FY 2011 Oklahoma Water Resources Research Institute Grant

Final Technical Report

Title:

Investigation of the Viability of Rainfall Harvesting for Long-term Urban Irrigation: Bioaccumulating Organic Compounds and the First Flush in Rooftop Runoff

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Congressional Districts:
03 – Stillwater, Oklahoma State University and OSU Agronomy Farm
05 – Oklahoma City, Project Sites at OSU-OKC

Focus Category:
RAINWATER HARVESTING, WATER QUALITY, RUNOFF

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Publications:
Lay, J.J., J.R. Vogel, J.B. Belden, and G.O. Brown, 2012. An Update on Quantifying the First Flush in Rooftop Rainwater Harvesting. Conference proceedings paper, 2012 ASABE International Meeting, Dallas, TX, Jul. 29-Aug. 1, 2012.

Lay, J.J., J.R. Vogel**,** J.B. Belden, and G.O. Brown, 2011. Quantifying the First Flush in Rooftop Rainwater Harvesting through Continuous Monitoring and Analysis of Stormwater Runoff. Conference proceedings paper, 2011 International Conference of the ASABE. Louisville, KY, Aug. 7-10, 2011.

Summary Table of Student Support

Student Status	Number	Disciplines
Undergraduate	2	Biosystems and Agricultural Engineering
M.S.	2	Biosystems and Agricultural Engineering, Zoology
Ph.D.	0	
Post Doc	0	
Total	4	Biosystems and Agricultural Engineering, Zoology

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Background and Research Objectives

One of the conclusions of the Senate Bill 1627 Marginal Quality Water (MQW) Work Group Final Report concludes that stormwater "could be utilized… for non-potable uses (in locations) where suitable storage could be provided to buffer the intermittent supply against demands placed upon this source" (OWRB, 2010). Utilization of stormwater in this manner is also called rainwater harvesting, and is one of the practices that falls under the stormwater management practices called low impact development (LID). By storing and reusing rooftop runoff across the landscape in urban areas, flooding and water-quality issues caused by urban runoff can be lessened. Additionally, the MQW report recommended that "the potential for storage and use of stormwater runoff to meet non-potable demands should be further examined in urbanized areas in central and eastern Oklahoma".

Control and management of stormwater volume and water quality is an important concern for the people of all across Oklahoma. In 2003, the Oklahoma Department of Environmental Quality adopted "Phase II" stormwater regulations that required smaller cities with "Urbanized Area" to comply with Phase II stormwater permits. In Oklahoma, the two Phase I cities (Tulsa and Oklahoma City) each have individual permits, while approximately 45 Phase II areas come under the General Permit (OKR04) Phase II Small Municipal Separate Storm Sewer System. To meet EPA requirements, these communities, along with the Phase I communities of Oklahoma City and Tulsa, will need to implement stormwater control structures and practices, such as rainwater harvesting, that are both practical and sustainable.

Past research has indicated that a wide variety of contaminants can be present in rooftop runoff that could potentially be used for rainfall harvesting and reuse. Most of these contaminants have minimal long-term risk associated with them when used for non-potable uses. However, the organic polyaromatic hydrocarbons (PAHs), flame retardants such as polybrominated diphenyl ethers (PBDEs), and some pyrethroid insecticides have known or suspected endocrine disrupting effects, have been shown to be widely present in urban stormwater runoff (Wilkinson et al., 2009***;*** Vogel et al., 2009), and may have the potential for long-term accumulation on soils if they are present in water that is used as the major source of urban irrigation.

The Low Impact Development Research and Extension Program at Oklahoma State University has several priority topics related to rainwater harvesting including:

(1) Occurrence and potential for soil accumulation of organic compounds in rooftop runoff
(2) Characterization of the first flush from rooftop runoff, and using this quantification to redesign the rainfall harvesting first flush diverter; this will optimize the rainfall harvesting system to allow for collection of the largest quantity of good-quality water.
(3) Investigation of the impacts of widespread rainfall harvesting on downstream flows in rivers and streams
(4) Optimization of the 'rainwater sand cistern' concept developed at OSU

(5) Socio-economic barriers to widespread implementation of rainfall harvesting in Oklahoma
(6) Creation of a web-based design tool that utilizes Oklahoma Mesonet data for optimal, site-specific designing of rainwater harvesting systems
(7) Effects of climate change on rainfall harvesting in Oklahoma

This research addressed the first two OSU LID program priority topics.

If rainfall can be successfully harvested and utilized for non-potable uses such as urban irrigation, it can conserve treated drinking water for potable uses. This will lessen the demand on surface and ground water used as drinking water sources and decrease the cost to municipalities and taxpayers for treating drinking water. Implementation of rainfall harvesting will also reduce stormwater runoff and flooding potential. The results of this project will also potentially allow for a data-based design of a new rainfall harvesting first-flush device that will allow for the optimum usage of the rooftop runoff water and minimize the potential for build-up of contaminants in irrigated urban areas.

The objective of this research was to investigate two questions that remain regarding the widespread implementation of rainwater harvesting as a solution for decreasing demand on water systems from water used for urban irrigation. These two questions are:

1. Does the runoff from the beginning part of a storm, also referred to as the "first flush" contribute a substantial portion of contaminants in rooftop runoff, and, if it does, can design of the rainfall harvesting system decrease the concentration and bioaccumulation potential of contaminants in harvested rainfall?
2. Do PAHs, flame retardants, and pyrethroid insecticides occur in rooftop runoff, and what is the bioaccumulation potential of these compounds in lawns if the water is used for urban irrigation?

This objective was investigated by testing two hypotheses: (1) a site specific first flush can be quantified based on the roofing material and geographical location by continuous monitoring and analysis of contaminants found in the rooftop runoff throughout a storm event, and (2) PAHs and selected flame retardants and pyrethroid insectidies have the potential for long-term accumulation in soils from harvested rainfall used as urban irrigation.

Methods, Procedures, and Facilities

This water-quality portion of the study was conducted at two different locations in Oklahoma: the Oklahoma State University Oklahoma City campus (OSU-OKC) and the OSU Agronomy Farm located in Stillwater. The OSU-OKC campus is located west of Interstate 44 (I – 44) and the OSU Agronomy Farm is located north of Highway 51. The sites' close proximity to the two highways allows for a more accurate representation of the environmental occurrence of PAHs and other contaminants from anthropogenic sources (i.e. motor vehicles) as dust from the highway is expected to be atmospherically deposited onto the nearby buildings and roof structures.

Soil samples were collected from beneath downspouts of buildings having asphalt shingle, metal, or tar & gravel roofing materials from various locations in both Stillwater and Oklahoma City. Each downspout sample had a paired sample that was taken away from the downspout for comparison. A total of 17 paired samples were collected and analyzed for the presence of the selected PAHs, flame retardants, and pyrethroid insecticides.

Oklahoma City Field Study

Three different roof types were analyzed for selected contaminants in the rooftop runoff at the OSU – OKC site. Runoff samples were collected from two commercial buildings, the Horticulture Pavilion (HP) (Figure 1) and the Maintenance Shop (MS) (Figure 2), representing metal and built-up roof types, respectively, as well as from a constructed asphalt-shingle roof structure (AS) (Figure 3) located next to MS. Table 1 gives details on each building, including roofing material, the year the building was constructed, and the contributing rooftop area that water samples were collected from.

Table 1. OSU-OKC building characteristics.

Building	**Roofing Material**	**Year Built**	**Contributing Area (m^2)**
Horticulture Pavilion (HP)	Metal	2004	88 (87.8)
Maintenance Shop (MS)	Tar & Gravel	1983	92
Asphalt Shingle (AS)	Asphalt Shingle	2011	9.3

Figure 1. OSU-OKC Horticulture Pavilion (HP).

Figure 2. OSU-OKC Maintenance Shop (MS).

Figure 3. OSU-OKC Asphalt Shingle (AS).

Paired samples were collected from the storm events listed in Table 2 between the months of April and July 2012. Complications in the field resulted in not all of the buildings being sampled from each storm event.

Table 2. Storm events sampled in 2012 at OSU-OKC.

Date	Storm Event	Rainfall (mm) for Sampling Events	Antecedent Dry Period (days)	Buildings Sampled
3 April	S1	12.4 (AS)*	11	HP
11 April	S2	5.08 (AS)*	7	HP, MS, AS
13 April	S3	21.1 (AS)*	1	HP, MS, AS
19 April	S4	9.40 (AS)*	3	HP, MS, AS
28 April	S5	6.10 (AS)*; 6.35 (MS)	8	HP, MS
11 May	S6	4.57 (MS); 4.06 (AS)	9	MS, AS
20 May	S7	5.84 (HP); 6.86 (MS)	6	HP, MS
29 May	S8	6.60 (HP); 15.5 (MS); 20.8 (AS)	6	HP, MS, AS
6 June	S9	9.65 (HP); 9.91 (MS); 8.89 (AS)	2	HP, MS, AS
15 June	S10	32.0 (HP); 34.5 (MS)	7	HP, MS
9 July	S11	2.29 (HP); 3.05 (MS); 2.79 (AS)	17	HP, MS, AS

*Used for HP and MS rainfall data also when no rain gauge present at given site.

Field Equipment

A single downspout on both the Horticulture Pavilion and the Maintenance Shop were replaced and modified with a PVC pipe configuration in order to allow for continuous water quality readings and sampling (Figures 4 and 5). A PVC downspout configuration was placed on the constructed asphalt shingle structure similar to the downspouts installed on HP and MS, but using smaller PVC pipe and fittings (Figure 6). The configuration was designed to pool water in order to (1) store water in-between storm events to keep the water-quality sonde wet and (2) allow for easy sampling of storm water runoff from the buildings.

Figure 4. OSU-OKC HP downspout configuration.

Figure 5. OSU-OKC MS downspout configuration.

Figure 6. OSU-OKC AS downspout configuration.

In order to account for mixing between the stored downspout water and incoming rainfall runoff, a rhodamine tracer study was conducted on the larger downspout configurations prior to the field study. A known rhodamine dye concentration mixture was constantly injected into the downspout using a peristaltic pump and samples were taken every 30 seconds in order to see how long it took the water in the downspout to become completely mixed with the incoming mixture. Three flow rates were tested and a regression equation was found from the data in Excel,

$$X = \left(\frac{EC_{downspout}}{102.71}\right)^{\frac{1}{0.1508}}$$

Where $EC_{downspout}$ is the electrical conductivity of the water already in the downspout and X is the fraction of the downspout water with the given electrical conductivity concentration. Using the fraction calculated from the regression equation, the electrical conductivity of the incoming rainwater was determined based on its mixing with the downspout water that was present before the storm. [Note: the water was in the downspout to keep the water-quality sonde wet while it took turbidity, conductivity, and temperature readings.] The following equation was used to calculate the conductivity concentration of the rainfall runoff.

$$EC_{rain} = \frac{EC_{downspout} - X(EC_{downspout\ initial})}{(1 - X)}$$

Teledyne Isco 6712 Portable Sampler

Three Teledyne Isco 6712 portable samplers were used to collect 12 paired samples throughout the course of a rainfall event at each building. The samplers all utilized the standard twenty-four bottle kit supplied by Isco where one L polypropylene bottles were used to store the samples in. The sampler was programmed to take sequential samples at irregular time intervals, with the majority of the samples collected during the rising limb of the storm. Table 3 provides details of the sampler programming. Teflon-lined tubing (3/8” ID x 1/2”OD) was used for the suction line. Prior to collecting each sample, the suction line was rinsed twice by the pump. Three retries were programmed if no water was detected. A total of 12 paired samples were collected, with the second sample of each pair programmed to be immediately collected after the first sample.

Table 3. Portable sampler programming as seen on the sampler screen.

Bottle (1-24)	**Sampler Programming (mins)**	**Total time (mins)**
1	0 (sample at enable)	0
1	1	1
2	2	3
3	1	4
4	2	6
5	1	7
6	2	9
7	1	10
8	2	12
9	1	13
10	2	15
11	1	16
12	10	26
13	1	27
14	10	37
15	1	38
16	10	48
17	1	49
18	30	79
19	1	80
20	60	140
21	1	141
22	60	201
23	1	202
24	0	202

Hach Hydrolab MS5 Water Quality Multiprobe

A Hach Hydrolab MS5 Water Quality Multiprobe (sonde) was used to record continuous, one-minute data on the turbidity, specific conductance, and temperature of the runoff passing through each building's modified downspout during a storm event. The sondes were installed in the 45° extended arm in the downspout configuration at each building (Figure 7). The HP and MS sondes were battery powered while the AS sonde was powered using a 110 VAC power adapter.

Figure 7. Sonde inside the HP downspout configuration.

Weir Box & Submerged Probe

A 90° contracted V-notch weir attached to a 0.914 m x 1.52 m (3 ft x 5 ft) constructed plywood box was placed at the outlet of each downspout configuration in order to measure storm water runoff flow in conjunction with a Teledyne Isco 720 Submerged Probe Flow Module, as shown in Figure 8. The weir box had a width of 0.914 m and a length of 1.52 m, and the V-notch weir was placed 7.62 cm (3 in) above the bottom of the box at the end of the length of the box. The design was based off of recommendations provided by the United States Department of the Interior Bureau of Reclamation for 90 degree contracted V-notch weirs.

Figure 8. HP downspout setup, including weir box and portable sampler.

The submerged probe connected to the module contains an internal differential pressure transducer that measures the water's hydrostatic pressure and converts that pressure to analog signals and the analog signals to level readings through an amplifier. The probe's minimum level is approximately 3.0 cm (0.1 ft); however it can measure levels less than 2.5 cm (0.08 ft) but the accuracy is not guaranteed. The probe was installed 0.915 m (3 ft) upstream from the weir plate in order to be at least 3 times the maximum head, which in this case was 0.229 m (0.75 ft).

The following equation was used to calculate the discharge over the weir:

$$Q = 2.49{h_1}^{2.48}$$

where:

Q = discharge over weir in ft^3/s

h_1 = head on the weir in ft

The head on the weir was provided by the submerged probe level readings. The readings provided by the probe had 7.62 cm (3 in) subtracted from the measured readings in order to account for the 7.62 cm (3 in) between the bottom of the V-notch weir and the bottom of the weir box. For level readings below 7.62 cm, the continuity equation was used to calculate the flow rate inside the weir box:

$$Q = VA$$

where:

V = velocity in ft/s, which was determined by calculating the change in level reading and dividing by 60 seconds (the time increment recorded for each level reading)

A = weir box area, in ft^2

Rainfall Measurements

Isco 674 Rain Gauges were used to record rainfall data at the OSU-OKC sites. This rain gauge uses a tipping bucket design that is factory-calibrated to tip at 0.10 mm (0.01 in) of rainfall. Initially, only one rain gauge was installed at AS. Later on in the study, rain gauges were also installed at the MS and HP sites. The AS rain gauge was installed on top of the roof while the HP and MS rain gauges were installed next to the portable samplers off of the ground and away from any obstructions.

Sample Collections

Prior to a storm event, the portable samplers were programmed and filled with 24 one liter bottles. The pump and discharge tubing in the samplers were replaced with clean tubing before each collection event. The Teflon suction lines between the downspouts and the sampler were not replaced as they were considered part of the downspout design. The weir boxes were drained and the downspout water was replaced with city tap water via garden hoses located on site. The sondes were calibrated in the field before each event using a two-point calibration curve for turbidity readings using 100 NTU and 1000 NTU standards and for specific conductance using a 1413 µS/cm standard.

In order to trigger the portable samplers to begin sampling, two methods were used in the study. Initially, the submerged probes were programmed to trigger the samplers when the water level in the weir box was above 7.0 cm (0.230 ft). This level was chosen to allow time for the water being stored inside the downspout between events to pass through so that only the runoff water would be sampled. This triggering method was initially used on HP and MS. AS was triggered by means of an Isco 674 Rain Gauge due to its smaller catchment area; whenever the gauge had a reading of >1.27 mm for 15 minutes (>0.05 in for 15 minutes), the sampler would begin to collect samples. The submerged probe method was used on MS for S1 to S4 and the rain gage method from S5 to S10. HP utilized the submerged probe method for S1 to S6 and the rain gage method from S7 to S10.

All samples were collected from the portable samplers within 12 hours of a storm event and immediately placed on ice. Rainfall activity was monitored from Stillwater, OK using real-time data from the Oklahoma Mesonet station Oklahoma City West (OKCW) located on the OSU-OKC campus, within 300 meters of all three buildings. An aerial photo of the OKCW station's location is shown in Figure 9.

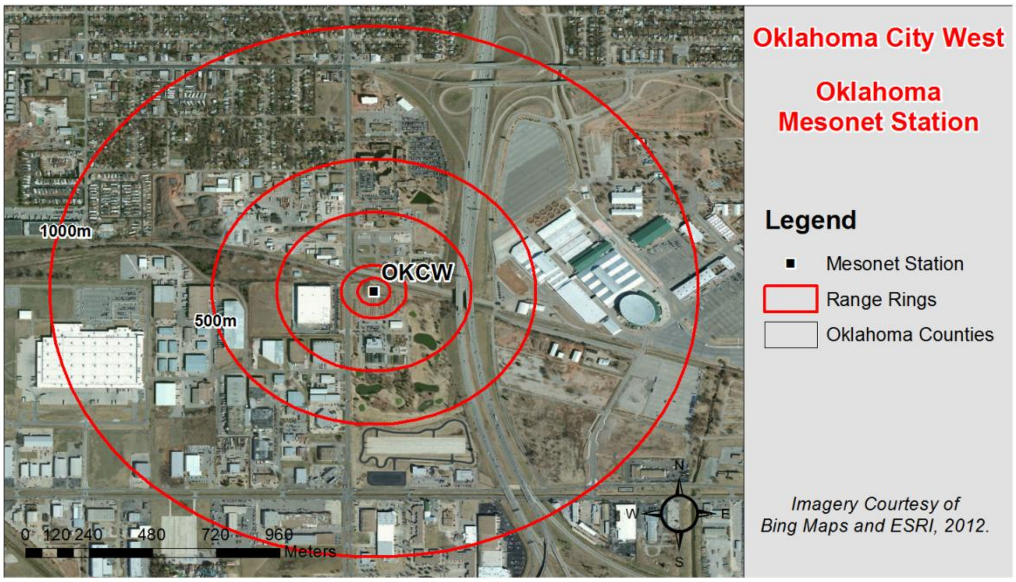

Figure 9. Aerial photo (1000 m) of the OKCW Mesonet station.

The portable sampler reports and sonde data were downloaded onto laptops after all samples were placed on ice. Samples were brought back to Stillwater from OSU-OKC, where they were immediately split between the various labs for water-quality testing. The six paired samples used for analysis were chosen based on where they occurred during the storm event, which was recorded by the samplers and viewed using Flowlink 5.1 software. The first sample of each paired samples was used for organics analysis of PAHs and selected flame retardants and pyrethroid insecticides; the second of each paired sample was split for analysis on conductivity, pH, nitrate-nitrogen, total suspended solids, total coliforms and *E. coli* concentrations.

The organics analysis was performed by graduate and undergraduate students of both the biosystems engineering and the zoology department and Dr. Belden in the zoology department's analytical laboratory using the solid-phase extraction method. Table 4 lists the analytes tested for in the water samples.

Table 4. Analytes for organic analysis.

PAHs	Flame Retardants	Pyrethroid Insecticides
Napthalene	TCEP	Bifenthrin
2-Methyl Naphthalene	TDCPP	Cypermethrin
Acenapthylene		Lambda Cyhalothrin
Acenapthene		
Fluorene		
Phenanthrene		
Anthracene		
Flouranthene		
Pyrene		
Benzo(a)anthracene		
Chrysene		
Benzo(b)fluoranthene		
Benzo(k)fluoranthene		
Benzo(a)pyrene		
Ideno(1,2,3-cd)pyrene		
Dibenzo(a,h)anthracene		
Benzo(g,h,i)perylene		

Total suspended solids analysis was performed by Biosystems Engineering undergraduates in the BAE labs. Total coliform and *E. coli* testing was performed by Ward Laboratories, Inc. in Kearny, Nebraska. Table 5 lists when bacteria samples were collected and shipped for processing and analysis. Every attempt was made to collect the samples from OKC as soon as possible and place them on ice to preserve the samples. Samples sent for bacteria testing were transferred from the field collection bottles to sterilized, 100 mL bottles provided by Ward Laboratories and shipped in coolers containing ice and blue-ice packs via UPS using next-day air shipping. Bacteria samples were processed immediately upon arrival at Ward Laboratories using the IDEZZ Quanti-Tray/200 Most Probable Number (MPN) method.

Table 5. OKC bacteria sample information.

DATE (2012)	OKC SITE	TIME OF FIRST SAMPLE (24:00)	DATE & APPROXIMATE TIME PLACED ON ICE (24:00)	DATE SHIPPED	GUARANTEED ARRIVAL TO WARD LABS
APRIL 3	HP	4/3 @ 10:19	April 3 @ 17:00	April 4	4/5 10:30
APRIL 11	HP, MS, AS	4/11 @ 8:30	April 11 @ 15:30	April 12	4/13 10:30
APRIL 13	None	4/13 @ 16:05	April 14 @ 8:45	N/A	N/A
APRIL 19-20	None	4/19 @ 20:54	April 20 @ 8:30	N/A	N/A
APRIL 28-29	None	4/28 @ 23:03	April 29 @ 12:00	N/A	N/A
MAY 11	MS, AS	5/11 @ 9:10	May 11 @ 12:30	May 11	5/14 10:30 *Received 5/12
MAY 20	HP, MS	5/20 @ 1:06	May 20 @ 10:00	May 21	5/22 10:30
MAY 29	HP, MS, AS	5/29 @ 20:19	May 30 @ 9:30	May 30	5/31 10:30
JUNE 6	HP, MS, AS	6/6 @ 10:15	June 6 @ 14:00	June 6	6/7 10:30
JUNE 15	HP, MS	6/15 @ 3:11	June 15 @ 9:30	June 15	6/16 12:00
JULY 9	HP, MS, AS	7/9 @ 19:41	July 10 @ 8:30	July 10	7/11 10:30

Lastly, samples were also sent to the OSU Soil, Water, and Forage Analytical Laboratory (SWFAL) and analyzed for conductivity, pH, and nitrate-nitrogen concentrations.

Analytes

Samples collected at the OSU-OKC sites were analyzed for several parameters: concentrations of PAHs, selected flame retardants and pyrethroid insecticides, conductivity, nitrate-N, bacteria, and total suspended solids concentrations. Table 6 provides detailed information on which PAHs were analyzed for in the water samples.

Table 6. Reporting limits and categories of PAHs.

Reporting Limit (ng/L)	Sum of PAHs	Commonly Detected PAHs	Carcinogenic PAHs
30	Napthalene	Flouranthene	Benzo(a)anthracene
30	2-Methyl Naphthalene	Pyrene	Chrysene
30	Acenapthylene	Chrysene	Benzo(b)fluoranthene
30	Acenapthene	Benzo(b)fluoranthene	Benzo(k)fluoranthene
30	Fluorene	Benzo(k)fluoranthene	Benzo(a)pyrene
30	Phenanthrene	Benzo(a)pyrene	Ideno(1,2,3-cd)pyrene
15	Anthracene	Ideno(1,2,3-cd)pyrene	Dibenzo(a,h)anthracene
15	Flouranthene		
10	Pyrene		
10	Benzo(a)anthracene		
10	Chrysene		
10	Benzo(b)fluoranthene		
10	Benzo(k)fluoranthene		
10	Benzo(a)pyrene		
10	Ideno(1,2,3-cd)pyrene		
10	Dibenzo(a,h)anthracene		
10	Benzo(g,h,i)perylene		

Rainfall Simulations at Stillwater Agronomy Farm

Eighteen simulated roof structures, 1.67 m^2 (18 ft^2) in catchment area, were constructed and placed at the Agronomy Farm in Stillwater, OK, for evaluation of first flush occurrence from simulated rainfall events for new TAMKO® Elite Glass-Seal® three tab asphalt shingles, new MasterRib® acrylic coated Galvalume® sheeting, and 60 year-old clay tile roofing materials (Figure 46). Each roofing material was replicated six times. Nine roofs, consisting of three replicates of each roofing material, were oriented north-south while the remaining nine roofs are oriented east-west in order to determine if roof orientation in relation to the sun and prevailing wind direction have a significant impact on rooftop runoff water quality (Figure 47).

Figure 46. Constructed roof layout for rainfall simulations.

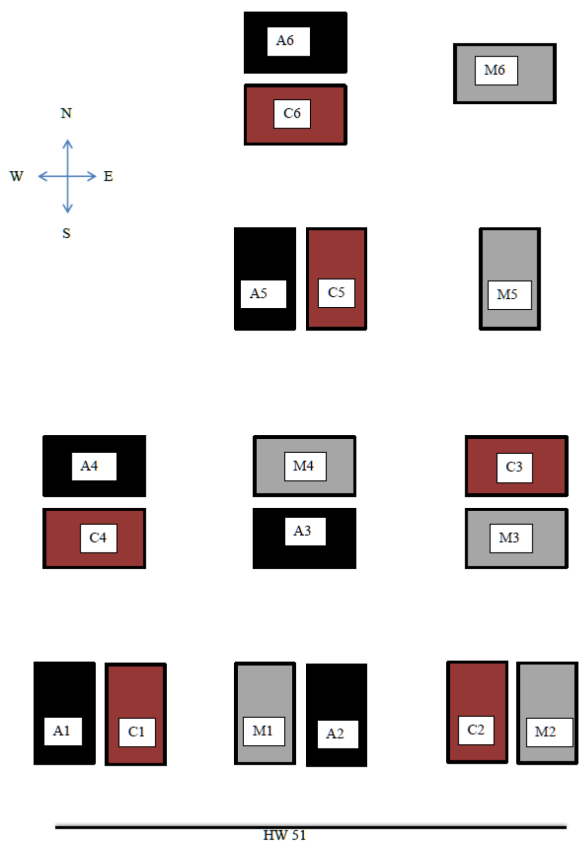

Figure 47. Layout of the 18 structures (not to scale).

A rainfall simulator was used to simulate a high, medium and low intensity storm on the roofs, resulting in a total of three experimental runs on each roof. The high intensity storm had an average intensity of 64 mm/hr (2.52 in/hr); the medium intensity storm had an average intensity of 38 mm/hr (1.50 in/hr); and the low intensity storm had an average intensity of 28 mm/hr (1.10 in/hr). In order to create this intensities for the simulations, three difference spray nozzles were used. Each nozzle emitted a square spray pattern. Nozzles were purchased from Spraying Systems and chosen based upon previous research by Humphrey et al. (2002). Uniformity tests were performed on each nozzle in order to determine the intensity provided by the nozzle at a pressure of 5 psi. Table 12 provides a summary of the three rainfall simulations performed.

Table 12. Nozzles used for rainfall simulations.

INTENSITY	DATES	NOZZLE
64 MM/HR (HIGH)	Aug 30-31, 2012	30 WSQ
38 MM/HR (MEDIUM)	Nov 16-17, 2012	24 WSQ
28 MM/HR (LOW)	Feb 1-2, 2012	14 WSQ

Water used in the simulations was passed through a SpectraPure reverse osmosis (RO) water purification system, the Producer™ system, before passing through the simulator nozzle in order to mimic rainwater quality. Water was stored in a plastic tank attached to a trailer. A rainfall simulator was constructed on the trailer (Figure 48). A PVC constructed boom, fitted with 3 separate nozzles for the three separate rainfall intensities, was raised 10 feet into the air via square metal tubing attached to the trailer. Water was pumped from the water tank through vinyl tubing leading up to the boom. The boom and required nozzle was centered over the roofs.

Figure 48. Rainfall simulator trailer with two constructed roofs.

