Final Report on

A Side-by-Side Comparison of Pervious Concrete and Porous Asphalt

31 August 2009

Prepared for

Prince George's County
PA DEP
RMC Foundation

VILLANOVA URBAN STORMWATER PARTNERSHIP

Executive Summary

This report covers all work completed on the Porous Asphalt/Pervious Concrete comparison study from its inception in August 2007 to August 2009. The grant period from all three funding agencies expires on or before 1 September 2009.

The porous asphalt/pervious concrete comparison study was performed by Villanova University under the direction of the Villanova Urban Stormwater Partnership (VUSP). The study commenced in the fall of 2007 when construction of the site was completed. For approximately one year, the water in the stone beds beneath the pavements drained too quickly. After several failed attempts, the leak was isolated, and the leaking pipe was grouted. Although this leak hampered our ability to collect all of the data we wanted, we still found some very interesting and valuable results. In summary, the major conclusions of this work are:

- Both pavements are wearing well, however, the asphalt side is showing slightly more spalling and signs of wear.
- The pavements respond well to vacuum-street sweeping with a noticeable increase in permeability after cleaning.
- A survey revealed that the pavements are viewed favorably amongst the people that park there.
- Since the grouting of the outflow pipes, we have had 8 rain events that exceeded the capacity of the stone beds.
- The infiltration rate of the native soil below the beds varies between 0.3 and 0.7 in/hr.
- The variability of the water quality of the inflow is larger than anticipated considering that the two pavements types are adjacent to one another.
- From a water quality standpoint, both pavement types are performing well, with no real difference observed between the two pavements.
- The BMP is extremely effective at mitigating high temperature inflows.
- A bench top study revealed that the asphalt pavement did not release any hydrocarbons after soaking for 100 days.

This report describes all work completed on this site from August 2007 to August 2009.

Background

Many state BMP manuals and the US EPA lump all pervious pavements together under one category. This study ascertained the differences between pervious concrete and porous asphalt in regards to durability, maintenance requirements, and ability to transmit or filter key contaminants such as hydrocarbons. Two nearly identical parking areas were constructed on Villanova University’s campus to ascertain the performance characteristics of pervious concrete and porous asphalt. This parking area joins a number of other BMPs on Villanova’s campus under the direction of VUSP.

August 2007 was considered as the beginning of the project. Table 1 summarizes the instrumentation locations and purpose. Figure 1 provides a sketch of the instrumentation locations.

Table 1. Summary of Instrumentation

Instrument	Number	Location	Purpose
Tipping bucket rain gage	1	Rooftop	Measure amount of rainfall at site
First flush samplers	2	Interface between pervious/porous pavements and conventional pavement	Obtain first flush samples for water quality testing
Pressure transducer with V-notched weir at overflow pipe	2	Drop inlets located at the edge of each bed	Measure depth of water in bed to determine infiltration rates, measure flow and volume of water exiting the site, measure temperature of water in bed
Pressure-vacuum soil water samplers (lysimeters)	6	Three samplers located below each bed	Obtain soil water samples to determine water quality
Temperature sensors	10	One in each first flush sampler and one in each sampling bottle from the lysimeters	Determine impact of the BMP of water temperature

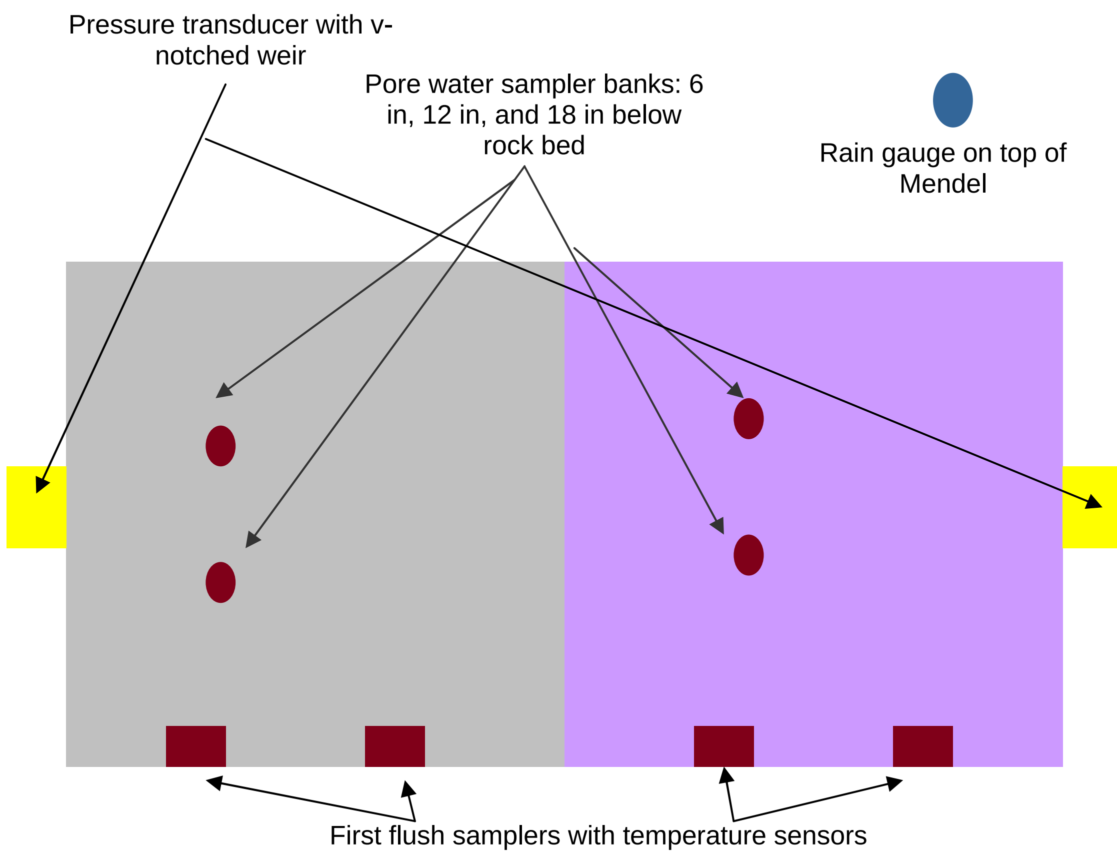

Figure 1. Location of Instrumentation

Study Goals

The major goals of this project were:

1. Design the BMP
2. Construct the BMP
3. Instrument the site and keep equipment calibrated
4. Objectively and subjectively summarize the installation process
5. Develop inspection methodology to document the performance of the pavements over time and inspect the site quarterly
6. Sample and test for all rain events over 0.25 in within an 8 hour period, specifically:
    a. Inflow and outflow
    b. Infiltration rates
    c. Temperature
    d. pH
    e. Total Suspended Solids (surface samples only)
    f. Total Dissolved Solids (surface and subsurface)
    g. Chlorides
    h. Total N and total P
    i. Particulate metals: Pb, Cu, Cd, Zn
    j. PAHs
7. Perform a bench top, side-by-side comparison of the pavement types focusing only on hydrocarbons.
8. Mathematically model the temperature reduction caused by the BMPs
9. Conduct a survey of those parking in the area to ascertain public perception of the pavements
10. Disseminate the results of the work via the website, seminars, etc.

Inspections

Inspections of each pavement type were conducted quarterly. All of the inspection reports are included in Appendix 1. Some clogging and oil spots have been noted on each side. Table 2 presents the hydraulic conductivity data obtained for each pavement type during the inspections. Obviously, clogging has a huge impact on the hydraulic conductivity.

The site is vacuumed periodically and the site scheduled to be vacuumed again shortly. Over the winter months, some icing on the concrete side was observed during precipitation events. Next winter this should not be a problem because conventional de-icing salt on the pavements will be applied. The manufacture of the concrete recommended that de-icing salt not be used on the concrete for 18 months after installation.

Table 2. Drainage Results

Pavement Drainage Times (seconds)

	5/13/2008	8/5/2008	11/17/2008	7/3/2009	8/22/2009
Concrete - Good Condition	8	26	21	22	22
Concrete - Poor Condition	13	106	62	58	58
Asphalt - Good Condition	16	49	42	50	50
Asphalt - Poor Condition	40	183	80	125	125
Non-Porous Asphalt	--	270	405	339	339

Pavement Hydraulic Conductivity (in/hr)

	5/13/2008	8/5/2008	11/17/2008	7/3/2009	8/22/2009
Concrete - Good Condition	1542	505	689	648	648
Concrete - Poor Condition	1131	4	54	69	69
Asphalt - Good Condition	939	121	187	114	114
Asphalt - Poor Condition	212	0	18	1	1
Non-Porous Asphalt	--	0	0	0	0

Survey Results

To determine the public opinion regarding the porous pavements used in this study, a survey was conducted. The survey was distributed to people who had parking permits for the studied parking lot and returned 22 responses. The questions fell into three categories, aesthetics, performance, and the overall opinion of the pavements.

Aesthetics: Survey participants were asked whether they preferred the appearance of conventional asphalt or porous pavements. 14% of respondents preferred the look of porous pavements, 18% preferred the look on conventional asphalt, and 54% felt that the pavements looked the same, and 14% had no observation. Additionally, survey participants were asked whether they preferred the appearance of porous asphalt or pervious concrete. 18% of respondents preferred the look of porous asphalt, 23% preferred the look of pervious concrete, and 59% had no opinion.

Performance: Three questions were asked regarding users experience with the performance of the porous pavements. Of those surveyed 24% felt that the porous pavements provided more traction than the conventional asphalt, 14% felt the traction was the same, and 62% had no observation. When asked about the amount of snow and ice on the porous pavements, 5% respondents felt that there was less snow than on conventional asphalt and 5% stated that the amount of snow and ice was the same as on conventional asphalt. 90% of respondents had no observation. This is likely due to the fact that few snow storms have occurred at the site, and those that did occur were nearly a year before the survey was conducted. Finally, survey participants were asked about the roughness of the porous pavements. 100% of those surveyed stated that they had no difficulties associated with the roughness of the pavements.

