 3.8 L glass bottles were installed in the automatic samplers to facilitate the collection of larger volumes of samples for analysis. The samplers were programmed to collect four flow weighted composite samples representing different portions of the runoff so that pollutant concentrations as a function of runoff volume could be investigated. Flow intervals were changed to reflect weather patterns at different times of the year.

2.5 Chemical Analyses

During rainfall events the runoff flow rates were measured and samples were collected automatically. Water quality parameters analyzed in the laboratory for all runoff samples included: turbidity, total and volatile suspended solids (TSS and VSS), 5-Day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), oil and grease (O&G), nutrients (nitrate and total phosphorus), heavy metals (iron, lead, cadmium, nickel, zinc, and copper), and bacteria (total coliform, fecal coliform, and fecal streptococcus). Analyses were performed at The Center for Research in Water Resources in Austin, Texas. Results of all analyses performed as part of this study are reported in the Appendix.

The detection limits for the analytical procedures (analyses and instrumentation) used to determine constituents in the rainfall and runoff samples are summarized in Table 2.3. The detection limit was used in calculating EMCs for concentrations of constituents which were present in the runoff samples at concentrations below the detection limit. Therefore, the EMC of a constituent which is present below the detection limit will be reported as being greater than the actual concentration in the sample.

Table 2.3 Detection Limits at CRWR Laboratory

Analytical Procedure	Detection Limit (mg/L)
TSS	4
VSS	4
BOD	2
COD	5
Total Carbon	10.0
Dissolved Total Carbon	10.0
Nitrate	0.10
Total Phosphorus	0.005-0.05
Oil and Grease	1.0
Copper	0.002-0.006
Chromium	0.0023-0.007
Cadmium	0.0013-0.004
Nickel	0.005-0.015
Iron	
Lead	0.0014-0.042
Zinc	0.0007-0.005

3. RESULTS

3.1 Water Quality of Highway Runoff

Summary water quality characteristics for runoff samples are presented as median event mean concentrations (EMC) in Table 3.1. The concentrations measured in flow weighted composite samples at were used to calculate the EMC. The EMC's for each constituent were derived from the average value of the constituent for each of the runoff events monitored and for which a sufficient volume of runoff was generated to complete the chemical analyses. Median EMCs for the rainfall which could be sampled (i.e. sufficient accumulation to yield the volume required for analyses) also are included in Table 3.1. The volume of rainfall collected usually was insufficient to allow complete chemical characterization.

Table 3.1 Constituents in Highway Runoff

Parameter	35th Street		Convict Hill Rd.		Walnut Creek		Rainfall
	Median	Mean	Median	Mean	Median	Mean	Median
Total Coliform (CFU/100ml)	13000	48000	4200	7900	189000	145000	0
Fecal Coliform (CFU/100ml)	5800	13000	1000	22000	102000	116000	0
Fecal Streptococcus (CFU/100ml)	12000	16000	3800	17000	78000	89000	0
pH	7.15	6.94	5.61	6.14	6.51	7.16	
TSS (mg/L)	131	202	118	142	19	27	0
VSS (mg/L)	36	41	20	22	7	7	0
BOD_5 (mg/L)	12.2	16.5	5.0	6.3	3.5	4.1	ND[a]
COD (mg/L)	126	149	40	48	35	33	6
Total Carbon (mg/L)	47	58	21	24	16	18	ND
Dissolved Tot. Carbon (mg/L)	25	31	11	14	13	15	ND
NO_3-N (mg/L)	1.03	1.25	0.73	0.96	0.28	0.36	0.52
Total Phosphorus (mg/L)	0.33	0.42	0.11	0.13	0.10	0.10	0.05
Oil & Grease(mg/L)	4.1	6.5	1.7	2.2	0.5	0.5	ND
Cu (mg/L)	0.034	0.038	0.007	0.010	0.008	0.007	0.003
Fe (mg/L)	2.606	3.537	1.401	2.437	0.361	0.442	0.079
Pb (mg/L)	0.050	0.099	0.016	0.041	0.007	0.009	ND
Zn (mg/L)	0.208	0.237	0.050	0.077	0.022	0.019	0.019

a) ND = not detected

Nickel and cadmium were rarely present at concentrations above detection limits; therefore they are not shown in Table 3.1. Many of the constituents found in runoff are present in measurable quantities in the rainfall itself. The impact of constituents in rainfall on the quality of highway runoff is limited to nutrients and some metals.

Median EMCs for the runoff at the high traffic sites compare well with the data summarized by Driscoll (1990a, b, and c) for various locations throughout the United States with the exception of lead and zinc. Table 3.2 shows the comparison between the median concentrations measured at 35th Street with the median value reported by Driscoll et al. (1990a) for all sites with average daily traffic greater than 30,000 vehicles per day. The concentrations are extremely similar except for lead which is much lower at 35th Street. The elimination of lead in gasoline is probably responsible for this difference.

