Project: **Green Infrastructure, Water Quality, and GHG Emissions**

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Summary Points

- Water quality services and greenhouse gas emissions were evaluated for green stormwater infrastructure in Ithaca, NY
- Water quality services were variable across 6 measured basins, with several basins having higher pollutant concentrations in basin outflow
- Greenhouse gas (CH_4 and N_2O) emissions were generally low from the 5 measured basins, though nitrous oxide emissions did increase in 3 basins relative to soil outside the basin, and very high methane emissions were observed in the wettest basin
- The wetland-like basins experienced high salinity, had higher methane emissions and had mixed water quality services, indicating that very slow infiltration is not desirable when designing the most effective green infrastructure

Introduction

Green infrastructure refers generally to practices that use vegetation and soil to manage stormwater, as opposed to traditional hard-infrastructure like sewers. The intent of green infrastructure is to take advantage of natural processes within our built environments to mitigate nonpoint source pollution and reduce impacts of runoff on peak stream discharge. Although largely developed in the context of storm water management, green infrastructure is often promoted as providing a broad range of environmental benefits including improved air quality, mitigating urban air temperatures, improving urban habitat and aesthetics, and much more (EPA 2012). However, there is limited actual data to support some of these claims and the studies that have been published generally consider short time frames and/or are based on single case studies. At least one local study has shown that storm water detention systems are sometimes constructed such that the system is more likely to be a contaminant source than a sink (Rigden et al. 2012). Additionally, depending on their design some water-retaining structures may accumulate nutrients and harbor moist conditions; together, these factors may actually favor ecological processes that generate potent greenhouse gases like nitrous oxide (Bettez and Groffman 2012).

New York’s Hudson and Mohawk Valleys are no strangers to population growth and the accompanying increasing growth in suburban communities (Roberts 2006). As housing and commercial developments are constructed, there is a need to manage the hydrologic impacts that these land-use changes cause. As green infrastructure is increasingly touted as a good option for managing stormwater pulses (NYSDEC 2010a) as explicitly endorsed as part of the Hudson River Estuary Action Agenda (NYSDEC 2010b, p. 47), having a comprehensive understanding of the full hydrologic and ecological impact is essential.

In order to help inform design of future green infrastructure in New York State, the goal of this project was to assess the effectiveness of common green infrastructure practices on (1) protecting water quality and (2) reducing greenhouse gas (GHG) emissions. In this way, we will be able to support the perceived environmental benefits of these structures, or highlight any negative impacts so that design of these structures can be amended to minimize such impacts.

Methods

The green infrastructure evaluated for water quality services and greenhouse gas emissions included a variety of vegetated stormwater basins located on the Cornell University campus in Ithaca, NY (Figure 1). These basins are representative of those located in the Hudson and Mohawk Valleys and across New York State. The basins ranged from 4 to 11 years old and from 70 to 1470 m^2 in size (Table 1). Inlet types included stone spillways, scuppers, and pipe inlets. All basins were constructed using local fill (though precise specifications were not available for all basins) and contained an underdrain that connected to the campus sewer system. The basins also had variable management strategies, with some being mowed regularly and others not mowed at all.

Figure 1. Photographs of two of the sampled basins, Oxley (left) and LARTU- Large Animal Research and Teaching Unit (right)

Water Quality Impacts

In order to evaluate the impact of the stormwater basins in the quality of water routed through the basins, inflow and outflow was sampled during multiple storm events in 2012-2013. Inflow samples were collected by burying 125 mL plastic bottles at the base of the basin spillway or inlet prior to storm events. These bottles were collected immediately following storm events and processed in the lab. Outflow samples were obtained either by clamping a 250 mL plastic bottle to the outflow drain where accessible or by manually taking a sample from the outflow immediately following storm events. Eight campus basins were sampled between summer 2012 and spring 2013; however, only six basins yielded both inflow and outflow samples from at least one storm event.