Overall: The final question of the survey was whether users had a generally positive or negative opinion of the porous pavement parking lot. 73% of respondents have a positive opinion of the parking lot, while 27% had a neutral opinion. No survey participants had a negative opinion of the porous pavement parking lot. When asked to comment on this, most participants cited the environmental benefits of the project as their reason for having a positive opinion.

Temperature Mitigation

The BMP is extremely effective in mitigating high temperature inflows. This observation was made even when the site was leaking. This distinction is important because it indicates that the heat from the water is being transferred to the cool rocks in the bed. An example of this temperature mitigation is shown in Figure 2. This temperature mitigation was successfully mathematically modeled using a model developed by Jones 2008[1]. Figure 3 shows a comparison of predicted and measured temperature.

Porosity and Infiltration

The porosity of the pavements when new was determined by placing samples of the pavements into a water bath and measuring the volume of water displaced. The porosity of the porous asphalt was 25% and the porosity of the pervious concrete was 27% when it was placed.

The soil underlying the area was classified according to the Unified Soil Classification System as ML: silt with sand. Generally, infiltration BMPs are not built on this type of material because it typically has a low hydraulic conductivity. Interestingly, despite the low hydraulic conductivity of the material, the site is infiltrating water. This result may encourage designers and regulators to consider infiltration BMPs on sites that were here-to-for ignored. The site has overflowed 8 times since it was built; it was designed to hold the 2 year storm (51 mm or 2 in) for the watershed. The bed overflows when the bed depth exceeds 2 ft. Since the leak in the pipe was repaired in November 2008, the average infiltration rate has been 0.5 in/hr; the range of infiltration rates measured at the site has varied between 0.3 and 0.7 in/hr (Figure 4). The bed depth with the cumulative rain fall for August 2009 is presented as Figure 5; the bed overflowed 4 times in that month. The bed depth and temperature for April 2009 are included as Figure 6.

Polyaromatic Hydrocarbons

The testing performed for PAHs yielded no peaks. We suspect that any incoming hydrocarbons are removed as the stormwater travels through the pavements and the stone beds. To determine if any hydrocarbons are released by the asphalt, a bench top study was performed.

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[1] Jones, M.P. (2008) *Effect of Urban stormwater Runoff in Trout Sensitive Region*. PhD dissertation, North Carolina State University, Raleigh NC.

After one pore volume of flow, no hydrocarbons were detected (Figures 7 and 8). Similarly, a 100 day soak test revealed that no hydrocarbons were released from the pavements; this data is presented in Appendix 2.

Water Quality

The results of the sampling and testing to date are presented in Figures 9 through 18. Graphs for mean concentrations are provided for pH (Figure 9), dissolved cadmium (Figure 10), dissolved lead (Figure 11), dissolved copper (Figure 12), dissolved chromium (Figure 13), dissolved zinc (Figure 14), nitrogen (Figure 15), and phosphorous (Figure 16). Concentrations as a function of time for chlorides (Figure 17) and dissolved solids (Figure 18) are also presented. The first flush samples are identified with an FF. The samples from the pore water samplers are identified by their depth. Thus, in these graphs C = concrete, A = Asphalt, 06 = 6 in below bed, 12 = 12 in below bed, 18 = 18 in below bed, FF = First Flush sample, AVG = Average of two samples from the same surface, at the same depth, but different locations reported.

Future Work

We intend to continue monitoring this site with funding from the National Monitoring Program. This continued monitoring will include:

- Quarterly inspections
- Temperature
- Inflow, outflow, and bed depth (to determine infiltration)

Mr. James Barbis anticipates that his thesis will be completed in October. His thesis will be posted on the VUSP website as part of our dissemination and outreach efforts. In addition to posting Mr. Barbis’s thesis, the website will updated with the new data presented in this report, we will continue to include the PAPC site on our tours, and Mr. Barbis, Mr. Jeffers, and I will be collaborating on articles for conferences and journals.

Conclusions

The major conclusions of this work (covering the time period from August 2007 to August 2009) are:

- Both pavements are wearing well, however, the asphalt side is showing slightly more spalling and signs of wear.
- The pavements respond well to vacuum-street sweeping with a noticeable increase in permeability after cleaning.
- A survey revealed that the pavements are viewed favorably amongst the people that park there.
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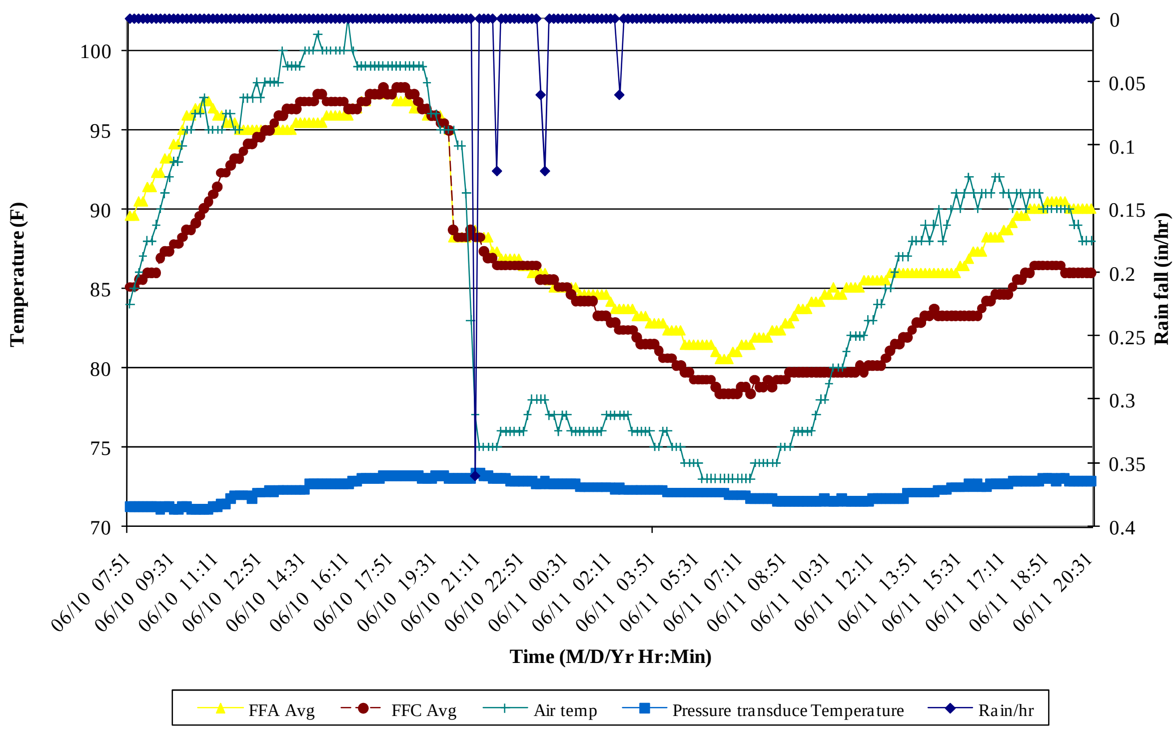


Figure 2. Temperature Data from 10 June 2008 Storm

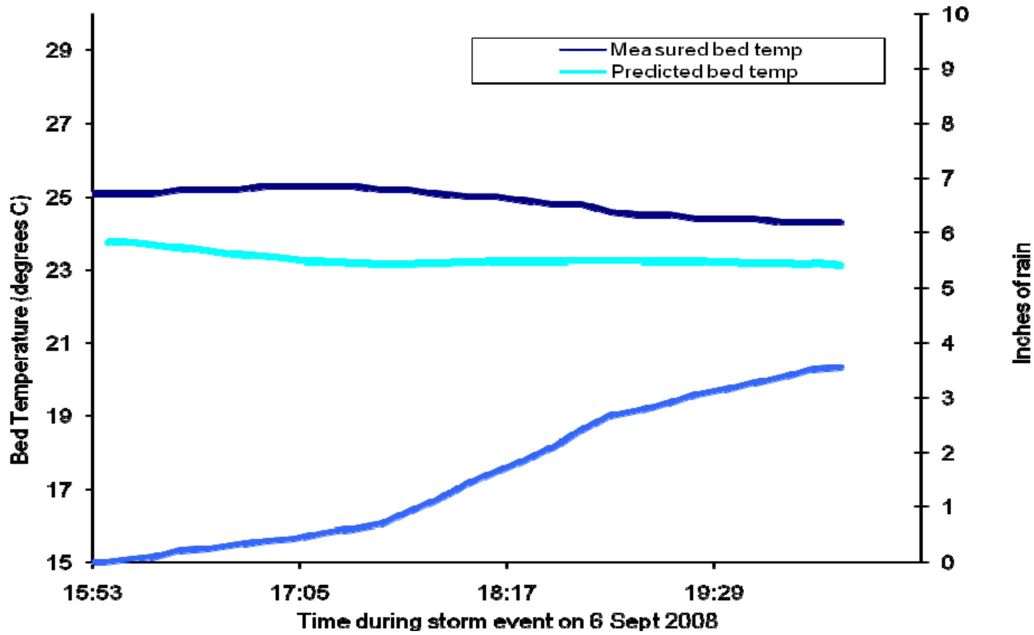


Figure 3. Comparison between predicted and measured bed temperature during the 6 September 2008 storm