Table 3.2 Comparison of High Traffic Site Concentrations

Parameter	MoPac at 35th Street (mg/L)	Driscoll et al. (1990a) (mg/L)
TSS	131	142
VSS	36	39
COD	126	114
NO_2+NO_3	1.03[a]	0.76
Copper	0.034	0.054
Lead	0.050	0.400
Zinc	0.208	0.329

a) NO_3 only

Table 3.3 contains a comparison with the median EMC at Convict Hill Road with the median value reported by Driscoll et al. (1990a) for all sites with an average daily traffic of less than 30,000 vehicles per day. Concentrations at Convict Hill Road were lower for metals and COD, but were much higher for suspended solids. Three factors may have contributed to the higher solids concentrations. Urban development was occurring near this site during the monitoring period. The increased construction traffic may have contributed more solids than a normal vehicle mix might. In addition, the concrete barrier lining the roadway may retain more solids on the road surface, which would then be mobilized during storms. In contrast to most low traffic, rural highways, the catchment sampled had an impervious cover of 100% so that the runoff did not flow across any grassy areas which might have reduced solids concentrations.

Table 3.3 Comparison of Low Traffic Site Concentrations

Parameter	MoPac at Convict Hill Rd. (mg/L)	Driscoll et al. (1990a) (mg/L)
TSS	118	41
VSS	20	12
COD	40	49
NO_2+NO_3	0.73[a]	0.46
Copper	0.007	0.022
Lead	0.016	0.080
Zinc	0.050	0.080

a) NO_3 only

The event mean concentrations reported for the site having the high traffic density are higher for all water quality parameters than the observed EMC's for the other sites. However, the event mean concentrations observed at the site with medium traffic density are lower than those observed for the other two sites, including the low traffic site. This phenomenon may be explained by the fact that the runoff from the highway at the high traffic and low traffic sites is directly from the pavement into a catch basin where the samples are collected. However, the highway runoff at the medium traffic density site passes over approximately 60 m of grassy area (swale) before entering the storm drain pipe from which samples are collected. The lower concentrations of the various water quality parameters at this site may reflect removal by the grassy swale. The effects of the grassy swale on the water quality at this site is reported in Section 3.3.

3.2 Estimate of Annual Pollutant Loads

The product of the volume of runoff from a section of highway, over a given period of time, and the concentration of a specific constituent yields the pollutant load contributed by the highway. For many types of water bodies, the pollutant load is a more important indicator of potential water quality impacts than is EMC. Annual constituent loads for the three highway sites were calculated based on the “simple method” described by Schueler (1987).

$$L = \left[\frac{(P)(CF)(R_v)}{20.4}\right](C_i)$$

where:
- L = Annual pollutant load (kg/ha)
- P = Annual precipitation (825 mm/yr)
- CF = Correction factor that adjusts for storms where no runoff occurs (0.9)
- R_v = Average runoff coefficient
- C_i = Event mean concentration (mg/L)

Estimated annual loadings (grams per square meter of pavement) are presented in Table 3.4. The loads for each site were normalized by watershed area to facilitate a comparison between the three sites.

Table 3.4 Estimated Annual Pollutant Loadings

Pollutant	**35th Street** (kg/ha)	**Convict Hill Rd.** (kg/ha)	**Walnut Creek** (kg/ha)
TSS	229	145	3.3
VSS	46	23	0.8
BOD_5	18.7	6.5	0.5
COD	169	49	4.0
Total Carbon	66	25	2.2
Dissolved Tot. Carbon	35	14	1.8
NO_3-N	1.42	0.98	0.04
Total Phosphorus	0.48	0.13	0.01
Oil & Grease	7.36	2.25	0.06
Cu	0.043	0.010	0.001
Fe	4.008	2.497	0.053
Pb	0.112	0.042	0.001
Zn	0.269	0.079	0.002

All estimated loadings at Walnut Creek are far less than those at the other two sites. This is the result of the initial low concentrations of constituents in the runoff at Walnut Creek combined with the low runoff coefficient caused by the grassy swale. Differences between expected loads at 35th Street and Convict Hill Road are primarily the result of differences in the EMC's for the constituents.

3.3 Effect of Drainage System Type

Grassy swales are vegetated ditches which have gentle slopes and cover large areas of land. Swales have been shown in studies to effectively remove many constituents from highway runoff. The swales promote settling of suspended solids and infiltration of the runoff into the soil. A curb and gutter system, which tends to concentrate and transport constituents in highway runoff, also is eliminated by a grassy swale (Schueler, 1991). Factors reported to affect the removal efficiency include type of grass, grass density, blade size, blade shape, flexibility and texture (Umeda, 1988). Channel dimensions and swale area affect removal efficiencies and the amount of infiltration that occurs.

A second sampler was installed to collect runoff directly from the road surface for comparison with the runoff from the swale to investigate the effect of the grassy swale on the runoff quality at the Walnut Creek site. A limited number of samples were collected from the overpass and concentrations of constituents were similar to those at Convict Hill Road. The data observed for the runoff samples collected from the two surfaces (the overpass before the runoff reached the grassy swale and from the outfall into which the runoff flowed after passage through the grassy median strip) at MoPac at Walnut Creek are presented in Table 3.5.