In order to minimize interference from the wind on the spray pattern, a fifteen-foot wind block was constructed and placed around the roofs being sampled by use of a forklift (Figure 49).

Figure 49. Wind block placement over constructed roofs before a simulation.

Six samples, five individual and one composite, were manually collected from each roof during the three simulated rainfall events (Figures 50 and 51). The 68 mm/hr simulation was performed for 21 minutes and 21 seconds; the time it took to completely fill the 6^{th} sample bottle from the metal roofs. The 38 mm/hr and 28 mm/hr intensity rainfall simulations were both performed for 30 minutes each. The first five samples were 2 L in volume each; the composite sampled varied from 10 L to 36.2 L, depending on the rainfall intensity and roofing material. An antecedent dry period of 8 days was used prior to each rainfall simulation.

Figure 50. Field sampling setup for rainfall simulations.

Figure 51. Collecting the composite sample during a rainfall simulation.

Rainfall simulations were conducted over a period of 2 days. For the high and medium intensity simulations, the N-S structures were sampled from the first day and E-W on the second day; the low intensity simulation had the E-W sampled first and the N-S structures sampled on the second day. Due to the limits of the spray coverage from the nozzles, only two roofs were sampled at a time. This resulted in a total of five simulations each day over the two day period.

Samples were split in the field into separate plastic bottles for turbidity, total suspended solids, and for analysis of conductivity, pH, and nitrate-nitrogen concentrations at the OSU Soil, Water, and Forage Analytical Laboratory (SWFAL) (Figure 52). The remainder of each sample was left in the original glass sample container and taken to Dr. Belden's laboratory for organic analysis. No bacteria testing was performed on the rainfall simulation samples.

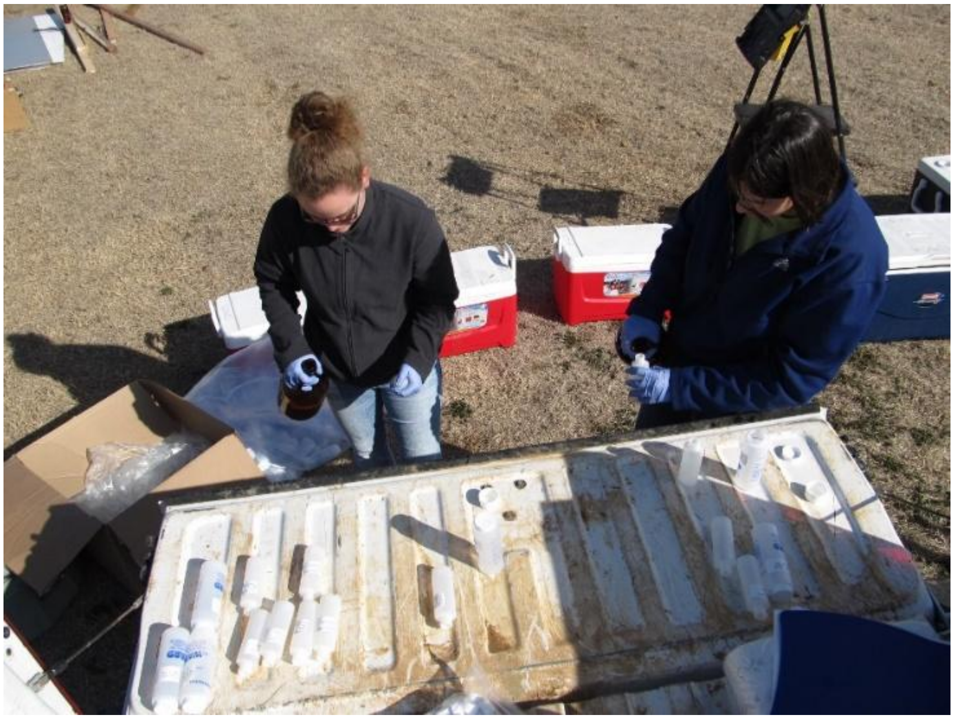

Figure 52. Splitting samples in the field.

Results

Oklahoma City Field Sites

PAHs from the Horticulture Pavilion with a Metal Roof

Runoff volumes sampled from HP ranged from 13 L up to 2267 L. Figures 10 to 13 show the concentration results from HP samples for the selected PAHs and are broken down into three main categories: Total PAHs, Sum of the Commonly Detected PAHs, and the Sum of Carcinogenic PAHs. These categories are described in detailed in Table 6. When looking at Figures 10 and 11, PAHs are detected in the runoff up to 1,033 L. When looking at Figure 12, the carcinogenic PAHs, detection was seen up to 862 L of runoff. To get a better look at the trend of carcinogenic PAHs detected, Figure 13 was created with a smaller runoff volume scale.

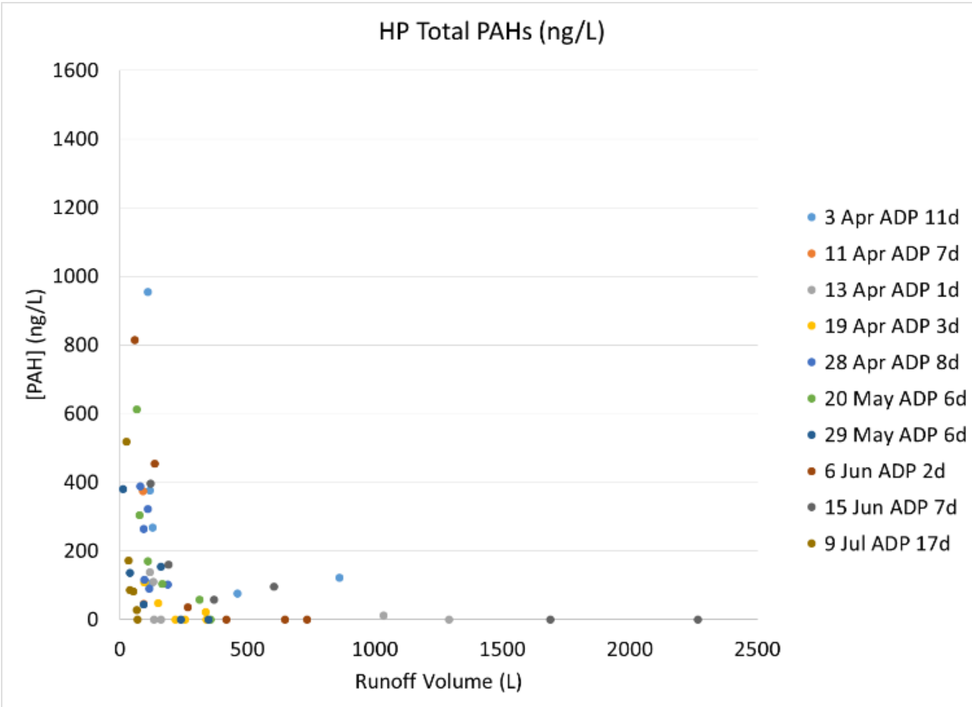

Figure 10. Concentrations of PAHs analyzed in HP runoff.

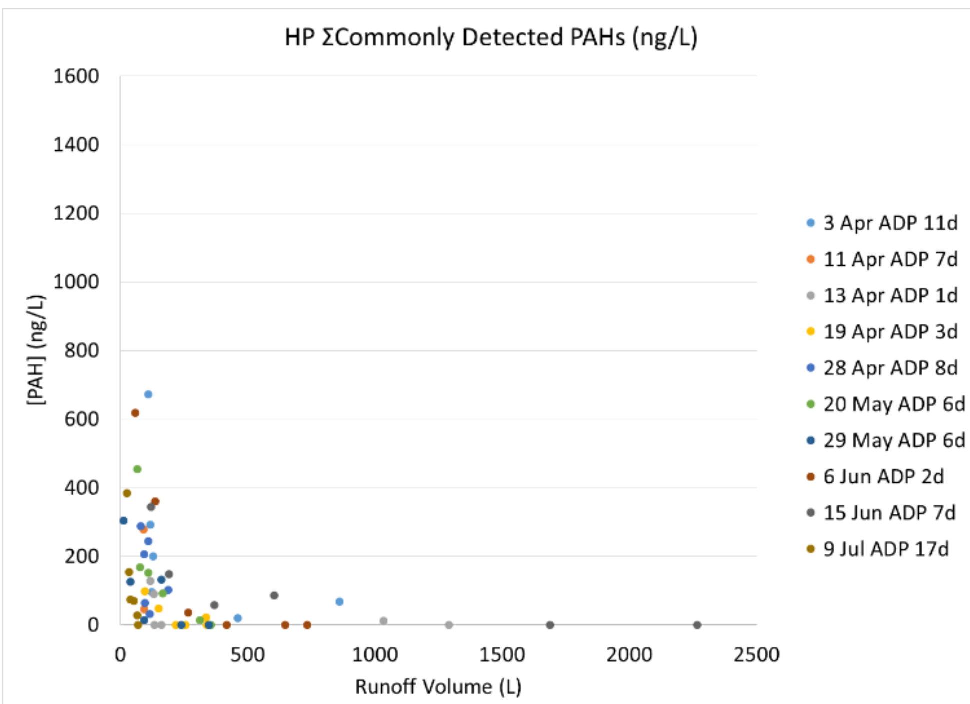

Figure 11. Concentrations of commonly detected PAHs analyzed in HP runoff.

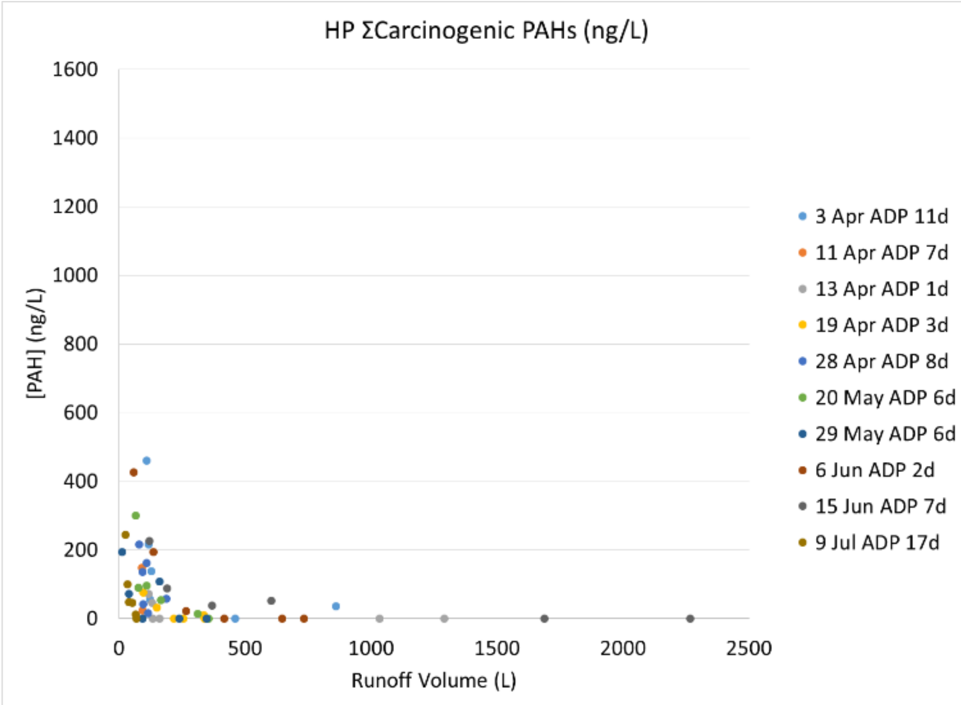

Figure 12. Concentrations of carcinogenic PAHs analyzed in HP runoff.

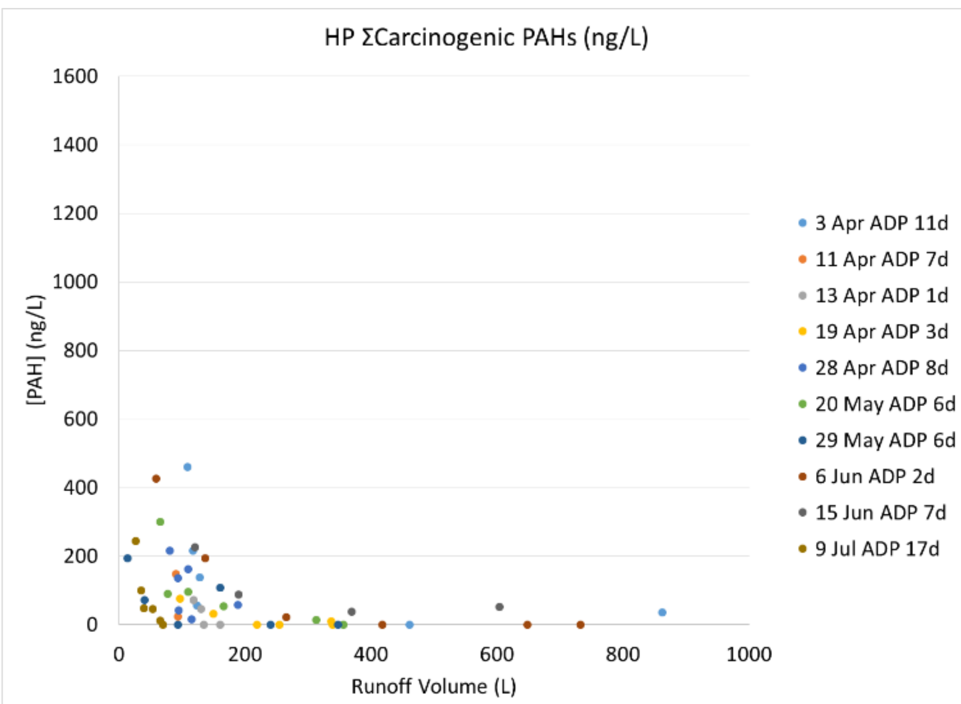

Figure 13. Concentrations of carcinogenic PAHs analyzed in first 1000 L of HP runoff.

The majority of the carcinogenic PAHs seen in the runoff occur up to 400 L. Given that the catchment area sampled from HP was 87.8 m^2, if the first 400 L of runoff were diverted, that would be the equivalent of diverting the 4.55 L/m^2 of catchment area (11 gal/100 ft^2).

PAHs from the Maintenance Shop with a Tar and Gravel Roof

Due to the physical features of MS (i.e. it being a flat roof covered with gravel), MS had a very low harvesting efficiency of the rainwater. Efficiencies ranged between 4 – 55%, with the majority of the storms having less than 28% efficiencies. Therefore, although MS had the largest catchment area of the three sites, the samples were collected from a smaller range of runoff volumes than was to be expected. Data collected from S11 was not included as there was not enough runoff due to the small storm event to warrant acceptable data. Additionally, samples that were taken when there was no flow in the downspout during various storms were also removed.

Runoff volumes sampled from MS ranged from 3 L up to 1058 L. Figures 14 to 17 show the concentration results from MS samples for the selected PAHs and are broken down into three main categories: Total PAHs, Sum of the Commonly Detected PAHs, and the Sum of Carcinogenic PAHs. These categories were described in detailed in Table 6. When looking at Figures 14 and 15, PAHs are detected in the runoff up to 265 L. When looking at Figure 16, the carcinogenic PAHs, detection was seen up to 265 L of runoff. To get a better look at the trend of carcinogenic PAHs detected, Figure 17 was created with a smaller runoff volume scale.

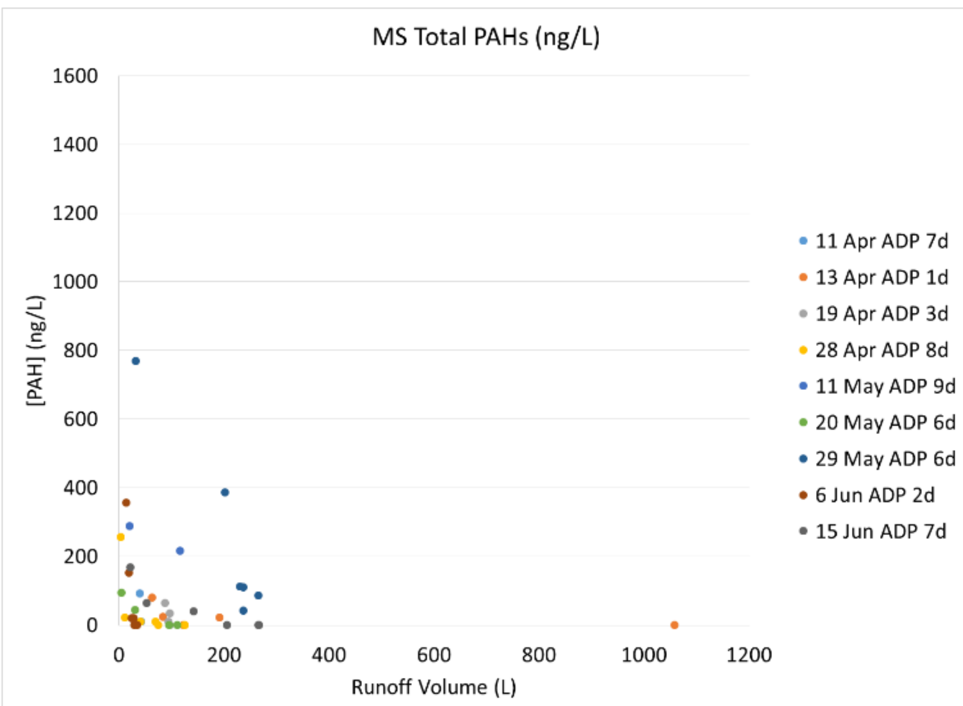

Figure 14. Concentrations of PAHs analyzed in MS runoff.

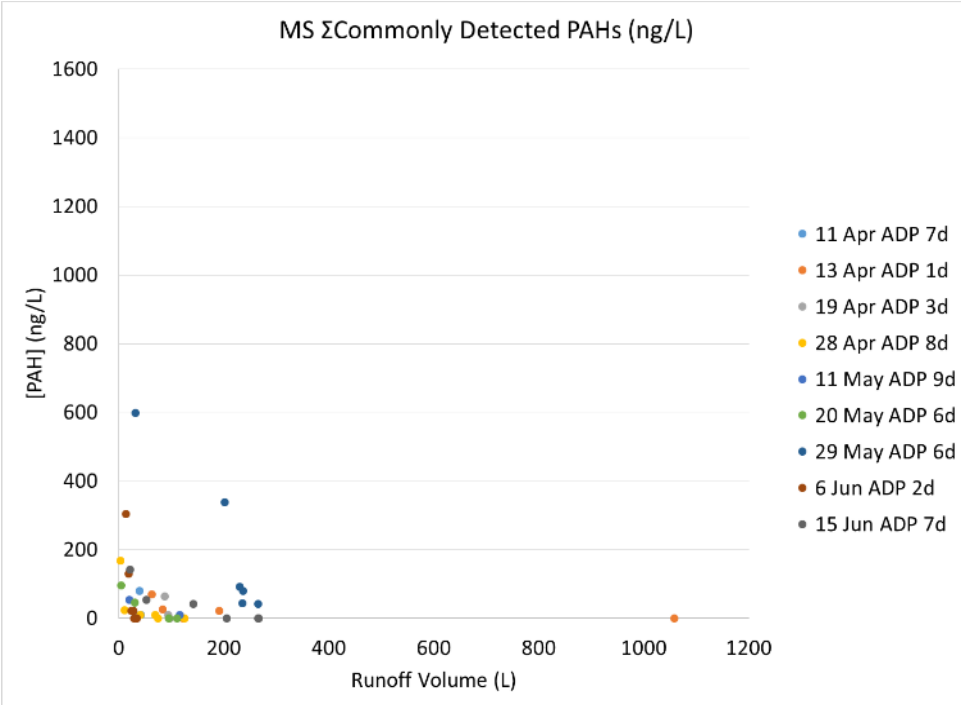

Figure 15. Concentrations of commonly detected PAHs analyzed in MS runoff.

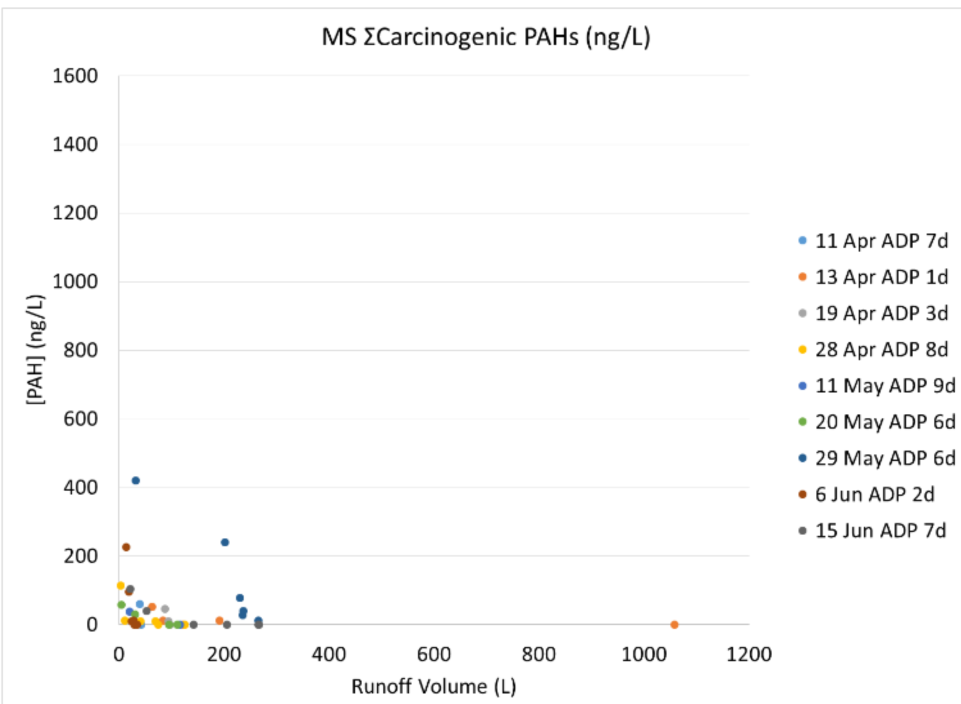

Figure 16. Concentrations of carcinogenic PAHs analyzed in MS runoff.

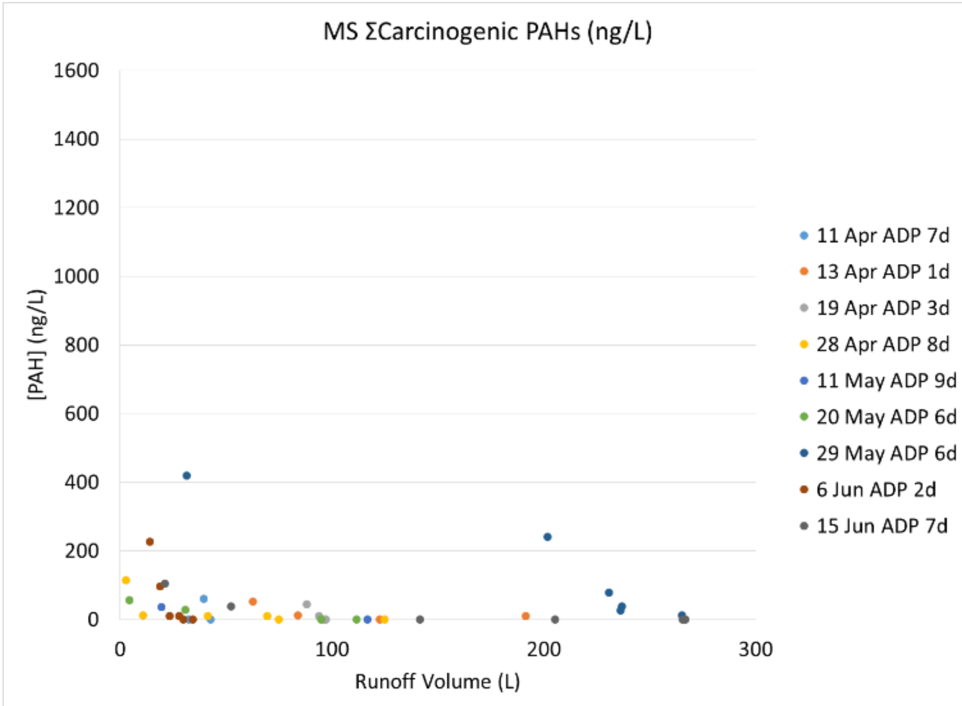

Figure 17. Concentrations of carcinogenic PAHs analyzed in first 300 L of HP runoff.

The carcinogenic PAHs seen in the runoff occur up to 265 L. Given that the catchment area sampled from MS was 92 m^2, if the first 265 L of runoff were diverted, that would be the equivalent of diverting the 2.88 L/m^2 of catchment area (7 gal/100 ft^2).

PAHs from Asphalt Shingle Roof

Runoff volumes sampled from AS ranged from 3.68 L up to 144 L. Figures 18 to 20 show the concentration results from AS samples for the selected PAHs and are broken down into three main categories: Total PAHs, Sum of the Commonly Detected PAHs, and the Sum of Carcinogenic PAHs. These categories were described in detailed in Table 6. When looking at Figures 18 and 19, PAHs are detected in the runoff up to 146 L.

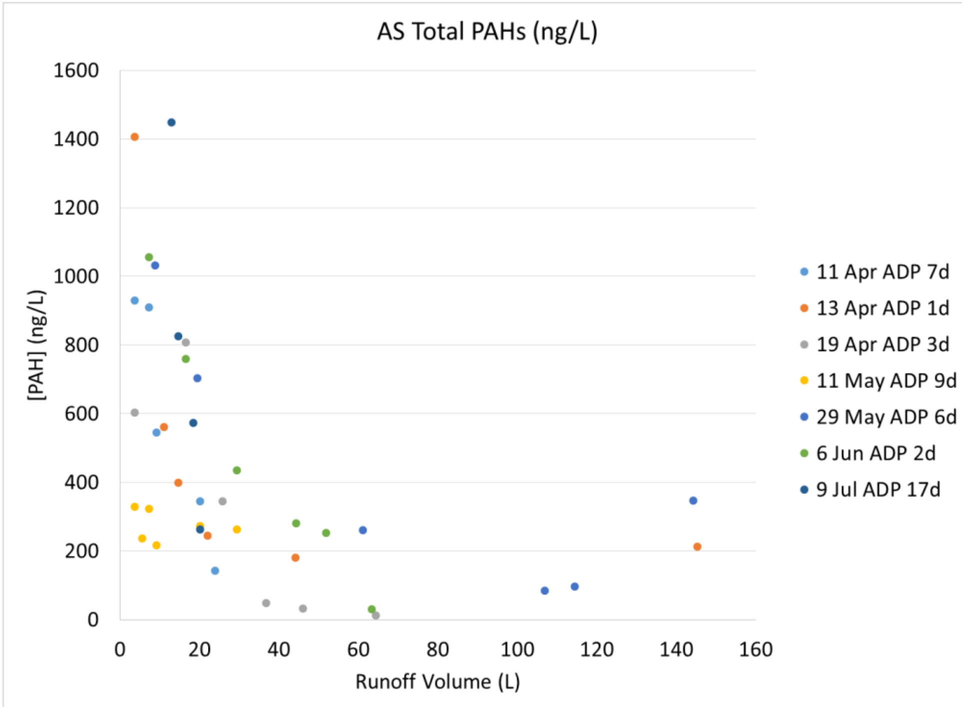

Figure 18. Concentrations of PAHs analyzed in AS runoff.