Upon return to the lab, a portion of each water sample was filtered using 0.45µm Pall mixed cellulose ester filters and filtrate was stored at 4°C until analysis. The filtrate was analyzed for anions (NO_3-,NO_2-,SO_4^{2-},Cl-) using a Dionex ICS-2000 Ion Chromatograph with IonPac AS-18 analytical column and 25 µL sample loop. The remaining unfiltered water was analyzed for total metal and cation content. Since many cations sorb to sediment, a nitric acid digestion was used to process the samples prior to analysis. Briefly, concentrated nitric acid (HNO_3) was added to each sample in a glass test tube and the tubes were heated in a water bath over a hot plate until the solutions are clear, indicating complete digestion (Jarvis et al. 1992). Digested samples were then analyzed for total cations and metals using a Jarrell Ash ICP-AES (Inductively Coupled Plasmography with Atomic Emission Spectrometer).

Greenhouse Gas Emissions

Emissions of methane (CH_4) and nitrous oxide (N_2O), both potent greenhouse gases, were measured using *in situ* static chambers located in five basins across campus. The chambers were 30 cm in diameter and constructed using two plastic buckets. A chamber bottom was created by cutting a 5 gallon bucket in half such that the ribbed top of the bucket could be installed in soil. These chamber bases were permanently installed in each basin, with three bases located inside each study basin and two located outside of the basin as a control. Two 1.5 cm holes were drilled in each chamber base to allow for flow of water during storm events. Measurement of greenhouse gases (CH_4 and N_2O) occurred periodically starting in summer 2012. In preparation for making a gas flux measurement, a 5 cm wide rubber band was placed around the chamber base and the two holes in the chamber base were plugged with rubber stoppers. The chamber top was constructed from a 3.5 gallon bucket equipped with a rubber septa and a vent tube made of 0.5 cm OD aluminum tubing attached to 18.5 cm length of flexible plastic tubing and anchored in a second septum (Figure 2).

Figure 2. Photograph of static chamber configuration

For a single gas flux measurement, the chamber top was mounted and a 20 mL syringe was inserted into the main septum to take an initial gas sample. Samples were injected into pre-evacuated 10 mL glass vials with butyl rubber septa. Vials were over-pressurized with injection of 15 mL gas in order to maintain the integrity of samples until analysis. Additional gas samples were taken from the chamber at 10, 20, and 30 minutes. Samples were analyzed for N_2O and CH_4 using an Agilent 6890N gas chromatograph equipped with a HP 7694 Headspace Autosampler (Hewlett-Packard Company). N_2O separation was performed using a Supel-Q™ PLOT capillary column (30m x 0.32mm; Supelco Inc.) with ultra-pure helium carrier gas (2.6 mL min^{-1}) and 95:5 Ar:CH_4 make-up gas (8.2 mL min^{-1}) and a μECD (electron capture detector) set to 250°C. CH_4 separation was performed using a Carboxen 1006 PLOT capillary column (30m x 0.32mm; Supelco, Inc.) and an FID (flame ionization detector) set to 200°C with H_2 gas (30 mL min^{-1}), air (400 mL min^{-1}), and N_2 makeup gas (25 mL min^{-1}) . Oven temperature was initially set to -22°C for 4.7 min, then increased to 30°C for 2.3 min to allow for elution of both gases of interest. Calibration curves were made using serial dilutions of 1ppm N_2O and 20 ppm CH_4 (Airgas Inc.)Gas fluxes were calculated by determining the slope of the concentrations of the four timepoints (Hutchinson and Mosier 1981; Rochette and Bertrand 2007).

In order to aid in interpretation of emission patterns of CH_4 and N_2O, additional environmental parameters were measured in each basin. Decagon EM50 dataloggers were installed in four basins where gas samples were also taken. Each datalogger was equipped with five 5TE sensors for volumetric soil content, soil temperature, and soil electrical conductivity that were set to log at 10 minute intervals. Each sensor was buried in the top 5 cm of soil adjacent to the five gas chamber bases. A datalogger was not installed in the fifth basin due to logistical issues; instead measurements of soil moisture and temperature were made manually here at each gas sampling.