Table 3.5 Removal Efficiency of a Grassy Swale

Parameter	Roadway	Grassy Swale	Removal (%)
Total Coliform (CFU/100mL)	3,678	188,197	-
Fecal Coliform (CFU/100mL)	1,934	101,545	-
Fecal Streptococcus (CFU/100mL)	6,909	89,482	-
TSS (mg/L)	104	27	74
VSS (mg/L)	23	7	72
BOD_5 (mg/L)	7.5	4.1	46
COD (mg/L)	51	33	35
Total Carbon (mg/L)	34	18	48
Dissolved Tot. Carbon (mg/L)	17	15	9
NO_3-N (mg/L)	0.88	0.36	59
Total Phosphorus (mg/L)	0.15	0.10	31
Oil & Grease (mg/L)	3.9	0.5	88
Cu (mg/L)	0.014	0.007	49
Fe (mg/L)	2.066	0.442	79
Pb (mg/L)	0.014	0.009	35
Zn (mg/L)	0.074	0.019	74

Significant pollutant removal occurs for all constituents except bacteria and dissolved total carbon. These reductions in concentration are similar to that reported by other studies. Schueler et al. (1991) reported that well-designed, well-maintained grassed swales may remove up to 70% of TSS, 30% of total phosphorus, 25% of total nitrogen, and 50-90% of various trace metals. Little et al. (1982) found removal efficiencies of 67-93% of oil and grease, and TSS and VSS reductions of at least 65%.

The use of a grassy swale as a runoff control device raises some concerns. The bacterial counts found in samples of runoff from the swale were much higher than at the other sites. The concentrations also show that more bacteria are in the samples from the outfall than in the runoff of the roadway. Apparently, the soil of the swale or the storm sewer act as a source of bacteria. It is unlikely, given the setting, that the high levels of fecal coliform and fecal streptococcus are of human origin or that they are indicative of significant human health risk.

3.4 Pollutant Washoff Patterns

Concentrations of pollutants in runoff are often higher at the beginning of a runoff event, a phenomenon commonly referred to as the "first flush." Many storm water treatment systems are designed to capture the initial runoff from storm events to remove and treat the runoff with the highest concentrations of pollutants. It is thought by many that the majority of pollutants are contained in the first flush. Suspended solids often display the first flush effect as shown in Figure 3.1. If the rate that material is washed from the road is proportional to the amount on the road then a simple exponential function will describe the instantaneous concentrations. The magnitude of the first flush phenomenon varied between events and monitored sites in this study.

The first flush effect was more evident at West 35th Street than at Convict Hill Road or Walnut Creek because the concentrations of the constituents were higher at West 35th Street and changes were more evident. A first flush was most pronounced during short storms with fairly constant rainfall intensities. For longer events, changes in traffic volume, rainfall intensity and other variables reduced the magnitude of the first flush. Vehicles acted as a continuing source of pollutants during storm events, so complete washoff never occurred. For all storms monitored at this site the percentage of total mass

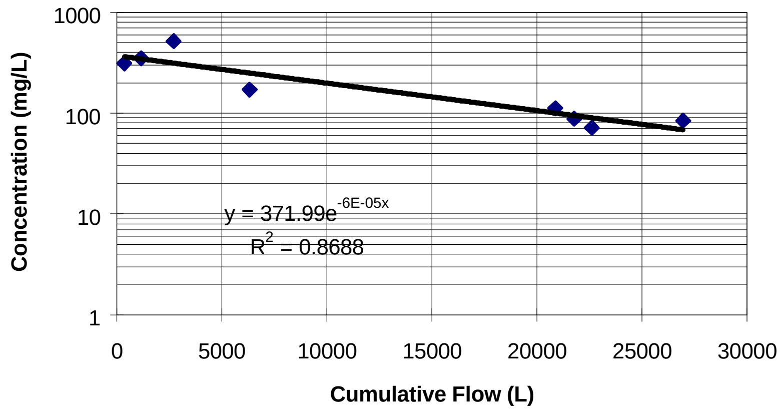

Figure 3.1 Washoff of TSS at 35th Street, 10/29/93

discharged at any point in the storm was only slightly higher than the percentage of the total runoff volume at that point. A more detailed description of the first flush effect at 35th Street is contained in CRWR Technical Report #264 (Irish et al, 1995).

At Convict Hill Road most sample collection was limited to the first 12.1 mm of runoff, because of the requirements of the NPDES permit and the rainfall characteristics in the Austin area. This limited the evaluation of the first flush characteristics at this site. Higher concentrations were recorded during approximately the first 3 mm of runoff for most constituents; however, the concentrations quickly became approximately constant for the duration of the sampling period. The typical pattern is shown in Figure 3.2 for TSS. Since the concentration of TSS stabilizes at approximately 100 mg/L, significant loading continues for the duration of the sampling period.