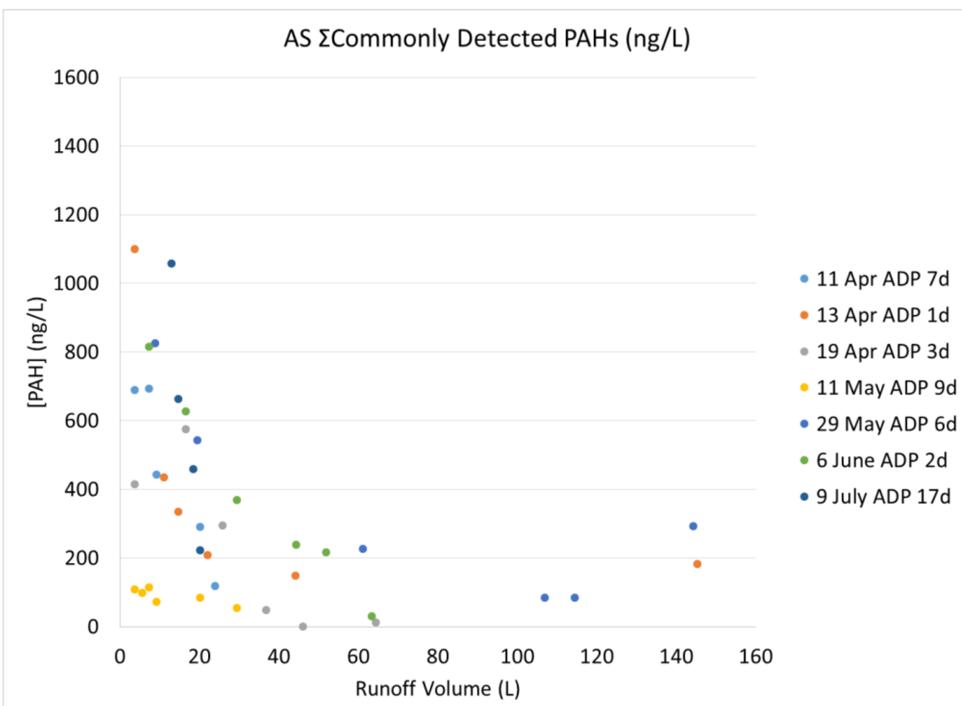

Figure 19. Concentrations of commonly detected PAHs analyzed in AS runoff.

When looking at Figure 20, the carcinogenic PAHs, detection was seen up to 146 L of runoff.

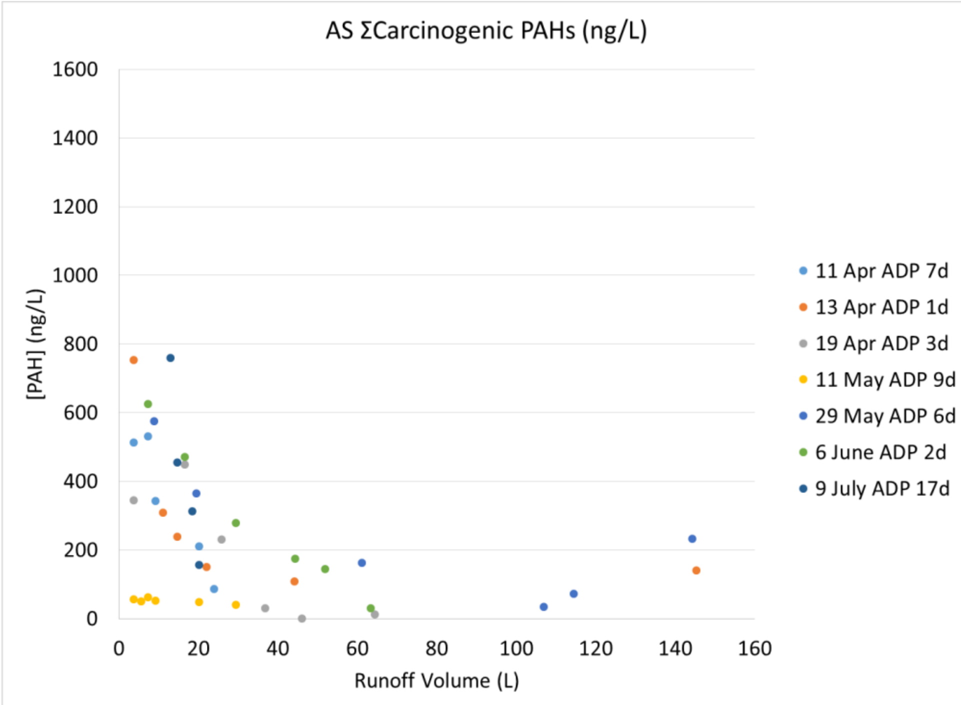

Figure 20. Concentrations of carcinogenic PAHs analyzed in AS runoff.

The carcinogenic PAHs seen in the runoff occur up to 265 L. However, the majority of carcinogenic PAHs drop off at about 63 L of runoff. Given that the catchment area sampled from MS was 9.3 m^2, if the first 265 L of runoff were diverted, that would be the equivalent of diverting the 28.5 L/m^2 of catchment area (70 gal/100 ft^2). If the first 63 L were diverted, only 6.77 L/m^2 (16.6 gal/100 ft^2).

The AS roof had the highest concentrations of PAHs, followed by HP, then MS. It was expected that MS, the tar & gravel roof, would have the highest concentrations and HP have the lowest, based on the roofing materials. One reason that MS PAH concentrations were lower than expected could be due to the fact that it is the oldest of the three roofs, having been constructed in in 1983 (see Table 1). Also, MS has never been resurfaced since its construction; therefore, PAHs coming from the tar itself could have already been washed away and all that we are seeing is from atmospheric deposition.

Flame Retardants

Runoff samples were analyzed for the presence of two flame retardants, TCEP and TDCPP. The reporting limits of the flame retardants are shown in Table 7. Results from the analysis for TCEP are shown in Figures 21-23 and for TDCPP in Figures 24-26 for HP, MS, and AS.

Table 7. Reporting limits of flame retardants.

Reporting Limit (ng/L)	Flame Retardants
30	TCEP
30	TDCPP

The highest concentrations of TCEP were found in AS runoff, followed by HP, then MS.

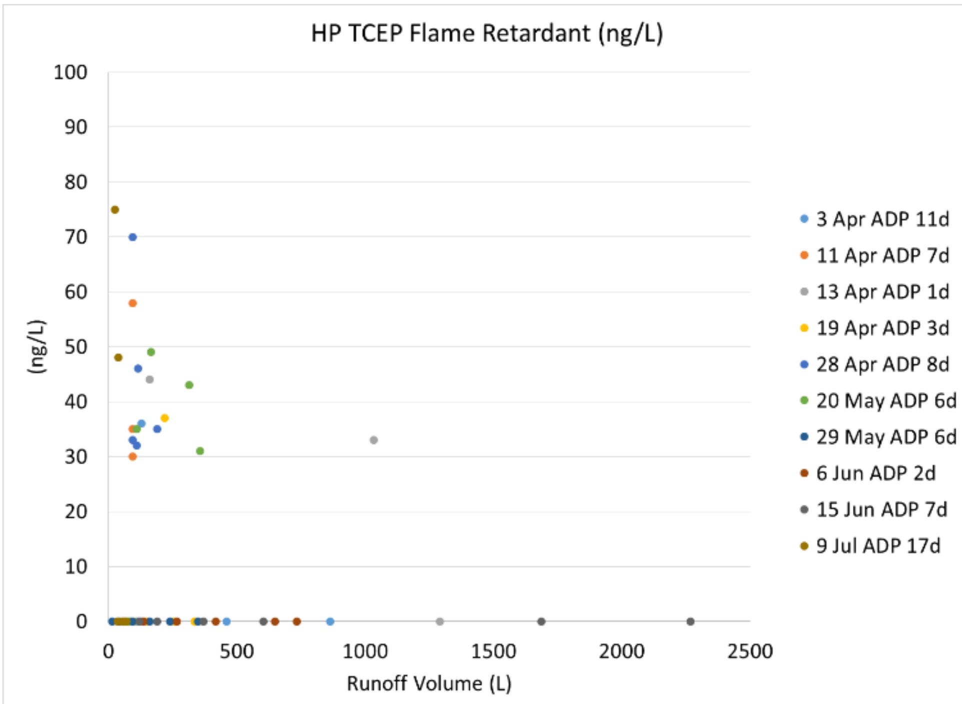

Figure 21. TCEP concentrations from HP.

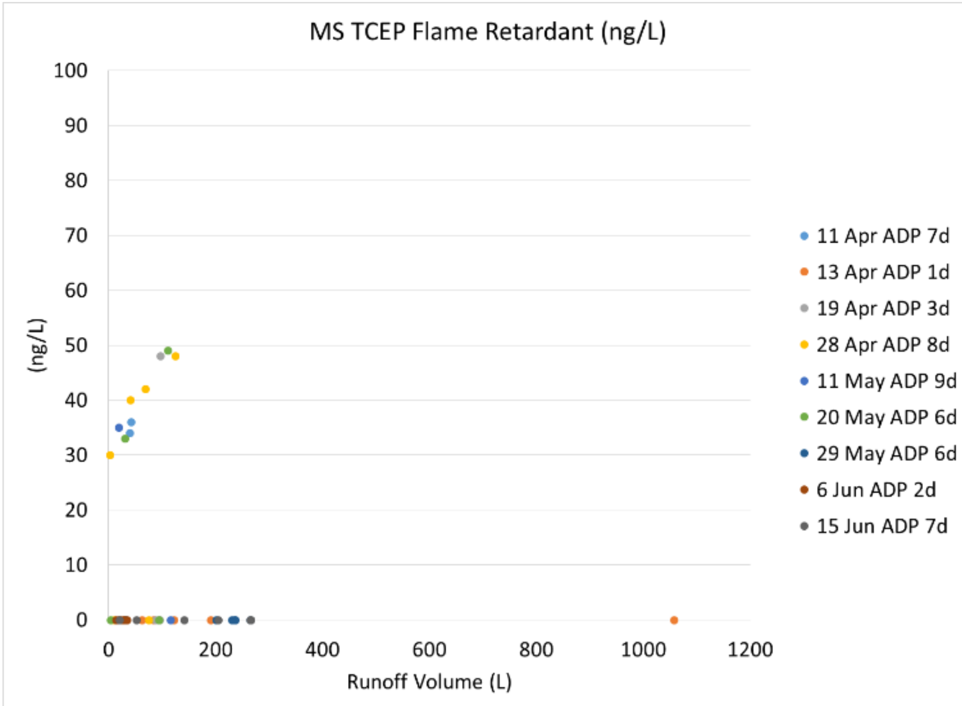

Figure 22. TCEP concentrations from MS.

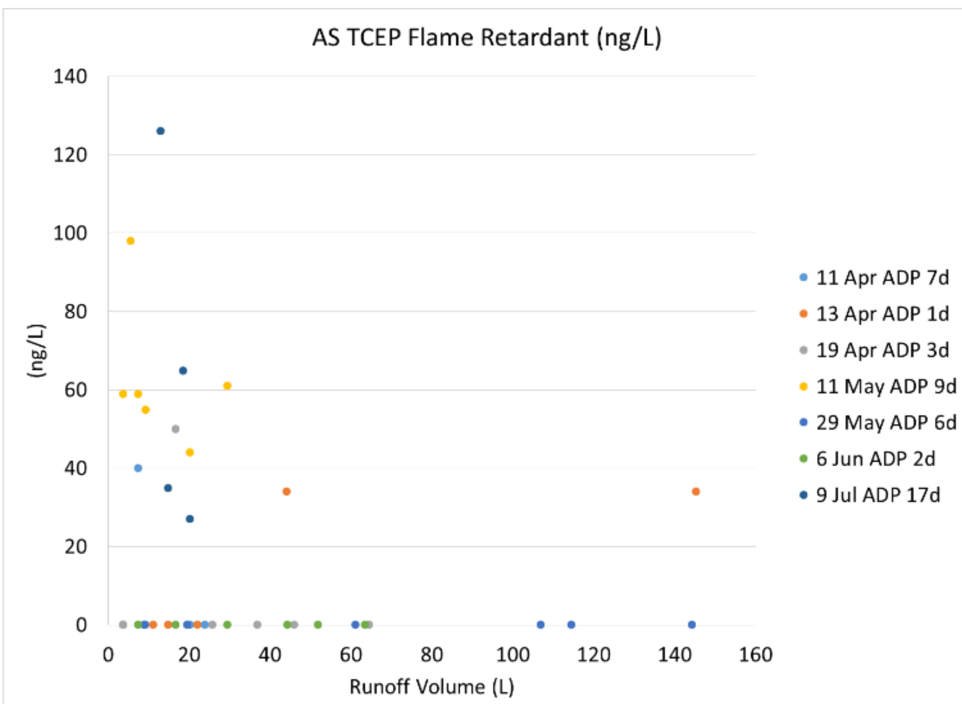

Figure 23. TCEP concentrations from AS.

The highest concentrations of TDCPP were found in MS, HP, then AS.

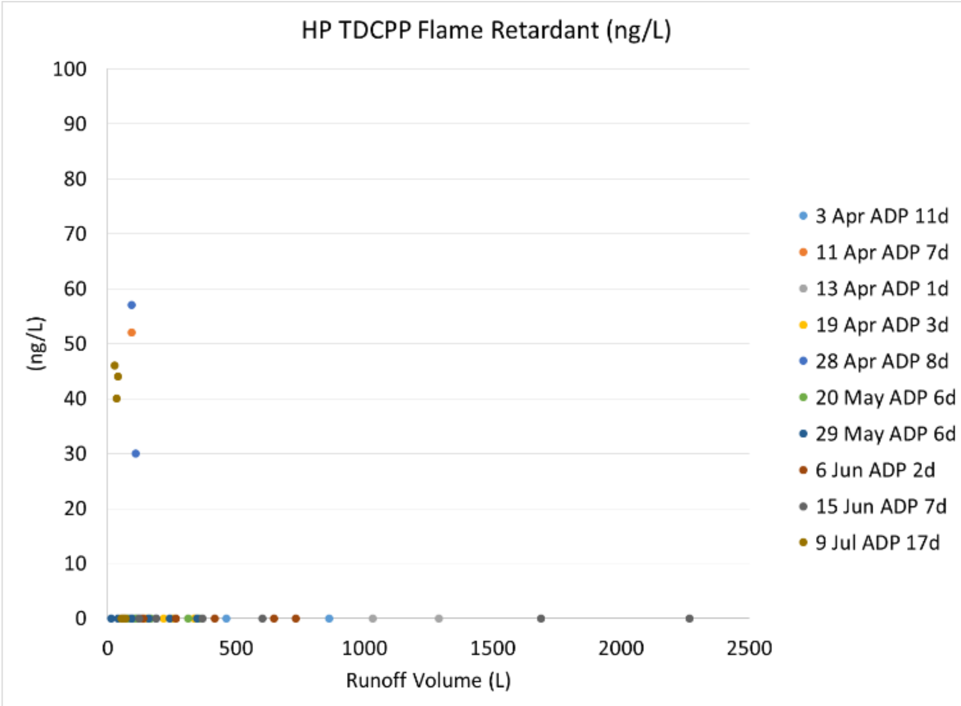

Figure 24. TDCPP concentrations from HP.

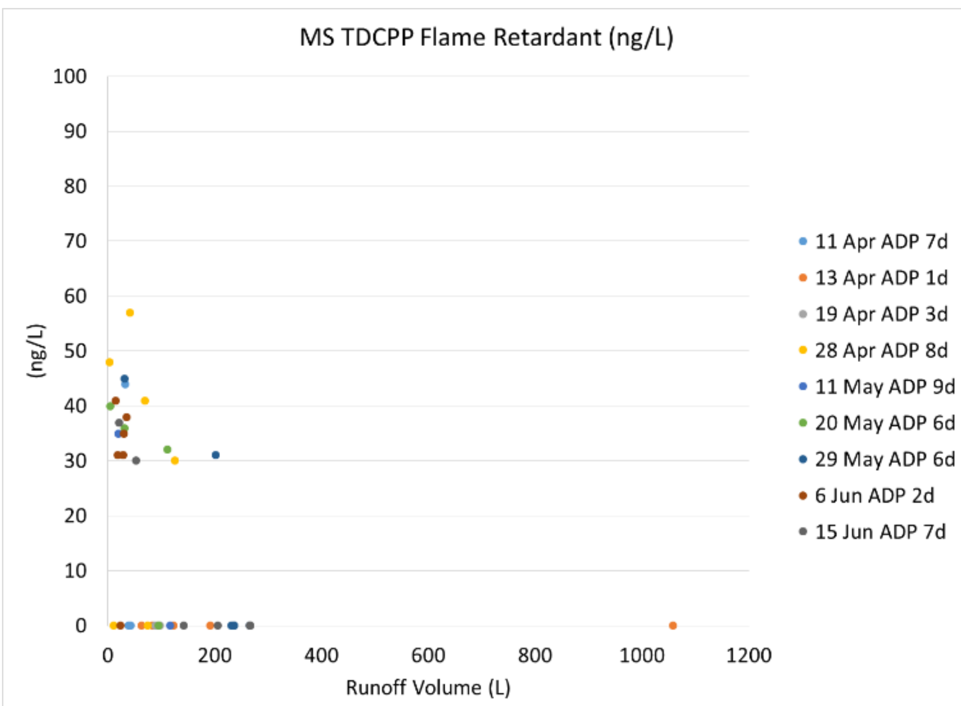

Figure 25. TDCPP concentrations from MS.

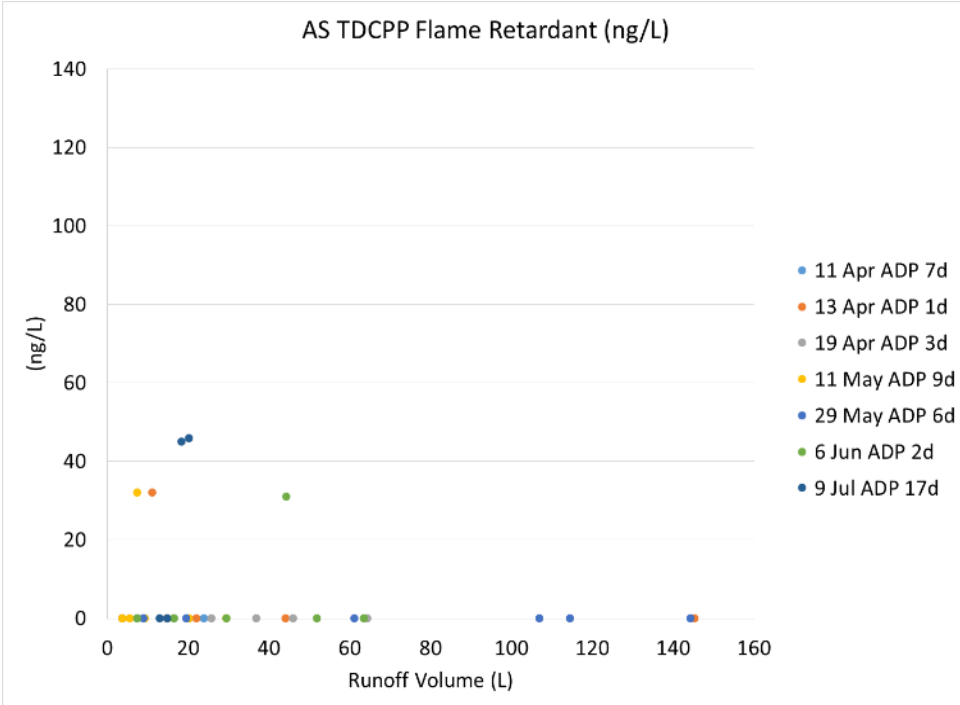

Figure 26. TDCPP concentrations from AS.

Higher concentrations of TCEP were found in the runoff samples than TDCPP. Presence of the flame retardants in samples from all three roofs suggests atmospheric deposition as the cause. However, one may also argue that TCEP can be found in the AS material itself and would explain why AS had higher concentrations.

Pyrethroid Insecticides

Runoff samples were analyzed for the presence of three pyrethroid insecticides; bifenthrin, cypermethrin, and lambda cyhalothrin. The reporting limits of the pyrethroid insecticides are shown in Table 8.

Table 8. Reporting limits of pyrethroid insecticides.

Reporting Limit (ng/L)	Pyrethroid Insecticides
10	Bifenthrin
90	Cypermethrin
10	Lambda Cyhalothrin

No concentrations of the three pyrethroid insecticides were found in HP runoff above the reporting limit except for on the 9 July storm event. Results are reported below in Table 9.

Table 9. Pyrethroid insecticide concentrations reported from July 9 HP samples.

Sample Date	Sample Time	Runoff Volume (L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhalothrin (ng/L)
9-Jul-12	19:42	26.0	<10	<90	<10
9-Jul-12	19:45	35.1	<10	<90	<10
9-Jul-12	19:48	39.0	<10	<90	12
9-Jul-12	19:51	53.4	<10	<90	<10
9-Jul-12	19:54	65.0	<10	<90	<10
9-Jul-12	20:08	69.9	<10	<90	<10

A similar situation was found for MS runoff. Only two storm events, 20 May and 29 May, showed concentrations for the pyrethroid insecticides above the reporting limit. Results are reported below in Tables 10 and 11.

Table 10. Pyrethroid insecticide concentrations reported from 20 May MS samples.

Sample Date	Sample Time	Runoff Volume (L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhalothrin (ng/L)
20-May-12	1:13	4	<10	<90	<10
20-May-12	1:16	31	<10	<90	<10
20-May-12	1:19	95	<10	<90	<10
20-May-12	1:22	111	<10	<90	157
20-May-12	1:44	111	<10	<90	<10
20-May-12	3:27	111	<10	<90	<10

Table 11. Pyrethroid insecticide concentrations reported from 29 May MS samples.

Sample Date	Sample Time	Runoff Volume (L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaolthrin (ng/L)
29-May-12	20:24	31	<10	<90	117
29-May-12	20:30	202	<10	<90	<10
29-May-12	20:33	231	<10	<90	<10
29-May-12	20:36	236	<10	<90	<10
29-May-12	21:12	237	<10	<90	<10
29-May-12	22:44	265	<10	<90	27

No concentrations were found in AS runoff for the bifenthrin and cypermethrin pyrethroid insecticides above the reporting limit. However, concentrations for lambda cyhalotrhin were found in AS runoff on several events (11 April, 11 May, 29 May, and 9 July) and are shown in Figure 27.

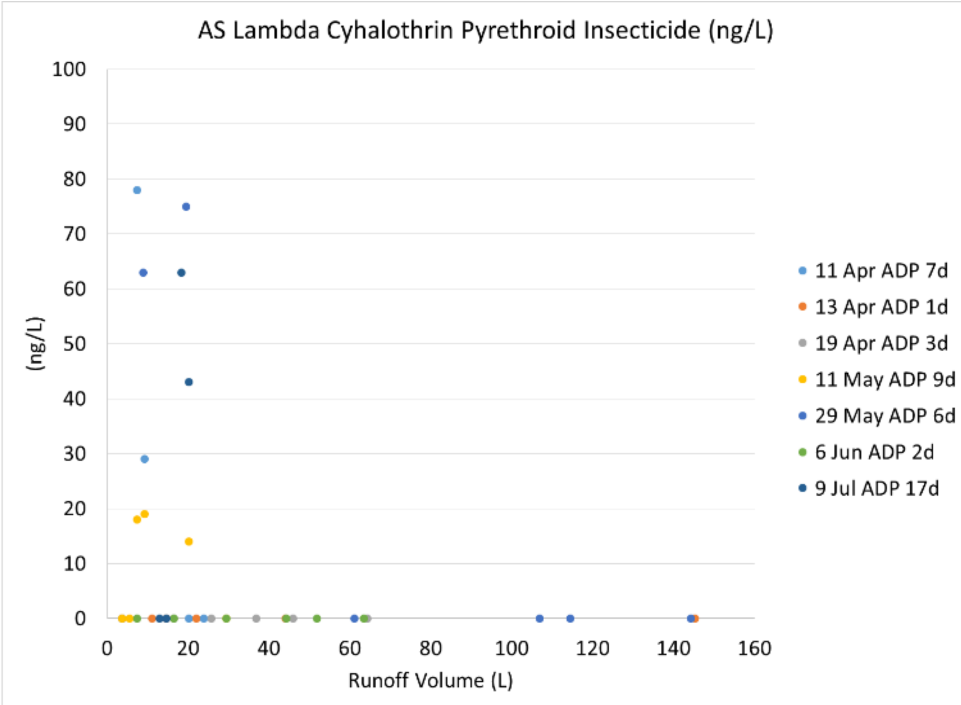

Figure 27. Lambda cyhalothrin concentrations found in AS runoff.

Reasons as to why concentrations of lambda cyhalothrin were seen in AS runoff more than in HP or MS runoff could be due to the rough texture of the AS roof and it's lower proximity to the ground compared to HP and MS. The roughness of the roofing material would allow the lambda-cyhalothrin-bounded particles to stick to the roof more easily than the HP or MS roofs. Also, if the insecticide were being applied at the ground level located next to AS and MS, then there is a chance some of the spray was blown onto the AS roof by the wind.

Conductivity

Figures 28 to 30 show conductivity concentrations seen from the discrete-sampling events. Conductivity concentrations are never higher than the recommended limit, 750 µs/cm, for irrigation water to not have any limitations (Bauder et al., 2011). There is an exponentially decreasing trend in conductivity levels seen in the samples as the volume of runoff increases for all three roofs. AS had the highest concentration, followed by MS, then HP.

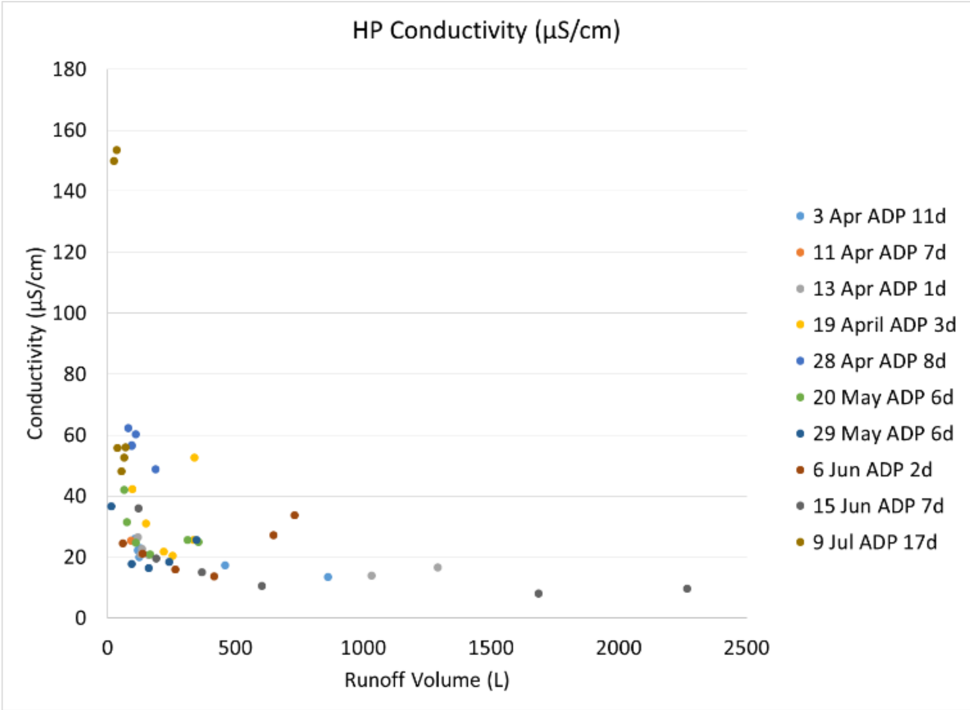

Figure 28. Conductivity results from HP.

