Storm Water:
Causes, Consequences, and Management

The Water Resources Monitoring Project's

2005 State of the Water Resources Report

Published with support from Trout Unlimited and the Spring Creek Chapter

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Table of Contents

The Water Resources Monitoring Committee would like to extend a special Thank You to Bob Donaldson, Chair of the Spring Creek Watershed Coordinating Committee, for his contribution to this report.

From the Chair...

"Why monitor?" "Why collect the same data several times a year, year after year?" "When will you be finished monitoring?" Participants of the Water Resources Monitoring Project (WRMP) are sometimes confronted with these questions – and they are legitimate questions.

From my perspective, water resource monitoring is analogous to medical checkups. The frequency of medical checkups varies with one's age and specific health issues. Physicians examine a variety of body conditions and functions to develop an overall assessment of our health and to look for warning signs. Clinicians examine our vital signs; they measure pulse rate and blood pressure, listen to our heart and lungs, peek into our ears, and make all sorts of other observations.

Similarly, environmental professionals conduct periodic health assessments of our watershed, and particularly of our water resources. To make these health assessments, we need to frequently measure vital signs such as stream flow, pollutant concentrations in surface waters, water levels in wells, and water quality of springs. We need to know what conditions are normal for our watershed; therefore, we need a historical perspective, i.e., a long-term database. Because vital signs of a watershed can change over a short period of time, we need to measure these vital signs at regular intervals. And, if conditions change, we want to know about it in a timely manner, so that corrective action can be implemented before irreparable damage occurs.

Photos on Front Cover: K. Ombalski and M. Ralston

This report focuses on how those vital signs are influenced by storm water runoff. We have tried to show how water quality changes as a result of storm water runoff, how human activities affect runoff, and how residents of the watershed can help to minimize harmful effects of storm water runoff. The Millbrook Marsh Bio-retention Project is a great example of public and private interests working together to find non-regulatory solutions to environmental problems. And hopefully, 'low impact development' will become a common practice here in the Spring Creek Watershed.

The success and effectiveness of the Water Resources Monitoring Project is directly related to strong local support. Since the project began in 1997, we have received numerous grants from public and private sources. These grants have enabled us to purchase and install all the equipment necessary to collect the needed information. However, the yearly operation and maintenance of the project has been funded by local public and private entities that are listed on page 6. Without this strong local support, the WRMP could not persist.

Our goal is to provide useful information to local decision makers. When information needs have been brought to our attention, we have tried to address those needs. We are encouraged by the number of requests for data that we receive, and from the testimonials offered by those who make the requests. We look forward to continue working with our supporters and to serving the community.

1.0 INTRODUCTION

Welcome to the Water Resources Monitoring Project's (WRMP) 2005 Annual Report. The intent of this year's report is to present the WRMP Committee's efforts to measure the effects of local storm-water events both on the Spring Creek Watershed and on downstream basins such as the Susquehanna River and the Chesapeake Bay. In 2005, the WRMP measured the quantity and quality of several storm events in the watershed. These measurements coupled with the ongoing measurement of base flow (normal streamflow) at the same sites were used to calculate the additional load of pollutants transported to the streams during storms.

Storm water is produced from precipitation that causes overland runoff to surface waters. In contrast, precipitation that percolates through the soil is filtered and enters the ground water with much fewer pollutants than surface runoff entering streams. The quality of storm-water runoff is dependent on the surrounding land use. Solids such as clay or soil can be transported into streams by storm water that runs over agricultural, industrial, urbanized, and construction areas when proper preventive measures are not taken. Nutrient (nitrate and phosphate) loads are commonly higher in residential and agricultural areas where runoff can wash fertilizers and livestock wastes into streams. Impervious (paved) surfaces prevent infiltration into the soil and increase the volume and velocity of runoff, resulting in ineffective ground-water recharge.

A natural way of mitigating the effects of storm events is to allow the stream to overflow into streamside floodplains and wetlands which will retain the runoff and allow it to slowly infiltrate into the ground.

The Slab Cabin Run sub basin of the Spring Creek Watershed, consisting of Slab Cabin Run and Thompson Run, is one of the more heavily urbanized portions of the watershed. Storm events here can result in rapid increases in stream flows due to significant amounts of impervious surface coupled with the collection and discharge of storm water from sewers and culverts. A project called the Slab Cabin Run Stormwater Bio-Retention Project is underway and sponsred by the Pennsylvania State University, the Pennsylvania Department of Environmental Protection, and the Spring Creek Chapter of Trout Unlimited. The intent of this effort is to construct instream flow devices which will divert storm-water runoff from Slab Cabin Run into 16 acres of floodplain wetlands in the vicinity of the Millbrook Marsh. In anticipation of this project, WRMP conducted storm-water sampling during 2005 upstream and downstream of the project area in order to quantify pre-construction conditions. Future sampling after project completion will allow an objective evaluation of the wetlands' effectiveness in treating storm-water runoff. Refer to section 5.0 for a detailed discussion of the results of the initial sampling.

Figure 1. Spring Creek watershed boundary sign.

Photo: ClearWater Conservancy

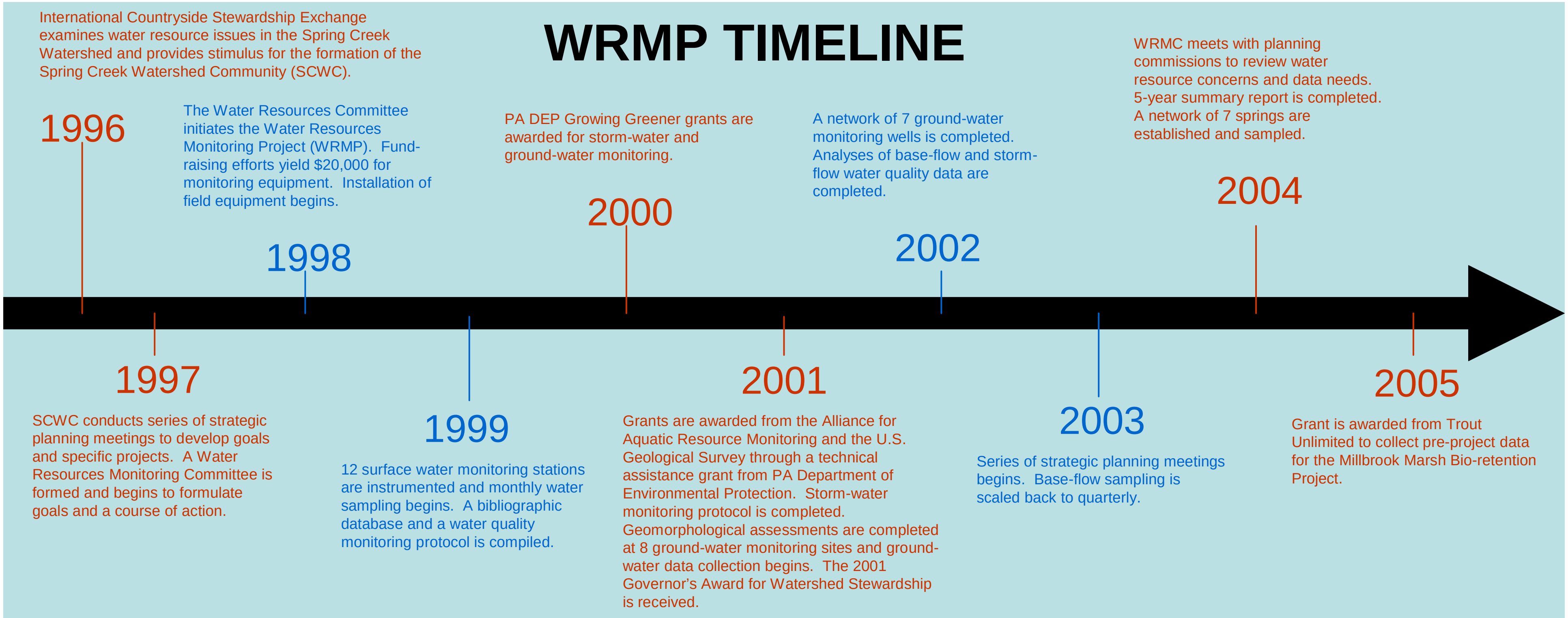

Figure 2. WRMP timeline.

WRMP BACKGROUND

The Water Resources Monitoring Project was initiated in 1998 as part of the strategic planning of the Spring Creek Watershed Community. The WRMP, comprised of base-flow, storm-water, and ground-water monitoring, was designed to be used for the long-term protection of Spring Creek and its tributaries. The project was created by the Water Resources Monitoring Committee (Table 1.), a volunteer group of environmental professionals, to

1. Provide a description of the quantity and quality of surface waters,
2. Provide a description of the quality of storm-water runoff,
3. Monitor ground-water levels,
4. Provide the means to detect changes in quantity and/or quality of base flow, storm water, and ground water,
5. Provide sufficient measurement sensitivity to permit assessment of these changes.

Project Funding

Local municipalities and organizations donated over $51,000 in 2005 for the project's continuation. 2005 Financial contributors include:

- Bellefonte Borough
- Benner Township
- College Township
- Ferguson Township
- Halfmoon Township
- Harris Township
- Patton Township
- Penn State University Office of Physical Plant
- Spring Creek Chapter of Trout Unlimited
- Spring Township
- Spring Township Water Authority
- State College Borough
- State College Borough Water Authority
- University Area Joint Authority

In 2005, WRMP received in-kind contributions including professional services, laboratory analyses and supplies, technical assistance, and transportation from:

- Ground water well owners (Corning Asashi, Howard Dashem, PA Department of Conservation and Natural Resources, Todd Giddings, Penn State University – Office of Physical Plant, and United States Geological Survey)
- PA Department of Environmental Protection
- Pennsylvania Cooperative Fish and Wildlife Research Unit, United States Geological Survey
- University Area Joint Authority
- Volunteer field assistants
- Water Resources Monitoring Committee

Table 1. The 2005/2006 water resources monitoring committee.

WRMP Committee Member	Affiliation
Robert Carline, Ph.D. **Committee Chair,** Adjunct Professor and Unit Leader	Pennsylvania Cooperative Fish & Wildlife Research Unit, USGS
Bert Lavan **Committee Vice-Chair,** West Nile Virus Program Coordinator	Centre County Planning Office
Jason Brown Project Manager	University Area Joint Authority
Hunter Carrick, Ph.D. Assistant Professor of Aquatic Ecology	School of Forest Resources The Pennsylvania State University
Ann Donovan Watershed Specialist	Centre County Conservation District
Rebecca Dunlap (Staff) Water Resources Coordinator	ClearWater Conservancy
Todd Giddings, Ph.D., P.G.* Hydrogeologist	Todd Giddings and Associates, Inc.
James Hamlett, Ph.D. Associate Professor of Agricultural Engineering	Department of Agricultural and Biological Engineering The Pennsylvania State University
Mark Ralston, P.G.* Hydrogeologist	Converse Consultants
Kristen Saacke-Blunk Extension Associate Agricultural and Environmental Policy	The Pennsylvania State University
John Sengle Water Quality Specialist	PA Department of Environmental Protection
David Smith Assistant Executive Director	University Area Joint Authority
Rick Wardrop, P.G.* Hydrogeologist and Industrial Contamination Specialist	Shaw Environmental & Infrastructure
Dave Yoxtheimer, P.G.* Senior Hydrogeologist	N.A. Water Systems

* Professional Geologist

2.0 MONITORING STATIONS

Stream Monitoring Stations

WRMP monitored base flow conditions at fourteen stream locations in 2005 (Figure 4). Twelve of the stations were established in 1998 with the premise of including at least one station in each of Spring Creek's sub-watersheds or sub-basins that would best represent land use patterns. The existence of three U.S. Geological Survey gaging stations on the main stem of Spring Creek and three gaging stations maintained by the Pennsylvania Cooperative Fish and Wildlife Research Unit was also taken into account.