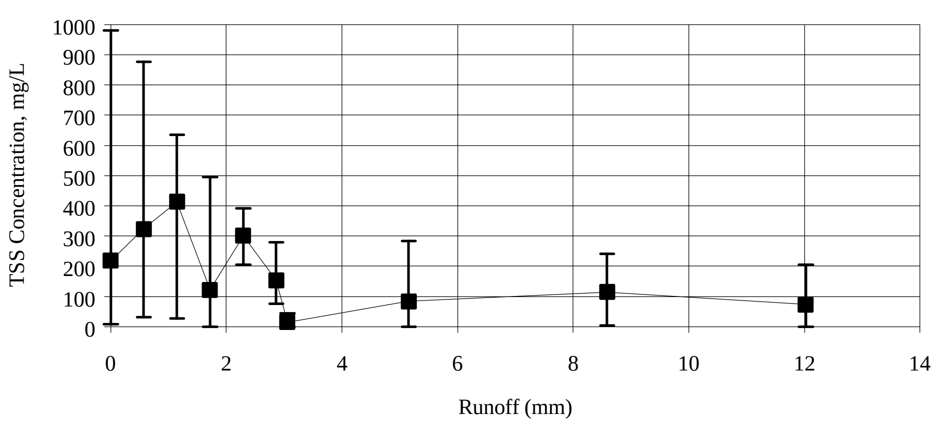

Figure 3.2 TSS Washoff Pattern at Convict Hill Road Site

First flush effects were less evident at Walnut Creek than at the other two sites because of the lack of variability and low concentrations of constituents in runoff. Low concentrations of most pollutants minimized the differences in concentrations between the start and end of the storm. The range of concentrations tend to narrow with more rainfall and average concentrations near the end of the storm are smaller than those observed at the start of the storm. Only a few constituents showed somewhat higher concentrations at the beginning of an event. The higher concentrations were limited to approximately the first 5 mm of runoff. The concentrations stabilized at this point resulting in continued input of each constituent for the duration of the event.

Although concentrations were somewhat higher at the beginning of runoff events at the sites monitored in this study, the effect was not pronounced. Concentrations stabilized at elevated levels resulting in a continuous input of pollutant load for the duration of the event. Decisions about the size of proposed runoff controls should be based on the assumption that storm water runoff has a constant concentration for each storm event.

4. SUMMARY AND CONCLUSIONS

Water quality of highway runoff in the Austin, Texas area was determined by monitoring runoff at three locations on MoPac, which represented different daily traffic volumes, surrounding land uses, and highway drainage system types. MoPac at West 35th Street is a high traffic site (60,000 vehicles per day) located in central Austin. The land use of the area is mixed residential and commercial. MoPac at Convict Hill Road is a low traffic site (8700 vehicles per day) located on the southern edge of Austin. The land use around Convict Hill Road is mostly residential and rural undeveloped. The Walnut Creek site is located in north Austin and consists of a combination of paved highway and grassy shoulder and median. The land use classification of the area is mostly commercial and high density residential, and approximately 47,000 vehicles per day pass this location. At Walnut Creek, the highway runoff crosses a large grassy median before entering the storm sewer system where the samples were collected. The watersheds of the other two sites were 100 % impervious.

Runoff flow rates were measured and samples were collected automatically during rainfall events. Water quality parameters analyzed in the laboratory for all runoff samples included: turbidity, total and volatile suspended solids (TSS and VSS), 5-Day Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), oil and grease (O&G), nutrients (nitrate and total phosphorus), heavy metals (iron, lead, cadmium, nickel, zinc, and copper), and bacteria (total coliform, fecal coliform, and fecal streptococcus).

The highest concentrations of all constituents were measured at the high traffic site at 35th Street. The lowest concentrations were found at the Walnut Creek monitoring site. The concentrations at all sites were similar to median values compiled in a nationwide study of highway runoff quality.

The total load of pollutant discharged is more important for estimating water quality impacts for many receiving waters than is concentration. Pollutant load is a function of concentration and volume of runoff. Normalized for surface area, the greatest loads were generated at 35th Street, while the lowest amounts were found at the Walnut Creek monitoring site. The monitored watershed at Walnut Creek had a runoff coefficient of only about 10 % while the other two sites had runoff coefficients of approximately 90 %. The lower concentrations at Walnut Creek combined with the much lower flows at this site were responsible for the low loads at this site.

Little adverse impact would be expected for all but the most sensitive receiving waters based on the quantity and quality of highway runoff generated during storms. The water quality of highway runoff is generally similar to that reported for urban runoff, and does not contain appreciably higher concentrations of toxic metals or oil and grease. The impacts of highway runoff alone, like many other nonpoint sources of pollution generally are not significant when considered singly, but may result in degradation of water quality when combined with other sources such as urban runoff.

The effectiveness of grassy swales for treating highway runoff was evaluated by comparing the runoff at Walnut Creek, before and after passing across a swale. The grassy swale proved effective for reducing the concentrations of most constituents in runoff. The low runoff coefficient due to infiltration of runoff into the swale produced a large reduction (90%) in pollutant load discharged. This reduction of runoff volume effectively reduces the impact of constituents whose concentrations are not reduced by the swale. Large increases in bacteria counts occurred in either the swale or the storm sewer system; however, they probably do not indicate the presence of a significant human health threat. The use of a grassy swale precludes the installation of hazardous material traps designed to catch spills of gasoline or other chemicals during traffic accidents.

A first flush effect (i.e., higher pollutant concentrations at the beginning of an event) was very evident during selected events, but was generally limited to a small volume. When all monitored events were considered, the overall effect was small or negligible. The concentrations appeared to be affected by changes in traffic volume, rainfall intensity, and other factors. In addition, vehicles provided a continuous input of pollutants to the road surface and runoff for the duration of runoff events. In considering the potential effectiveness of storm water treatment systems, constant concentrations for individual storm events should be assumed.