Preliminary Results

Water quality data collected thus far revealed mixed results in terms of the basins' ability to remove pollutants. Table 2 summarizes the change in metal concentration between basin outflow and inflow, where a negative change indicates a lower concentration in outflow or removal of pollutants by the basin. Rice Basin was the most effective basin at reducing load of metals, with only one metal (Na) that increased in concentration in outflows. EHOB Basin was the least effective basin at reducing the load of metals in outflow, with increases in 14 measured metals. Comparing the physical design of these two basins, they are similar in age and their drainage area to basin ratio (Table 1). Observations indicate that a difference between the two is their infiltration rate- Rice is a steep and well-draining basin while EHOB is flatter and oft-characterized by standing water and likely anaerobic conditions.

Table 3 summarizes the change in anion concentration between basin outflow and inflow. Results were again mixed. Five of six basins demonstrated increases in nitrate concentrations, with two basins having average increases of more than 10 ppm NO_3- in outflow. The fact that nitrate is increasing indicates that denitrification, the microbial reduction of NO_3- to N_2O or N_2 gas, is not a dominant process in these basins. Additionally, large increases in chloride were observed in five of six basins. It is likely that basins are accumulating large quantities of road salt from parking lot runoff during winter and continuing to release this salt in outflows throughout the year. The accumulation of salt in the basins is further demonstrated by examining the soil electrical conductivity (EC) data (Figure 3). While soil EC is relatively low (< 2 mS/cm) in all basins during the fall, it rapidly increases in the two wettest basins (EHOB and LARTU- Figure 4) in winter and remains high into spring. This accumulation of salt could influence the ability of the basin soils to retain certain ions as well as impact the composition of microbial communities, which are also important in taking up and transforming a variety of compounds and generating various greenhouse gases (Wichern et al. 2006).

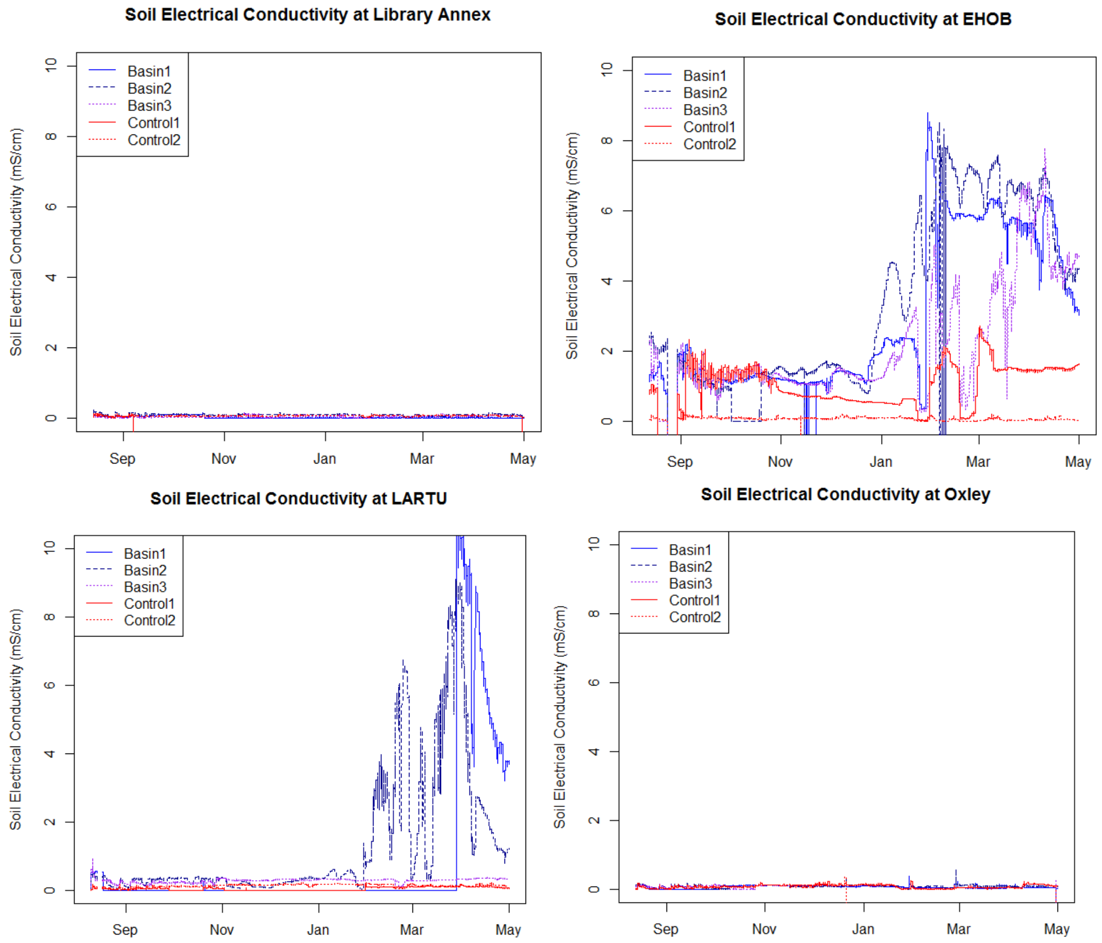
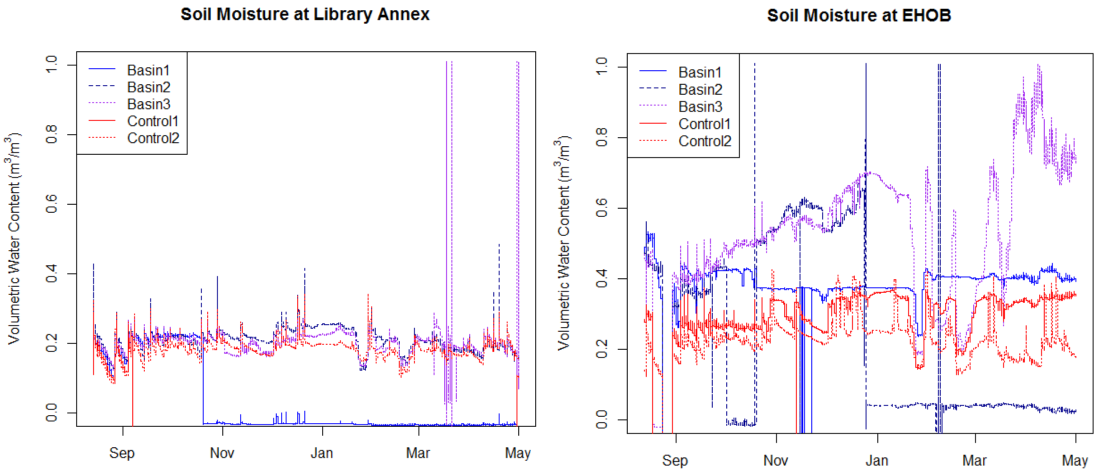