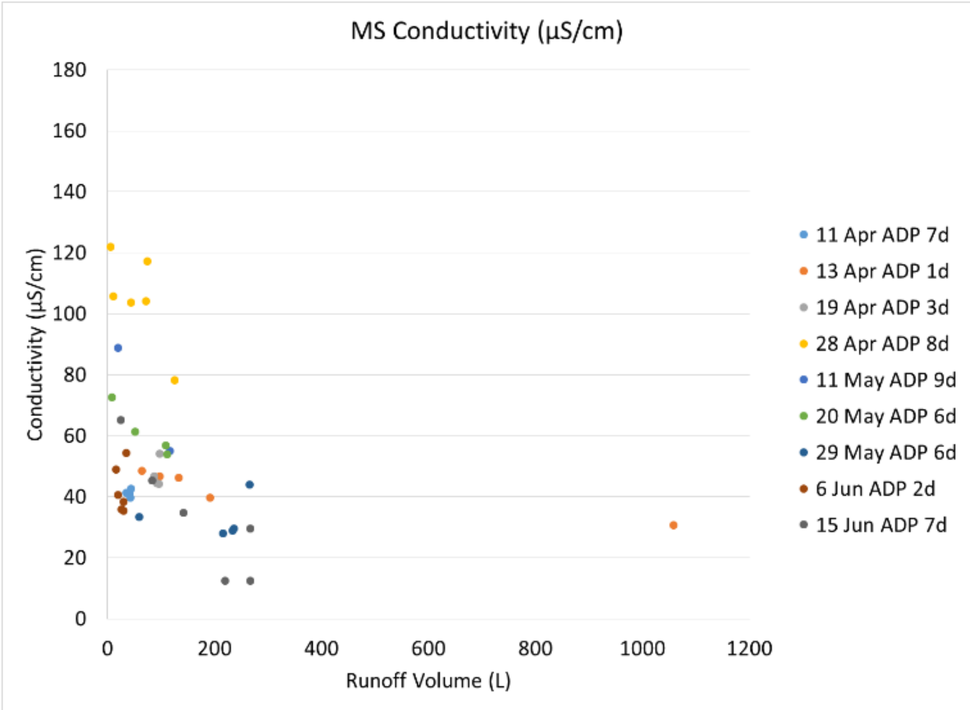

Figure 29. Conductivity results from MS.

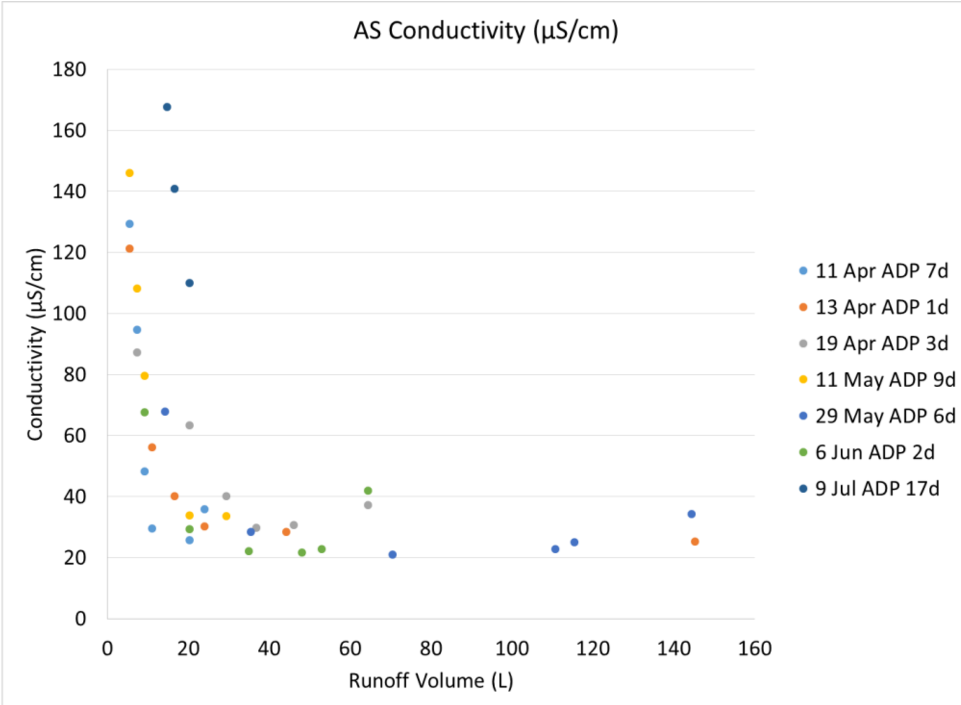

Figure 30. Conductivity results from AS.

Nitrate-N

All three roofs showed concentrations of Nitrate-N in the sampled runoff (Figures 31 to 33). Concentrations were higher initially for all three roofs, followed by a gradual decline as the runoff volume increased. Nitrate-N concentrations were a result of atmospheric deposition.

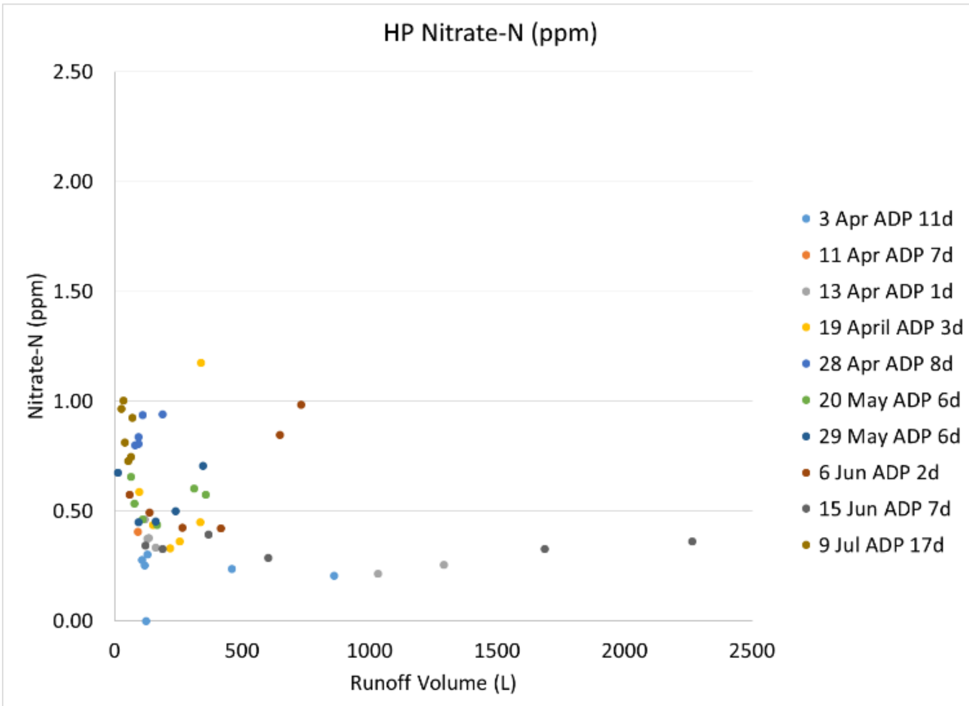

Figure 31. Nitrate-N results for HP.

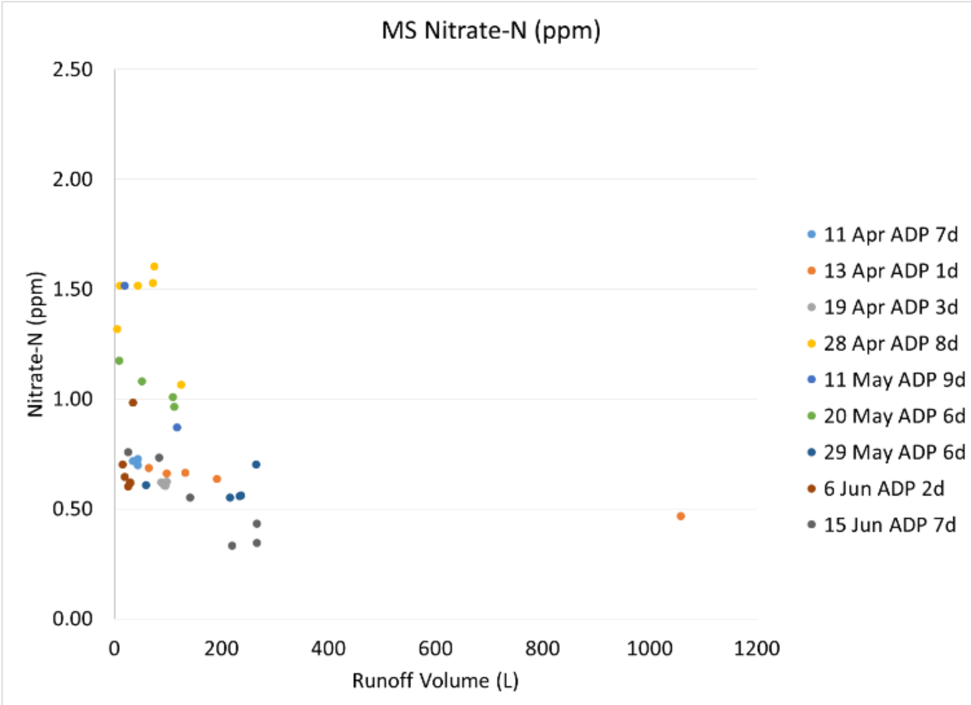

Figure 32. Nitrate-N results for MS.

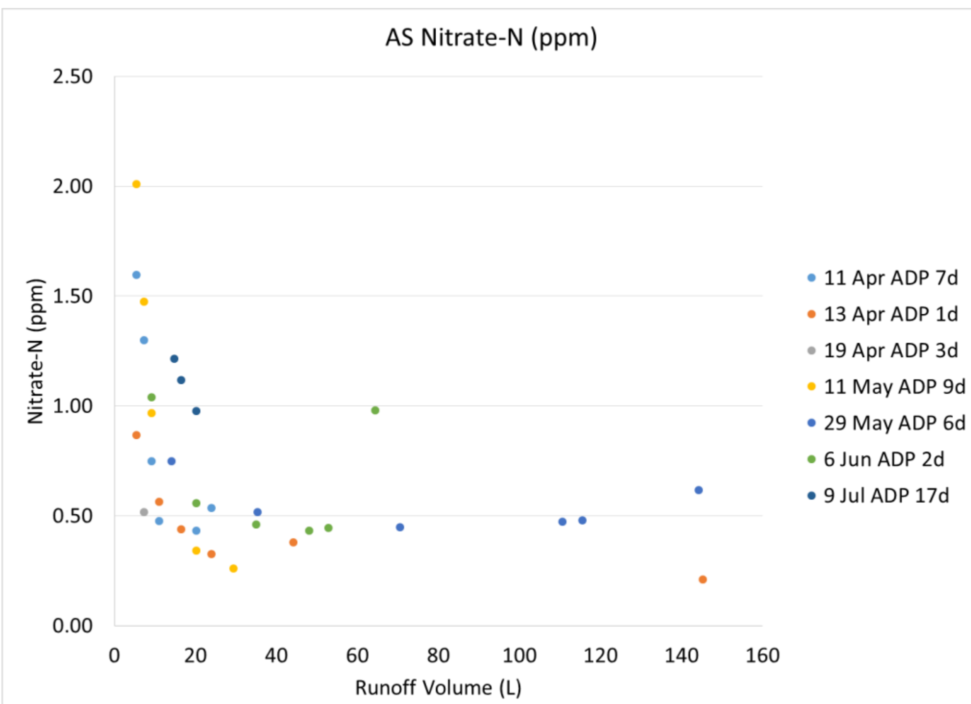

Figure 33. Nitrate-N results for AS.

Bacteria

For the bacteria testing, Ward Laboratories processed a 100 mL and 1 mL sample dilution for each sample. If the 100 mL sample had a reading <2419 col/100 mL, then that value was reported; if the value was greater than 2419, the 1 mL dilution reading was used as long as it too was <2419 col/100 mL. If neither reading was <2419 (the MPN method fails when above 2419), then TNTC was reported for the sample. Figures 34 to 39 show all the bacteria results that did not result in a Too Numerous To Count (TNTC) reading.

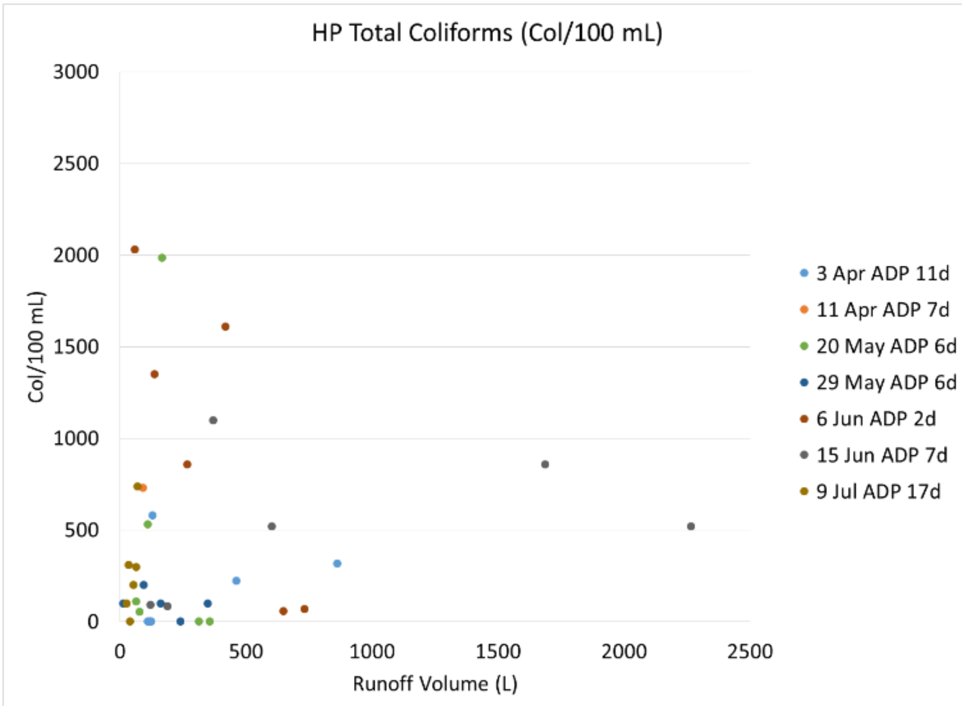

Figure 34. Total coliforms results for HP.

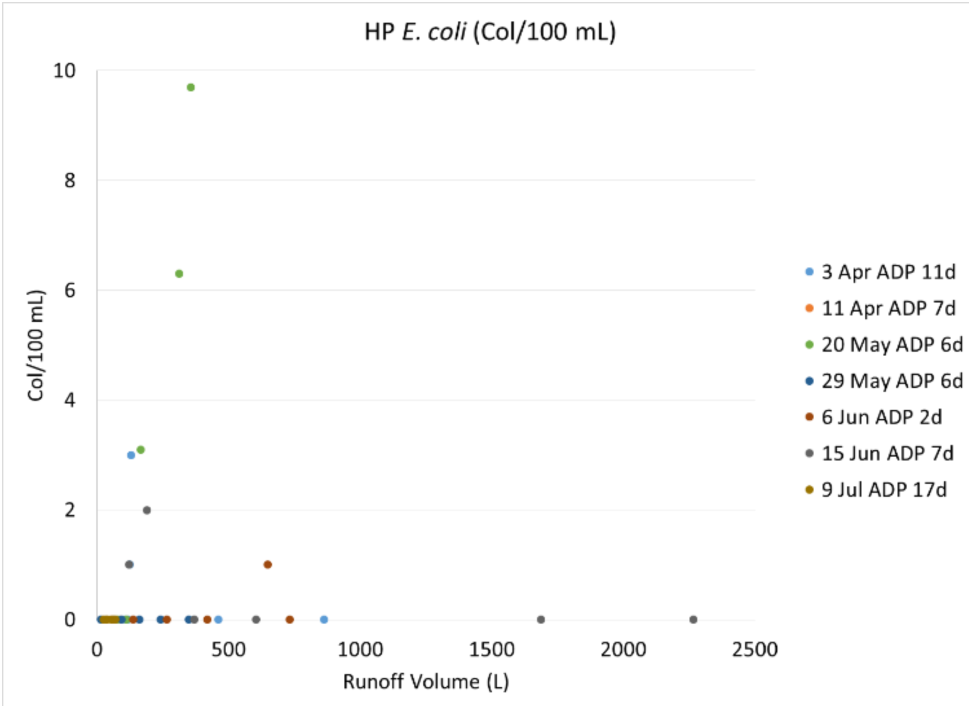

Figure 35. *E. coli* results for HP.

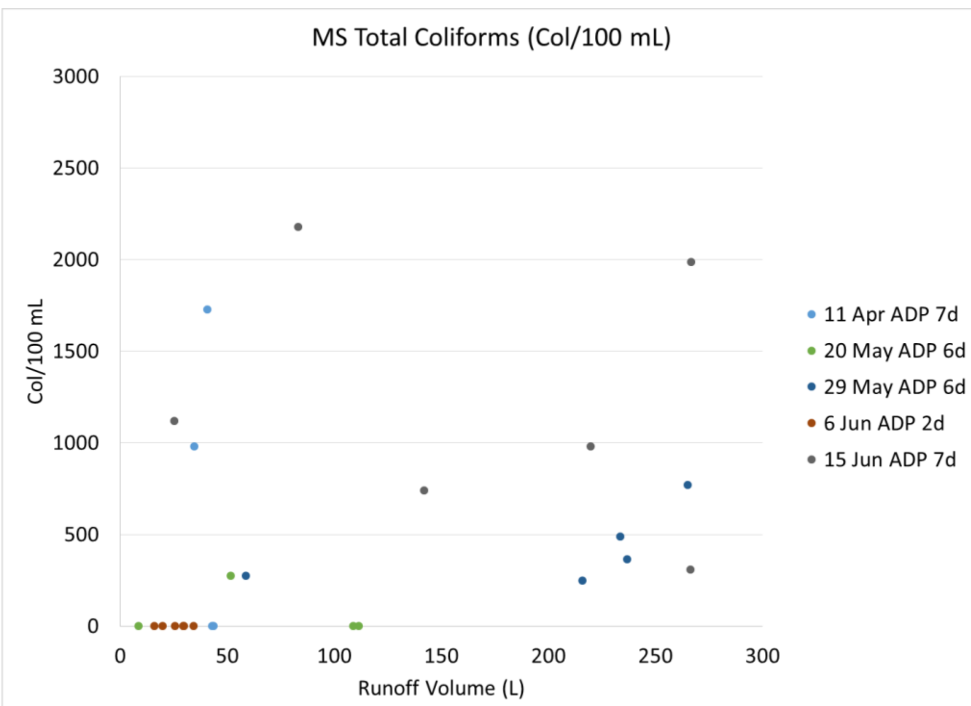

Figure 36. Total coliforms results for MS.

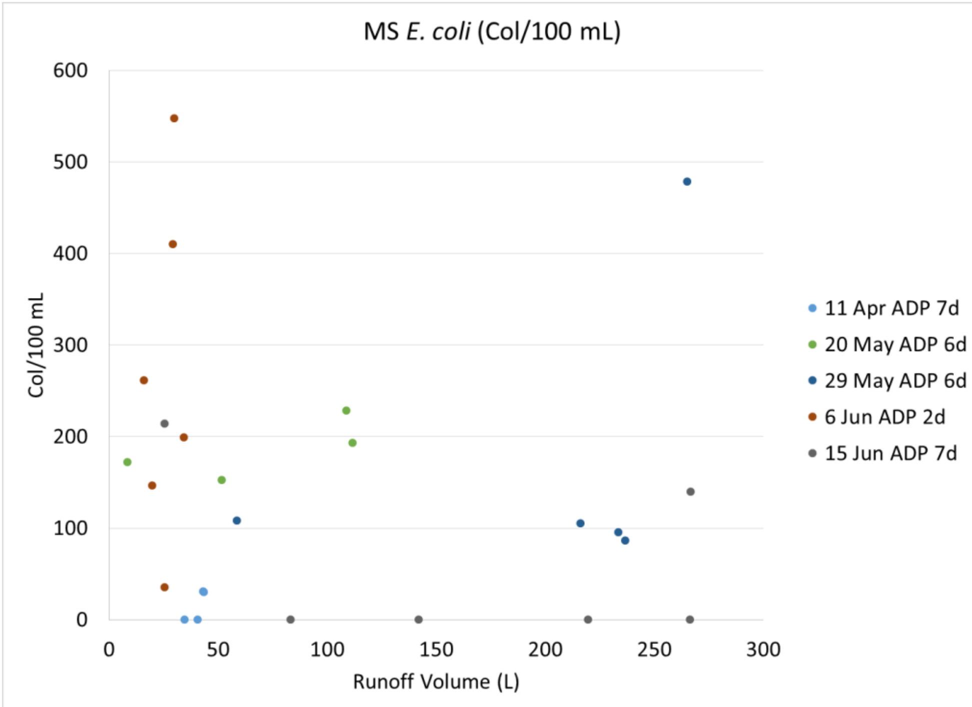

Figure 37. *E. coli* results for MS.

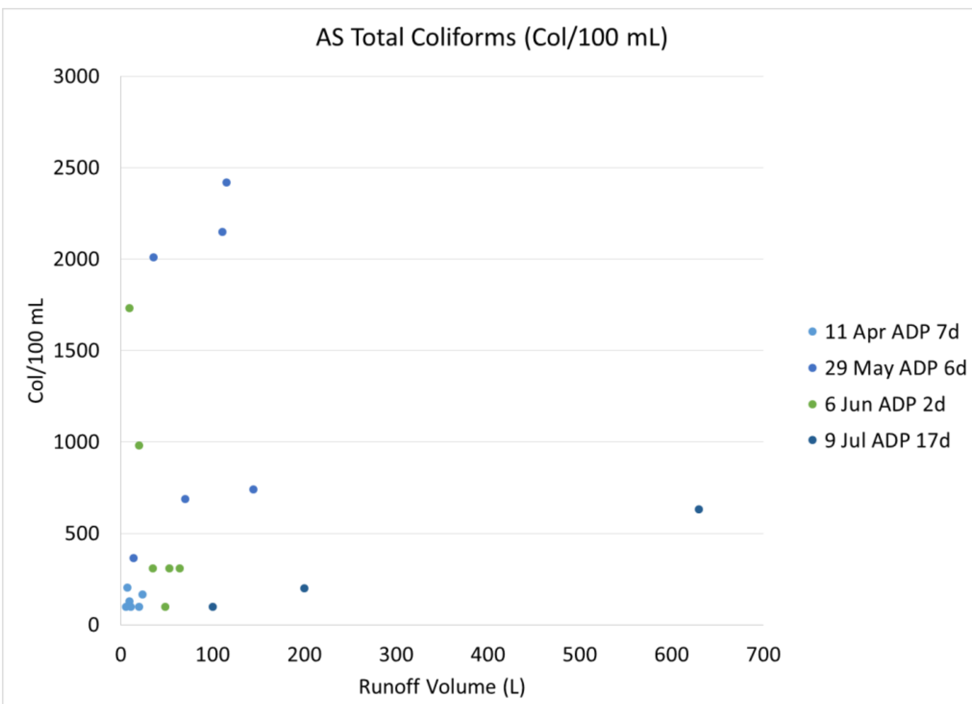

Figure 38. Total coliforms results for AS.

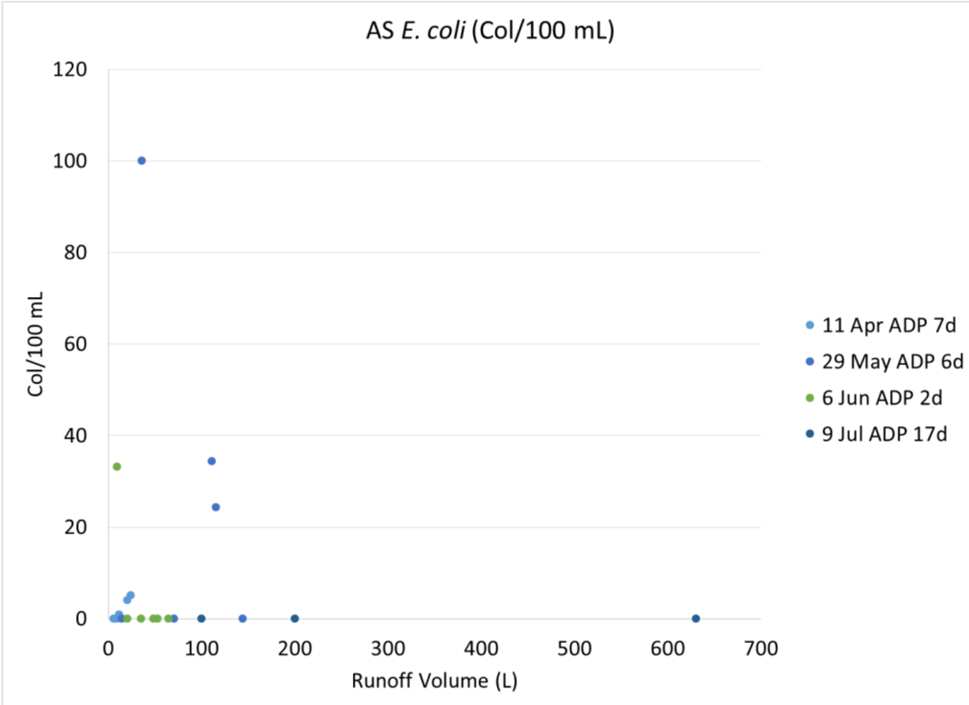

Figure 39. *E. coli* results for AS.

There was no noticeable trend with the total coliforms and *E. coli* results for each building in regards to runoff volume. MS did have the highest counts of *E. coli* out of the three roof types. The results from the bacteria testing suggest that if the harvested water was to be used for any potable purposes, then it would need to be treated first, as bacteria concentrations were found in the runoff at both the beginning and towards the end of the storm event.

Total Suspended Solids

Results from the TSS analysis are shown in Figures 40 to 42. Of the three roofs, AS had the highest TSS concentrations in its runoff (Figure 42), followed by MS (Figure 41), with HP having the lowest TSS concentrations (Figure 40). AS has a rougher texture than MS and HP, which could lead to more particles being trapped on the roof's surface prior to a storm event. Also, AS was a relatively new roof, having only been installed for a year, and particles from the roofing material alone could have also been washed off along with any dust that had been deposited atmospherically.

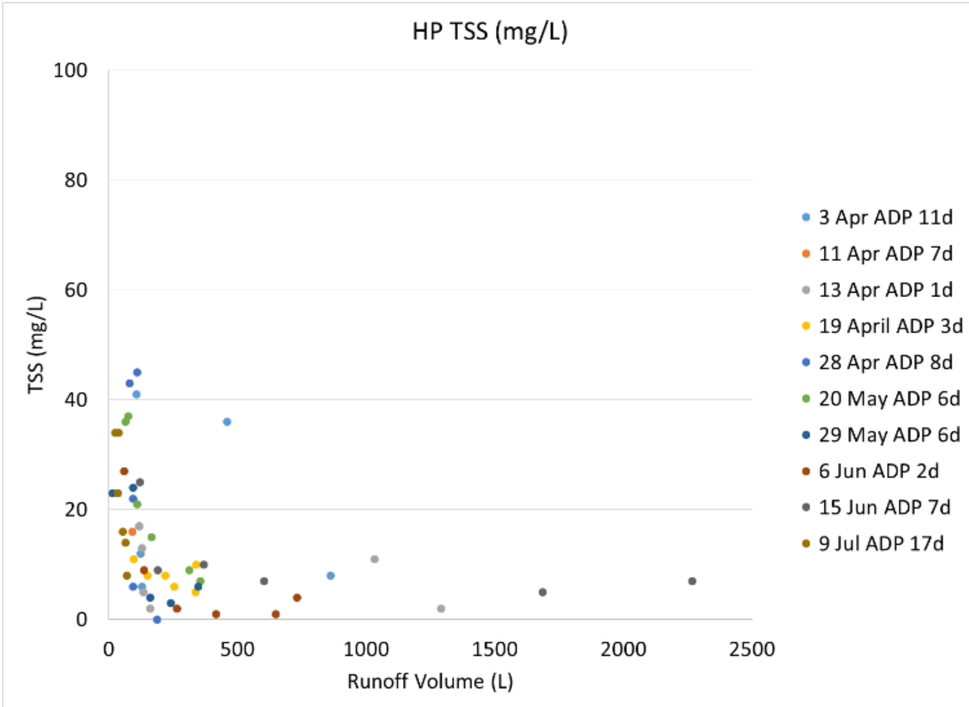

Figure 40. TSS results for HP.