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APPENDIX

Table A-1 Event Mean Concentrations for Events at West 35th Street

DATE	Flow	TSS	VSS	BOD	COD	TC	DTC	N	TP	O&G	Cu	Fe	Pb	Zn	T.col.	F.col.	F.strep.
	(liters)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	CFU/100 mL		
9/13/93	450	58	26	19	248	N/A	N/A	2.74	0.61	4.2	0.04	0.3	0.02	N/A	N/A	N/A	N/A
10/12/93	1832	106	26	25	190	84	72	3.26	0.61	3.2	0.04	1.2	0.44	0.28	N/A	N/A	N/A
10/19/93	10243	385	36	12	42	32	15	0.52	0.30	0.8	0.05	2.0	0.12	0.18	N/A	28004	3356
10/19/93	1264	157	42	28	195	79	33	1.11	0.50	4.3	0.08	5.6	0.24	0.36	12470	48662	39701
10/19/93	1601	116	47	28	185	68	31	1.07	0.47	4.7	0.08	4.4	0.23	0.34	NA	30197	23479
10/28/93	26957	147	33	18	126	53	33	0.84	0.33	9.6	0.06	2.5	0.09	0.24	5199	2029	4113
11/1/93	5620	175	44	21	209	82	45	2.11	0.39	5.0	0.07	2.7	0.19	0.29	N/A	N/A	N/A
12/21/93	6271	48	8	0	149	66	38	1.32	0.30	5.9	0.06	3.5	0.13	0.22	N/A	N/A	N/A
1/12/94	10408	123	24	6	142	35	33	1.41	0.15	4.1	0.01	0.7	0.03	0.06	N/A	366	2350
1/19/94	10444	286	81	40	336	145	80	3.44	1.04	35.1	0.05	5.7	0.04	0.36	N/A	N/A	15849
1/21/94	5988	79	40	43	264	128	85	2.36	0.51	24.0	0.04	5.3	0.05	0.30	N/A	3750	28044
2/21/94	87156	370	40	5	88	16	11	0.37	0.33	N/A	0.12	3.1	0.12	0.23	N/A	N/A	N/A
2/27/94	45877	N/A	N/A	N/A	N/A	39	10	0.43	N/A	N/A	0.04	7.7	0.27	0.59	787	N/A	N/A
3/8/94	65514	N/A	N/A	7	64	33	13	0.49	0.27	N/A	N/A	4.7	0.15	0.31	N/A	N/A	N/A
3/12/94	31975	40	20	9	75	26	19	1.08	0.12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3/14/94	36692	313	37	9	79	46	14	0.41	0.30	N/A	0.02	4.4	0.10	0.21	2694	N/A	2896
3/26/94	1964	131	57	15	90	N/A	N/A	1.03	N/A	N/A	N/A	N/A	N/A	N/A	32203	N/A	1021
4/4/94	41803	808	86	23	135	79	20	0.73	0.70	N/A	0.05	9.7	0.23	0.26	6153	407	19421
4/10/94	7627	540	114	23	292	153	53	0.96	0.73	N/A	0.07	7.8	0.21	0.51	N/A	N/A	N/A
4/14/94	13203	914	130	22	203	80	20	0.00	0.93	N/A	0.05	7.5	0.18	0.40	N/A	N/A	N/A
4/18/94	12084	N/A	N/A	N/A	217	61	28	1.39	0.76	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4/27/94	3471	126	44	56	452	123	89	3.66	1.09	N/A	N/A	N/A	N/A	N/A	14715	7032	85896
4/28/94	31525	266	49	10	80	39	18	0.62	0.39	N/A	0.02	2.0	0.06	0.16	N/A	N/A	N/A
5/1/94	11322	33	24	12	167	37	29	0.902	N/A	N/A	0.0188	0.4465	0.0000	0.0340	N/A	N/A	N/A
5/1/94	24113	184	60	4	115	37	13	0.360	0	N/A	0.0020	0.4590	0.0350	0.0390	N/A	N/A	N/A
6/2/94	37176	287	42	10	125	49	25	0.922	0	4	0	10	0	0	N/A	N/A	N/A
6/12/94	5496	372	56	N/A	124	130	78	0.000	1	N/A	0	10	0	1	N/A	N/A	N/A
6/13/94	25782	110	23	9	41	36	22	0.620	0	N/A	0	3	0	0	N/A	N/A	N/A

Table A-1 Event Mean Concentrations for Events at West 35th Street (Con't)