A thirteenth station was added in early 2004 in response to the acid rock drainage issues raised by the uncovering of pyritic rock during roadway construction near the headwaters of Buffalo Run. This station is located on an unaffected tributary to Buffalo Run and serves as a reference for comparison with the headwaters of Buffalo Run that have been affected by acidic runoff. The fourteenth station was added in 2005 as part of WRMP's storm-water monitoring program and is located on Slab Cabin Run downstream of the Millbrook Marsh.

Ground-Water Monitoring Wells

The ground-water reservoir in the Spring Creek Watershed is monitored with a network of seven wells equipped with water-level monitoring devices (Figure 4). The wells were established at locations where they represented ground-water conditions over a large area and were not influenced by high-yield pumping wells or well fields, storm water, artificial ground-water recharge, or surface water discharges.

Spring Monitoring Stations

WRMP incorporated a network of seven springs (Figure 5) into quarterly base flow monitoring in 2005. Springs that best represented the range of land-use, geologic, and hydrogeologic conditions found in the basin were selected for monitoring. Section 4.3 provides more details on site location and sampling procedures.

Storm-Water Monitoring Stations

Storm water is monitored at two sites on Slab Cabin Run and one site on Thompson Run (Figure 4). WRMP initiated this sampling in 2005 to collect pre-project data for the Slab Cabin Run Stormwater Bio-retention Project. More information about storm-water monitoring and the Bio-retention Project can be found in sections 5.1 and 5.4.

Plans for 2006

2006 plans include an eighth ground-water monitoring well in the Scotia Barrens and a 4th storm-water monitoring station in the Millbrook Marsh.

Figure 3. Todd Giddings, water resources committee member, and project staff install monitoring equipment at Slab Cabin Run. Photo: R. Carline

3.0 DATA COLLECTION METHODS

Methods

Standardized methods have been developed for data collection and sample processing to provide quality assurance for all data collected by the WRMP. Detailed methods are documented in the Spring Creek Watershed Water Resources Monitoring Protocol which is available at www.springcreekwatershed.org or by request at (814) 237-0400.

Continuous Measurements

Stream stage was continuously measured at thirteen of the stream monitoring stations in 2005. Ten stations are equipped by the WRMP with instruments that record the water level every 30 minutes. Streamflow was recorded every fifteen minutes by the U.S. Geological Survey at Spring Creek Houserville, Spring Creek Axemann, and Spring Creek Milesburg.

Water temperature was recorded hourly at twelve of the stream monitoring stations.

Ground-water levels at the seven ground-water wells were recorded at three-hour intervals. Five of the wells are operated by the WRMP and two (CE118 and CE686) are operated by the U.S. Geological Survey.

All data collected by the WRMP are available upon request. To submit a request, contact the project manager at 814-237-0400.

Monthly Measurements

A flow meter was used to measure stage and velocity at thirteen of the stream monitoring stations on a monthly basis. These data were used to construct a rating curve which converts the stage measurements taken by the water level recorders into discharge. The monthly stage and volume measurements are also used to detect stream channel change resulting from sediment erosion or deposition.

Quarterly Measurements

Water samples were collected quarterly during base-flow conditions at each of the stream and spring monitoring stations. The samples were analyzed for the range of constituents listed in Appendix I. Field measurements of dissolved oxygen, pH, temperature, and conductivity were also taken.

Storm Water Measurements

The WRMP deployed automatic storm-water samplers at 3 storm-water monitoring stations (Figure 4) if a significant amount of precipitation was forecasted (>0.5 inches) and subsequent runoff was expected. The samplers were programmed to take a sample at a predetermined interval based on the pending precipitation event. After the event, the samples were processed and shipped to the PA Department of Environmental Protection's Bureau of Laboratories for analysis. Section 5.1 describes the results of the WRMP's storm-water monitoring efforts.

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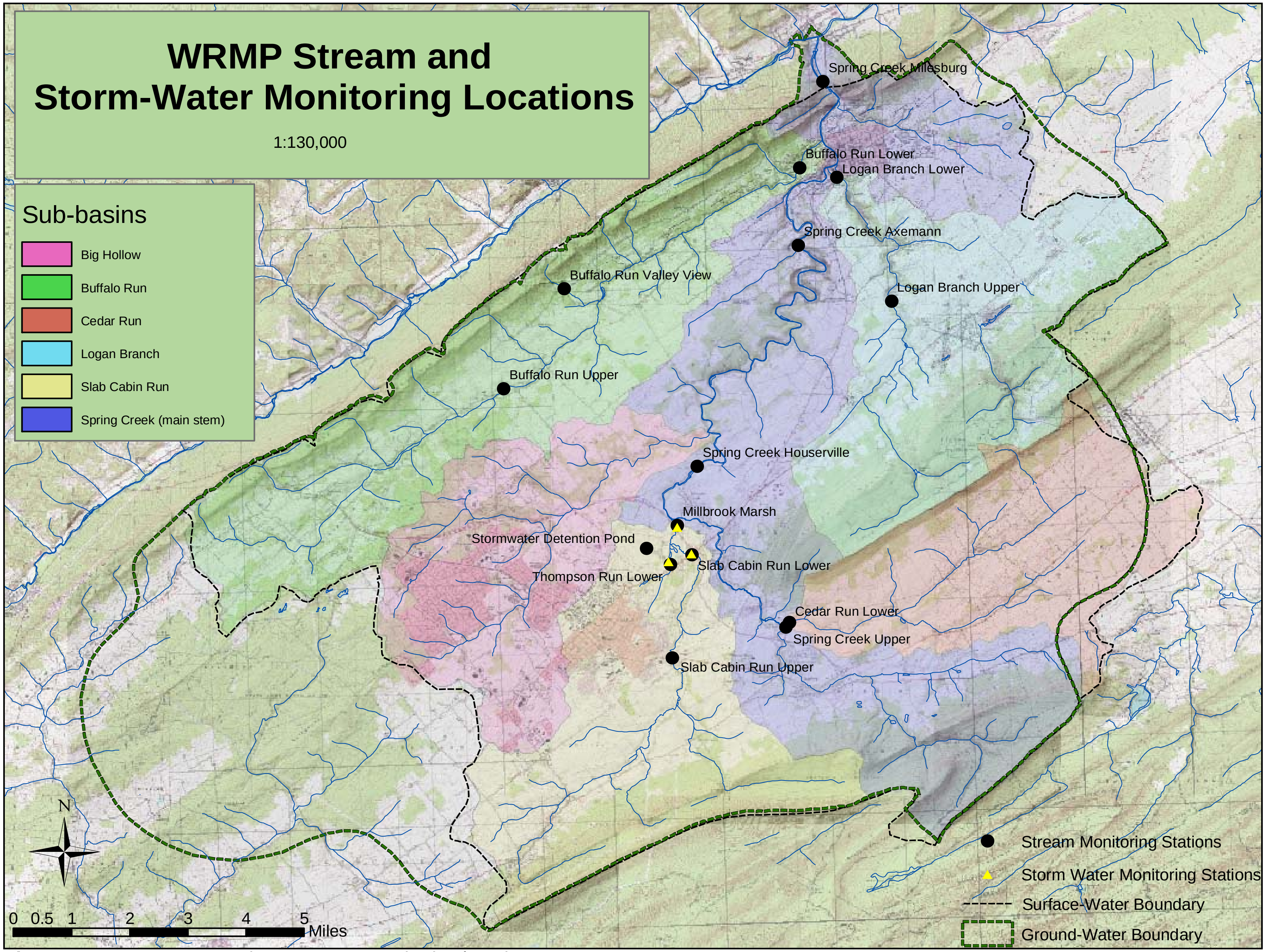

Figure 4. WRMP stream and storm-water monitoring locations.

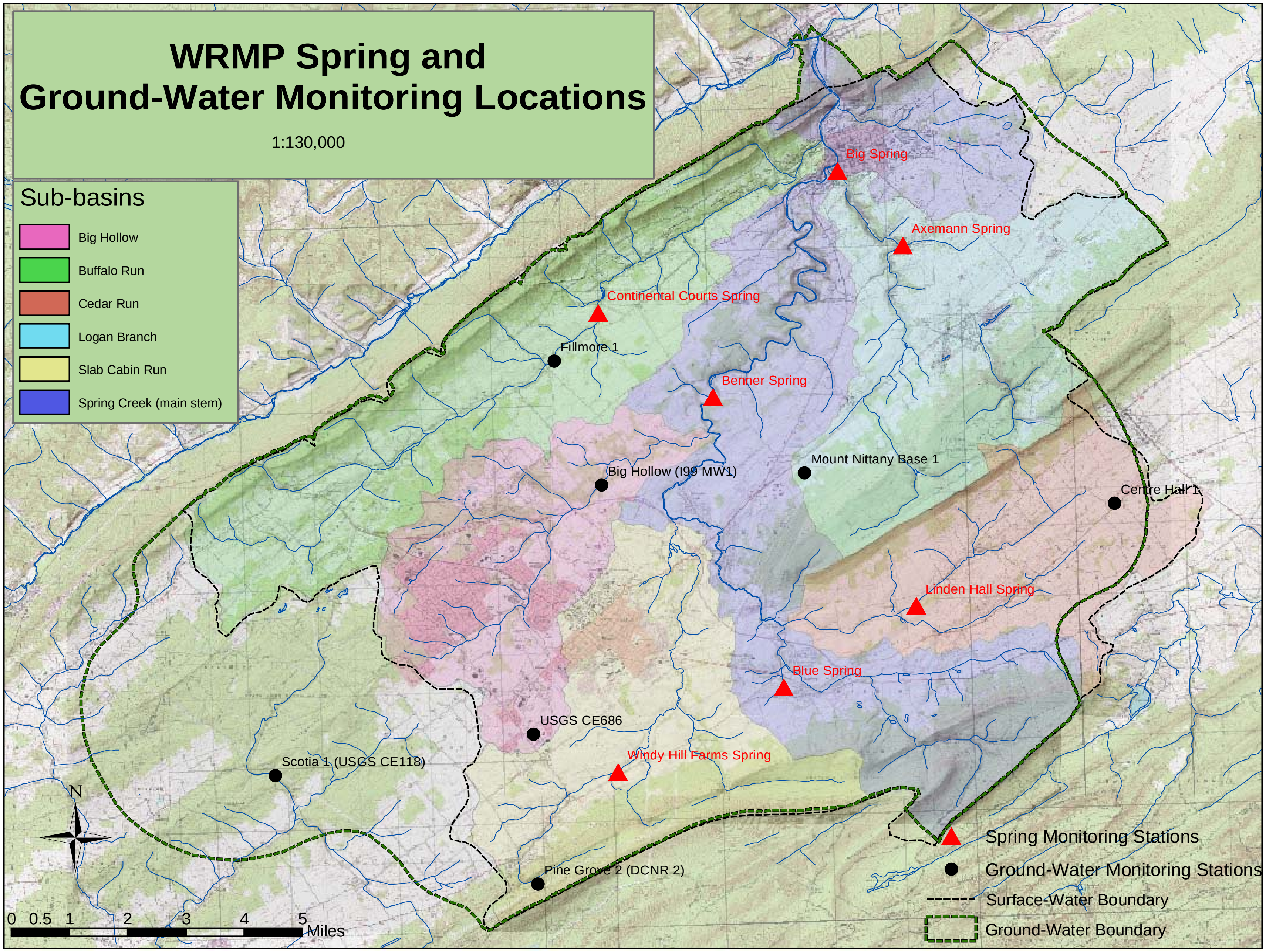

Figure 5. WRMP spring and ground-water monitoring locations.