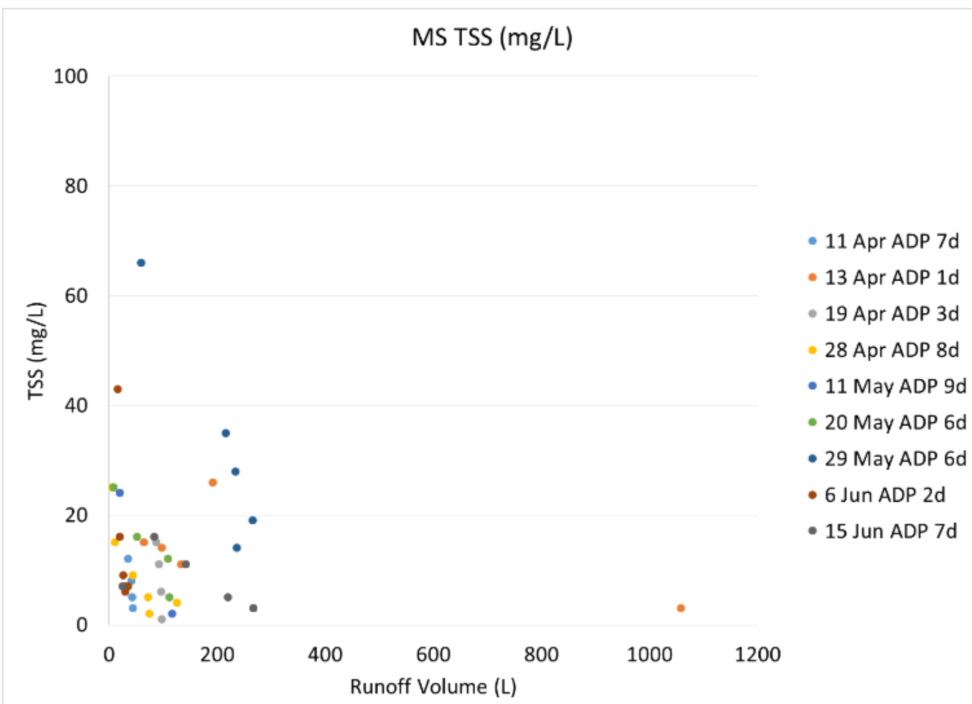

Figure 41. TSS results for MS.

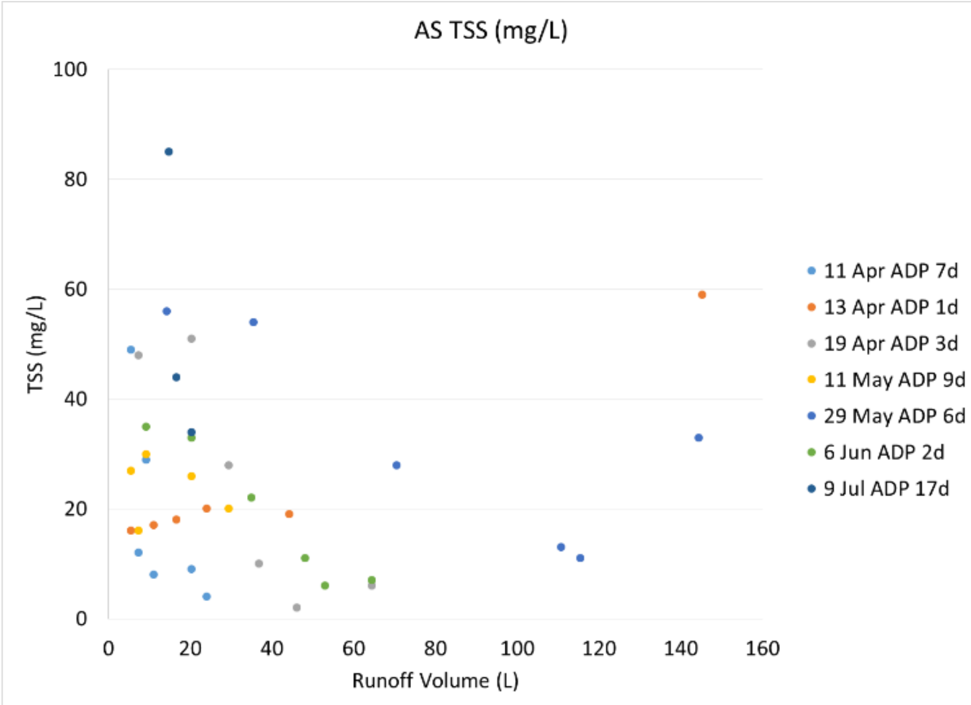

Figure 42. TSS Results for AS.

While MS had a higher TSS concentration than HP had reported, HP had higher TSS values than MS throughout most of the samples. As was mentioned earlier, MS had a poor harvesting efficiency, which could have an impact on the TSS results, i.e. not all of the TSS were being washed off. HP has a very slick roof, which would allow for the dust to be more easily washed off. The TSS results appear to line up well with the PAH concentrations in the runoff. This is due to the fact that the PAHs themselves adhere to particles and the particles are being accounted for in the TSS concentrations.

Continuous Monitoring

Continuous data was recorded using water-quality sondes that were placed in the downspouts for all three roofs. The temperature, conductivity, and turbidity was recorded throughout each storm event at one-minute intervals. Of the two main parameters, the conductivity and turbidity, only the conductivity data proved to be useful. The turbidity readings recorded by the sondes were constantly interrupted by air bubbles that occurred in the downspout either due to water entering the downspout or from the pumping action when samples were being collected by the Isco sampler, as was therefore considered unreliable data. Figures 43 to 45 show the continuous conductivity data from each of the storms sampled for HP, MS, and AS.

The storm events that resulted in extremely high conductivity concentrations were graphed on the right side of the figure. These storm events were S10 and S11 for HP; S9, S10, and S11 for MS; and S11 for AS. This was done so to easily compare these results with results from storms that had lower conductivity concentrations. The x-axis shows the time from the start of the storm event, in minutes. This allowed for an easier comparison of the data to be performed. For HP and MS, it appears that the majority of the storms' conductivity levels started to level out by 20 minutes into the storm event; AS data generally started to level out between 10-15 minutes after the storm event started.

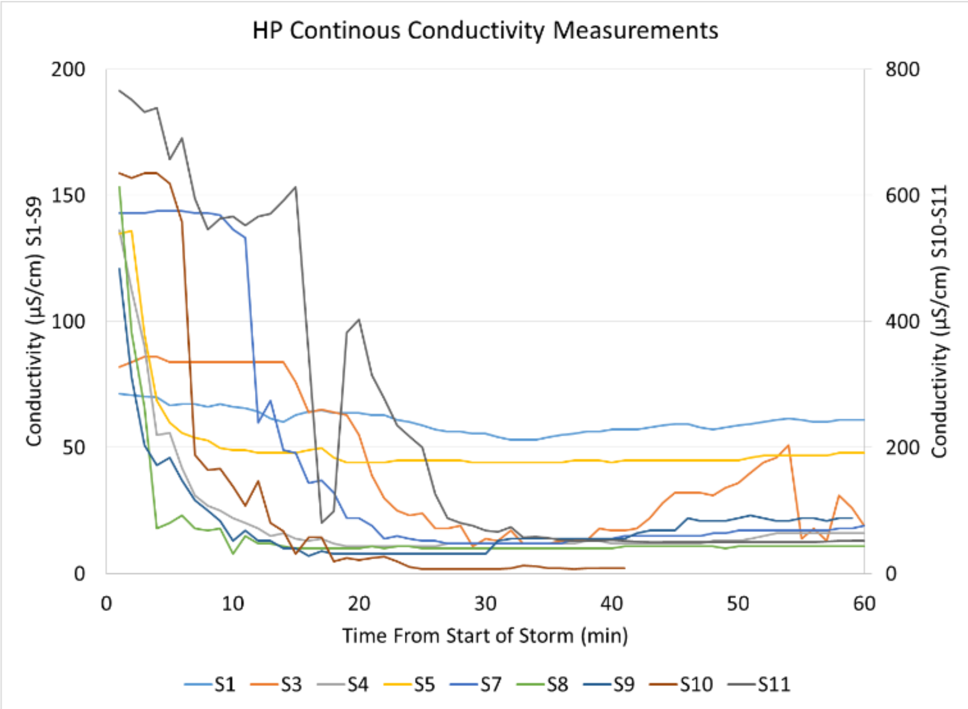

Figure 43. Continuous conductivity data for HP.

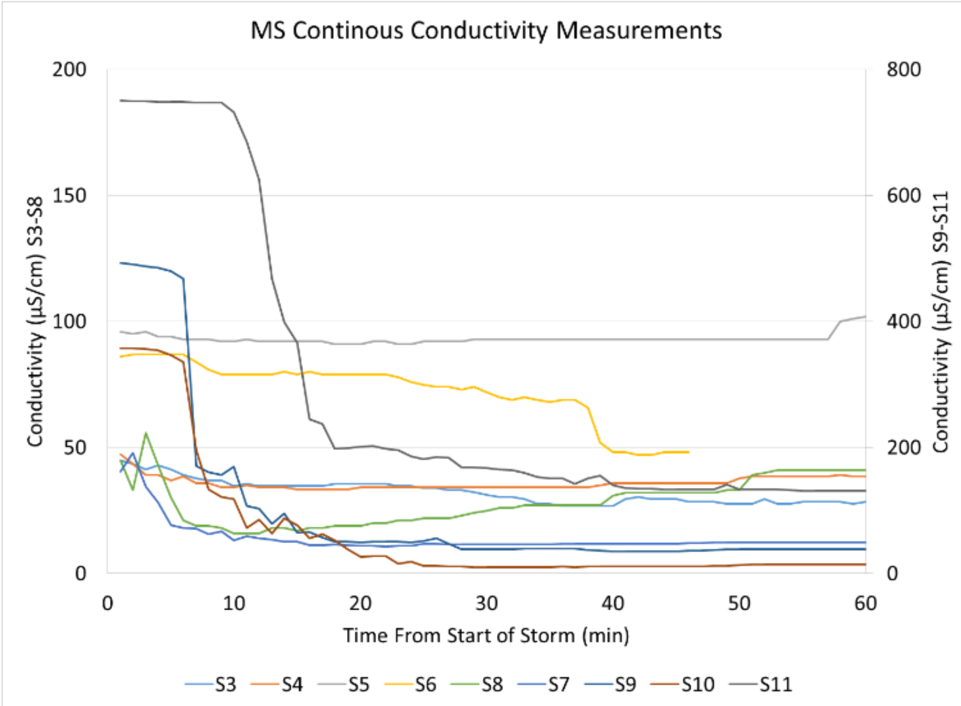

Figure 44. Continuous conductivity data for MS.

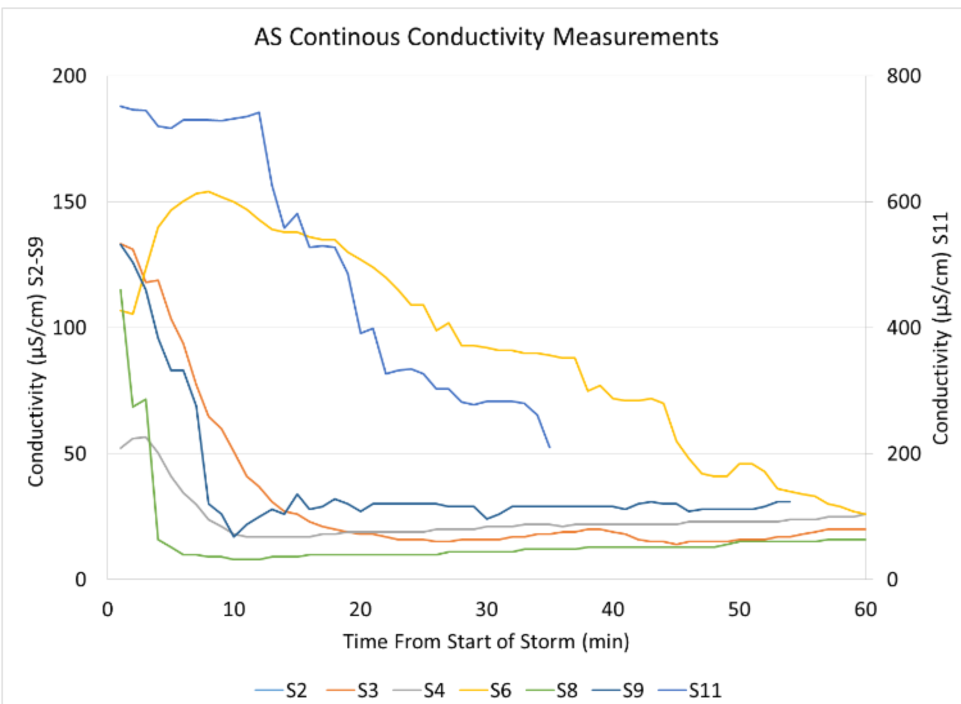

Figure 45. Continuous conductivity data for AS.

Agronomy Farm Rainfall Simulations

Tables 13 to 15 provide information on the volume of water each of the 6 samples collected during the rainfall simulations contained. The first five samples were all collected in 2 L bottles while the sixth sample collected the remaining runoff for the rest of the simulation. As the three simulations varied in rainfall intensities, and each roof produced different amounts of runoff based on the roofing materials, the sixth sample varies between each roof. Table 16 gives a summary on what the average volume was for the sixth sample from each rainfall simulation based on roofing material. Results show averages of samples 1-6 for all 6 roofs per roofing material.

Table 13. 64 mm/hr intensity runoff sample volumes.

Sample	Samples 1-5 (L)	Sample 6 (L)	Total Volume Collected (L)
A1	10.0	23.0	33.0
A2	10.0	23.3	33.3
A3	10.0	13.0	23.0
A4	10.0	21.7	31.7
A5	10.0	23.8	33.8
A6	10.0	18.8	28.8
M1	10.0	22.3	32.3
M2	10.0	24.2	34.2
M3	10.0	17.9	27.9
M4	10.0	21.8	31.8
M5	10.0	26.1	36.1
M6	10.0	26.2	36.2
C1	10.0	17.9	27.9
C2	10.0	16.4	26.4
C3	10.0	15.1	25.1
C4	10.0	11.7	21.7
C5	10.0	15.9	25.9
C6	10.0	17.8	27.8

Table 14. 38 mm/hr intensity runoff sample volumes.

Sample	Samples 1-5 (L)	Sample 6 (L)	Total Volume Collected (L)
A1	10.0	20.3	30.3
A2	10.0	15.1	25.1
A3	10.0	12.2	22.2
A4	10.0	7.12	17.1
A5	10.0	21.0	31.0
A6	10.0	6.98	17.0
M1	10.0	20.6	30.6
M2	10.0	20.1	30.1
M3	10.0	15.8	25.8
M4	10.0	6.67	16.7
M5	10.0	13.4	23.4
M6	10.0	10.3	20.3
C1	10.0	10.8	20.8
C2	10.0	8.53	18.5
C3	10.0	11.7	21.7
C4	10.0	11.8	21.8
C5	10.0	15.0	25.0
C6	10.0	8.3	18.3

Table 15. 28 mm/hr intensity runoff sample volumes.

Sample	Samples 1-5 (L)	Sample 6 (L)	Total Volume Collected (L)
A1	10.0	9.71	19.7
A2	10.0	8.44	18.4
A3	10.0	9.25	19.3
A4	10.0	7.76	17.8
A5	10.0	8.53	18.5
A6	10.0	6.76	16.8
M1	10.0	9.57	19.6
M2	10.0	11.3	21.3
M3	10.0	9.57	19.6
M4	10.0	N/A	10.0
M5	10.0	6.71	16.7
M6	10.0	7.08	17.1
C1	10.0	5.35	15.4
C2	10.0	10.5	20.5
C3	10.0	7.71	17.7
C4	10.0	10.0	20.0
C5	10.0	6.49	16.5
C6	10.0	8.57	18.6

Table 16. Summary of the average composite sample for each roof per intensity.

ROOFING MATERIAL	INTENSITY (MM/HR)	AVERAGE COMPOSITE SAMPLE VOLUME (L)
ASPHALT SHINGLE	68	20.6
METAL	68	23.1
CLAY TILE	68	15.8
ASPHALT SHINGLE	38	13.8
METAL	38	14.5
CLAY TILE	38	11.0
ASPHALT SHINGLE	28	8.4
METAL	28	8.8
CLAY TILE	28	8.1

PAHs

From the rainfall simulations, only the samples 1-3 and sample 6 were analyzed for the presence of the organics of interests. Results for PAH concentrations from all of the rainfall simulations are shown in Figures 53 to 61.

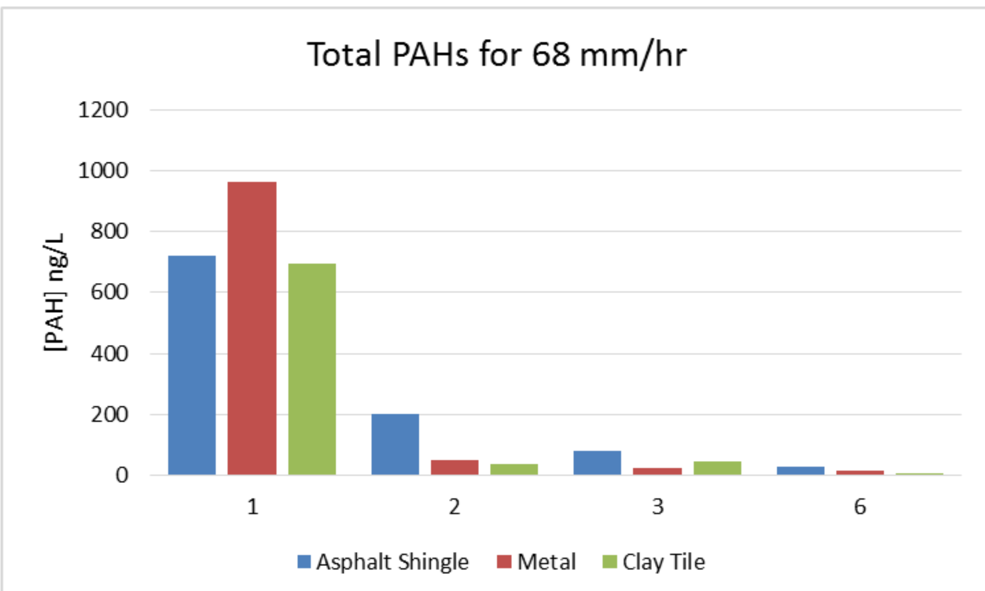

Figure 53. Total PAHs for the high intensity rainfall simulation.

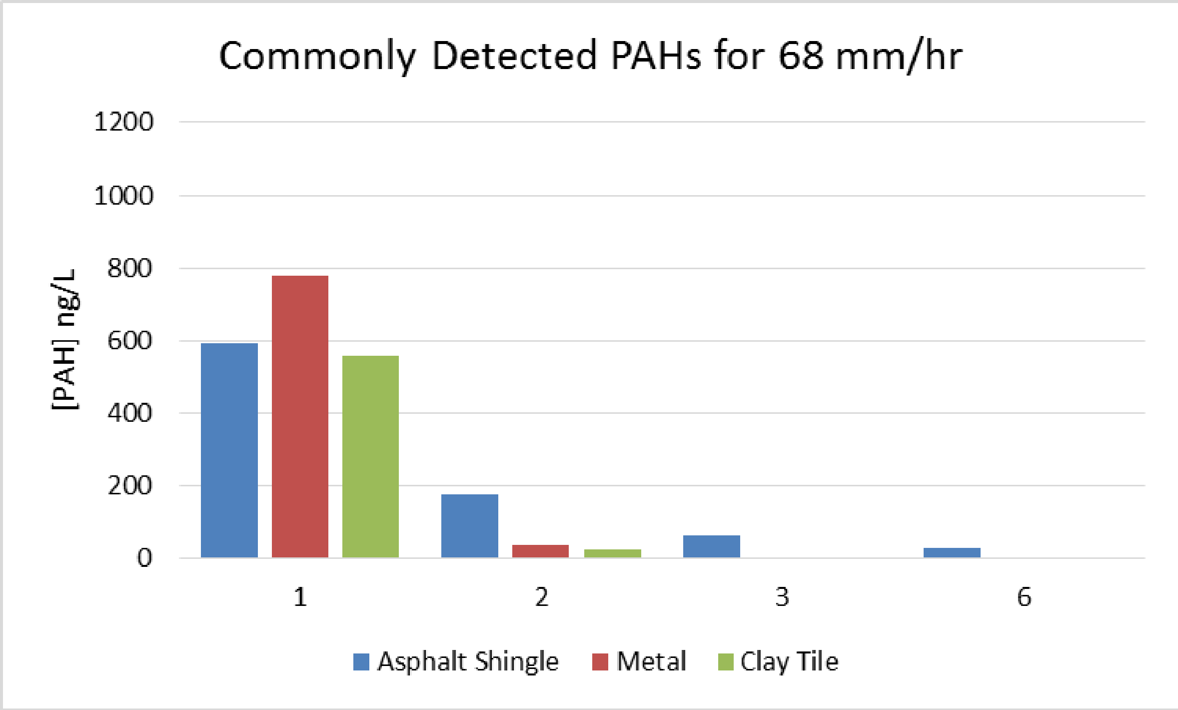

Figure 54. Commonly detected PAHs for the high intensity rainfall simulation.

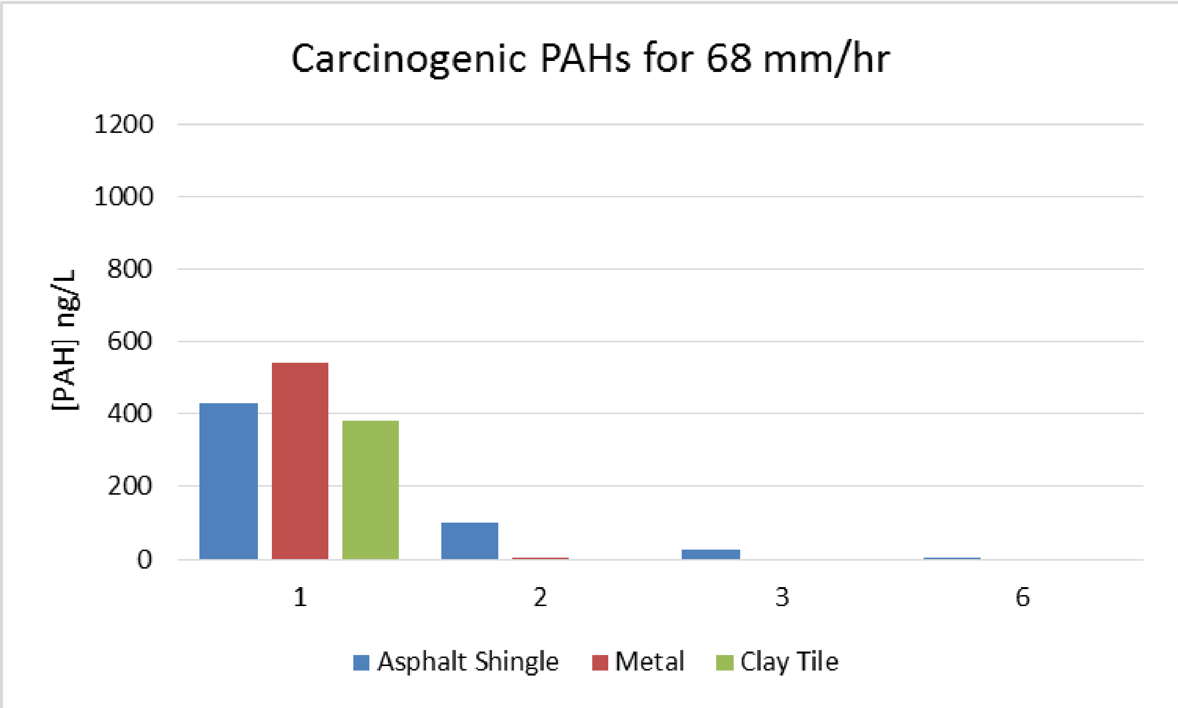

Figure 55. Carcinogenic PAHs for the high intensity rainfall simulation.

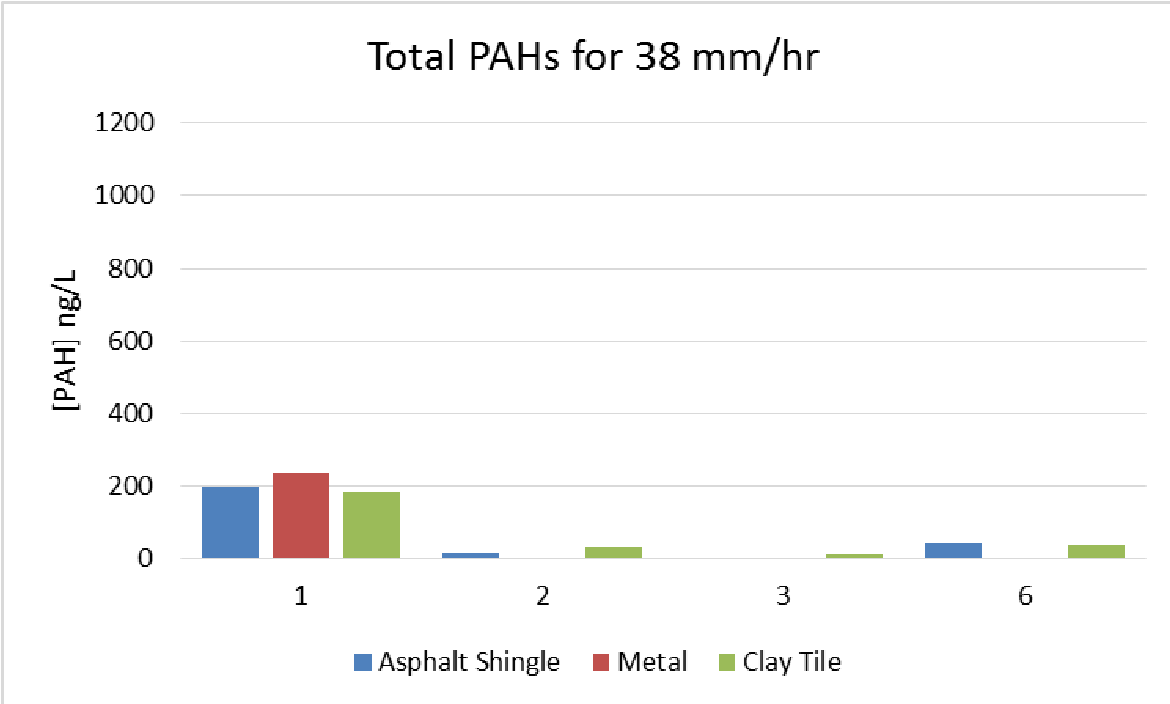

Figure 56. Total PAHs for the medium intensity rainfall simulation.