DATE	Flow	TSS	VSS	BOD	COD	TC	DTC	N	TP	O&G	Cu	Fe	Pb	Zn	T.col.	F.col.	F.strep.
	(liters)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	CFU/100 mL		
8/13/94	23669	105	22	9	94	38	32	1.35	0.33	3.54	0.005	1.5	0.014	0.132	N/A	N/A	N/A
8/14/94	43020	67	13	10	70	27	23	1.40	0.23	3.66	0.002	1.1	0.014	0.083	N/A	N/A	2222
8/21/94	23660	58	22	15	167	59	51	1.02	0.30	N/A	0.021	1.8	0.028	0.131	37420	23875	19700
9/7/94	31634	91	36	37	464	N/A	N/A	3.65	0.60	2.51	0.034	1.0	0.014	0.248	601564	N/A	19878
9/9/94	443549	27	23	14	184	68	49	1.94	0.19	4.17	0.016	0.9	0.007	0.095	N/A	N/A	30669
9/15/94	33746	160	39	9	64	29	13	0.25	0.42	N/A	0.006	1.2	0.007	0.143	N/A	N/A	N/A
10/7/94	108126	93	28	27	209	75	52	1.76	0.60	3.95	0.028	1.4	0.084	0.192	8354	724	622
10/25/95	43590	N/A	N/A	N/A	18	5	5	N/A	0.07	N/A	0.005	0.7	0.015	0.057	N/A	N/A	1730
10/28/94	16200	129	42	16	124	54	22	N/A	0.25	3.70	0.029	3.8	0.027	0.204	40851	34307	36628
11/15/94	23946	96.00	32.00	N/A	135	64.9	27.5	N/A	0.26	N/A	N/A	N/A	N/A	N/A	18333	7000	16667
12/2/94	45312	205	28	12	65	38	9	0.48	0.30	3.20	0.013	1.7	0.012	0.107	N/A	N/A	N/A
12/9/94	7408	20.00	8.00	14	152	53.1	40.4	2.20	0.19	5.1	0.012	0.404	0.007	0.068	N/A	N/A	N/A
12/14/94	21710	80	28	19	157	60	30	1.32	0.31	N/A	0.020	2.9	0.019	0.149	17824	13995	29138
12/15/94	206825	88	32	7	89	36	13	0.44	0.22	N/A	0.015	1.8	0.019	0.111	4943	3662	N/A
2/11/95	9549	128.00	48.00	31	N/A	99.5	73.7	N/A	0.78	3.5	0.062	2.958	0.026	0.192	47000	600	5350
2/24/95	47345	336	48	N/A	196	95	26	2.27	0.65	N/A	0.068	8.8	0.037	0.316	N/A	N/A	N/A
3/7/95	20806	57	30	8	55	25	14	1.43	0.18	3.30	0.021	1.4	0.023	0.102	1334	70	3155
3/13/95	45325	225	24	7	68	25	10	0.63	0.25	4.10	N/A	N/A	N/A	N/A	391	85	1118
4/20/95	51063	218	35	5	48	15	4	0.21	0.19	N/A	N/A	N/A	N/A	N/A	14385	N/A	11546
5/8/95	37976	165	41	9	55	32	N/A	N/A	0.33	N/A	N/A	N/A	N/A	N/A	N/A	18915	6921
5/18/95	20960	N/A	N/A	N/A	N/A	36.5	N/A	N/A	0.00	N/A	N/A	N/A	N/A	N/A	N/A	4500	22500

