Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Supplemental Documentation
Volume 12

TTF Watershed Comprehensive Characterization Report

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TOOKANY/TACONY-FRANKFORD WATERSHED COMPREHENSIVE CHARACTERIZATION REPORT

NOVEMBER 2005
PREPARED BY THE PHILADELPHIA WATER DEPARTMENT

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Section 1
Introduction

To meet the regulatory requirements and long-term goals of its CSO, stormwater, and drinking water source protection programs, The Philadelphia Water Department (PWD) has embraced a comprehensive watershed characterization, planning, and management program. Watershed management fosters the coordinated implementation of programs to control sources of pollution, reduce polluted runoff, and promote managed growth in the city and surrounding areas, while protecting the region's drinking water supplies, fishing and other recreational activities, and preserving sensitive natural resources such as parks and streams. PWD has helped form watershed partnerships with surrounding urban and suburban communities to explore regional cooperation based on an understanding of the impact of land use and human activities on water quality.

Coordination of these different programs has been greatly facilitated by PWD's creation of the Office of Watersheds (OOW), which is composed of staff from the PWD's planning and research, CSO, collector systems, laboratory services, and other key functional groups. One of OOW's responsibilities is to characterize existing conditions in local watersheds to provide a basis for long-term watershed planning and management.

OOW is developing a series of watershed management programs for each of the city's watersheds. Cobbs Creek was the first watershed for which an integrated watershed management plan was completed; the Tookany/Tacony-Frankford Watershed Partnership was second to complete a plan. This Comprehensive Characterization Report contains a series of technical documents that form the scientific basis for the Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP), released in 2005. The report characterizes the land use, geology, soils, topography, demographics, meteorology, hydrology, water quality, ecology, fluvial geomorphology, and pollutant loads found in the watershed. It presents and discusses data collected through the end of 2004. This report is intended as a single compilation of background and technical documents that can be periodically updated as additional field work or data analyses are completed. Sections of this report were completed at different times by different authors.

Section 2
Characterization of the Study Area

2.1 Watershed Description and Demographics

The Tookany/Tacony-Frankford Watershed is defined as the land area that drains to the mouth of Tacony Creek at the Delaware Estuary, encompassing approximately 36 square miles in southeastern Pennsylvania. This area includes portions of Montgomery and Philadelphia Counties. Figure 2-1 includes the watershed boundaries, hydrologic features, and political boundaries. Much of the information is based on the U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) database.

The Tookany/Tacony-Frankford Watershed discharges to the Delaware River, and is made up of three linked stream segments: the Tookany Creek in the headwaters, which drains into the Tacony Creek, which becomes the Frankford Creek in the lower reaches. Named tributaries of the Tookany Creek include Mill Run, Rock Creek and Jenkintown Creek.

In a relatively undisturbed watershed, watershed boundaries follow topographic high points or contours. The U.S. Geological Survey (USGS) has subdivided the Tookany/Tacony-Frankford Watershed based on topography, as shown in Figure 2-2. These USGS subwatersheds are determined from the land area draining to a particular point of interest, such as a stream confluence or gauging site. These boundaries allow initial determinations of drainage areas and modeling elements. However, adjustments are made where necessary to include the effects of man-made alterations to the natural drainage patterns.

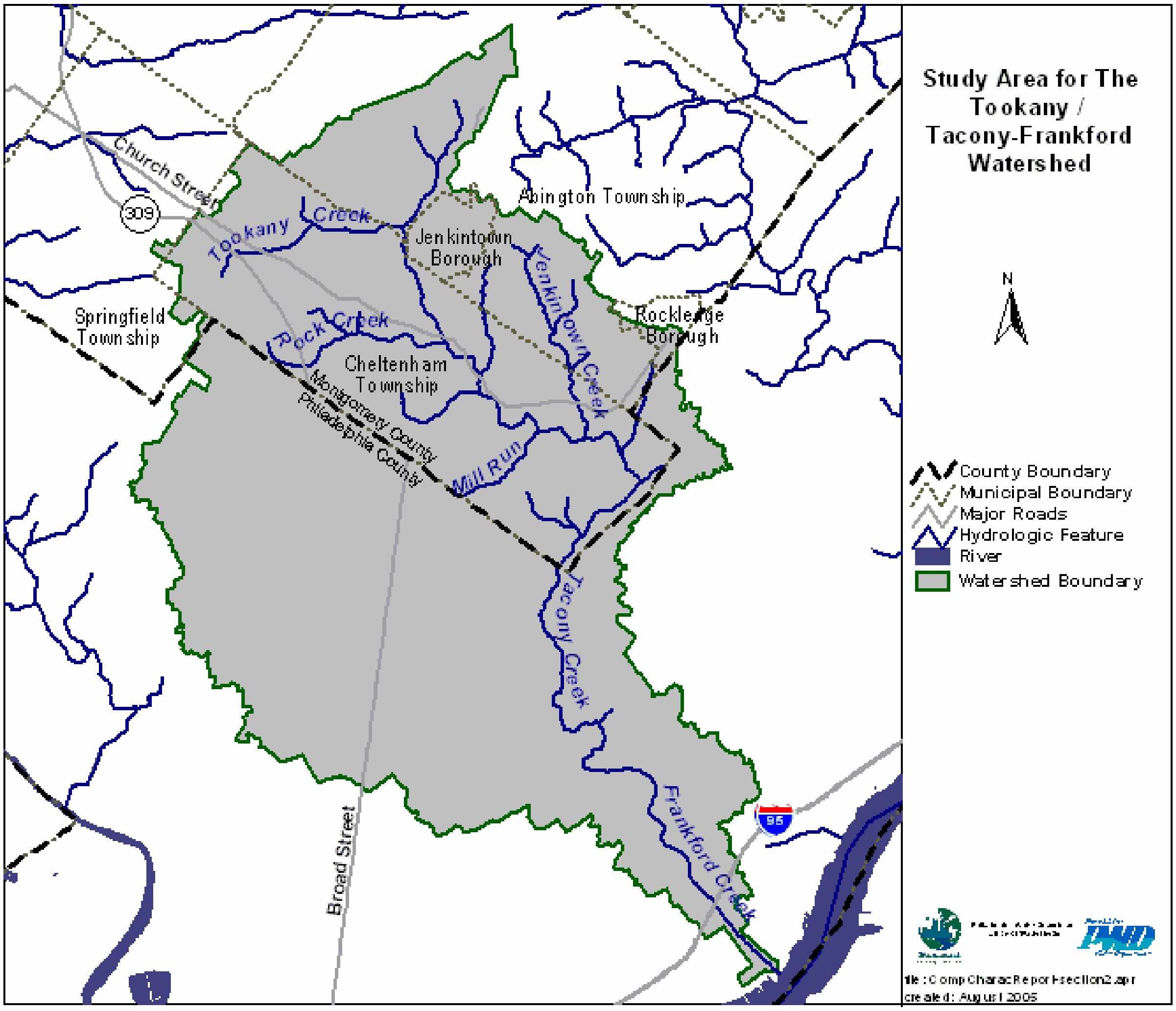


Figure 2-1 Tookany/Tacony-Frankford Study Area

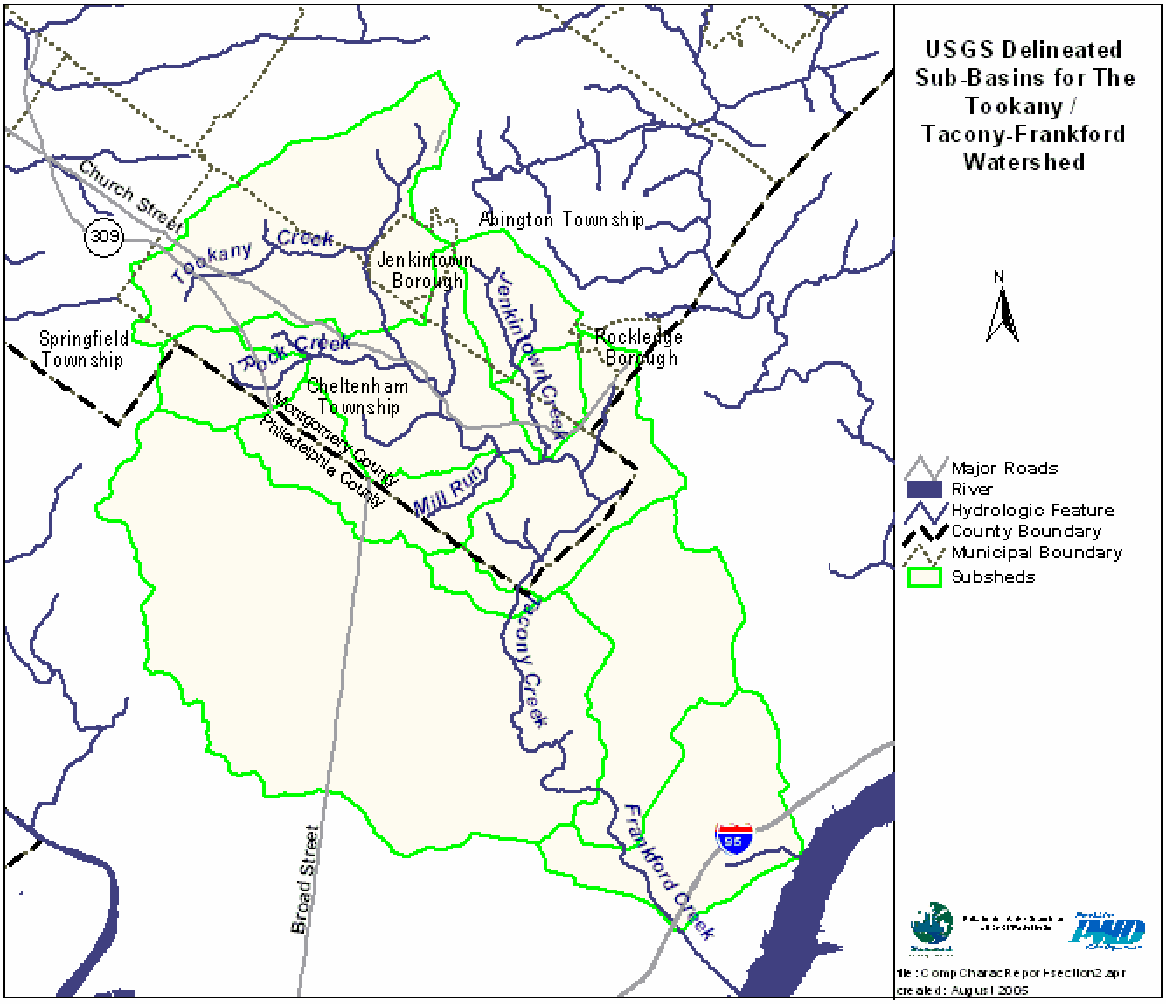


Figure 2-2 USGS Topographic Subwatersheds of the Tookany/Tacony-Frankford Watershed

2.2 Demographic Information

Population density and other demographic information in the watershed are available from the results of the 2000 census. Approximately 357,000 people live within the drainage area of the Tookany/Tacony-Frankford Watershed. Figure 2-3 shows the population density in the watershed at the census block level. Spatial trends in population correspond closely to land use, with multi-family row homes displaying the greatest population density of 20 people per acre or more, single-family homes displaying a lower density, and other land use types displaying the lowest density. In addition to population data, the U.S. Census Bureau provides a range of socioeconomic data that are often useful in watershed planning and general planning studies. Median household income and mean home value (Figures 2-4 and 2-5) are two of the many sample datasets provided.

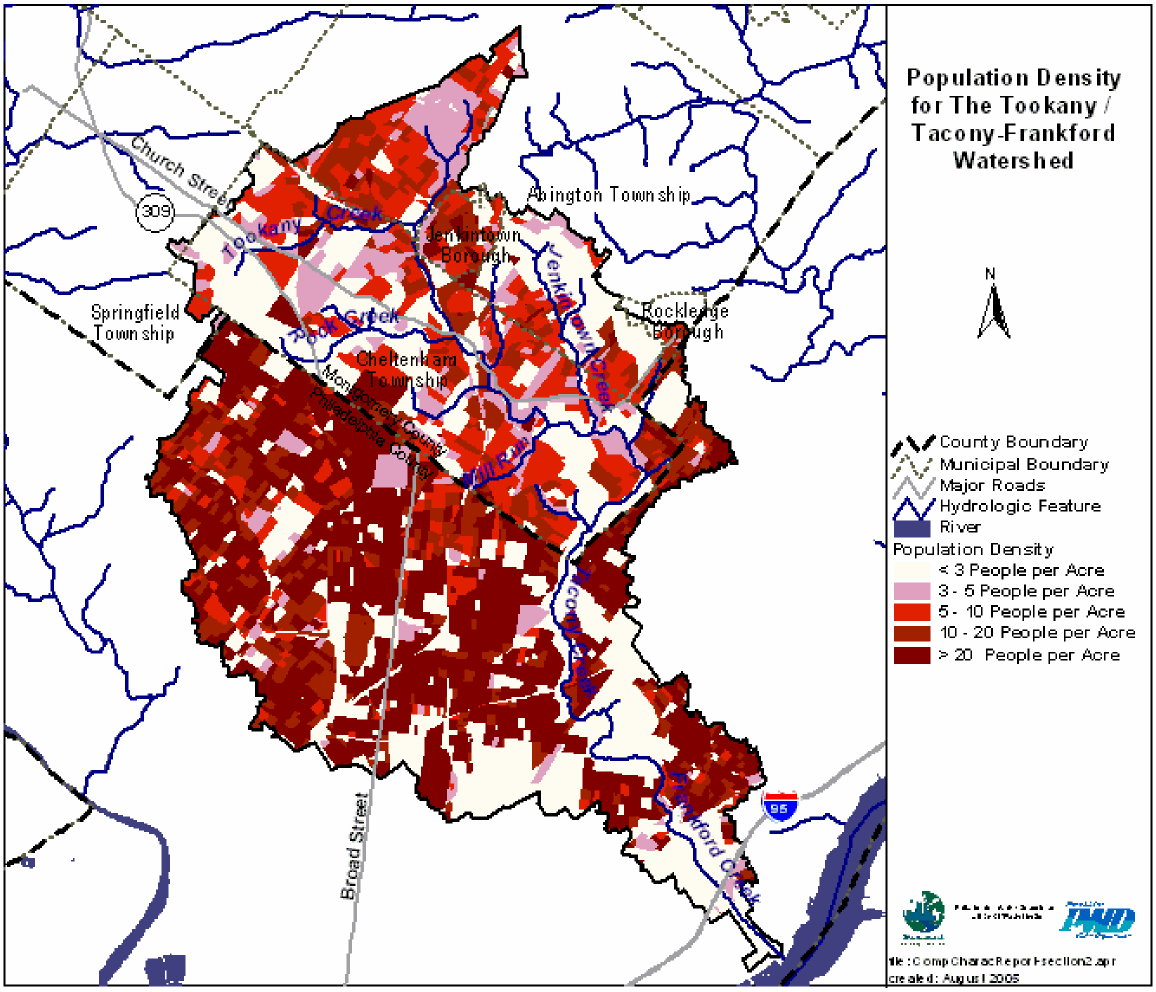


Figure 2-3 Population Density in Tookany/Tacony-Frankford Watershed by Census Block Group (Source: U.S. Census, 2000)

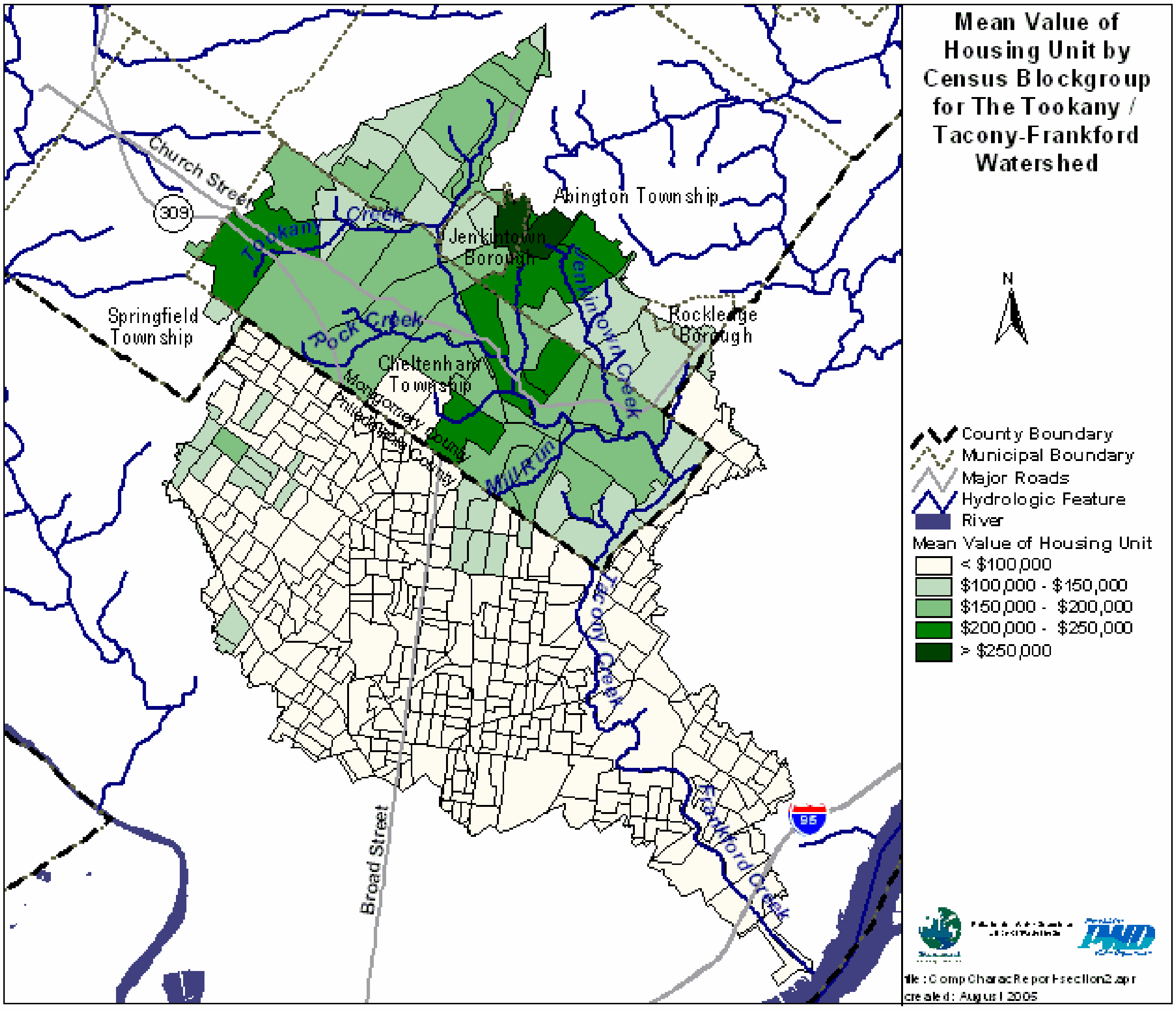


Figure 2-4 Mean Value of Housing Units in Tookany/Tacony-Frankford Watershed by Census Block Group (Source: U.S. Census, 2000)

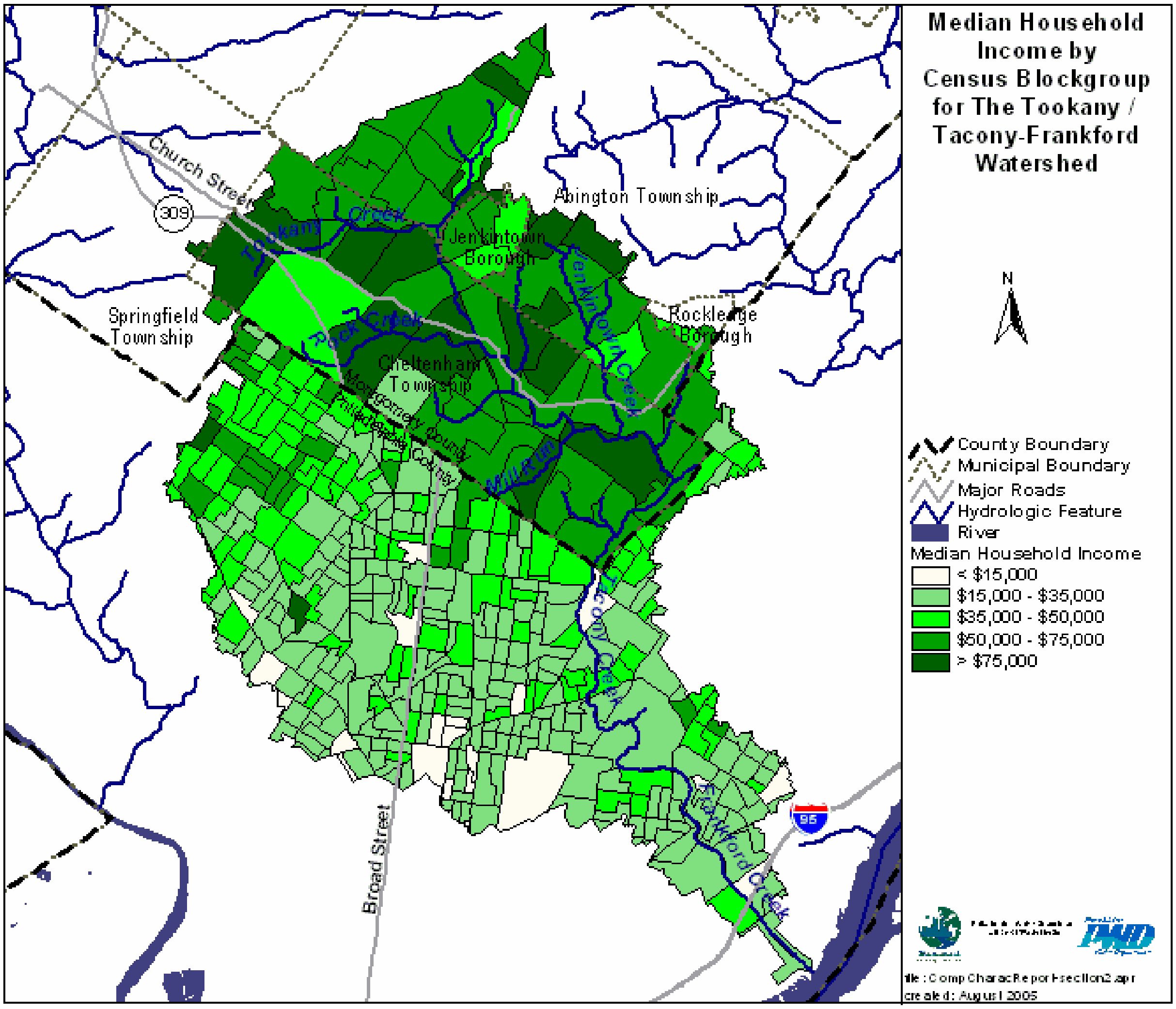


Figure 2-5 Median Household Income in Tookany/Tacony-Frankford Watershed by Census Block Group (Source: U.S. Census, 2000)

2.3 Land Use

Land use information for the Tookany/Tacony-Frankford Watershed was obtained from the Delaware Valley Regional Planning Commission (DVRPC). Figure 2-6 is the 1996 land use map for the study area. The upper reaches and headwaters of the Tookany/Tacony-Frankford Watershed are characterized primarily by a mix of multiple-family and detached single-family residential areas, golf courses and parkland. The lower portions of the Tookany/Tacony-Frankford Watershed are primarily high-density residential areas in the City of Philadelphia, with commercial areas along highway corridors. Riparian lands within the City consist mainly of relatively undisturbed parkland.

