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16. Abstract

This project documents the impact of a porous asphalt overlay on the quality of highway stormwater runoff. A porous asphalt overlay, also known as a permeable friction course (PFC) or open graded friction course (OGFC), is a layer of porous asphalt approximately 50 mm (2 in.) thick which is often applied on top of conventional asphalt highways to enhance safety and reduce noise. The quality of stormwater runoff from a four-lane divided highway in the Austin, Texas area was monitored before and after the installation of a PFC. Observed concentrations of total suspended solids and pollutants associated with particulate material were much lower in the runoff from the PFC than that derived from the conventional asphalt surface. Concentration reductions were observed for total suspended solids (91 percent), total lead (90 percent), total copper (49 percent), and total zinc (76 percent). Concentrations of chemical oxygen demand and total Kjeldahl nitrogen were initially lower in the runoff from the PFC, but increased abruptly after about 6 months to concentrations that were similar to the concentrations in runoff from conventional pavement. Concentrations of dissolved constituents were not significantly different between the two pavement types. Observed concentrations of polycyclic aromatic hydrocarbons (PAHs) were below the detection limit for both pavement types.

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Stormwater Quality Benefits of a Porous Asphalt Overlay

Michael E. Barrett

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Project:	0-4605
Project Title:	Stormwater Quality Documentation of Roadside Shoulders Borrow Ditches
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Center for Transportation Research
The University of Texas at Austin
3208 Red River
Austin, TX 78705

www.utexas.edu/research/ctr

Disclaimers

Engineering Disclaimer

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Products

This report contains Product P3: Recommendations on how PFC can reduce the environmental impacts of highway runoff. These recommendations are summarized in the conclusions of the report.

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Chapter 1. INTRODUCTION

1.1 Background

Porous asphalt is an alternative to traditional hot mix asphalt and is produced by eliminating the fine aggregate from the asphalt mix. A layer of porous asphalt approximately 50 mm (2 in.) thick is placed as an overlay on top of an existing conventional concrete or asphalt surface. The overlay typically is referred to as Permeable Friction Courses (PFC), Open Graded Friction Courses (OGFC), Porous European Mixtures (PEM), or plant mix seal coats. The void space in a PFC overlay layer generally is 18–22 percent *(1)*. Rain that falls on the friction course drains through the porous layer to the original impervious road surface, at which point the water drains along the boundary between the pavement types until the runoff emerges at the edge of the pavement.

Porous asphalt overlays are used increasingly by state transportation agencies, including those in Georgia, Texas, California, and Utah, to improve drivability in wet weather conditions and to reduce noise from highway traffic. Acknowledged benefits include reduced splash and spray, better visibility, better traction, reduced hydroplaning, and less noise *(2),(3)*. The dramatic difference in spray is illustrated in Figure 1.1, which shows the same truck passing from PFC to a conventional pavement. These pavements also may reduce the runoff volume and peak runoff velocity, as well as increase the lag time between rainfall and runoff, especially for smaller storm events.

1.2 Objectives

The main objective of this study was to compare the water quality of stormwater runoff derived from a PFC overlay with that from a conventional hot mix asphalt pavement. This comparison was made by collecting runoff samples at the same location along a highway in the Austin, Texas area before and after a PFC overlay was applied. A secondary objective was to determine whether any changes in water quality between the two pavement surfaces would persist as the PFC overlay aged and the pore spaces filled with accumulated material.

Figure 1.1: Difference in Spray from Conventional and PFC Pavements

Chapter 2. LITERATURE REVIEW

The impact of PFC on stormwater runoff quality has been evaluated in few scientific studies; however, there are several reasons to think that improved water quality may result from the installation of this material. PFC might be expected to reduce the generation of pollutants, retain a portion of generated pollutants within the porous matrix, and impede the transport of pollutants to the edge of the pavement.

It has been reported that the concentrations of selected constituents in highway runoff were affected by the number of vehicles passing the site during a storm event *(4)*. These constituents included oil/grease, copper, and lead. Spray generated from tires was assumed to wash pollutants from the engine compartments and bottoms of vehicles. It is reasonable to expect that the amount of material washed off vehicles while driving in the rain will be reduced because PFC reduces splash and spray. This reduction in the amount of material washed from vehicles is expected to decrease the concentrations of these pollutants in the runoff generated from roads paved with PFC.