Table A-2 Event Mean Concentraitons for Events at Convict Hill

Date	Rainfall	Rainfall	Flow	Flow	TSS	VSS	BOD	COD	TC	DTC	N	TP	O&G	Cu	Fe	Pb	Zn	T.col.	F.col.	F.strep.
	(in)	(mm)	(gal)	(L)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL		
4/29/94	0.09		375		239	39	10	72	49	28	1.47	0.062	NA	0.015	NA	NA	0.063	NA	NA	20500
5/2/94	0.11		375		86	23	6	78	41	23	0.89	0.109	NA	0.020	2.9	NA	0.081	NA	NA	NA
5/13/94	0.46		1050		403	42	5	92	39	17	0.71	0.260	NA	0.010	8.9	0.141	0.174	NA	NA	0
5/14/94	0.25		350		348	20	7	NA	29	11	0.78	0.358	1.5	0.009	4.0	0.090	0.099	12000	400	7667
5/16/94	0.07		400		6	6	7	46	24	21	0.75	0.078	2.0	0.002	1.0	0.033	0.053	2000	167	20667
6/10/94	0.17		400		512	50	24	174	89	43	NA	0.380	NA	0.032	11.8	0.223	0.310			
6/19/94	0.23		400		4	0	5	75	20	20	0.60	NA	1.9	0.011	4.5	0.100	0.292	NA	NA	NA
6/21/94	0.16		600		40	12	6	68	31	22	1.61	0.112	2.4	0.001	0.5	0.171	0.033	NA	NA	NA
8/8/94	0.18		600		176	68	13	114	NA	NA	NA	0.200	8.1	0.003	2.2	0.021	0.042	0	0	100
8/9/94	0.36		900		42	14	3	32	11	5	0.21	0.048	1.6	0.001	0.9	0.007	0.010	7550	1250	775
8/16/94	0.3		900		80	8	10	39	23	21	1.80	NA	1.7	0.001	1.1	0.007	0.028	NA	NA	NA
8/22/94	0.27		900		40	12	3	15	14	11	0.43	0.060	0.8	0.002	0.8	0.012	0.017	NA	NA	3525
9/7/94	0.17		450		292	44	16	49	22	19	1.02	0.080	1.8	0.009	1.8	0.017	0.079	11500	9500	4000
9/8/94	0.27		900		0	0	5	17	5	5	0.53	0.025	0.4	0.003	0.3	0.016	0.022	1750	NA	750
9/9/94	0.47		1800		3	2	3	10	5	5	0.40	0.025	1.3	0.008	0.5	0.007	0.028	6788	NA	1475
10/7/94	0.37		1350		68	7	8	49	21	16	0.60	0.077	0.9	0.003	0.8	0.011	0.019	NA	NA	NA
10/14/94	0.24		1275		24	16	6	43	32	14	0.78	0.030	2.4	0.003	0.9	0.021	0.055	14800	110000	90000
10/25/94	0.56		1800		146	15	4	19	18	8	NA	0.041	0.9	0.003	0.7	0.009	0.016	NA	NA	9500
10/27/94	0.29		1575		68	16	4	40	24	10	NA	0.113	1.8	0.007	2.5	0.014	0.215	4500	6000	20625
11/5/94	0.49		1800		192	24	3	29	19	8	NA	0.078	0.9	0.007	1.5	0.013	0.045			NA
11/15/94	0.15		300		12	4	5	33	20	17	NA	0.060	1.7	0.006	1.2	0.014	0.081	4000	1500	3600
12/2/94	0.3		900		156	28	5	39	21	5	0.39	0.070	7.6	0.007	1.4	0.007	0.052		186667	156667
12/9/94	0.09		375		136	28	3	29	13	12	0.55	0.005	NA	NA	NA	NA	NA	NA	NA	NA
12/15/94		23.16		11679	96	21	3	41	23	10	0.23	0.14	2.6	0.004	1.2	0.015	0.037	1099	1349	2866
1/13/95		19.56		7137	346	29	5	26	17	10	0.18	0.14	N/A	0.005	1.4	0.014	0.035	0	0	0
2/13/95		2.75		4522	24	8	13	46	23	15.3	1.75	0.13	3.6	0.032	2.1	0.024	0.075	1150	350	1450
2/24/95		8.32		9381	245	20	N/A	85	45	14	1.37	0.19	N/A	0.032	6.8	0.027	0.118	NA	NA	NA
3/7/95		8.35		9230	147	26	4	31	19	4	1.24	0.12	0.9	0.014	1.8	0.027	0.049	681	404	834
3/13/95		30.46		15087	118	3	2	16	12	9	5.50	0.09	N/A	0.024	2.3	0.024	0.042	119	NA	150

Table A-2 Event Mean Concentraitons for Events at Convict Hill (Con’t)

Date	Rainfall	Rainfall	Flow	Flow	TSS	VSS	BOD	COD	TC	DTC	N	TP	O&G	Cu	Fe	Pb	Zn	T.col.	F.col.	F.strep.
	(in)	(mm)	(gal)	(L)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	CFU/100 mL		
3/16/95		5.81		2244	148	24	2	44	29.1	10	1.75	0.16	2.0	N/A	N/A	N/A	N/A	2550	100	3300
4/4/95		16.76		12091	153	30	5	40	21	10	0.20	0.19	1.1	N/A	N/A	N/A	N/A	8366	2306	13266
4/18/95		9.84		6838	86	26	7	38	24	11	0.79	0.20	N/A	N/A	N/A	N/A	N/A	56103	698	19212
4/19/95		7.33		3336.6	260	52	7	57	32.1	10	0.35	0.26	N/A	N/A	N/A	N/A	N/A	17500	NA	20000
4/20/95		19.03		8420	198	20	4	21	12	10	0.11	0.13	N/A	N/A	N/A	N/A	N/A	NA	NA	NA
5/8/95		27.42		11723	85	15	3	18	13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5829	667	4175
5/18/95		7.11		2574	N/A	N/A	N/A	N/A	14.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66000	25500

Table A-3 EMC's at Walnut Creek for Events with Flow Similar to Base Flow (Swale)