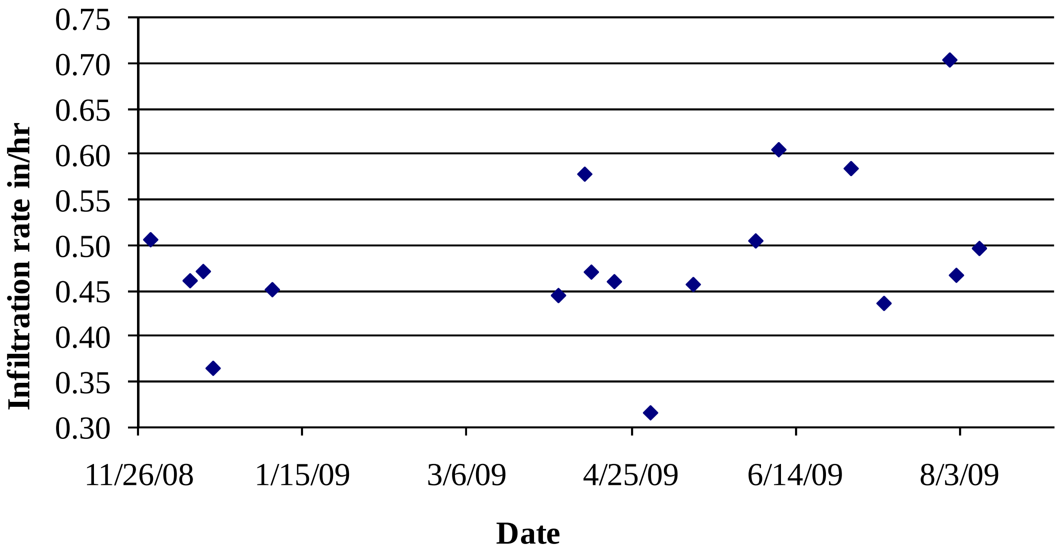


Figure 4. Infiltration rate of native soils

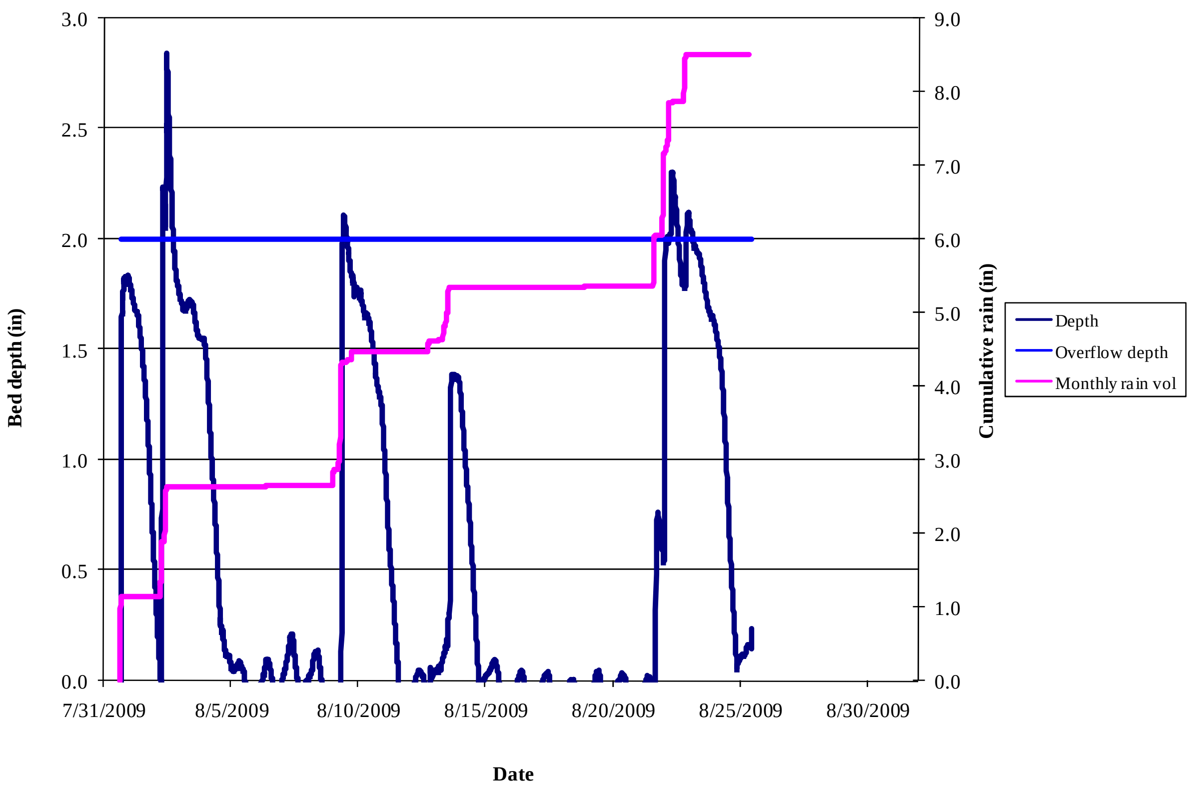


Figure 5. Bed depth, rain fall, and overflow for August 2009

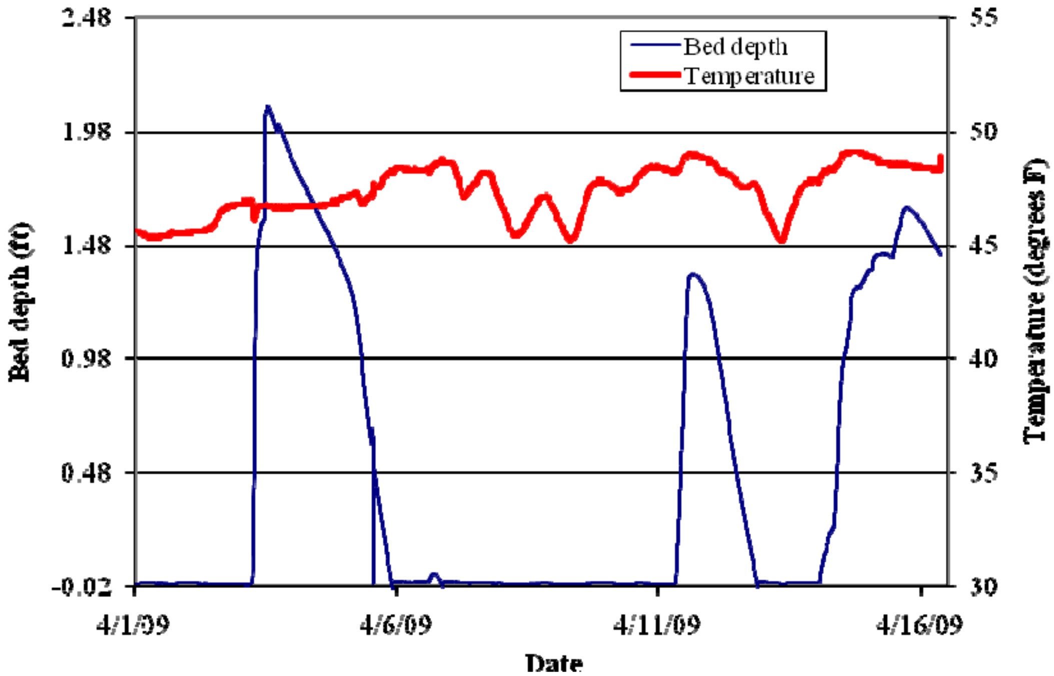


Figure 6. Bed depth and temperature in April 2009

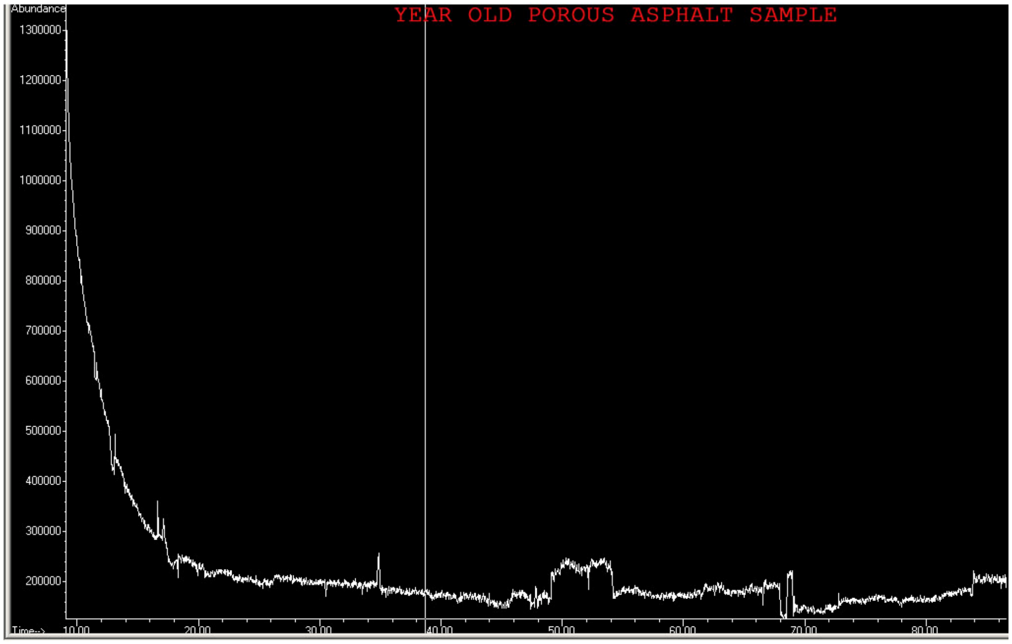


Figure 7. Chromatograph on water passed through one year old porous asphalt (note that there are no peaks)