The porous structure of PFC also may act as a filter of the stormwater. Runoff enters the pores in the overlay surface and is diverted towards the shoulder by the underlying conventional pavement. Pollutants in the runoff can be filtered out as the water flows through the pores, especially suspended solids and other pollutants associated with particles. Filtering occurs when pollutants become attached to the PFC matrix by straining, collision, and other processes. Material that accumulates in the pore spaces of PFC is difficult to transport and may be trapped permanently. On the surface of a conventionally-paved road, splashing created by tires moving through standing water easily can transport even larger particulate matter rapidly to the edge of pavement. However, water velocities within the pore spaces of the PFC are low and likely could only transport the smallest material.

Several studies have been conducted to examine the distribution of solids and associated pollutants on road surfaces. These studies generally indicate that the majority of pollutants are located within 3 ft of the curb *(5), (6)*. The pollutants are transported to the area of the curb by wind turbulence generated by vehicles traveling along the roadway. These materials accumulate in the gutter and are transported easily by rainfall runoff to the storm drain system. Roadways with a PFC surface accumulate particulate material and the associated pollutants within the pores of the structure and the solids are not blown to the side of the road. In fact, air pressure in the vicinity of tires likely forces particles further into the void spaces of the PFC.

The quality of runoff generated from both porous and non-porous road surfaces in the Netherlands is one of the few previous studies that evaluated the water quality of porous overlays *(3)*. The porous pavement site had an average daily traffic count of 83,000 and was paved with a 55 mm (2 in.) layer of pervious asphalt on top of an impervious base. The pervious asphalt surface was three years old at the time of the study. A second highway site had an average daily traffic count of 53,000 and was paved with conventional impervious asphalt. Runoff samples were collected over 1-week periods to provide an average profile of the concentrations of the constituents in the runoff. Lower concentrations of pollutants were observed in runoff sampled from the porous asphalt than from impervious asphalt for many of the constituents monitored. Specifically, total suspended solids (TSS) concentrations were 91 percent lower, total Kjeldahl nitrogen (TKN) 84 percent lower, chemical oxygen demand (COD) 88 percent lower, and total copper (Cu), lead (Pb), and zinc (Zn) ranged from 67-92 percent lower than in runoff from the conventional asphalt pavement *(3)*. The dissolved fractions of copper and zinc were higher in the runoff from porous asphalt overlay. Solids, as well as some of the metals, were believed to be trapped in the porous asphalt overlay.

Researchers have also quantified the differences in the quality of runoff generated from a porous asphalt overlay and an impervious road surface in Germany *(2)*. The results indicated that the load of suspended solids in runoff from the porous surface were 60 percent lower than runoff from an impervious surface, indicating that the overlay surface acts as a filter and detains the particles. Similarly, the load of total copper and total lead in runoff from the porous surface was 31 percent and 55 percent less than in runoff from conventional asphalt pavement.

In each of the previous studies of runoff quality from porous overlays, the quality of the runoff was compared to conventional pavements located on different highways, with different traffic characteristics and adjacent land uses. This study compares the quality from the same highway immediately before and after resurfacing the road with a PFC overlay and presents an additional year of data as compared with a previous publication describing this study site *(7)*.

The Netherlands study *(3)* was the most comprehensive previous research, but their samples represent runoff occurring over 1-week periods, while this research collected samples from individual storms, which facilitated meeting holding times for all analyses.

Chapter 3. METHODOLOGY

3.1 Site Description

Stormwater runoff quality was monitored at a site located on Loop 360 in Austin, Texas during the period from February 2004 through June 2006. Loop 360 is a 14-mile, four-lane state highway in the western part of Austin, which extends from the Barton Creek/Mopac area on the south to US Highway 183 on the north. The site is adjacent to the two southbound lanes of the highway. The average daily traffic count is estimated at 43,000 *(8)*.

Because of the small length of pavement sampled and safety constraints on the roadside, it was not possible to instrument the site with automatic samplers, flow meters, and recording rain gauges. Instead, GKY FirstFlush Samplers were installed to collect the runoff. These samplers collect runoff over a width of about 1 ft (300 mm), which means that the total area of roadway sampled was only about 34 ft^2 (3 m^2) because the width of the road was 34 ft and it was assumed that the roadway base had a constant slope. These passive stormwater samplers can hold up to 5 L (1.3 gal) of water. The lid of each sampler is constructed with five sampling ports, each of which can be plugged to better control the rate at which collected runoff enters the sampler. Plastic flaps on the underside of each port function as closing mechanisms, preventing additional water from entering the sampler once capacity is reached. Each sampler is fitted with a 5-L, removable plastic container and lid to allow for easy removal and transport of the sample. A picture of the edge of pavement sampler is presented in Figure 3.1. A rain gauge also was installed at the site to provide storm totals of rainfall.

