APPENDIX B

Water Quality Studies

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EXECUTIVE SUMMARY

The goal of the water quality monitoring was to examine the human impact on stream water quality and potential factors to mitigate this impact. This study did not attempt to measure the overall water quality of the Pennypack Creek, which has been addressed by previous stream assessments (e.g., Philadelphia Water Department (PWD), 2003). Instead, we examined several problems on a small scale where human activity has the potential to alter water quality.

Specifically, we conducted four small-scale water quality studies in the spring/summer of 2003 and 2004. The details of the methods and results are described in each subsection below. The first study examined how water quality changes traveling from a storm pipe through a buffer zone to Pennypack Creek. The second study evaluated the effects of upstream ponds on temperature in tributaries and Pennypack Creek. The third study measured nitrate concentration daily upstream and downstream of the Upper Moreland – Hatboro Wastewater Treatment Plant (WTP), a source of point discharge in the basin. The fourth project was a comparison of urban and non-urban drainages that discharge in the same location. In each of the studies, continuous monitoring was conducted so that the water quality response to storm events as well as baseflow was measured over time. Several large data sets were generated; only a small portion of the data (example responses) is shown in this report. The complete data set is available from the author and will also be provided to the PWD.

One theme that emerged from these small scale studies is that overland flow is an important contribution to stream water quality. When we monitored both in the stream and at the point source of several stressors, such as storm pipes and upstream ponds, we found that downstream water quality was homogenized. In other words, overland flow contributes nutrients, chloride, and warmer waters that impact the overall water quality. One exception is that downstream of the WTP, the water quality (e.g. nitrate) was distinctly higher than upstream (increasing from 1 mg/L to 10-20 mg/L NO_3-N).

Observations from the small scale studies include:

- Rapid rises in water levels after storms show the importance of overland flow
- Similarity in conductivity and nutrients at the storm pipe and in the buffer zone also shows the importance of overland flow
- Temperatures were warmer in upstream ponds, but rapidly dissipated downstream
- Water downstream of the WTP had higher nitrate, conductivity, and temperature
- Urban discharge had generally higher conductivity and more variability than the non-urban discharge monitored at the same site; the variability could not be predicted by land use patterns but was influenced by a combination of source terms and local hydrology

An implication of this work is that effective Best Management Practices include those that increase infiltration (reduce overland flow). For example, infiltration galleries and wetlands would have more effect on water quality than small scale stream restoration such as bank stabilization. Nonetheless, regulation of large point sources (such as the WTP) continues to be important. By using more detailed monitoring – continuous data on smaller scale – we were able to better understand how urbanization affects the watershed.

BUFFER ZONE STUDY

Buffer zones are areas of restricted development next to a stream; often it is implied that these are forested areas. Buffer zones can improve bank stability and increase infiltration. However, the importance of buffer zones for improving water quality has not been documented. The buffer zone provides a longer drainage path before stormwater discharge reaches the main stream. Does the water quality change along this path? Does overland flow dilute nutrient concentration significantly or instead contribute nutrients or other contaminants?

Storm samplers and loggers were installed in the Pennypack Creek basin to compare data at the point of stormwater discharge and a second site along the buffer zone before the water reaches the main stem (Fig 1). Two samplers and loggers were installed in Lorimer Park, and two samplers and loggers were installed in Huntingdon Valley Country Club (Figs 2-3). The sampler in the buffer zone in Lorimer Park was about 900 ft downstream from the stormpipe draining the Heritage Rd neighborhood in Abington Township. The sampler in the buffer zone in Huntingdon Valley Country Club (HVCC) was about 300 ft downstream of the stormpipe draining Country Club Dr in Upper Moreland Township. A note should be made about greens treatment at the HVCC, since strictly speaking, this does not represent undeveloped land. The HVCC practices minimal lawn chemical treatment by encouraging the grass on their greens to have deeper roots. The low nutrient concentrations observed in the drainage that crossed a green on the HVCC property supports the use of this site for buffer zone study.

The storm samplers had two bottles to collect storm water; one bottle collected the first flush of stormwater, the second bottle collected a composite of stormwater over 4 hours. The sampler was activated when the water level rises above the water level sensor for the pump. The samples were analyzed for nutrients (nitrate or NO_3-N and ammonia or NH_4-N) as well as other cations and anions, such as chloride (Cl^-). Approximately 8 storms were collected at each site, or 72 stormwater samples overall from May 2003 to early Sept 2003.

The loggers had sensors to collect conductivity and water level data at 20 minute intervals (Fig 4). Thus data are available for every storm. Conductivity is a measure of the overall ion content of the water and was measured continuously at all of the sites. The rise in water level shows when the storm water reached the sampling site.

Conductivity and water level

Conductivity decreases during storm events then returns to the pre-storm value. In May and early June there was an observable lag between the conductivity drop at the pipe and the conductivity drop in the buffer zone (Fig 5). The lag times vary for different storms. The range was from 20 minutes to 1.5 hours at the HVCC. At the L1 and L2 sites, which are further apart, the lag reached as high as 6 hours. This lag represents storm water moving downstream from the pipe to the buffer zone. By mid June, the timing of the conductivity drop coincided at the pipe and the buffer zone in HVCC and was closer together at L1 and L2. At this point, frequent rainfall saturated the ground and overland flow increased. Once overland flow dominated the stream input during storms, the storm pulse from the pipe was not observed in the buffer zone, but instead the overland flow created the conductivity drop. Thus the buffer zone had less influence on water quality as the number of storms increased.

Water level was also measured for all of the storms. The water level rise occurred simultaneously at the pipe and in the buffer zone both in the spring and the summer. The rapid rise in water level shows the importance of overland flow on the water quality. The water level rose at the beginning of the storm, but changes in water quality may lag the water level rise as older baseflow water was displaced by stormwater.

Nutrient concentrations

Nutrient concentrations in 50 of the nations streams were assessed by the U.S. Geological Survey (1999, Circular 1225). In undeveloped areas, background concentrations of 0.6 mg/L NO_3-N were obtained on average. In urban streams, the average concentration was 1.5 mg/L with a range of 0.5 to 4.5 mg/L total N. These data provide comparison for observations in the Pennypack Creek buffer zone study. Nutrients can enter the water from lawn chemical use, atmospheric deposition, soil erosion, and animal waste.

The nutrient concentrations were low in the summer of 2003 at both sites. Frequent rainfall may have reduced lawn chemical use in the neighborhoods that the storm pipes drained. Sites in Huntingdon Valley Country Club had NO_3-N concentrations typically less than 1 mg/L with an increase to 1.5 mg/L at the buffer zone site on 7/30/03 (Fig 6a). The NO_3-N was less than or just above the average non-urban concentration in the USGS survey. Concentrations in the first flush and composite samples were similar. NH_4-N measured in first flush samples was around 1 mg/L or less except for a concentration of 2 mg/L on 5/9/03.

The sites that drained into Lorimer Park had less than 2 mg/L of NO3-N (Fig 6b). Concentrations were above the average non-urban concentration in streams, but typically below the average urban concentration. In May and June the concentrations in the buffer zone were higher than at the pipe, but the remainder of the summer the concentrations were similar. The first flush and composite concentrations were also similar. The storm on 8/7/03 showed dilution of all of the constituents. Animal waste may contribute to somewhat higher concentrations in Lorimer Park than at HVCC, in particular for the buffer zone. NH_4-N was again less than 1mg/L, except for a concentration of 2.5 mg/L on 5/9/03.

Chloride

Chloride showed the most variability of the ions analyzed in the study. At HVCC, the chloride ranged from nearly 0 to 70 mg/L and at Lorimer Park the chloride ranged from nearly 0 to 95 mg/L (Fig 7). At HVCC the trends were similar in the pipe sample and the buffer zone as well as the first flush and composite. The storm on 8/7/03 again showed dilution. At Lorimer Park, the buffer zone concentrations were high in May and June, but similar to the storm pipe concentrations in Aug and Sept. Because the chloride concentrations are more variable, and higher than the nutrients, the similarity between the samples at the pipe and the buffer zone show more clearly the lack of alteration in water quality. The cause of the temporal variability in the chloride concentrations is not known, but may be related to episodic release of pockets of road salts or to other anthropogenic releases such as swimming pools. Although chloride is also found in lawn chemicals, the low concentrations of nutrients suggest that this is not the source.