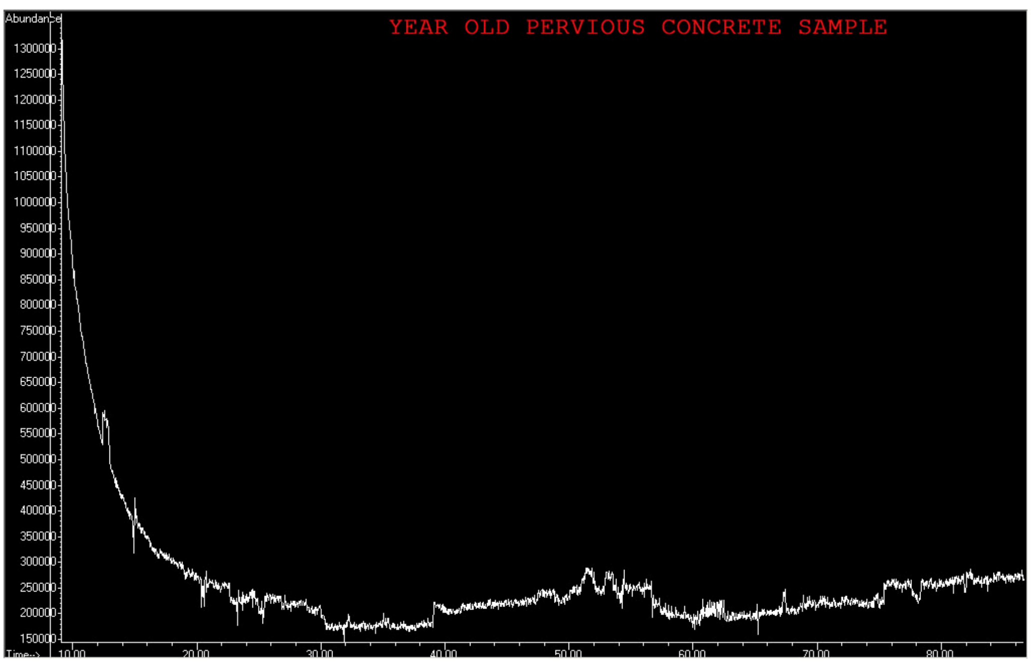


Figure 8. Chromatograph on water passed through one year old pervious concrete (note that there are no peaks)

