Analysis of stormwater runoff in Mount Holly Springs and its impact on Mountain Creek, a tributary to Yellow Breeches Creek, Cumberland County, PA

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ABSTRACT

Mountain Creek, in Cumberland County, PA flows through a 123 square-kilometer watershed of predominantly forested and agricultural land; it passes through the Borough of Mount Holly Springs (MHS) just before its confluence with Yellow Breeches Creek. MHS, the only urban area in the Mountain Creek watershed, covers 3.9 square kilometers of residential, commercial, and industrial land use. Although MHS is a relatively small urban area, urban stormwater runoff can impair receiving streams due to increased impervious cover and pollution from urban land use. This study investigates the potential impairment of Mountain Creek from increased pollutant loads during runoff events in MHS. Sampling sites were located 5 meters upstream, at, and 8 meters downstream of two stormwater discharge pipes which drain the majority of MHS. Water samples were collected during and between storm and snowmelt events from September, 2007 to March, 2008. Samples were analyzed for pH, conductivity, dissolved oxygen, alkalinity, total hardness, nitrate-nitrogen, reactive phosphorus, chloride, lead, copper, zinc, iron, cadmium, chromium, manganese, magnesium, total suspended solids, total dissolved solids, and fecal coliform. Water chemistry analysis showed increased concentrations of lead, copper, zinc, iron, chromium, and manganese directly downstream of the discharge pipes. Snowmelt caused an increase in downstream chloride concentrations, and contained high levels of cadmium and manganese. Stormwater discharged from these pipes exceed EPA aquatic life standards for cadmium, copper, lead, and zinc. The two storm events analyzed for metal concentrations showed that longer dry antecedent conditions result in higher concentrations of runoff pollutants. MHS has much lower annual per acre pollutant loads than Carlisle, a neighboring town, but had higher manganese pollutant loads which require further investigation into the source and effects of this metal on Mountain Creek. Further research on stormwater in MHS should incorporate stream sediment analysis to determine if metals are accumulating in sediment downstream of the pipes.

Table of Contents

List of Tables and Figures

INTRODUCTION

Urban development has a major influence on stream quality, as it increases the impervious land area which diminishes infiltration and increases runoff (Brezonik and Stadelmann 2002, Maryland Department of the Environment 2000). These impervious surfaces accumulate pollutants from atmospheric deposition of contaminants, vehicle leaks and exhaust, lawns, pet waste, and eroded soils. As rainwater flows over impervious surfaces, it accumulates pollutants and enters local waterways without being treated (Maryland Department of the Environment 2000). Urban stormwater runoff is considered nonpoint source pollution, and has been identified as an important cause of surface water quality degradation throughout the United States (Brezonik and Stadelmann 2002).

In 1983, the U.S. Environmental Protection Agency published the results of the Nationwide Urban Runoff Program (NURP) and established common pollutants and concentrations found in stormwater runoff across the country. Heavy metals, particularly copper, lead, and zinc were the most prevalent pollutants found in urban runoff and often exceeded drinking water standards and ambient water criteria (U.S. EPA 1983). In Carlisle, PA, Wilderman (1997) found that higher metal concentrations are attributed to higher densities of vehicular traffic. Corrosion and wear on vehicles' alloys, brake linings, tires, and paint, as well as fluid leaks, and atmospheric fallout from exhaust are primary constituents of the metals present in stormwater runoff (Wilderman 1997). Many metals in the runoff are found in solid form bound to sediments and particulates, which increases the build-up of contaminated sediments in the stream (Kayhanian *et al.* 2007). NURP also reported that lower pH in rain and streams may result in increased metal concentrations (U.S. EPA 1983). The goal of this research was to determine what pollutants were present in stormwater runoff from MHS and if these pollutants were having an effect on water quality in Mountain Creek.

Mountain Creek is a major tributary to Yellow Breeches Creek, and flows northeast from its headwaters in northern Adams County to its convergence with Yellow Breeches in Cumberland County, Pennsylvania (Figure 1). Mountain Creek is approximately 29 km long, and includes a drainage basin of approximately 123 km^2 (Herbert *et al.* 2005).

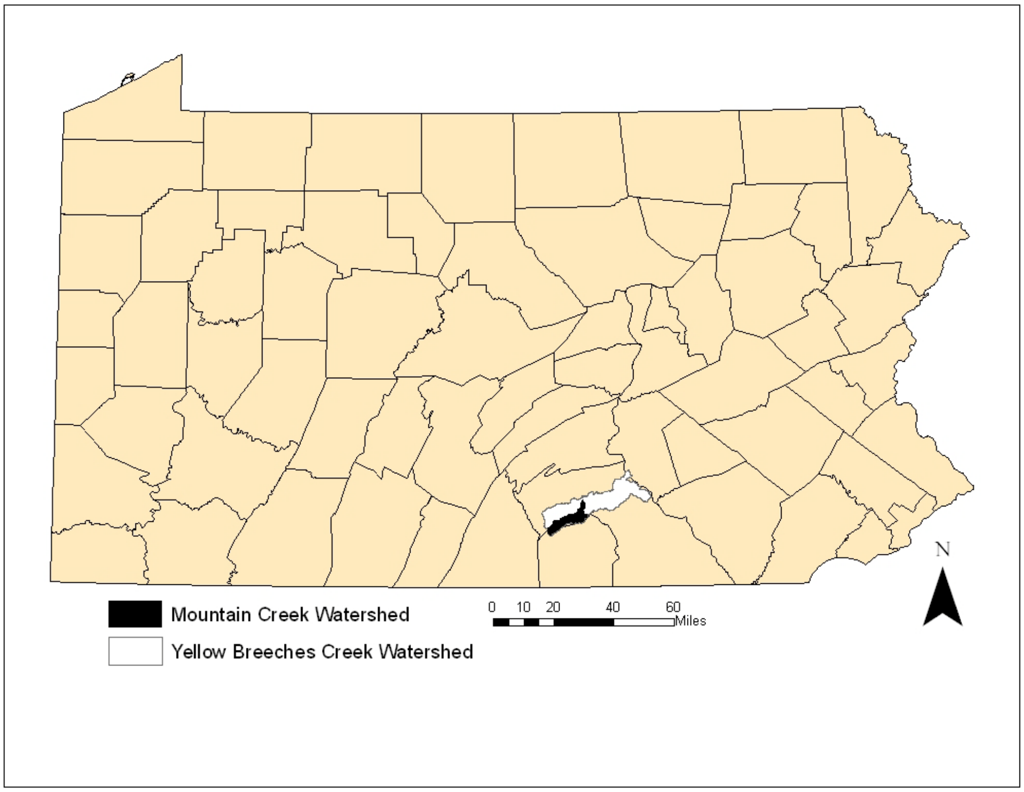


Figure 1. Location of Mountain Creek watershed in Pennsylvania (DuPrey 2006).

Beginning in the Blue Ridge Province, Mountain Creek meets with the Yellow Breeches Creek at the southern boundary of the Valley and Ridge Province. The predominant geological formations are metarhyolite, Weaverton quartzite, Montalto member of Harpers formation, and Tomstown dolomite (Figure 2). The Tomstown dolomite, as well as the Elbrook and Waynesboro limestone formations, provide streams with carbonate ions that aid in neutralizing acids (Freedman 2006).

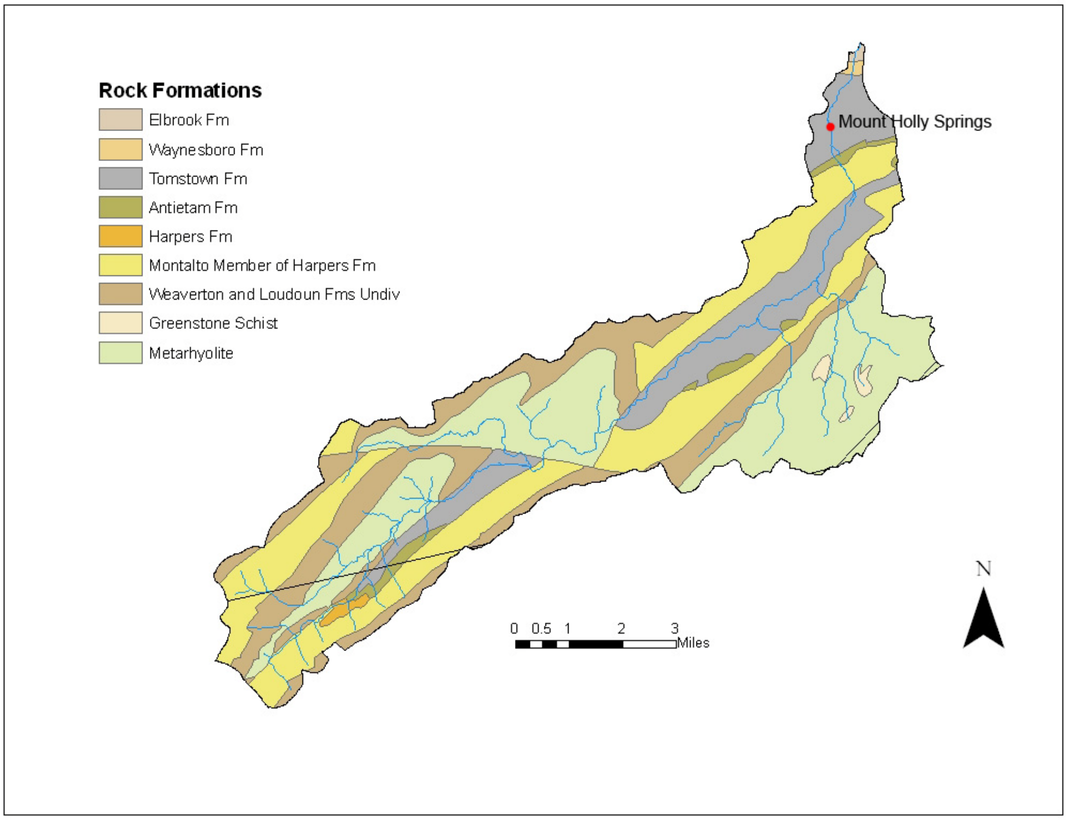


Figure 2. Geology of Mountain Creek watershed (DuPrey 2006).

The designated uses of Mountain Creek were determined based on criteria set forth by the Commonwealth Chapter 93 Water Quality Standards (Pennsylvania Code 2004). Designated use refers to the highest possible use of the stream based on unimpaired ecological capabilities, rather than the actual site use. As Mountain Creek travels from the headwaters into increasingly developed areas, its designated use diminishes (Table 1, Figure 3). When Mountain Creek enters Mount Holly Springs (MHS) its designated use is lowered to a trout stocking fishery, but the reason for the change is not specified.