<u>Summary</u>

Concentrations of nutrients, chloride, and overall conductivity overlapped between the source pipe and water down stream in the buffer zone. Although nutrient concentrations were low, the chloride concentrations were over 50 mg/L at times, and did not show a dilution effect downstream. Interestingly, the sampler placed on the golf course (HV2) did not show significantly higher concentrations than the other 3 samplers in the study.

Dilution in water quality was not observed in either buffer zone. These data, along with the similar response in conductivity and water level data for each storm, point out the importance of overland flow in addition to pipe discharge in determining the water quality of urban streams.

Figure 1: Location of two monitoring sites in 2003. Each location has two monitoring stations, one at the storm pipe and one downstream. Huntingdon Valley Country Club is HV, in Upper Moreland Township. Lorimer Park is L, in Abington Township. An additional site was mointored in HVCC in 2004.

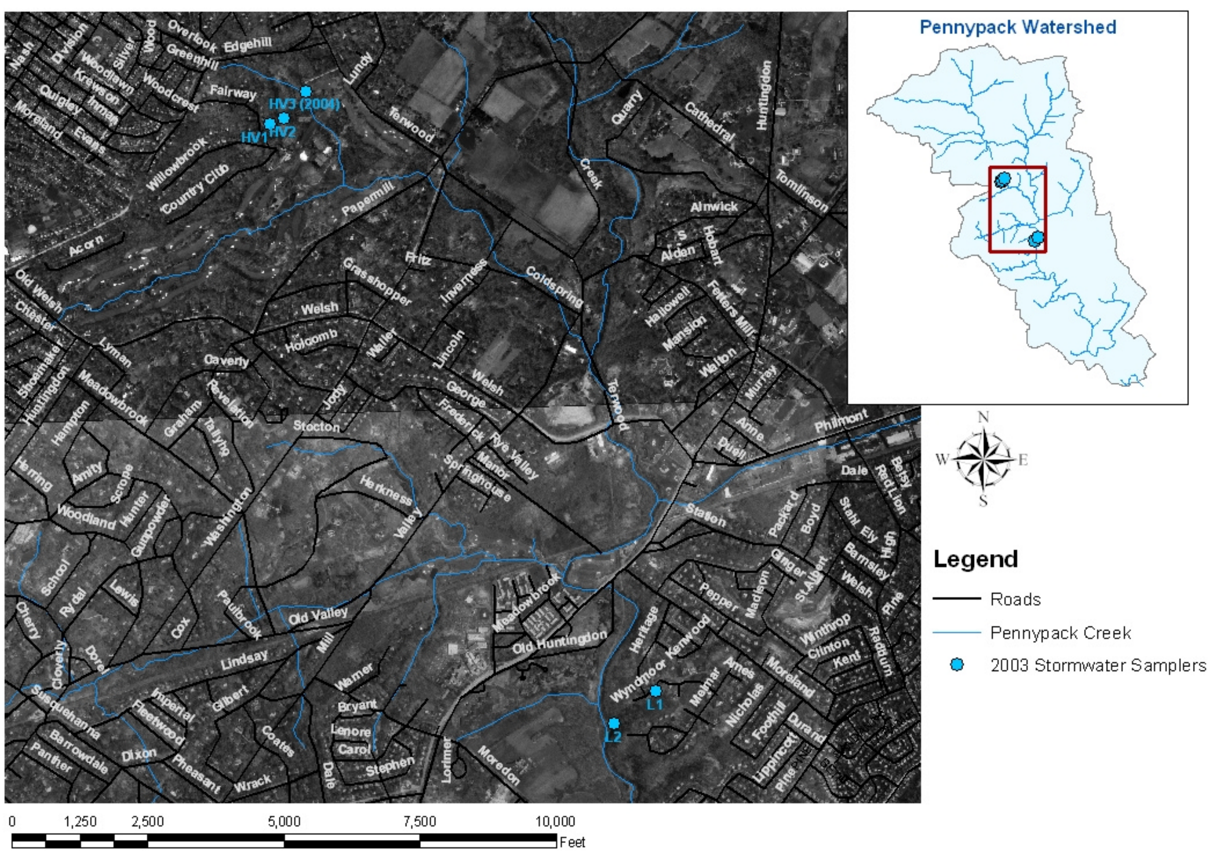


Figure 2a: Stormpipe L1 in Abington Township, which discharges through Lorimer Park.

Figure 2a: Stormpipe L1 in Abington Township, which discharges through Lorimer Park.

Figure 2b: L2 in Lorimer Park, in the buffer zone about 900 ft downstream of the stormpipe.

Figure 3a: Stormpipe HV1 in Upper Moreland Township discharging to the Huntingdon Valley Country Club. (Shown in February 2003).

Figure 3b: HV2 in Huntingdon Valley Country Club, about 300 ft downstream of the stormpipe. The drainage crosses one green before the monitoring point.

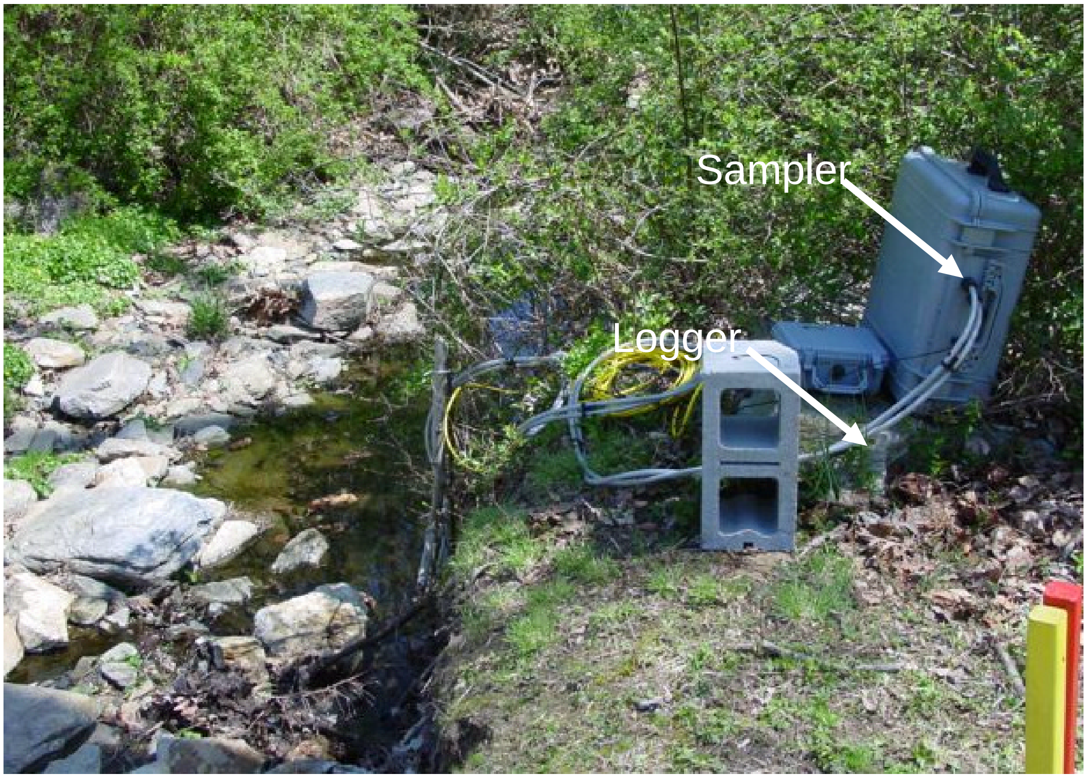


Figure 4: Close up of sensors (HV1)