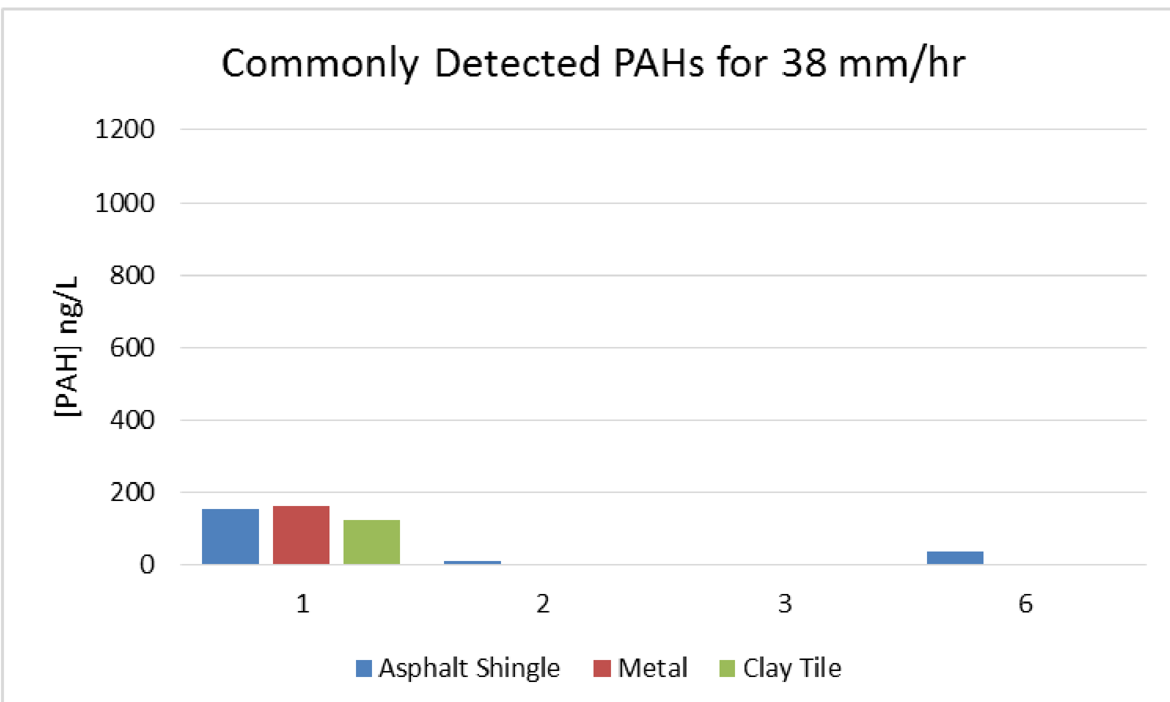

Figure 57. Commonly detected PAHs for the medium intensity rainfall simulation.

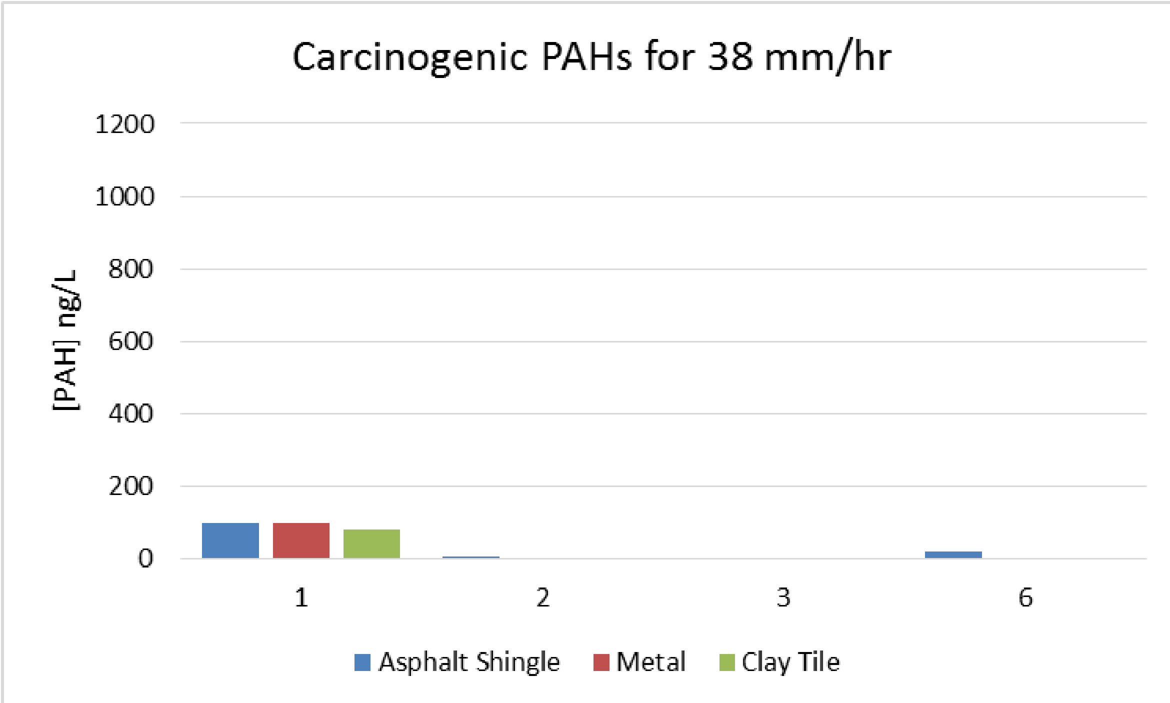

Figure 58. Carcinogenic PAHs for the medium intensity rainfall simulation.

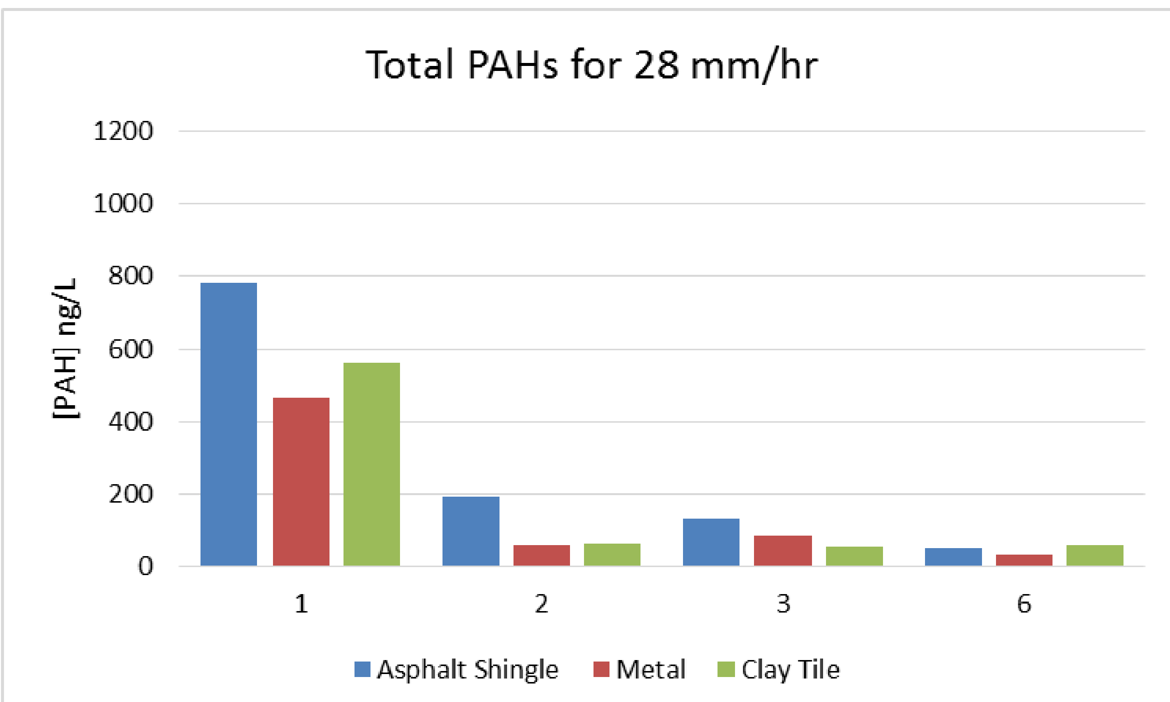

Figure 59. Total PAHs for the low intensity rainfall simulation.

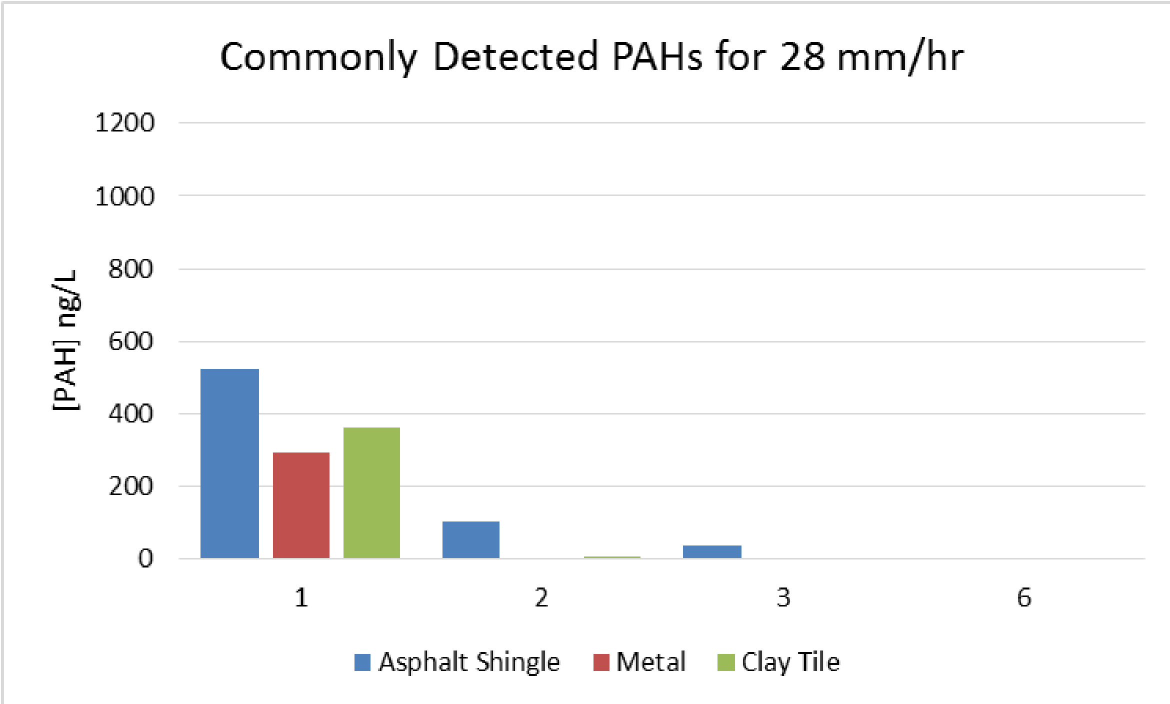

Figure 60. Commonly detected PAHs for the low intensity rainfall simulation.

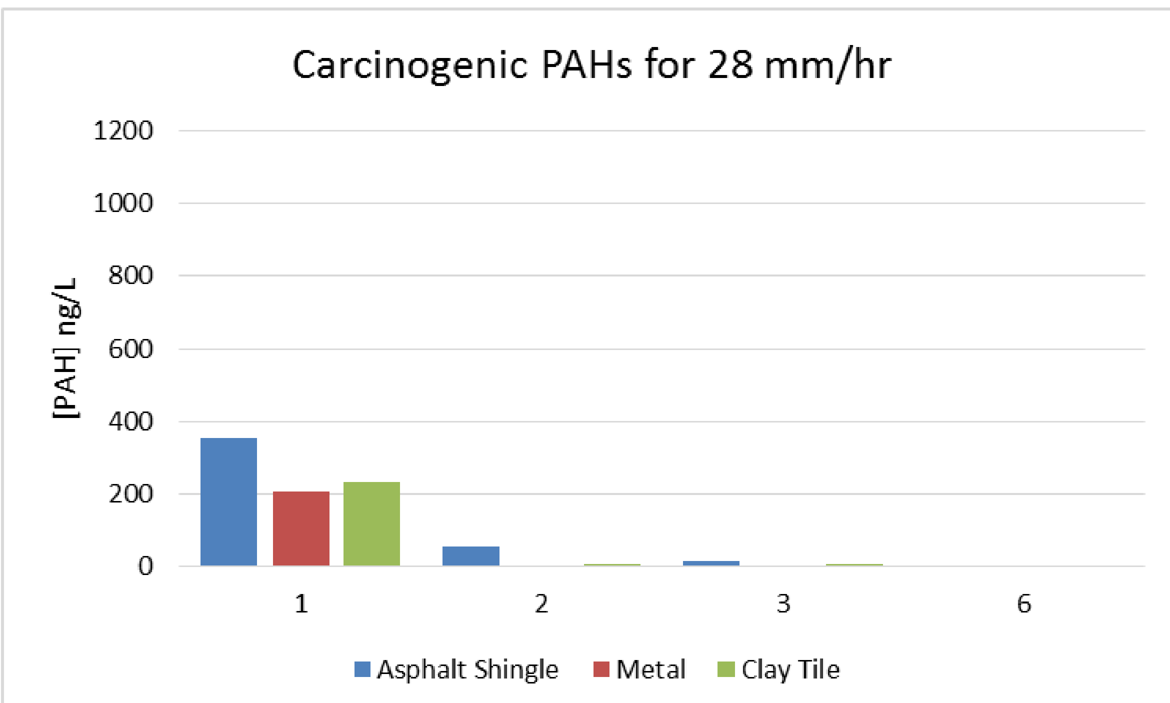

Figure 61. Carcinogenic PAHs for the low intensity rainfall simulation.

For all of the rainfall simulation, the PAH concentrations drastically reduce between the first sample and the second sample. It was hypothesized that the asphalt shingle roofs would have the highest concentrations; however, the metal roofs had the highest concentrations of PAHs for the high and medium intensity simulations while the asphalt shingle roofs had the highest concentrations for the low intensity simulation. The metal roofs could have attracted more particles with an electrical charge from the metal, explaining why it had higher PAH concentrations than the asphalt shingles for two of the simulations. Also noted was the fact that the asphalt shingle roofs had a longer retention of PAHs in the runoff. This is most likely due to the fact that the asphalt shingles contain PAHs in their makeup.

It was expected that the medium intensity simulation would have higher PAH concentrations than the low intensity simulation. However, when conducting the medium intensity simulation in November, there was frost on all of the roofs that started to melt prior to starting the simulations. It is believed that with the melting frost, the roofs were pre-washed prior to collecting samples.

The first two samples correspond to the first 4 L of runoff from the roofs and contained the majority of the PAHs seen in the samples. Given that the roofs were each 1.67 m^2 in catchment area, if the first 4 L of runoff were diverted, that would equate to diverting 2.4 L/m^2 (5.9 gal/100 ft^2).

Flame Retardants

Figures 62 to 65 show results for TCEP and TDCPP concentrations from the rainfall simulations. TCEP was hardly found in the runoff samples; trace amounts were found from the high intensity storm (Figure 62) in the first 2 L of runoff but no traces were found from the medium and low intensity simulations. These results contradict the findings from the OSU-OKC sample collection where TCEP was seen more in runoff samples than TDCPP. In the OSU-OKC results, it was suggested that TCEP came from the asphalt shingles themselves whereas from the controlled rainfall simulations, there were no traces of TCEP in the asphalt shingle runoff.

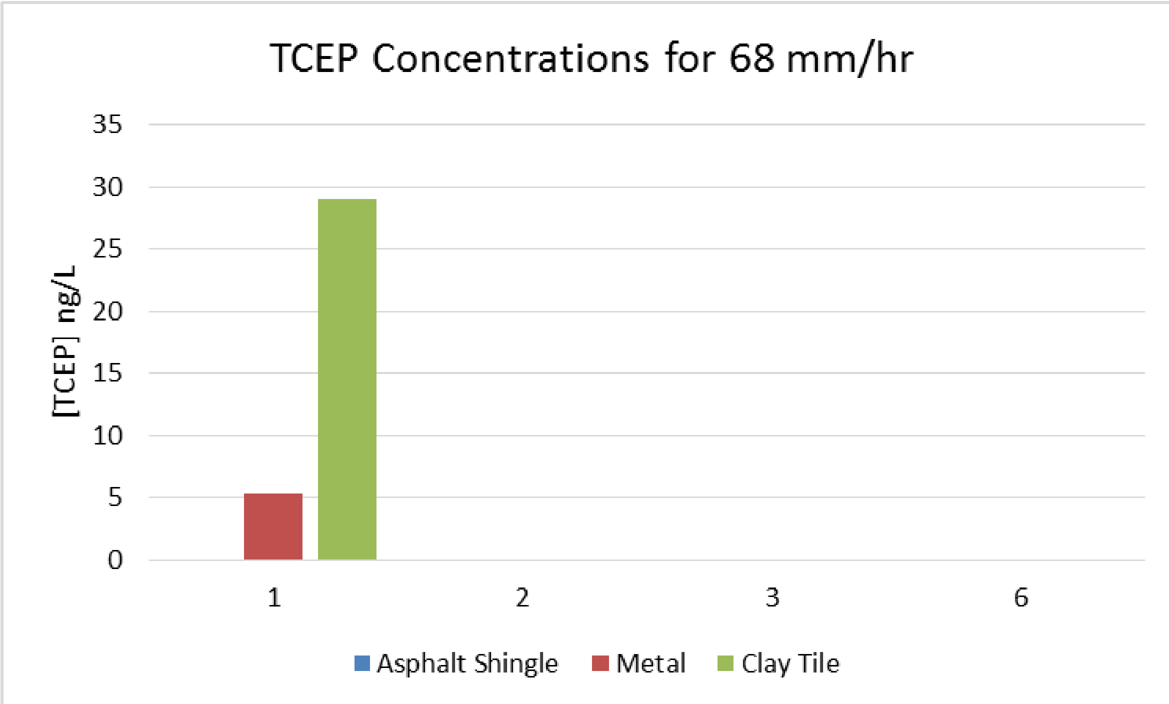

Figure 62. TCEP concentrations from the high intensity simulation.

High levels of TDCPP were seen in all of the runoff samples from the high intensity simulation, peaking at 4 L of runoff, and trace amounts were seen in the medium and lower simulations. The high intensity simulation was performed during the month of August while the medium intensity was performed in November and the low intensity performed in February. Results seen from the high intensity simulation could be seasonally related if the flame retardant was found in the runoff due to atmospheric deposition. TDCPP could have been more easily released into the environment during the summer months due to the heat and is why we saw higher concentrations in the August simulation.

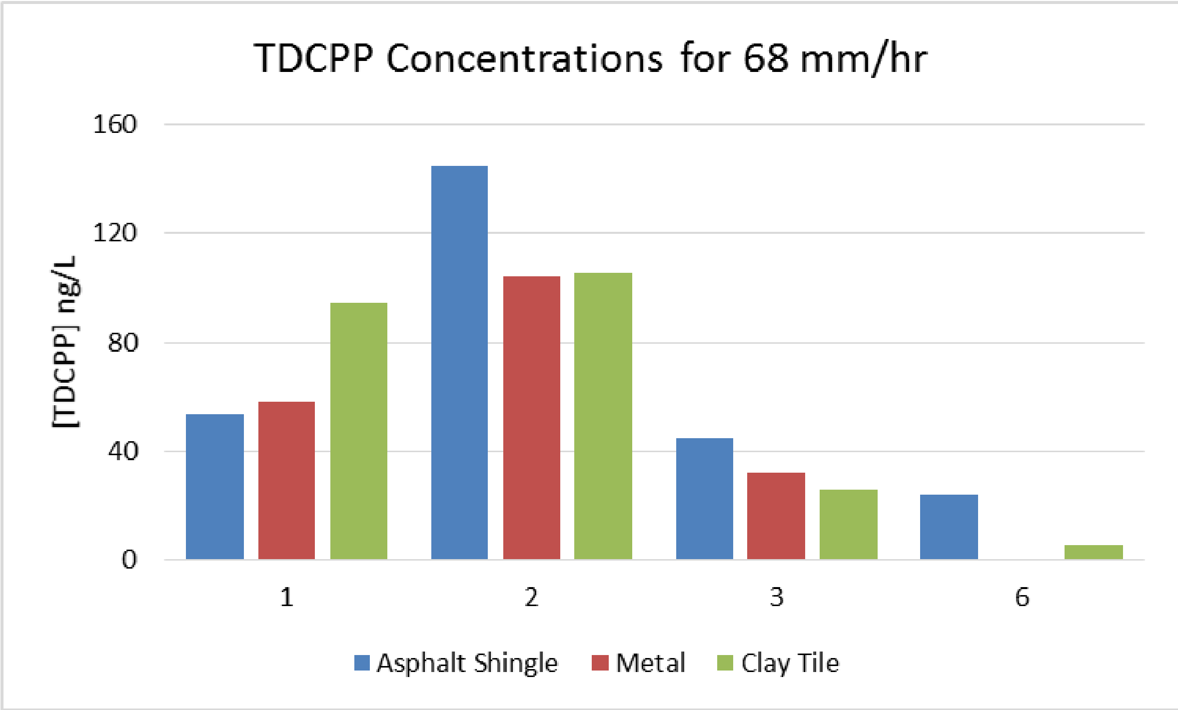

Figure 63. TDCPP concentrations from the high intensity simulation.

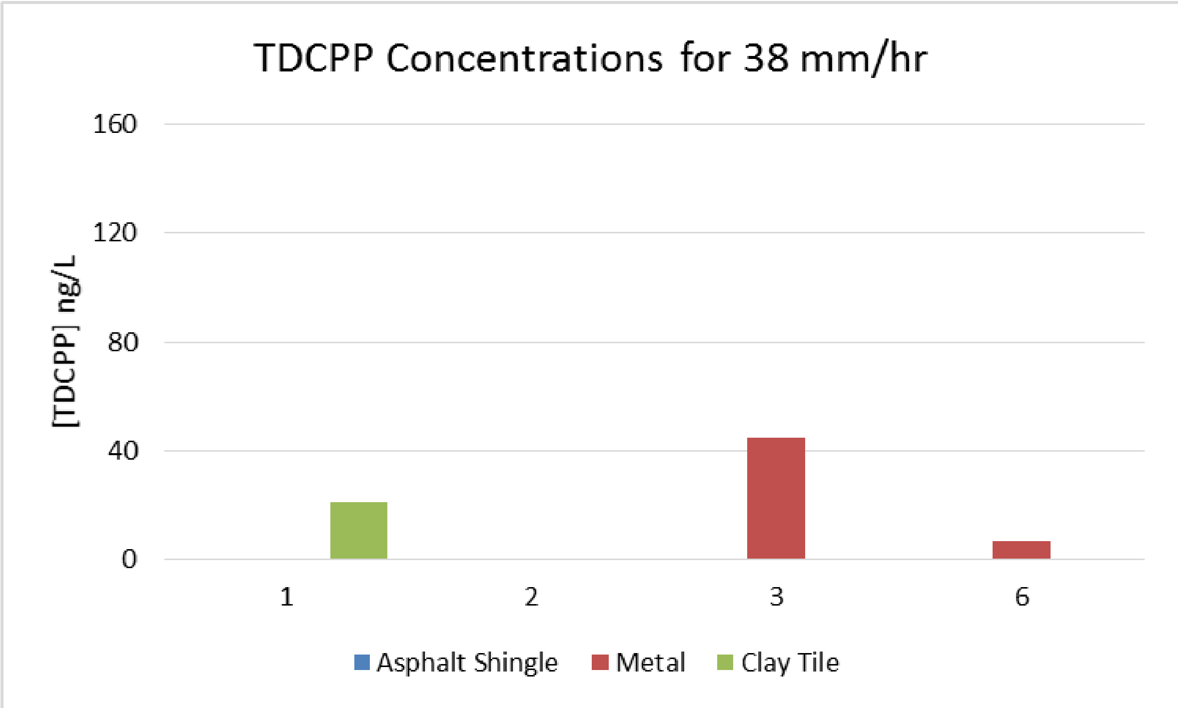

Figure 64. TDCPP concentrations from the medium intensity simulation.

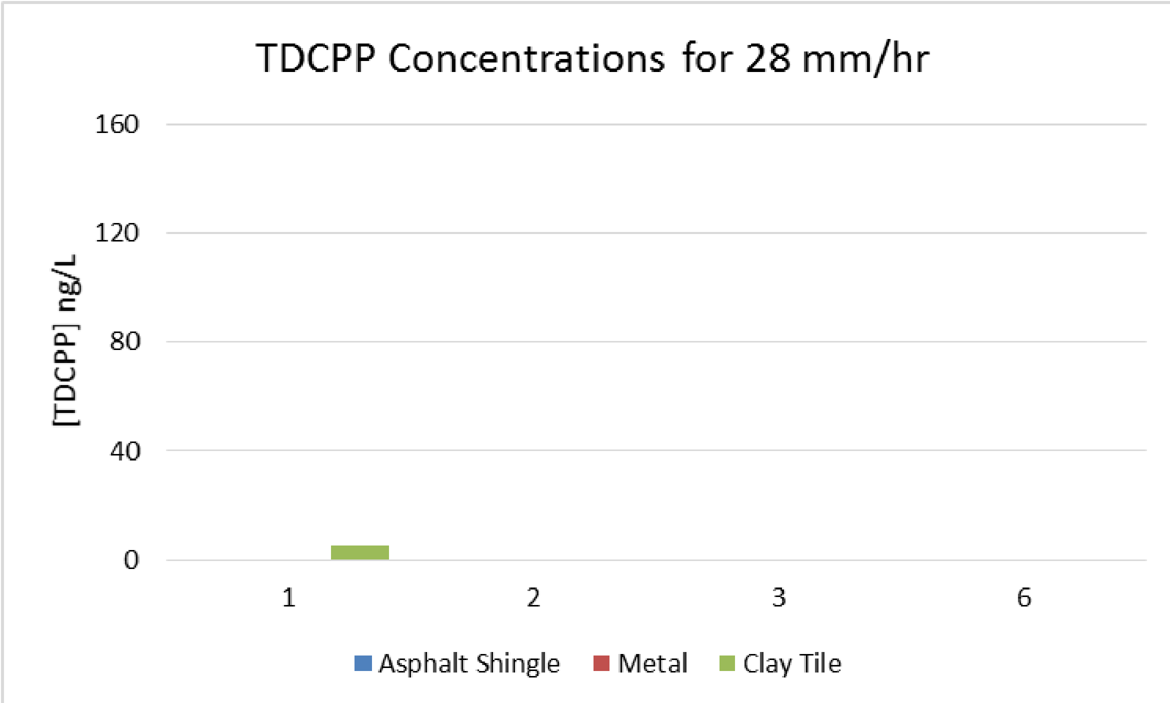

Figure 65. TDCPP concentrations from the low intensity simulation.

Pyrethroid Insecticides

Only one trace hit of the pyrethroid insecticide bifenthrin was found in one asphalt shingle sample from the low intensity rainfall simulation. It was from the second sample from AS2 and was a 43 ng/L concentration. All other samples from every roof had no reported concentrations of bifenthrin, cypermethrin, or lambda cyhalothrin in their runoff.

Conductivity

All six samples collected from each roof were analyzed for conductivity. The conductivity of the runoff from the rainfall simulations (Figures 66 to 68) appeared to follow the same trend. The highest conductivity concentrations were seen in the first 2 L of runoff and then leveled off for the remainder of the simulation. The conductivity levels seen in the runoff never exceeded 750 µs/cm, the maximum conductivity for irrigation water without any limitations on its use.