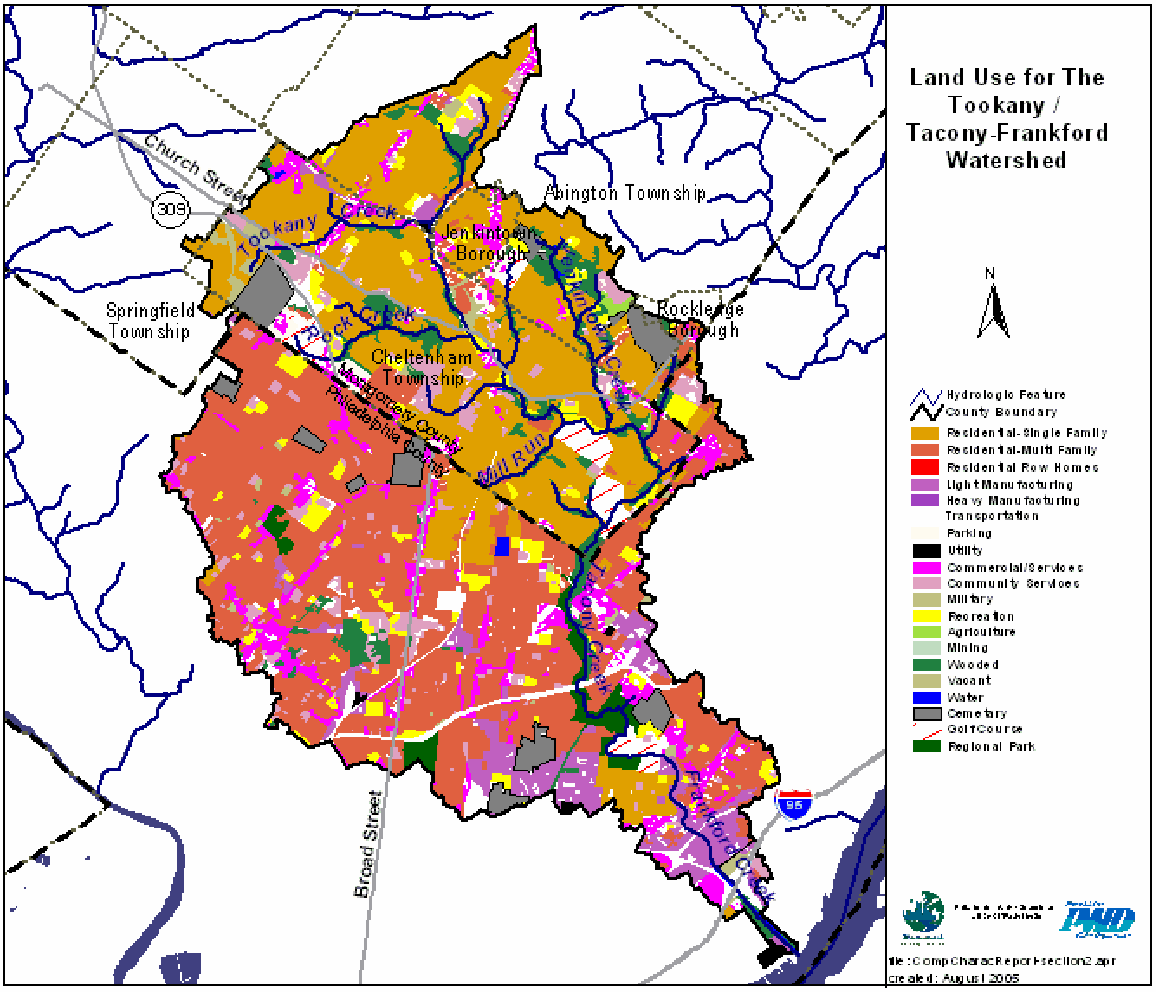


Figure 2-6 Land Use in the Tookany/Tacony-Frankford Watershed (Source: DVRPC 1995)

One of the primary indicators of watershed "health" is the percentage of impervious cover within the watershed. Based on numerous research efforts, studies and observations, a general categorization of watersheds has been widely applied to watershed management based on percent impervious cover (Schueler 1995). Percent impervious cover and other indicators of stream health are summarized in Table 2-1. Table 2-2 illustrates that the entire watershed has greater than 25% impervious cover, placing it in the "Non-Supporting" category of stream health.

Table 2-1 Impervious Cover as an Indicator of Stream Health (Schueler 1995)

Characteristic	Sensitive	Degrading	Non-Supporting
Percent Impervious Cover	0% to 10%	11% to 25%	26% to 100%
Channel Stability	Stable	Unstable	Highly Unstable
Water Quality	Good to Excellent	Fair to Good	Fair to Poor
Stream Biodiversity	Good to Excellent	Fair to Good	Poor
Pollutants of Concern	Sediment and temperature only	Also nutrients and metals	Also bacteria

Table 2-2 Estimated Total Impervious Cover

Watershed	County	Total Area (ac)	Acres Impervious	Percent Impervious
Tacony-Frankford	Philadelphia	10,844.5	5810.0	53.6
Tookany	Montgomery	10,226.7	2808.6	27.5

Table 2-3 summarizes several of the impacts of traditional development on streams and watersheds, most of which are created by the addition of impervious cover across the portions of the land surface. Figure 2-7 illustrates the changes to the volume and duration of runoff before and after development. Figure 2-7 also illustrates the benefits of using various BMPs and low impervious techniques to manage stormwater.

Table 2-3 Impacts of Traditional Development on Watershed Resources (from Schueler 1995)

Changes in Stream Hydrology ▪ Increased magnitude/frequency of severe floods ▪ Increased frequency of erosive bankfull and sub-bankfull floods ▪ Reduced ground water recharge ▪ Higher flow velocities during storm events	**Changes in Stream Morphology** ▪ Channel widening and downcutting ▪ Streambank erosion ▪ Channel scour ▪ Shifting bars of coarse sediments ▪ Imbedding of stream substrate ▪ Loss of pool/riffle structure ▪ Stream enclosure or channelization
Changes in Stream Water Quality ▪ Instream pulse of sediment during construction ▪ Nutrient loads promote stream and lake algae growth ▪ Bacteria contamination during dry and wet weather ▪ Higher loads of organic matter ▪ Higher concentrations of metals, hydrocarbons, and priority pollutants ▪ Stream warming ▪ Trash and debris jams	**Changes in Stream Ecology** ▪ Reduced or eliminated riparian buffer ▪ Shift in external production to internal production ▪ Reduced diversity of aquatic insects ▪ Reduced diversity of fish ▪ Creation of barriers to fish migration ▪ Degradation of wetlands, riparian zones and springs ▪ Decline in amphibian populations

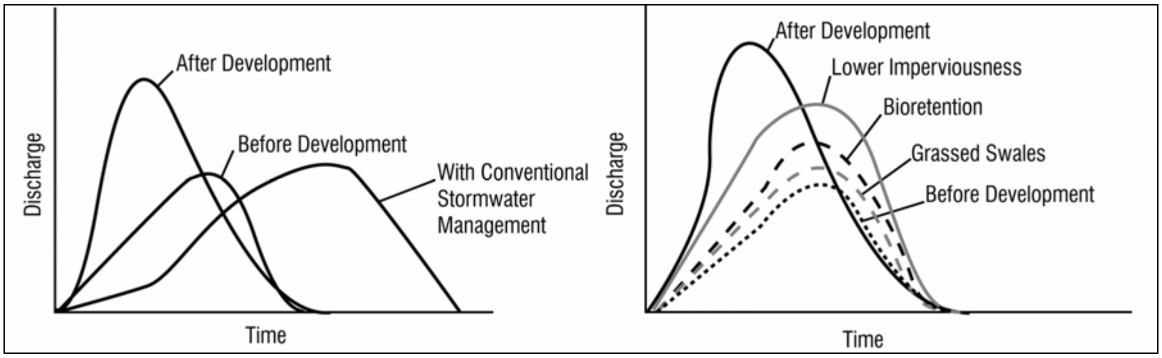


Figure 2-7 Comparison of Volume and Duration of Stormwater Runoff Before and After Land Development, and Reductions in Runoff from BMPs. (Prince George's County Department of Environmental Resources *et. al.*, undated)

2.4 Geology and Soils

Geology and soils play a role in the hydrology, water quality, and ecology of a watershed. The Tookany/Tacony-Frankford Watershed is located primarily within the Piedmont physiographic province. Geologic formations on the surface in the area include gneiss and schist in most of the watershed; sand is dominant in the lower reaches of the watershed (as shown in Figure 2-8). Soils in the upper portions of the Tacony Creek subwatershed include stony and silty loams, as shown in Figure 2-9. Soil in much of the rest of the watershed is classified as urban or made land and is not representative of the original undisturbed soil.

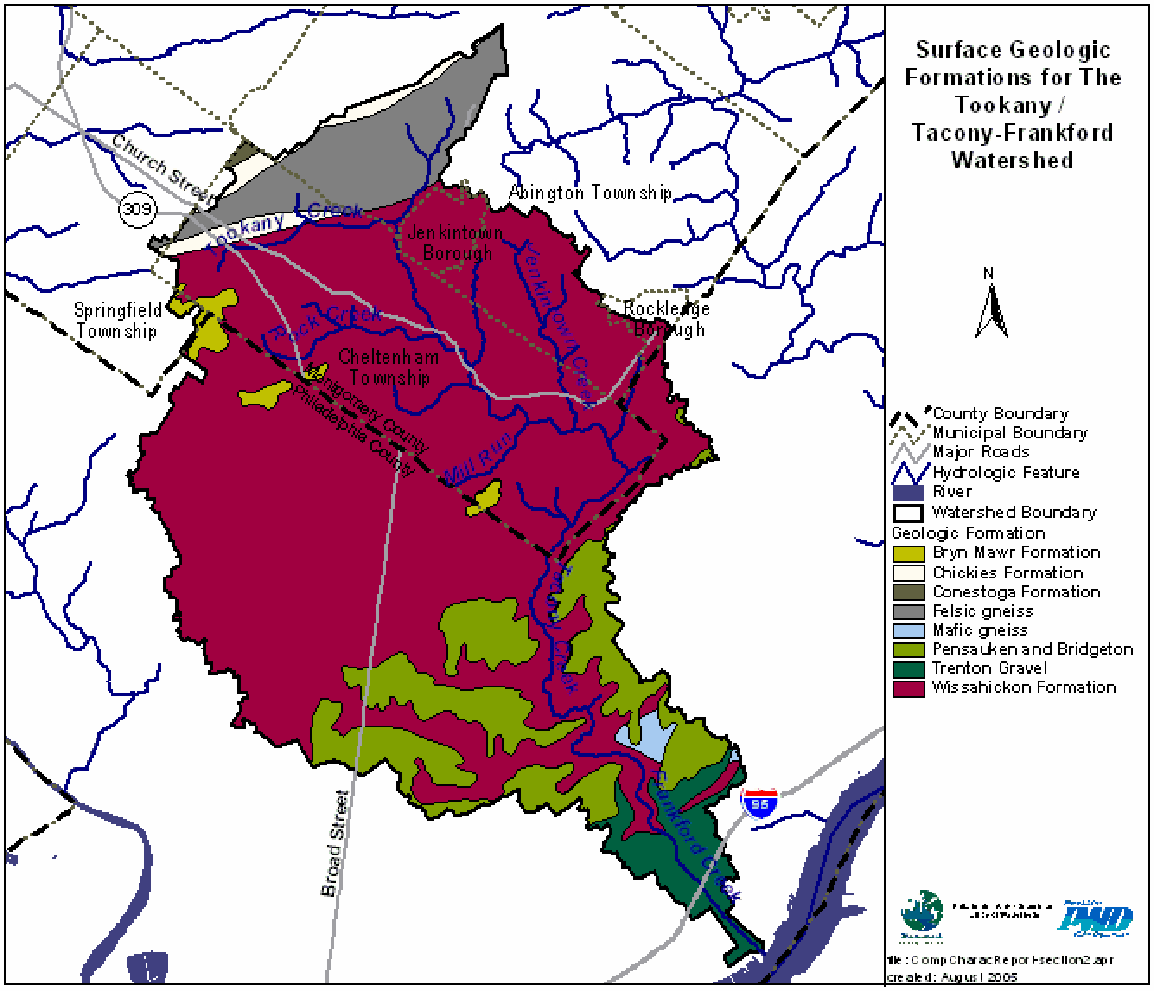


Figure 2-8 Surface Geologic Formations of the Tookany/Tacony-Frankford Watershed (Source: USGS)

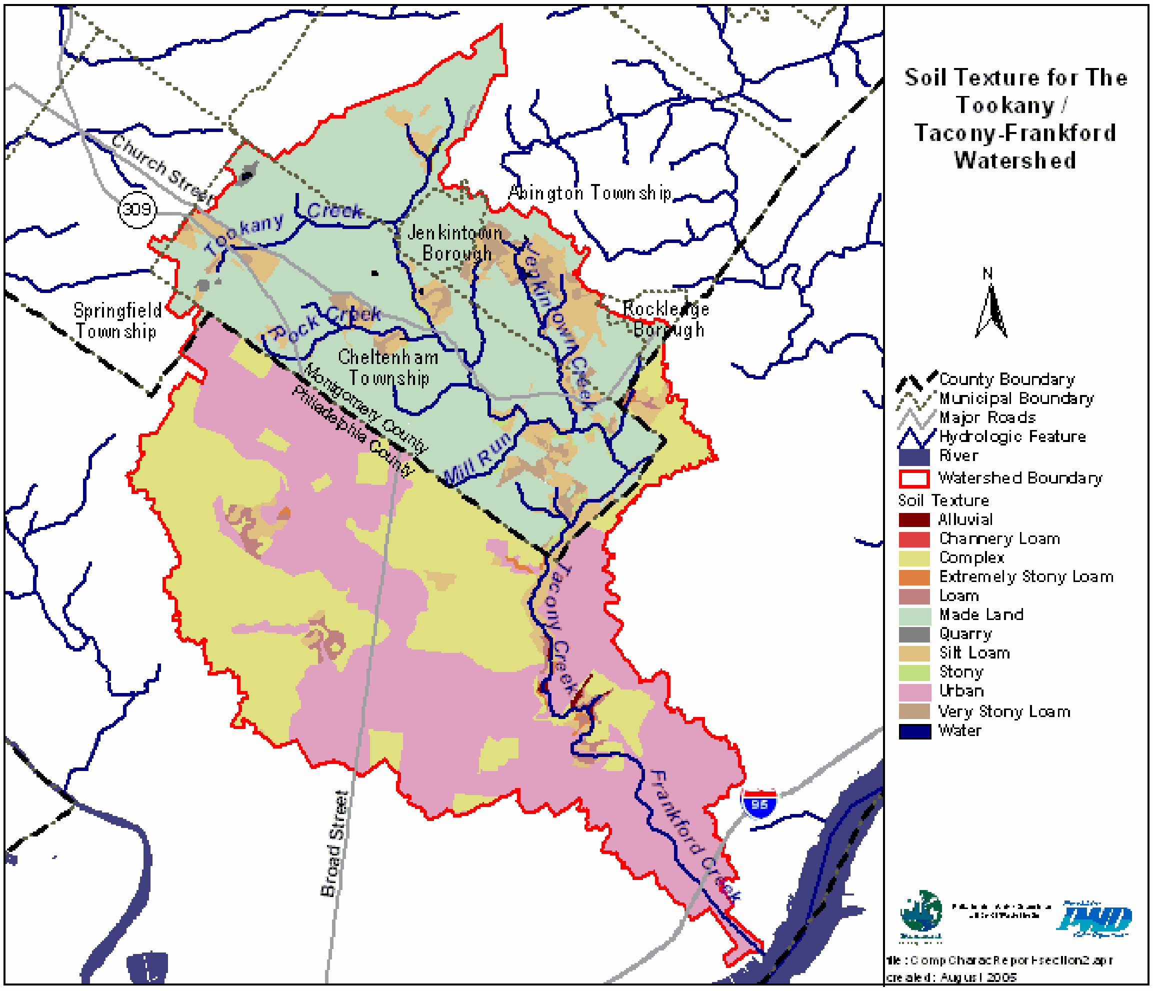


Figure 2-9 Soil Texture Types in the Tookany/Tacony-Frankford Watershed (Source: USDA, NRCS from the Soil Survey Geographic (SSURGO) database)

Section 3
Sampling and Monitoring Program Methods

3.1 Background

PWD's Office of Watersheds (OOW) has carried out an extensive sampling and monitoring program to characterize conditions in the Tookany/Tacony-Frankford Watershed. The program is designed to document the condition of aquatic resources and to provide information for the planning process needed to meet regulatory requirements imposed by EPA and PA DEP. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological aspects. OOW is well suited to carry out the program because it merges the goals of the city's stormwater, combined sewer overflow, and source water protection programs into a single unit dedicated to watershed-wide characterization and planning.

Under the provisions of the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) requires permits for point sources that discharge to waters of the United States. In the Tookany/Tacony-Frankford Watershed, stormwater outfalls and wet weather sewer overflow points discharging to surface waters are classified as point sources and are regulated by NPDES.

EPA's Combined Sewer Overflow Control Policy, published in 1993, provides the national framework for regulation of CSOs under NPDES. The Policy guides municipalities and state and Federal permitting agencies in meeting the pollution control goals of the CWA in as flexible and cost-effective a manner as possible. As part of the program, communities serviced by combined sewer systems are required to develop long-term CSO control plans (LTCPs) that will result in full compliance with the CWA in the long term, including attainment of water quality standards. PWD completed its LTCP in 1997 and is currently implementing its provisions. The strong focus of the National CSO Policy on meeting water quality standards is a main driver behind PWD's water quality sampling and monitoring program.

Regulation of stormwater outfalls under the NPDES program requires operators of medium and large municipal stormwater systems or MS4s, such as the separate-sewered portions of the Tookany/Tacony-Frankford Creek watershed, to obtain a permit for discharges and to develop a stormwater management plan to minimize pollution loads in runoff over the long term. Partially in administration of this program, PA DEP assigns designated uses to water bodies in the state and performs ongoing assessments of the condition of the water bodies to determine whether the uses are met and to document any improvement or degradation. These assessments are performed primarily with biological indicators based on the EPA's Rapid Bioassessment Protocols (RBPs) for benthic invertebrates and physical habitat. The Tookany/Tacony-Frankford Creek is listed by the PA DEP as impaired for one or more designated uses, not requiring a TMDL.

The Tookany/Tacony-Frankford Creek and its tributaries are designated warm water fisheries. All of the Tookany portion of the watershed plus tributaries, and the upper, non-tidal portion of the Tacony Creek are classified as unattained by PA DEP. For this reason, the stormwater permit for the City of Philadelphia specifies that the state of the aquatic resource must be evaluated periodically. Because PA DEP has endorsed biomonitoring as a means of determining attainment of uses, PWD periodically performs RBPs in the Tookany/Tacony-Frankford Creek.

OOW is responsible for characterization and analysis of existing conditions in local watersheds to provide a basis for long-term watershed planning and management. The extensive sampling and monitoring program described in this section is designed to provide the data needed for the long-term planning process.

3.2 Summary of Physical and Chemical Monitoring

PWD's Office of Watersheds (OOW) and Bureau of Laboratory Services (BLS) have planned and carried out an extensive sampling and monitoring program to characterize conditions in the Tookany/Tacony-Frankford Creek watershed. The program includes hydrologic, water quality, biological, habitat, and fluvial geomorphological components. Again, because the OOW has merged the goals of the city's stormwater, combined sewer overflow, and source water protection programs into a single unit dedicated to watershed-wide characterization and planning, it is uniquely suited to administer this program.

Sampling and monitoring follow the Quality Assurance Project Plan (QAPP) and Standard Operating Protocols (SOPs) as prepared by BLS. These documents cover the elements of quality assurance, including field and laboratory procedures, chain of custody, holding times, collection of blanks and duplicates, and health and safety. They are intended to help the program achieve a level of quality assurance and control that is acceptable to regulatory agencies.

Tables 3-1 and 3-2 summarize the types, amounts, and dates of recent sampling and monitoring performed by PWD, PA DEP, and USGS. A river mile-based naming convention is followed for sampling and monitoring sites located along waterways in the watershed. The naming convention includes three letters and three or more numbers which denote the watershed, stream, and distance from the mouth of the stream. For example, site TFJ110 is named as follows:

- "TF" indicates the Tookany/Tacony-Frankford watershed.
- "J" indicates Jenkintown Creek, a tributary to Tookany Creek.
- "110" places the site 1.10 miles upstream of the confluence of Jenkintown Creek and Tookany Creek.

Table 3-1 Summary of Physical and Biological Sampling and Monitoring

		Physical			**Biology**			
	USGS		**USGS**	**USGS Annual**	**PWD**			**PA DEP**
Site Name	**Gauge**	**Stream Name**	**Daily Flow**	**Peak Flow**	**RBP III***	**RBP V****	**Habitat**	
	1467089	Frankford Creek	1965-1982	1966-1980				
TF280	1467087	Tacony Creek	1982-Present	1982-Present				
TF324		Tacony Creek			November 2000 March 2004	November 2000 June 2004	November 2000 March 2004	
TF396		Tacony Creek			Mar-04	Jun-04	Mar-04	
TF500		Tacony Creek			November 2000 March 2004	Jun-04	November 2000 March 2004	
TF620	1467086	Tacony Creek	1965-1982	1966-1985	November 2000 March 2004	November 2000 June 2004	November 2000 March 2004	1999
TF760		Tookany Creek			Nov-00		Nov-00	
TF827		Tookany Creek			Mar-04	Jun-04	Mar-04	
TF975		Tookany Creek			November 2000 March 2004	November 2000 June 2004	November 2000 March 2004	
TF1120	1467083	Tookany Creek	1973-1978	1974-1978	November 2000 March 2004	November 2000 June 2004	November 2000 March 2004	
TF1270		Tookany Creek			Mar-04		Mar-04	1999
TFU010		Unnamed Tributary			Mar-04		Mar-04	1999
TFJ013		Jenkintown Creek			Mar-04		Mar-04	1999
	1467085	Jenkintown Creek	1973-1978	1974-1978				
TFJ110		Jenkintown Creek			Nov-00		Nov-00	
TFM006		Mill Run			Mar-04		Mar-04	
TFR064		Rock Creek			Mar-04		Mar-04	1999

* EPA Rapid Bioassessment Protocol III Benthic Macroinvertebrates

** EPA Rapid Bioassessment Protocol V Ichthyofaunal (Fish)

3.3 Water Quality Sampling and Monitoring

A range of water quality samples were collected between 1999 and 2004 at 9 sites in the watershed. The sites are listed in Table 3-2 and are shown on Figure 3-1. Three different types of sampling were performed as discussed below. Parameters were chosen based on state water quality criteria or because they are known or suspected to be important in urban watersheds. The parameters sampled during each type of sampling are listed in Table 3-4. Water quality in each reach and section of the watershed is characterized in Section 5.