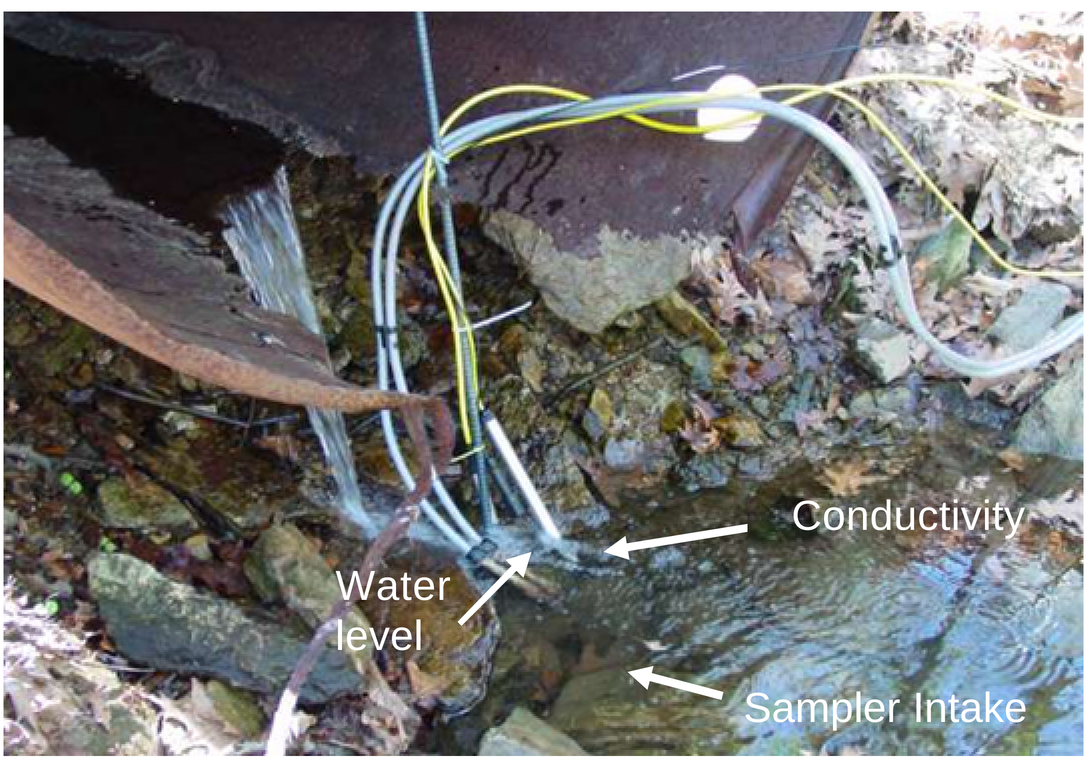
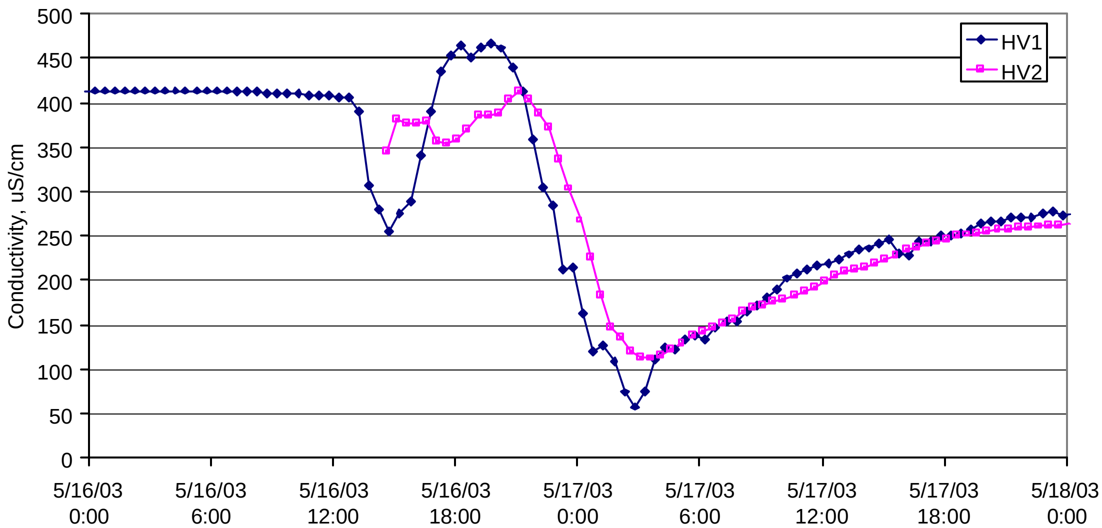
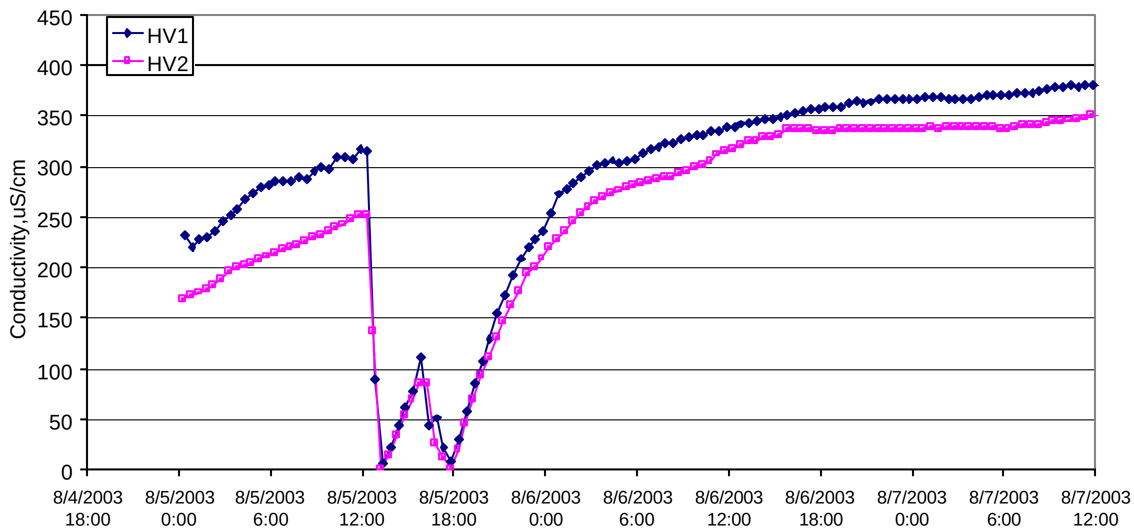
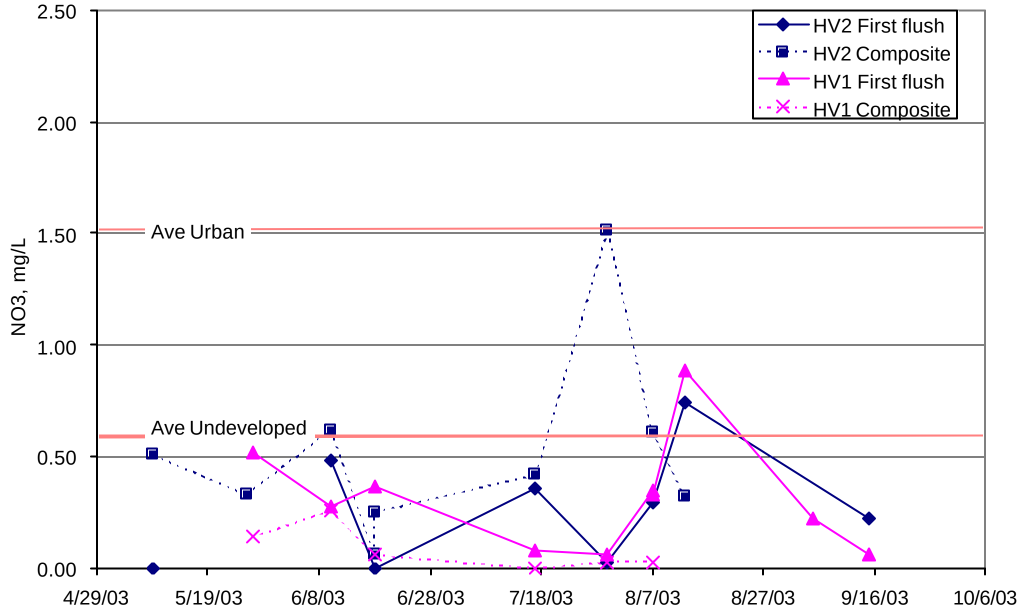


Figure 5: Example data showing storm response in conductivity at HVCC in the spring when there is a lag between the stormpipe and the buffer zone, and later in the summer when the drop in conductivity during the storm is simultaneous.