4.0 RESULTS

4.1 WATER QUALITY

The WRMP collected water quality samples for the parameters listed in Appendix I at fourteen sites across the basin (Figure 4) on a quarterly schedule in 2005. Sampling frequency was reduced from monthly to quarterly in 2004 in an effort to focus more comprehensively on the ground-water and storm-water components of the project. Water quality results met the PA Department of Environmental Protection's Water Quality Criteria (Pennsylvania Code Title 25, Chapters 16 and 93) with the exception of 229 ug/L of total zinc at Spring Creek at Houserville measured on August 23, 2005.

Figure 6. Bryce Boyer, WRMP volunteer, collects water quality samples at Spring Creek Milesburg. Photo: ClearWater Staff

Figure 7. Bryce Boyer fixes water quality samples before they are shipped to the PA Department of Environmental Protection for analysis. Photo: ClearWater Staff

Water quality trends in 2005 reflected previous year's observations:

- Chloride levels were highest in the urbanized sub-basins of Thompson Run and Slab Cabin Run and lowest in the predominantly agricultural Cedar Run sub-basin.
- Nitrate levels were highest in the Cedar Run sub-basin.
- Metals were generally undetected with the exception of copper and lead in Logan Branch.
- Sulfates were not detected at the Buffalo Run sampling locations.

Data User Testimonial

"HRG used a statistical analysis of the data provided (baseline streamflow) to design a temporary crossing of Slab Cabin Run for the construction of the beneficial re-use transmission line."

Douglas E. Weikel, PE, CSI, Herbert, Rowland & Grubic, Inc.

4.2 STREAMFLOW

The WRMP collected discharge data at ten locations throughout the basin (Figure 4) in 2005. Figure 8 shows 2005 surface water trends at seven of the ten WRMP stations equipped with water level recorders. Discharge calculations for the WRMP's Thompson Run station are not included in this figure because a reliable rating curve has not been established since the station was relocated in late 2004. Project staff and volunteers continue to collect rating curve data to address this issue.

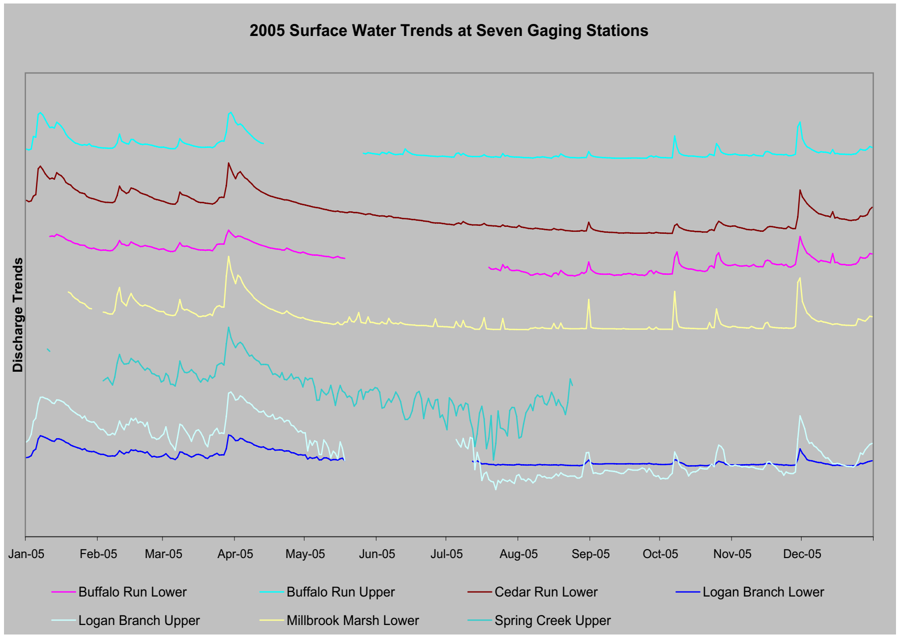

Figure 8. 2005 surface water trends at seven gaging stations.

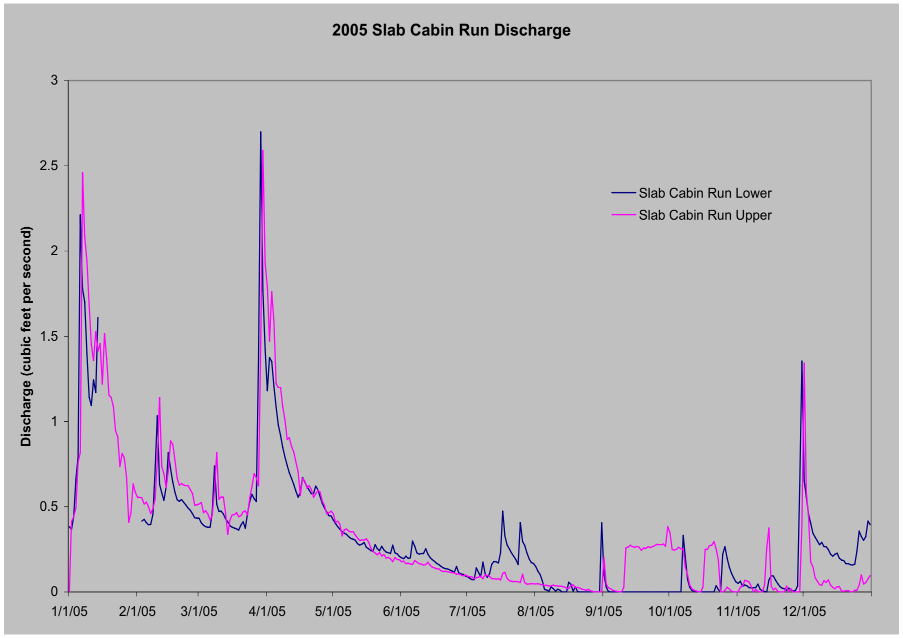

Figure 9. 2005 Slab Cabin Run discharge.

In summer months, streams without significant ground-water input may experience very low-flow or dry conditions. This was the case in 2005 in Slab Cabin Run (Figure 9). The hydrographs for the two stations on this stream become extremely variable beginning in August. The hydrograph gaps reflect dry or no-flow conditions and the peaks illustrate the flashy rise and fall of water levels associated with these periods. Figure 9 also shows that there is more water in Upper Slab Cabin Run than there is in Lower Slab Cabin Run in mid-September. This phenomenon is associated with losing streams, or streams with a higher surface elevation than the adjacent water table. In a losing stream water infiltrates through the stream bottom and recharges the ground water.

4.3 GROUND WATER

The WRMP collected ground-water data in 2005 from a network of five wells across the Spring Creek basin. In addition, the U.S. Geological Survey collected continuous data from two wells (CE118 and CE686). The location of these seven wells are shown in Figure 5.

The 2005 ground-water levels in the Spring Creek basin were within their normal range of historical levels. Figure 10 depicts historical ground-water level data collected by the U.S. Geological Survey at well CE118. The 53.69 inches of precipitation received in 2004 helped to replenish the decreased levels caused by the drought beginning in 1999 and extending through early 2001. 2005 shows a slight decrease in ground-water levels from the record high levels experienced the previous year.

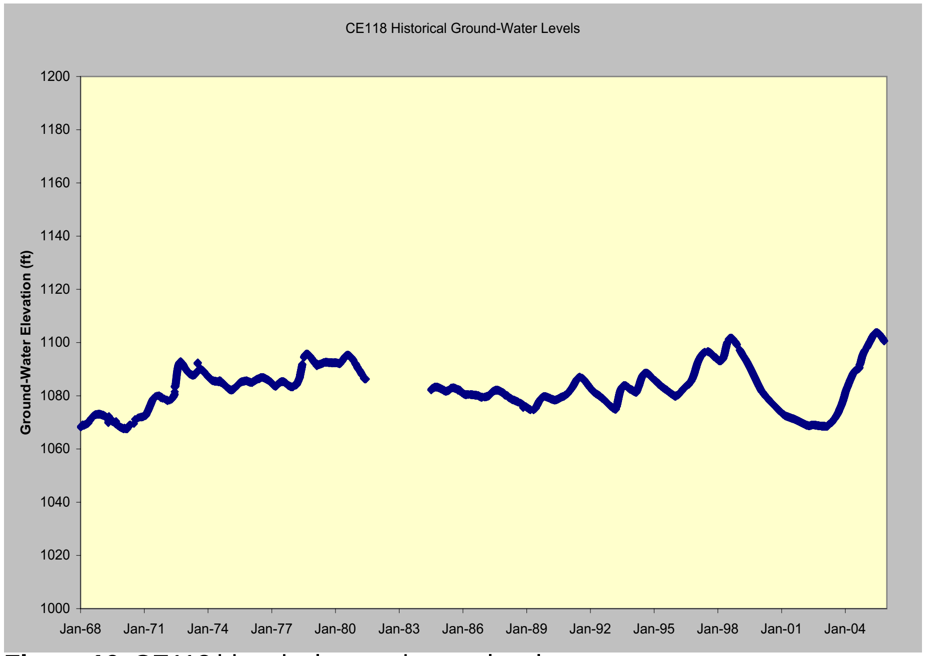

Figure 10. CE118 historical ground-water levels.

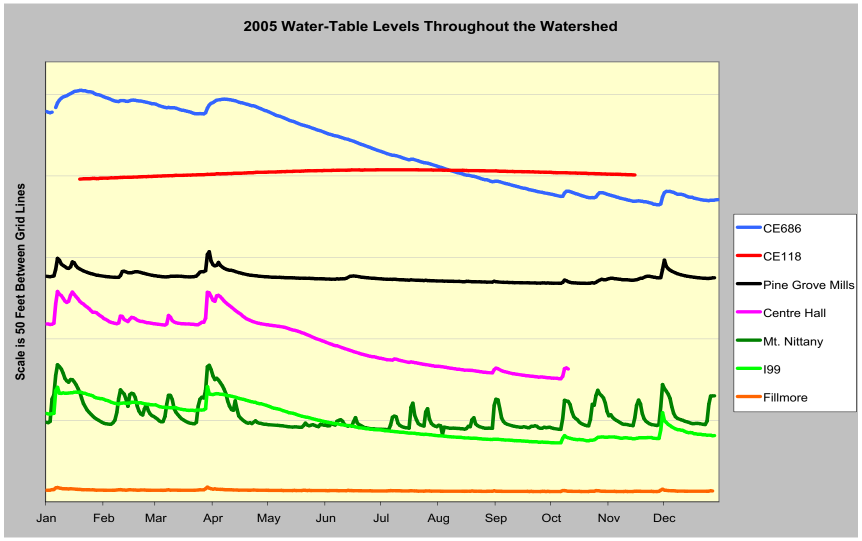

Figure 11. 2005 water-table levels throughout the watershed.