The sampling and analysis program meets AMSA (2002) *et al.* recommendations for the minimum criteria that should form the basis for impairment listings:

- Data collected during the previous five years may be considered to represent current conditions.
- At least ten temporally independent samples should be collected and analyzed for a given parameter.
- A two-year minimum data set is recommended to account for inter-year variation, and the sample set should be distributed over a minimum of two seasons to account for inter-seasonal variation.
- No more than two-thirds of the samples should be collected in any one year.
- Samples collected fewer than four days apart at the same river location should be considered one sample event.
- Samples collected within 200 meters [about 0.1 miles] of each other will be considered the same station or location. This convention was followed except where two sampling sites were chosen to represent conditions upstream and downstream of a modification such as a dam.

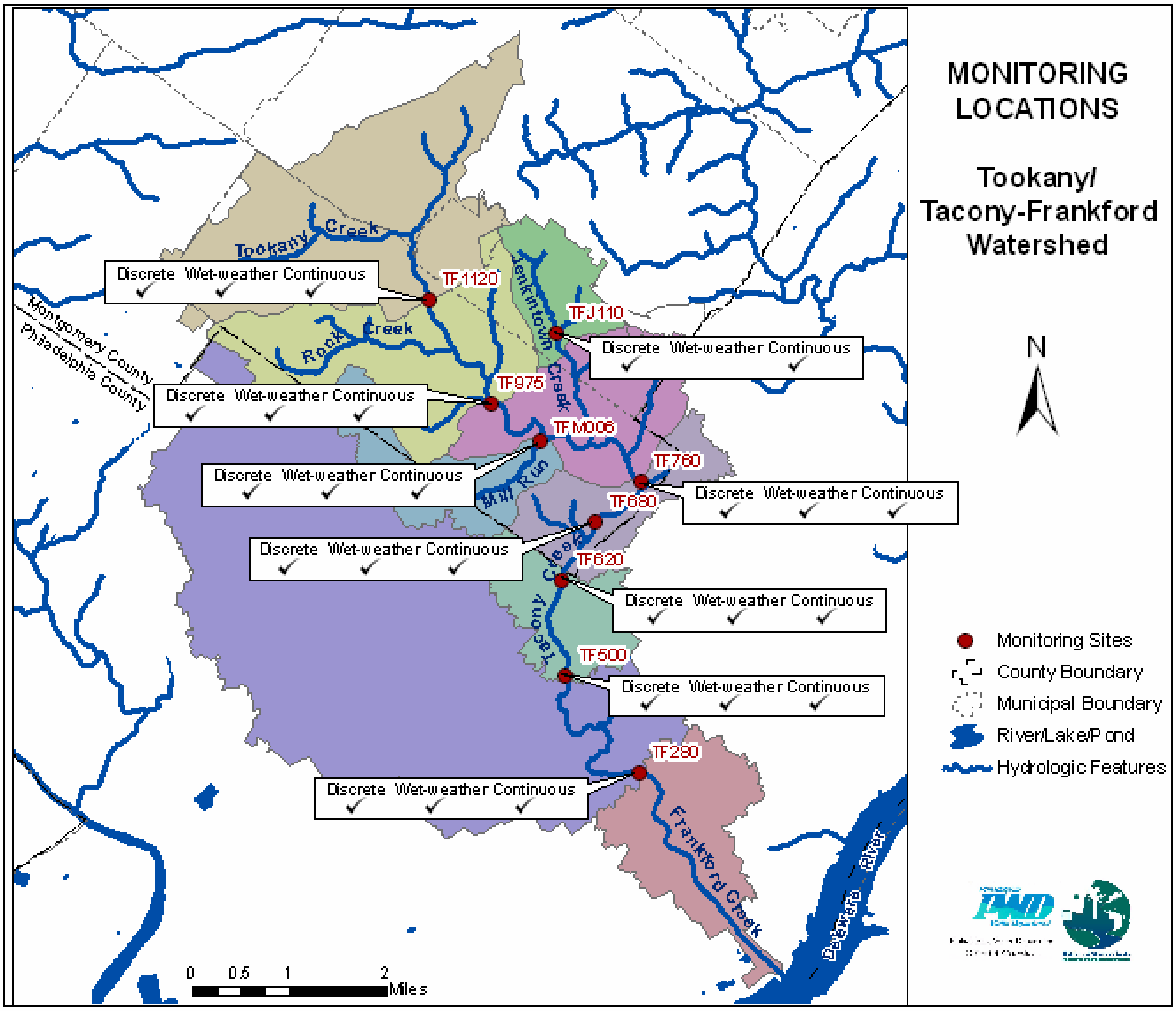


Figure 3-1 Water Quality Sampling Sites in the Tookany/Tacony-Frankford Watershed

Table 3-2 Summary of Water Quality Sampling and Monitoring

		Chemical		
		PWD		
Site	**USGS Gauge**	**Discrete**	**Continuous (hrs)**	**Wet Weather**
TF280	1467087	32 samples 6/29/2000 - 9/2/2004	11109	12 periods 3/19/2001 - 9/1/2004
TF500		25 samples 6/29/2000 - 8/26/2004	3335.5	2 periods 5/21/2001 - 11/1/2002
TF620*	1467086	27 samples 6/29/2000 8/26/2004	9972.5	13 periods 10/15/2002 - 3/7/2003
TF680*		4 samples 7/27/2004 - 9/2/2004		9 periods 5/1/2003 - 9/1/2004
TF760		22 samples 6/29/2000 - 8/26/2004	1701.25	2 periods 5/21/2001 - 11/1/2002
TF975		27 samples 6/29/2000 - 9/2/2004	6298	12 periods 10/29/2002 - 9/1/2004
TF1120	1467083	24 samples 6/29/2000 - 9/2/2004	6462.75	10 periods 10/15/2002 - 9/1/2004
TFJ110	1467085	21 samples 6/29/2000 - 8/26/2004	2593.25	
TFM006		16 samples 11/29/2001 - 9/2/2004	2543.25	2 periods 7/7/2004 - 9/1/2004

*** Sites TF620 and TF680 were combined for analysis in many instances.**

Table 3-3 Water Quality Parameters Sampled

Parameter	Units	Discrete	WETW	Continuous
Physical Parameters				
Temperature	deg C	X	X	X
pH	pH units	X	X	X
Specific Conductance	µMHO/cm @ 25C	X	X	X
Alkalinity	mg/L	X	X	
Turbidity	NTU	X	X	X
TSS	mg/L	X	X	
TDS	mg/L	X	X	
Oxygen and Oxygen Demand				
DO	mg/L	X	X	X
BOD_5	mg/L	X	X	
BOD_{30}	mg/L	X	X	
$CBOD_5$	mg/L	X	X	
Nutrients				
Ammonia	mg/L as N	X	X	
TKN	mg/L	X	X	
Nitrite	mg/L	X	X	
Nitrate	mg/L	X	X	
Total Phosphorus	mg/L	X	X	
Phosphate	mg/L	X	X	
Metals				
Aluminum (Total)	mg/L	X	X	
Aluminum (Dissolved)	mg/L	X	X	
Calcium (Total)	mg/L	X	X	
Cadmium (Total)	mg/L	X	X	
Cadmium (Dissolved)	mg/L	X	X	
Chromium (Total)	mg/L	X	X	
Chromium (Dissolved)	mg/L	X	X	
Copper (Total)	mg/L	X	X	
Copper (Dissolved)	mg/L	X	X	
Fluoride (Total)	mg/L	X	X	
Fluoride (Dissolved	mg/L	X	X	
Iron (Total)	mg/L	X	X	
Iron (Dissolved)	mg/L	X	X	
Magnesium (Total)	mg/L	X	X	
Manganese (Total)	mg/L	X	X	
Manganese (Dissolved)	mg/L	X	X	
Lead (Total)	mg/L	X	X	
Lead (Dissolved)	mg/L	X	X	
Zinc (Total)	mg/L	X	X	
Zinc (Dissolved)	mg/L	X	X	
Biological				
Total Chlorophyll	µg/L	**X**	**X**	
Chlorophyll-*a*	µg/L	X	X	
Fecal Coliform	CFU/100mls	X	X	
E. coli	CFU/100mls	X	X	
Osmotic Pressure	mOsm	X		
Miscellaneous				
Phenolics	mg/L	X	X	

3.3.1 Discrete Interval Sampling

Discrete, or "grab" samples were collected at nine sites on a weekly basis for four weeks during three seasonal monitoring periods (Fall/winter, spring and summer). Samples were collected regardless of flow or precipitation. Each site along the stream was sampled once during the course of a few hours, to allow for travel time and sample processing/preservation. The purpose of discrete sampling was initial characterization of water quality under both dry and wet conditions and identification of parameters of possible concern. Discrete sampling followed the Standard Operating Protocol (SOP) "Field Procedures for Grab Sampling".

3.3.2 Continuous Monitoring

Continuous data were collected at eight sites for a total of over 44,000 hours. During continuous sampling, data for selected parameters were collected at 15-minute increments by a submerged instrument (YSI Sonde 6600) over approximately two weeks. The instrument measured parameters using voltage and diffusion-based probes rather than physically collecting samples. Parameters measured included stage, dissolved oxygen, temperature, pH, and turbidity. This method produces 96 measurements per parameter every 24 hours, but cost and quality control are more challenging compared to discrete sampling. The SOP for continuous sampling describes the extensive quality control and assurance procedures applied to the data.

3.3.3 Wet Weather Event Sampling

At eight sites, a series of samples was collected over the course of several wet weather events. During wet weather sampling, several discrete samples were collected just before and during the course of a wet weather event. The data allow characterization of water quality responses to stormwater runoff and wet weather sewer overflows.

3.3.4 PWD/USGS Cooperative Water Quality Monitoring Program (1970-1980)

In the early 1970s, the Philadelphia Water Department began a study in cooperation with the U.S. Geological Survey (USGS) titled, "Urbanization of the Philadelphia Area Streams." The purpose of this study was to quantify the pollutant loads in some of Philadelphia's streams and possibly relate the degradation in water quality to urbanization. PWD and the USGS established six stream gauging stations in Tookany/Tacony-Frankford Watershed and conducted monthly water quality sampling from 1971 to 1980 at 5 of these locations. Of six original gauges, only the gauge at Castor Avenue (01467087) remains operational today. Monthly "snapshot" water quality samples were collected at each site and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform. The program collected about ten years of monthly samples. Figure 3-2 and table 3-4 show the locations of the monitoring stations from the PWD/USGS Cooperative Program.

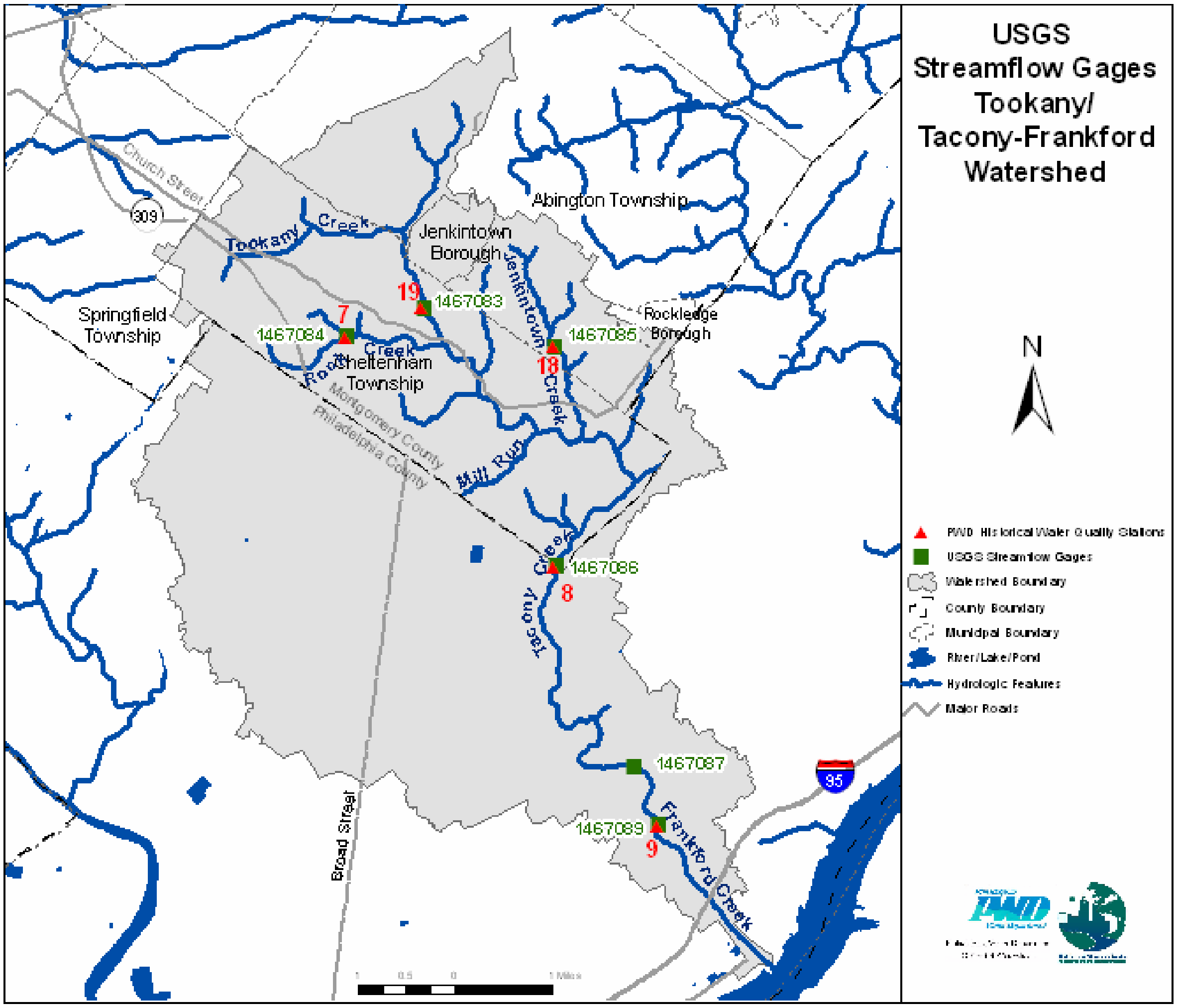


Figure 3-2 PWD/USGS Cooperative Program Water Quality Stations in the Tookany/Tacony-Frankford Watershed

Stream discharge was recorded at the time samples were collected, enabling comparisons to present day water quality. Historic samples were characterized as wet or dry based on a flow frequency analysis conducted in 2001. Spring and winter flows were typically higher than summer and fall flows, so samples were analyzed by season. For each season, a sample was determined to be wet if the instantaneous flow was greater than the estimated wet/dry weather flow break point. Some samples with discharge below the break point that had noticeably lower conductivity and greater TSS concentration were also characterized as "wet". Despite this check, it is assumed that many samples were collected within 48 hours of a rain event but classified as "dry".

3.4 Hydrologic and Outfall Monitoring

Hydrologic monitoring included a system of precipitation gauges and measurement of flows at stream gauges and at points within the sewer system (outfalls and CSO regulators). Characterization of hydrologic and hydraulic data is presented in Section 4.

3.4.1 Precipitation Data

Precipitation data are available from the National Oceanography and Atmospheric Administration (NOAA) and from local gauges operated by PWD and other organizations. NOAA's gauge at the Philadelphia International Airport, located in southeastern Philadelphia, has over 100 years of hourly precipitation data; the period of record runs from January 3, 1902 through the present. Additional precipitation data can be obtained from PWD's network of 24 rain gauges throughout the city; these data are available in 15-minute increments from the early 1990s to the present. Nine of the City gauges are located in or near the Tookany/Tacony-Frankford Creek watershed, as shown in Figure 3-3.

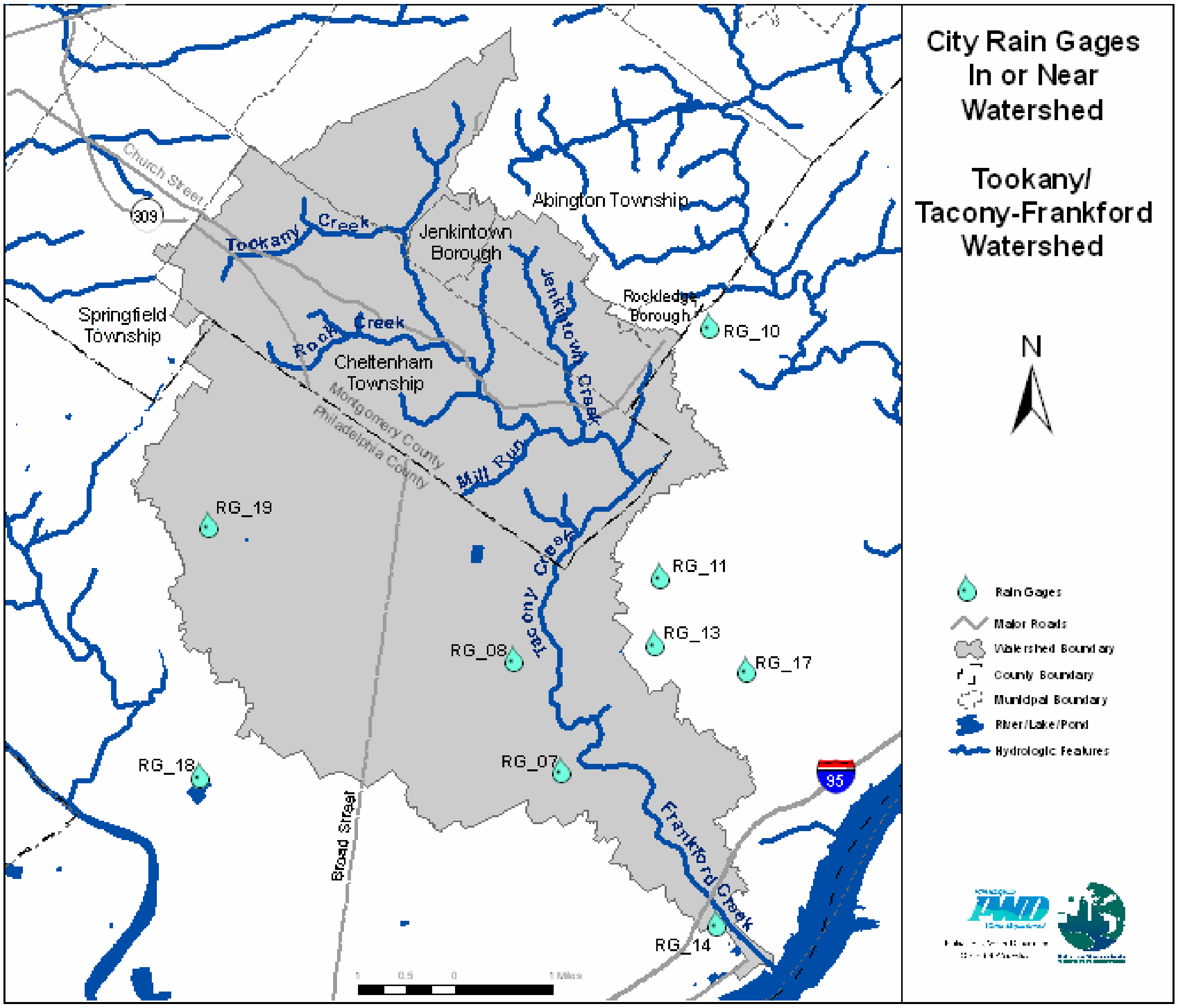


Figure 3-3 PWD Rain Gauges located in or near Tookany/Tacony-Frankford Watershed

3.4.2 Sewer Flow Instrumentation

PWD maintains real-time level monitors in the Tacony-Frankford Creek sewer system. At these points, monitors are typically present in the trunk sewer just above the regulator and in the outfall pipe itself. The magnitude of discharges from the city's CSO outfalls are estimated using a combination of this monitored data and calibrated computer models.

3.4.3 Streamflow Data

PWD and the USGS augmented the existing stream gauging network in the watershed as part of the Cooperative sampling program, establishing three new stream gauges from 1971 to 1973. A gauge was established at Castor Avenue in 1982, which is the only gauge still in operation. However, PWD and USGS are in the process of re-establishing the former gauge at the city line. Table 3-5 contains summary information for each of the six gauging stations for their respective periods of record. Historical stage-discharge rating curves are available for four of the stations and are shown in Figure 3-4.

Table 3-4 Periods of Record for Flow and Water Quality Data

Station ID	Location	Quality Data (Period)	Streamflow Data (Period)
01467089	Frankford Creek at Torresdale Ave.	10/9/67 - 3/7374	10/1/64 - 6/29/82, 5/14/82 – 6/29/82
01467087	Frankford Creek at Castor Ave.*	9/24/25 - 8/24/76	7/1/82 - 9/30/03
01467086	Tacony Creek at County Line	11/9/67 - 10/1/73	10/1/65 - 11/17/88
01467085	Jenkintown Creek At Elkins Park		10/01/73 - 9/30/78
01467084	Rock Creek above Curtis Arboretum near Philadelphia	10/4/71 - 10/1/73	5/1/71 – 9/30/78
01467083	Tookany Creek near Jenkintown		10/1/73 - 9/30/78

*Active Gauge

Table 3-5 Summary Statistics for Six Gauge Stations

Station ID	Average Daily Flow Statistics (cfs)		
	Minimum	**Mean**	**Maximum**
01467089	3.7	57.3	1980
01467087	0.39	40.5	3140
01467086	2.5	26.5	900
01467085	0.14	2.07	45
01467084	0.33	2.51	87
01467083	1.6	9.74	207

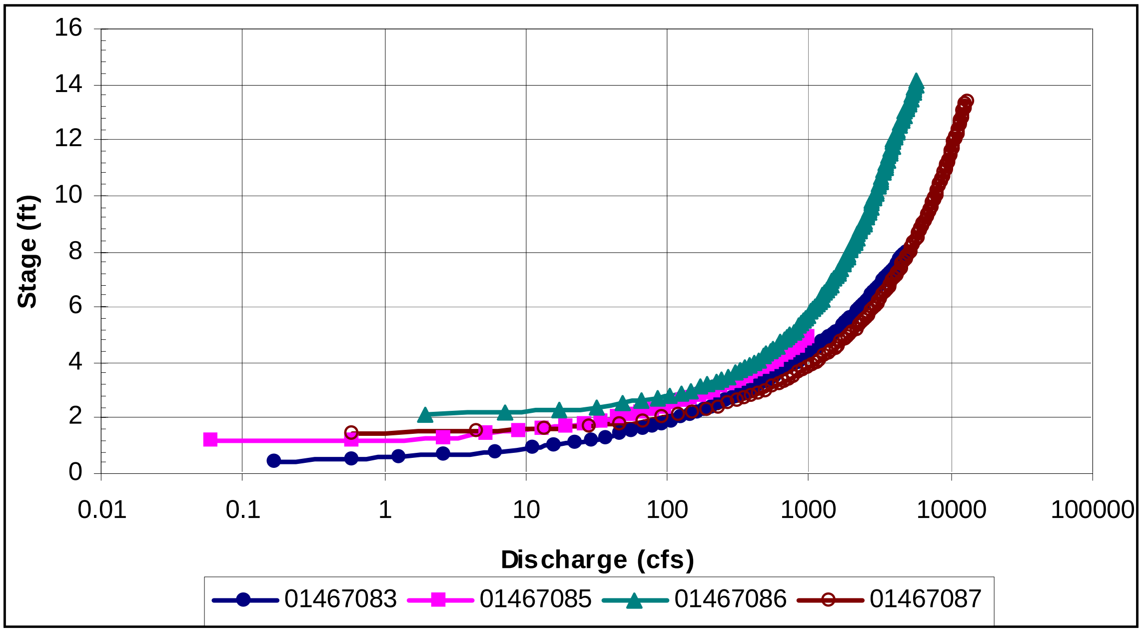


Figure 3-4 Historical stage-discharge rating curves available for four stations

3.4.5 STORET

The majority of the data available from STORET, USEPA's water quality database, for the Tookany/Tacony-Frankford Watershed were from the PWD/USGS Cooperative Program, "Urbanization of the Philadelphia Area Streams." The STORET inventory of water quality data within the Tookany/Tacony-Frankford Creek Watershed will be attached as an Appendix at a later date.