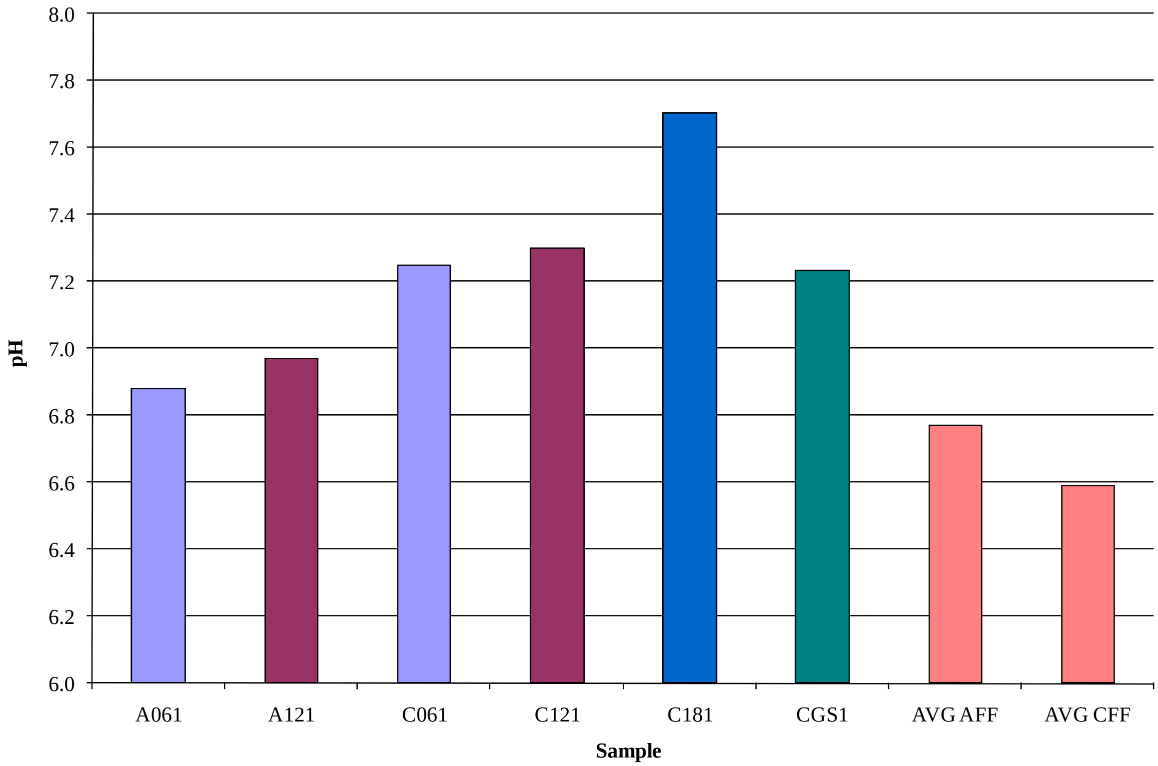


Figure 9. Mean pH

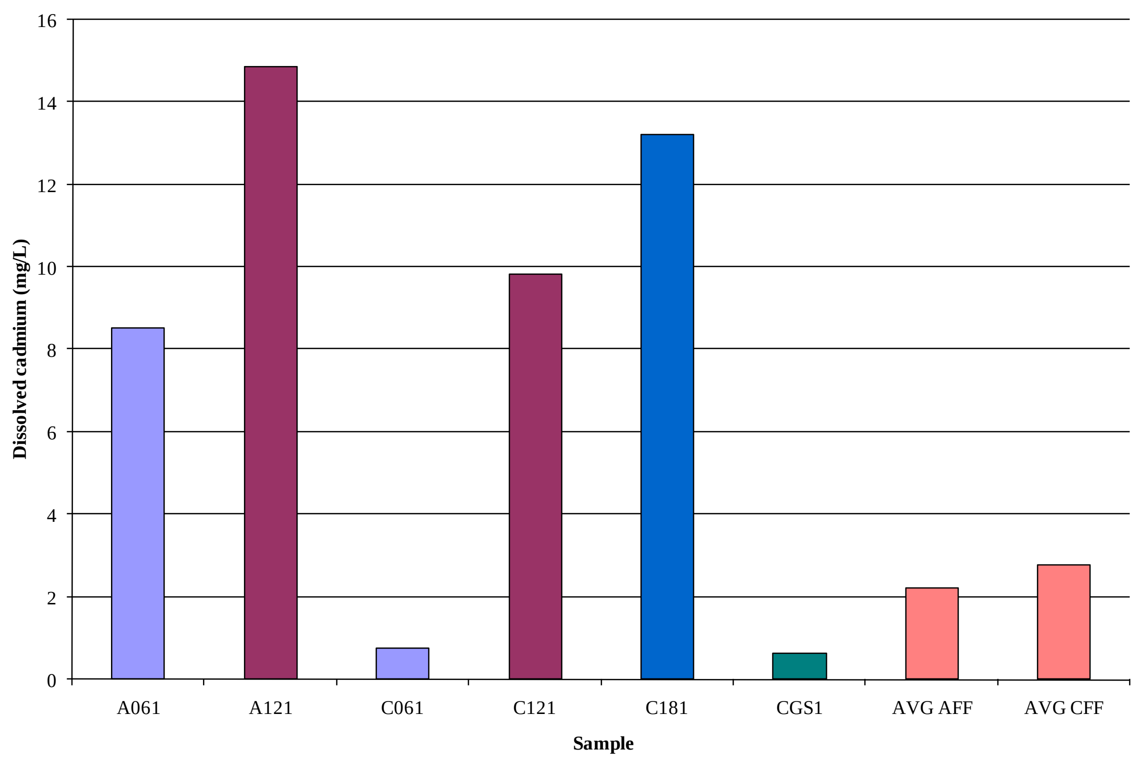


Figure 10. Mean Dissolved Cadmium

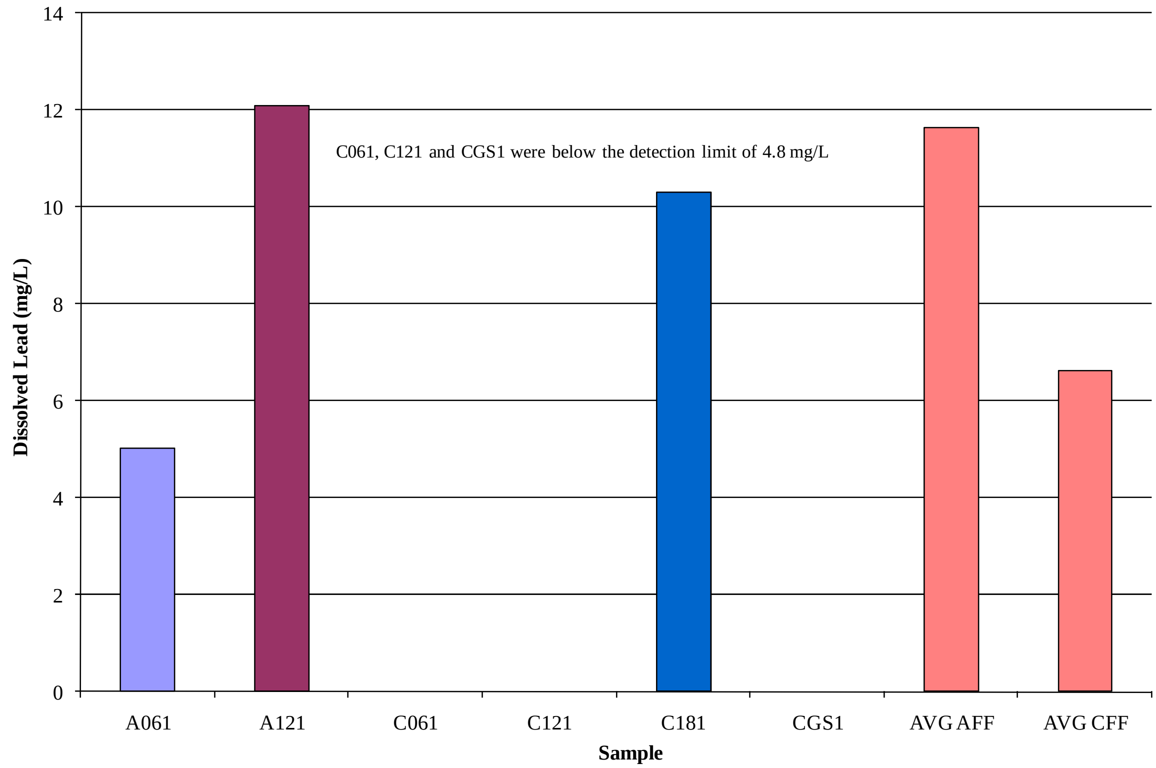


Figure 11. Mean Dissolved Lead

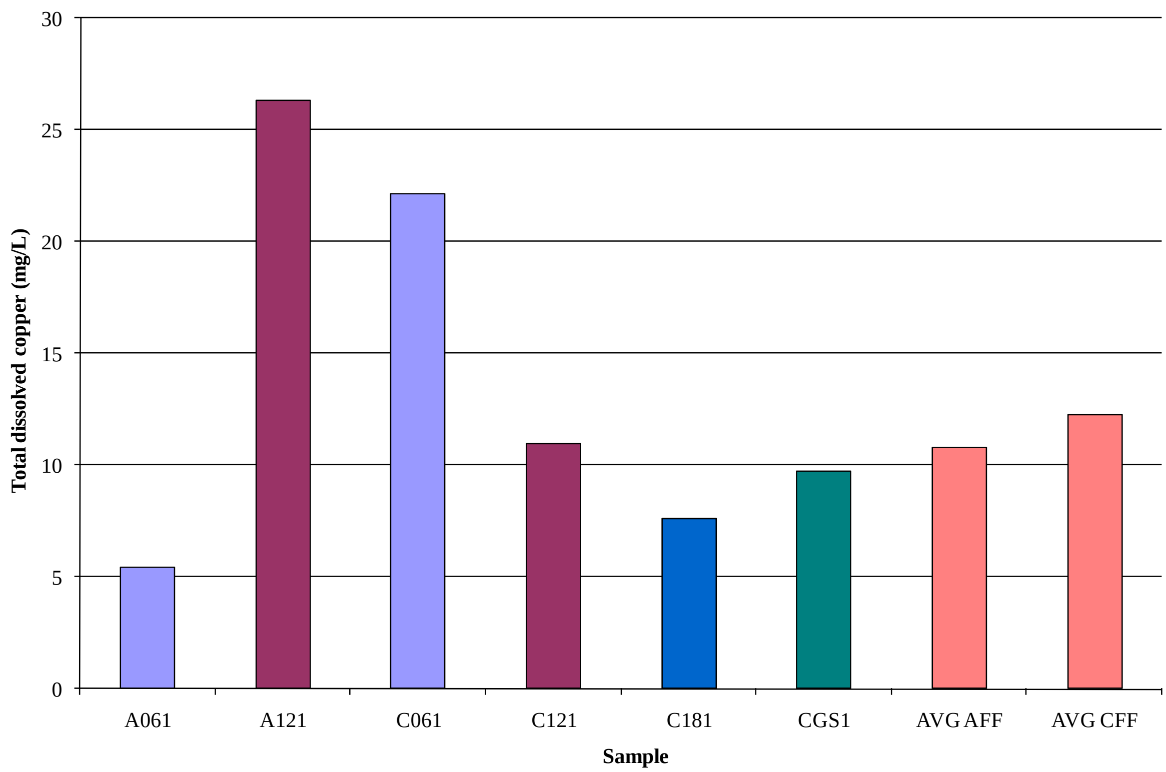


Figure 12. Mean Dissolved Copper

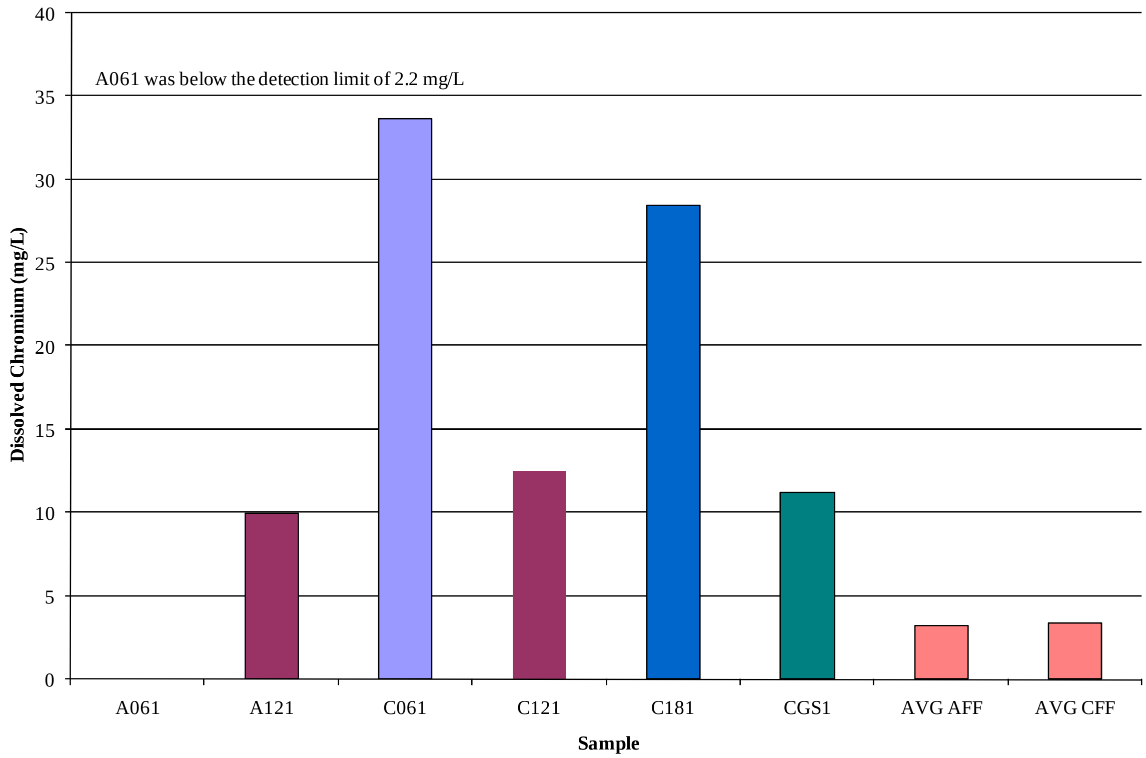


Figure 13. Mean Dissolved Chromium

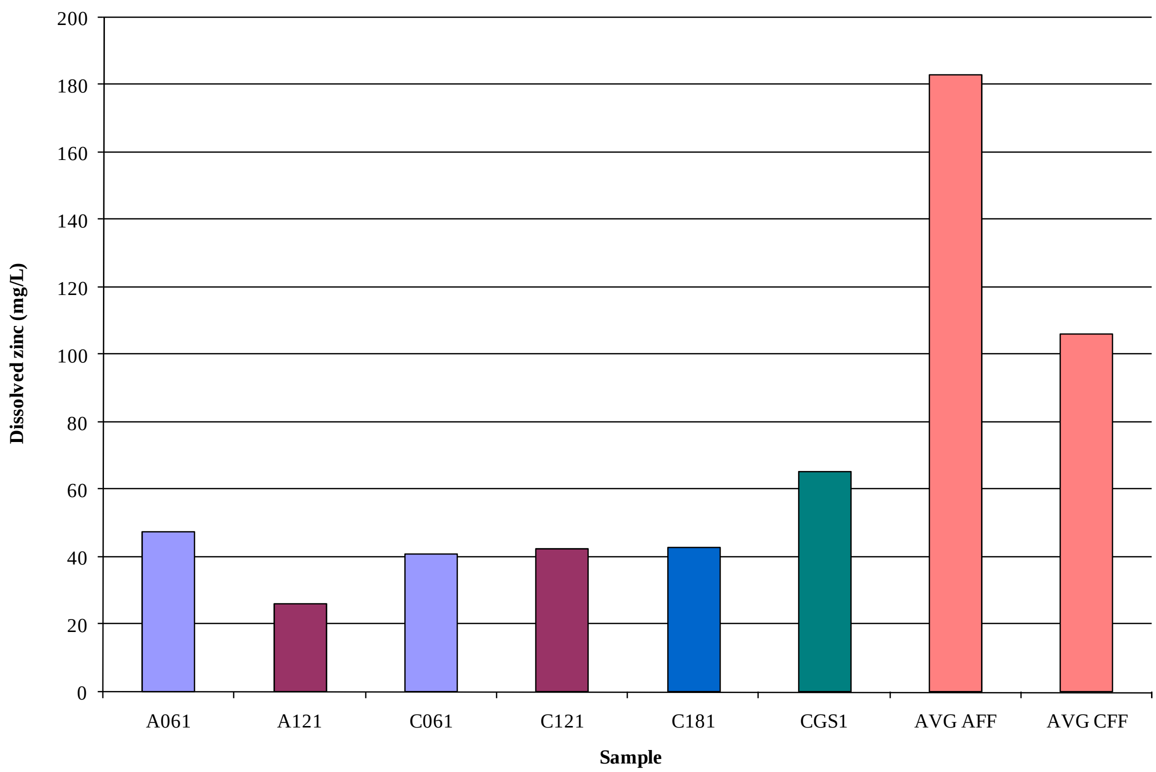


Figure 14. Mean Dissolved Zinc

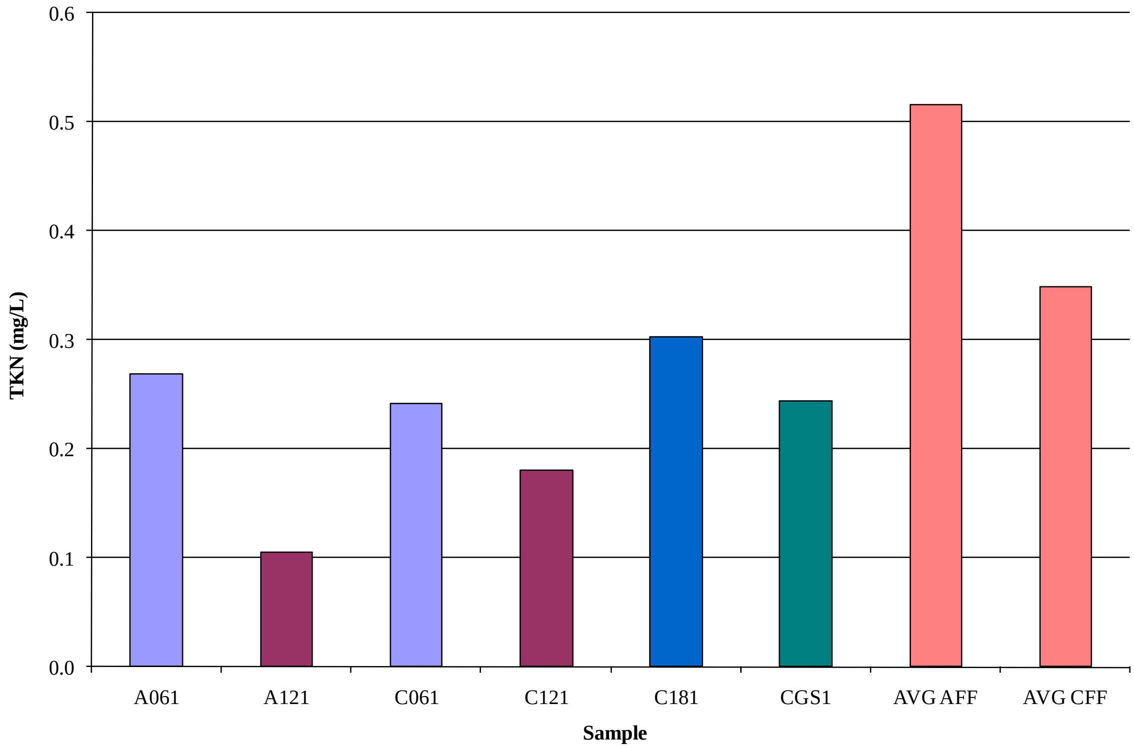


Figure 15. Mean TKN Concentration

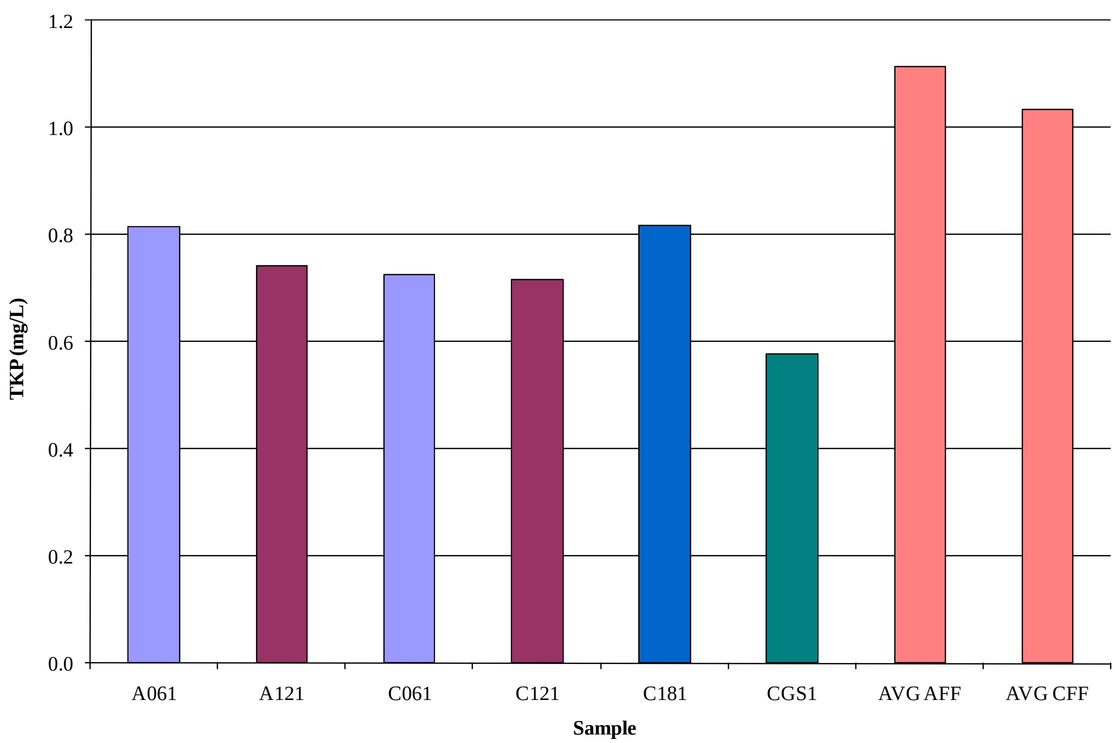


Figure 16. Mean TKP Concentration

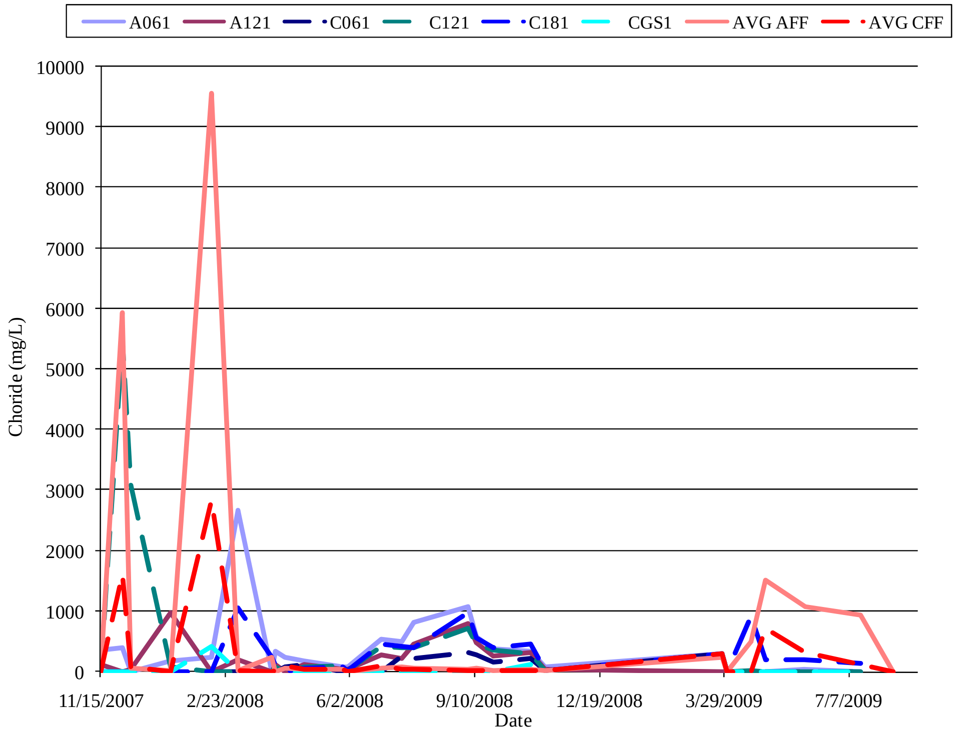


Figure 17. Chloride Concentration

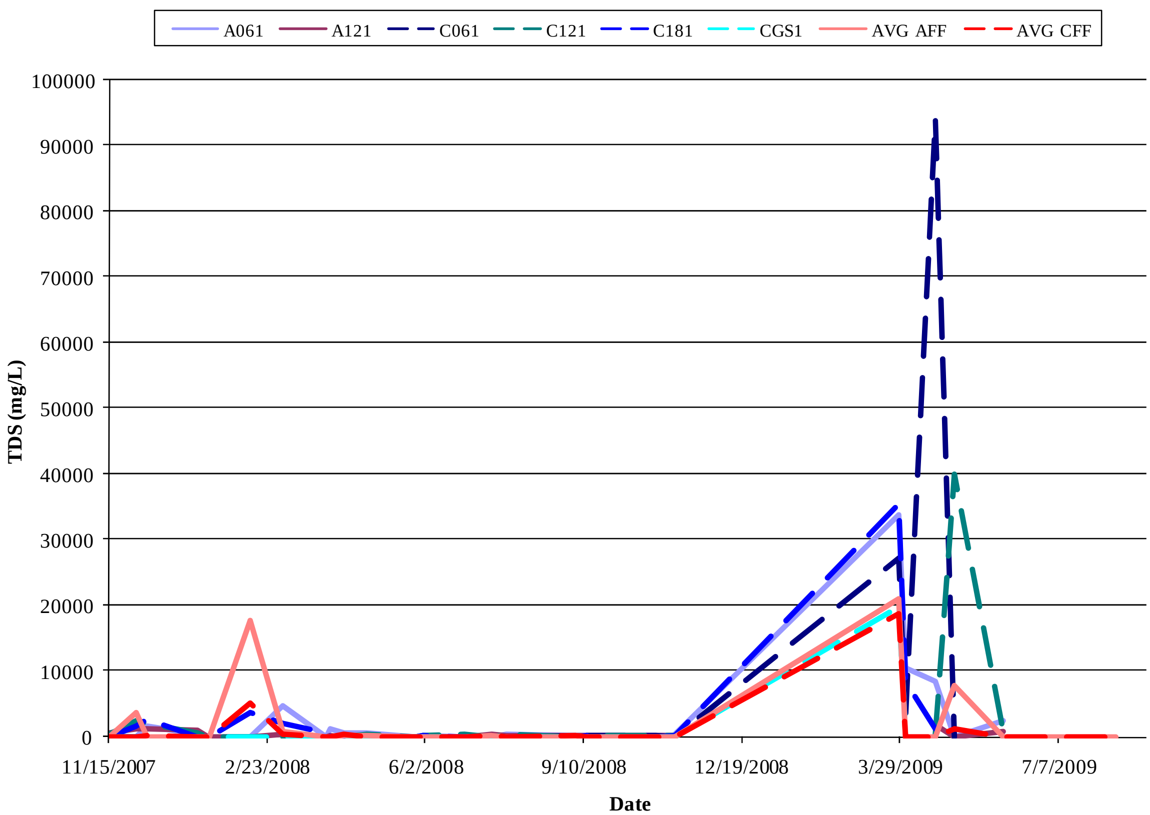