In general, water table fluctuations are the greatest in wells farthest from ground-water discharge points. The Fillmore well resides within several feet of Buffalo Run causing its hydrograph to have a subdued response to precipitation events (Figure 11). In comparison, the hydrograph of the Mt. Nittany well located approximately three miles from its discharge location accentuates the rise and fall of ground-water levels. An exception to this general rule is well CE118 whose discharge location is thirteen miles away at Bellefonte's Big Spring. The subdued hydrograph of this well illustrates the high storage capacity of the ground-water reservoir of the Scotia Barrens.

The hydrograph of the Spring Creek Watershed's headwaters at well CE686 illustrates the effect of evapotranspiration during summer months. During this time, ground-water levels decrease as the discharge of water from storage into the streams exceeds recharge rates due to the direct uptake of water by plants.

4.4 TEMPERATURE

Ground-water inputs play an important role in regulating stream temperatures in the Spring Creek basin. Temperatures in streams with high amounts of ground water (i.e. Thompson Run and Logan Branch) are less variable than temperatures in streams with low or no ground-water inputs (Buffalo Run and Slab Cabin Run).

Temperature is vitally important to the trout fishery in the Spring Creek basin. The kind of fishes that can be supported and how fast these fishes grow is strongly influenced by this variable. For instance, brown trout either die or begin to show obvious signs of stress such as weight loss when maximum daily temperatures exceed 76°F. Brown trout will seek the cooler waters associated with ground-water inputs when warmer temperatures persist.

In late June 2005, low flow conditions combined with high temperatures were partially responsible for a large brown trout kill in Slab Cabin Run between Atherton Street and the Centre Hills Country Club.

Figure 13. Brown trout kill in Slab Cabin Run, June 2005. Photo: PA Fish and Boat Commission Photo File

Data User Testimonial

"On 6/26/05, a fish kill occurred in Slab Cabin Run and was investigated by Wildlife Conservation Officer David Decker of the PA Fish & Boat Commission. While nothing was discounted and other possible causes were investigated to rule them out, it was the contemporary, historical temperature data furnished by the WRMP that allowed the investigation to conclude the event was a result of natural thermal stresses of low water levels, scant riparian shading and summer air temps / solar heating of the water. Water temperature data hovered at levels considered very stressful to trout for two days.

Much the same as in any "death investigation" performed by the law enforcement community, ruling out causes and/or clearing suspects is as important as verifying the villain. In an environmental investigation, ruling out possible causes relieves concern of agencies and the public on environmental health and public safety lest it go unresolved or cause further damage.

Thank you to staff and supporters who enabled this data collection and referral."

Brian B. Burger, Regional Manager
Northcentral Region – PA Fish & Boat Commission

Figure 13. Slab Cabin Run at Atherton Street in 2001.
Photo: K. Ombalski

4.5 SPRINGS

In 2005, the WRMP began the important task of conducting long-term water quality monitoring at seven major springs across the Spring Creek basin. As a result of the complex karst topography that covers a significant portion of the basin, and that exerts a controlling influence on the hydrology and geochemistry, it has been a goal of the WRMP to implement a basin-wide effort to monitor key water quality parameters at representative springs. Springs contribute a major portion of stream base flow to Spring Creek tributaries, and account for the stable delivery of large volumes of cold, limestone enriched water that provide optimum conditions for our renowned cold water fishery. To date there has not been a concerted, basin-wide effort to collect long-term water quality data at important springs, and such an effort is essential to detect changes in spring water (ground-water) quality as a result of land-use changes and population growth.

Figure 14. Continental Courts Spring in Benner Township. Photo: R. Dunlap

The WRMP committee evaluated a large number of potential spring monitoring sites across the basin and chose a group of seven springs based upon locations that represented the range of land-use, geologic, and hydrogeologic conditions, that provided ready access for monitoring activities and important water quality data for previously unmonitored contributions to Spring Creek, and that represented major ground-water contributions to the major stream sub-basins tributary to Spring Creek. While monitored springs do include several large flow springs such as Big Spring in Bellefonte, and Benner Spring on SCI-Rockview property, these springs are not the seven largest flow springs in the basin. Some selected springs were off the main reach of Spring Creek and capture contributions from the prominent non-carbonate ridges that bound the Spring Creek basin.

The seven selected springs are Windy Hill Spring (WIS) along SR-45 east of Pine Grove Mills, Blue Spring (BLS) at Blue Spring Park in Boalsburg, Linden Hall Spring (LIS) just east of Linden Hall, Axemann Spring (AXS) in Axemann, Big Spring (BIS) in Bellefonte, Continental Courts Spring (COS) at Continental Courts Village in Benner Township, and Benner Spring (BES) on SCI-Rockview property in Benner Township. The springs are monitored quarterly, and samples are analyzed for the same water quality parameters as the base-flow stream monitoring network (Appendix I). Thanks to the generous efforts of the University Area Joint Authority, the springs are also analyzed for fecal coliform bacteria. To date flow data are not being collected at springs. Analytical results from PA Department of Environmental Protection Central Lab and University Area Joint Authority are stored in hard-copy and electronic format in the same WRMP database currently in use for stream base-flow and storm-water monitoring.

Figure 15. Jack Williams, WRMP volunteer, records data at Linden Hall Spring. Photo: R. Dunlap

On the basis of three sets of water samples in 2005, several generalizations can be made:

Total metals are generally low or slightly above detection limit for most springs, and dissolved metals are almost entirely below detection limits. Metals, especially dissolved metals, are expected to be low at the neutral pH measured at nearly all springs.

While hardness at most springs is relatively high (>250 mg/L), typical of ground water in limestone/dolomite settings, data for Blue Spring and Big Spring reveal both hardness and nitrate-nitrogen at roughly half (or less than half) than at the other springs. This may be a direct result of the predominantly non-karst geology, and forested cover of their source basins.

Fecal coliform counts were generally below detectable levels, but several springs had low but detectable levels of fecal coliform bacteria. With the exception of several anomalies during very low flow/no flow conditions in August, suspended solids were very low, reflecting very clear, low sediment conditions.

The quarterly collection of data at these springs into the foreseeable future will provide data for making important comparisons between springs in different geologic settings, and perhaps more importantly, allow us to view how changes in land-use, hydrology and population impact the springs that provide a significant portion of drinking water to residents in the Spring Creek basin and the base flow that sustains the aquatic resources of Spring Creek and its tributary basins.

Data User Testimonial

"The U.S. Geological Survey, in cooperation with American Rivers, Pennsylvania Fish and Boat Commission, and Pennsylvania State University, has recently proposed a study of the McCoy-Linn Dam removal, scheduled for 2007. The water quality data provided by WRMP (especially data for nutrients and heavy metals) were used to determine the range of concentrations during baseflow and storm events prior to removal of McCoy-Linn Dam in Milesburg, Pa. In addition, these baseline data are invaluable for evaluating the potential for nutrient and heavy metal accumulation in sediments behind the dam. As part of the McCoy-Linn Dam study, data from WRMP will be compiled into a pre-removal dataset that, along with additional pre-removal data collected for the project, will serve to describe baseline conditions prior to dam removal."

Jeffrey J. Chaplin, U.S. Geological Survey

5.0 STORMWATER

5.1 STORM-WATER MONITORING AT MILLBROOK MARSH

In 2005, the WRMP initiated storm-water runoff monitoring at three locations adjacent to Millbrook Marsh to collect data prior to installation of rock vanes planned for the Millbrook Marsh area in 2006. (Refer to section 5.4 for a more detailed description of the rock vanes). Two stations, Slab Cabin Run Lower (SLL) and Thompson Run (THL), are located upstream from the planned construction, and one station, Millbrook Marsh Lower (MIL), is located immediately below the confluence of Slab Cabin Run and Thompson Run downstream from the Millbrook Marsh (see Figure 16 for locations of these storm-water monitoring sites). Through monitoring and water quality sampling during storm events, the WRMP will compare flows and water quality conditions before and after construction; thereby assessing the relative effectiveness of the rock vanes in modifying flow and constituent concentrations during storm flow events.

Stormwater runoff events and parameters monitored

During 2005, 9 rainfall-runoff events occurred for which water quality samples were collected. Table 2 provides a brief summary of the dates of occurrence, total precipitation, number of stations where water quality data were collected, and days since previous measurable rainfall. Complete flow and water quality data for all three stations were collected for five storms, which occurred on July 16th, July 24th, August 30th, September 26th and October 7th. Monitored rainfall for these events (measured at the Walker Building Weather Station on the Penn State campus) ranged from the smallest event of 0.38 inches on September 26 to the largest event of 2.89 inches on October 10. The total number of water quality samples collected varied dependent upon storm event and station location, but in all instances at least three discrete or composite water quality samples were collected; one on the rising stage of the hydrograph, one at or near the peak rate of flow, and one on the falling limb of the hydrograph. For most events an additional 2 to 5 samples were collected, dependent upon duration and magnitude of the storm event.

Table 2. Storm events sampled.

Storm Number	Start Date	End Date	Precipitation Amount (inches)	# of Stations with WQ Data	Days Since Previous Event
20050330	3/28/2005	3/29/2005	1.73	2	5
20050402	4/5/2005	4/3/2005	0.76	2	3
20050705	7/5/2005	7/6/2005	0.32	2	8
20050707	7/7/2005	7/8/2005	0.41	2	6
20050716	7/16/2005	7/17/2005	1.05	3	7
20050724	7/25/2005	7/25/2005	0.79	3	6
20050830	8/30/2005	8/31/2005	1.29	3	1
20050926	9/26/2005	9/26/2005	0.38	3	26
20051007	10/7/2005	10/8/2005	2.89	3	5

Water quality parameters assessed for these monitored events included; solids (total residue, total suspended solids, total dissolved solids, and turbidity), common metals (aluminum, copper, iron, lead, and zinc), nutrients (total nitrogen, total phosphorous), chloride, total organic carbon, and pH. These parameters represent a range of commonly measured constituents that are typically observed to vary with storm events and that may be influenced by the rock vanes, once installed.

Concentration box plots of water quality parameters

Figure 19 presents box plots of concentration data for the various water quality parameters at each station across all nine events monitored or partially monitored (actual concentration statistical data corresponding to the box plots provided in Appendix B). As shown, the median concentrations of most parameters were greater for Thompson Run (more urbanized) than for Slab Cabin Run (less urbanized). This was the case for all the parameters with the exception of total organic carbon and total dissolved solids. Concentrations at the Millbrook site (below the confluence of Slab Cabin Run and Thompson Run) reflected the range of concentrations observed at the two upstream sites.