3.5 Benthic Macroinvertebrate Sampling

During 3/24/04 to 4/1/04, the Philadelphia Water Department conducted Rapid Bioassessment Protocols (RBP III) at twelve (n=12) locations within the Tookany/Tacony-Frankford Watershed (Figure 3-5). Using EPA guidelines, macroinvertebrates were collected by placing a standard (1m^2) kicknet at the downstream portion of a riffle. The substrate was then kicked and scraped manually one meter from the net aperture to remove benthic invertebrates. Four rocks of varying size were randomly chosen within the sampling sites and manually scraped to remove benthic invertebrates. This procedure was repeated at another riffle location with less flow. Specimens were then preserved in 70% ETOH (ethyl alcohol) and returned to the laboratory in polyethylene containers. In the laboratory, samples were placed in an 11" x 14" gridded (numbered) pan and random subsamples, or "plugs" were examined until 100 individuals were collected. Macroinvertebrates were identified to genus, with the exception of mollusks, aquatic worms, chironomids, crayfish, and leeches, which were identified to the family level.

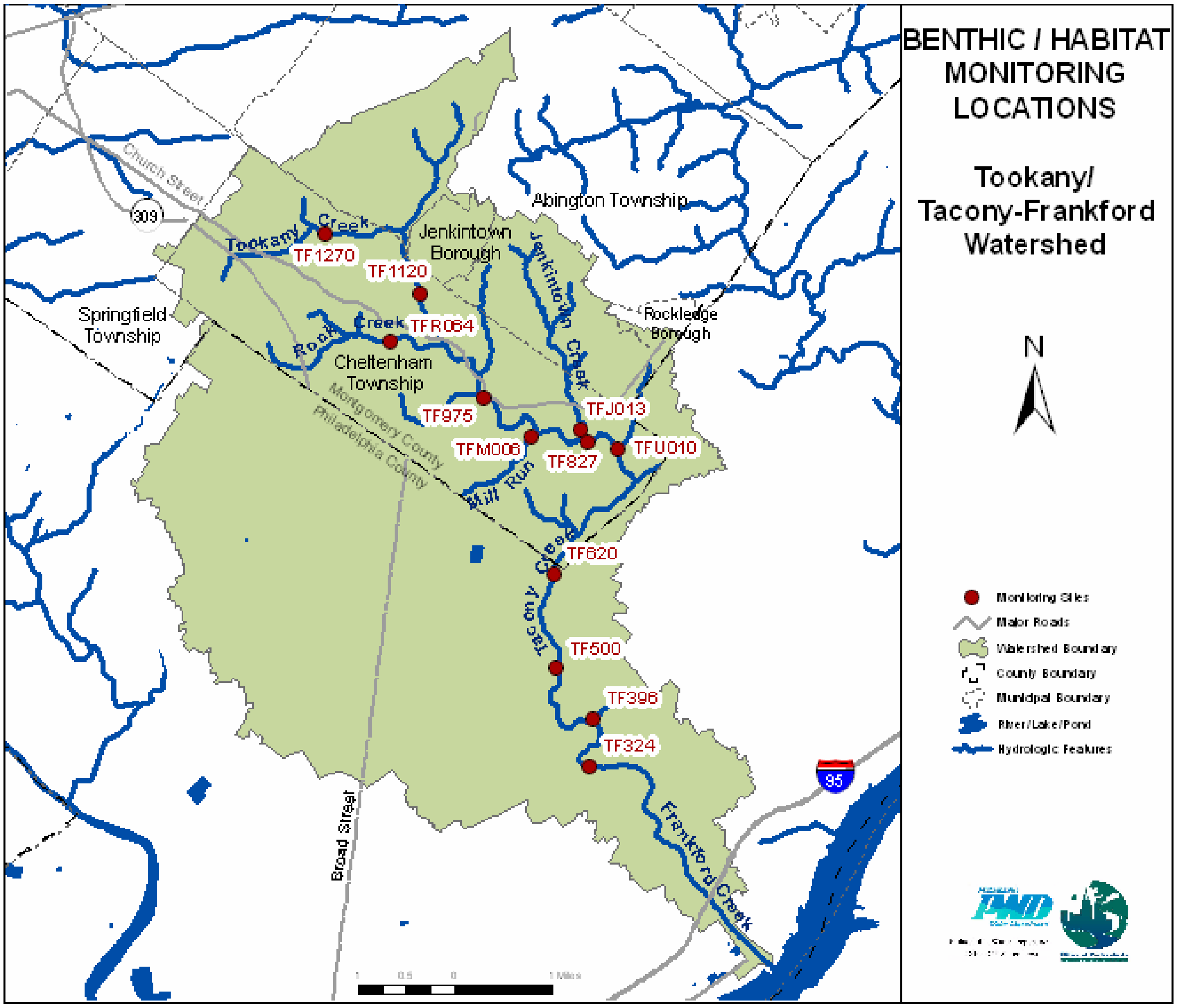


Figure 3-5 Benthic Macroinvertebrate Monitoring and EPA Habitat Assessment Sites in the Tookany/Tacony-Frankford Watershed, 2004

3.5.1 Metrics:

Biological integrity and benthic community composition of the 12 sites were assessed using the metrics in table 3-6. (EPA guidelines for RBP III and PA DEP Modified Rapid Biological Assessments)

Table 3-6 Biological Condition Scoring Criteria for RBP III

Metric	Biological Condition Scoring Criteria			
	6	4	2	0
Taxa Richness [(a)]	>80%	79-70%	69-60%	<60%
Hilsenhoff Biotic Index (Modified) [(a)]	<0.71	0.72-1.11	1.12-1.31	>1.31
Modified EPT Index [(a)]	>80%	79-60%	59-50%	<50%
Percent Contribution of Dominant Taxon [(a)]	<10	11-16	17-22	>22
Precent Modified Mayflies [(a)]	<12	13-20	21-40	>40
Ratio of Scrapers/Filter [(b)] Collectors	>50%	35-50%	20-35%	<20%
Community Loss Index [(b)]	<0.5%	0.5-1.5	1.5-4.0	>4.0
Ratio of Shredders/Total [(b)]	>50%	35-50%	20-35%	<20%

[a] Metrics used to quantify scoring criteria (PA DEP)
[b] Additional metrics used for qualitative descriptions of sampling locations (EPA)

Upon completion of the total biological scoring criteria, each site was compared to a reference site according to its drainage area and geomorphologic attributes. The reference sites chosen were French Creek, located at Coventryville, and Rock Run, a tributary of French Creek. Using the following chart, benthic quality of each site was established to identify spatial trends of impairment along the river continuum (Table 3-7).

Table 3-7 Biological Condition Categories for RBP III

% Comparison to Reference Score [(a)]	Biological Condition Category	Attributes
>83%	Nonimpaired	Comparable to the best situation within an ecoregion. Balanced trophic structure. Optimum community structure for stream size and habitat quality.
54-79%	Slightly impaired	Community structure less than expected. Species composition and dominance lower than expected due to loss of some intolerant forms. Percent contribution of tolerant forms increases.
21-50%	Moderately impaired	Fewer species due to loss of most intolerant forms. Reduction in EPT index.
<17%	Severely impaired	Few species present. If high densities of organisms, then dominated by one or two taxa.

(a) Percentage values obtained that are intermediate to the above ranges will require subjective judgment as to the correct placement. Use of the habitat assessment and chemical data may be necessary to aid in the decision process.

3.6 Ichthyofaunal (Fish) Sampling

3.6.1 Fish Collection in Non-Tidal Portions

Between 6/2/04 and 6/16/04, PWD biologists conducted fish assessments at seven (n=7) locations within the Tookany/Tacony-Frankford Watershed (Figure 3-5). Fish were collected by electrofishing as described in EPA's Rapid Bioassessment Protocol V (RBP V) (Barbour *et al*., 1999). Depending on stream conditions, Smith-Root backpack or tote barge electrofishers were used to stun fish. A 100m reach of the stream was blocked at the upstream and downstream limits with nets to prevent immigration or emigration from the study site. Each reach was uniformly sampled, and all fish captured were placed in buckets for identification and counting. An additional pass without replacement was completed along the reach to ensure maximum likelihood population and biomass estimates.

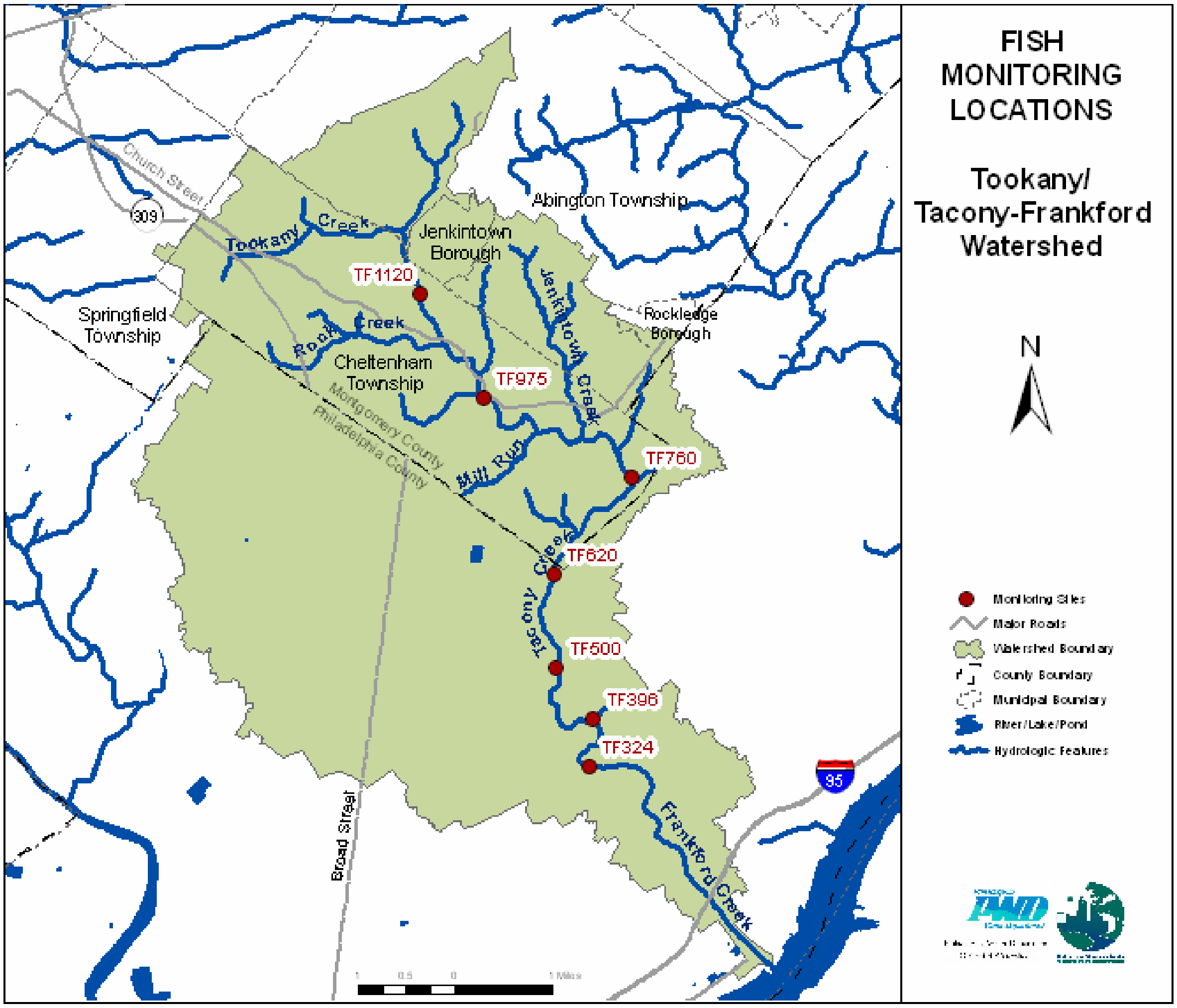


Figure 3-5 Non-Tidal Fish Monitoring Sites in the Tookany/Tacony-Frankford Watershed, 2004

3.6.2 Fish Collection in Tidal Portions

Between 8/1/04 and 8/8/04, staff biologists completed fish assessments at two (n=2) tidal locations in the Tookany/Tacony-Frankford Watershed (Figure 3-6). Fish inhabiting tidal portions of Frankford Creek were collected with Smith-Root electrofishing apparatus mounted aboard a small aluminum-hulled johnboat. Electrofishing was conducted for ten-minute intervals in a downstream direction, targeting areas with suitable fish habitat. It was not feasible to install block nets or otherwise prevent net movement of fish into or out of the sampling area.

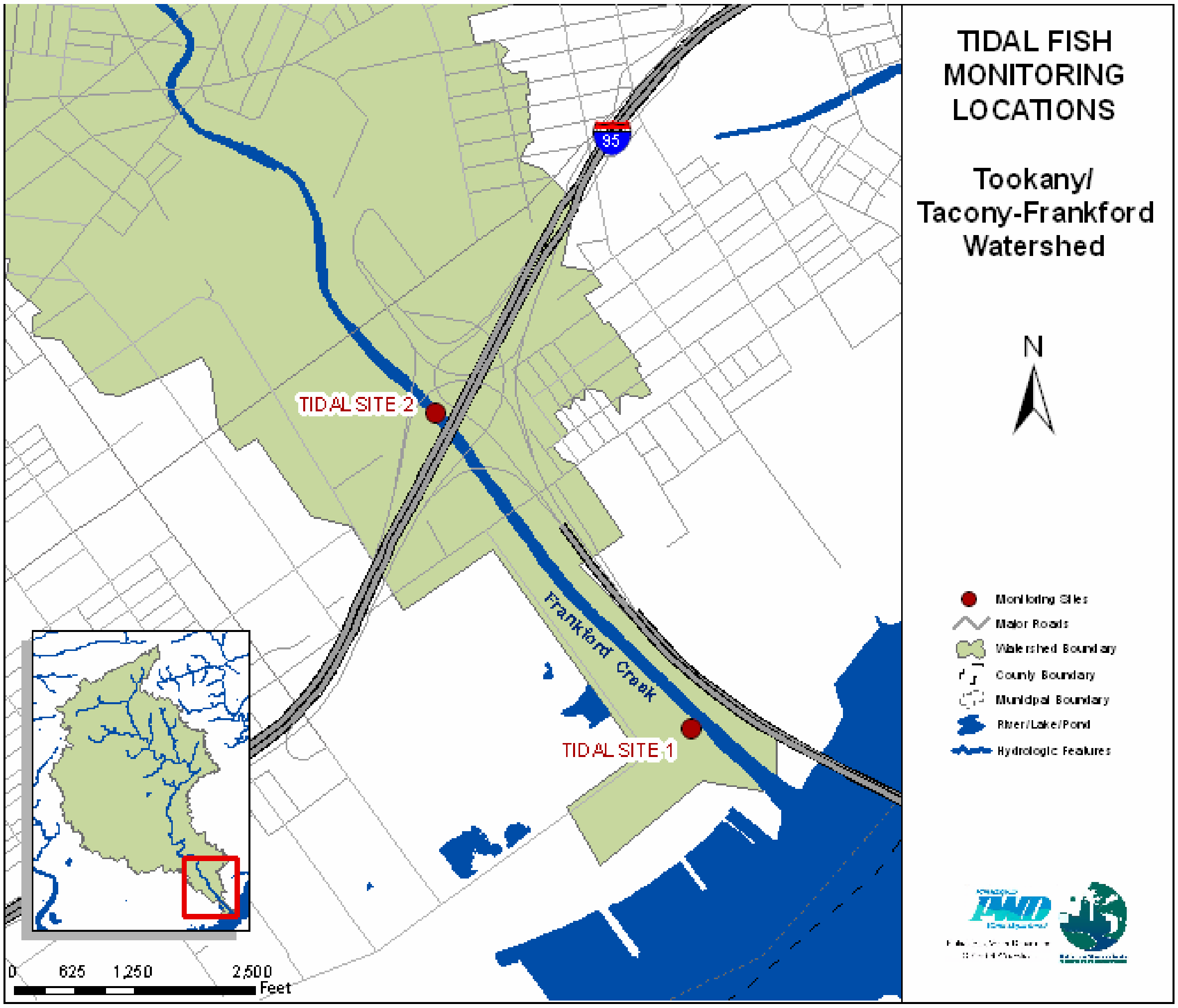


Figure 3.6 Tidal Fish Monitoring Sites in Frankford Creek, 2004

3.6.3 Sample Processing

Fish were identified to species, weighed (± 0.01 g) with a digital scale (Model Ohaus Scout II) and measured to the nearest 0.1 cm using a Wildco fish measuring board. Large fish that exceeded the digital scale's capacity were weighed using spring scales (Pesola). Any external deformations, lesions, tumors, cysts, or disease were noted during processing. Species that could not be identified in the field (*e.g.*, small or juvenile cyprinids) were preserved with 10% formalin solution and stored in polyethylene bottles for laboratory identification.

To facilitate the process of acquiring total fish biomass and to reduce field time, a simple linear regression was developed between weight (g) and length (cm). Approximately 20 individuals of each species were weighed, and total lengths were measured. Once 20 individuals of each species were measured (both weight and length), biomass (g) for each fish was calculated using the regression analysis. Similar procedures were conducted at the reference locations (*i.e.*, French Creek and Rock Run) to obtain a discrete measure of the condition of the fish assemblages at each assessment location.

3.6.4 Fish IBI Metrics:

The health of fish communities in Tookany/Tacony-Frankford Watershed was assessed based on the technical framework of the Index of Biological Integrity (IBI) developed by Karr (1981). The analysis entailed the definition of "ecoregional-specific" metrics pertinent to the fish assemblages located in the lower Schuylkill River Drainage. Standardized metrics (*i.e.*, indices) were then integrated to provide an overall indication of the condition of fish assemblages at each assessment location. Individual metrics within the fish IBI framework were also used to provide quantitative information regarding a specific attribute of the respective assessment location (*e.g.*, pollution tolerance values). In addition to IBI metrics, other metrics were incorporated into the design to evaluate the overall ecological health of fish assemblages and as a means of comparison of each assessment site. Tables 3-8 and 3-9 describe the various indices and scoring criteria used for the IBI metrics in the Tookany/Tacony-Frankford Watershed. Additional metrics used in the analysis are displayed in Table 3-10.

Table 3-8 Metrics Used to Evaluate the Index of Biological Integrity (IBI) at Representative Sites.*

Metric	**Scoring Criteria**		
	5	**3**	**1**
1. Number Of Native Species	>67%	33-67%	<33%
2. Number Of Benthic Insectivore Species	>67%	33-67%	<33%
3. Number Of Water Column Species	>67%	33-67%	<33%
4. Percent white sucker	<10%	10-25%	>25%
5. Number Of Sensitive Species	>67%	33-67%	<33%
6. Percent Generalists	<20%	20-45%	>45%
7. Percent Insectivores	>45%	20-45%	<20%
8. Percent Top Carnivores	>5%	1-5%	<1%
9. Proportion of diseased/anomalies	<1%	1-5%	>5%
10. Percent Dominant Species[a]	<40%	40-55%	>55%

* Metrics used are based on modifications as described in Barbour, *et al*., 1999.

[a] Metric based on USGS NAWQA study (2002).

Table 3-9 Index of Biological Integrity (IBI) Score Interpretation.*

IBI	**Integrity Class**	**Characteristics**
45-50	Excellent	Comparable to pristine conditions, exceptional assemblage of species
37-44	Good	Decreased species richness, intolerant species in particular
29-36	Fair	Intolerant and sensitive species absent; skewed trophic structure
10-28	Poor	Top carnivores absent or rare; omnivores and tolerant species dominant
<10	Very Poor	Few species and individuals present; tolerant species dominant; diseased fish frequent

* IBI score interpretation based on Halliwell, *et al*., 1999.

Table 3-10 Additional Metrics Used to Evaluate Fish Assemblage Condition

Metric	Assessment Type
Species Diversity	Shannon (H') Diversity Index
Trophic Composition	Percentage of Functional Feeding Groups
Tolerance Designations	Percentage of Pollution Tolerant, Moderate And Intolerant Species
Modified Index Of Well-Being	MIwb Index

3.6.5 Species Diversity:

Species diversity, a characteristic unique to the community level of biological organization, is an expression of community structure (Brower *et al.*, 1990). In general, high species diversity indicates a highly complex community. Thus, population interactions involving energy transfer (*e.g.*, food webs), predation, competition and niche distribution are more complex and varied in a community of high species diversity. In addition, many ecologists support species diversity as a measure of community stability (*i.e.*, the ability of community structure to be unaffected by, or recover quickly from perturbations). Using the Shannon (H′) Diversity Index formula, species diversity was calculated at each sampling location:

$$H' = -\Sigma\, n_i/N \,{*}\ln\,(n_i/N): \qquad \text{(eq. 1)}$$

where n_i is the relative number of the *i*th taxon and N is the total number of all species.

3.6.6 Trophic Composition and Tolerance Designations:

Trophic composition metrics were used to assess the quality of the energy base and trophic dynamics of the fish assemblages (Plafkin *et al.*, 1989). The trophic composition metrics offer a means to evaluate the shift toward more generalized foraging that typically occurs with increased degradation of the physiochemical habitat (Barbour *et al.*, 1999). Pollution tolerance metrics were also used to distinguish low and moderate quality sites by assessing tolerance values of each species identified at the sampling locations. This metric identifies the abundance of tolerant, moderately tolerant and pollution intolerant individuals at the study site. Generally, intolerant species are first to disappear following a disturbance. Species designated as intolerant or sensitive should only represent 5-10% of the community; otherwise the metric becomes less discriminatory. Conversely, study sites with fewer pollution intolerant individuals may represent areas of degraded water quality or physical disturbance. For a more detailed description of metrics used to evaluate the trophic and pollution designations of fish assemblages, see Barbour *et al.*, (1999).

3.6.7 Modified Index of Well-Being (MIwb):

Modified Index of Well-Being (MIwb) is a metric that incorporates two abundance and two diversity measurements. Modifications from the Ohio EPA (1987), which eliminate pollution tolerant species, hybrids and exotic species, were incorporated into the study in order to increase the sensitivity of the index to a wider array of environmental disturbances. MIwb is calculated using the following formula (equation 2):

$$MIwb = 0.5{*}\ln N + 0.5{*}\ln B + H_N + H_B \qquad \text{(eq. 2)}$$

where;

N = relative numbers of all species
B = relative weight of all species
H_N = Shannon index based on relative numbers
H_B = Shannon index based on relative weight

3.7 Algae Sampling

Between 8/17/2004 and 9/17/2004, replicate algae samples were collected from three (n=3) sites within the Tookany/Tacony-Frankford Watershed (Figure 3-7). Samples were collected on six occasions to determine the biomass of benthic algae in terms of chlorophyll-*a* (chl-*a*), spatial variation in biomass within and between sites, the scouring effects of high flows, and algal accrual rates following a high flow event.