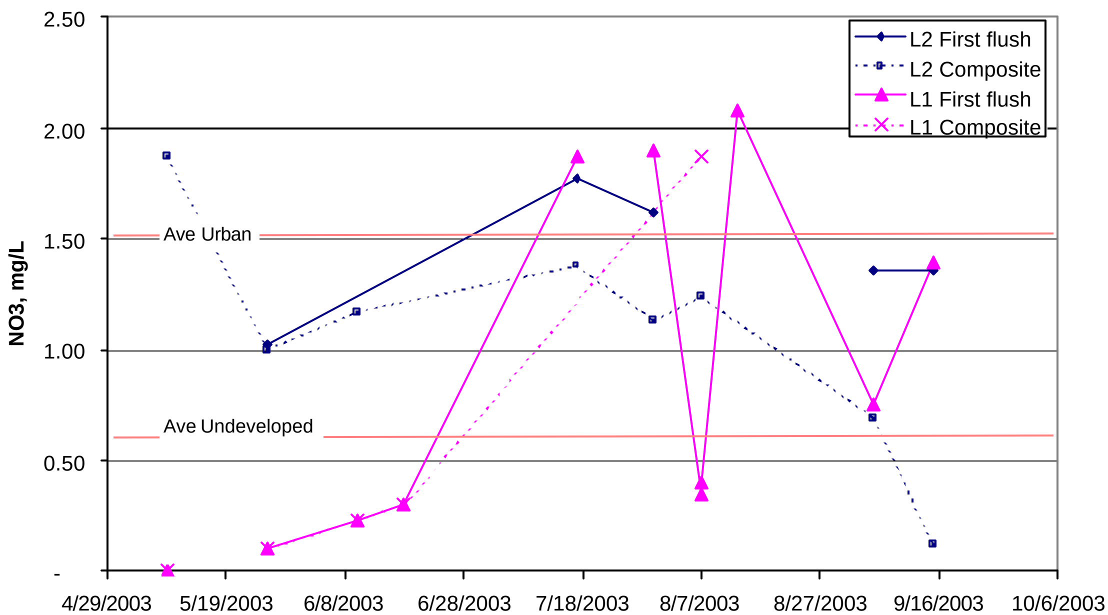
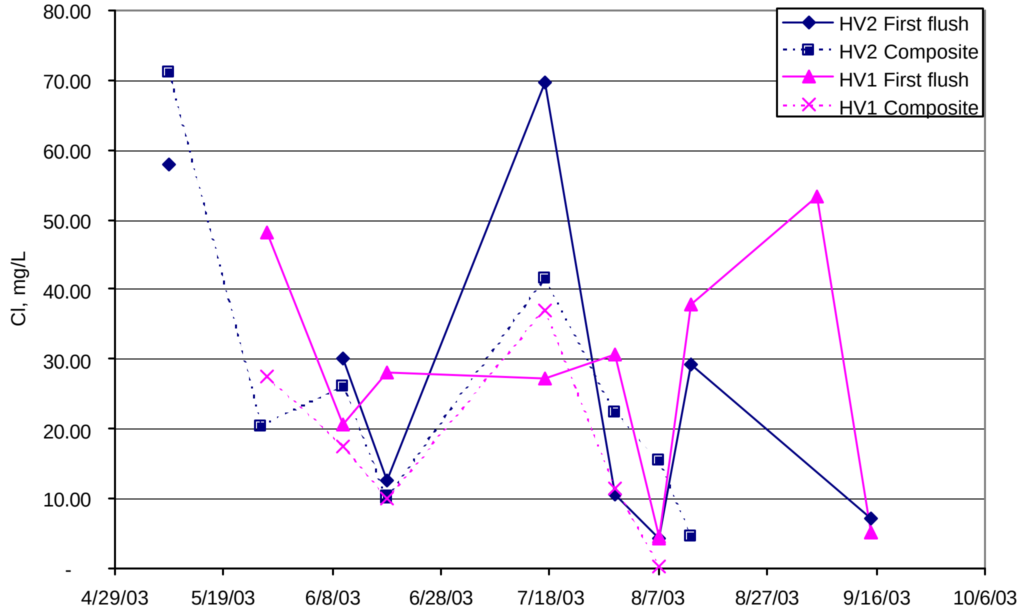


Figure 6: Nitrate data from storm samples. Site 1 is the storm pipe and Site 2 is in the buffer zone. Average values are from a USGS report of water quality across the nation.



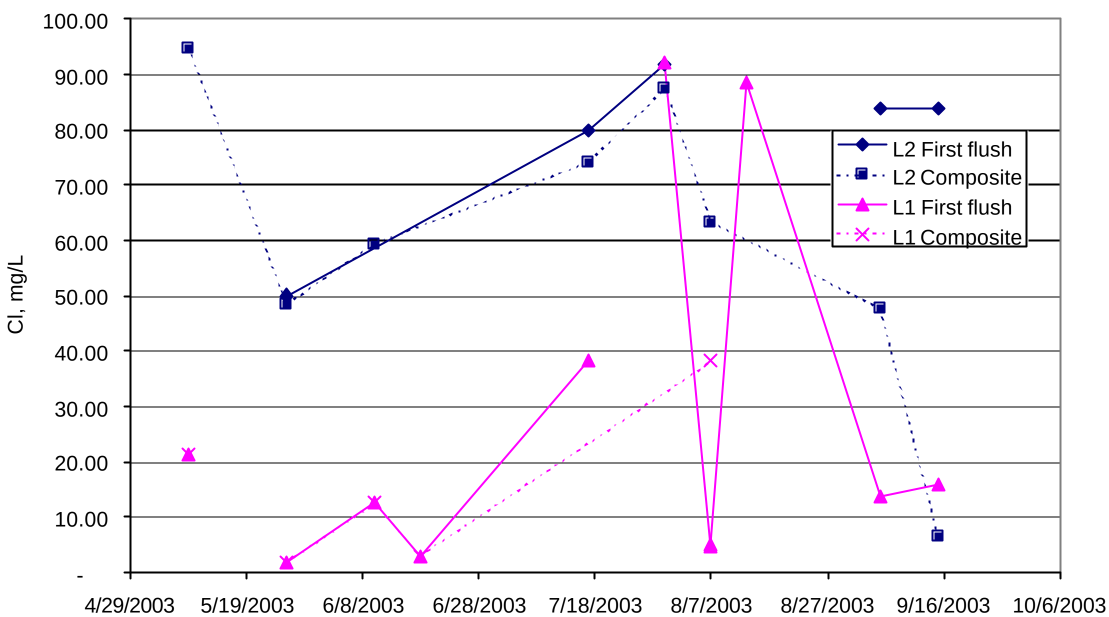


Figure 7: Chloride data from storm samples. Site 1 is the storm pipe and Site 2 is in the buffer zone. Spikes in concentration are observed at both sites.

TEMPERATURE VARIATION ON TRIBUTARIES WITH AND WITHOUT UPSTREAM PONDS

Stream temperature affects microfauna, fish reproduction, and aquatic metabolism rates; warm temperature is a commonly cited habitat threat in urban streams. Many of the tributaries feeding the Pennypack have ponds upstream that can heat up in the summer months. The influence of these ponds on downstream temperature was unknown, and a study was designed to begin to address this question.

Temperature loggers were installed in ponds, the tributary running from the pond, and in the main stem of Pennypack Creek up and down stream of the tributaries. Three ponds and one tributary with no pond were selected for study (Fig 8). The ponds selected were open from tree cover for most of their area, and thus exposed to sunlight that would cause heating in the summer. The temperature loggers in the creek were placed in sheltered areas where they would not receive direct sunlight. However, it is known that the temperature recorded is highly influenced by placement of the loggers. In addition to variability in temperature due to placement, all sites have a diurnal fluctuation in temperature, influenced by local weather among other things. Since only one logger was placed upstream and one logger downstream, the natural variability of temperature could not be assessed in this initial study. However, this more limited study was conducted to see if more detailed temperature monitoring would be needed to assess the issue.