3.2 Sample Collection and Analysis

The GKY sampler was placed in a test flume and several calibration tests were run at flow depths of less that 0.25 in. (6 mm) to depths of 2 in. (50 mm) at Texas A&M University (unpublished) before installation. The shallow sheet flows gave very good performance, requiring approximately 15–45 minutes to collect a 1.3-liter sample, depending on the number of openings unplugged. Although these are called *first flush* samplers, a substantial amount of rainfall was required to collect sufficient volume of runoff for analysis. The smallest event providing sufficient runoff volume was 0.5 in. (13 mm); consequently, this configuration allowed sampling of the entire storms for rainfall volumes less than about 1.5 in. (38 mm).

Figure 3.1: *Photograph of installed sampler at edge of pavement.*

Prior to each event, a clean sampling container was also placed inside the sampler and the sampler ports and flaps inspected and cleaned to remove any collected mud or dirt. The rain gauge also was emptied and flushed of collected leaves and dirt. The plastic sampling container was removed and capped at the conclusion of each rain event. Occasionally, sites were visited during rain events to confirm that the sampler was accepting the runoff properly. The samples were transported to the laboratory for preservation and analysis when storms produced enough runoff volume to adequately collect in the samplers. Records were made during each site visit of rainfall volume, of volume collected in samplers, and of general site conditions.

Samples were transported to Environmental Laboratory Services, operated by the Lower Colorado River Authority (LCRA), for preservation and analysis. The LCRA's lab is U.S. EPA certified and has been contracted for stormwater analyses in the past. Samples were delivered to the laboratory as soon after rain events as possible, when permitted by operating hours. If samples were collected outside of the lab's normal business hours, samples were stored in a 4°C-cold room until they could be transported to the laboratory. All applicable Quality

Assurance/Quality Control (QA/QC) procedures were followed. The analytical parameters and methods are presented in Table 3.1. During the course of the study, five samples of runoff were collected from the conventional pavement and 21 samples of runoff were collected after the PFC overlay.

Table 3.1: Parameters for Analysis by Environmental Laboratory Services

Parameter	Units	Method (USEPA, 2003)	Practical Quantification Limit
Total Suspended Solids	mg/L	E160.2	1
Total Kjeldahl Nitrogen	mg/L	E351.2	0.02
Nitrate and Nitrite as N	mg/L	E353.2	0.02
Total Phosphorus	mg/L	E365.4	0.02
Dissolved Phosphorus	mg/L	E365.4	0.02
Total Copper	ug/L	E200.8	2
Dissolved Copper	ug/L	E200.8	1
Total Lead	ug/L	E200.8	1
Dissolved Lead	ug/L	E200.8	1
Total Zinc	ug/L	E200.8	5
Dissolved Zinc	ug/L	E200.8	4
Chemical Oxygen Demand	ug/L	E410.4	7
Semi-volatile Organics	ug/L	SW8270C	varies

In October 2004, TxDOT implemented a PFC overlay project on a section of Loop 360. The overlay was applied on top of the existing conventional asphalt according to TxDOT specifications *(9)*.The overlay is visible in Figure 3.1 and the coarse nature of this paving material is evident in this photograph. The lighter gray asphalt at the edge of pavement is the conventional surface below the PFC. Runoff sampling at the site was discontinued during the overlay installation and resumed upon completion of the overlay project. Runoff samples from two events from the conventional surface and two events immediately following the overlay project were analyzed for semivolatile organics, including PAHs.

3.3 Data Analysis

The analytical laboratory results from each rain event sampled were inspected for completeness, and the data then was compiled into a database and initial plots were analyzed to observe trends. Several statistical diagnostic tests were performed on the data to determine the overall distribution and to inspect and evaluate any suspected outliers. The use of standard statistical descriptions, such as mean and standard deviation, mean EMC comparisons, and box and whisker plots were employed to demonstrate differences in EMCs, as well as the effectiveness of the PFC overlay. Boxplots were employed for displaying the data. Minitab, a commercially available statistical software package, was used to perform the t-tests and create the boxplots. Comparisons of the mean EMCs for each constituent were made using t-tests of the runoff generated by both kinds of pavement. Linear regression of the data was performed to determine whether runoff quality has changed since the overlay was applied.