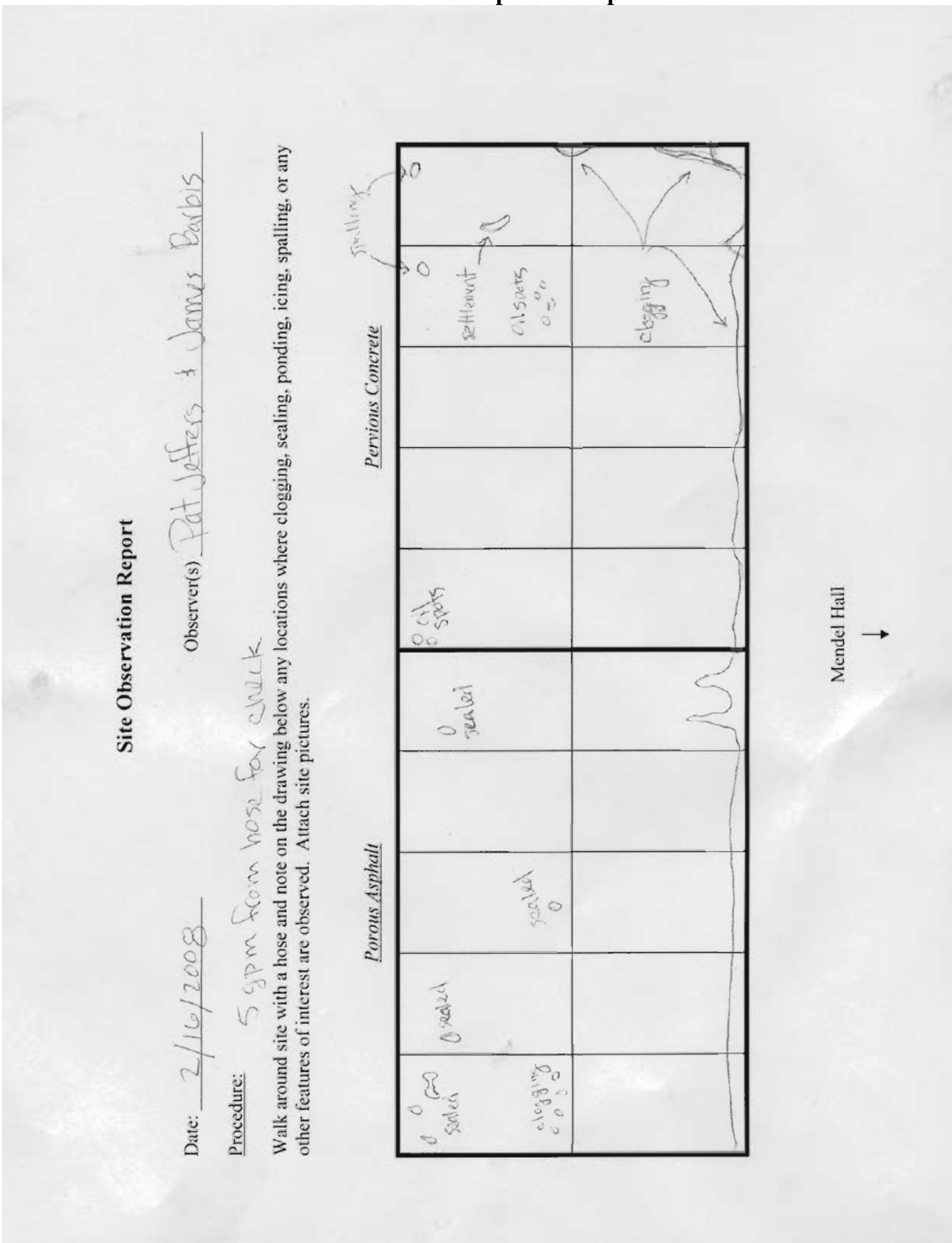


Figure 18. Total Dissolved Solids

APPENDIX 1: Inspection Reports



Site Observation Report

Date: 2/16/2008 Observer(s) Pat Jeffers & James Barbis

Procedure:

5 gpm from hose for check

Walk around site with a hose and note on the drawing below any locations where clogging, scaling, ponding, icing, spalling, or any other features of interest are observed. Attach site pictures.

Site Observation Report

Date: 8/5/2008

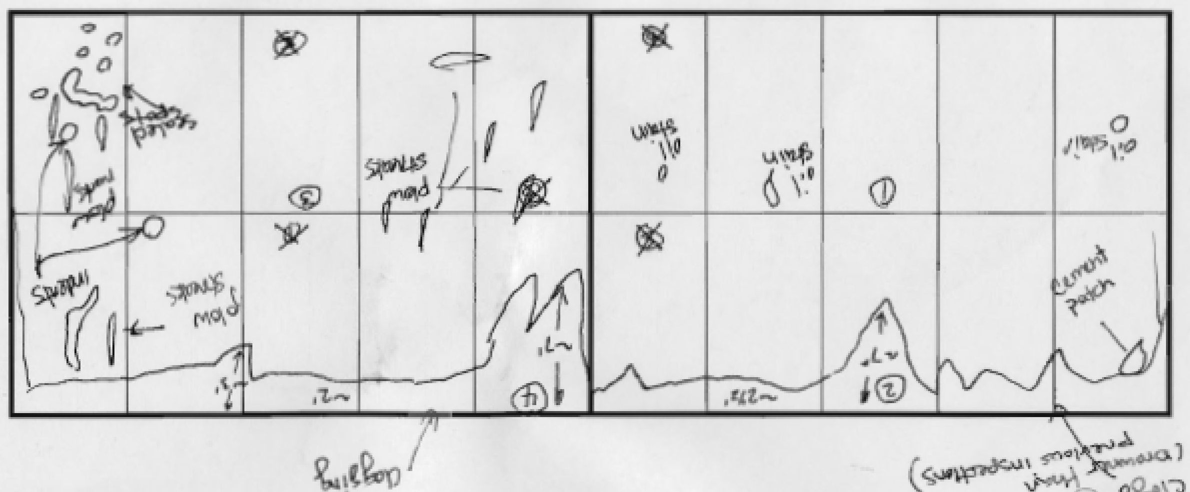
Observer(s) Pat Jeffers & James Barbis

Procedure:

Walk around site with a hose and note on the drawing below any locations where clogging, sealing, ponding, icing, spalling, or any other features of interest are observed. Attach site pictures.