Segment of Mountain Creek	**Length (mi)**	**Drainage Area (km^2)**	**Designated Use**
Headwaters to Toland	12.1	87.4	High Quality Cold Water Fishery
Toland to Mt. Holly Springs	4.5	29.2	Cold Water Fishery
Mt. Holly Springs to Mouth	1.5	6.2	Trout Stocking Fishery

Table 1. Length, drainage area, and designated uses of Mountain Creek (Herbert et al. 2005).

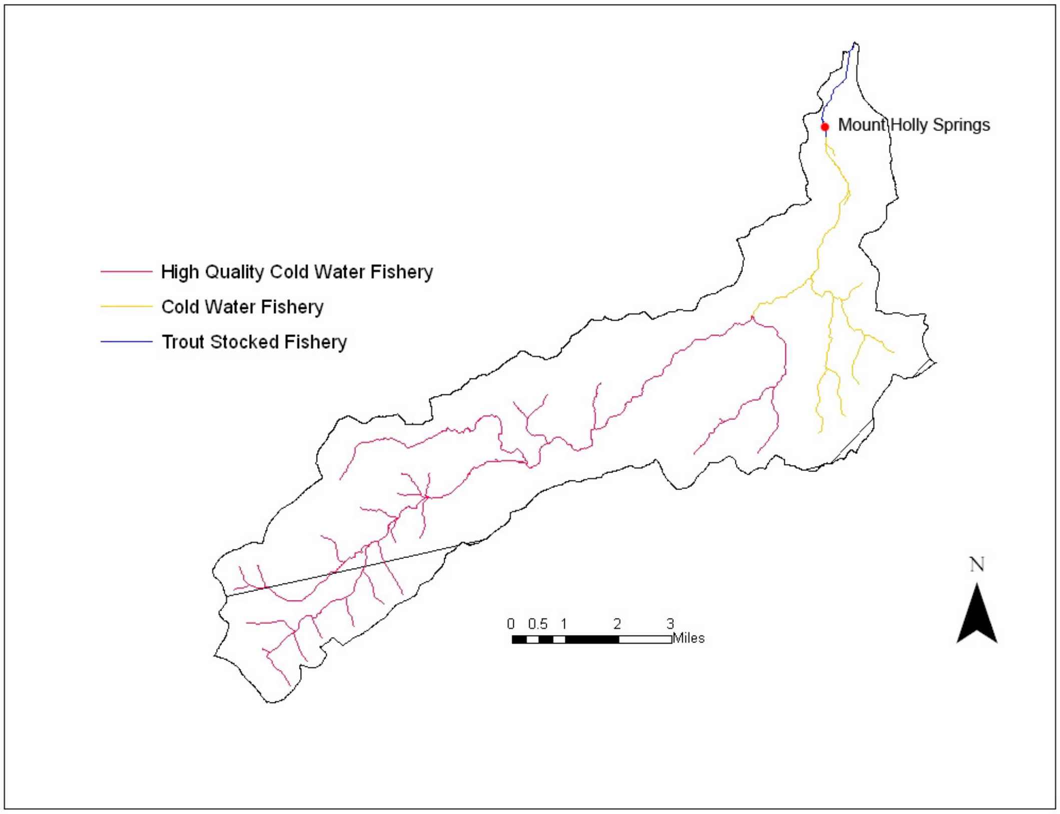


Figure 3. Designated uses for Mountain Creek (DuPrey, 2006).

The Mountain Creek watershed deserves attention as it contains pristine habitat and potentially high water quality. The creek runs along Laurel Lake and Fuller Lake in Pine Grove Furnace State Park, two popular recreational areas. From the headwaters to approximately 1.6 km east of Fuller Lake, Mountain Creek runs through forests lands of the Michaux State Forest (Figure 4).

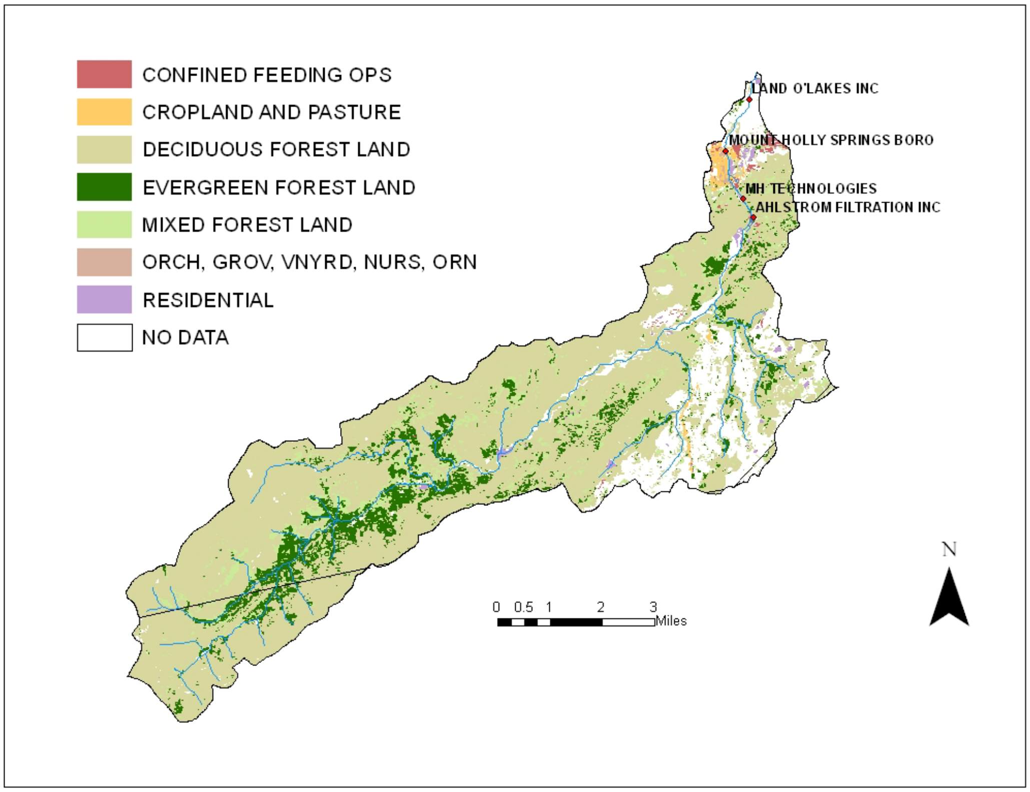


Figure 4. Land use and location of point dischargers in Mountain Creek (DuPrey, 2006).

Although a significant portion of the watershed falls within the Michaux State Forest, the stretch from MHS to the confluence with Yellow Breeches covers 6.2 km^2 of the drainage basin (Table 1; Herbert *et al.* 2005). This area is the first major urban area through which Mountain Creek flows. MHS is located just south of Carlisle, PA, and may share similar stormwater runoff characteristics. Wilderman (1997) found that stormwater runoff from trucking areas in Carlisle had the highest concentration of pollutants per acre, followed by urban, suburban, agricultural, and upstream areas. Due to the proximity of MHS to Carlisle, it is possible that truck traffic as well as suburban and urban land use may be contributing to stormwater pollution in MHS. Route 34 is the largest highway through the Mountain Creek watershed and shifts from a primarily non-urban to an urban highway as it passes through MHS, which may cause an increase in runoff pollutant concentrations (Kayhanian *et al.* 2007).

A preliminary study on the Mountain Creek watershed provides baseline data for the areas of headwater acidification near Dead Woman's Hollow, establishment of a reference site near Fuller Lake, and an initial study on the impact of Land O' Lakes creamery, a NPDES point discharger, on Mountain Creek (Freedman 2006). Due to time and personnel restrictions, stormwater runoff in MHS was not assessed in this study. Cioce (2006) and Korman (2006) researched the impact of Mt. Holly Sewage Treatment Plant (STP) and Land O' Lakes creamery, two NPDES point dischargers, on Mountain Creek. Mt. Holly STP is located in the northern part of MHS along Mill Road, and Land O' Lakes is located north of MHS before the confluence with Yellow Breeches Creek. Korman (2006) used macroinvertebrates as a bioindicator of stream impairment, and found that the Fuller Lake reference site had the highest overall bioassessment. The macroinvertebrate communities indicated degradation between Fuller Lake and Mount Holly STP, with slight recovery between the STP and upstream Land O' Lakes, followed by further degradation from the Land O' Lakes effluent. As the STP is located on the northern edge of MHS, it is important do an assessment of macroinvertebrate communities in the MHS portion of Mountain Creek to determine if stream biota are impacted by stormwater runoff before the creek reaches the STP point discharger. Miller (2007) found that stormwater runoff was not having an immediate impact on macroinvertebrate populations in the MHS portion of Mountain Creek. Instead, silt and sediment deposited by the stormwater effluent pipes degraded the benthic habitat after a storm, resulting in a decline in healthy macroinvertebrate populations (Miller 2007).

As MHS is the first urban area in the Mountain Creek watershed and is in close proximity to the confluence with Yellow Breeches Creek, it is important to study the potential impacts of MHS on Mountain Creek; metals and other pollutants from runoff events in MHS could be impacting Mountain Creek as well as Yellow Breeches Creek. This study investigates the impacts of stormwater runoff in MHS on the water column chemistry of Mountain Creek, and compares the chemical composition of stormwater in MHS to Carlisle, PA to determine if MHS produces more polluted runoff than neighboring towns. The data may also be useful to groups such as the Yellow Breeches Watershed Association (YBWA) and Cumberland Valley Trout Unlimited (CVTU) to develop a monitoring program for the MHS portion of Mountain Creek and promote best management practices (BMPs) to reduce stormwater pollution in MHS.

METHODS

Site Selection and Rationale

Three stormwater discharge pipes are located along Mountain Creek at East Pine Street Bridge, Mountain Creek Alley behind the Exigent Bike Cover shop (just north of Church Street), and at the end of Butler Lane. The size and structure of the pipes indicates that they were designed to discharge different volumes of stormwater. There is no map of the storm sewer system in MHS, so it is difficult to determine the exact drainage area for each stormwater pipe. Jim Horner from the Mt. Holly STP (personal communication, October 5, 2007) provided information as to the general drainage area for each pipe:

- **Pine Street Bridge pipe (PSBP):** two corrugated galvanized metal pipes approximately 0.4m in diameter, left pipe was observed to be the stormwater discharger, drains the Hill Street and West Pine Street areas.
- **Mountain Creek Alley pipe (MCAP):** one corrugated galvanized metal pipe approximately 0.8m in diameter drains a portion of Baltimore Avenue and Church Street.
- **Butler Lane pipe (BLP):** one concrete pipe approximately 1.0m in diameter, observed to discharge a much larger volume of runoff during storms than PSBP and MCAP, drains most of the central and northern regions of MHS.