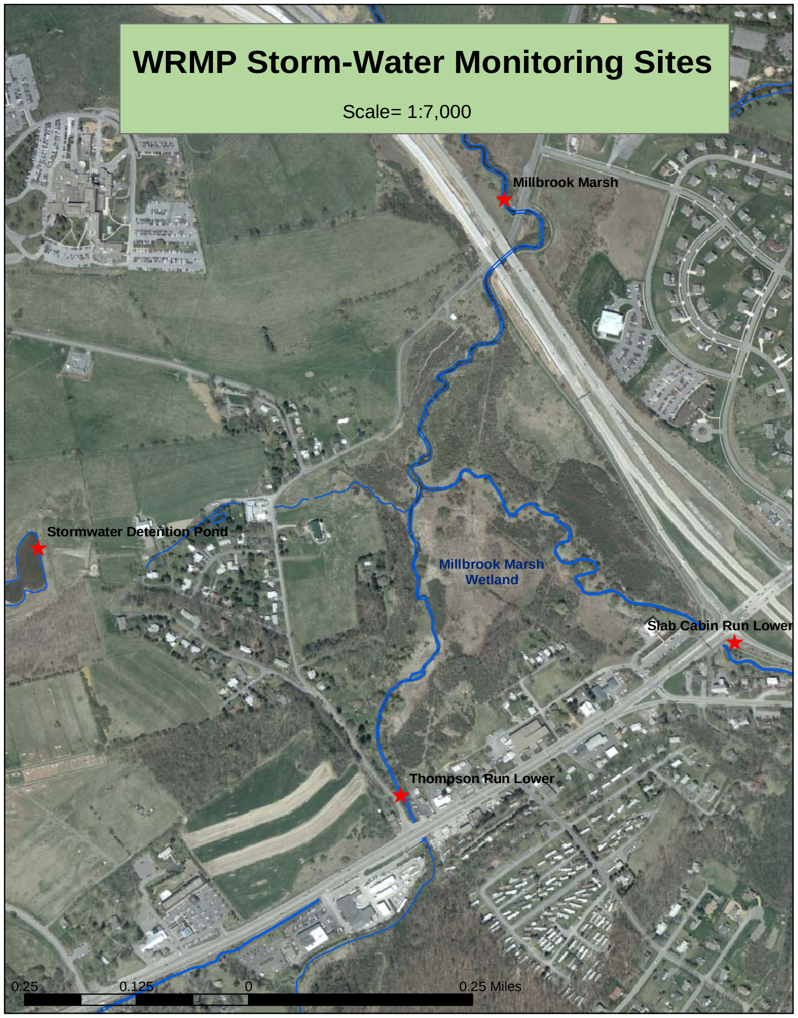

Figure 16. WRMP storm-water monitoring locations.

Figure 17 & 18. Storm-water equipment located at each site.
Photos: R. Dunlap

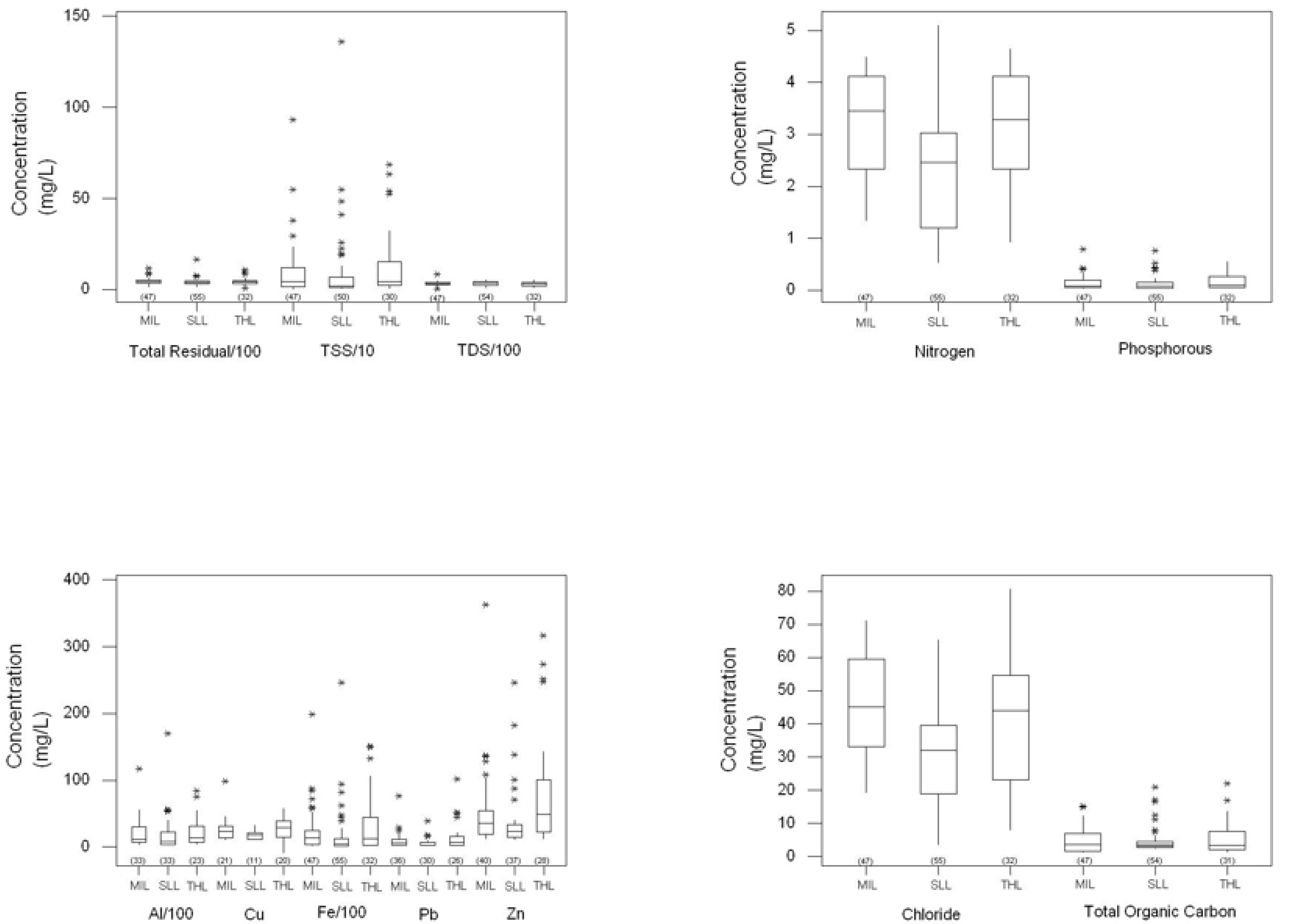

Figure 19. Box plots of concentration data for the various water quality parameters at each station across all nine events monitored or partially monitored.

In reviewing the concentrations of solids parameters (total residue, total suspended solids, and total dissolved solids) one can observe that the ranges and medians of concentrations were fairly similar for each of the parameters at all three stations. The inter-quartile range (middle 50 % of sample values) of the measured concentrations for total residue and total dissolved solids were similar for the three stations and were between 300 and 500 mg /L and 200 and 400 mg/L, respectively. The inter-quartile range of concentrations for total suspended solids varied more among the three sites, with the Thompson Run site showing the largest range (24 to 148 mg/L), followed by Millbrook (12 to 110 mg/L), and Slab Cabin (10 to 62 mg/L). Slab Cabin Run seemed to have less suspended materials in storm flows than did the other two stations, based on median values.

Higher concentrations of metals were generally measured at the Thompson Run station as compared to the Slab Cabin Run station. This is consistent with previous observations that show higher metals runoff from more urbanized (developed) watersheds. Iron was detected in all samples collected at all locations, with median values of 1300, 1211, and 453 mg/L for the Millbrook, Thompson Run, and Slab Cabin Run stations, respectively. Copper was the least frequently detected of the metals, with 78% of samples at Slab Cabin, 57% of samples at Millbrook, and 44% of samples at Thompson Run having no detectable concentrations. Aluminum was the second least detected metal, again with the Slab Cabin Run samples being the least frequently detected and having the lowest median concentrations. Clearly the more urbanized Thompson Run watershed contributes higher metals concentrations to the stream system than does Slab Cabin Run.

Nitrogen, phosphorus, and chloride concentrations also tended to be greater from the more urbanized Thompson Run watershed than from Slab Cabin Run. Median total nitrogen and total phosphorus concentrations in runoff were larger for the Thompson Run station than for Slab Cabin Run, with median total nitrogen concentrations being 3.28 and 2.46 mg/L and median total phosphorus concentrations being 0.095 and 0.072 mg/L, respectively. The box plots for the Millbrook station were similar in range and values to the Thompson Run station. Chloride concentrations (median values and inter-quartile range) were greater at the Thompson Run station than at the Slab Cabin Run site, and the Millbrook location showed a pattern of concentrations similar to the Thompson Run location. The inter-quartile range at the Thompson Run site was 20 to 40 mg/L whereas the inter-quartile range was approximately 25 to 60 at the other two stations. Median concentrations of total organic carbon were not appreciably different among the three stations.

Figure 20. Jeremy Harper, Penn State graduate student, places storm-water equipment in the stream in anticipation of a storm-water event.
Photo: R. Dunlap

Patterns of concentrations during an event

Figure 23 shows the preliminary hydrographs (station rating curves are still being developed) at the three stations for the July 16 event. Similar presentations of hydrographs for the other four events are also available and allow comparison of flows at the three stations across each of the events monitored. Corresponding plots of concentrations versus time during the events (pollutographs) for the July 16 event for total N (nitrogen) and total P (phosphorus); aluminum and iron; TSS (total suspended solids), TDS (total dissolved solids) and total residue; and copper, lead and zinc at the Thompson Run site are presented in Figure 24. For this double-peaked event of July 16, those constituents that are primarily attached to sediment particles or solids (total P, TSS, total residue, and all metals) show peak concentrations occurring prior to or simultaneous with the peak flows. On the other hand, the other constituents, which are transported in dissolved form, tend to decrease in concentrations as flow rates increase. Similar patterns are observed for the other two locations and for all events monitored. Total storm event loads and event mean concentrations (not included herein) can be determined based on these observed flows and concentrations.

Figure 21. Storm-water runoff in Thompson Run. Photo: K. Ombalski

Summary

Initial storm-water monitoring equipment at stations adjacent to the Millbrook Marsh have been installed and data collection is underway. Data for the five events for which samples were collected at all three stations show that the highest concentrations of most parameters are measured for the more urbanized Thompson Run watershed, which is consistent with previous storm-water sampling conducted during the January, 2001 through May, 2002 period. As expected when viewing the pollutographs of various parameters, those constituents that are solids or carried primarily attached to solids show highest concentrations either immediately preceding or concurrently in time with the peak flow rates. On the other hand, those parameters that are carried primarily in dissolved form tend to have more dilution, and hence lower concentrations, during times of the peak flows. Measurements of concentrations and flow rates with time will allow total event loads and event mean concentrations to be calculated; thereby facilitating comparisons of these loads and concentrations, and will also allow mass balances of parameters for various storm events both preceding and after construction of the rock vanes within the Millbrook Marsh area.