Figure 3. Soil electrical conductivity (mS/cm) as measured at Library Annex, EHOB, LARTU, and Oxley basins during 2012-2013



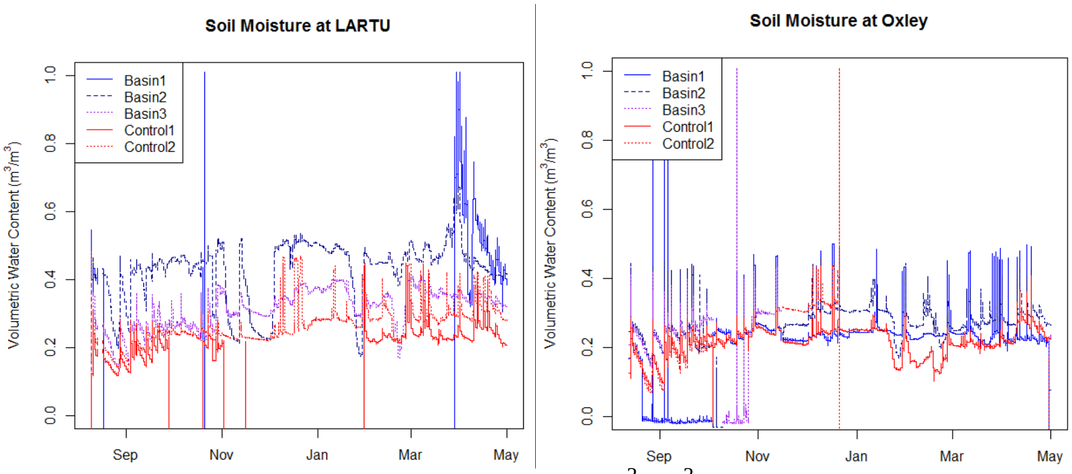
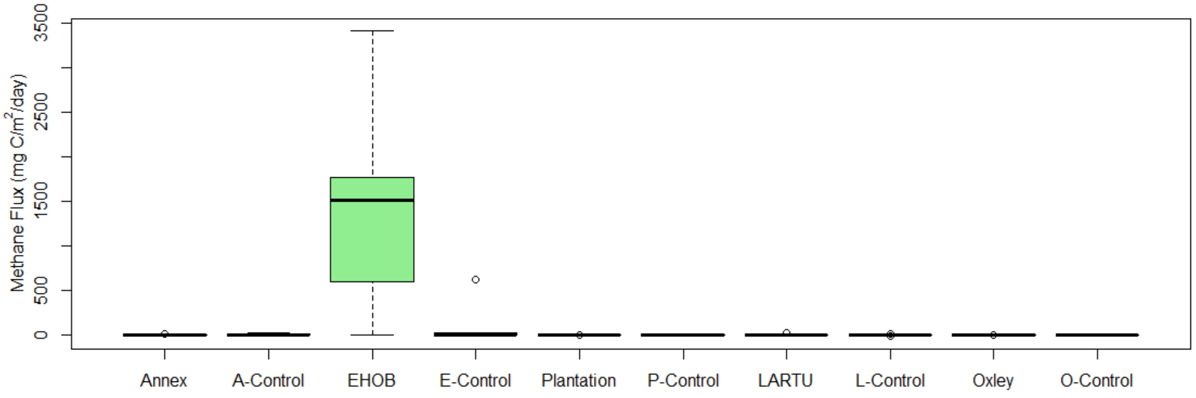


Figure 4. Volumetric soil moisture content ($m^3\ m^{-3}$) as measured at Library Annex, EHOB, LARTU, and Oxley basins during 2012-2013

Emission of greenhouse gases (N_2O and CH_4) from the basins was relatively low except for strong methane emissions from the EHOB basin, with an average of 1500 mg C/m^2/day during fall 2012 (Figure 5). This basin was chronically wet (Figure 4) and oft-characterized by standing water, and such saturated conditions typically promote microbial production of methane. Nitrous oxide emissions typically occur as a product of incomplete denitrification and are usually highest at moderate moisture levels with ample nitrate (Christiansen et al. 2012). There were higher N_2O fluxes in three basins compared to their control comparisons- Library Annex, EHOB, and LARTU basins (Figure 5). Since EHOB and LARTU were often characterized by moderate to very moist conditions, it is not surprising that they showed such a pattern in N_2O fluxes.



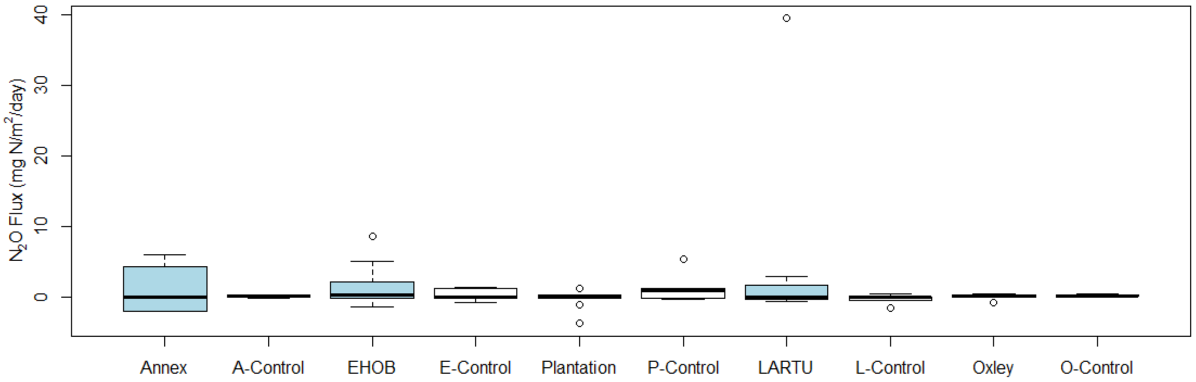


Figure 5. Methane fluxes (top) in mg C m^{-2} d^{-1} and nitrous oxide fluxes (bottom) in mg N m^{-2} d^{-1} as measured at three time-points in fall 2012