PSBP and BLP were selected as sampling sites because PSBP is the first stormwater outfall pipe in MHS and BLP is the furthest downstream (Figure 5). Also, these pipes are downstream of MH Technologies point discharge and upstream of Mount Holly STP discharge, thus avoiding these interferences. Sampling sites were selected between 5-8m upstream and downstream from PSBP and BLP so that the direct impact of stormwater outfall from the pipes can be determined (Table 2).

Figure 5. Location of Pine Street Bridge pipe (PSBP) and Butler Lane pipe (BLP) along Mountain Creek, flowing north. *Aerial image courtesy of Google Maps.*

Site # [Name]	Site Description
Site 1 [PSBU]	5m upstream of PSBP outfall
[PSBP]	Directly from the pipe discharge
Site 2 [PSBD]	8m downstream of PSBP outfall
Site 3 [BLU]	5m upstream of BLP outfall
[BLP]	Directly from the pipe discharge
Site 4 [BLD]	8m downstream of BLP outfall

Table 2. Site number, name abbreviations, and short descriptions.

Sampling and Analysis

In order to determine the composition of MHS stormwater runoff and its impact on Mountain Creek, samples were collected in the creek approximately 5-8 meters upstream and downstream from PSBP and BLP between storm events, during storm events, and during a snowmelt event. During storm and snowmelt events, stormwater was also sampled directly from the outfall pipes. Water chemistry was assessed using the methods listed in Table 3. Sample bottle preparation, sampling, and analysis techniques followed the protocol in *Standard Methods* 21st Edition (Eaton *et al.* 2005).

Parameter	**Method Used for Analysis**
pH	YSI 60 pH and temperature meter
Conductivity	YSI 30 Salinity, conductivity, and temperature meter
Dissolved oxygen	YSI 550A Dissolved oxygen and temperature meter
Alkalinity	LaMotte Test Kit
Total Hardness	LaMotte Test Kit
Nitrate-nitrogen	HACH Spectrophotometer 2010: Cadmium Reduction Method
Reactive phosphorus	HACH Spectrophotometer 2010: Ascorbic Acid Method
Chloride	HACH Spectrophotometer 2010: Thiocyanate Method
Total Suspended Solids	Filtration, gravimetric method
Total Dissolved Solids	Filtration, evaporation method
Fecal Coliform	Membrane filtration and incubation
Metals (Pb, Cu, Zn, Fe, Cr, Cd, Mg, Mn)	Inductively coupled plasma mass spectroscopy at Towson University

Table 3. Water chemistry parameters and methodology used to analyze samples.

Sampling Dates

Water samples were collected from sampling sites between storm events, during two storm events, and during a snowmelt event (Table 4). PSB Pipe and BL Pipe could not be sampled on October 5, 2007, as there was not a storm. On September 11, 2007, only metal samples were collected from PSB Pipe as this storm occurred before the study was fully designed and other sample bottles were not prepared. Samples from October 19, 2007 were collected during the first 45 minutes of the storm for all sites. The March 2, 2008 snowmelt event was not anticipated, and only enough sample bottles were prepared for 4 sites. During this event, there was no effluent coming from BL Pipe, as the accumulated snow in this portion of MHS may have melted during the previous day. PSB Pipe drains a portion of MHS that is a slightly higher elevation than the rest of the town, which may explain why the snow in this area was just starting to melt. This also indicates that the accumulated snow had been melting for a few days, which would result in lower pollutant concentrations in the snowmelt collected on March 2.

Site	Between Storm 10/5/07	Storm Runoff 9/11/07	Storm Runoff 10/19/07	Snowmelt 3/2/08
Site 1: PSBU	X		X	X
PSB Pipe		X	X	X
Site 2: PSBD	X		X	
Site 3: BLU	X		X	X
BL Pipe			X	
Site 4: BLD	X		X	X

Table 4. Sampling dates and sites for between storm, runoff, and snowmelt events.

Modeling Annual Pollutant Loads

A simple linear model called the "Poison Runoff Index" was used to estimate the total annual load of various stormwater pollutants to Mountain Creek (Nezil-Salvaggio *et al.* 1990). Calculations are based on land use, total rainfall, and average pollutant concentrations for the specific area using the formula:

$$\mathbf{L = [\ (P)\ (Pj)\ (Rv)/12\ ]\ (C)\ (A)\ 2.72}$$

where L = pollutant load [in pounds] over a given time interval

P = rainfall depth per given time interval (per year) [in inches]

Pj = corrects P for storms that produce no runoff, 0.9

Rv = 0.05 + 0.9 (I), I = site imperviousness

C = average concentration of pollutant in urban runoff (mg/L)

A = area [in acres]

2.72 and 12 are unit conversions factors

Although there are no maps of the storm sewer system in MHS, Jim Horner (2007) provided insight on which streets drain into the different stormwater outfall pipes. Based on this information, MHS was divided into two subwatersheds for the Pine Street Bridge pipe and the Butler Lane pipe (Figure 6, altered zoning map). The imperviousness for each subwatershed was estimated by measuring the area of land in each zoning code within the MHS Borough boundaries using a Lasisco Model L10 planimeter. Each zoning code was assigned a percent imperviousness value, as described by Nezil-Salvaggio *et al.* (1990), which was multiplied by the area of each zoning code in the subwatersheds and summed to estimate the total impervious cover. In MHS, zoning for V-1 and V-2 Village were treated as R-1 Residential, as visual observation of these areas found similar lot size and housing density.

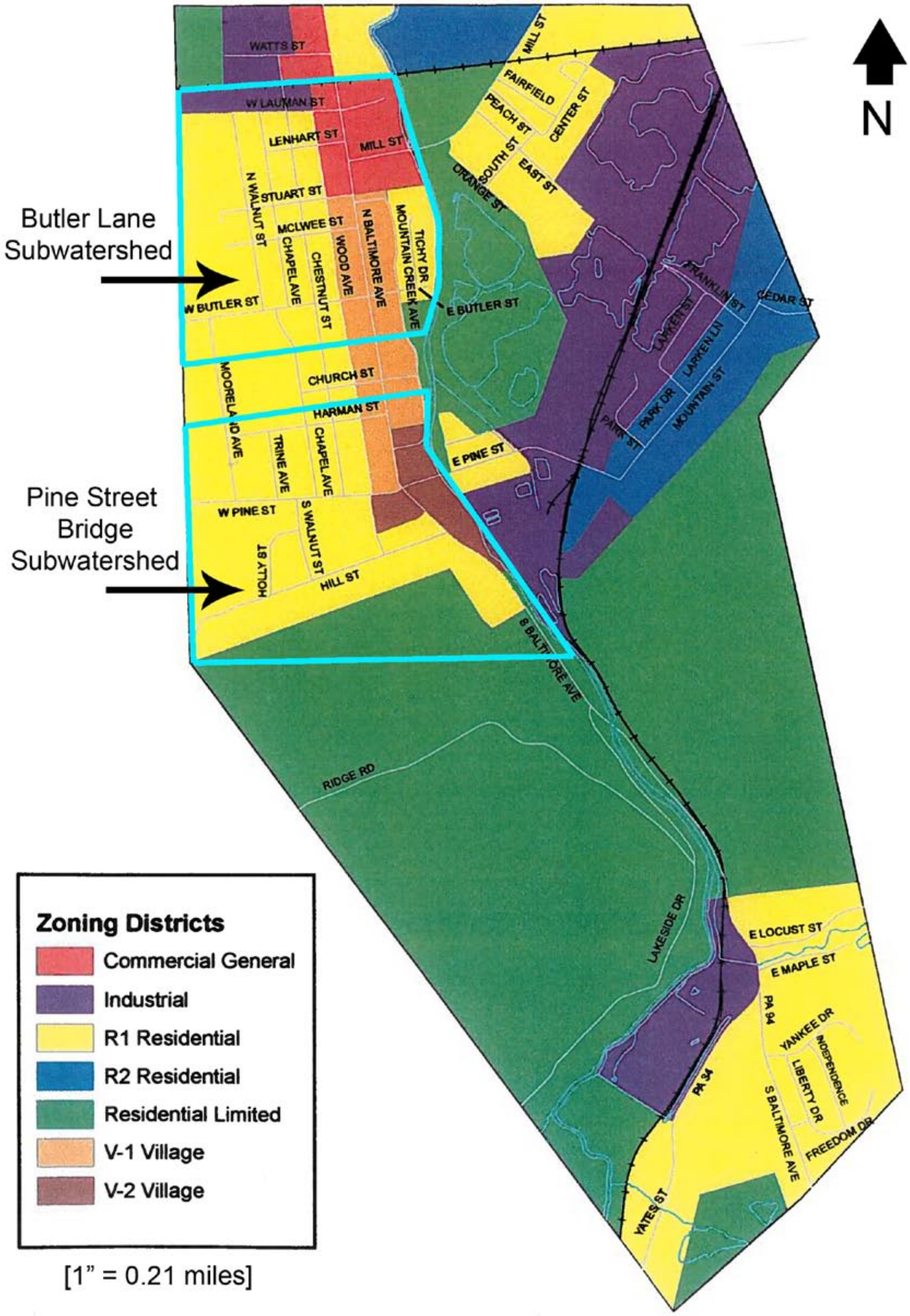


Figure 6. Zoning map of MHS divided into subwatersheds to PSBP and BLP. *Map courtesy of Matt Bonanno.*

RESULTS AND DISCUSSION

Impact of Runoff on Mountain Creek

In order to determine if runoff from the Pine Street Bridge and Butler Lane pipes impacts water quality in Mountain Creek downstream of the pipes, the between storm data were compared to stormwater runoff and snowmelt events (Table 4). This portion of the analysis only includes stormwater runoff data from October 19, 2007, as all sites were sampled. Due to the different antecedent conditions and incomplete data set for the September 11, 2007 storm event, these data were not included in determining the downstream impacts.

There was only slight variation in temperature at Sites 1, 2, 3, and 4 during between storm and runoff events, indicating that runoff does not impact temperature in Mountain Creek (Figure 7). Although temperature was higher at PSB Pipe and BL Pipe during the storm runoff event, it did not cause a downstream increase in temperature. These higher temperatures can be attributed to the runoff flowing over warm pavement and other surfaces in MHS before it is concentrated into the discharge pipes. Snowmelt temperatures were much lower due the winter weather conditions, and did not show variation between the sites. The snowmelt effluent from PSB Pipe was similar to the in-stream conditions, since the overcast conditions may have prevented pavement and other surfaces from absorbing heat from the sun. The decrease between Sites 1 and 2 could be explained by the shadow cast by Pine Street Bridge over Site 2, resulting in a slightly colder stream temperature.