Porous Asphalt

Pervious Concrete



Mendel Hall

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Drain Times

1. good concrete 0:26:46
2. bad concrete 1:46:81
3. good asphalt not wet 0:45:67 wet 0:48:86
4. bad asphalt not wet 4:30:30 wet 3:02:99

no pavement 0:5:58

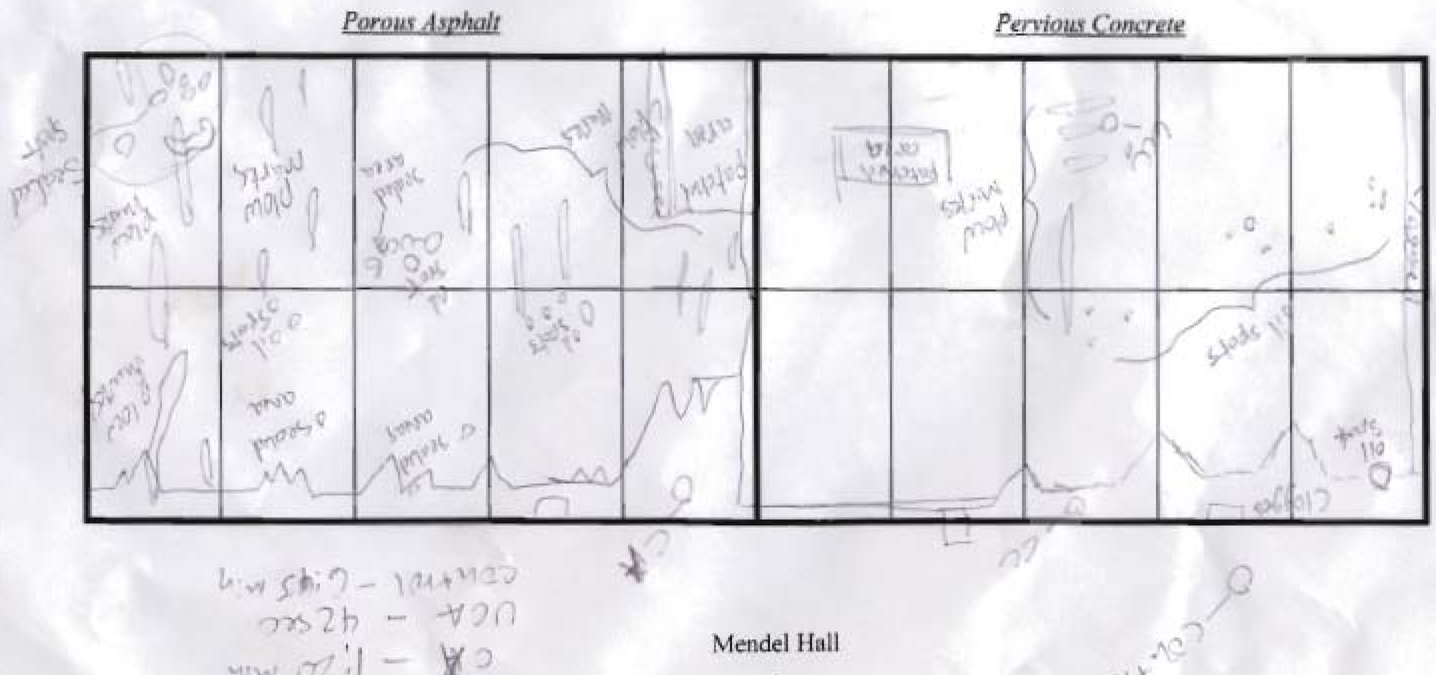
reg. asphalt 4:29:15

Site Observation Report

Date: 11/17/08 Observer(s) Pat Jeffers & James Barbis

Procedure:

Walk around site with a hose and note on the drawing below any locations where clogging, sealing, ponding, icing, spalling, or any other features of interest are observed. Attach site pictures.