Date	Rainfall (mm)	Flow (L)	TSS (mg/L)	VSS (mg/L)	BOD (mg/L)	COD (mg/L)	TC (mg/L)	DTC (mg/L)	N (mg/L)	TP (mg/L)	O&G (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Zn (mg/L)	T.col. (mg/L)	F.col. (mg/L)	F.strep. (mg/L)
5/16/94			0	0	3	26	42	39	0.54	0.09	1.00	0.019	0.10	0.062	0.027	35000	10000	25000
6/3/94			18	6	4	55	39	38	N/A	0.09	1.30	0.001	0.27	0.062	0.042	na	na	na
8/8/94			136	48	12	124	51	33	3.10	0.38	NA	0.001	1.12	0.007	0.047	tntc	tntc	200000
8/15/94			39	12	8	42	41	47	2.45	0.23	0.50	0.001	0.31	0.009	0.004	356667	150000	15000
8/21/94			32	0	7	47	32	27	0.60	0.12	0.50	0.011	0.98	0.021	0.018	na	na	na
9/8/94			26	4	4	16	10	8	0.52	0.13	0.70	0.005	0.80	0.007	0.032	100375	na	na
9/12/94			8	4	1	36	17	13	0.33	NA	0.70	0.001	0.49	0.007	0.008	na	na	na
10/14/94			28	8	4	27	43	38	2.05	0.15	NA	0.004	0.12	0.007	0.013	na	na	na
10/16/94			8	3	4	27	53	51	1.21	0.01	0.70	0.002	0.09	0.007	0.041	na	na	na
11/15/94			4	0	6	28	38	36	N/A	0.11	N/A	N/A	N/A	N/A	N/A	133	100	233
12/14/94			10	8	3	36	43	42	0.67	0.11	0.80	0.002	0.17	0.014	0.009	20375	12375	10875
1/13/95			14	1	2	6	46	45	1.24	0.01	1.40	0.007	0.03	0.014	0.009	0	0	0
3/13/95			15	1	2	18	32	28	1.22	0.09	2.35	0.004	0.17	0.014	0.009	na	na	na
3/16/95			7	1	3	22	38	27	0.81	0.05	2.80	0.006	0.43	0.014	0.007	4417	7133	7000
4/4/95			61	11	2	14	35	30	0.37	0.04	1.00	0.005	0.24	0.014	0.011	825	163	725
4/20/95			9	3	4	30	39	31	0.53	0.05	N/A	N/A	N/A	N/A	N/A	44000	5400	103500

Table A-4 EMC's at Walnut Creek for Events with Significant Storm Flow (Swale)

Date	Rainfall (mm)	Flow (L)	TSS (mg/L)	VSS (mg/L)	BOD (mg/L)	COD (mg/L)	TC (mg/L)	DTC (mg/L)	N (mg/L)	TP (mg/L)	O&G (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Zn (mg/L)	T.col. (mg/L)	F.col. (mg/L)	F.strep. (mg/L)
4/29/94	14.46	66284	62	12	5	35	12	13	0.49	0.22	N/A	0.013	0.25	N/A	0.041	na	na	na
4/30/94	4.83	37536	15	4	3	40	24	24	0.45	0.12	N/A	0.013	0.14	N/A	0.024	na	na	na
5/2/94	8.3	41068	19	N/A	3	47	34	30	0.28	0.10	N/A	0.012	0.47	N/A	0.020	na	na	na
5/28/94	12.43	31004	10	4	3	30	24	25	0.87	0.10	N/A	N/A	N/A	N/A	N/A	na	na	na
10/7/94	124.91	1473204	8	0	3	20	5	5	0.23	0.11	0.50	0.003	0.71	0.021	0.001	380000	185000	153333
10/18/94	14.99	154861	55	9	5	38	16	10	0.20	0.09	0.89	0.003	1.09	0.007	0.031	144958	116085	79830
5/8/95	44.44	197330	20	10	5	21	9	0	0.00	0.00	0.00	0.000	0.00	0.000	0.000	39634	3552	35283

Table A-5 EMC's at Walnut Creek for Direct Road Runoff

Date	Rainfall (mm)	Flow (L)	TSS (mg/L)	VSS (mg/L)	BOD (mg/L)	COD (mg/L)	TC (mg/L)	DTC (mg/L)	N (mg/L)	TP (mg/L)	O&G (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Zn (mg/L)	T.col. (mg/L)	F.col. (mg/L)	F.strep. (mg/L)
10/17/94	5.33	757	216	52	5	42	58.3	12.8	0.26	0.17	1.70	0.01	1.67	0.01	0.07	na	na	na
11/5/94	5.33	1514	24	20	3	4	5	5	N/A	0.04	N/A	0.01	0.40	0.01	0.01	na	na	na
11/15/94	5.08	2271	40	12	8	71	35	28	N/A	0.19	2.50	0.01	2.34	N/A	0.10	2500	1363	4775
12/2/94	5.08	946	100	16	9	56	29.6	14.5	0.35	0.14	4.10	0.01	1.28	0.01	0.06	na	na	na
12/14/94	3.05	2839	42	22	9	84	40	24	1.19	0.17	7.90	N/A	N/A	N/A	N/A	5000	5100	21600
1/13/95			24	11	4	42	25	17	1.60	0.05	3.0	0.004	0.8	0.017	0.042	625	625	250
2/13/95	0.75	307	44	16	22	99	43.4	29.3	N/A	0.16	5.1	0.022	2.1	0.020	0.105	3500	350	500
2/24/95	11.39	1909	143	13	N/A	97	47	14	1.60	0.20	5.7	0.037	5.3	0.032	0.147	5793	4886	12381
3/13/95	32.23	4184	128	7	3	28	17	11	0.34	0.11	2.3	0.025	2.3	0.017	0.045	314	324	584
3/16/95	5.3	1705	240	40	9	24	50.8	16.5	1.40	0.22	3.8	0.017	4.0	0.014	0.124	2000	1200	4400
4/4/95	0.25	618	190	54	8	31	45	15	0.76	0.21	2.9	0.004	0.6	0.004	0.027	9690	1622	10779
4/20/95	9.14	1007	128	24	7	68	33.3	13.6	0.43	0.17	N/A	N/A	N/A	N/A	N/A	na	na	na
5/8/95	57.58	4595	33	12	3	16	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	na	na	na