Chapter 4. RESULTS AND DISCUSSION

4.1 Results

The observed concentrations from all runoff events are presented in Table 4.1. Each storm is designated as being runoff from conventional hot mix asphalt (HMA) or PFC. Results from first storm after PFC installation were much higher than any subsequent set of samples and are not shown in the table. This is believed to be due to lingering disturbances to the soil and vegetation at the research site that resulted from the installation process; consequently, this event has been excluded from the data analysis.

The average EMCs measured during the sampled storm events at the edge of pavement before and after installation of the PFC are shown in Table 4.2. The p-values that resulted from these tests as well as the arithmetic mean of the measured EMCs from each surface are also presented in Table 4.2. Concentrations of TSS, and total lead, copper, and zinc are significantly lower in runoff generated from the PFC surface than in runoff generated from the conventional asphalt surface. A negative sign on the removal efficiency indicated that an increase in concentration was observed; however, these differences were not statistically significant.

The data indicate that the runoff generated from the PFC surface has consistently lower concentrations of particles and particle-associated pollutants than that from the traditional asphalt surface. This difference in water quality also was noted upon visual inspection of the runoff samples collected at the edge of pavement. The concentrations of nitrate/nitrite, dissolved copper and zinc, and total and dissolved phosphorus did not exhibit a significant difference between the two road surfaces. These data indicate that the PFC has little to no effect upon the concentrations of dissolved constituents in the stormwater runoff. A boxplot demonstrating the differences between TSS concentrations in the runoff from the conventional hot mix asphalt (HMA) pavement and PFC is presented in Figure 4.1.

Table 4.1: Concentrations Observed at the Edge of Pavement

Date	Rainfall (mm)	Surface	TSS (mg/L)	TKN (mg/L)	NO2/NO3 (mg/L)	D P (mg/L)	T P (mg/L)	COD (mg/L)	T Cu (ug/L)	T Pb (ug/L)	T Zn (ug/L)	D Cu (ug/L)	D Pb (ug/L)	D Zn (ug/L)
3/1/04	12.70	HMA	85	1.3	1.4	< 0.02	0.08	72	23.9	6.17	207	9.88	< 1	95.1
4/12/04	44.45	HMA	44	0.70	0.26	0.03	0.08	29	16.9	7.56	101	5.24	< 1	45.4
5/14/04	41.91	HMA	130	1.05	0.13	0.08	0.17	65	28.4	15	157	2.06	< 1	7.5
6/3/04	20.32	HMA	121	1.53	0.32	0.07	0.16	84	29.7	9.93	163	9.32	< 1	46.3
6/9/04	63.50	HMA	209	1.06	0.06	< 0.02	0.17	70	35.3	24.2	209	3.18	< 1	41
11/15/04	24.13	PFC	9	0.86	0.72	0.04	0.029	77	11.1	1.54	58.5	8.84	< 1	47.2
11/22/04	117.09	PFC	3	0.41	0.27	< 0.02	< 0.02	13	2.9	< 1	26.7	2.26	< 1	20.3
1/28/05	37.85	PFC	16	0.48	0.24	< 0.02	0.524	22	6.1	1.14	54	2.73	< 1	43.1
3/3/05	23.88	PFC	4	0.43	0.35	0.271	0.368	10	2.8	< 1	41.1	1.94	< 1	24.4
5/9/05	37.08	PFC	6	1.02	0.30	0.056	0.047	52	11.0	< 1	21.9	9.33	< 1	19.3
7/14/05	24.38	PFC	10	1.42	0.45	0.048	0.12	69	14.7	< 1	37.1	11.8	< 1	41.9
7/28/05	5.33	PFC	14	0.92	1.04	< 0.02	0.033	71	13.6	< 1	35.4	10.8	< 1	38.6
10/10/05	17.78	PFC	12	1.3	0.48	< 0.02	< 0.02	91	10.2	< 1	23.1	8.58	< 1	21.3
11/1/05	23.62	PFC	11	1.4	0.59	0.048	0.089	90	13.2	< 1	52.9	9.5	< 1	40.8
11/26/05	4.57	PFC	12	NA	NA	NA	NA	NA	45.7	< 1	81.3	37.5	< 1	61.7
1/22/06	7.11	PFC	10	4.97	2.41	0.13	0.162	388	67.1	2.4	116	58.7	< 1	103
1/28/06	36.07	PFC	12	0.90	0.51	< 0.02	0.038	85	17.4	1.3	36.9	14	< 1	27.3
2/10/06	7.62	PFC	16	1.54	0.62	< 0.02	< 0.02	124	23.9	2.25	57.9	15.8	< 1	37
2/25/06	13.97	PFC	3	1.15	0.73	< 0.02	< 0.02	67	14.7	< 1	31.4	12.8	< 1	27
3/20/06	51.82	PFC	14	0.47	0.05	< 0.02	0.028	13	3.8	< 1	12.7	1.84	< 1	6.16
3/28/06	43.69	PFC	23	0.81	0.11	< 0.02	0.043	36	12.0	< 1	47.9	4.98	< 1	23.2
4/30/06	21.84	PFC	10	1.80	0.33	< 0.02	0.027	34	8.0	< 1	61.4	6.73	< 1	51.4
5/5/06	51.82	PFC	8	1.22	0.25	< 0.02	< 0.02	30	6.58	< 1	24.7	4.88	< 1	19.9
5/6/06	2.54	PFC	6	0.38	0.19	< 0.02	< 0.02	19	4.00	< 1	14.2	3.16	< 1	10.3
5/7/06	78.23	PFC	4	0.23	0.11	< 0.02	< 0.02	14	2.96	< 1	12.8	1.82	< 1	8.17
6/17/06	9.14	PFC	6	0.37	0.08	< 0.02	0.023	16	4.49	< 1	14.7	2.57	< 1	13.9