Figure 22. Storm-water runoff in Spring Creek. Photo: K. Ombalski

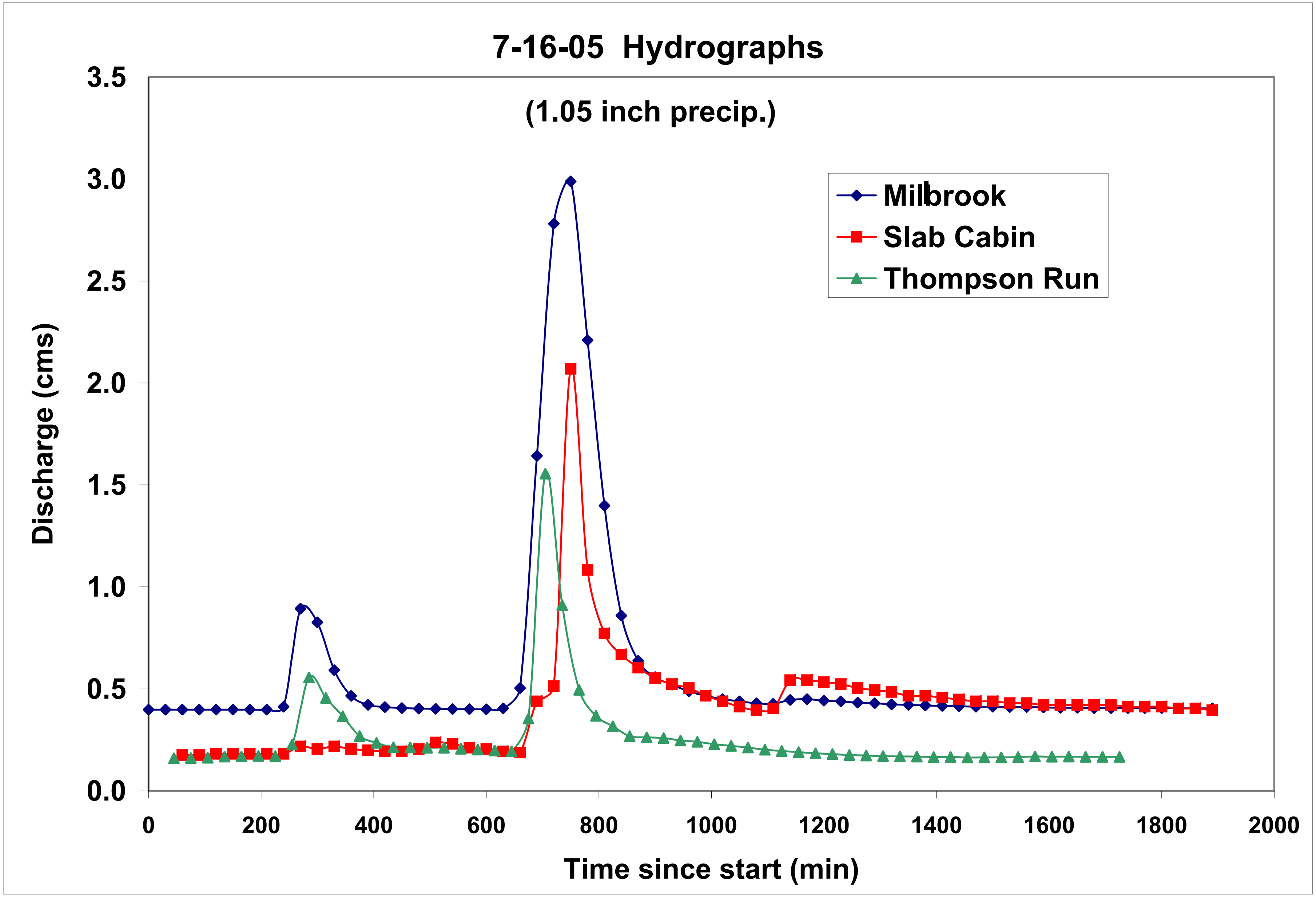

Figure 23. Preliminary hydrographs at the three stations for the July 16 event.

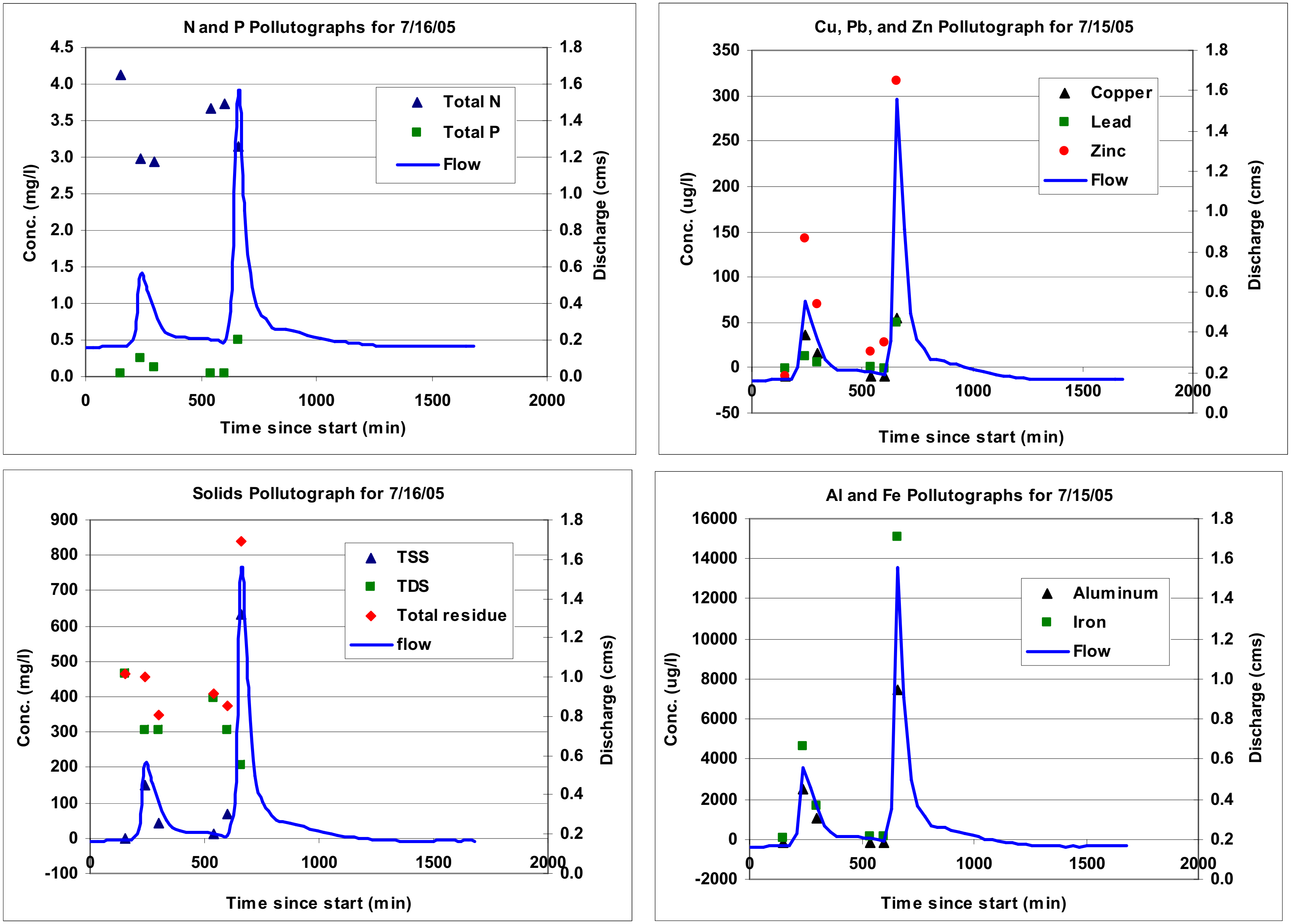

Figure 24. Pollutographs for the July 16 event at Thompson Run location.

5.2 CONSEQUENCES OF STORMS

Precipitation from storms can have consequences including erosion, flooding, and reduced ground-water recharge. Proper management of storm water is essential to prevent soil erosion, minimize flood damage, enhance ground-water recharge, and preserve our region's streams. The land surface has a certain capacity to facilitate infiltration of water during a precipitation or snowmelt event, which is largely a function of the soil type, soil moisture, and land cover (grass, trees, paved, etc). If the infiltration capacity of the land surface becomes saturated and is overwhelmed by precipitation, then surface runoff (storm water) occurs. Surface runoff is a natural input to stream flow; however, too much surface runoff can cause excess soil erosion and flooding, which ultimately causes adverse impacts to stream health, such as aquatic habitat and riparian (streambank) vegetation loss. A discussion of some of the consequences of storm water and its mismanagement is presented below.

As more development occurs within the Spring Creek Watershed, there will be an inevitable increase in impervious surface (rooftops, paved areas), which results in additional storm-water runoff. Increased amounts of storm-water runoff during precipitation events provides more energy to surface flow thus increasing the runoff's erosive potential. This increased surface runoff can then remove fertile topsoil, thereby ultimately reducing soil productivity. The downstream effects of erosion can include deposition of the eroded soils in unwanted areas such as streambeds (stream siltation), which can reduce or degrade aquatic habitat. In addition, focused storm-water runoff can increase the potential for sinkholes to form in areas prone to sinkhole development.

Figure 25. Sinkhole example. Photo: D. Yoxtheimer

During extreme precipitation or snowmelt events, excess storm-water runoff into surface streams can cause localized or regional flooding. The damage to homes and property during flood events can be catastrophic and deadly. The damage to the stream's health can be difficult or impossible to restore as aquatic and streambank habitat for fish, birds and other stream species is washed away. The erosive damage during a flood event can forever change the appearance of a stream in a matter of hours. To a certain degree, floods are natural events; however, increased storm water from development can play a significant role in increasing the number and intensity of floods, especially in low-lying or downstream portions of the watershed.

As more storm-water runoff is produced in the watershed, it is at the expense of ground-water recharge. Impervious surfaces effectively remove the soil's capacity to facilitate infiltration of precipitation, which would have otherwise recharged the area's prolific aquifers. As ground-water recharge is reduced, the amount of available water stored within the earth's natural reservoir (aquifer) is reduced, which can reduce well yields, spring flow, and sustained streamflow.

Proper storm-water management is essential for preserving the Spring Creek Watershed's fertile soils, high quality streams, and valuable ground-water resources. As development continues to occur in the area, the potential for increased amounts of storm-water runoff and associated erosion, flooding, and ground-water recharge problems will persist.

Figure 26. Erosive damage from storm-water runoff. Photo: D. Yoxtheimer

A Sampling of WRMP Data Users

- Confidential Engineer User
- Confidential Industrial Users
- Glenn O. Hawbaker, Inc.
- Graymont
- Municipalities
- PA Department of Environmental Protection
- PA Fish & Boat Commission
- PA Watersheds and Rivers
- Pennsylvania Cooperative Fish & Wildlife Unit
- PSU Graduate Students
- Spring Creek Watershed Commission
- Spring Creek Watershed Community
- Spring Township Water Authority
- State College Borough Water Authority
- Susquehanna River Basin Commission
- United States Geological Survey (USGS)
- University Area Joint Authority
- Upper/Middle Susquehanna Regional Committee
- Waters Edge Hydrology

5.3 NUTRIENT AND SEDIMENT TRANSPORT OUT OF THE SPRING CREEK BASIN

The amount of pollutants and other materials transported out of the watershed is influenced by the frequency, duration, and severity of rainfall and snow melt events that produce runoff. To illustrate the effects of storm flow on nutrient and sediment transport, we compared a dry and wet year. In 2001, when mean daily stream flow was 32% below normal, water samples were regularly collected during base flow and storm flow at the Milesburg gage. We used average concentrations of nutrients and sediment together with daily flow to compute the amount of materials transported out of the watershed (Table 3). Of the two major nutrients, a relatively small amount of phosphorus was transported, but there was a substantial export of nitrogen – 503 tons. During this dry year, most of the nitrogen was exported during base flow. Transport of suspended solids was rather large – nearly 2,600 tons, and approximately equal amounts were transported during base flow and storm flow.