TABLE 1: Summary of mean temperatures (°C) recorded, May-Sept 2004

Site	Pond	Pond tributary	Upstream on Pennypack	Downstream on Pennypack
Cairnrun Pond	24.25	20	20.1	20
Silverbrook Pond	22.8	23.5	22.7	22.45 (limited dataset)
Willow Grove Day Camp Pond	Not accessible	Direct to Pennypack	22.2	22.4
No pond	Not applicable	Not applicable	21.8	22.25

This initial study does not show significant differences in temperature between the tributaries with and without a pond, nor between upstream and downstream temperature. The sensitivity of the temperature loggers is approximately +/- 0.1°C, but the environmental variability (from placement of the loggers) is higher. Thus, differences of less than 0.5°C between up and downstream samples are not significant. Furthermore, the tributary with no pond showed slightly warmer temperatures than the Cairnrun Pond tributary and little difference from the other two tributaries.

Details for each site are provided below.

Cairnrun Pond

At the beginning of the summer, the pond was 4 °C higher than the tributaries, by the end of the summer it was about 6 °C higher. There was some missing data in the pond because this logger malfunctioned several times.

The diurnal cycle was 2 to 4 °C at all sites (Fig 9). The tributary and the Pennypack downstream sites had a larger swing in the diurnal cycle in the beginning of the summer. This trend ended in August and September, when all three sites look similar, with the Pennypack upstream site having slightly warmer temperatures.

Mean temperature in the Pennypack was about 20 °C (cooler at the beginning and end of the season). The warming of the pond seemed to dissipate by the time it reaches the outflow tributary. There was no consistent trend in the upstream and downstream temperature sensors at this location.

No pond

The mean temperature was about 21°C and the diurnal swing was about 2°C. The upstream and downstream sensors were very similar to each other and to other sites.

Willow Grove Day Camp

The pond was not monitored at this site (permission not granted). The upstream and downstream sensors were nearly identical. The mean temperature was about 22°C and the diurnal swing was about 2°C.

Silverbrook Pond

The pond and the water in the culvert at the exit of the pond had warmer temperatures the first week of July, but had mean temperatures similar to the Pennypack site the rest of the season. However, the diurnal cycle was larger in the pond and the culvert. Their cycle was 4 °C or more, whereas the Pennypack Creek sites had 1-2 °C variation diurnally. The downstream logger was missing in July and August, so data were limited. For the limited monitoring period, the upstream and downstream Pennypack sites were similar, with slightly more variation in the downstream site.

Summary

The warmth of the ponds seems to dissipate rapidly downstream. There was no obvious variation in temperature or diurnal cycles caused by the discharge of the pond tributaries. In other studies, shading has been observed to cool stream temperatures. All of the outlets in this study had shading although the ponds were open. Even the short drainage from the Willow Grove Day Camp pond was shaded. Furthermore, the other two ponds had long drainage paths before reaching the Pennypack which can dissipate temperature. Finally, if overland flow contributes significantly to the runoff, temperature will be more uniform in the basin, rather than influenced by a single discharge site such as a pond.

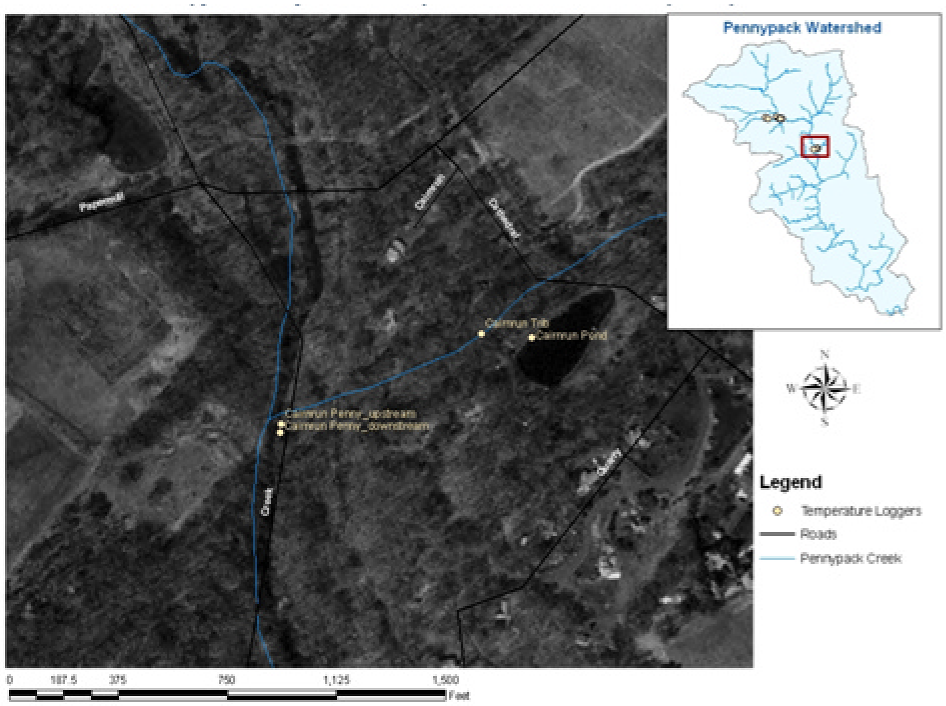


Figure 8a: Location of temperature loggers near Cairnrun Pond. GIS overlay of streams is slightly offset (blue line).

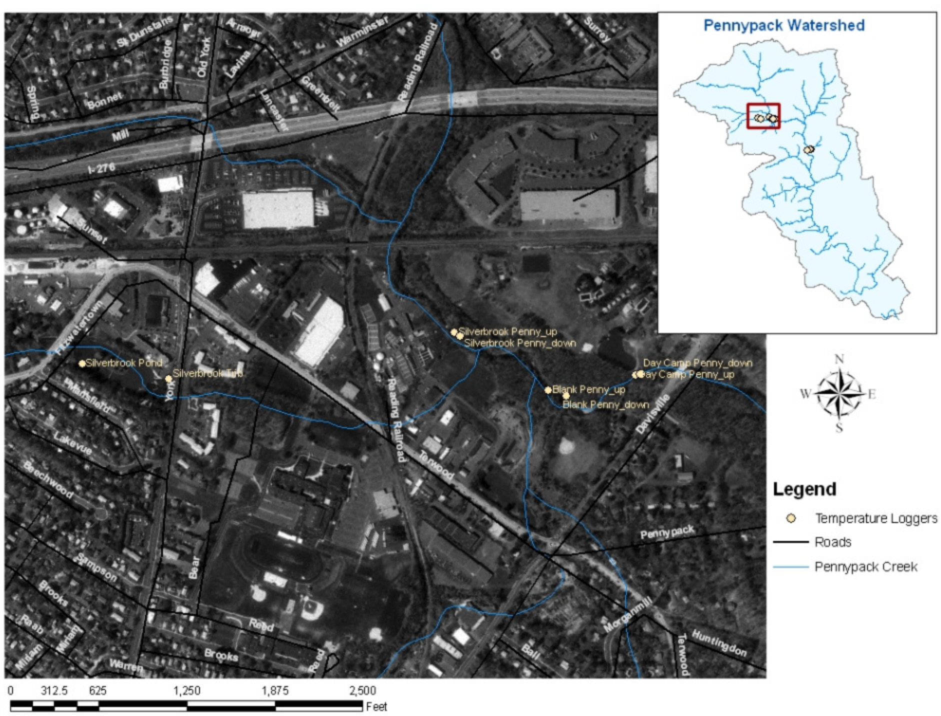


Figure 8b: Location of temperature loggers near Silverbrook Pond, Willowgrove Day Camp Pond, and the blank tributary (no pond). GIS overlay of streams is slightly offset (blue line).