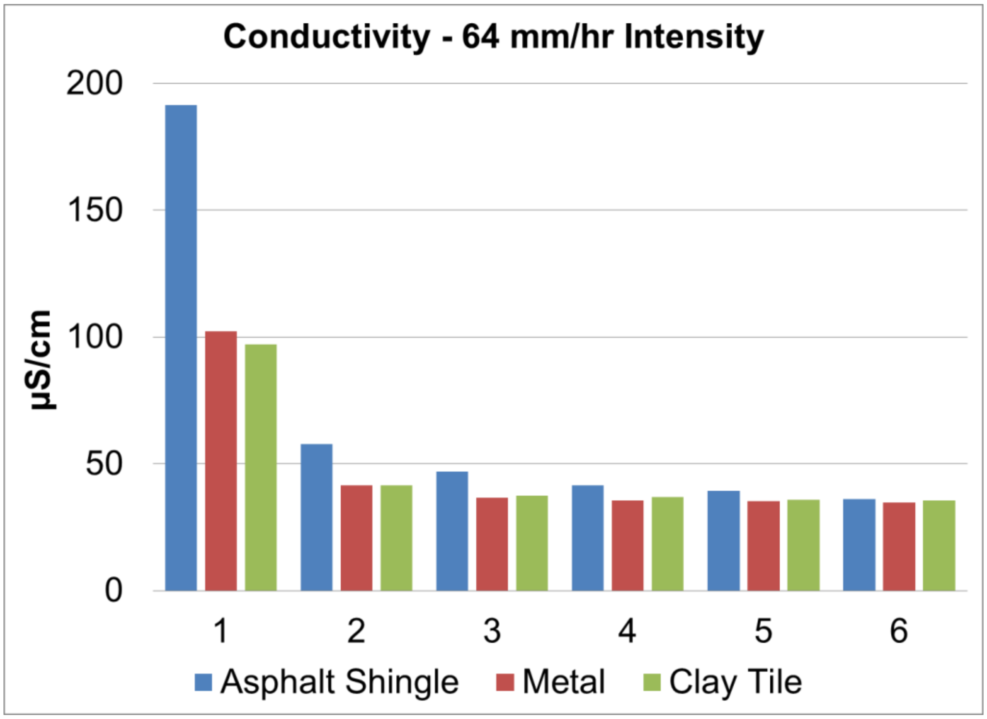

Figure 66. Conductivity results from the high intensity simulation.

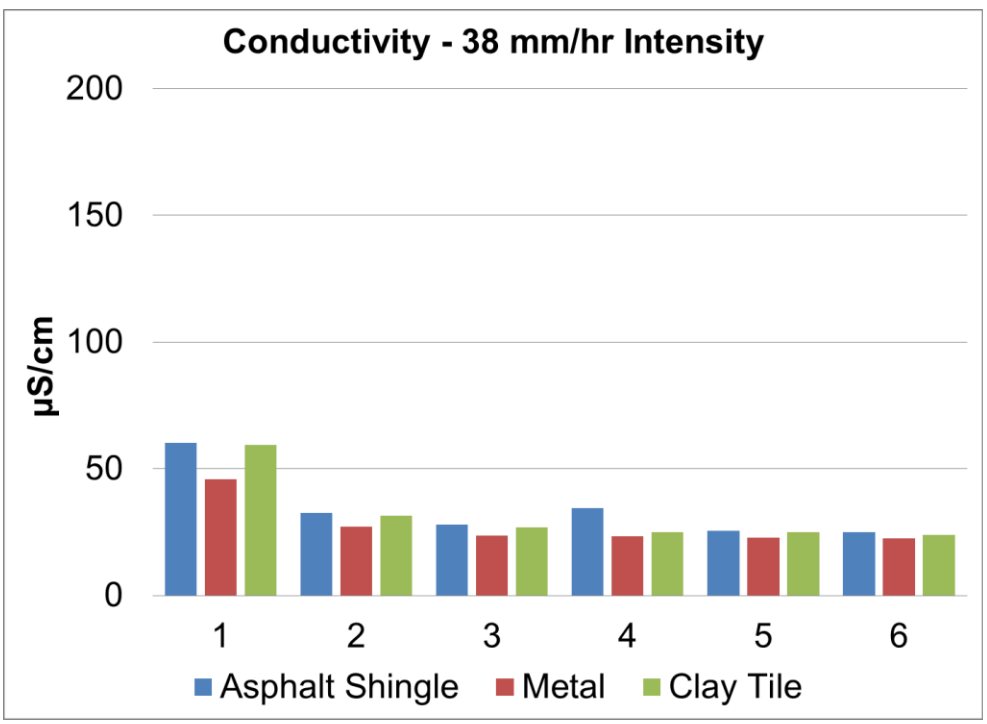

Figure 67. Conductivity results from the medium intensity simulation.

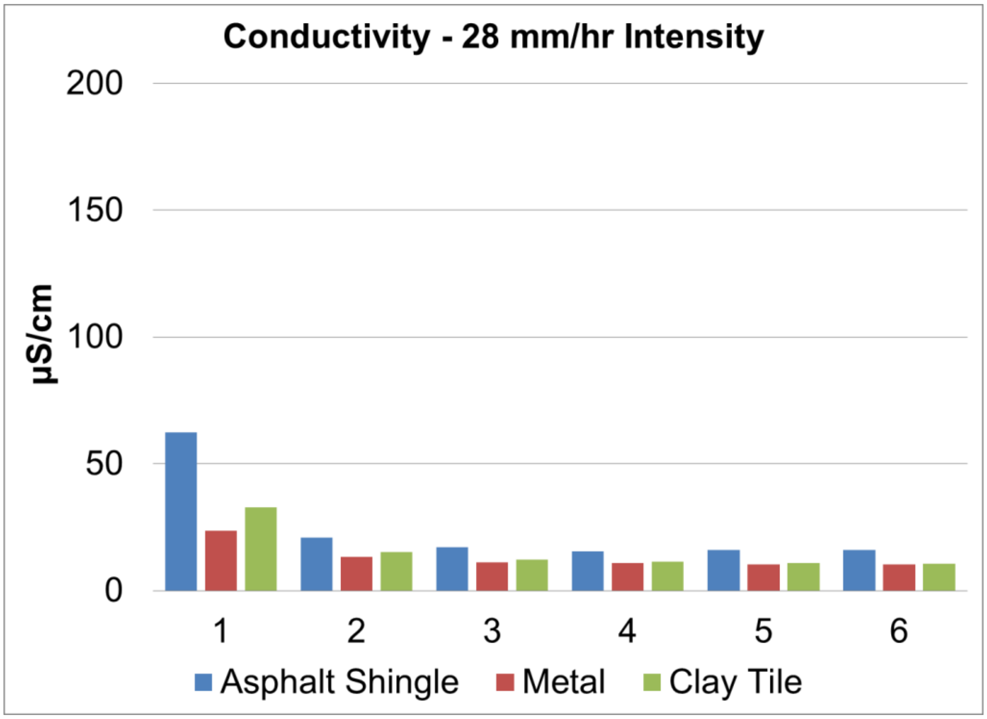

Figure 68. Conductivity results from the low intensity simulation.

Nitrate-N

All six samples collected from each roof were analyzed for the presence of nitrate-nitrogen. The nitrate-nitrogen concentrations seen in the runoff also appeared to follow a trend similar to the conductivity results. Figures 69 to 71 show the first sample (first 2 L of runoff) as having the highest concentrations, followed by an immediate drop and leveling off of concentrations in the subsequent samples. The nitrate-N seen in the runoff was due to atmospheric deposition. The high intensity simulation (Figure 69) had the highest concentrations of all three simulations.

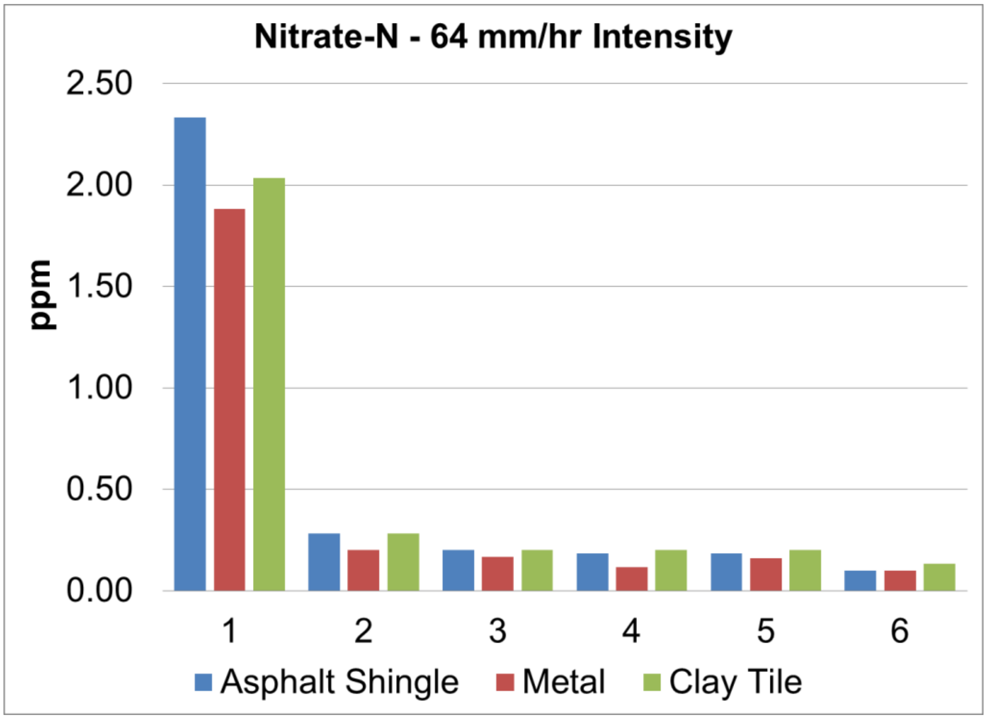

Figure 69. Nitrate-N concentrations from the high intensity simulation.

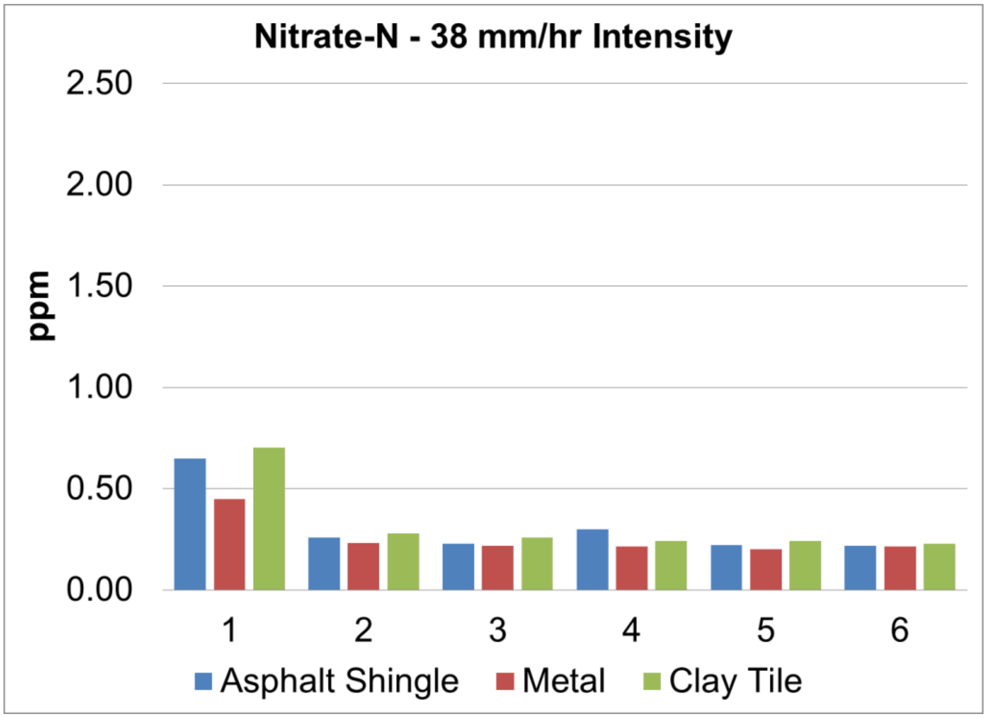

Figure 70. Nitrate-N concentrations from medium intensity simulation.

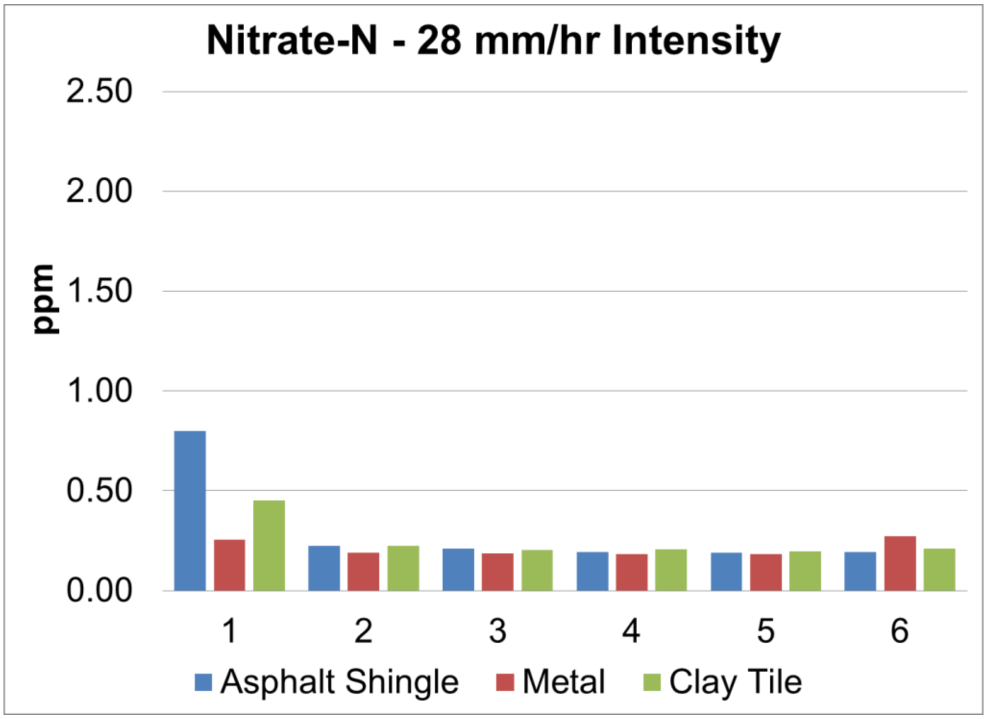

Figure 71. Nitrate-N concentrations from low intensity simulation.

Total Suspended Solids

All six samples collected from each roof were analyzed for total suspended solids (TSS). The high intensity simulation event does not have any TSS results. The same trend seen in the previous parameters are again seen with the TSS concentrations; the first sample had the highest concentrations, followed by an immediate drop and near leveling off in subsequent samples, as shown in Figures 72 and 73. While the metal roofs had higher TSS values in the first 2 L of runoff on the medium intensity simulation (Figure 72), the asphalt shingle roofs had higher TSS values further on in the simulation. On the lower intensity simulation (Figure 73), the asphalt shingle roofs had the highest initial TSS concentrations compared to the metal and clay tile roofs and kept that trend throughout the simulation, except for the second samples, where the metal roofs had higher TSS concentrations.

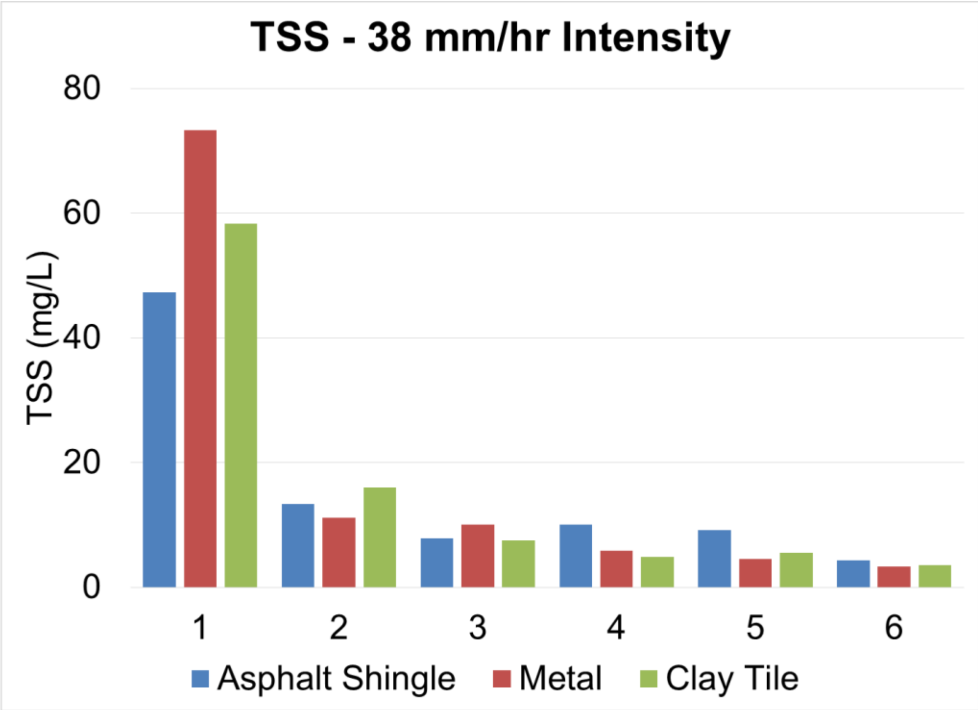

Figure 72. TSS concentrations for medium intensity simulation.

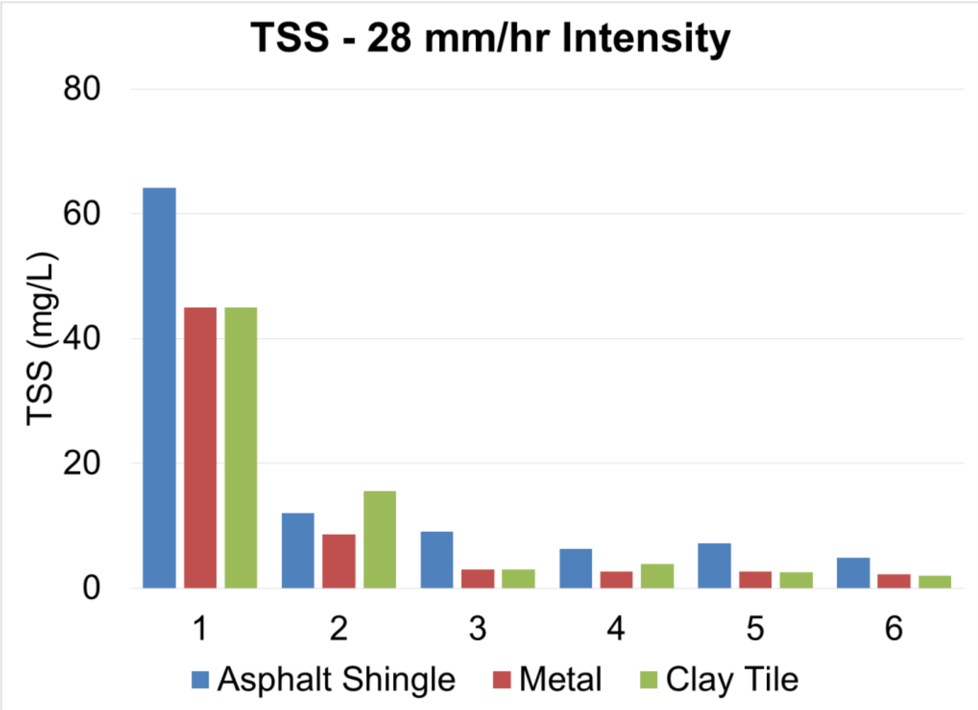

Figure 73. TSS concentrations for low intensity simulation.

Soil Downspout Survey

A total of 17 paired soil samples were analyzed for the presence of selected PAHs, flame retardants, and pyrethroid insecticides beneath downspouts for asphalt shingle, metal, and tar & gravel buildings in Oklahoma City (OKC) and Stillwater (STW). Approximately 200 g soil sample was taken from beneath each downspout, with a pair sample taken in an area where the downspout did not drain into. Samples were taken from the first 2-5 cm of topsoil.

Each soil sample was well mixed and 1.5 g of soil was measured out for the analysis. After the soil sample was measured out and transferred into a mortar, 100 µL of the surrogate p-Terph d14 was added in two 50 µL increments so as to fully saturate the soil. The soil was then mixed with 0.75 g of diatomaceous earth, 900 mg of Florisil PR, and 50 mg of PSA bonded silica 100 gram using a mortar and pestle. A column was constructed using a hollow solid-phase extraction tube filled with 0.5 g of silica, followed by 1.0 g of sodium sulfate, and then the soil mixture was added on top. The column was then eluted with 15 mL of 1:2 hexane: ethyl ether into test tubes. The solvent was then evaporated down to 0.5 mL and processed on the GC/MS machine.

Results of the soils analysis are given in Tables 17 and 18, showing the sum of the Total PAHs and the sum of the carcinogenic PAHs, respectively.

Table 17. Sum of Total PAHs (ng/g soil).

Location	**Roofing**	**Year**	**Downspout**	**Away**
Residential House - OKC	Asphalt	1998	666	61
Jones Village - STW	Shingle	2000	3202	9917
Allen Suites - STW		2001	105	155
Residential Barn - STW		2003	101	7
Residential House - STW		2004	742	87
BAE Lab – STW	Metal	1965	515	653
Physical Plant North - STW		1970	610	303
Career Tech - STW		1973	938	308
Fire Prot. Safety Lab - STW		2003	4658	2751
Horticulture Pavilion - OKC		2004	3487	726
BAE Bioenergy Lab - STW		2008	276	16
Thatcher - STW	Tar &	1925	25042	150
Public Info. Bldg – STW	Gravel	1930	831	725
Const. Tech. Lab - STW		1968	1050	513
HSEC - OKC		1972	977	483
Physical Plant Admin - STW		1975	359	1213
Ag. Resource Center - OKC		2008	651	179

Table 18. Sum of carcinogenic PAHs (ng/g soil).

Location	Roofing	Year	Downspout	Away
Residential House - OKC	Asphalt	1998	354	44
Jones Village - STW	Shingle	2000	1336	4541
Allen Suites - STW		2001	13	83
Residential Barn - STW		2003	9	0
Residential House - STW		2004	411	19
BAE Lab – STW	Metal	1965	220	305
Physical Plant North - STW		1970	354	190
Career Tech - STW		1973	391	140
Fire Prot. Safety Lab - STW		2003	2376	1393
Horticulture Pavilion - OKC		2004	1768	358
BAE Bioenergy Lab - STW		2008	12	0
Thatcher - STW	Tar &	1925	13377	14
Public Info. Bldg – STW	Gravel	1930	347	370
Const. Tech. Lab - STW		1968	438	300
HSEC - OKC		1972	544	290
Physical Plant Admin - STW		1975	183	595
Ag. Resource Center - OKC		2008	386	118

The results indicate that there is a potential for accumulation of PAHs beneath downspouts as well as shows the ubiquitous nature of PAHs in the environment, as traces of PAHs were also found in soil sampled away from downspouts. Some of the samples taken away from downspouts may not have been the same parent material as the downspout soils as some locations had been new sod placed in the past.

Soil samples were also analyzed for the presence of the selected flame retardants and pyrethroid insecticides. However, there was only one detection of TCEP (28.3 ng/g on the Public Info. Bldg downspout sample) and one detection of bifenthrin (76.7 ng/g on the Residential House – STW downspout sample) in all of the 34 samples tested.

Summary & Conclusions

The objective of this research was to investigate two questions that remain regarding the widespread implementation of rainwater harvesting as a solution for decreasing demand on water systems from water used for urban irrigation: (1) Does the runoff from the beginning part of a storm, also referred to as the "first flush" contribute a substantial portion of contaminants in rooftop runoff, and, if it does, can design of the rainfall harvesting system decrease the concentration and bioaccumulation potential of contaminants in harvested rainfall? and (2) Do PAHs, flame retardants, and pyrethroid insecticides occur in rooftop runoff, and what is the bioaccumulation potential of these compounds in lawns if the water is used for urban irrigation?

Results from this study showed that a substantial portion of contaminants in rooftop runoff did occur in the initial "first flush" of a rain event. In particular, the organic compounds of interest in this study showed this trend, along with other parameters such as conductivity and total suspended solids.

Based on the field data collected from actual storm events in OKC, results indicated diverting 4.6 L/m^2 of catchment area (11 gal/100 ft^2) for the metal roof, the 2.9 L/m^2 of catchment area (7 gal/100 ft^2) for the tar and gravel roof, and 6.8 L/m^2 (17 gal/100 ft^2) for the asphalt shingle roof would remove the majority of PAHs seen in the runoff samples. However, the tar & gravel roof sampled in the study had poor collection efficiency, so this value may not be representative of all roofs of this type.

The controlled rainfall simulations performed in Stillwater on 18 constructed roofs told a different story. In order to divert the majority of PAHs and flame retardants, the results indicated that 2.4 L/m^2 (6 gal/100ft^2) be diverted. These rainfall simulations were performed using a constant intensity, which is not often the case in real-life scenarios as was seen in the OKC storm events.

All of these first-flush recommendations are greater than the rule of thumb of diverting the first 1-2 gallons per 100 ft^2 of catchment area suggested by the Texas Water Development Board (2005). Further analysis is to be performed in order to determine the optimal diversion. Overall, results showed that metal roofs are preferable over asphalt shingle roofs for rainwater harvesting as contaminants have a shorter retention time in the runoff from metal roofs when compared to asphalt shingle roofs. Further research should be conducted focusing on the varying intensities of storm events and how that affects the first-flush effect.

The selected PAH compounds did show bioaccumulation potential as was seen in the organic analysis performed on soils located beneath and away from downspouts; the flame retardants and pyrethroid insecticides did not. Not all soils located beneath downspouts had higher PAH concentrations than their paired samples, showing the variable nature of PAHs in the environment.

References

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Humphrey, J.B., T.C. Daniel, D.R. Edwards, A.N. Sharpley. 2002. A portable rainfall simulator for plot-scale runoff studies. Applied Engineering in Agriculture 18(2): 199-204.

TWDB. The Texas Manual on Rainwater Harvesting. 2005. Texas Water Development Board. Third Edition.