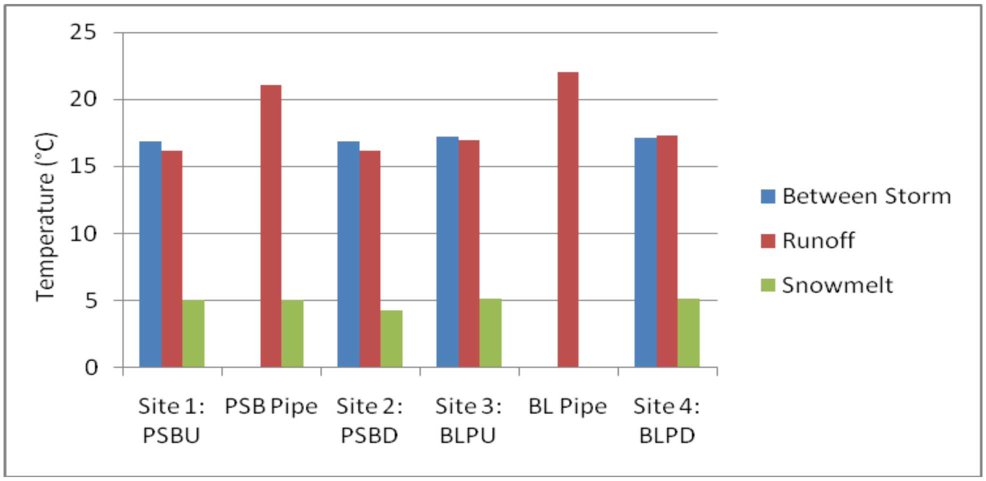


Figure 7. Temperature (°C) for between storm, runoff, and snowmelt events.

When compared to between storm conditions, dissolved oxygen was slightly lower during the storm runoff event and higher the during snowmelt event (Figure 8). As MHS is towards the end of the Mountain Creek watershed, the lower in-stream values during the storm may be due to increased flow from runoff throughout the watershed—higher stream levels from increased flow may cover shallow riffle zones, which help in oxygenating the water. Although the pipes have lower dissolved oxygen values during the storm, there is no downstream impact. Also, there was no downstream impact from snowmelt.

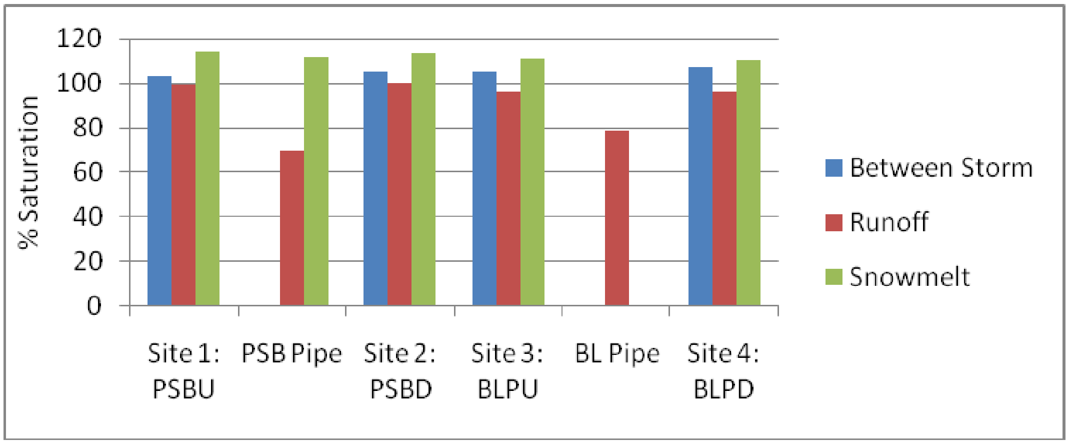


Figure 8. Dissolved oxygen(% saturation) for between storm, runoff, and snowmelt events.

pH was rather consistenent for between storm, storm, and snowmelt events (Figure 9). Despite the acidic nature of rain in Pennsylvania, all values were between pH 7.68 – 8.52. The in-stream values remain fairly stable, with no downstream impact. This could be attributed to the alkalinity and hardness derived from the dolomite bedrock underlying the MHS portion of Mountain Creek. While the pH of rainwater and snow in MHS before surface contact was not measured, the pH of effluent from both pipes is slightly basic and similar to the in-stream values. Unless the runoff encounters sources of alkalinity as it flows into the effluent pipes, this indicates that acid deposition is not a problem in MHS.

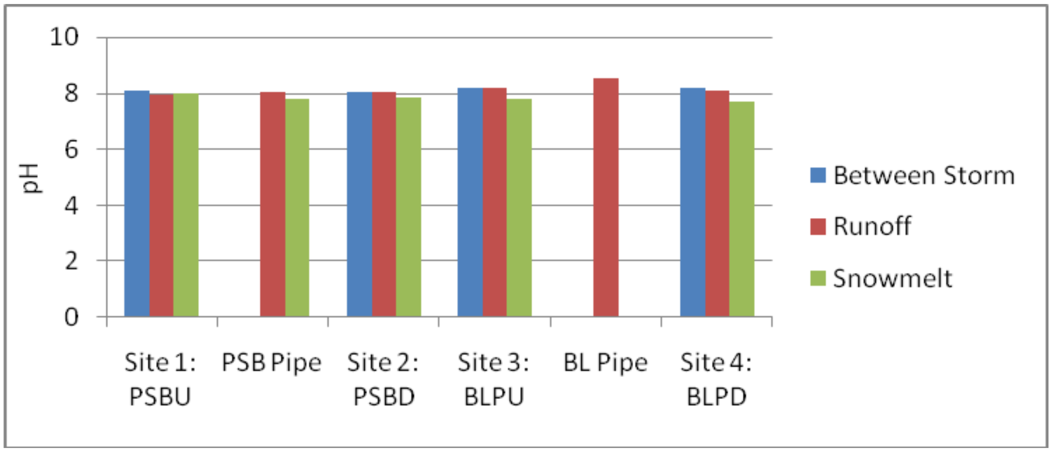


Figure 9. pH for between storm, runoff, and snowmelt events.

There was a slight decrease in in-stream alkalinity levels during the storm runoff event compared to between storm levels (Figure 10). Natural rainwater does not have any alkalinity, therefore the runoff throughout the Mountain Creek watershed may cause a dilution of the alkalintiy concentration within the stream. This slight decrease may also be attributed to alkainity being used up to neutralize acidic rainfall, but the pH data does not support this relationship. Alkalinity declines between Sites 1-4 during the storm event, which can be attributed to a dilution effect from the lower alkalinity concentrations at the pipes. Although discharge of Mountain Creek was not measured during any of the sampling dates, higher stream levels were observed during the snowmelt event. Snowmelt conditions were not assessed throughout the Mountain Creek watershed, but it is possible that a large volume of snowmelt in the upstream portions of the watershed would have enough of a dilution effect to significanlty reduce the alkalinity to the low levels at the sampling sites.

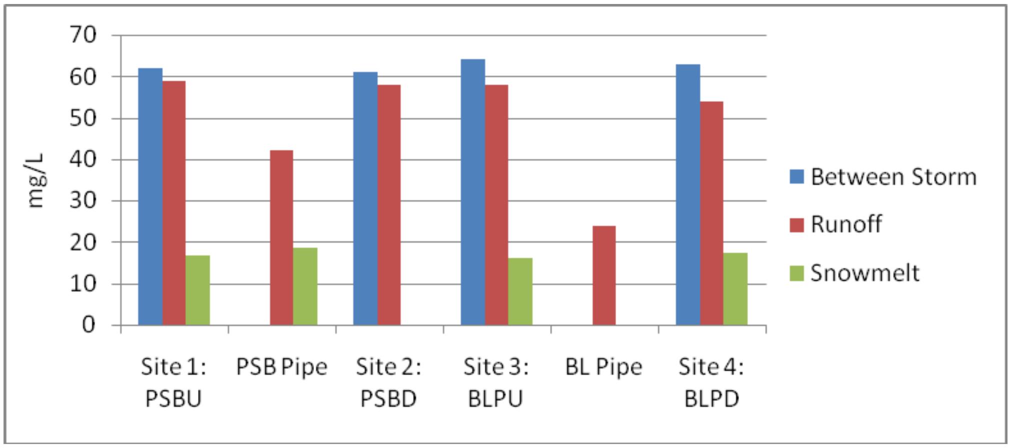


Figure 10. Alkalinity (mg/L) for between storm, runoff, and snowmelt events.

Hardness showed similar trends as alkalinity, and is naturally occuring in Mountain Creek from the dolomite in the region. While alkalintiy and hardness exhibit the same trends, it is interesting to note that there is more in-stream variation during both between storm and storm events (Figure 11). The hardness at Site 3 during the storm event had the highest values, indicating that calcium or magnesium ions were entering the stream between Sites 2 and 3. A large pile of crushed, light colored rock was observed along the stream bank between Site 2 and 3, but was located on private property and could not be closely examined. It is possible that this rock was limestone and some of it was dissolved by runoff or washed into the stream, but alkalinity levels did not increase between the sites (Figure 10, Figure 11).

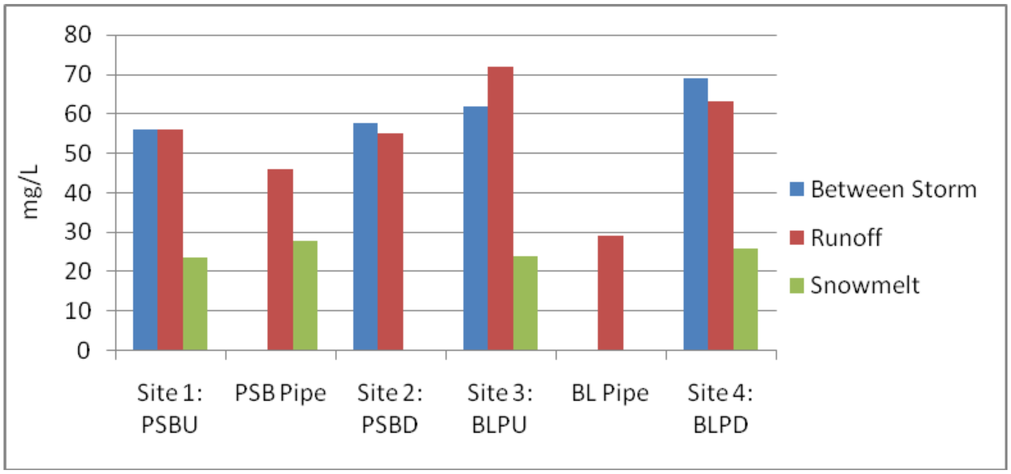


Figure 11. Hardness (mg/L) for between storm, runoff, and snowmelt events.