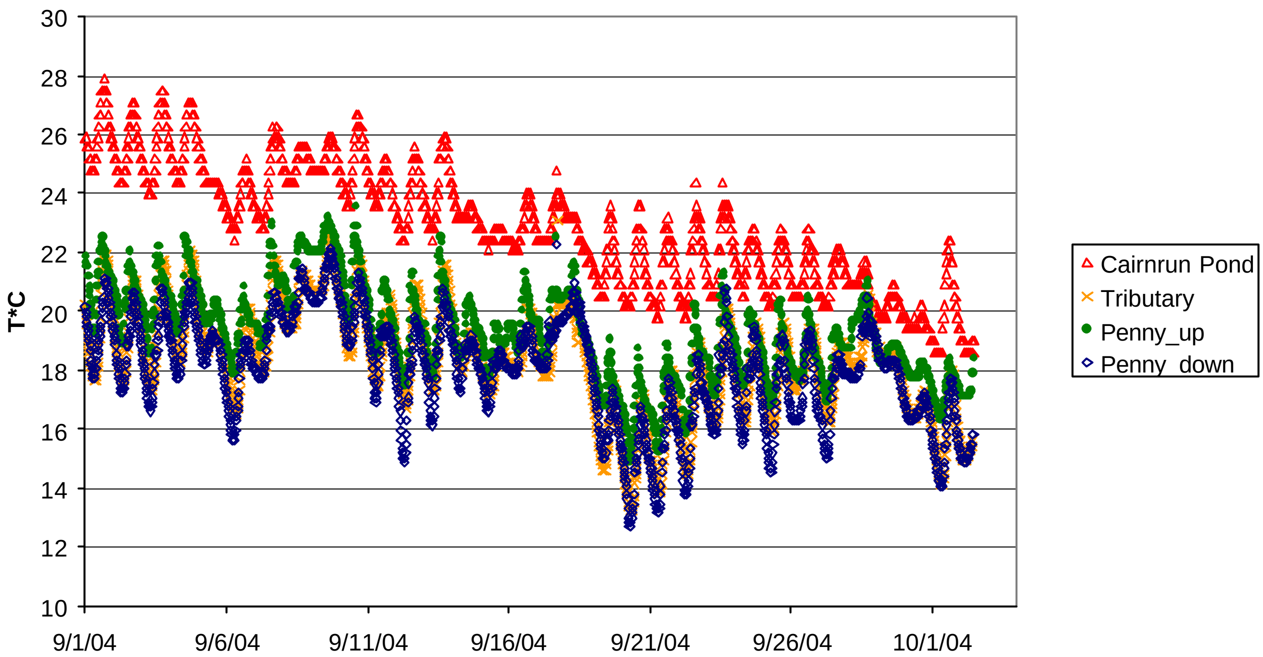


Figure 9: Example data from Cairnrun Pond, the pond tributary, and the upstream and downstream sites on Pennypack Creek for September 2004. The pond is warmer than the stream, but there are no significant differences between the upstream and downstream monitoring sites.

PARISON OF WATER QUALITY UPSTREAM AND DOWNSTREAM OF WASTEWATER TREATMENT PLANT

Nitrate is a common element in wastewater discharge, and it has a drinking water limit of 10 mg/L. No standard has been set for aquatic life, but EPA and the NJ Dept of Environmental Protection have suggested a level of around 3 mg/L. As mentioned in the study of buffer zones, the USGS study of urban streams found the average concentration was 1.5 mg/L with a range of 0.5 to 4.5 mg/L total N. This is higher than the average concentration of 0.6 mg/L found in non-urban streams.

Stream assessment by the Philadelphia Water Dept (PWD) noted higher nitrate concentrations in the vicinity of the Upper Moreland – Hatboro Wastewater Treatment Plant (WTP). They observed an average of 8 mg/L and up to 14 mg/L. However, samples were not collected directly upstream of the plant or with a frequency to determine how much variation in nitrate could be attributed to the plant.

For this study, automatic samplers (manufactured by ISCO) were placed up and downstream of the WTP (Fig 10). The upstream sampler was about 2200 ft from the treatment plant property and the downstream sampler was about 1300 ft from the treatment plant (very close to the PWD sampling site). The samplers collected a water sample from Pennypack Creek at 10 am every day for three weeks. The samplers held 24 bottles and were emptied once a week. The study was intended to last 1 month, but Tropical Storm Jeanne wiped out the sampling sites on 9/28/04, with data lost from 9/24/04 when the last samples were collected by field personnel. A hand sample was taken on 9/30/04 when the sites could be reached after the storm. The water samples were analyzed for cations and anions, including nitrate. Water level, temperature, and conductivity data were also recorded at 20 minute intervals.

Upstream of the plant, the nitrate concentrations were steady at 1-2 mg/L. Downstream of the plant, concentrations were much higher, typically over 10 mg/L and up to 22 mg/L (Fig 11). Concentrations dipped below 10 mg/L during storm events on 9/8/04 and 9/18/04, and were lower in the hand sample collected after Tropical Storm Jeanne. In addition to nitrate, other ions such as chloride were measured. Water affected by the WTP also had higher chloride, typically greater than 80 mg/L, and nitrate concentrations increased with increasing chloride (Fig 12).

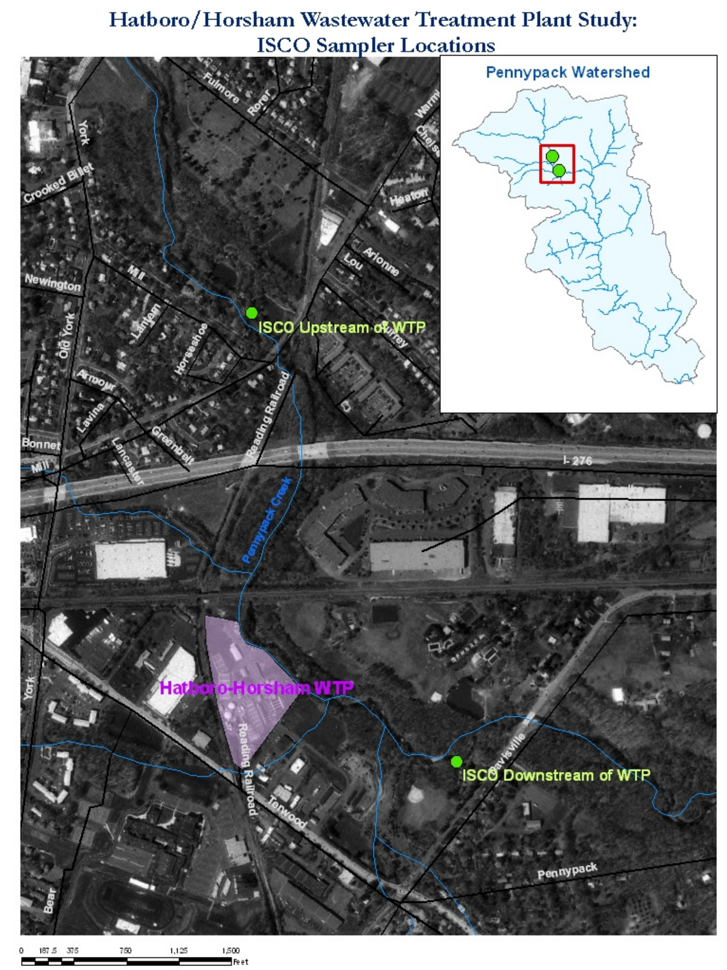


Figure 10: Location of samplers upstream and downstream of the Wastewater Treatment Plant (WTP).

The conductivity of the water downstream of the WTP is about 100 us/cm higher than upstream. This is a measure of the overall ion content of the water, showing an increase after the WTP. There is a daily fluctuation in the conductivity, with higher values at night (approximately 30 to 40 uS/cm higher). In addition to the increase in conductivity the temperature downstream is 2°C higher on average.

Discharge from treatment plants is regulated by the National Pollution Discharge Elimination System (NPDES) of the EPA. They are considered to be a major contributor to water quality impairment in urban streams. This study confirms the impact of the WTP on water quality on the Pennypack.