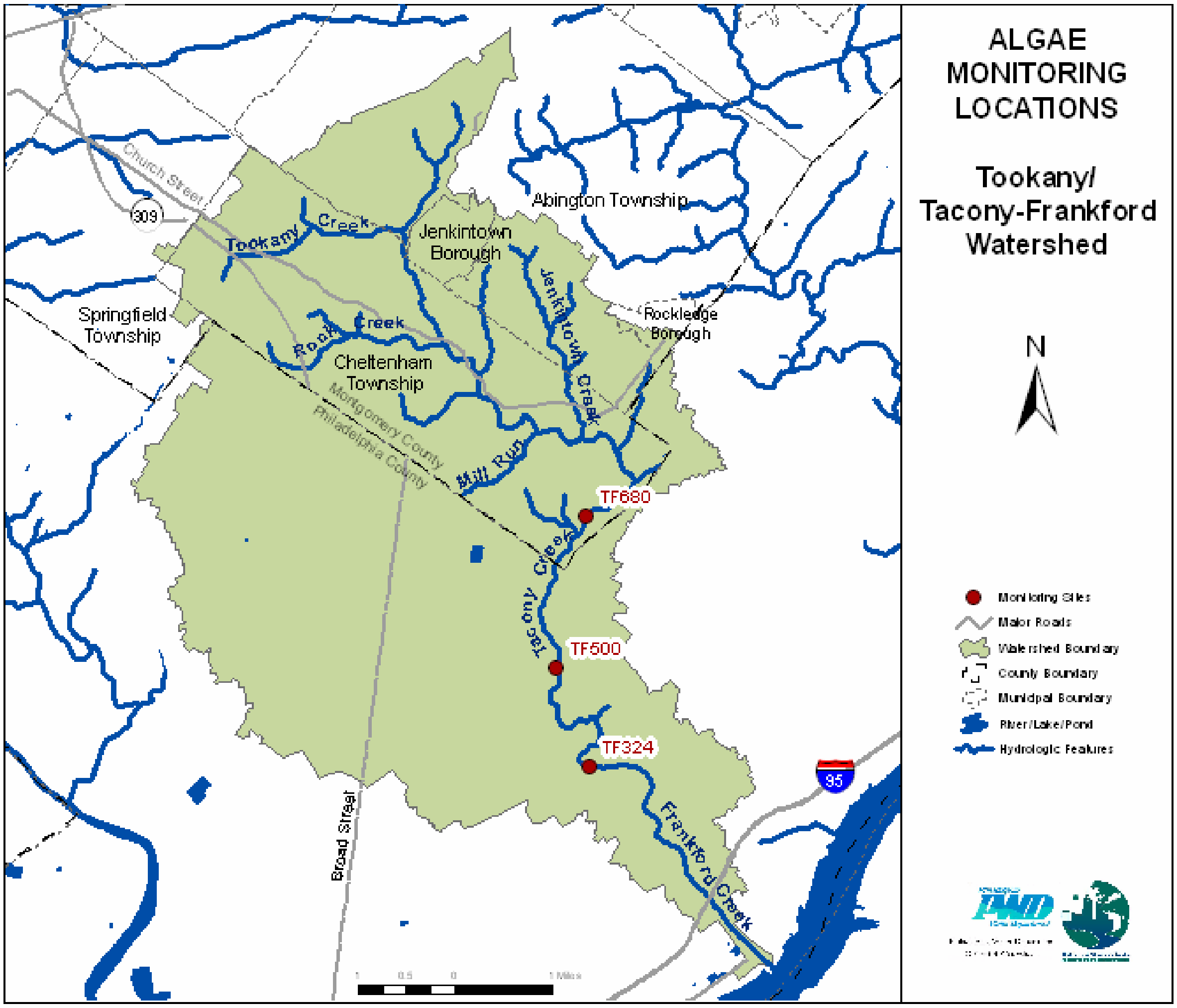


Figure 3-7 Algae Monitoring Locations in the Tookany/Tacony-Frankford Watershed, 2004

3.7.1 Periphyton Collection Procedure

Sampling was conducted on the main channel of the Tookany/Tacony-Frankford Creek at or near stations where continuous water quality parameters (*i.e.*, DO, temperature, pH, conductivity) were recorded. During the course of the study, TF280, TF500, and TF620 were the only stations that had continuously recording sondes. Because of heavy shading and different habitat conditions (*e.g.*, deeper water, slower flow) at TF500 than at TF280 and TF620, sampling focused on the latter two sites. Samples were collected near site TF280 at site TF324 and near site TF620 at site TF680. On one occasion, algal samples were also collected from TF500 (8/19/2004). The total number of samples collected with respect to site and date are shown in Table 3-11.

Table 3-11 Number of Periphyton Samples Collected with Respect to Site and Date from the Tookany/Tacony-Frankford Watershed, 2004

Date	Site	Sampling Program	# samples chl-*a*
8/19/04	TF324	Monitor	8
	TF500	Monitor	5
	TF680	Monitor	8
8/23/04	TF324	Monitor	5
	TF680	Monitor	5
8/26/04	TF324	Monitor	5
	TF680	Monitor	5
9/8/04	TF324	Monitor	0
	TF680	Monitor	4
	TF680	Scour	4
9/13/04	TF324	Monitor	4
	TF324	Scour	4
	TF680	Monitor	4
	TF680	Scour	4
9/17/04	TF324	Monitor	4
	TF324	Scour	4
	TF680	Monitor	4
	TF680	Scour	4

Because we were interested in determining how algal biomass was reduced following scouring by a high flow event, we attempted to collect initial algal samples near a predicted rain event, and additional algal samples following the rain event. However, during the sampling period, a rain event adequate to cause scouring did not occur. Because we were concerned that seasonal changes in biomass would occur before a sufficient scouring event did, we artificially simulated effects of a high flow event by removing algae from approximately 50 rocks at TF324 and TF680 and placing them back in the stream. Algal material was removed by scrubbing the rocks with plastic scouring pads. Algal material was sampled at TF680 on the same date for "pre-scour" data. "Pre-scour" samples could not be collected at TF324 because of elevated stream levels from a brief rain event. Subsequent "post-scour" samples were collected from both TF324 and TF680 on 9/13/2004 (Day 5) and 9/17/2004 (Day 9). Scoured substrates on day 0 were presumed to have chl-*a* concentrations less than 5 mg/m^2 and daily accrual rates for each site determined by dividing the net gain or loss of algae by time (days).

All samples were collected using the same methods. Composite algal samples (2-6 rocks) were collected from randomly selected rocks by brushing and scraping using toothbrushes and scalpels or other scraping tools. Material from each composite sample was placed in a separate container, labeled, and placed on ice in darkened containers until arrival at the laboratory. Composite algal samples were collected rather than individual rocks because when algal biomass is low or coverage is heterogeneous, sampling at the rock scale can artificially increase within-site variation and reduce the power of the data collected. To ensure adequate algal biomass and reduce within-site variation, all replicate algal samples were a composite of material from 2-6 rocks.

The area sampled was determined by wrapping the sampled area in aluminum foil. The 3-dimensional foil mold was carefully removed from the rock and cut with scissors so the foil lay as flat as possible. The area of the foil was then digitized using Scion Image (Beta 4.0.2), a windows version of NIH Image for the Macintosh, to calculate surface area.

In addition to algal biomass samples, samples were collected for quantitative taxonomic analysis. Composite samples were collected in the same manner as biomass samples and algal material removed by brushing and scraping. Algal material for each sample was placed in a separate container and preserved in 5-10% formalin for taxonomic identification of soft algae and diatoms. These samples will be analyzed by the Phycology Section at the Academy of Natural Sciences, but data will not be presented in this report.

3.7.2 Laboratory Procedures

Composite algal samples were processed by homogenizing the sample in a blender. The sample was measured in a graduated cylinder and the total volume brought to 1 L with deionized water. A 15 mL sub-sample for chl-*a* analyses was filtered through a 47 mm glass fiber filter (Whatman, 0.7-µm nominal pore size). For a subset of samples, an algal sub-sample was filtered through a weighed, pre-combusted glass fiber filter to determine percent solids and percent organic matter. Filters for both measures were stored frozen.

Algal samples were analyzed for chl-*a* according to Standard Methods for fluorometry (APAH 1992). Percent solids and percent organic matter were determined by drying the filters to a constant weight at 105ºC for 24 h (mass of solids) and burning the sample in a muffle oven at 550ºC for 1 h (APAH 1992). However, laboratory errors resulted in questionable AFDM data and these data are not reported.

3.7.3 Data Analyses

Spatial and temporal variation in algal biomass was examined using ANOVA (SYSTAT 10.2.01, 2002). Two-factor ANOVA was used to examine differences in chl-*a* with respect to site and sampling date for the general monitoring program. Because samples were only collected at TF500 on one occasion, these data were not included in the analyses. A three-factor ANOVA identified differences in chl-*a* between “scoured” and natural rocks with respect to site and date.

3.8 Habitat Assessment

3.8.1 EPA Habitat Assessment

Prior to benthic macroinvertebrate sampling procedures, habitat assessments at twelve (n=12) sites (Figure 3-5) were completed based on the Environmental Protection Agency's *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers* (Barbour *et al*., 1999). Reference conditions were used to normalize the assessment to the "best attainable" situation. Habitat parameters are separated into three principal categories: (1) primary, (2) secondary, and (3) tertiary parameters. Primary parameters are those that characterize the stream "microscale" habitat and have greatest direct influence on the structure of indigenous communities. Secondary parameters measure "macroscale" habitat such as channel morphology characteristics. Tertiary parameters evaluate riparian and bank structure and comprise three categories: (1) bank vegetative protection, (2) grazing or other disruptive pressure, and (3) riparian vegetative zone width. Table 3-12 lists the various parameters addressed during habitat assessments.

Table 3-12 Habitat assessment criteria used at benthic monitoring stations.

Condition/Parameter	Condition			
	Optimal	Suboptimal	Marginal	Poor
Epifaunal Substrate/Available Cover	16-20	11-15	6-10	0-5
Pool Substrate Characterization	16-20	11-15	6-10	0-5
Pool Variability	16-20	11-15	6-10	0-5
Sediment Deposition	16-20	11-15	6-10	0-5
Embeddedness	16-20	11-15	6-10	0-5
Velocity/Depth Regime	16-20	11-15	6-10	0-5
Frequency of Riffles (or bends)	16-20	11-15	6-10	0-5
Channel Flow Status	16-20	11-15	6-10	0-5
Channel Alteration	16-20	11-15	6-10	0-5
Channel Sinuosity	16-20	11-15	6-10	0-5
Bank Stability*	9-10	6-8	3-5	0-2
Vegetative Protection*	9-10	6-8	3-5	0-2
Riparian Vegetative Zone Width*	9-10	6-8	3-5	0-2

*Both right and left banks are assessed separately.

3.8.2 Habitat Suitability Index (HSI) Model Methods

3.8.2.1 Model History and Assumptions

Prior to the development of Instream Flow Incremental Methodology (IFIM), a number of Habitat Suitability Index (HSI) models were developed by the U.S. Fish and Wildlife Service (USFWS). Based on empirical data and supported by years of research and comprehensive review of scientific literature, these models present numerical relationships between various habitat parameters and biological resources, particularly gamefish species and species of special environmental concern. Through evaluation of various input parameters, models arrive at a final index value between 0 and 1, a score of 1 corresponding to the ideal habitat condition, and zero indicating that some aspect of the habitat is unsuitable for supporting a naturally reproducing population of the species of interest.

Numerous assumptions are inherent with use and interpretation of the models. First and foremost is the assumption that habitat features alone are responsible for determining abundance or biomass of the species of interest at the study site. Clearly, no species exists in a vacuum; aside from habitat variables, other ecological and environmental interactions can strongly influence biological communities. HSI indices assume that users will use good professional judgment, consult with regional experts when necessary, and consider the possible effects of other factors (*e.g.*, competition, predation, toxic substances and other anthropogenic factors) when interpreting model output.

3.8.2.2 Model Data Requirements

Most types of data required by HSI models were available for all sites within Tookany/Tacony-Frankford Watershed. However, a number of habitat parameters were not directly measured in a fashion best suited for use with HSI models and required additional interpretation or normalization. Few water quality parameters were measured with equal sampling effort across all sites; some parameters were measured with continuous monitoring instruments at some sites and grab samples or hand-held meters at other sites. Some variables were not directly measured at some sites. To facilitate HSI analysis at these sites, (conservative) values were substituted based on sampling conducted at nearby sites and reference sites in neighboring watersheds. Turbidity data were excluded from the analyses entirely because all HSI were developed using Jackson Turbidity Units (JTU), which cannot be converted to/from modern Nephelometric Turbidity Unit (NTU) data. Any other significant modifications to the variables or the modeling approach are explained in Section 5.3.5 (Habitat Suitability Indices). A list of all HSI input variables for the seven HSI models applied to Tookany/Tacony-Frankford Watershed appears in Table 3-13.

Table 3-13 Habitat Suitability Index (HSI) variable matrix.

HSI Model Variable Matrix	Variable Type	Blacknose Dace	Common shiner	Creek Chub	Fallfish	Longnose Dace	Redbreast Sunfish	Smallmouth Bass
Total number of HSI variables		**16***	**9**	**20**	**6**	**6**	**10**	**13***
Average Temperature during growing season (May-Oct.)	temperature	X						X
Average Temperature in spawning season**		X	X		X		X	X
Maximum temperature sustained for 1 week			X			X	X	
Average Summer Temperature (Jul-Sep)				X	X			
Average temperature during spring (May-Jun)				X				
Average Turbidity (JTU)***	water quality	X	X	X	X		X	X
Average yearly pH value			X					X
Least suitable pH value (instantaneous)							X	
pH fluctuation classification				X				
Minimum dissolved oxygen concentration				X			X	X
Minimum dissolved oxygen conc. During spring				X				
Percent instream cover during average summer flow	general stream characteristics			X		X	X	X
Instream cover classification					X			
Percent shading of stream between 1000 and 1500 hrs.		X		X				
Percent vegetative cover							X	
Availability of thermal refugia (winter) (Y/N)				X				
Stream gradient (m/Km)		X		X				X
Average stream velocity during average summer flow				X		X		
Dominant substrate characterization					X		X	
Stream width		X		X			X	
Mode of stream depth during average summer flow					X			
Water level fluctuations								X
Stream margin substrate characterization (Y/N)		X						
Average velocity along stream margins		X		X				
Stream margin vegetation characterization				X				
Substrate food production potential				X				
Percent riffles	riffles					X		
Riffle substrate characterization		X	X	X		X		
Average velocity in riffles		X	X	X				
Average depth of riffles		X						
Average maximum depth of riffles						X		
Percent pools	pools	X	X	X			X	X
Pool substrate characterization		X						X
Pool classification			X	X				
Average depth of pools				X				X
Average velocity at 0.6 depth in pools		X	X					

* Some variables used more than once, applied to different life stages
**Spawning season varies by species. Common Shiner and Fallfish use a Y/N index.
*** Turbidity relationships developed using Jackson candle units; cannot be converted to NTU values

3.8.2.3 Suitability Index Expressions

HSI models use three major types of Suitability Index (SI) expressions or mathematical relationships to compute the suitability of a given habitat variable; they are (in increasing order of complexity): 1) categorized relationships, 2) linear equations (or more commonly, series of linear equations bounded by inflection points), and 3) suitability curves. Categorized relationships are used for a limited number of HSI variables in which the relationship between the habitat feature and suitability for the species of interest is fairly simple. Substrate size categorization is one example; many HSI models use dominant substrate type categories (*e.g.*, silt, sand, gravel, cobble, boulder, bedrock). Other SI variables that may be defined by simple categorization are temperature, dissolved oxygen, pH or, or in some cases, the variability of these measurements (Figure 3-8). Categorized data were processed directly within Microsoft Excel spreadsheet HSI models.

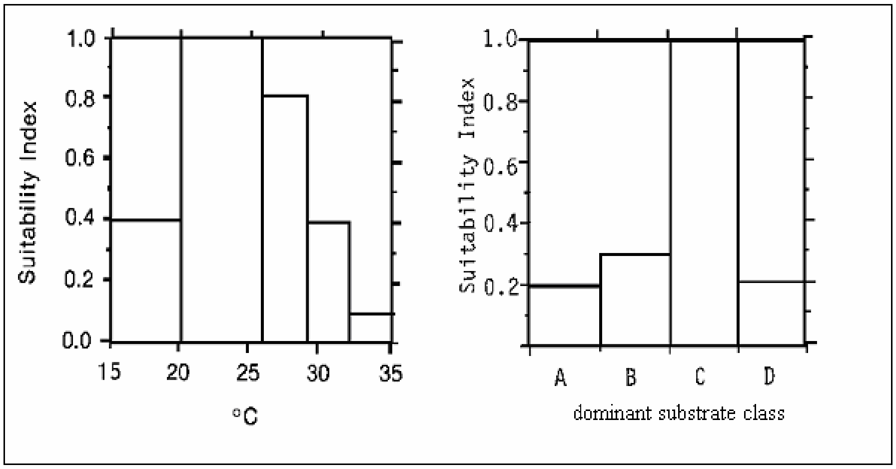


Figure 3-8 Categorized expressions in HSI models.

Many SI variables are defined by a series of linear relationships bounded by inflection points (*i.e.*, a collection of linear relationships that roughly approximate a curve). Many of these relationships include a range of unsuitable (SI=0) values, a range of ideal (SI =1.0) values, or both. Although all types of SI variables were, in some cases, defined by series of linear relationships (Figure 3-9), these expressions were less likely to be employed as models increased in complexity. As models become more complex, there is a corresponding increased focus on development of SI curves. SI variables defined by linear relationships were processed using linear equations and Boolean commands directly in Excel spreadsheet models.

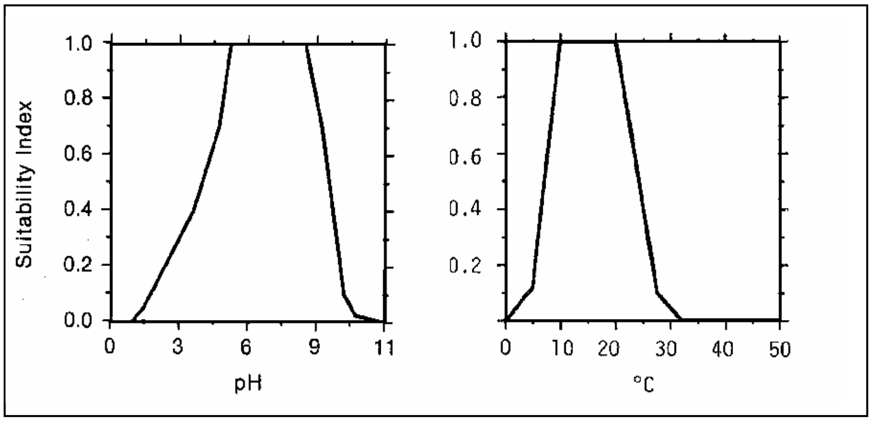


Figure 3-9 Linear expressions in HSI models.

SI curve relationships are considered the most precise and continuous of SI relationships, and therefore, appear more frequently in more complex HSI models. For example, curves allow models to accurately represent the non-linear, sub-asymptotic change in SI expected as a habitat variable approaches complete unsuitability or ideal suitability (SI score 0 or 1 respectively). Two general SI curve shapes were common, modified parabolae and "s-curves", though there was considerable variation in actual curve shape between different SI variables (Figure 3-10). As curve equations were not provided with HSI model documentation, lookup tables were generated by scanning curves with data extraction software (Data Thief). Subsequent data processing was handled in Excel.

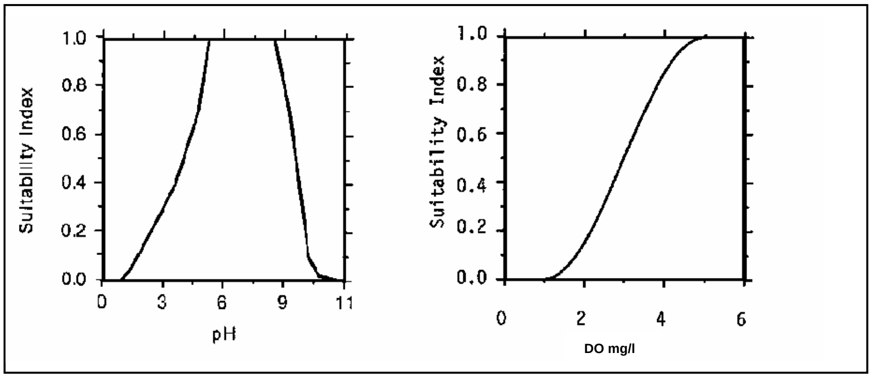


Figure 3-10 Curve relationships in HSI models.

3.8.2.4 Model Evaluation

HSI model output for each site was compared to EPA habitat data results. With the exception of longnose dace, smallmouth bass and fallfish HSI data, HSI model output was compared to observed fish abundance and biomass with correlation analyses. Several habitat models likely require modification in order to be useful in guiding or evaluating stream habitat improvement activities. While time constraints precluded the modification of models to better suit Tookany/Tacony-Frankford Watershed, it is hoped that such modifications will increase the usefulness of these models in the future.

3.9 Chemical Assessment

3.9.1 Fixed Interval Chemical Sampling

Bureau of Laboratory Services staff collected surface water grab samples at eight (n=8) locations within Tookany/Tacony-Frankford Watershed for chemical and microbial analysis (Figure 3-11). Samples from sites TF620 and TF680 were combined for analysis and considered TF620. Sampling events were planned to occur at each site at weekly intervals for one month during three separate seasons. Actual sampling dates were as follows: "winter" samples collected 1/15/04, 1/22/04, 1/29/04, and 2/5/04; “spring” samples collected 4/21/04, 4/29/04, 5/6/04, and 5/13/04; “summer” samples collected 8/5/04, 8/12/04, 8/19/04 and 8/26/04. A total of 96 discrete samples, comprising 3552 chemical and microbial analytes, were collected and recorded during the 2004 assessment of the Tookany/Tacony-Frankford Watershed. To add statistical power, additional discrete water quality samples from PWD's wet-weather chemical sampling program were included in analyses when appropriate. Sites TF280, TF500, TF620, TF760, TF975, TF1120 and TFJ110 were included in PWD's baseline chemical assessment of Tookany/Tacony-Frankford

Watershed in 2000. A single new site (TFM006), located on Mill Run and the Tacony Creek confluence was added for 2004.