Figure 27. Spring Creek at McCoy's Dam in Milesburg. Photo: R. Dunlap

The above described pattern of export changed markedly in 2003, when daily stream flow was 30% above normal. Water samples were not collected during storm flow in 2003; hence, we used the same concentrations as in 2001. Total transport of nitrogen was 951 tons, and most was transported during storms. Export of suspended solids increased greatly to more than 7,200 tons, and most was exported during storms.

Table 3. Estimated amounts of nitrogen, phosphorus, and suspended solids transported out of the Spring Creek Watershed in 2001, a relatively dry year, and 2003, a relatively wet year. Average concentrations used in calculations were based on water samples collected during base flow and storm flow in 2001 at the Milesburg gage.

	Nitrate Nitrogen			Orthophosphate Phosphate	Total Suspended Solids		
	Baseflow		Stormflow	Baseflow and Stormflow	Baseflow		Stormflow
Concentration (mg/L)	3.3		3.2	0.03	12		30
2001 @ 156 cfs							
Yields (tons)	373		130		1355		1228
Total Annual Yield (tons)		503		5		2582	
2003 @ 299 cfs							
Yields (tons)	296		655		1078		6137
Total Annual Yield (tons)		951		9		7215	

5.4 WHAT CAN WE DO TO REDUCE INFLUENCES OF STORMFLOW?

Slab Cabin Run Stormwater Bio-Retention Project Example

Fall 2006 brings to the Spring Creek Watershed the construction of a storm-water management practice that holds much potential for addressing our community's storm-water related stream impairments. This practice is called "bio-retention". It is the application of in-stream mechanisms called "cross vanes" – structures made of either rocks or logs – that reconnect streams with their floodplains and restore and maximize the floodplain's ability to retain floodwaters, dissipate the energy of storm water, and to filter out water pollutants – namely sediments and their attached nutrients.

Figure 27. Millbrook Marsh. Photo: ClearWater Staff

This project has its origins through a PA Department of Environmental Protection Growing Greener grant awarded to the Penn State Office of Physical Plant (OPP) in 2003. Through this grant and the support of partners like the Canaan Valley Institute and the US Fish & Wildlife Service, Penn State OPP sponsored a study to design a floodplain wetland restoration project in the Slab Cabin basin in the vicinity of the Millbrook Marsh, a Penn State property under long-term lease to the Centre Region Council of Governments for use as a nature center.

Millbrook Marsh, a 65-acre wetland located in College Township, is central to the urban activities of the watershed and receives a majority of the storm water emanating from downtown State College via Thompson Run, and the lower Slab Cabin watershed that is defined by increasingly impervious surface runoff from the South Atherton – 322 Expressway – E. College Avenue vicinity.

For years, Millbrook Marsh has served the vital function of flood control and pollution abatement through its retention capability, providing a buffer to Spring Creek by absorbing the energies and sediment load that Thompson Run and Slab Cabin Run brought to it during storms and reducing the potential for flood impact to the downstream communities of Bellefonte and Milesburg. Over time, the ever increasing volumes of storm water have caused a deepening of the streambed – essentially disconnecting the stream channel from the critical floodplain wetlands that define Millbrook Marsh. This disconnect has resulted in the storm-water flow quickly moving downstream through the stream channel and not overflowing into the adjacent floodplain where the storm water is best retained, pollutants in the storm water are filtered out by the wetland vegetation and soils, and the storm water can be slowly reabsorbed and returned to the ground water and aquifers that are crucial to the local drinking water supplies and base flow of the area's streams.

Once the cross vanes are installed this fall, three sections of Slab Cabin will be equipped to improve the bioretention of floodwaters under certain storm events, maximizing Millbrook Marsh's ability to retain the storm water and provide an overall improvement to the quality of water that eventually discharges from the floodplain wetland area. The project will be built in phases. Two rock vane structures will be built in Slab Cabin Run on Penn State and College Township property in the vicinity of Puddintown Road immediately downstream of the Millbrook Marsh Nature Center property. The other two phases will both take place within the Millbrook Marsh Nature Center – a log cross vane will be installed in Slab Cabin Run between the College Township building and the boardwalk bridge crossing on Slab Cabin Run on the Nature Center grounds. The third structure will be installed downstream of the confluence of Thompson Run and Slab Cabin Run adjacent to the trail that parallels Puddintown Road.

Figure 29. Cross vane structure installed by Dave Rosgen of Wildlands Hydrology, Inc. . Photo: T. Rightnour

Project consultant, Terry Rightnour, a principal for Water's Edge Hydrology, has had success with these structures in other parts of the Commonwealth – mostly in streams impaired due to acid mine drainage. But Terry sees the Slab Cabin Run bio-retention project as an opportunity to "address the stormwater management needs of an urbanizing watershed and to protect the values of the stream." When asked whether he thinks the technology may work in other impaired streams in the Spring Creek Watershed, Terry responded

..."Absolutely – this technology is a well understood way of protecting the stream – helping to control downstream flooding by dissipating the energy out into the floodplain." He added "we shouldn't be using the floodplains for anything other than storing water."

Terry Rightnour, Water's Edge Hydrology

A key partner to this project has been the PA Department of Environmental Protection through the Growing Greener grant program. Department of Environmental Protection Watershed Coordinator, Joan Sattler, out of the Williamsport office summed up the project saying,

..."This project represents a unique opportunity to reconnect an incised stream channel to its floodplain. This will both reduce the stress on the stream channel and replenish the wetland creating a healthier ecosystem for both."

Joan Sattler, Department of Environmental Protection
Watershed Coordinator

The project's current status – the permit for construction was submitted in April 2006. Additionally, the PA Department of Environmental Protection has devoted a second Growing Greener award of $169,000 for the construction of the cross vanes. The construction contractor has been selected and is prepared to break ground in September and project construction should be completed by December 2006.

Even after the work is completed, the project partnership will continue. Rob Cooper, Penn State OPP Director of Energy and Engineering acknowledged OPP's appreciation for

...“how well everyone worked together in terms of the many partners who contributed to the planning, permitting, funding, monitoring, and construction phases of the project...The Water Resources Monitoring Project's work to establish baseline water quality data in the streams up- and down-stream of the cross vanes will be immensely helpful for measuring the effectiveness of the project.”

Rob Cooper, Penn State Director of Energy and Engineering

Data User Testimonial

“Beginning in 2001 the U.S. Geological Survey (USGS) and the ClearWater Conservancy (CWC) partnered to develop a fully-coupled surface-water and ground-water model (GSFLOW) capable of providing outputs that could be used to assess the impact of land-use decisions on the water resources within the Spring Creek Basin. Streamflow and ground-water level data collected through the Water Resources Monitoring Project are being used to calibrate the GSFLOW model. The nine WRMP streamflow-gaging stations and five wells provide long-term continuous data for sub-basins of Spring Creek watershed, which help constrain the range of allowable model parameters -- ultimately resulting in a more realistic hydrologic model that links ground-water and surface-water resources. The monitoring sites for temperature and other water-quality constituents operated by WRMP provide key data that will be needed for future development of GSFLOW for simulation of water-quality of the Spring Creek Basin.”

Dennis W. Risser, U.S. Geological Survey

Data User Testimonial

“The information I received was total suspended solids (TSS) concentrations for Spring Creek Upper. I used these data to statistically arrive at background concentrations of TSS for that part of Spring Creek. These background concentrations were then used to calculate a non-degrading TSS discharge limit for a temporary discharge request. The request was submitted for approval to discharge treated groundwater from a remediation system from a regulated tank site.”

John J. Twardowski, P.E., PA DEP

Recently Adopted Stormwater Plan

The Centre County Commissioners, on November 15, 2001, gave final approval to the Stormwater Management Plan For The Spring Creek Watershed. The Plan was subsequently approved by the state Department of Environmental Resources on August 6, 2002. The Plan contained a Model Stormwater Ordinance which each of the watershed's fourteen municipalities were required to adopt.

The Stormwater Plan is a planning tool intended to (1) reduce urban runoff and downstream nuisance flooding; and (2) protect and preserve our supply of high quality water throughout the watershed, including both stream quality and underground drinking water supplies.

Further, the Plan is intended to meet the following performance criteria: (1) provide improved control of increased runoff from land development activities; (2) manage overbank and extreme flood events; (3) maintain ground-water recharge; (4) reduce channel erosion; (5) preserve and protect well-head areas; (6) encourage low-impact development; and (7) minimize non-point source pollution resulting from urban runoff though implementation of best management practices.

Examples of Best Management Practices include: grassed swales; buffer strips; riparian buffers; infiltration basins and trenches; porous pavement; detention and retention ponds; and constructed wetlands.

The Spring Creek Stormwater Management Plan contains a significant statement:

"Not only will increased development have an impact on the high quality surface waters within the watershed, the carbonate geology creates direct connections between surface and ground waters, putting the region's high quality ground water at risk also. As a result, stormwater management, as it relates to both water quality and quality, has been identified as the most important issue facing the watershed".

Spring Creek Stormwater Management Plan

Figure 30. A riparian buffer, an example of a best management practice for storm water. Photo: ClearWater

Promotion of Low-Impact Development

The concept of Low Impact Development, also referred to as LID, is an ecological approach to site development that aims to mitigate adverse impacts to land, water, and air by conserving or replicating natural systems. LID procedures include infiltration, storm-water management, low impact design, and the technology involved in creating green roofs.

The basic premise of LID is based on the hydrologic cycle, which simply put, is the constant recycling process of water. In the natural landscape the grass, plants, trees, and soil help to soak up rain and slow runoff. The vegetation builds organic, absorbent soil. Trees break the momentum of rain pelting the ground so there is less erosion and the tree roots anchor the soil. In the natural landscape the runoff peaks more slowly and at a lower volume than in the developed landscape. Urban growth changes the way rain reaches the stream—more water moves and at a faster rate. In a developed landscape pavement and rooftops shed water instead of absorbing it. Streets act like speedy conduits and drains deliver water directly to rivers and streams. Run off peaks more quickly and at a higher volume in a developed landscape.

LID attempts to mimic the natural water cycle by using small scale, decentralized practices that infiltrate, evaporate, and transpire rainwater. The primary goal of LID is to design each development site to protect, or restore, the natural hydrology of the site.

Since LID is site specific, the first step is to identify and then work to protect and conserve the most sensitive, highly valued natural areas. Special attention should be paid to the natural topography, and efforts made to minimize the destruction of the natural area. Roadways and housing lots are designed around the sensitive open spaces.