Conductivity was higher during the storm runoff events, indicating a higher concentration of dissolved ions such as metals, chloride, nitrates, and phosphates (Figure 12). There was no change downstream from the pipes at Site 2 and 4, however the higher levels at Sites 3 and 4 compared to Sites 1 and 2 suggest that stormwater from MHS is increasing conductivity in Mountain Creek as it flows through the town. Interestingly, snowmelt had lower levels of conductivty and was fairly consistent between all sites.

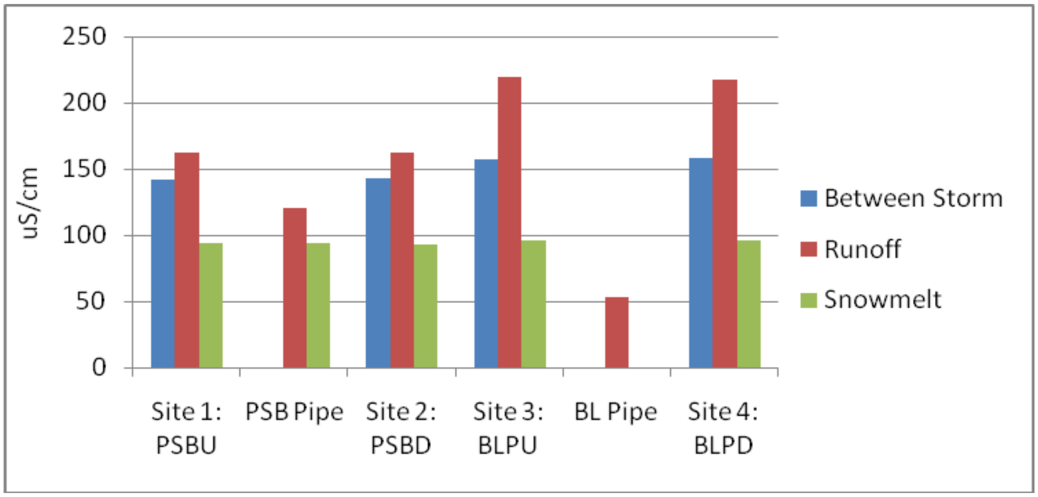


Figure 12. Conductivity (uS/cm) for between storm, runoff, and snowmelt events.

Total dissolved solids (TDS) were generally much higher during the storm, with the exception of Site 2 (Figure 13). During the storm there was a continual increase in TDS between Sites 1 and 3, indicating that the stormwater runoff is increasing TDS concentrations in Mountain Creek as it flows through the town. Snowmelt does not follow this trend and instead shows a decrease in TDS between Sites 1 – 4. The concentration of TDS added to the stream by

PSBP may have been diluted downwstream by the increased flow of Mountain Creek, and there was no snowmelt entering the stream from BLP.

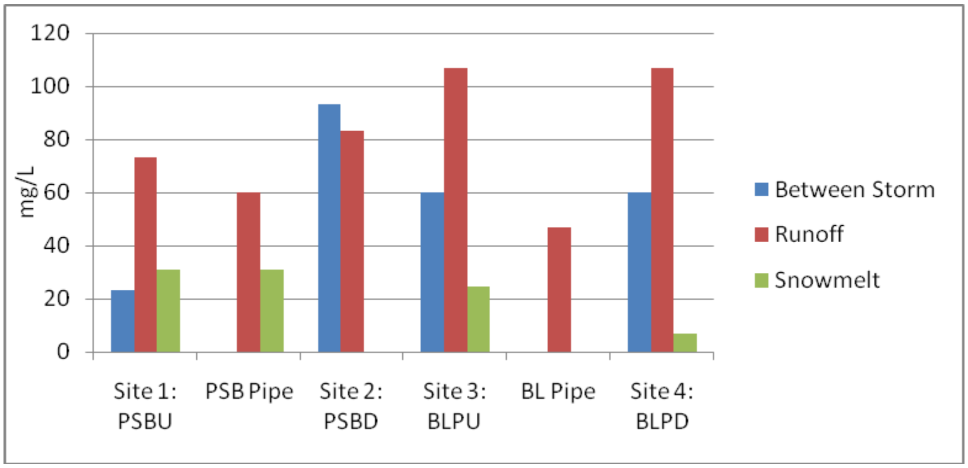


Figure 13. Total dissolved solids (mg/L) for between storm, runoff, and snowmelt events.

The methodology for total suspended solids (TSS) often produced negative results, as when there were low suspended solids in a sample, small particles of the filter paper were removed by the filtration process and resulted in less mass. These negative values were assigned 0.0 mg/L TSS. With the exception of Site 4, there were no suspended solids during between storm events (Figure 14). The high levels of TSS at Site 4 were probably due to the disruption of the silt and sediments deposited on the stream bottom by BLP during previous runoff events. The steep banks downstream of BLP make it difficult to access Site 4 without walking in the stream, thereby disturbing and re-suspending some sediment. BLP had the highest TSS during the storm, and could be attributed to the increase at Site 4. The snowmelt event had higher TSS than the storm for Site 1, PSBP, and Site 3, but had 0.0 mg/L at Site 4. This could be explained by the lack of snowmelt from BLP.

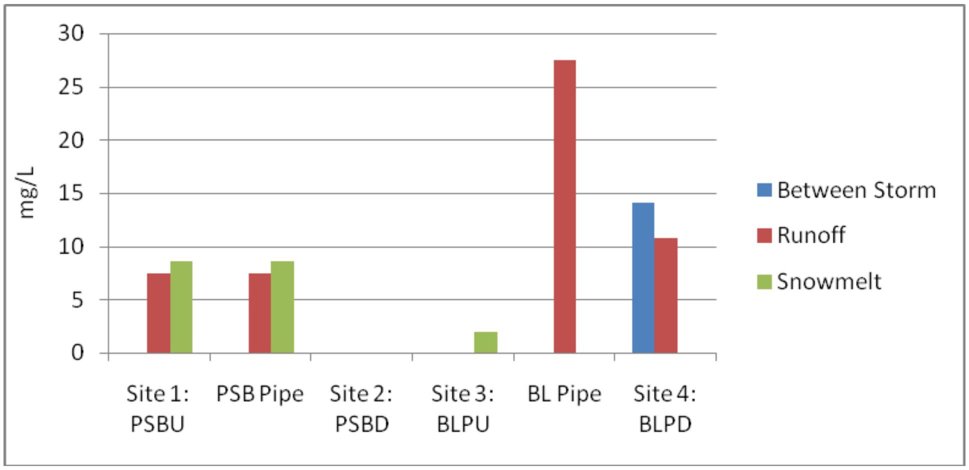


Figure 14. Total suspended solids (mg/L) for between storm, runoff, and snowmelt events.

Nitrate-nitrogen concentrations were not impacted by stormwater runoff, as the between storm levels were much higher (Figure 15). Although the nitrate concentration was high at PSBP during the storm, it did not increase levels downstream. The snowmelt had much higher in-stream nitrate concentrations than the storm event, but had lower concentrations at PSBP. There was an increased algae presence observed during the snowmelt event, indicating that the higher in-stream nutrient levels may be attributed to seasonal differences or from the release of pet waste and fertilizers trapped in the snow.

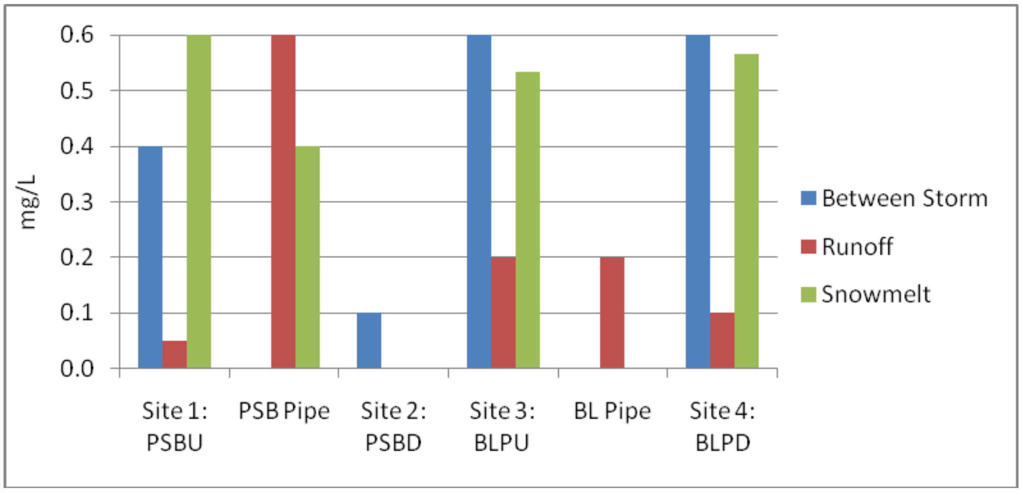


Figure 15. Nitrate-nitrogen (mg/L) for between storm, runoff, and snowmelt events.

Reactive phosphorous fluctuates between sites during all events (Figure 16). Only the snowmelt event shows a consistent trend as it decreases between Sites 1 and 4, suggesting that snowmelt is not a significant source of phosphorous and is instead diluting phosphorous levels in the stream. The slight increase between Sites 1 and 2 during the storm can be attributed to higher concentration from PSBP. The large increase between Sites 3 and 4 should not be attributed to BLP, as reactive phosphorous concentrations at BLP were only slightly higher than Site 3 and could not cause the extreme increase found at Site 4—this value is significantly higher than any other site, suggesting a contaminated or erroneous sample. The house just south of Butler Lane has a well-maintained lawn that is mowed right up the steep stream bank, suggesting that a heavy amount of phosphorous-rich fertilizers running off of the grass into the stream at Site 4. Further sampling will determine if this is a reproducible result.