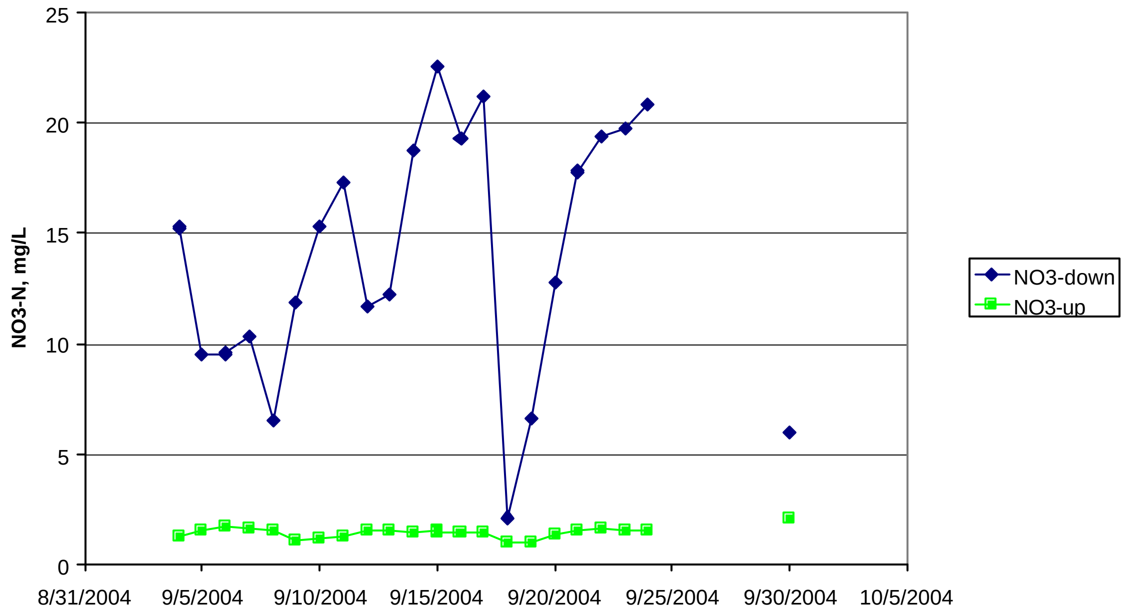


Figure 11: Daily nitrate concentrations collected at 10 a.m. upstream and downstream of the WTP.

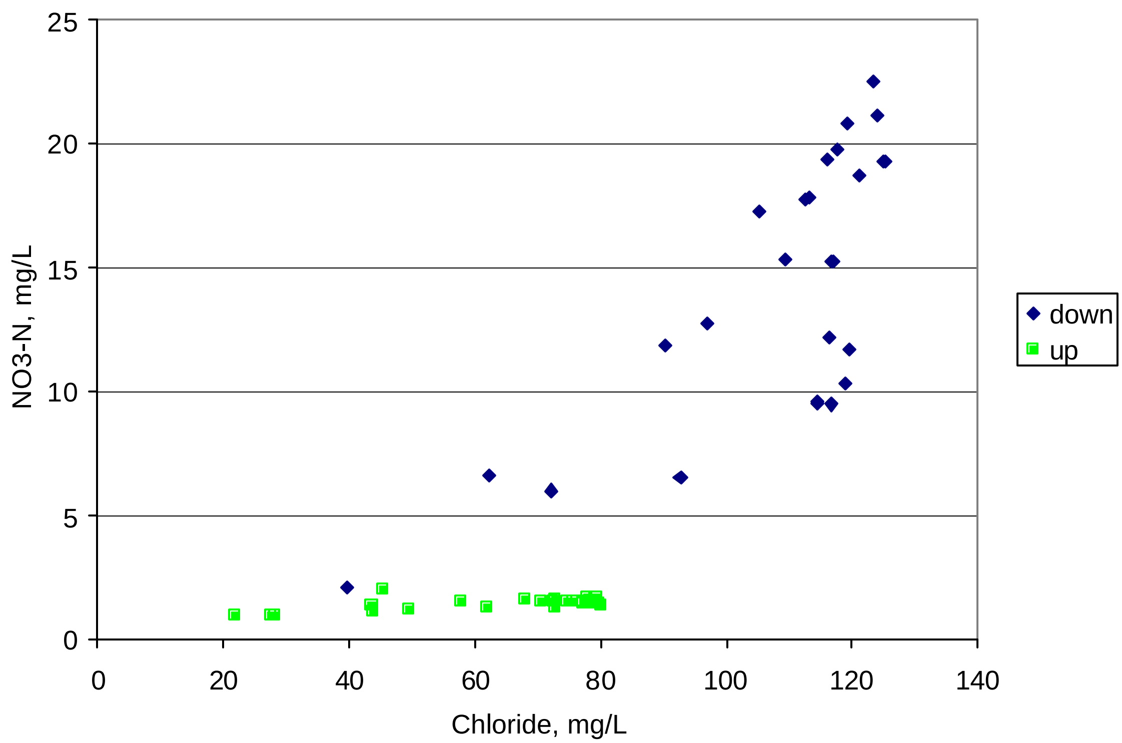


Figure 12: Nitrate versus chloride in daily samples collected upstream and downstream of the WTP.

COMPARISON OF CONDUCTIVITY IN THREE LOCAL TRIBUTARIES

A comparison of water quality in two urban and one non-urban tributary was conducted from mid-May through Sept 2004. The three tributaries are in the same basin, and merge on the Huntingdon Valley Country Club (Fig 1). Loggers were installed to monitor conductivity, temperature and water level to see how each tributary responded to storms and how the water quality varied through the summer. By comparing tributaries in the same location, we can better understand how water quality varies naturally and due to impact of urbanization.

TABLE 2: Summary of conductivity data in baseflow and in stormflow (in parentheses) from 3 tributaries in the Pennypack watershed near Huntingdon Valley Country Club

	Conductivity uS/cm		
	BOG **Baseflow (storm)**	**WEST** **Baseflow (storm)**	**EAST** **Baseflow (storm)**
May	175 (20)	260 (40)	430 (60)
June	225-235 (low)	230 (75-200)	410-425 (100-350)
July	120-300 (50-100)	225 (150) Spike on July 6-7	350-390 (350)
Aug	150-300 (0-100)	165, 250 (100)	375 (350)
Sep	200-250 (0-100)	225 (150)	300-350 (300)

The east tributary had the highest conductivity and the most variability during storms compared to the bog and the west tributary (Fig 13). During the summer, there was a decline in the conductivity although it still remained above 300 uS/cm except during storms. The west tributary and the bog had lower conductivity than the east tributary, generally below 250 uS/cm. In spring when the sampling began, the bog had the lowest conductivity. Then as the summer approached, the conductivity of the bog increased and the west tributary decreased so that they were more similar. However, the west tributary usually declined more during storms. For most storms there was little or no effect on the bog conductivity, although there was up to a 100 uS/cm decline later in the summer. The east tributary had the largest declines in conductivity during storms, up to 350 uS/cm.

The more stable conductivity in the bog compared to the urban tributaries reflects the difference in source waters. The bog receives groundwater discharge, and the geochemistry shows less influence from surface runoff and contaminants. The increase in conductivity during the summer likely indicates additional groundwater inputs (with higher conductivity) and increased dissolved organic matter in the growing season. The sharp decline in conductivity for the urban tributaries indicates the input of surface runoff with dilute rainwater during storms. Sometimes this is accompanied by temperature changes (storms can either increase or decrease the water temperature). These changes can affect the microfauna in streams, making them less inhabitable.

The higher conductivity of the east tributary is hard to account for based on land use patterns. Both source areas are primarily residential, with each having about 10 acres of golf course as well; the bog had a small drainage basin, receiving primarily groundwater discharge

(Fig 14). Again, note that the Huntingdon Valley golf course uses minimal impact fertilization and is not believed to be the major contributor to water quality. The residential source area for the west tributary is somewhat larger, and has more homes. There are over 400 homes in the source area of the west tributary and only 50-70 homes in the east tributary source area (Fig 14), so the higher number of homes is not related to higher conductivity. It is unclear whether there is a source term difference (more application of chemicals or road salts) on the west tributary or if the water distribution pattern puts more dilute storm water into the east tributary. The west tributary has more sewer drains (Fig 14). The variability in conductivity points to the fact that both source term and hydrology are important in determining water quality. Thus, it can be hard to predict which urban drainages will be more contaminated based on land use alone.