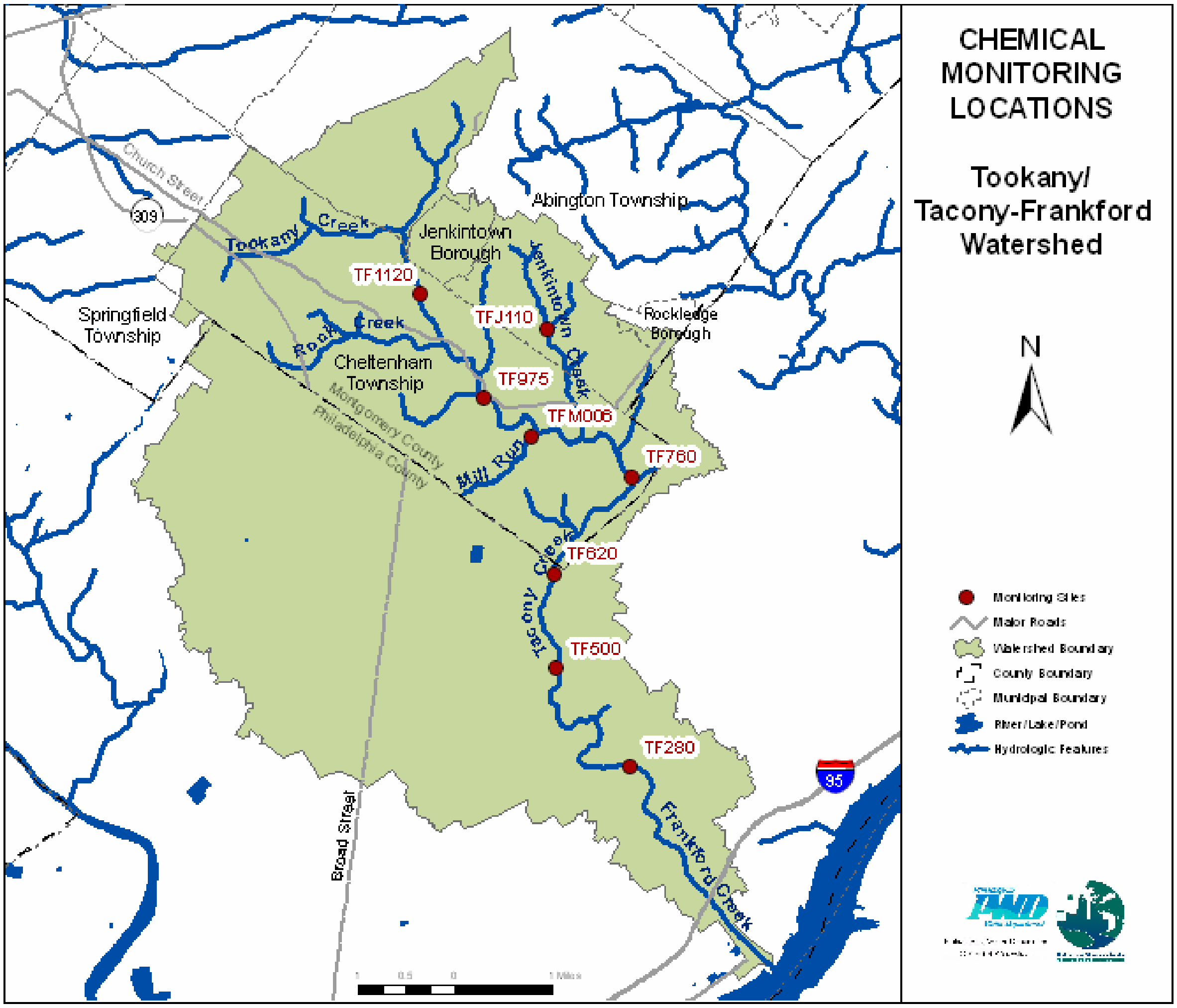


Figure 3-11 Fixed Interval Chemical Sampling Locations in the Tookany/Tacony-Frankford Watershed, 2004

Discrete sampling was conducted on a weekly basis and was not specifically designed to target wet or dry weather flow conditions. Depending on which definition of "dry weather" was used (*i.e.*, 48 hr interval or 72 hr interval), between 6-7 sampling events occurred during dry weather- this data is most pertinent to Target A of the Watershed Management Plan (Dry Weather Water Quality and Aesthetics). Specifically addressed are indicators 7 and 8 – chemical and microbial constituents that are influential in shaping communities of aquatic systems or that are indicative of anthropogenic degradation of water quality in the watershed.

3.9.2 Wet-Weather Targeted Sampling

Target C of the Watershed Management Plan addresses water quality in wet weather. Yet characterization of water quality at several widely spatially distributed sites simultaneously over the course of a storm event presents a unique challenge. Automated samplers (Isco, Inc.) were used to collect samples during nine runoff producing rain events in 2003 and 2004. Seven events took place in 2003 on 10/14/03, 5/2/03, 5/5/03, 5/7/03, 5/15/03, 7/10/03, and 9/23/03 and were monitored from four locations. Two events took place in 2004 on 7/7/04 and 8/30/04 and were monitored from six locations (Figure 3-12). Samples from sites TF620 and TF680 were combined for analysis and considered TF620.

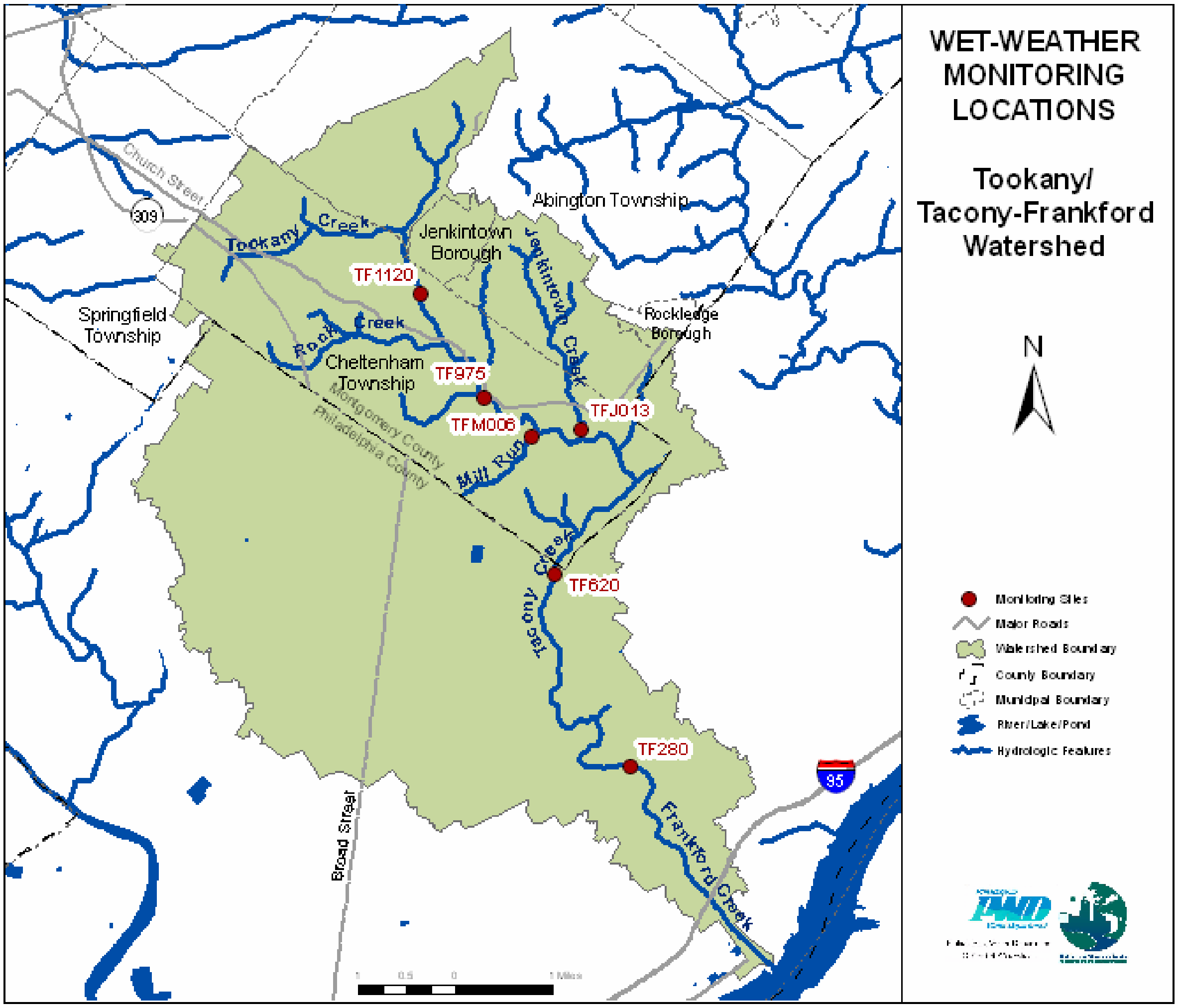


Figure 3-12 Wet Weather Sampling Sites in the Tookany/Tacony-Frankford Watershed, 2004

The automated sampler system obviated the need for BLS team members to manually collect samples, thereby greatly increasing sampling efficiency. Automated samplers were equipped with vented instream pressure transducers that allowed sampling to commence beginning with a small (0.1ft.) increase in stage. Once sampling was initiated, a computer-controlled peristaltic pump and distribution system collected the first 4 grab samples at 20 minute intervals and the remaining samples at 1.5 hr. intervals.

Use of automated samplers allows for a greater range of flexibility in sampling programs, including flow-weighted composite sampling based on a user defined rating curve, but stage discharge rating curves at these sites were poorly defined for larger flows. Though some difficulties were encountered due to a combination of mechanical failure, individual site characteristics, and/or vandalism, the 20 minute and 1.5 hour intervals were found to be generally satisfactory in collecting representative samples over the course of a storm event.

3.9.3 Continuous Water Quality Monitoring

Physicochemical properties of surface waters are known to change over a variety of temporal scales, with broad implications for aquatic life. Several important, state-regulated parameters (*e.g.*, dissolved oxygen, temperature, and pH) may change considerably over a short time interval, and therefore cannot be measured reliably or efficiently with grab samples. Self-contained data logging continuous water quality monitoring Sondes (YSI Inc. Models 6600, 600XLM) were deployed between 3/20/2001 and 10/5/2004 at seven (n=7) sites within Tookany/Tacony-Frankford Watershed in order to collect DO, pH, temperature, conductivity and depth data (Figure 3-13). Samples from sites TF620 and TF680 were combined for analysis and considered TF620. Sondes continuously monitored conditions and discretized the data in 15 min increments.

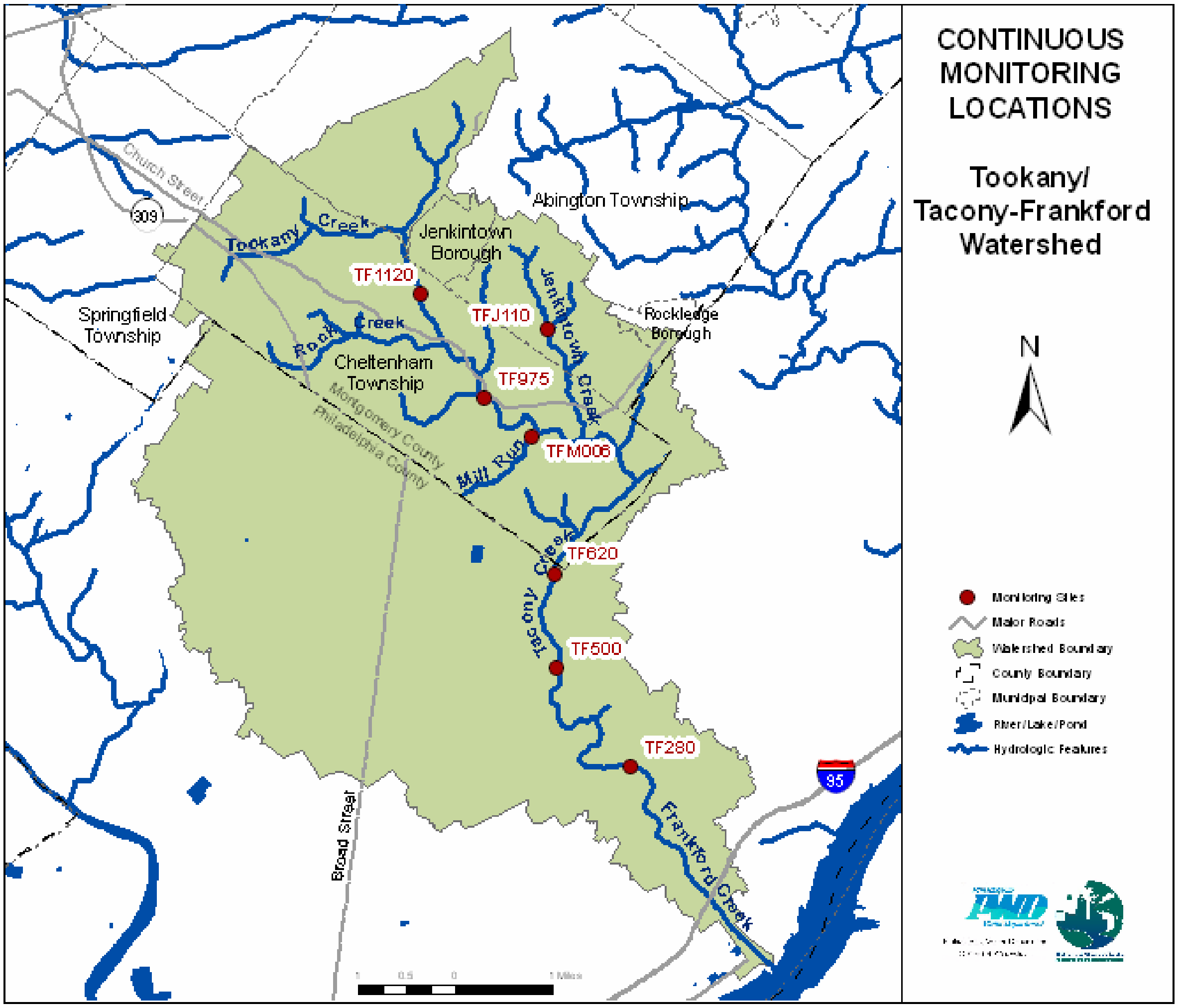


Figure 3-13 Continuous Water Quality Monitoring Sites in Tookany/Tacony-Frankford Watershed, 2004

Extended deployments of continuous water quality monitoring instruments in urban streams present challenges: drastic increases in stream flow and velocity, probe fouling due to accumulation of debris and algae, manpower required for field deployment and maintenance, and the need to guard against theft or vandalism. With refinements to Sonde enclosures and increased attention to cleaning and maintenance, PWD's Bureau of Laboratory Services has made wide-reaching improvements in the quality and recoverability of continuous water quality data, particularly dissolved oxygen (DO) data. Despite improvements, some DO data was rejected (Table 3-14) (See Appendix B). All pH and Temperature data was acceptable.

Table 3-14 Total Sonde hours and rejected DO data.

	2001			
Site	**Total Hours Sonde Deployment**	**Rejected DO Data (hours)**	**Accepted DO Data (hours)**	**Percent DO Data Accepted**
7th and Cheltenham	286.0	286.0		0.0
TF1120	978.3	560.0	418.3	42.8
TF280	432.5	347.5	85.0	19.7
TF500	307.5	230.3	77.3	25.1
TF620	307.3	229.8	77.5	25.2
TF760	979.3	897.0	82.3	8.4
TF975				
TFJ110				
TFM006				

	2002			
Site	**Total Hours Sonde Deployment**	**Rejected DO Data (hours)**	**Accepted DO Data (hours)**	**Percent DO Data Accepted**
7th and Cheltenham				
TF1120	808.0	398.0	410.0	50.7
TF280	404.3	228.3	176.0	43.5
TF500	750.8	252.0	498.8	66.4
TF620	1308.0	666.0	642.0	49.1
TF760	720.5	84.5	636.0	88.3
TF975	806.8	311.8	495.0	61.4
TFJ110				
TFM006				

	2003			
Site	**Total Hours Sonde Deployment**	**Rejected DO Data (hours)**	**Accepted DO Data (hours)**	**Percent DO Data Accepted**
7th and Cheltenham				
TF1120	3015.5	184.5	2831.0	93.9
TF280	4791.3	1620.3	3171.0	66.2
TF500				
TF620	3535.0	185.8	3349.3	94.7
TF760				
TF975	3284.3	384.3	2900.0	88.3
TFJ110				
TFM006				

	2004			
Site	**Total Hours Sonde Deployment**	**Rejected DO Data (hours)**	**Accepted DO Data (hours)**	**Percent DO Data Accepted**
7th and Cheltenham				
TF1120	1962.8	409.7	1553.0	79.1
TF280	5545.3	2344.0	3201.2	57.7
TF500	2278.0	759.5	1518.5	66.7
TF620	4815.5	408.5	4407.0	91.5
TF760				
TF975	2203.5	499.0	1704.5	77.4
TFJ110	2592.0	359.3	2232.8	86.1
TFM006	2541.8		2541.8	100.0

3.9.4 RADAR Rainfall Data and Analysis

Because storm events are inherently variable and do not evenly distribute rainfall spatially or temporally, PWD contracted with Vieux and Associates to obtain discretized measurements of rainfall intensity during storm events targeted by wet weather sampling. For each 15 minute interval, RADAR tower-mounted equipment measured high frequency radio wave reflection in the atmosphere above Tookany/Tacony-Frankford watershed. This information was provided to PWD as a series of relative reflectivity measurements for individual 1km^2 blocks. The resulting grid allowed for the summing of relative rainfall intensity within the sub-shed served by each sampling site over the course of each individual storm event (Figure 3-14). Individual intensity measurements were also graphed and arranged sequentially to produce animated time-series rainfall accumulation graphics. This analysis, combined with data from the PWD rain gauge network and stream stage measurements logged by the automated sampler, allowed for more thorough analysis of water quality data, particularly in determining whether some areas or sub-sheds may have contributed more runoff than others.

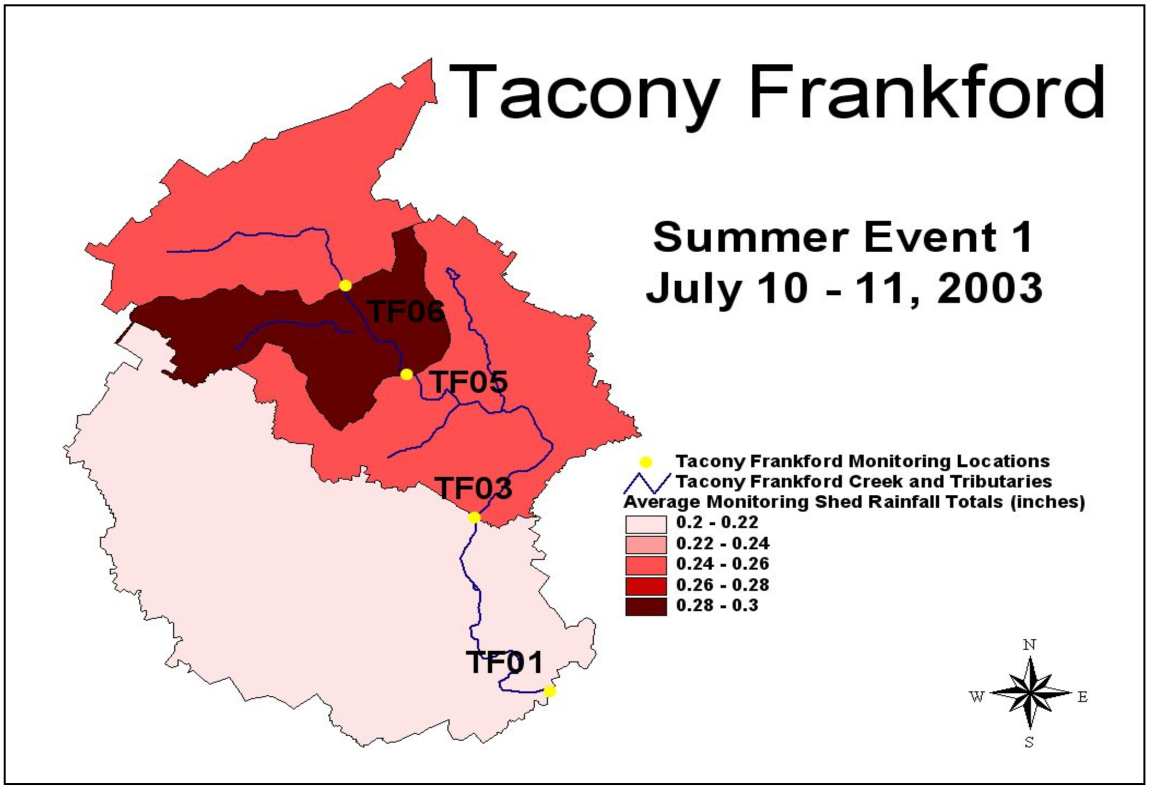


Figure 3-14 RADAR Rainfall Totals by Subshed (7/10/03-7/11/03)

3.10 Fluvial Geomorphological (FGM) Analysis

Between December 2003 and March 2004, Philadelphia Water Department staff conducted FGM analysis on the Tookany/Tacony-Frankford Creek and its tributaries. Analysis was conducted in order to characterize channel morphology, disturbance, stability, and habitat parameters as well as to provide a template for hydrologic and hydraulic modeling and serve as a baseline for assessing channel bank and bed changes.

3.10.1 Watershed Characterization

Philadelphia Water Department staff collected existing information from key stakeholders including existing maps, GIS layers, aerial photographs, studies, and documents. Topographic information, geological maps, soils maps, and aerial photographs were reviewed to identify key features along the stream corridor that may not be apparent in the field. Regional curve data developed for the Northeast was used to determine ranges of hydraulic geometry relationships based on the bankfull discharge. This information was used strictly for field calibration purposes and comparison to actual observations.

3.10.2 Stream Survey

Philadelphia Water Department staff cruised 30 miles of streams within the study area. Cruising consisted of a team of environmental engineers and biologists walking the entire length of Tookany/Tacony-Frankford Creek and its tributaries and characterizing channel morphology, disturbance, stability, and habitat parameters. Philadelphia Water Department staff also performed a qualitative habitat assessment using customized parameters from the *Rapid Steam Assessment Technique* (RSAT, Washington Metropolitan council of Governments) and the *Qualitative Habitat Evaluation Index* (Ohio). Data was recorded on a *Measured Reach Stream Morphology, Channel Stability, and Habitat Evaluation Field Form*. Digital photographs were taken at strategic points throughout the cruised reaches and coded for reference. Base maps were used to mark stream classification boundaries, channel stability zones, and habitat features.

A *Cruised Reach Field Form* and a *Watershed Data Summary Spreadsheet* was completed for each reach. Data from the field forms was entered into a *Watershed Data Summary Spreadsheet.* The spreadsheet was programmed to generate qualitative ratings on bank and bed erosion conditions, shear stresses, channel stability and habitat value.

3.10.3 Stream Cross Sections

Philadelphia Water Department staff surveyed cross sections of Tookany/Tacony-Frankford Creek to characterize the morphological features of the channel, provide a template for hydrologic and hydraulic modeling, and serve as a baseline for assessing channel bank and bed changes (erosion and sediment accretion). Approximately 4 cross sections were surveyed per mile (102 cross sections). Each cross section extended a minimum of 25′ beyond the top of bank on both sides of the stream. Features surveyed included breaks in slope, bankfull stage, water surface and thalweg. A permanent monument (5/8″ reinforcing bar with a color cap) was established on one side of the cross section to mark the location and relative elevation. The approximate location of each cross section was also coded and mapped. Three digital photographs of each cross section were taken (upstream, downstream, and across the stream) to photo-document existing conditions.

Using the elevations established, cross section data was entered into an excel spreadsheet to provide an illustration of the cross section along with defining certain morphological characteristics.