The next step is to address the developmental impacts. Grading should be conducted in a manner that will avoid steep slopes that will erode readily. It is important to minimize tree removal and reduce impervious surfaces. There is a direct correlation between the amount of impervious surface in a watershed and the quality of the streams in the watershed. The more impervious pavement there is, the greater the impairment to the stream.

Figure 31. The rain garden at ClearWater Conservancy. An example of low-impact development. Photo: ClearWater Staff

The reduction of impervious surfaces can be accomplished in a variety of ways. Road widths and lengths can be decreased. Small cul-de sacs with islands in the middle, t-or u-shaped turn arounds or looped roads can replace the typical oversized neighborhood cul-de-sacs. Vegetated open channels along a street are alternatives to the traditional paved stormwater curbs and gutters. Large impervious parking lots can be replaced with smaller versions with the overflow parking located on a gravel surface. Pervious paving materials such as porous asphalt and concrete, pavers and gravel can replace impervious materials. Storm water treatment for parking lot runoff can include bioretention areas and filter strips. Curbs can be eliminated and rain gardens created utilizing plants that will absorb the water from the parking lots. Infiltration planters can be strategically placed in order to absorb storm water. Impervious cover can be further reduced by locating sidewalks on only one side of the street or eliminating them. Pavers and/or gravel can be used for driveways. It might be desirable to design housing lots with shared driveways.

Roof top runoff is another storm water issue that can be addressed through LID.

Roof top runoff can be directed to pervious areas such as yards or open channels of vegetated areas that will absorb and filter the water. Drip lines instead of gutters are an alternative. Large flat buildings are particularly suitable for the installation of green roofs. This technology, widely used in European countries, allows the rain water to be absorbed into the roof material.

LID practices include the promotion of establishing riparian buffers that will serve as floodplains and filter systems for pollutants. Streamside buffers also reduce erosion by holding the soil in place.

Finally, one of the easiest LID techniques to adopt is to simply harvest your storm water in a rain barrel. Storm water can be used to water plants, wash the car or even flush toilets.

Figure 32. A rain barrel at the ClearWater Conservancy. Photo: ClearWater Staff

LID techniques are common sense, cost effective approaches to development. The main impediment to their widespread acceptance is that they represent a departure from traditional thinking. In the past we have viewed storm water as a nuisance that required immediate disposal. Our mindset has been to capture the storm water in a pipe and send the untreated water directly to the stream.

Conversely, LID treats storm water as the resource that it is. The on-site infiltration of the storm water filters the pollutants, replenishes the ground water and completes the hydrologic cycle.

APPENDIX

Copies of this report and data collected by the Water Resources Monitoring Project are available at:
Spring Creek Watershed Community's Website www.springcreekwatershed.org
or
ClearWater Conservancy
2555 North Atherton St
State College, PA 16803
(814) 237-0400

Appendix A. Water quality constituents sampled during base flow conditions.

Parameter	Description	Sources	Environmental Effects	Base-Flow Monitoring	Storm-Water Monitoring (2005)
Aluminum	The most abundant metal on Earth.	Urban runoff, industrial discharges and natural sources.	May adversely affect the nervous system in humans and animals.	✓	✓
Cadmium	Natural element found in the earth's crust.	Industrial sources and urban sources including fertilizers, non-ferrous metals production, and the iron and steel industry.	Toxic to humans and aquatic life.	✓	
Chloride	The concentration of chloride salt ions dissolved in the water.	Washes off roads where it is applied as a deicing agent.	Very high chloride concentrations can be toxic to macroinvertebrates.	✓	✓
Chromium	A Trace element essential for animals in small quanities.	Found in natural deposits as ores containing other elements.	Toxic to humans and aquatic life if present in excess.	✓	
Conductivity	Conductivity measures the ability of water to conduct an electrical current. A stream's conductivity is directly proportional to the concentrations and types of positively and negatively charged ions present.	Sources of ions are both naturally occurring and anthropogenic in origin, and include soil, bedrock, human and animal waste, fertilizers, pesticides, herbicides, and road salt.	Suspended solids clog fish gills and alter stream-bed habitat when settled. Particles may carry bound toxic compounds or metals.	✓	
Copper	A heavy metal less common than lead and zinc in nature.	Used in wiring, plumbing, and electronics, and to control algae, bacteria, and fungi.	Toxic to humans and aquatic life. Toxicity is affected by water hardness.	✓	✓
Dissolved Oxygen (DO)	Oxygen gas dissolved in the water is crucial to aquatic life. The amount of oxygen dissolved at saturation is inversely related to temperature.	DO is depleted by respiration and the microbial breakdown of organic wastes. It is restored by photosynthesis and physical aeration.	Low levels of dissolved oxygen are harmful to aquatic animals. This is usually the result of organic pollution or elevated temperatures.	✓	
Coliform Bacteria	Bacteria that are common in the intestines and feces of warm and cold blooded animals.	Animal wastes and sewage contamination.	Pathogenic to humans.		✓
Iron	Common element found in the earth's crust.	Urban runoff, industrial discharges and natural sources.	Toxic to humans and aqutic life.	✓	✓
Lead	A heavy metal that occurs naturally as lead sulfide but may exist in other forms.	Urban & industrial uses include gasoline, batteries, solder, pigments, and paint.	Toxic to humans and aquatic life. Toxicity is affected by water hardness.	✓	✓
Manganese	Common element found in the earth's crust.	Urban runoff, industrial discharges and natural sources.	Toxic to humans and aquatic life.	✓	
Nickel	A Trace element essential for animals in small quanities.	Industrial wastewaters.	Toxic to humans and aquatic life if present in excess.	✓	

Appendix A. Water quality constituents sampled during base flow conditions continued.

Parameter	Description	Sources	Environmental Effects	Base-Flow Monitoring	Storm-Water Monitoring (2005)
Nitrate (NO3)	One of three forms of nitrogen found in water bodies, nitrate is the form used by aquatic plants. Organic nitrogen (N) is converted to nitrate (NO3) by bacteria.	Any nitrogen-containing organic waste, including sewage from water treatment plants and septic systems, and runoff from fertilized lawns, farms and livestock areas.	High nitrate levels promote excessive plant growth and eutrophication. Excess nitrate in drinking water can cause illness of death in infants.	✓	✓
Ortho-phosphate	Orthophosphate is the form of inorganic phosphorous required by plants. Its availability is often the limiting factor in plant growth.	Rocks and minerals provide a low natural level. Human sources include commercial cleaning products, water treatment plants, and fertilized lawns and farmland.	A small increase in orthophosphate can cause eutrophication, the loss of dissolved oxygen through the stimulation and decay of excessive plant growth.	✓	✓
pH	A measure of the acidity of water on a logarithmic scale of 1 to 14. A pH below 7 is acidic, above 7 is basic or alkaline, and a pH of 7 is neutral.	The pH of Spring Creek is slightly alkaline because of the carbonate bedrock. pH can be lowered by acid mine drainage or acid rain.	Extreme pH can inhibit growth and reproduction.in aquatic organisms. Acidic waters also release metals from the sediment, creating toxic conditions.	✓	
Sodium	Soft metal commonly found in nature.	Various salts of sodium occur in considerable concentrations in the earth's crust.	There is some evidence to suggest that these high levels of sodicity are toxic to some plants.	✓	
Sulfate	Element commonly found in nature.	Urban runoff, industrial discharges and natural sources.	Toxic to humans and aquatic life.	✓	
Total Organic Carbon	A measure of the amount of carbon- containing compounds and thus the amount of organic material present.	Animal wastes, human wastes, plant material, agricultural chemicals, and petroleum compounds.	High carbon content in streams increases the growth of microorganisms, which depletes dissolved oxygen.	✓	✓
Total Suspended Solids (TSS)	Any particles carried by the water and include silt, plankton, organic stream litter, industrial waste and sewage.	Sources include urban runoff, wastewater treatment plants, soil erosion, and decaying plant and animal material.	Suspended solids clog fish gills and alter stream-bed habitat when settled. Particles may carry bound toxic compounds or metals.	✓	✓
Turbidity	A measure of water clarity expressed as the amount of light penetrating the water. It is relative to the amount of suspended material in the water.	While some clean rivers are naturally turbid, turbidity can be increased by earth-moving activities, urban runoff, and erosion from agricultural fields.	High turbidity blocks light from the water column and inhibits submerged aquatic plants. By absorbing sunlight, the particles also increase water temperature.	✓	✓
Zinc	A heavy metal commonly found in rock-forming minerals.	Urban runoff, industrial discharges and natural sources. Used in many alloys.	Somewhat toxic to humans and aquatic life. Toxicity is affected by water hardness.	✓	✓

Appendix B. Actual concentrations and statistical data used to construct Figure 18.

		Metals					Nutrients				Solids				
		Al	Zinc	Cu	Iron	Lead	Total N	Total P	pH	Cl	TOC	Tot. Residue	TSS	TDS	Turbidity
		ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	mg/l	su	mg/l	mg/l	mg/l	mg/l	mg/l	NTU
MIL	# Samples			47			47		47				47		
	Minimum	201	11.0	10.0	63	1.4	1.33	0.016	7.0	19.0	1.1	82	0	6	1.3
	1st Quartile	786	19.0	13.0	327	2.4	2.44	0.047	7.5	33.4	1.6	330	12	249	5.5
	Median	1070	35.5	23.0	1300	5.5	3.45	0.082	8.3	45.1	3.4	406	42	312	21.7
	3rd Quartile	2920	52.8	31.0	2312	10.0	4.10	0.183	8.5	59.5	6.8	496	110	398	47.9
	Maxium	11700	363.0	98.0	19900	76.0	4.51	0.785	8.9	71.3	15.0	1164	932	810	394.0
	# Non-detects	14	7	27	0	11	0	0	0	0	0	0	0	0	0
SLL	# Samples			55			55		55				55		
	Minimum	220	10.0	10.0	35	1.0	0.51	0.018	6.9	3.2	2.1	92	2	38	1.2
	1st Quartile	367	15.0	11.5	157	1.5	1.33	0.033	8.0	19.6	2.6	308	10	212	3.9
	Median	738	23.0	17.0	453	2.2	2.46	0.072	8.1	32.1	3.5	386	18	332	11.8
	3rd Quartile	1864	29.0	20.5	1212	5.5	3.03	0.135	8.4	39.1	4.3	449	62	397	28.7
	Maxium	17000	246.0	33.0	24600	38.6	5.12	0.755	8.9	65.5	20.8	1656	136	526	360.6
	# Non-detects	22	17	43	0	25	0	0	0	0	0	0	0	0	0
THL	# Samples			32			32		32				32		
	Minimum	365	11.0	11.0	58	1.1	0.92	0.028	5.7	7.7	1.0	46	2	44	1.3
	1st Quartile	704	24.8	15.0	257	2.3	2.37	0.044	7.8	24.5	1.9	323	24	202	9.9
	Median	1252	49.0	28.5	1211	6.6	3.28	0.095	8.1	44.0	3.3	413	43	305	22.8
	3rd Quartile	2945	97.5	38.8	4085	13.4	4.12	0.251	8.4	54.7	6.9	460	148	397	56.1
	Maxium	8430	317.0	58.0	15100	102.0	4.66	0.560	8.8	81.0	22.0	1050	686	556	238.0
	# Non-detects	9	4	14	0	6	0	0	0	0	0	0	0	0	0