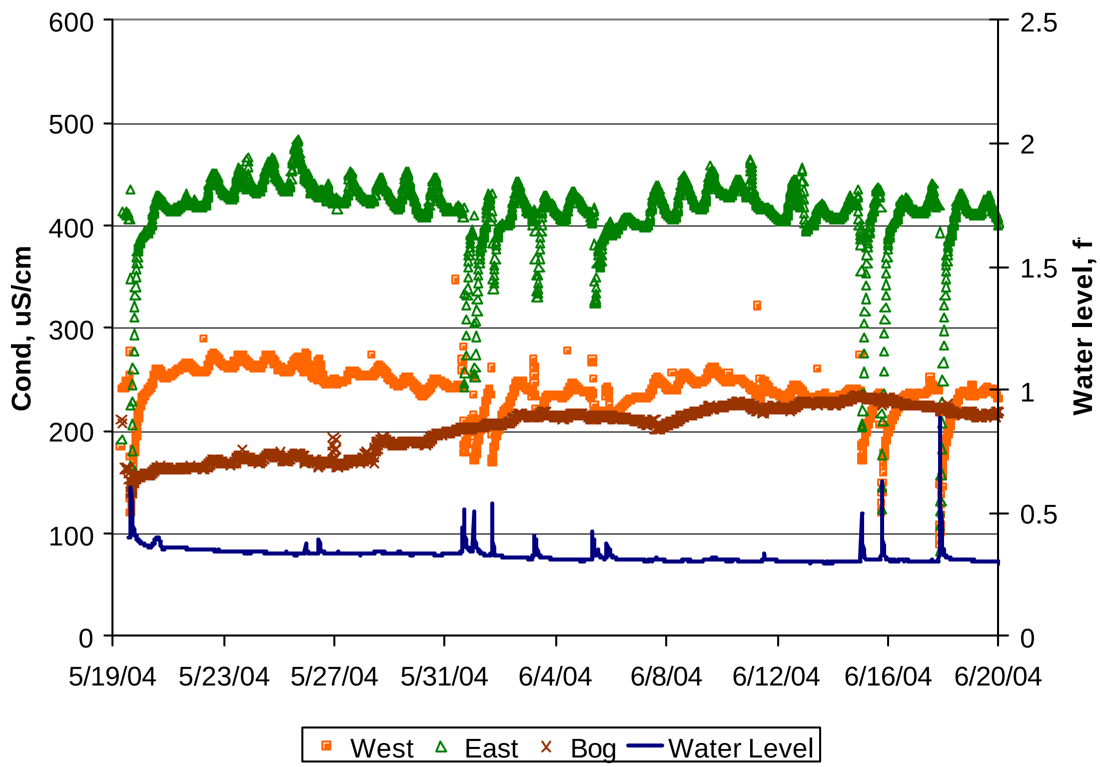


Figure 13: Example conductivity data from the three tributaries for late spring 2004. The water level increases show storm events.

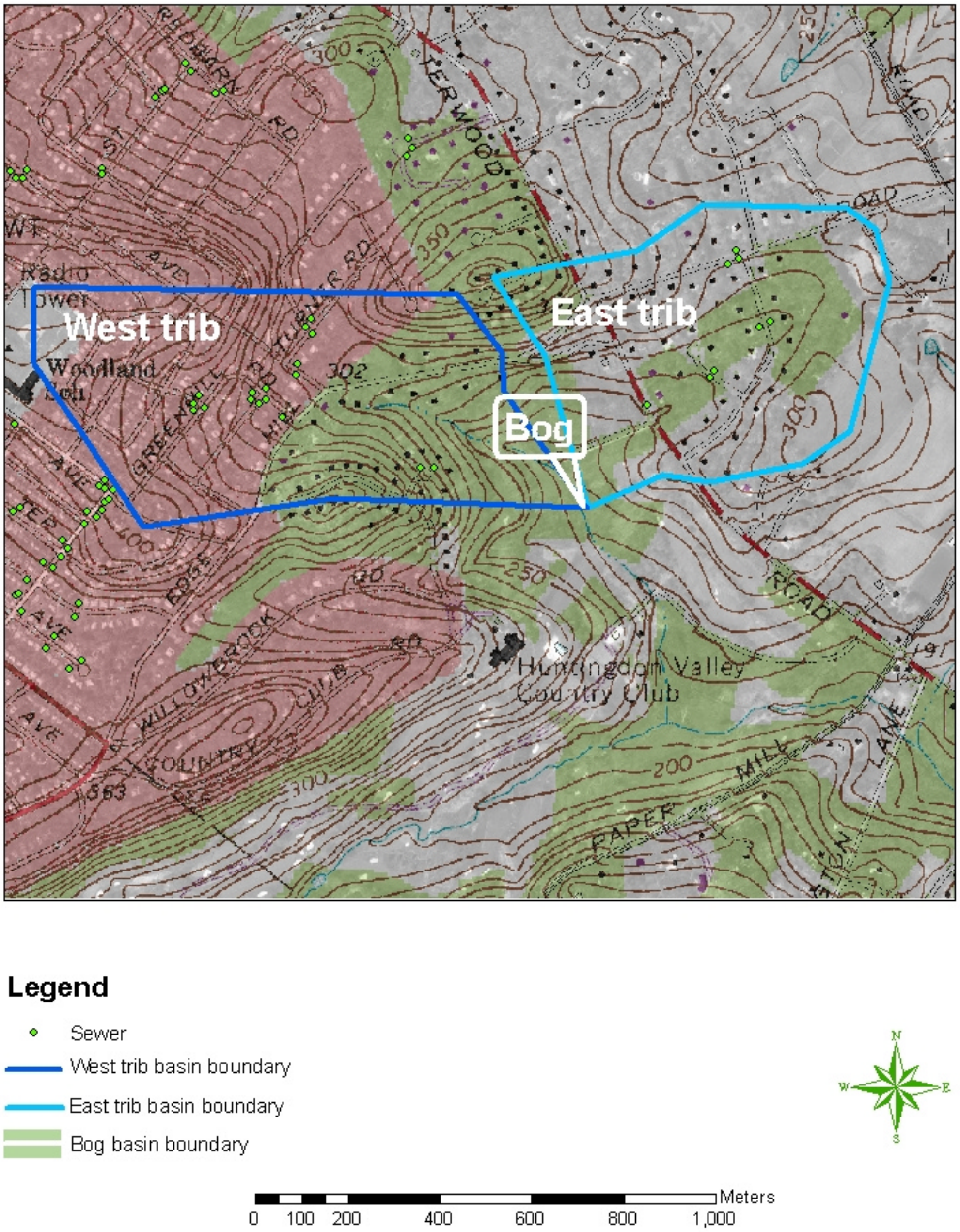


Figure 14: Basin maps for the three tributaries. The bog receives groundwater discharge and has a very small basin (outlined in white) up to the junction of the tributaries (and monitoring point). The west tributary is somewhat larger, has more homes, and also more sewer drains.

ACKNOWLEDGMENTS

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Environmental Restoration Trust suggested monitoring sites. Derron LaBrake suggested the monitoring on HVCC and introduced us to the maintenance staff and board of directors who kindly provided access. Access to Lorimer Park was provided by Scott Morgan and his staff. Thank you also to the townships who provided stormpipe maps, members of Trout Unlimited who suggested sampling sites, and especially the homeowners who provided access for sampling.

Most of the field work and laboratory analysis was conducted by a terrific crew of undergraduate students at Temple University over the two years of the study: Cecilia Mejias, Kathy Gross, Ken Hayes, Szilvia Mathe-Puckey, and Jeff Ham. Jeff Ham constructed the GIS maps for the report. The dedication and hard work of these students was indispensible!