3.10.4 Bank Pins and Scour Chains

Bank pins and scour chains have not been installed in Tookany/Tacony Creek; however they may be installed in the future. Bank pins and scour chains will provide PWD the opportunity to measure stream bank erosion rates and observe streambed degradation/aggradation.

3.10.5 Guiding Principles for Fluvial Geomorphologic Restoration of Tacony Creek

3.10.5.1 Identification Ranking and Analysis of Stream Impacts

A Geographic Information System (GIS) map and associated relational database for the information collected in the field was created. This system was used to assess the geographic distribution of impacted and vulnerable areas. Stream impacts were ranked on a comparative subwatershed basis as to their impacts and relative magnitude of contribution to overall water quality deterioration in the entire watershed. Impacts were ranked by both type of problem and by subwatershed. Rankings are shown in Tables 3-15 and 3-16.

Table 3-15 Ranking for Stability Parameters

Outfall Area (ft^2)	Ranking Value
0	0
0.1 to 5.0	1
5.1 to 10.0	2
10.1 to 15.0	4
15.1 to 20.0	6
20.1 to 30.0	10
30.1 to 40.0	12
40.1 to 50.0	14
50.1 to 60.0	16
60.1 to 80.0	18
80.1 to 100.0	20
100.1 to 120.0	21
120.1 to 140.0	22
140.1 to 160.0	23
160.1 to 180.0	24
>180.1	25

Culverts (% Culverted)	Ranking Value
0	0
0.1 - 5.0	3
5.1 to 10.0	6
10.1 to 15.0	9
15.1 to 20.0	12
21.0 to 40.0	15
40.1 to 60.0	18
>60	20

Channels (% Channelized)	Ranking Value
0	0
0.1 - 5.0	2
5.1 to 10.0	4
10.1 to 15.0	6
15.1 to 20.0	8
21.0 to 40.0	10
40.1 to 60.0	12
>60	15

Infrastructure Pts	Ranking Value
0	0
1 to 5	1
6 to 10	2
11 to 15	3
16 to 20	4
>20	5

Shear Stress	Possible Size Range of Material Moved	Ranking Value
<0.01	0.1-2	1
<0.02	0.2-5	2
<0.2	1-10	3
<1	10-50	3
<2	20-500	7
<10	50-1000	10

Channel Type	Ranking Value
C	0
E	0
B	2
G	3
F	5
D	5

Reach Bed Stability	Ranking Value
Aggrading	4
Degrading	5
Indeterminate	3
Stable	0

Bank Erosion	Value	Ranking Value
Low	10-19.5	1
Moderate	20-29.5	3
High	30-39.5	5

Entrenchment Ratio	Value	Ranking Value
Entrenched	1-1.4	5
Moderately Entrenched	1.41-2.2	3
Slightly Entrenched	>2.2	1

Bed Materials	D50 (mm)	Stability Ranking Value
Silt and Clay	2<	5
Sand	<2 through 12	5
Gravel	12 through 96	3
Cobble	96 through 512	2
Boulder	512 through 4096	1
Bedrock	> 4096	0

Table 3-16 Ranking for Habitat Parameters

Riparian Width	Ranking Value DSL	Ranking Value DSR
<10	5	5
10-25'	3	3
25-100	1	1
>100	0	0

Riparian Composition	Ranking Value DSL	Ranking Value DSR
Paved/Bare Ground	5	5
Yards/Lawn/Pasture	4	4
Vines/Herbaceous/Shrubs	3	3
Modified/Mixed/Broken Forest	1	1
Natural Forest (Multi-Tiered)	0	0

Canopy Cover	Ranking Value DSL	Ranking Value DSR
0-20	5	5
21-40%	4	4
41-60%	3	3
61-80%	1	1
81-100%	0	0

Bed Materials	D50 (mm)	Ranking Value
Silt and Clay	<2	5
Sand	<2 through 12	4
Gravel	12 through 96	2
Cobble	96 through 512	0
Boulder	512 through 4096	1
Bedrock	> 4096	5

Sediment Supply	Ranking Value
Low	1
Moderate	3
High	5

Sinuosity	Ratio	Ranking Value
Low	1-1.2	5
Moderate	1.2-1.4	3
High	>1.4	0

Woody Debris	Ranking Value
Absent	5
Few	3
Moderate	1
Frequent	0

Attachment Sites	Ranking Value
<25% Exposed	0
25-75% Exposed	3
>75% Exposed	5

Section 4
Characterization of Watershed Hydrology

This section examines the components of the hydrologic cycle for the Tookany/Tacony-Frankford Watershed. The hydrologic cycle includes precipitation, evaporation, infiltration into soil, stormwater runoff over the land surface and in the sewer system, surface water flow in streams, and groundwater. The different types of sewer systems that serve the area are discussed in this section because they are an important part of the hydrologic cycle in the urban environment.

4.1 Components of the Urban Hydrologic Cycle

One way to develop an understanding of the hydrologic cycle is to develop a water balance. The balance is an attempt to characterize the flow of water into and out of the system by assigning estimated rates of flow for all of the components of the cycle. It is also important to understand that the natural water cycle components including precipitation, evapotranspiration (ET), infiltration, stream baseflow, and stormwater runoff must be supplemented by the many artificial interventions related to urban water, wastewater, and stormwater systems.

The first step in developing a water balance for the urban hydrologic cycle is to identify the system boundaries and the pathways that allow water to cross those boundaries. For the Tookany/Tacony-Frankford Watershed, the system includes: the land surface within the watershed boundaries, structures and vegetation on the surface, and the subsurface beneath the watershed. Inputs to the system are precipitation and outside sources of potable water. Outflows from the system include streamflow through the system outlet, evaporation and transpiration losses to the atmosphere, and flows of wastewater to the system outlet. In addition, it is possible for subsurface exchanges to occur across the boundary.

Precipitation that falls on the land surface may evaporate, be taken up by plants and be lost through transpiration, or flow directly to a water body over land or through a storm sewer system. Flow in streams consists of stormwater runoff, combined sewer overflow, delayed wet weather inputs through shallow groundwater, and a baseflow component due to the discharge of groundwater to the creek during dry weather and wet weather. A portion of potable water pumped in from outside the watershed enters the sanitary sewer system and is sent to outside treatment plants, and a portion is lost to consumptive uses.

The system inflows and outflows can be split into a number of components. These are shown below as a simple, "input equals output" water balance with the many natural and anthropogenic components of a typical urban water cycle.

Inflows: ***P + OPW + WW/IND Rech + EDR + WW Disch***

Outflows: ***RO + SWW + GWW + EDW + BF + OWD + ET***

where:

P is the average precipitation at the Philadelphia gage,

OPW is the outside potable water brought in,

WW/IND Rech is the wastewater and industrial discharge back to groundwater,

EDR is the estimated domestic recharge from private septic systems,

WW Disch is the discharge of water to creeks from larger wastewater plants or industrial facilities,

RO is the surface water runoff component of precipitation,

SWW is the withdrawal of water from the creek, primarily for public water supply and industrial use,

GWW is the groundwater withdrawal from public water supply or industrial wells,

EDW is the estimated domestic withdrawal of groundwater from private wells,

BF is the median baseflow of streams,

OWD is the discharge of wastewater to outside plant, and

ET is the evaporation and transpiration of water and is used to close the equation. It thus contains the sum of errors of the other terms as well as the estimated ET value.

4.1.1 Precipitation

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation is the primary, natural inflow to the hydrologic system. Precipitation data used to estimate this component are available from the National Oceanography and Atmospheric Administration (NOAA) and from local gauges operated by PWD and other organizations. NOAA's gauge at the Philadelphia International Airport, located in southeastern Philadelphia, has over 100 years of hourly precipitation data covering a period of record from January 3, 1902 through the present. The average annual rainfall in the Philadelphia area based upon the airport gauge is 41 inches. Most months have average precipitation totals of 3-4 inches. The driest season is late fall, and the wettest is late summer when thunderstorms are common (Table 4-1). Average temperatures during the winter months are above the freezing point during the day and below the freezing point at night. Snow and snowmelt events occur, but it is rare for a snow pack to accumulate and last through the season.

Additional precipitation data can be obtained from PWD's network of 24 rain gauges throughout the city; these data are available in 15-minute increments from the early 1990s to the present. Nine of the city gauges are located in or near the Tookany/Tacony-Frankford Watershed, as shown in Section 3, Figure 3-1. Data from these gauges provide precipitation at a higher level of spatial and temporal detail.

Table 4-1 Average Monthly Precipitation, Temperature, and Potential Evaporation

Month	Average Precipitation (in)	Average Temperature High (°F)	Average Temperature Low (°F)	Potential Evaporation (in/month)
January	3.3	39.2	24.4	2.1*
February	2.9	42.1	26.1	2.1*
March	3.6	50.9	33.1	2.1
April	3.4	63	42.6	4.5
May	3.5	73.2	52.9	5.4
June	3.6	81.9	61.7	6.3
July	4.1	86.4	67.5	6.6
August	4.3	84.6	66.2	5.7
September	3.4	77.4	58.6	4.2
October	2.8	66.6	46.9	2.7
November	3.0	55	37.6	2.1
December	3.3	43.5	28.6	2.1*

** estimated*

4.1.2 Outside Potable Water

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The watershed is generally supplied with drinking water from sources of water outside the watershed. For the Philadelphia portion of the watershed, water is imported into the watershed through the drinking water distribution system from raw water drawn from the Schuylkill and Delaware Rivers. For the outside communities, most of the water is supplied by Aqua America (formerly Philadelphia Suburban Water Company).

For the Tookany/Tacony-Frankford Watershed, most of this water never leaves the urban infrastructure used to transmit drinking water to and convey wastewater from homes to wastewater treatment plants outside the watershed. In this sense, this component of the watershed water balance is not critical to watershed planning activities.

4.1.3 Wastewater and Industrial Recharge to Groundwater

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back to the groundwater, thus making it an "inflow" component. Available data suggest that there are no such discharges within the watershed. For this reason, this component is not included in the table of estimated flows for components of the hydrologic cycle.

4.1.4 Estimated Domestic Recharge

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes and is subsequently discharged to septic systems. In this way, it represents an inflow component to the groundwater portion of the hydrologic cycle. Although the number of septic tanks within the watershed is hard to accurately quantify; the 1990 census data indicated that about 1075 septic tanks were present in the watershed, 706 of which are within the city of Philadelphia. This number is believed to be a high estimate of the actual number.

Based on this information and an estimate of 50 gallons of sewage per person per day discharged to septic systems, this component represents potential 53,750 gallons per day in the Tookany/Tacony-Frankford Watershed. These flows may also be expressed as approximately 0.03 inches per year for the Tookany/Tacony-Frankford Watershed.

4.1.5 Wastewater Discharges to the Stream

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This component represents water that has been used in homes or industry, has been treated, and is subsequently discharged back into the stream, thus making it an "inflow" component. There are believed to be three active industrial point source dischargers and five sites with industrial stormwater permits in the Tookany/Tacony-Frankford Watershed (see Table 9-4). The permit for one facility, Biello Auto Parts Inc., that was once listed as active has expired. This component is assumed to be negligible in comparison to the main inflow components and is not included in the table of estimated flows for components of the hydrologic cycle.

4.1.6 Runoff

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation is the primary natural inflow component of the water cycle. This inflow component generally results in three natural outflow components: evapotranspiration (ET), runoff, and infiltration into the groundwater. Thus runoff is one of the major, natural outflow components to be estimated.

The amount of stormwater runoff depends on a variety of factors, including rainfall intensity, surface ponding of rain, ground slope, and, most importantly, the imperviousness of the ground surface. The amount of impervious cover follows patterns of land use and population density because manmade structures and pavement are the cause of impervious surface. Estimates of imperviousness can be further refined by examining the relative proportion of impervious surfaces on the USGS quadrangles and in aerial photos. Because of the urbanized nature of the watershed, runoff is almost always collected into a sewer system. Depending on the location within the watershed, it can either be discharged through storm sewers or through combined sewers. Therefore, this component is further discussed under the Runoff/Outside Wastewater Discharge component below.

4.1.7 Surface Water Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This outflow component represents intakes for water withdrawal for drinking water or industrial use. For the Tookany/Tacony-Frankford Watershed, no permitted withdrawals exist, and this component can be left out of the water balance table.

4.1.8 Groundwater Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

This outflow component represents groundwater pumping for industrial use or public water supply. There are no public supply or industrial wells of significance in the watershed, and this component can be left out of the water balance table.

4.1.9 Estimated Domestic Withdrawals

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

The entire watershed is served by a public water supply distribution system. There are no areas where domestic wells form a significant source of supply, and groundwater pumping can be ignored as a significant component of the water balance.

4.1.10 Baseflow

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Precipitation results in three natural outflow components: evapotranspiration (ET), runoff, and infiltration into the groundwater. In most shallow groundwater systems, the surface watershed generally corresponds to the recharge and discharge area of the groundwater system. This means that infiltration enters the groundwater aquifer, and flows underground to the stream for eventual discharge as stream baseflow. This allows us to equate infiltration with stream baseflow, making it possible to estimate infiltration through baseflow separation techniques at stream gauges.

In pervious areas, the amount of water that infiltrates the soil, and thus reappears as stream baseflow, depends on soil properties. At the beginning of a storm, when soil pores are usually not saturated, the moisture content of the soil determines the amount of infiltration that can occur. Capillary suction forces caused by surface tension in the pores also affect the infiltration rate. The size, shape, and distribution of soil pores determine the rate at which a soil can transmit flow in both the unsaturated and saturated states. The infiltration rate decreases as soil pores become filled with water during the course of the storm. When the pores become completely saturated, the water transmission rate reaches equilibrium. Sandy soils allow the highest infiltration rates, while soils with high clay content allow very slow infiltration; loams and mixtures of different soil types fall between the two extremes. Table 4-2 lists typical values for saturated hydraulic conductivity, capillary suction, and initial moisture deficit for a range of NRCS soil textures (Handbook of Hydrology, D.R. Maidment, Editor in Chief, McGraw-Hill, Inc., 1993, pp 5.1-5.39.) Soil textures found in the watershed were discussed in Section 1. It is important to remember that in urbanized areas, the original soils have often been disturbed, compacted, or replaced by fill material that may have different hydraulic characteristics from the undisturbed state.

Table 4-2 Typical Hydraulic Properties of Different NRCS Soil Textures

	Saturated Hydraulic Conductivity (in/hr)	Capillary Suction (in)	Initial Moisture Deficit (fraction)
Sand	9.3	2.0	0.35
Loamy Sand	2.4	2.4	0.31
Sandy Loam	0.86	4.3	0.25
Loam	0.52	3.5	0.19
Silt Loam	0.27	6.6	0.17
Sandy Clay Loam	0.12	8.6	0.14
Clay Loam	0.08	8.2	0.15
Silty Clay Loam	0.08	10.8	0.11
Sandy Clay	0.05	9.4	0.091
Silty Clay	0.04	11.5	0.092
Clay	0.02	12.5	0.079

The simplest way to compute infiltration, which is generally difficult to measure and/or model, is to perform baseflow separation on streamflow. In this way, if baseflow is assumed to equal infiltration, then the infiltration component can be directly balanced by the baseflow component. For the Tookany/Tacony Frankford Watershed, this approach results in an annual infiltration/baseflow component ranging from 7.1 to 14.0 inches per year, depending on the gage location within the watershed. Downstream locations on Frankford Creek (1467087 and 1467089) are the most urbanized, and have the lowest baseflow relative to drainage area. Smaller tributaries (Rock Creek, 1467084) are the least impaired and have higher baseflow relative to drainage area. Upstream areas of Tacony Creek (1467086) and Tookany Creek (1467083), as well as Jenkintown Creek (1467085) also have relatively high baseflow relative to drainage area.

4.1.11 Runoff and Outside Wastewater Discharges

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Almost the entire watershed is served by sewers. Depending on the area of the watershed, stormwater may enter surface water directly, enter a combined sewer, or enter a separate storm sewer system. Unsewered areas, where runoff flows overland to the stream system, make up approximately 9% of the Tookany/Tacony-Frankford Watershed. These areas are mainly natural areas located along the stream corridor, such as Tacony Creek Park, where storm sewers are not necessary.

Sewered areas within the watershed are served by two types of sewer systems. In areas served by combined sanitary and storm sewers, the sewer system conveys flows to an interceptor sewer and later to a wastewater treatment plant under dry weather conditions. During larger wet weather events, a combined flow regulator structure diverts a portion of the flow to a receiving stream. 47% of the Tookany/Tacony-Frankford Watershed is serviced by combined sewers, all of which is within Philadelphia County. The City of Philadelphia has 31 regulator structures within the watershed, as shown in Figure 4-1. 25 of these structures are instrumented with continuous flow monitors.

Except for park lands, the rest of the watershed area is serviced by separate sanitary and storm sewer systems. In these areas, the storm sewer system conveys most surface runoff directly to a receiving stream. A portion of stormwater, known as infiltration and inflow, enters the sanitary sewer system during wet weather. The occurrence of CSO and the categorization of sampling periods as wet or dry are discussed later in section 4.3.2.

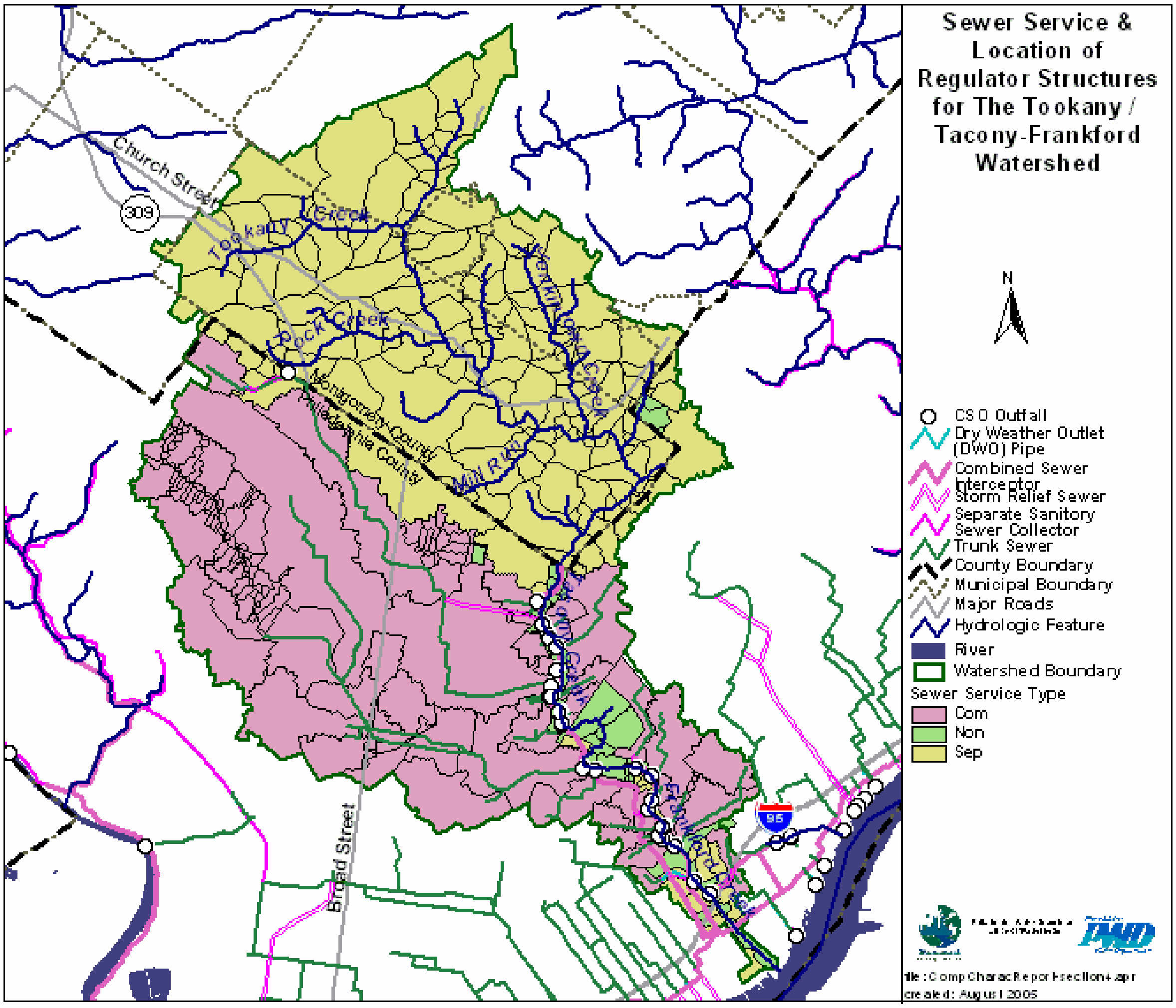


Figure 4-1 Types of Sewer Service and Locations of Regulator Structures

4.1.11 Hydrologic and Hydraulic Modeling

Estimates of the volume, frequency, and duration of combined sewer overflows are based on results from calibrated hydrologic and hydraulic models. Model calibration depends on data from PWD's extensive rainfall gauge network and sewer monitoring program.

The hydraulic and hydrologic model development process focused the greatest detail on the interceptor sewer system, using the USEPA Storm Water Management Model (SWMM)

Extended Transport (EXTRAN) module. The EXTRAN module of SWMM was chosen as the most appropriate tool for the interceptor model. This model is the most widely used and accepted model for interceptor and CSO modeling (Roesner *et al*., 1988). It accurately simulates complex hydraulic conditions that occur in combined sewer interceptors, including unsteady flow, surcharging, branched and looped pipe networks, pumps, orifices, and weirs.

Modeling took place in two tiers or levels of detail. To estimate the treatment rates of the combined sewer regulator structures, or the maximum flow that can pass through the regulator's connector pipe to the interceptor in wet weather, the Tier I sewershed hydrologic representation is in the form of ramp-function hydrographs loaded directly to EXTRAN. Later in the process, the combined sewersheds are modeled in the United States Army Corps of Engineers (USACOE) Storage, Treatment, Overflow, Runoff Model (STORM), providing a more detailed characterization of the hydrologic response of the system with an algorithm for the computation of rainfall excess. STORM thereby provides a wet weather characterization that is useful for assessment of impacts and for planning-level alternatives screening used to establish the direction for detailed facility planning and design.

At the Tier I level, STORM is run in continuous simulation mode using a long-term rainfall record. There is general agreement in the modeling community that single event or design storm simulations are not sufficient for the generation of long-term CSO statistics, including average annual frequency and volume (EPA, 1993). Continuous simulation more thoroughly accounts for antecedent conditions and inter-event conditions within the system. At the Tier II level, sewersheds, interceptors, and regulator structures all are represented in SWMM to support detailed facilities planning and design.

Discharge Monitoring Report and Annual Report Generation

The EXTRAN model is used for the hydraulic characterization of interceptors and regulators to a fine level of detail. The model supports estimates of sewer system overflow characteristics using STORM. This characterization of the combined sewersheds and trunk sewer system is at the correct level of detail for the hydrologic and hydraulic characterization requirements of NPDES permits for CSO and sanitary sewer facilities and for the alternatives analyses required for long term CSO control planning.

Quarterly discharge monitoring reports (DMR's) are required under the NPDES permit system. In addition, the results of the SWMM/NetSTORM model are used to prepare the CSO Annual Report required under Philadelphia's LTCP and Chapter 94 of the Pennsylvania Code. This report details progress on the three phases of the LTCP: implementation of the Nine Minimum Controls, construction of capital projects, and watershed-based planning. The report also summarizes CSO volume, frequency, and capture statistics for the year.