Conclusions and Future Work

Collection of both water quality and greenhouse data from the field sites is ongoing. Preliminary results of basin inflow and outflows indicates variable efficiency of basins in improving water quality, with some basins effectively reducing pollutant loads and others contributing to increased pollutant concentrations in outflow. Overall emissions of N_2O and CH_4, both potent greenhouse gases, were low except for high methane emissions in one basin. While further analysis on basin characteristics is necessary to fully understand what is driving these patterns, the chronically slow-draining basin (EHOB) performed poorly for water quality services and methane emissions. Site observations indicate that subsurface drainage is not working effectively, and intensive mowing may be contributing to further soil compaction and decrease in infiltration. While some detainment of stormwater is necessary to reduce flash flooding of nearby streams, extremely slow draining basins do not appear to be effective for water quality or greenhouse gas emissions.

Further analysis of both datasets will provide more insight to the drivers of observed environmental patterns- quantification of stormflow volumes will allow for estimation of total pollutant load in inflow and outflow from each basin. Additionally, regression of gas flux data with soil moisture, temperature, and other parameters will allow us to better determine the drivers of the N_2O and CH_4 emissions. With this forthcoming information, we will be able to further inform the design of future green infrastructure for stormwater management in New York.

References

Bettez , N.D. and P.M. Groffman. (2012) Denitrification potential in stormwater control structures and natural riparian zones in an urban landscape. Env. Sci. Tech.46:10909-10917.

Christiansen, J.R., L. Vesterdal, and P. Gunderson (2012) Nitrous oxide and methane exchange in two small temperate forest catchments- effects of hydrological gradients and implications for global warming potentials of forest soils. Biogeochemistry, 107: 437-454.

EPA (US Environmental Protection Agency). (2012) http://water.epa.gov/infrastructure/greeninfrastructure/ (accessed February 2012)

Hutchinson, G. L., and A. R. Mosier. (1981) Improved soil cover method for field measurement of nitrous oxide fluxes. *Soil Sci. Soc. Am. J.* 45:311-316.

Jarvis, K.E., A.L. Gray, and R.S. Houk, eds. (1992) Sample preparation for ICP-MS. Chapter 7 in Handbook of Inductively Couple Plasma Mass Spectrometry. Blackie & Son, Ltd., Glasgow and London, U.K.

NYSDEC (NY State Department of Environmental Conservation) (2010a) New York State Stormwater Management Design Manual. http://www.dec.ny.gov/chemical/29072.html

NTSDEC (2010b) Hudson River Estuary Action Agenda 2010-2014. pp. 55.

Rigden, A., R. Perlman, M.T. Walter. (2012) Are storm water detention basins removing contaminants from parking lot runoff? *ASCE Journal of Environmental Engineering* (in preparation)

Roberts, Sam. (2006). Hudson Valley becomes notable for its exurbanites, study finds. *New York Times.* October 19, 2006.

Rochette, P., and N. Bertrand. (2007) Soil-surface gas emissions. In: M.R.Carter and E.G.Gregorich, Eds, *Soil sampling and methods of analysis, 2nd ed.*, Canadian Society of Soil Science, CRC Press,pp.851-861.

Wichern, J., F. Wichern, and R.G. Joergensen. (2006) Impact of salinity on soil microbial communities and the decomposition of maize in acidic soils. Geoderma, 137: 100-108.