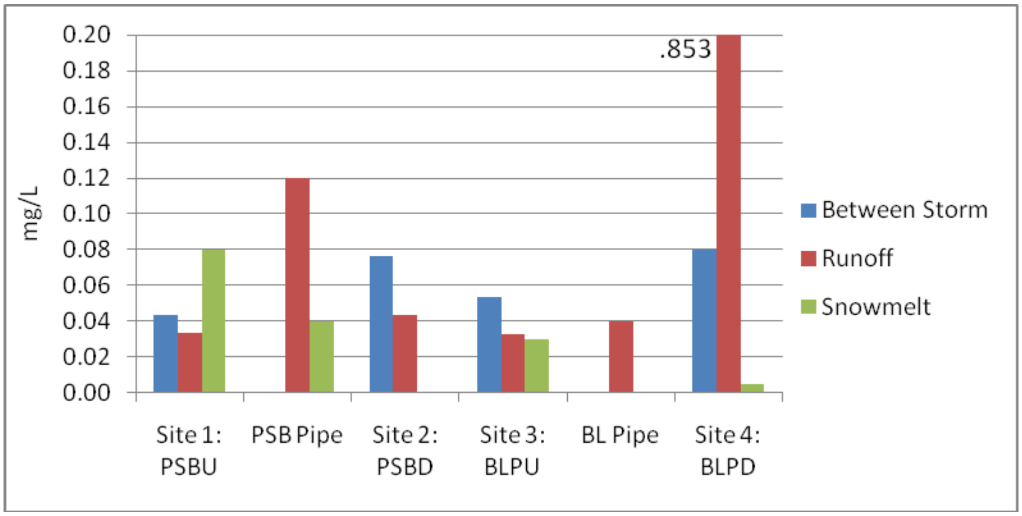


Figure 16. Reactive phosphorous (mg/L) for between storm, runoff, and snowmelt events.

There was no between storm data for chloride, as the proper reagents for the HACH thiocyanate method were not obtained until after these samples were no longer viable. Both Sites 2 and 4 show an increase in chloride downstream of the discharge pipes during the storm, but the decrease between Sites 2 and 3 indicates that the stream recovered from the increased chloride concentrations added by PSBP (Figure 17). The snowmelt event had higher chloride levels than the storm, especially at Site 3 and 4, which could be attributed to an accumulation of salts from roads and sidewalks. Despite the lack of snowmelt effluent from BLP, there is an increase between Site 3 and 4 which indicates that snowmelt in MHS may have increased chloride concentrations in Mountain Creek as it flows through the town.

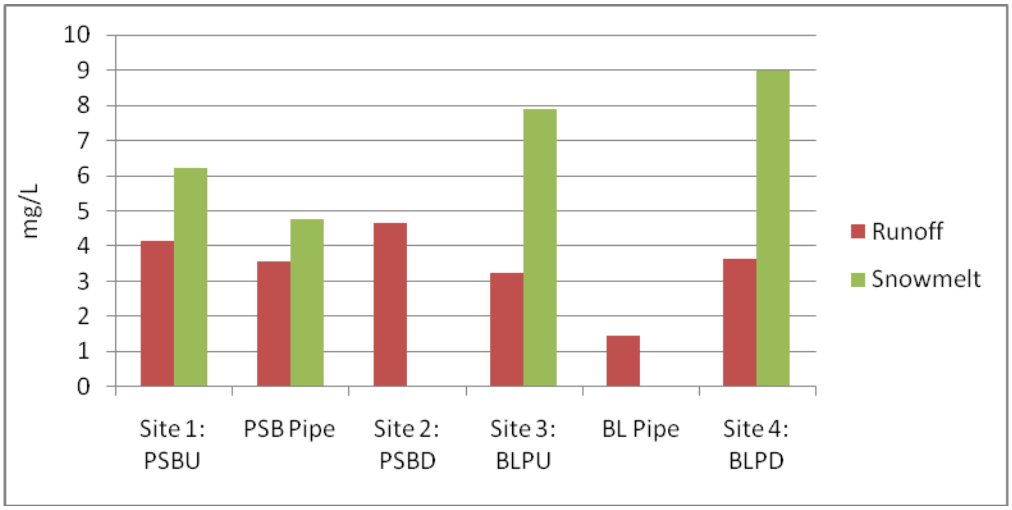


Figure 17. Chloride (mg/L) for storm runoff and snowmelt events.

Fecal coliform bacteria are generally found at high levels in urban runoff, and will usually exceed EPA water quality criteria during and immediately after storm events (U.S. EPA 1983). It is difficult to determine relationships for fecal coliform concentrations between the events due to an incomplete data set. Fecal coliform samples for between storm Sites 1 and 2 were incubated at the wrong temperature (which prevented colonization). Fecal coliform samples from the storm event were not diluted for stormwater concentrations, resulting in either "Too Numerous to Count" (TNC) or no coliform growth. The lack of coliform colonization could be attributed to high concentrations of coliform rapidly using up the nutrient agar, causing an entire population crash. Although the data set is incomplete, the storm runoff has much higher fecal coliform concentrations than the between storm event, and the low levels during the snowmelt event may be attributed to the cold conditions inhibiting bacterial growth (Table 5).

Site	Between Storm	Runoff	Snowmelt
Site 1: PSBU	x	226.3	8.1
PSB Pipe		x	3.4
Site 2: PSBD	x	108.3	x
Site 3: BLPU	57.33	x	3
BL Pipe		TNC	
Site 4: BLPD	33.5	x	1.40

Table 5. Fecal coliform (# colonies/100mL) for between storm, runoff, and snowmelt events. X's indicate when samples were not properly processed.

Lead concentrations during the storm event were higher than between storm and snowmelt values (Figure 18). The pipe concentrations were extremely high compared to in-stream concentrations during the storm, and caused a gradual increase in lead from Sites 1 to 3, then a large increase between Sites 3 and 4. Although both pipes had similar lead concentrations, BLP produces a larger volume of water and would add a larger load of lead into the stream.

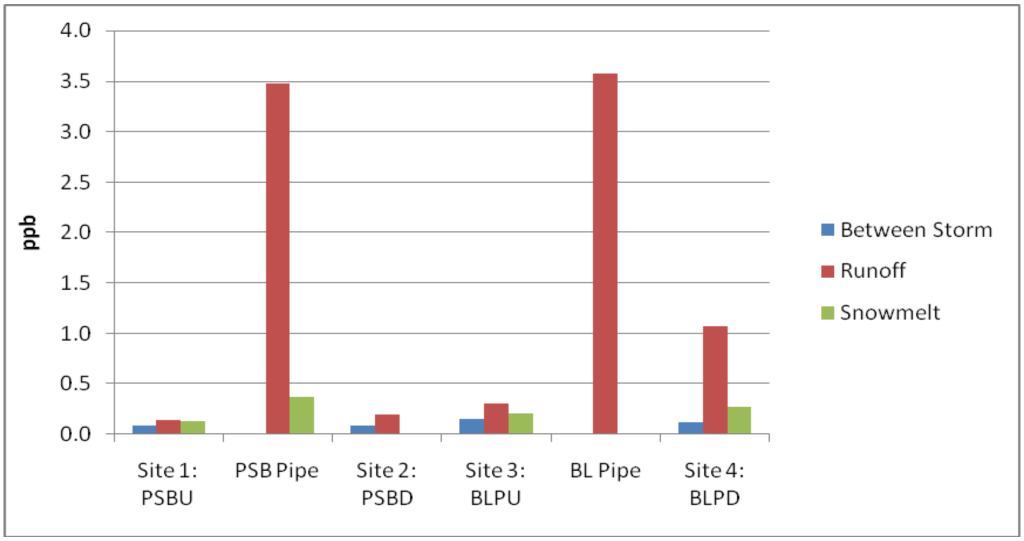


Figure 18. Lead (ppb) for between storm, runoff, and snowmelt events.

Copper results were similar to lead, and had the highest concentrations during the storm event (Figure 19). The pipe concentrations were rather high compared to in-stream concentrations during the storm, however Site 2 decreased despite the high cooper concentrations from PSBP. There was an increase between Sites 3 and 4 as a result of BLP. Although BLP had a lower copper concentration than PSBP, it produces a larger volume of runoff and may add a larger load of copper into Mountain Creek as a result.

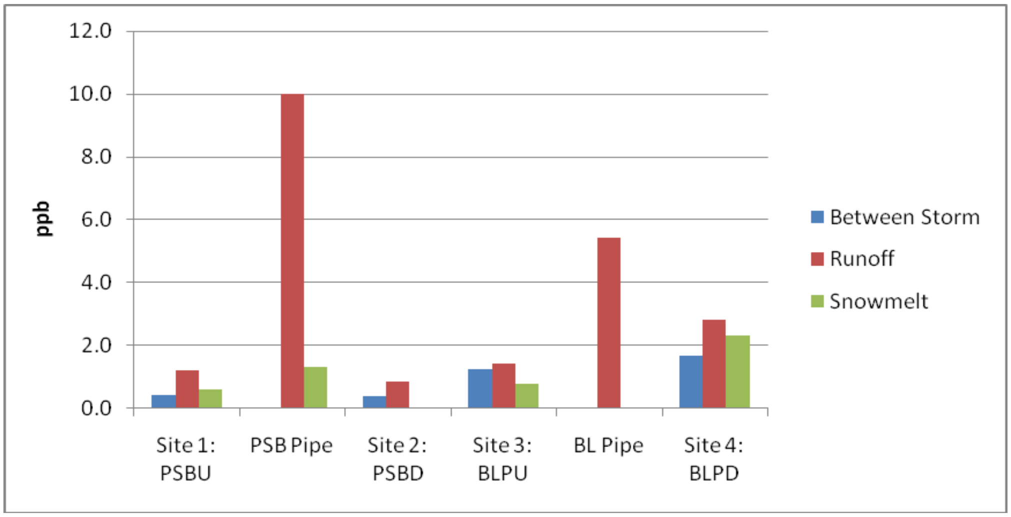


Figure 19. Copper (ppb) for between storm, runoff, and snowmelt events.

Zinc concentrations during the storm event were very high compared to between storm levels (Figure 20). The highest concentration of zinc was at PSBP, but it did not cause a downstream increase. The decrease between Site 2 and 3 during the storm indicates that the impacts of zinc, and potentially other metals, may be reduce further downstream from MHS.

Although the concentration at BLP is not as high as PSBP, the larger volume of water produced by BLP may have caused the increase at Site 4. Although snowmelt concentrations were slightly higher than between storm levels, there was no variation between the in-stream sites.