C.C - 1:02 min
UCC - 20.74 sec
CA - 1:20 min
UCA - 42 sec
control - 6:45 min

Site Observation Report

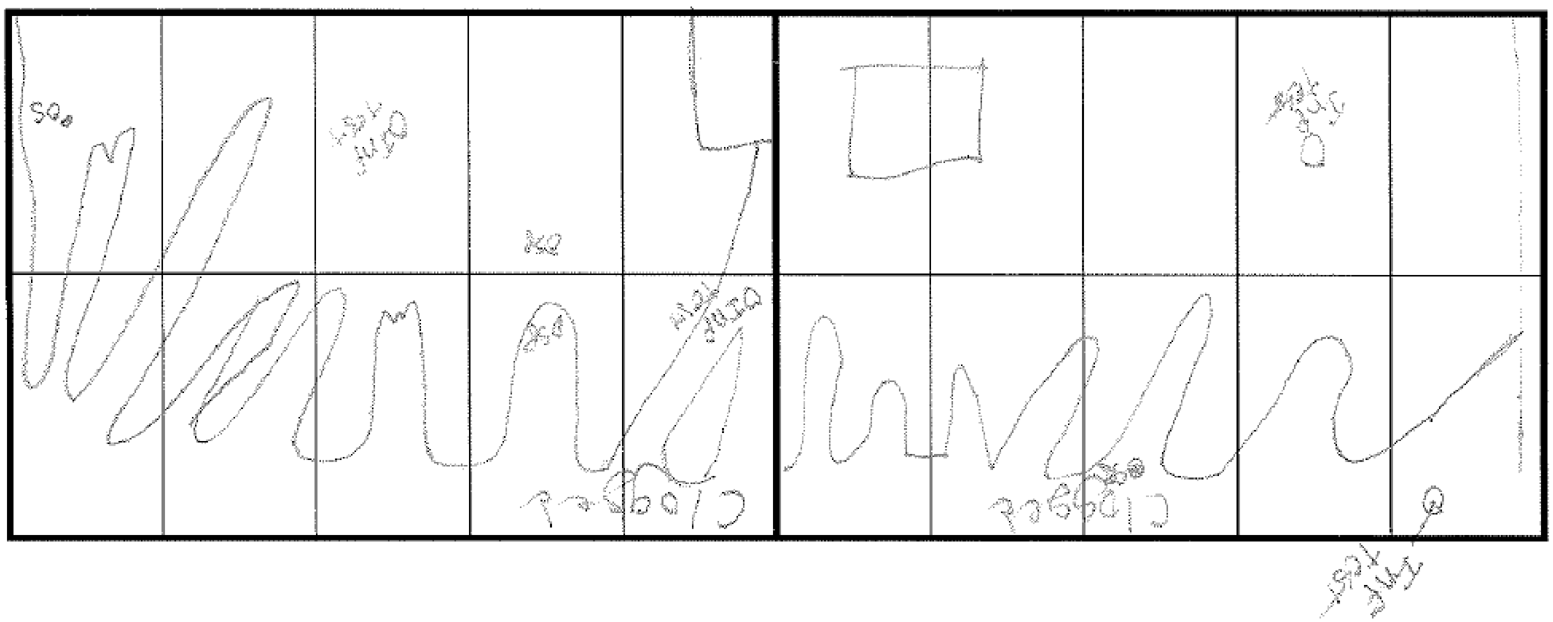
Date: 7/3/09

Observer(s) JB

Procedure:

Walk around site with a hose and note on the drawing below any locations where clogging, sealing, ponding, icing, spalling, or any other features of interest are observed. Attach site pictures.

Porous Asphalt *Pervious Concrete*



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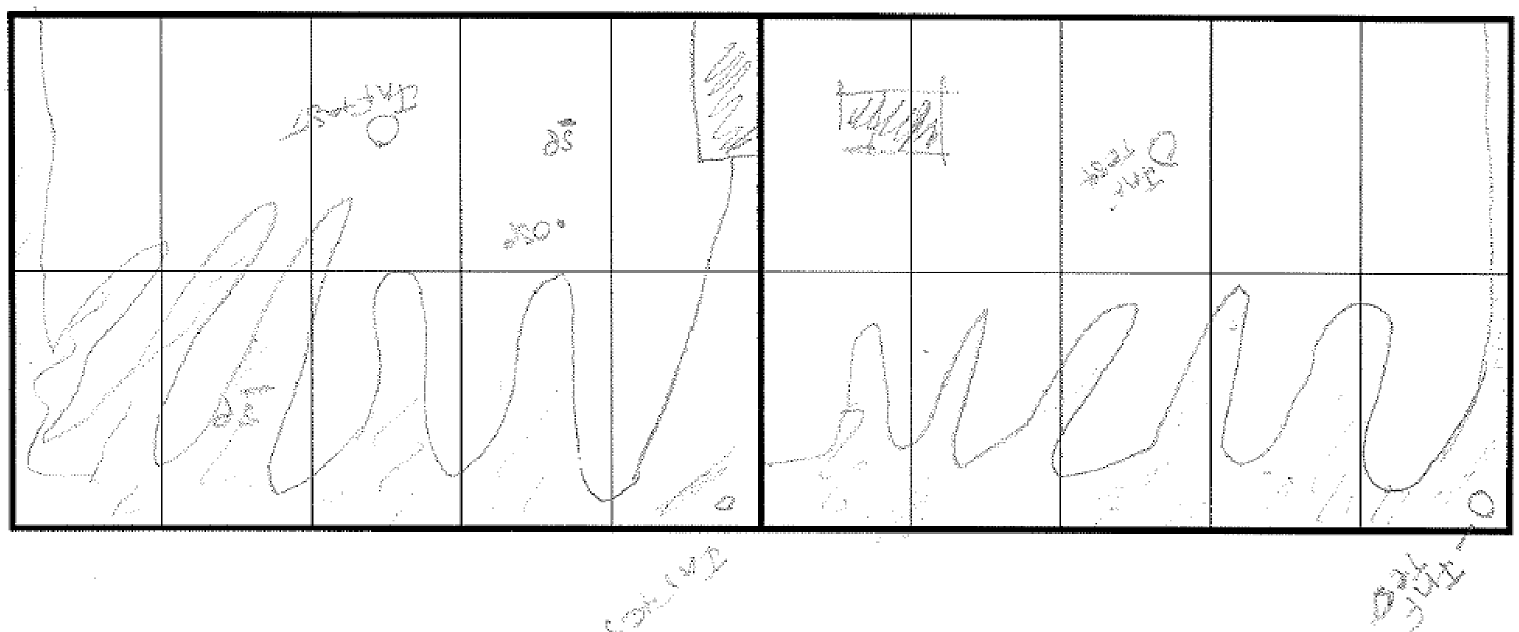
Site Observation Report

Date: 7/22/07 Observer(s) TB

Procedure:

Walk around site with a hose and note on the drawing below any locations where clogging, sealing, ponding, icing, spalling, or any other features of interest are observed. Attach site pictures.

Porous Asphalt *Pervious Concrete*



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APPENDIX 2: Soak Test Results

Compound	MDL µg/L	Blank µg/L	PVC µg/L	PC1A µg/L	PC1B µg/L	PC2A µg/L	PC2B µg/L	PA1A µg/L	PA1B µg/L	PA2A µg/L	PA2B µg/L
Napthalene	1.0	ND	0.07	ND	0.04	0.05	0.06	ND	0.04	ND	ND
Acenphthylene	0.9	ND	0.07	ND	ND	0.11	ND	ND	ND	ND	ND
Acenphthene	0.9	ND	0.11	0.14	0.15	0.12	0.16	ND	0.09	0.09	0.14
fluorene	0.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phenanthrene	0.2	ND	0.06	0.03	0.06	0.03	ND	ND	0.03	0.01	0.01
Anthracene	0.3	ND	0.08	0.04	0.07	0.04	ND	ND	0.04	0.01	0.01
fluoranthrene	0.4	ND	0.10	ND	0.03	ND	ND	0.04	ND	ND	ND
Pyrene	1.2	ND	0.11	ND	0.02	ND	ND	ND	ND	0.05	0.02
Benz(a)anthracene	1.3	ND	ND	0.01	ND	ND	ND	ND	0.09	0.05	ND
Chrysene	1.5	ND	1.23	0.11	0.03	ND	ND	ND	ND	0.03	ND
Benzo(b)fluoranthene	4.5	ND	0.02	0.02	0.09	ND	0.04	0.06	ND	ND	ND
Benzo(k)anthrene	4.7	ND	0.10	0.06	0.10	ND	0.06	ND	0.05	0.05	ND
Benzo(a)pyrene	38.2	ND	ND	0.05	ND	0.82	ND	0.12	0.17	ND	0.14
Ideno(1,2,3-d,d)pyrene	17.0	ND	0.20	ND	ND	0.78	ND	ND	ND	0.17	ND
Dibenz(a,h)anthracene	18.0	ND	ND	0.12	0.15	ND	0.14	0.10	ND	ND	ND
Benzo(g,h,i)perylene	20.0	ND	0.20	0.04	ND	ND	0.14	ND	ND	ND	0.23
Total PAH		ND	2.35	0.61	0.74	1.94	0.60	0.32	0.50	0.47	0.55

Blank	**Just reagent grade water no pvc or pavment**
PVC	**PVC pipe and reagent grade water**
PC1A	Porous concrete surface in PVC pipe and reagent grade water sample 1
PC1B	Duplicate of 1A
PC2A	PC sample, PVC pipe, reagent grade water sample 2
PC2B	Dupilicate of 2A
PA1A, B and PA2A, B	Same as concrete samples but with asphalt