Table 4.2: Constituent EMCs for Conventional Asphalt and PFC

Constituent	Conventional Asphalt	PFC	Reduction %	p-Value
TSS (mg/L)	117.80	9.95	91	<0.000
TKN (mg/L)	1.13	1.10	2	0.958
NO3/NO2 (mg/L)	0.43	0.47	-14	0.826
Total P (mg/L)	0.13	0.08	35	0.434
Dissolved P (mg/L)	0.04	0.06	-50	0.990
Total Copper (ug/L)	26.80	13.6	49	0.100
Dissolved Copper (ug/L)	5.90	10.6	-80	0.422
Total Lead (ug/L)	12.60	1.28	90	<0.000
Dissolved Lead (ug/L)	<1.0	<1.0	NA	NA
Total Zinc (ug/L)	167.40	40.7	76	<0.000
Dissolved Zinc (ug/L)	47.10	32.7	31	0.236
COD (mg/L)	64.00	62.8	2	0.957

The data in Table 4.2 indicates that the difference in mean concentrations of total phosphorus for the two pavement types is not significantly different. There were two storms monitored early in the life of the PFC (1/28/05 and 3/3/05) that had much higher than normal concentrations. If the 17 storms that occurred subsequently are used, then the difference is significant ($p<0.000$) and, in fact, 5 of the last 9 storms monitored had observed total phosphorus concentrations below the laboratory detection limit.

During the first four storms after installation of the overlay, EMCs of TKN and COD were also less than that in runoff from the conventional pavement, which agrees with the findings of previous research *(3)*. After the fourth storm, concentrations increased abruptly and returned to levels observed from the conventional pavement. This change corresponds to the time when the roadside shoulder was mowed. This maintenance activity distributed a substantial amount of cut grass, leaves, and other organic matter on the PFC, where it may have become lodged in the pavement pores, resulting in the observed increase in concentration.