Appendix A. OSU-OKC AS Data

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly	Sum of PAH Carcinogens	Bifenthrin (ng/L)	Cypermethri n	Lambda cyhaothrin	TCEP (ng/L)	TDCPP (ng/L)
11-Apr-12	8:30	1	3.68	930	689	513	0	0	0	0	0
11-Apr-12	8:33	2	7.36	910	693	531	0	0	78	40	0
11-Apr-12	8:39	3	9.20	546	443	343	0	0	29	0	0
11-Apr-12	8:45	4	9.20	484	408	300	0	0	10	0	0
11-Apr-12	8:56	5	20.2	345	290	211	0	0	0	0	0
11-Apr-12	9:18	6	23.9	142	118	87	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
11-Apr-12	8:31	1	5.52	20.10	49	100	0	129.4	7.3814	1.5951
11-Apr-12	8:34	2	7.36	7.58	12	202.9	0	94.6	7.1196	1.29908
11-Apr-12	8:40	3	9.20	5.48	29	127.3	0	48.3	6.9839	0.74745
11-Apr-12	8:46	4	11.0	16.10	8	98.4	1	29.6	7.0009	0.47669
11-Apr-12	8:57	5	20.2	5.43	9	98.4	4.1	25.7	6.986	0.43199
11-Apr-12	9:19	6	23.9	3.15	4	167.4	5.2	35.8	6.9889	0.53667

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly	Sum of PAH Carcinogens	Bifenthrin (ng/L)	Cypermethri n	Lambda cyhaothrin	TCEP (ng/L)	TDCPP (ng/L)
13-Apr-12	15:46	1	3.68	1406	1099	754	0	0	0	0	0
13-Apr-12	15:52	2	11.0	562	435	309	0	0	0	0	32
13-Apr-12	15:55	3	14.7	398	335	239	0	0	0	0	0
13-Apr-12	16:01	4	22.1	245	208	150	0	0	0	0	0
13-Apr-12	16:34	5	44.1	180	149	108	0	0	0	34	0
13-Apr-12	18:06	6	145	213	183	141	0	0	0	34	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
13-Apr-12	15:47	1	6	9.73	16	ND	ND	121.3	7.4382	0.86696
13-Apr-12	15:53	2	11	4.53	17	ND	ND	56.1	7.1753	0.56415
13-Apr-12	15:56	3	17	3.37	18	ND	ND	40.1	7.1149	0.43967
13-Apr-12	16:02	4	24	2.40	20	ND	ND	30.3	7.0728	0.32616
13-Apr-12	16:35	5	44	1.99	19	ND	ND	28.5	7.0302	0.38053
13-Apr-12	18:07	6	145	1.23	59	ND	ND	25.2	7.1178	0.21013

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethri n (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
19-Apr-12	20:56	1	4	604	416	344	0	0	0	0	0
19-Apr-12	20:59	2	17	808	575	450	0	0	0	50	0
19-Apr-12	21:02	3	26	345	294	231	0	0	0	0	0
19-Apr-12	21:08	4	37	49	49	31	0	0	0	0	0
19-Apr-12	21:22	5	46	32	0	0	0	0	0	0	0
19-Apr-12	22:15	6	64	12	12	12	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
19-Apr-12	20:57	1	7	3.85	48	ND	ND	87.3	7.36	0.26807
19-Apr-12	21:00	2	20	3.48	51	ND	ND	63.3	7.2095	0.51957
19-Apr-12	21:03	3	29	2.22	28	ND	ND	40.1	7.1187	0.49093
19-Apr-12	21:09	4	37	1.51	10	ND	ND	29.8	6.9956	0.36742
19-Apr-12	21:23	5	46	1.58	2	ND	ND	30.6	7.008	0.35821
19-Apr-12	22:16	6	64	2.120	6	ND	ND	37.2	7.0951	0.51818

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
11-May-12	9:12	1	4	329	108	56	0	0	0	59	0
11-May-12	9:15	2	6	237	98	51	0	0	0	98	0
11-May-12	9:21	3	7	322	114	63	0	0	18	59	32
11-May-12	9:27	4	9	217	72	52	0	0	19	55	0
11-May-12	10:00	5	20	273	84	49	0	0	14	44	0
11-May-12	10:31	6	29	262	54	41	0	0	0	61	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
11-May-12	9:13	1	6	13.50	27	ND	ND	146.1	7.1363	2.00945
11-May-12	9:16	2	6	13.20	19	ND	ND	134.6	7.0988	1.89342
11-May-12	9:22	3	7	11.90	16	ND	ND	108.2	7.0811	1.47616
11-May-12	9:28	4	9	10.50	30	ND	ND	79.5	7.0692	0.96751
11-May-12	10:01	5	20	11.50	26	ND	ND	33.9	7.0106	0.34034
11-May-12	10:32	6	29	5.21	20	ND	ND	33.6	7.0937	0.25953

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
29-May-12	20:19	1	9	1031	826	576	0	0	63	0	0
29-May-12	20:21	2	19	703	543	365	0	0	75	0	0
29-May-12	20:24	3	61	261	226	162	0	0	0	0	0
29-May-12	20:30	4	107	84	84	34	0	0	0	0	0
29-May-12	20:33	5	114	97	84	72	0	0	0	0	0
29-May-12	22:38	6	144	347	293	232	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
29-May-12	20:20	1	14	33.7	56	365.4	0	67.9	7.1654	0.7501
29-May-12	20:22	2	35	15.6	54	2010	100	28.5	6.9415	0.51631
29-May-12	20:25	3	70	8.0	28	686.7	0	20.9	6.6866	0.44914
29-May-12	20:31	4	111	6.7	13	2149.2	34.5	22.7	6.695	0.47371
29-May-12	20:34	5	115	6.5	11	2419.2	24.3	25	6.7785	0.47938
29-May-12	22:39	6	144	7.60	33	740	0	34.2	7.1117	0.61586

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
6-Jun-12	10:15	1	7	1056	815	626	0	0	0	0	0
6-Jun-12	10:18	2	17	760	627	471	0	0	0	0	0
6-Jun-12	10:21	3	29	435	369	278	0	0	0	0	0
6-Jun-12	10:24	4	44	280	238	175	0	0	0	0	31
6-Jun-12	10:27	5	52	252	217	144	0	0	0	0	0
6-Jun-12	11:03	6	63	30	30	30	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
6-Jun-12	10:16	1	9	14.9	35	1732.87	33.2	67.7	6.8523	1.04087
6-Jun-12	10:19	2	20	13.8	33	980	0	29.4	6.8387	0.5562
6-Jun-12	10:22	3	35	8.5	22	310	0	22.1	6.0739	0.45919
6-Jun-12	10:25	4	48	4.57	11	100	0	21.6	6.6547	0.43208
6-Jun-12	10:28	5	53	4.03	6	310	0	22.7	6.7601	0.44376
6-Jun-12	11:04	6	64	6.31	7	310	0	41.9	6.9995	0.97912

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
9-Jul-12	19:41	1	13	1448	1058	760	0	0	0	126	0
9-Jul-12	19:44	2	15	825	663	455	0	0	0	35	0
9-Jul-12	19:47	3	15	534	430	289	0	0	65	70	45
9-Jul-12	19:50	4	18	574	459	313	0	0	63	65	45
9-Jul-12	19:53	5	20	262	222	157	0	0	43	27	46
9-Jul-12	19:56	6	20	377	323	231	0	0	60	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
9-Jul-12	19:42	1	15	36.2	85	100	0	167.7	6.5979	1.21558
9-Jul-12	19:45	2	15	27.00	55	0	0	151.1	6.5622	1.12846
9-Jul-12	19:48	3	17	21.7	44	200	0	140.8	6.607	1.11779
9-Jul-12	19:51	4	20	18.7	34	630	0	109.9	6.6607	0.97758
9-Jul-12	19:54	5	20	15.30	25	100	0	109.4	6.6737	0.95598
9-Jul-12	19:57	6	20	12.60	20	0	0	113.3	6.6929	0.81399

Appendix B. OSU-OKC HP Data

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
3-Apr-12	10:19	1	109	955	672	459	0	0	0	0	0
3-Apr-12	10:22	2	117	375	291	216	0	0	0	0	0
3-Apr-12	10:28	3	123	106	96	56	0	0	0	0	0
3-Apr-12	10:45	4	128	267	199	138	0	0	0	36	0
3-Apr-12	12:39	5	461	76	19	0	0	0	0	0	0
3-Apr-12	13:40	6	862	122	67	35	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
3-Apr-12	10:20	1	113	5.81	41	TNTC	0	26	6.9764	0.27845
3-Apr-12	10:23	2	119	3.81	17	TNTC	0	22.3	7.027	0.25233
3-Apr-12	10:29	3	124	1.34	12	TNTC	1	19.9	6.8465	0
3-Apr-12	10:46	4	128	3.36	6	579	3	22.9	6.9064	0.30237
3-Apr-12	12:40	5	470	10.60	36	222	0	17.21	6.8617	0.23694
3-Apr-12	13:41	6	872	1.20	8	317	0	13.45	6.6859	0.204

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
11-Apr-12	8:45	1	91	373	277	148	0	0	0	0	0
11-Apr-12	8:48	2	93	45	45	23	0	0	0	58	0
11-Apr-12	8:51	3	93	96	64	25	0	0	0	0	0
11-Apr-12	8:54	4	93	82	40	25	0	0	0	35	0
11-Apr-12	9:11	5	93	233	0	0	0	0	0	0	52
11-Apr-12	9:22	6	93	61	0	0	0	0	0	30	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
11-Apr-12	8:46	1	93	3.78	16	730	0	25.4	6.9695	0.40598
11-Apr-12	8:49	2	93	3.63	10	520	0	24.1	6.8644	0.42694
11-Apr-12	8:52	3	93	4.28	9	200	0	26.2	6.9931	0.43904
11-Apr-12	8:55	4	93	5.64	9	410	0	25.8	6.7552	0.44258
11-Apr-12	9:12	5	93	3.70	6	200	0	29.6	6.8865	0.66583
11-Apr-12	9:23	6	93	3.96	5	630	0	31.5	6.9068	0.74066

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
13-Apr-12	16:22	1	119	138	127	71	0	0	0	0	0
13-Apr-12	16:25	2	130	110	89	45	0	0	0	0	0
13-Apr-12	16:28	3	134	0	0	0	0	0	0	0	0
13-Apr-12	16:48	4	160	0	0	0	0	0	0	44	0
13-Apr-12	17:41	5	1033	11	11	0	0	0	0	33	0
13-Apr-12	18:42	6	1291	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
13-Apr-12	16:23	1	129	5.01	17	ND	ND	26.4	6.538	0.46131
13-Apr-12	16:26	2	133	1.81	13	ND	ND	20.8	6.408	0.37389
13-Apr-12	16:29	3	134	2.99	5	ND	ND	22.7	6.4462	0.37767
13-Apr-12	16:49	4	160	5.33	2	ND	ND	20.6	6.2921	0.33497
13-Apr-12	17:42	5	1074	1.61	11	ND	ND	13.96	6.2152	0.21508
13-Apr-12	18:43	6	1291	MISSING	2	ND	ND	16.5	6.4237	0.25603

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
19-Apr-12	20:55	1	97	108	98	76	0	0	0	0	0
19-Apr-12	20:58	2	150	48	48	32	0	0	0	0	0
19-Apr-12	21:01	3	219	0	0	0	0	0	0	37	0
19-Apr-12	21:07	4	255	0	0	0	0	0	0	0	0
19-Apr-12	22:14	5	336	21	21	10	0	0	0	0	0
19-Apr-12	0:16	6	339	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
19-Apr-12	20:54	1	91	4.04	11	ND	ND	42.2	7.3497	0.58843
19-Apr-12	20:57	2	130	2.75	8	ND	ND	30.9	6.9999	0.43731
19-Apr-12	21:00	3	200	1.68	8	ND	ND	21.7	6.8271	0.33003
19-Apr-12	21:06	4	255	1.69	6	ND	ND	20.5	6.7745	0.36155
19-Apr-12	22:13	5	336	3.01	5	ND	ND	25.7	6.8076	0.44927
20-Apr-12	0:15	6	339	4.22	10	ND	ND	52.7	7.1729	1.1753

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
28-Apr-12	23:03	1	81	388	288	216	0	0	0	0	0
28-Apr-12	23:06	2	94	264	206	136	0	0	0	70	57
28-Apr-12	23:09	3	95	115	63	41	0	0	0	33	0
28-Apr-12	23:18	4	109	321	243	161	0	0	0	32	30
28-Apr-12	23:29	5	115	89	31	16	0	0	0	46	0
29-Apr-12	1:23	6	189	101	101	58	0	0	0	35	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
28-Apr-12	23:04	1	91	22.9	43	ND	ND	62.4	7.3672	0.8001
28-Apr-12	23:07	2	94	20.0	22	ND	ND	56.7	7.3042	0.80694
28-Apr-12	23:10	3	96	13.4	6	ND	ND	56.4	7.2642	0.83711
28-Apr-12	23:19	4	115	26.4	45	ND	ND	60.2	7.3213	0.93732
28-Apr-12	23:30	5	115	13.0	6	ND	ND	53.7	7.1813	0.92287
29-Apr-12	1:24	6	189	8.91	MISSING	ND	ND	48.7	7.1529	0.94192

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
20-May-12	1:06	1	65	611	454	300	0	0	0	0	0
20-May-12	1:09	2	77	303	168	90	0	0	0	0	0
20-May-12	1:12	3	110	169	152	95	0	0	0	35	0
20-May-12	1:15	4	167	104	92	53	0	0	0	49	0
20-May-12	1:32	5	313	58	14	14	0	0	0	43	0
20-May-12	2:25	6	357	0	0	0	0	0	0	31	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
20-May-12	1:08	1	71	17.4	36	112.4	0	42.1	7.1527	0.65473
20-May-12	1:10	2	85	15.7	37	53.8	0	31.4	7.0963	0.5326
20-May-12	1:13	3	129	12.3	21	529.8	0	24.8	6.999	0.46258
20-May-12	1:16	4	188	7.04	15	1986.28	3.1	20.9	6.9055	0.43723
20-May-12	1:33	5	318	6.45	9	TNTC	6.3	25.6	6.8559	0.60223
20-May-12	2:26	6	359	5.49	7	TNTC	9.7	24.9	6.8743	0.57309

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
29-May-12	20:20	1	13	379	304	193	0	0	15	0	0
29-May-12	20:23	2	40	136	126	72	0	0	0	0	0
29-May-12	20:26	3	94	44	13	0	0	0	0	0	0
29-May-12	20:29	4	160	153	132	107	0	0	0	0	0
29-May-12	20:46	5	241	0	0	0	0	0	0	0	0
29-May-12	22:40	6	347	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
29-May-12	20:21	1	40	11.8	23	100	0	36.6	6.831	0.6759
29-May-12	20:24	2	40	8.66	13	200	0	18.36	6.4834	0.47206
29-May-12	20:27	3	94	13.6	24	200	0	17.76	6.5251	0.45042
29-May-12	20:30	4	160	13.7	4	100	0	16.38	6.5339	0.45141
29-May-12	20:47	5	241	6.14	3	0	0	18.47	6.469	0.49998
29-May-12	22:41	6	347	5.22	6	100	0	25.5	6.6913	0.70734

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
6-Jun-12	10:16	1	59	815	618	425	0	0	0	0	0
6-Jun-12	10:19	2	137	453	359	194	0	0	0	0	0
6-Jun-12	10:22	3	266	36	36	22	0	0	0	0	0
6-Jun-12	10:25	4	418	0	0	0	0	0	0	0	0
6-Jun-12	10:53	5	649	0	0	0	0	0	0	0	0
6-Jun-12	11:04	6	733	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
6-Jun-12	10:17	1	86	10.8	27	2030	0	24.4	6.6656	0.57448
6-Jun-12	10:20	2	157	4.77	9	1350	0	21.1	6.3265	0.49463
6-Jun-12	10:23	3	323	2.55	2	860	0	15.84	6.3393	0.42601
6-Jun-12	10:26	4	457	1.84	1	1610	0	13.74	6.0711	0.42187
6-Jun-12	10:54	5	650	2.87	1	56.8	1	27.2	6.2331	0.84692
6-Jun-12	11:05	6	745	4.44	4	69.9	0	33.7	6.0446	0.98488

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
15-Jun-12	3:11	1	121	396	344	226	0	0	0	0	0
15-Jun-12	3:14	2	189	159	147	88	0	0	0	0	0
15-Jun-12	3:20	3	369	58	58	37	0	0	0	0	0
15-Jun-12	3:26	4	604	95	85	51	0	0	0	0	0
15-Jun-12	3:37	5	1687	0	0	0	0	0	0	0	0
15-Jun-12	3:48	6	2267	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
15-Jun-12	3:12	1	141	8.51	25	91.2	1	36	6.6821	0.34362
15-Jun-12	3:15	2	224	4.74	9	86.2	2	19.44	6.3626	0.32738
15-Jun-12	3:21	3	398	4.45	10	1100	0	15.12	6.3269	0.39399
15-Jun-12	3:27	4	672	4.84	7	520	0	10.49	6.3672	0.28814
15-Jun-12	3:38	5	1761	2.65	5	860	0	8.15	6.0486	0.32642
15-Jun-12	3:49	6	2285	3.57	7	520	0	9.52	6.0429	0.36341

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
9-Jul-12	19:42	1	26.0	517	384	243	0	0	0	75	46
9-Jul-12	19:45	2	35.1	172	153	99	0	0	0	0	40
9-Jul-12	19:48	3	39.0	86	74	48	0	0	12	48	44
9-Jul-12	19:51	4	53.4	82	70	46	0	0	0	0	0
9-Jul-12	19:54	5	65.0	27	27	12	0	0	0	0	0
9-Jul-12	20:08	6	69.9	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
9-Jul-12	19:43	1	29.8	15.1	34	100	0	149.8	6.774	0.96468
9-Jul-12	19:46	2	37.2	13.7	23	310	0	153.6	6.7766	1.00353
9-Jul-12	19:49	3	41.1	16.3	34	0	0	55.8	6.8256	0.81214
9-Jul-12	19:52	4	59.3	9.56	16	200	0	48.1	6.6672	0.72796
9-Jul-12	19:55	5	67.2	8.57	14	300	0	52.7	6.6542	0.74669
9-Jul-12	20:09	6	69.9	6.98	8	740	0	56	6.6861	0.92333

Appendix C. OSU-OKC MS Data

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
11-Apr-12	8:51	1	32	10	10	0	0	0	0	0	44
11-Apr-12	8:54	2	39	93	79	60	0	0	0	34	0
11-Apr-12	8:57	3	43	10	10	0	0	0	0	36	0
11-Apr-12	9:00	4	43	0	0	0	0	0	0	0	0
11-Apr-12	9:06	5	44	0	0	0	0	0	0	0	0
11-Apr-12	9:17	6	44	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
11-Apr-12	8:52	1	35	10.80	12	980	0	41.3	7.0486	0.71672
11-Apr-12	8:55	2	41	10.00	8	1730	0	41	6.9576	0.71436
11-Apr-12	8:58	3	43	10.90	5	TNTC	30.9	39.6	6.9809	0.69716
11-Apr-12	9:01	4	44	5.32	3	TNTC	30.5	42.6	7.1488	0.72682
11-Apr-12	9:07	5	44	5.72	4	TNTC	0	43.5	7.1862	0.74445
11-Apr-12	9:18	6	44	7.91	11	2030	200	46.7	7.1623	0.768

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
13-Apr-12	16:05	1	63	81	70	52	0	0	0	0	0
13-Apr-12	16:08	2	84	25	25	12	0	0	0	0	0
13-Apr-12	16:11	3	123	0	0	0	0	0	0	0	0
13-Apr-12	16:42	4	192	22	22	11	0	0	0	0	0
13-Apr-12	18:25	5	1058	0	0	0	0	0	0	0	0
13-Apr-12	19:26	6	1058	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
13-Apr-12	16:06	1	64	8.95	15	ND	ND	48.5	7.1254	0.6865
13-Apr-12	16:09	2	97	5.60	14	ND	ND	46.7	7.1442	0.66187
13-Apr-12	16:12	3	133	6.69	11	ND	ND	46.3	7.156	0.6634
13-Apr-12	16:43	4	192	3.72	26	ND	ND	39.8	7.1481	0.63472
13-Apr-12	18:26	5	1058	2.42	3	ND	ND	30.6	7.0559	0.46555
13-Apr-12	19:27	6	1058	2.01	8	ND	ND	35.6	7.1278	0.5651

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
19-Apr-12	21:07	1	87.9	64	64	45	0	0	39	0	0
19-Apr-12	21:10	2	93.8	10	10	10	0	0	0	0	0
19-Apr-12	21:13	3	96.2	0	0	0	0	0	0	0	0
19-Apr-12	21:55	4	97.2	34	0	0	0	0	0	48	0
19-Apr-12	22:26	5	97.2	0	0	0	0	0	0	0	0
19-Apr-12	0:28	6	97.2	0	0	0	0	0	0	36	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
19-Apr-12	21:06	1	87.7	5.04	15	ND	ND	46.7	6.9815	0.62046
19-Apr-12	21:09	2	92.2	3.80	11	ND	ND	44.5	7.0989	0.6073
19-Apr-12	21:12	3	95.7	4.92	6	ND	ND	44.2	7.0597	0.60459
19-Apr-12	21:54	4	97.2	2.82	1	ND	ND	54.1	7.2742	0.62385
19-Apr-12	22:25	5	97.2	5.27	7	ND	ND	55.7	7.3062	0.69233
20-Apr-12	0:27	6	97.2	2.160	2	ND	ND	96.9	7.5917	1.0279

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
28-Apr-12	23:20	1	3	256	168	114	0	0	0	30	48
28-Apr-12	23:26	2	11	23	23	12	0	0	0	0	0
28-Apr-12	23:37	3	41	10	10	10	0	0	0	40	57
28-Apr-12	23:48	4	69	10	10	10	0	0	0	42	41
29-Apr-12	0:19	5	75	0	0	0	0	0	0	0	0
29-Apr-12	1:20	6	125	0	0	0	0	0	0	48	30

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
28-Apr-12	23:21	1	5	18.50	25	ND	ND	122	7.6346	1.31818
28-Apr-12	23:27	2	11	14.60	15	ND	ND	105.8	7.5212	1.51514
28-Apr-12	23:38	3	44	11.30	9	ND	ND	103.7	7.5084	1.51677
28-Apr-12	23:49	4	72	11.20	5	ND	ND	104.2	7.4576	1.52798
29-Apr-12	0:20	5	75	7.51	2	ND	ND	117.1	7.5355	1.60284
29-Apr-12	1:21	6	125	7.40	4	ND	ND	78.3	7.5173	1.06484

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
11-May-12	9:10	1	0	293	10	0	0	0	0	45	42
11-May-12	9:13	2	0	171	0	0	0	0	0	26	33
11-May-12	9:19	3	0	141	0	0	0	0	0	0	31
11-May-12	9:36	4	0	207	0	0	0	0	0	0	0
11-May-12	9:58	5	20	289	53	37	0	0	0	35	35
11-May-12	10:29	6	117	216	10	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
11-May-12	9:11	1	0	6.8	10	ND	ND	88.3	7.3415	0.001
11-May-12	9:14	2	0	8.4	20	ND	ND	89.3	7.3426	0.20793
11-May-12	9:20	3	0	9.5	10	ND	ND	89.1	7.3984	0.21972
11-May-12	9:37	4	0	7.7	8	ND	ND	91.8	7.3946	0.22199
11-May-12	9:59	5	20	10.2	24	ND	ND	88.8	7.4103	1.51502
11-May-12	10:30	6	117	6.67	2	ND	ND	55.1	7.2771	0.87026

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
20-May-12	1:13	1	4	95	95	57	0	0	0	0	40
20-May-12	1:16	2	31	45	45	29	0	0	0	33	36
20-May-12	1:19	3	95	0	0	0	0	0	0	0	0
20-May-12	1:22	4	111	0	0	0	0	0	157	49	32
20-May-12	1:44	5	111	0	0	0	0	0	0	0	40
20-May-12	3:27	6	111	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
20-May-12	1:14	1	8	18.6	25	TNTC	172.5	72.5	7.265	1.17287
20-May-12	1:17	2	52	16.6	16	275.5	152.3	61.4	7.1993	1.08156
20-May-12	1:20	3	109	13.1	12	TNTC	228.2	56.8	7.1425	1.00793
20-May-12	1:23	4	111	9.07	5	TNTC	193.5	53.9	7.1742	0.96559
20-May-12	1:45	5	111	6.22	2	791.5	135.4	68	7.3418	0.95478
20-May-12	3:28	6	111	2.79	1	689.3	74.9	74.8	7.5856	0.99983

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
29-May-12	20:24	1	31	770	598	420	0	0	117	0	45
29-May-12	20:30	2	202	387	337	240	0	0	0	0	31
29-May-12	20:33	3	231	112	91	78	0	0	0	0	0
29-May-12	20:36	4	236	43	43	27	0	0	0	0	0
29-May-12	21:12	5	237	111	79	39	0	0	0	0	0
29-May-12	22:44	6	265	86	42	12	0	0	27	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
29-May-12	20:25	1	59	24.4	66	275.5	108.1	33.5	6.9236	0.60717
29-May-12	20:31	2	216	18.40	35	248.1	105	27.9	6.9164	0.55257
29-May-12	20:34	3	233	15.7	28	488.4	95.7	28.8	6.9202	0.55893
29-May-12	20:37	4	237	10.2	14	365.4	86.9	29.6	6.9302	0.55983
29-May-12	21:13	5	237	6.32	14	648.8	316.9	53	7.2778	0.72818
29-May-12	22:45	6	265	8.97	19	770.1	478.6	43.9	7.2336	0.70039

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
6-Jun-12	10:22	1	14	356	303	226	0	0	0	0	41
6-Jun-12	10:25	2	19	152	129	96	0	0	0	0	31
6-Jun-12	10:28	3	23	21	21	10	0	0	0	0	0
6-Jun-12	10:31	4	28	21	21	11	0	0	0	0	31
6-Jun-12	10:42	5	30	0	0	0	0	0	0	0	35
6-Jun-12	11:35	6	34	0	0	0	0	0	0	0	38

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
6-Jun-12	10:23	1	16	19.6	43	TNTC	261.3	49	7.1002	0.70061
6-Jun-12	10:26	2	20	10.20	16	TNTC	146.7	40.6	6.9979	0.64475
6-Jun-12	10:29	3	25	8.48	9	TNTC	35.5	35.9	6.9681	0.60225
6-Jun-12	10:32	4	29	6.97	6	TNTC	410.6	35.5	6.9642	0.6198
6-Jun-12	10:43	5	30	4.59	7	TNTC	547.5	38.3	7.0819	0.61827
6-Jun-12	11:36	6	34	4.06	7	TNTC	198.9	54.3	7.265	0.98253

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
15-Jun-12	3:16	1	21	168	141	104	0	0	0	0	37
15-Jun-12	3:19	2	52	64	54	39	0	0	0	0	30
15-Jun-12	3:25	3	142	41	41	0	0	0	0	0	0
15-Jun-12	3:36	4	205	0	0	0	0	0	0	0	0
15-Jun-12	3:47	5	265	0	0	0	0	0	0	0	0
15-Jun-12	4:29	6	267	0	0	0	0	0	0	0	0

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
15-Jun-12	3:17	1	25	11.3	7	1119.85	214.3	65.2	7.2709	0.75787
15-Jun-12	3:20	2	83	7.36	16	2180	0	45.3	7.2207	0.73322
15-Jun-12	3:26	3	142	6.96	11	740	0	34.8	7.1395	0.55278
15-Jun-12	3:37	4	220	3.63	5	980	0	12.51	6.4227	0.33238
15-Jun-12	3:48	5	266	2.91	3	310	0	12.39	6.4531	0.34492
15-Jun-12	4:30	6	267	2.37	3	1986.28	140.1	29.5	6.9443	0.43242

Sample Date	Sample Time	Samples Organics	Runoff Volume (L)	Total PAHs (ng/L)	Sum of Commonly Detected PAHs (ng/L)	Sum of PAH Carcinogens (ng/L)	Bifenthrin (ng/L)	Cypermethrin (ng/L)	Lambda cyhaothrin (ng/L)	TCEP (ng/L)	TDCPP (ng/L)
9-Jul-12	19:53	1		20	10	10	0	0	0	30	146
9-Jul-12	19:56	2		22	22	22	0	0	14	52	73
9-Jul-12	20:07	3		0	0	0	0	0	16	30	61
9-Jul-12	20:18	4		0	0	0	0	0	0	31	154
9-Jul-12	20:29	5		0	0	0	0	0	0	0	57
9-Jul-12	21:00	6		0	0	0	0	0	0	68	60

Sample Date	Sample Time	Samples Other	Runoff Volume (L)	Turbidity (NTU)	Total Suspended Solids (mg/L)	Total Coliforms (Col/100 mL)	E. coli (Col/100 mL)	Electrical Conductivity (µS/cm)	pH	Nitrate-N (ppm)
9-Jul-12	19:54	1		15.1	14	0	0	406	7.0306	1.61193
9-Jul-12	19:57	2		17.5	14	TNTC	29.2	178.2	6.8435	2.10951
9-Jul-12	20:08	3		11.9	10	TNTC	33.6	138.7	6.6996	1.82273
9-Jul-12	20:19	4		12.20	9	TNTC	56.3	135.2	6.7917	2.02276
9-Jul-12	20:30	5		9.37	7	TNTC	49.6	137.9	6.8419	2.06138
9-Jul-12	21:01	6		7.99	5	TNTC	19.7	145.6	6.8914	2.08889