Tables

Basin Name	**Inlet type**	**Age (yr)**	**Drainage area (m^2)**	**Basin area (m^2)**	**Lot to Basin Ratio**	**Mowing?**
Anna Comstock	scupper	10	1800	70	26	regularly
B Lot	stone spillway	5	30700	560	55	seasonally
EHOB	stone spillway	6	8100	1470	6	seasonally
LARTU	pipe	7	4000	550	7	not mowed
Oxley	stone spillway	11	5600	500	11	seasonally
Rice	stone spillway	8	2200	280	9	regularly
Rite Aid	pipe	6	11400	580	20	seasonally
Wrestling	stone spillway	6	1300	200	7	regularly

Table 1. Summary of physical characteristics of basins evaluated for water quality services

Basin		Al	B	Ba	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Si	Sr	Ti	Zn
Anna Comstock	Percent Change	-96	-191	35	-20	-94	-84	-99	64	7	-99	3884	-111	-100	-186	150	-73	394	-97	-95
	Change (ppm)	-8.34	-0.20	0.09	-57.53	-0.03	-0.09	-40.61	4.28	3.22	-1.38	168.59	-0.04	-1.59	-0.30	30.05	-9.62	3.99	-0.09	-0.57
EHOB	Percent Change	15	-79	145	-4	57	59	137	170	-37	155	136	78	82	98	-50	63	-17	6	57
	Change (ppm)	3.82	-0.08	0.10	-2.82	0.01	0.01	18.71	14.50	-4.64	0.43	81.20	0.01	0.31	0.07	-13.32	5.65	-0.10	0.00	0.06
LARTU	Percent Change	-88	40	-71	-58	-78	-76	-93	-53	-71	108	-5	-91	-39	-72	-66	-45	-62	-96	-85
	Change (ppm)	-3.43	0.03	-0.16	-69.05	-0.01	-0.02	-8.50	-5.86	-13.05	0.73	-5.90	-0.01	-0.11	-0.06	-11.21	-3.55	-0.20	-0.03	-0.13
Oxley	Percent Change	-64	100	3	29	-60	-28	-67	23	-45	-63	269	-27	-70	-32	-62	-12	5	-60	-59
	Change (ppm)	-8.27	0.08	0.00	7.73	0.00	0.00	-3.97	0.49	-2.05	-0.09	22.17	0.00	-0.39	-0.02	-3.56	-0.37	0.00	-0.01	-0.07
Rice	Percent Change	-37	-7	-32	-67	-67	-73	-61	-4	-73	-62	0	-25	-37	-6	-93	-15	-83	-48	-79
	Change (ppm)	-1.33	-0.01	-0.03	-56.19	-0.01	-0.03	-7.55	-0.07	-10.73	-0.22	0.01	0.00	-0.22	-0.01	-20.43	-0.73	-0.18	-0.02	-0.22
Rite Aid	Percent Change	-8	-258	22	-1	33	-14	-82	15	-4	113	40	281	150	-970	0	-19	0	-95	17
	Change (ppm)	-0.01	-0.18	0.01	-1.20	0.00	0.00	-0.75	0.72	-0.91	0.01	33.72	0.00	0.04	-0.24	0.02	-0.85	0.00	0.00	0.00

Table 2. Change in concentration (% and absolute, in ppm) of metals and cations, as calculated from the difference between the basin outflow and inflow concentrations. Note no data is available for B-lot or Wrestling basins since inflow and outflow samples were not able to be collected from the same storm events.

Basin		**NO_3^--N**	**NO_2^--N**	**Cl^-**	**SO_4^{2-}**
Anna Comstock	Percent Change	3907	99	13224	-98
	Change (ppm)	11.89	0.04	990.99	-858.93
EHOB	Percent Change	2583	147	869	-100
	Change (ppm)	10.04	0.22	2272.93	-1248.40
LARTU	Percent Change	4	-67	-62	-99
	Change (ppm)	0.06	-0.03	-824.89	-1554.78
Oxley	Percent Change	163	-7	340	-38
	Change (ppm)	0.43	0.00	94.46	-166.24
Rice	Percent Change	45	-26	1	-86
	Change (ppm)	0.11	-0.01	0.31	-801.86
Rite Aid	Percent Change	-41	44	40	3
	Change (ppm)	-0.18	0.01	76.23	30.05

Table 3. Change in concentration (% and absolute, in ppm) of anions, as calculated from the difference between the basin outflow and inflow concentrations. Note no data is available for B-lot or Wrestling basins since inflow and outflow samples were not able to be collected from the same storm events.