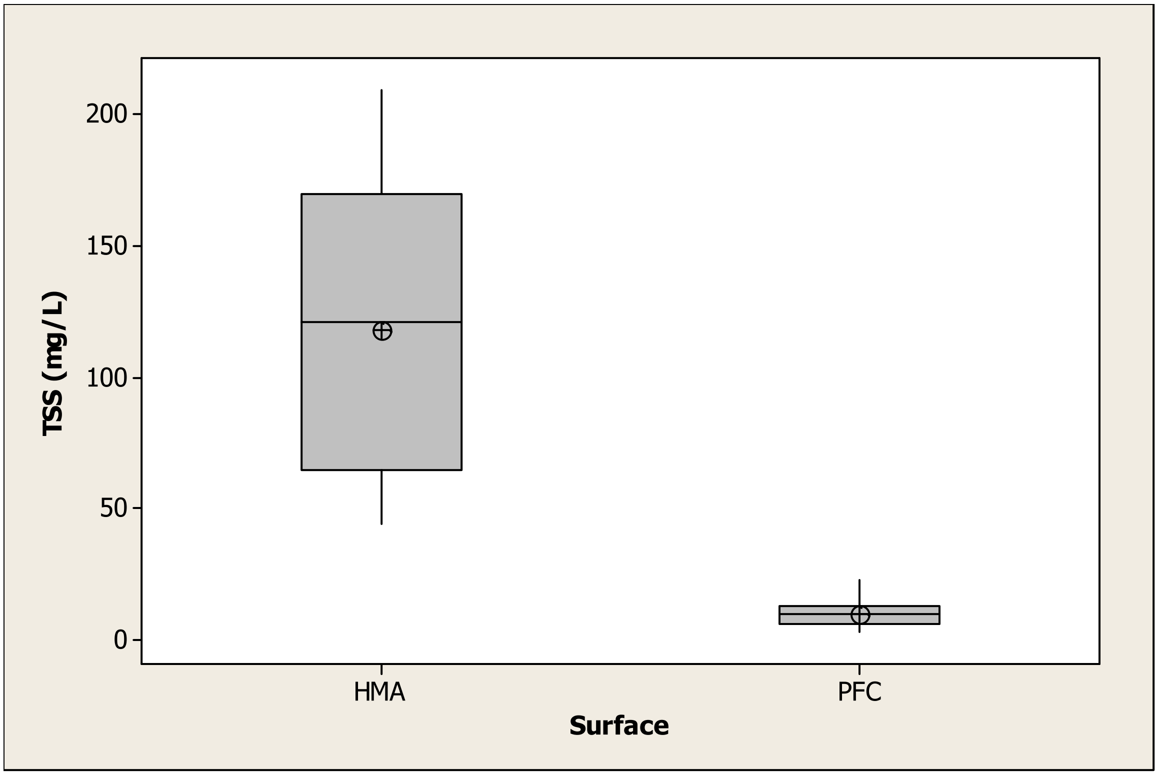

Figure 4.1: Boxplot of TSS EMCs for conventional HMA and PFC.

One of the concerns that arises with any road construction or paving project is the level of contamination generated by a new asphalt surface. It has been reported that lead and zinc are the trace metals most likely to be found in elevated concentrations in runoff from newly paved or sealed surfaces *(10)*. Polycyclic aromatic hydrocarbons (PAHs) also are a concern for some sealant types. All PAH concentrations observed in the collected water samples were below detection limits for events monitored from the PFC and the conventional asphalt surface. The laboratory practical quantification limits for the PAH compounds were about 5 μg/L, so it is possible that they were present at very low concentrations.

A total of 55.37 in. (1,406 mm) of rainfall has been measured at the site during the monitoring of the PFC overlay. No significant correlation between discharge concentrations at the edge of pavement and time since installation or cumulative rainfall volume has been observed. As examples, Figure 4.2 presents the concentrations of total zinc and Figure 4.3 depicts the concentrations of total suspended solids for each of the monitored events. The measurements prior to 8/1/04 were of runoff from the conventional pavement. The effect of the porous overlay on runoff quality over an extended period of time and increasing cumulative rainfall is the focus of ongoing research. To date, no significant relationship has been ascertained between time and concentration.