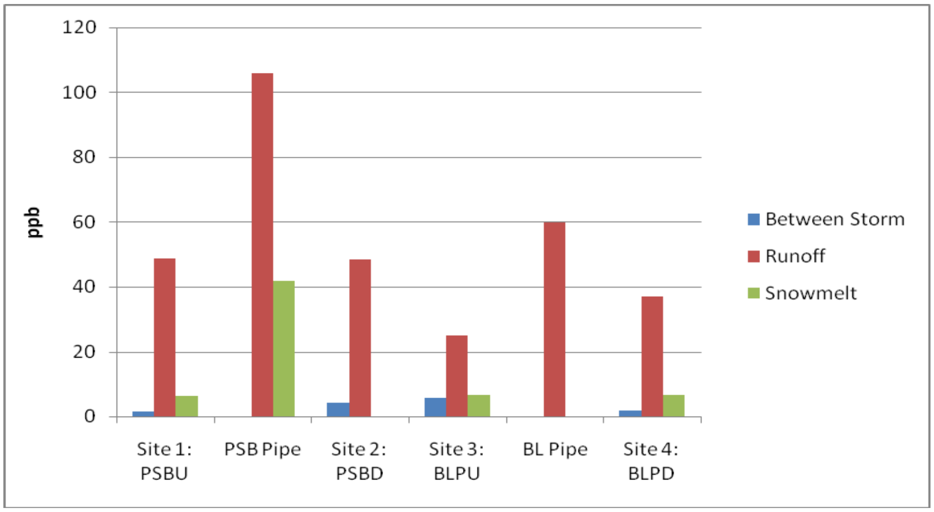


Figure 20. Zinc (ppb) for between storm, runoff, and snowmelt events.

Iron concentrations were similar for Sites 1 and 2 during storm and between storm events, and were not impacted by the high concentrations coming from PSBP (Figure 21). Iron at Site 3 was actually lower during the storm event than the between storm event, but had a notable increase at Site 4 as a result of the runoff from BLP. This increase between Sites 3 and 4 is similar during the snowmelt event, but there was no effluent from BLP to cause this difference.

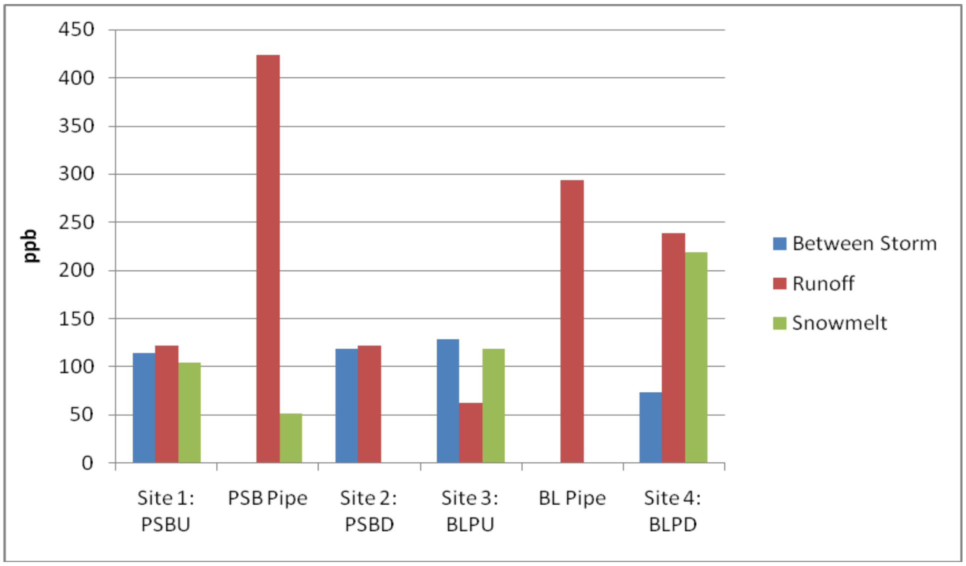


Figure 21. Iron (ppb) for between storm, runoff, and snowmelt events.

Cadmium concentrations varied between sites for both between storm and storm events, which shared similar concentrations (Figure 22). The snowmelt event showed the highest levels for all sites, with exceptionally high concentrations at Site 1 and PSBP. Despite these high concentrations, cadmium levels are greatly diminished downstream.

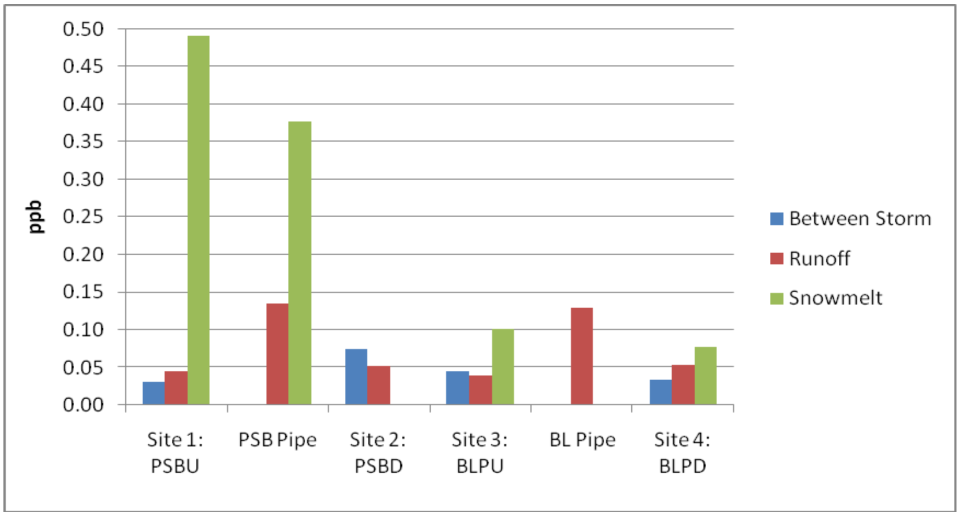


Figure 22. Cadmium (ppb) for between storm, runoff, and snowmelt events.

Chromium concentrations were similar at Sites 1 and 2 for between storm and storm events (Figure 23). During the storm event, there was a very high chromium concentration at PSBP but no increase at Site 2. Although BLP did not have a concentration as high as PSBP, there is a very large increase between Sites 3 and 4—this could be attributed to the larger volume of water discharged by BLP and therefore a larger pollutant load. Snowmelt showed a slight increase between Sites 1 and 4.

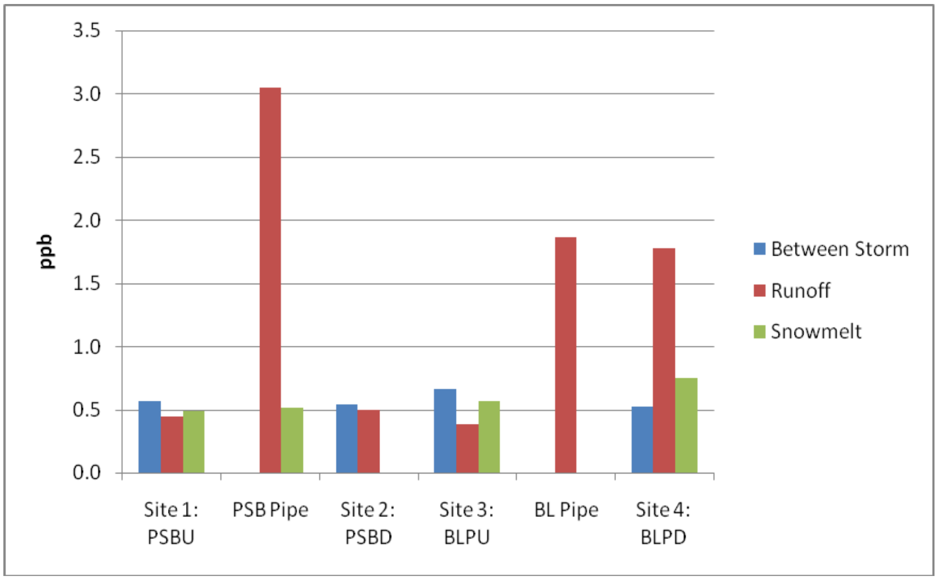


Figure 23. Chromium (ppb) for between storm, runoff, and snowmelt events.

The between storm magnesium concentrations were similar or higher than the storm runoff levels, and may be associated with magnesium present in the bedrock (Figure 24). The pipes have very low magnesium levels in comparison to in-stream values. Snowmelt concentrations of magnesium for in-stream sites were almost always half the between storm and storm event levels, possibly as a result of dilution from an influx of snowmelt throughout the watershed.

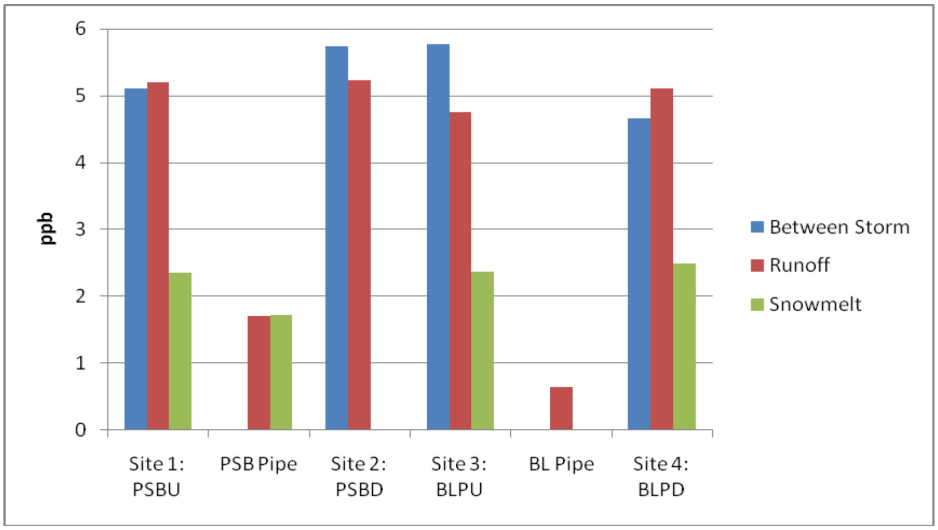


Figure 24. Mangesium (ppb) for between storm, runoff, and snowmelt events.

Manganese was higher during the storm event than between storm events, and was even higher during snowmelt the event (Figure 25). Although the in-stream concentrations during the storm event are higher than the pipe concentrations, there is an increase at Site 2 and Site 4, indicating that the runoff from the pipes caused increased manganese levels in the stream. The decrease between Site 2 and 3 during the storm indicates that the manganese concentration should also decrease downstream of Site 4. This decrease may be the result of manganese adsorption to the bottom sediments.

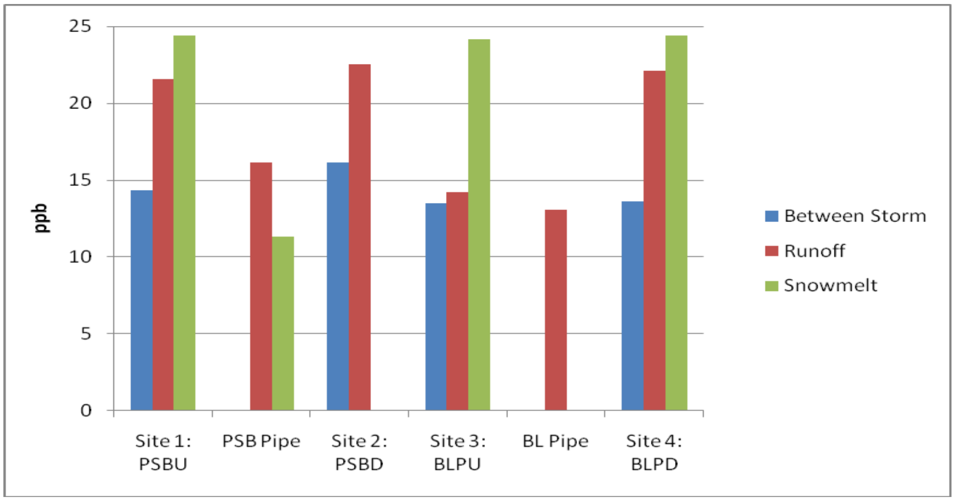


Figure 25. Manganese (ppb) for between storm, runoff, and snowmelt events.

Overall, storm runoff caused a decrease in alkalinity and hardness and an increase in conductivity and total dissolved solids within the MHS portion of Mountain Creek. Stormwater discharged from PSBP and BLP caused increased concentrations of lead, copper, zinc, iron, chromium, and manganese directly downstream of the pipes at Sites 2 and/or 4. While the snowmelt event had lower levels for many parameters than the between storm and storm events, snowmelt contributed to a large increase in downstream chloride concentrations, and contained the highest levels of cadmium and manganese.

When comparing the concentration of pollutants from the two stormwater pipes, PSBP had higher levels of alkalinity, hardness, conductivty, total dissolved solids, nitrate-nitrogen, reactive phosphorous, chloride, copper, zinc, iron, chromium, magnesium, and manganese. BLP had higher total suspended solids, and both pipes shared similar lead concentrations. Although the concentration of pollutants was generally higher for PSBP, there were usually greater increases between Sites 3 and 4 as a result of the larger volume of runoff discharged from BLP. In order to make a more substantial comparison, it is necessary to measure the volume of water discharged by each pipe for a single storm event.

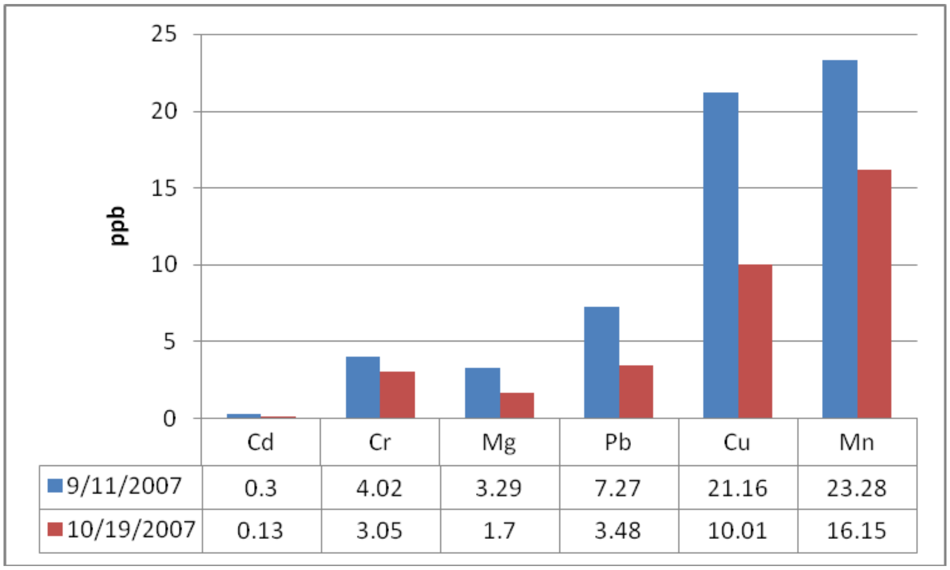
The average concentrations of runoff pollutants from PSBP and BLP were compared to EPA water criteria for aquatic life. The Criteria Maxiumum Concentration (CMC) is the maximum level of acute (short-term) exposure that will not harm aquatic life, and the Criteria Continuous Concentration (CCC) is the maximum level of chronic (long-term) exposure that will not harm aquatic life (US EPA 2008). PSBP exceeded the CCC for cadmium and lead, and exceeded both the CCC and CMC for copper and zinc (Table 6). BLP only exceeded the CCC for lead (Table 6). In-stream concentrations (Sites 1, 2, 3, and 4) did not exceed these criteria. Although the concentration of metals released into Mountain Creek during runoff events may decrease after the event, the copper and zinc concentrations from PSBP need to be reduced as they can harm aquatic life through acute exposure during a runoff event.

Priority Pollutants	**CMC**	**CCC**	**PSBP**	**BLP**
Cd (ppb)	2	**0.25**	**0.4**	0.1
Cu (ppb)	**13**	**9**	**15.6**	5.4
Pb (ppb)	65	**2.5**	**5.4**	**3.6**
Zn (ppb)	**120**	**120**	**218.8**	60.0

Table 6. Selected priorty pollutants for MHS compared to EPA water quality criteria (US EPA 2008); exceeded values are in **bold**.

Comparison of Storm Events

Metals from PSBP discharge were analyzed for two storm events, on 9/11/2007 and 10/9/2007. The storm on 9/11/2007 produced 0.96 inches of rainfall after a 22-day period of relatively dry antecedent conditions, during which six rain events produced between 0.01-0.12 inches of rain (PA State Climatologist 2008). The storm on 10/9/2007 produced 0.89 inches of rainfall after a 10-day period of relatively dry antecedent conditions, during which three rain events produced between 0.02-0.19 inches of rain (PA State Climatologist 2008). Although the 9/11/2007 storm produced more rainfall, the metal concentrations in Figures 26 and 27 were all higher due to the longer antecedent conditions would allow more pollutants and atmospheric deposition to accumulate on the impervious surfaces in MHS.



	Cd	Cr	Mg	Pb	Cu	Mn
🟦 9/11/2007	0.3	4.02	3.29	7.27	21.16	23.28
🟥 10/19/2007	0.13	3.05	1.7	3.48	10.01	16.15

Figure 26. PSBP concentrations of selected metals for two storm events.

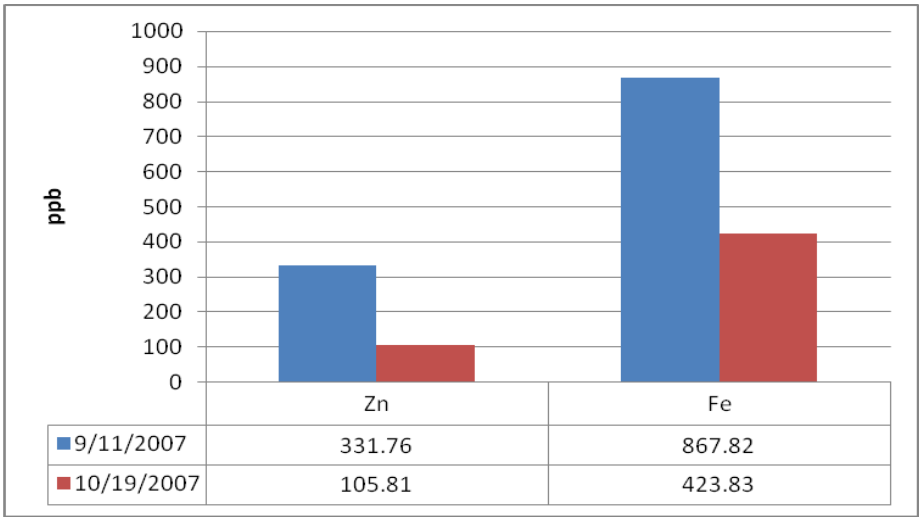


Figure 27. PSBP concentrations of zinc and iron for two storm events.

Comparison of Stormwater in Mount Holly Springs to Carlisle, PA

Wilderman (1994) studied the quality of stormwater runoff from many sites within Carlisle, PA. Samples were taken from the outfall pipes for four subwatersheds, ranging from medium-density residential (Subwatershed D) to areas of high trucking traffic (Subwatershed B). When compared to the annual per acre pollutant loads for the Pine Street Bridge Subwatershed and the Butler Lane Subwatershed in Mount Holly Springs, the four Carlisle subwatersheds had higher loads for all pollutants except manganese (Table 7). The MHS subwatersheds have similar acreage to Carlisle Subwatershed D, but much lower % imperviousness than any of the Carlisle subwatersheds. The MHS subwatersheds are producing generally higher manganese loads with comparatively low % imperviousness, indicating that an increase in impervious cover would increase the manganese load in surface runoff, further exceeding the Carlisle loads.

	Acreage	**% Imperviousness**	**Manganese (lbs/acre/year)**	**Manganese (total lbs/year)**
Pine Street Bridge Subwatershed	108	18.7	0.032	3.4
Butler Lane Subwatershed	97	35.8	0.044	4.2
Carlisle Subwatershed A	778	43.6	0.049	38.4
Carlisle Subwatershed B	313	78.1	0.122	38.1
Carlisle Subwatershed C	361	72.3	0.041	14.9
Carlisle Subwatershed D	110	66.2	0.017	1.9

Table 7. Comparison of subwatershed size, % imperviousness, and manganese loads (Wilderman 1994).

Further research on stormwater runoff in MHS is recommended based on the results of this study. In future studies, more between storm and storm events should be sampled to build a larger data set and find trends. Use of a mechanized water sampler would make this process exceedingly more efficient, as it is difficult to collect samples during multiple storm events. In addition, the total volume discharged from each pipe should be monitored to make stronger comparisons between PSBP and BLP. The high metal concentrations from the runoff events in this study and Miller's (2007) results on impact of sediments on macroinvertebrate populations suggest that metals may be accumulating in the sediments downstream of the discharge pipes—stream sediment sampling and analysis would be extremely useful to determine if accumulated metals are disrupting the benthic ecosystem. It would also be interesting to study the seasonal differences in water chemistry and stormwater composition, as the snowmelt event showed very different in-stream values than the fall sampling dates.

CONCLUSION

Stormwater runoff in MHS caused increased concentrations of lead, copper, zinc, iron, chromium, and manganese directly downstream of the discharge pipes. Snowmelt caused an increase in downstream chloride concentrations, and contained high levels of cadmium and manganese. Stormwater discharged from these pipes exceed the CMC for copper and zinc, and exceeded the CCC for cadmium and lead—these metals could be harming aquatic life in Mountain Creek. The two storm events analyzed for metal concentrations from PSBP showed that longer dry antecedent conditions result in higher concentrations of runoff pollutants. Although MHS has much lower annual per acre pollutant loads than Carlisle, the high manganese concentrations in MHS require further investigation into the source and effects of this metal on Mountain Creek.

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