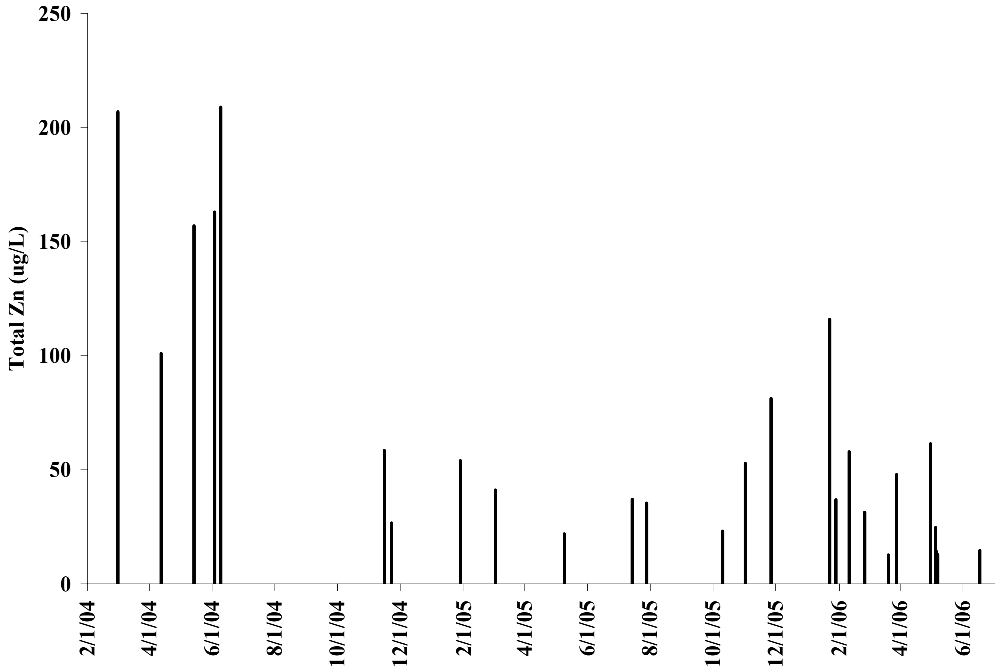

Figure 4.2: Total zinc concentrations for monitored events.

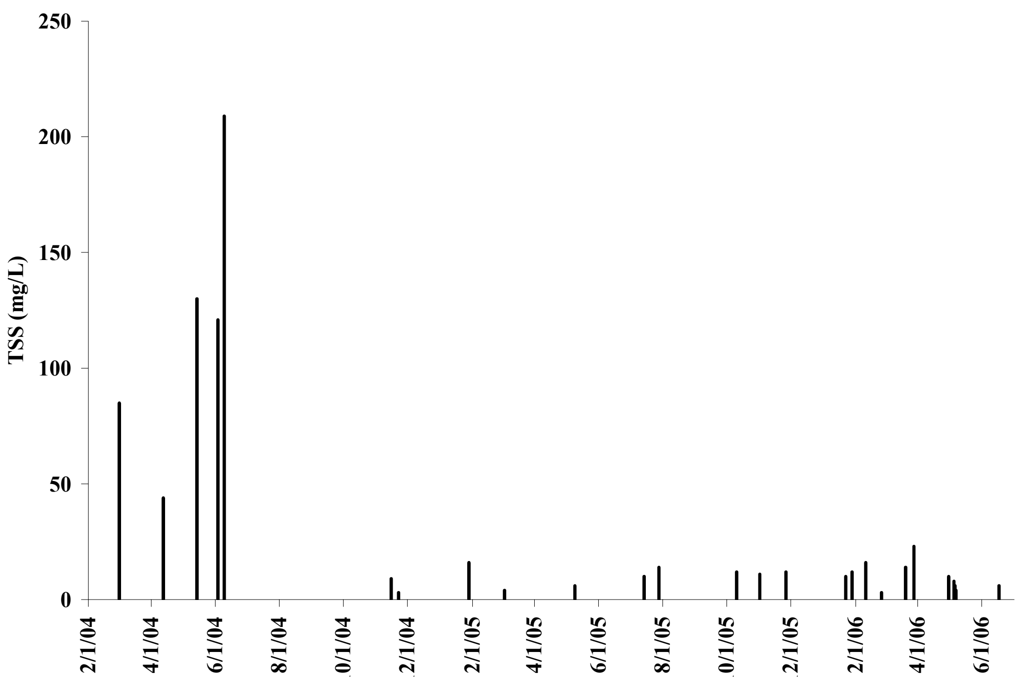

Figure 4.3: TSS concentrations for monitored events.

4.2 Discussion

A critical component in the assessment of the water quality benefits of PFC is whether the relatively low pollutant concentrations observed in this study is a function of removal of pollutants within the pavement, reduced generation of pollutants through reduction in washoff from vehicles, or the lack of accumulation of pollutants on the new road surface. It is unlikely that the latter is the cause of the low observed concentrations because it has been shown that 3-year-old PFC pavement still had better runoff quality than a conventional asphalt roadway*(3)*. As particles and particle associated pollutants accumulate within the pore structure it seems likely that more runoff will travel on the surface of the pavement, resulting in concentrations that might not be significantly different from those observed in runoff from conventional asphalt pavements, unless maintenance is performed to remove the accumulated material.

It has been demonstrated that an aggressive maintenance program that includes specially designed vehicles for cleaning the pavement can maintain the performance of PFC for a considerable period *(3)*. These vehicles contain both pressure washing and vacuum equipment to remove the accumulated pollutants (Figure 4.4). In the Netherlands, this type of street cleaner is used to wash the hard shoulders twice a year to maintain performance. It seems unlikely that the water quality benefits will persist without some effort of this type. A long-term monitoring project to document changes in performance and to evaluate different maintenance strategies is recommended for future research.

The type of equipment used for PFC cleaning in Europe has never been evaluated in the United States and its use might also improve the quality of runoff from conventional asphalt pavements. The problem with conventional sweepers is that they are substantially more effective for the larger particles and typically have had little impact on runoff quality (*4*). It is likely that street cleaning (as opposed to sweeping) would have to be conducted much more frequently on a conventional asphalt surface, because there is less room for storage of accumulated material in the surface roughness elements of conventional asphalt and this material is more subject to the forces of vehicle tires, which can remobilize the accumulated pollutants.

Figure 4.4: PFC (ZOAB in Dutch) cleaning machine.

Chapter 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Study Summary

This research examined the quality of runoff from a conventional asphalt pavement and a permeable friction course. This research was unique in that it provides a direct comparison of the two surface types at the same research site and analyzes runoff produced during discreet storm events over a 21-month sampling period.

Concentrations of TSS, the total metals, and phosphorus were found to be significantly lower in runoff generated from the PFC surface than in the runoff from the conventional hot mix asphalt surface. Concentrations of TSS, as well as the total forms of lead and zinc, are often one order of magnitude lower from the porous asphalt than from the traditional asphalt. Average concentrations of TKN, COD, nitrate-nitrite, and the dissolved forms of lead, zinc, and phosphorus show little change between the two surface types. From these results, it is evident that the runoff generated from the PFC surface is of better quality than that from the traditional asphalt surface. This improvement may be the result of several factors. The amount of pollutants derived from the bottoms of vehicles may be reduced by the reduction in splash and spray. In addition, these pollutants could be retained in the pores of the overlay and thereby prevented from leaving the paved area.

The passive sampler used in this study gave no information about runoff quantity or runoff rates and was not able to fully sample the largest events. Monitoring at this site is continuing under a revised plan. Collection systems are being installed to capture runoff from a larger area of the pavement, and a flume, flow meter, and automatic samplers will be installed so that the impact of PFC on runoff quantity and quality can be more fully assessed.

A critical component in the assessment of the water quality benefits of PFC is whether the pollutant reduction observed in this study will persist over the life of the pavement. As particles and particle-associated pollutants accumulate within the pore structure, it seems likely that more runoff will travel on the surface of the pavement, resulting in concentrations that might not be significantly different from those observed in runoff from conventional asphalt pavements. In addition, clogging of the pores in the pavement will likely reduce the other benefits associated with PFC (spray and noise reduction). The Netherlands study *(3)* showed that

3-year old pavement could still have substantial water quality benefit; however, the Dutch have an aggressive maintenance program that includes specially designed vehicles for cleaning the pavement. These vehicles contain both pressure washing and vacuum equipment to remove the accumulated pollutants. It seems unlikely that the water quality benefits will persist without some effort of this type. A long-term monitoring project to document changes in performance, evaluation of different maintenance strategies, and lifecycle costs of PFC is recommended for future research.

5.2 Recommendations on PFC Implementation for Water Quality

Many jurisdictions, including the TCEQ rules for the Edwards Aquifer, require that the total suspended solids in runoff from new development must be reduced by 80 percent. The data collected after the first 18 months of monitoring indicates that the TSS reduction compared to conventional pavement is about 90 percent, which far exceeds the regulatory requirement. If this improvement in runoff quality persists for approximately the life of the pavement, then TxDOT could meet the stormwater goals for highways by implementing PFC overlays for highways in the Edwards recharge zone. This means that TxDOT would not have to build and operate expensive, large footprint facilities that are used solely for stormwater treatment.

Even in areas where stormwater treatment is not required there may be environmental benefits associated with the use of PFC. For instance, the NEPA process often results in requirements to mitigate the environmental impacts of proposed projects. The use of PFC overlays on these projects will improve the quality of runoff and can be shown in the NEPA documentation as one type of mitigation. In conclusion, PFC implementation on highway projects in all areas of the state may potentially benefit from the improved water quality that has been documented in this study.

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