Annual CSO Frequency and Volume Stats

Table 4-3 lists estimated capture percentages for regulator structures in the Tookany/Tacony-Frankford Watershed, based on the modeling results listed in the CSO

Annual Reports. A capture percentage is defined as the percentage of combined sewage (mixed sanitary sewage and stormwater) that is "captured" and sent to a treatment plant during rainfall events over the course of a year. 85% capture is considered to be an ultimate goal for many communities as they implement CSO long term control plans. Based on Table 4-3, capture percentages are generally in the range 40-60% for the Tacony Creek High Level sewer system and 60-80% for the Upper Frankford Creek Low Level sewer system. It is important to note that percent capture for a given year is strongly dependent on the frequency and magnitude of rainfall events during that year. The five years of data listed in Table 4-3 are not sufficient to determine whether an increasing or decreasing trend has taken place. However, as the amount of data increases throughout implementation of the Long Term Control Plan, it will ultimately be possible to evaluate the effectiveness of the control measures.

Table 4-3 Estimated Annual Combined Sewage Capture Percentages

Year	Precipitation (in)	Capture (%) – Lowest and Highest Structure	
		Tacony	Upper Frankford Low Level
2003	46.72	43 - 45	64 - 65
2002	34.11	59 - 64	76 - 79
2001	30.62	51 - 53	70 - 72
2000	43.26	40 - 42	58 - 60
1999	48.6	39 - 40	57 - 59

4.1.12 EvapoTranspiration

P + OPW + WW/IND Rech + EDR + WW Disch = RO + SWW+ GWW + EDW + BF + OWD + ET

Once precipitation reaches the earth's surface, it may take a variety of paths. Typically, a portion enters soil pores through infiltration, a portion returns to the atmosphere through evaporation, and a portion runs off over the land surface (or often into a sewer in urbanized areas). A portion may also be stored temporarily in puddles, in plant parts, through freezing, or in manmade structures designed to detain stormwater; this portion then infiltrates, evaporates, or runs off at a later time.

One of the largest "outflows" of water from the system is evaporation and transpiration. Evapotranspiration includes evaporation, or loss of water to the atmosphere as water vapor, and transpiration, or loss of water to the atmosphere through plants. Evapotranspiration rates depend on temperature, wind speed, solar radiation, type of surface, type and abundance of plant species, and the growing season. Because of these factors, estimated evapotranspiration rates for the Philadelphia region vary seasonally. Neither the Philadelphia Airport nor the Wilmington Airport records evaporation data. One site in New Castle County, Delaware was located which has recorded daily evaporation data from 1956 through 1994. Average daily evaporation rates from this site were developed and are listed in Table 4-4 (City of Philadelphia Combined Sewer Overflow Program: System Hydraulic Characterization).

4.2 Tookany/Tacony-Frankford Watershed Water Cycle Component Tables

The relevant components of the urban water cycle have been estimated for the Tookany/Tacony-Frankford Watershed. Outside Potable Water is assumed to balance Outside Wastewater Discharges, with stormwater and CSOs considered as part of the Runoff component of the water cycle. Table 4-4 shows the results of the analysis, first in inches per year, then in million gallons per day. The inches per year figure simply takes all the flows over an average year, and divides by the area of the watershed. The million gallons per day table takes all the flows over an average year, and divides by 365 days to get an average daily value.

Table 4-4 Water Budget Components

		Inflow		Outflow		
	Period of Record*	P**	EDR	RO	BF	ET+Error
Component (in/yr)	1982 – 2002	42.1	0.085	11.4	7.06	23.7
Component (MGD)	1982 - 2002	66.1	0.134	17.9	11.1	37.3

***Period of Record applies to Runoff and Baseflow.**

****Precipitation uses 100 year rainfall record.**

4.3 Surface Water Characteristics

The above component tables contain values for runoff, ET, and baseflow. These values, however, are complicated by the fact that much of the water is collected in both separate and combined sewers. This section describes, in more detail, the surface water portion of the cycle.

Stormwater runoff ultimately reaches Tookany/Tacony-Frankford Creek and its tributaries through some limited direct surface runoff or through a combined or separate storm sewer. An understanding of the range and frequency of flows, the stage-velocity-discharge relationship, and trends over time is important for a more complete watershed characterization. This information is useful in water quality management, habitat restoration and management, and potable water and flood control applications.

During the USGS/PWD cooperative program in the 1970s, the USGS established streamflow gauging stations at six locations in the Tookany/Tacony-Frankford Watershed. These locations are presented in Section 3, Figure 3-2. Section 3, Table 3-4 contains summary information at each of the gauging stations for their respective periods of record. An historical rating curve is shown in Figure 4-2.

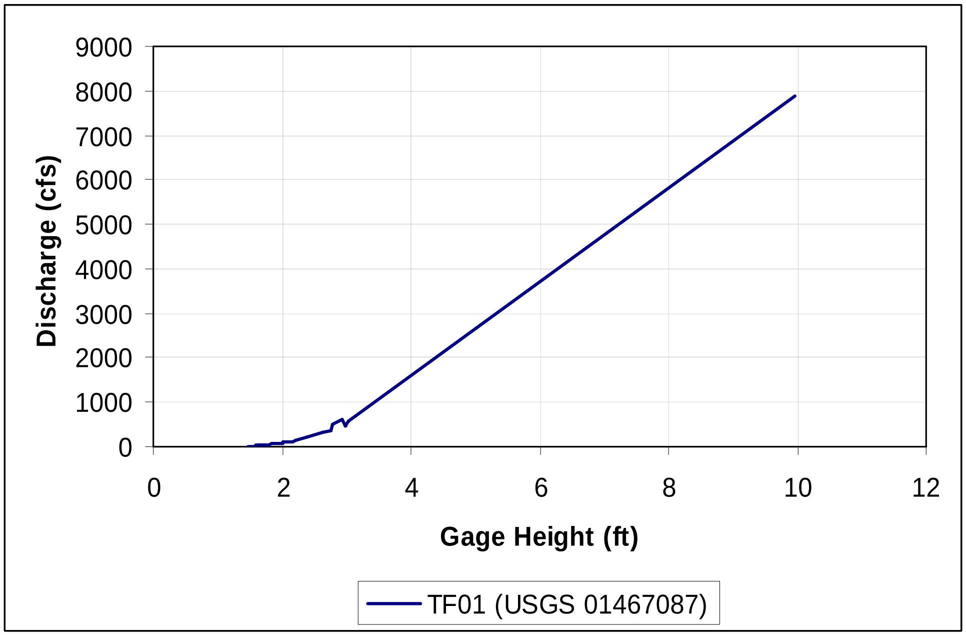


Figure 4-2 Historical Rating Curves for USGS Station 01467087

4.3.1 Evaluation of Total Flow for Trends

Magnitude and Frequency of Flow

Cumulative distribution plots for each of the six gauges listed in Section 3, Table 3-4 are presented in Figure 4-12. A cumulative distribution plot is a plot of discharge versus the percentage of time that a particular flow is not exceeded. These curves are not strictly probability curves because discharge is correlated to successive time intervals and is dependent upon season of the year. However, cumulative distribution plots provide a compact graphical summary of streamflow variability at the different gauging stations.

Trends in Total Flow

Modified Tukey box plots were used to identify seasonal and longer term discharge characteristics for the gauging station at Frankford Creek at Castor Ave. on the Tookany/Tacony-Frankford Creek. Tukey plots display statistical information including median, mean, minimum/maximum values, and selected percentile values as shown in Figure 4-3. Seasonal discharge characteristics are observed for an annual flow cycle using this approach. The discharge plots, discussed above, were used to delineate wet and dry flow regimes. A high flow season earlier in the year and a low flow season occurring later in the year are identified by the peak and trough locations on the plot. Discharges were plotted by weekly time segments, Figures 4-4, monthly in Figure 4-5, annual in, Figures 4-6 and by decade in Figure 4-7. Low flow years in 1985, 1992, and 1999 can be seen on the plots.

Figure 4-7 shows the decade modified Tukey box plots. This plot indicated that although daily flows in the 1980s and 1990s are somewhat lower than flows in the 1970s, the differences are statistically insignificant.

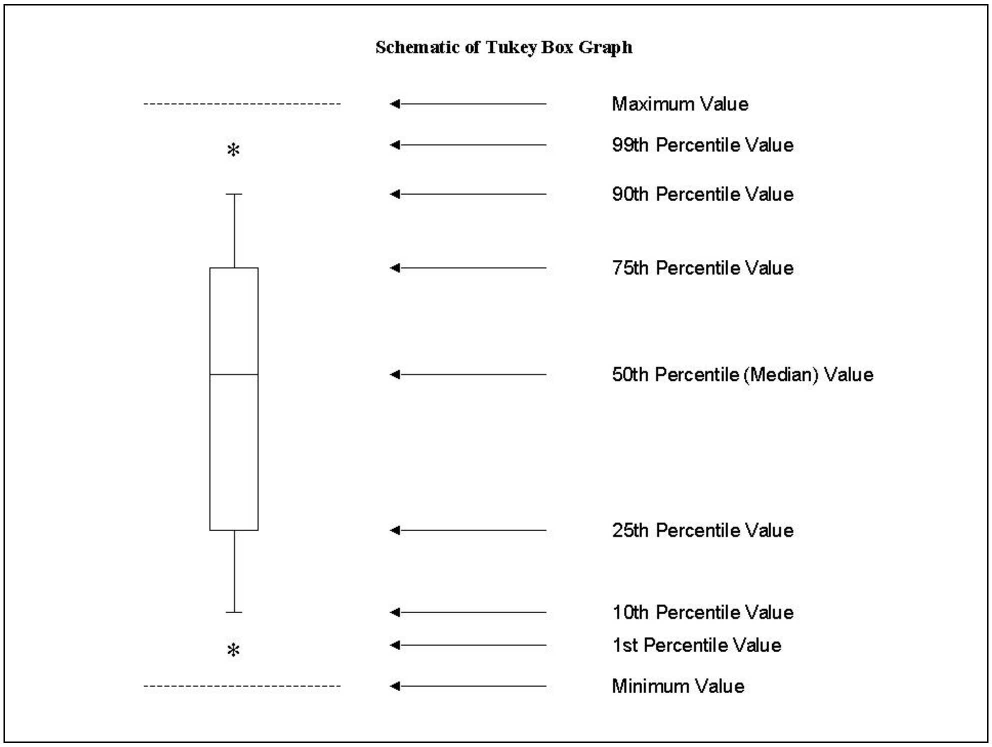


Figure 4-3 Explanation of Modified Tukey Box Plots

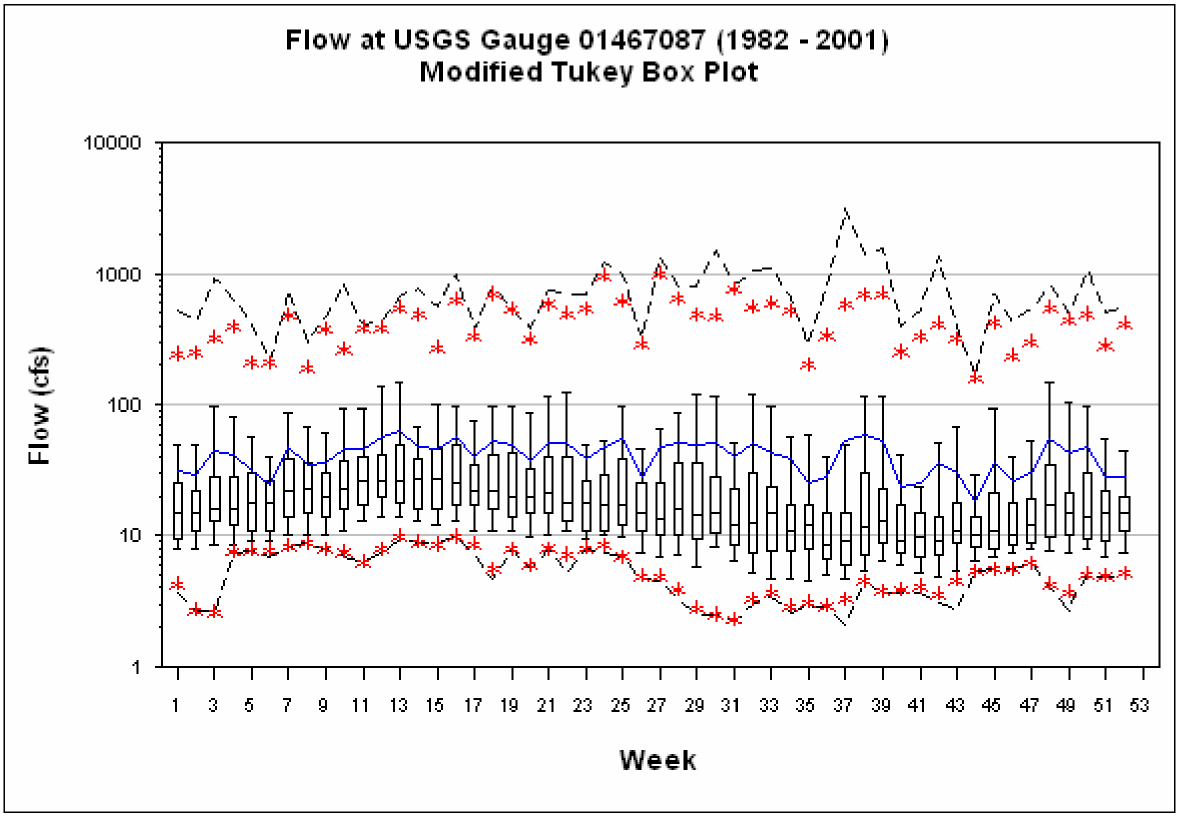


Figure 4-4 Temporal (weekly) trends in flow observed at USGS Gauge 01467087, 1982-2001.

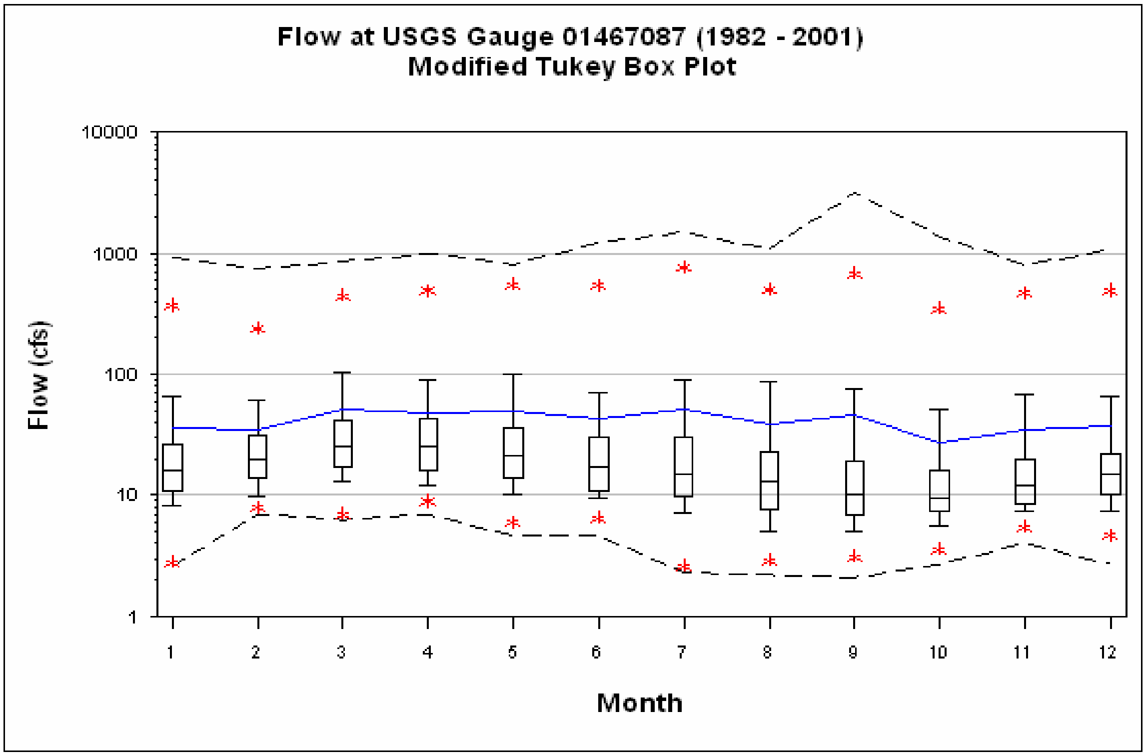


Figure 4-5 Temporal (monthly) trends in flow observed at USGS Gauge 01467087, 1982-2001.

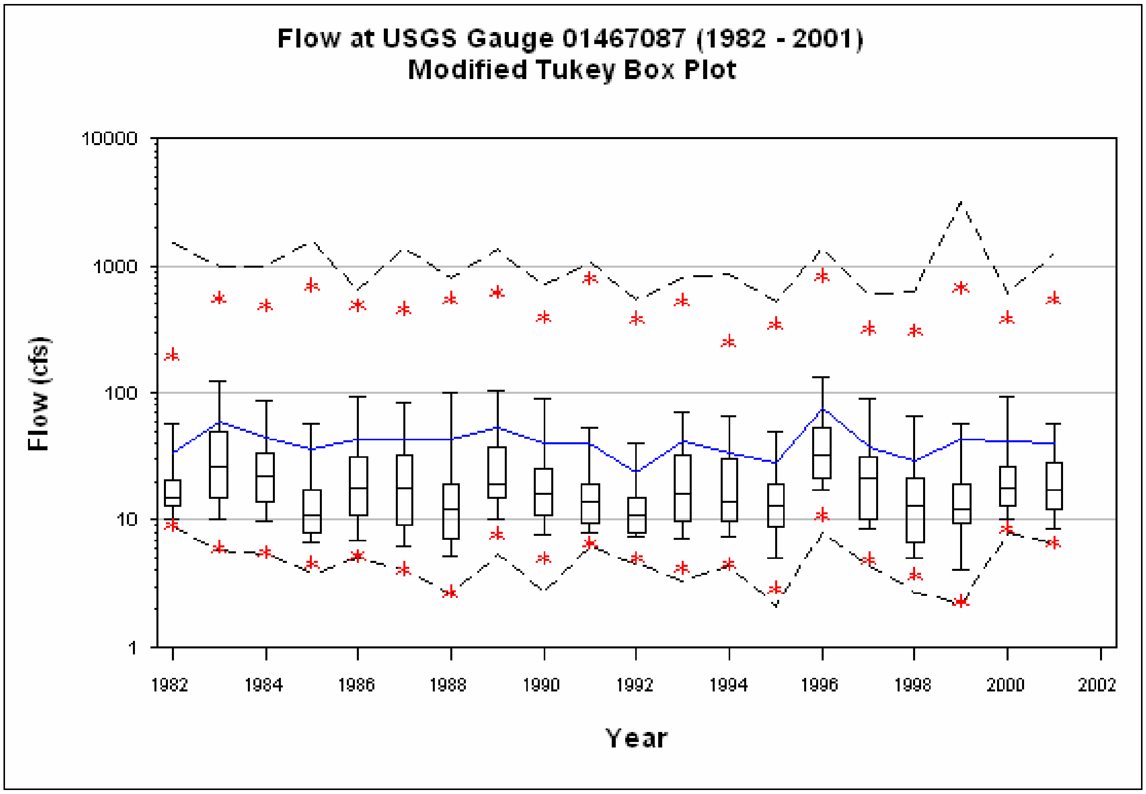


Figure 4-6 Temporal (yearly) trends in flow observed at USGS Gauge 01467087, 1982-2001.

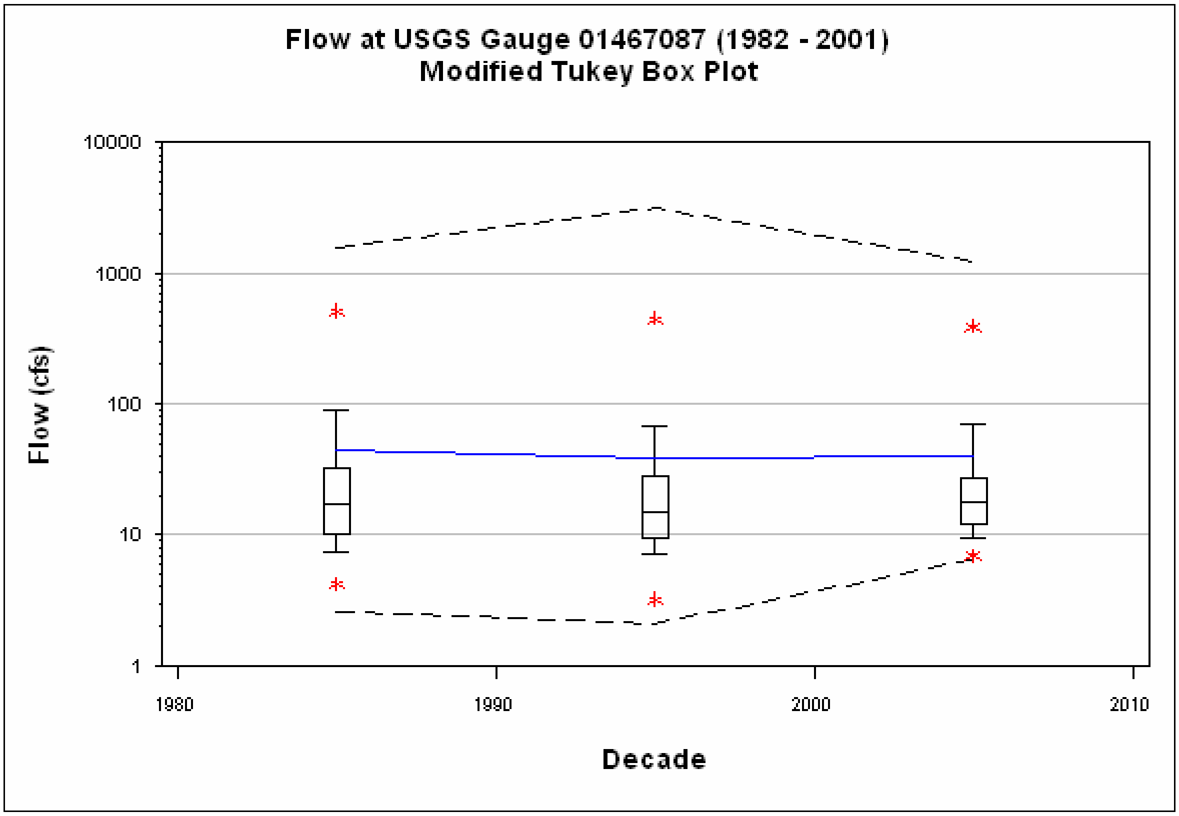


Figure 4-7 Temporal (decadal) trends in flow observed at USGS Gauge 01467087, 1982-2001.

4.3.2 Hydrograph Decomposition Analysis

Areas and Gauges Studied

The Tookany/Tacony-Frankford Watershed is highly urbanized and contains a large proportion of impervious cover. The hydrologic impact of urbanization can be observed through analysis of streamflow data taken from USGS gauges. Table 4-5 lists six gauges with available data, including their locations, periods of record, and drainage areas.

Table 4-5 Data Used for Baseflow Separation

Gauge	Name	Period of Record (yrs)	Drainage Area (sq. mi.)	N (days)	2N* (days)
01467083	Tacony Creek near Jenkintown	6	5.25	1.39	3
01467084	Rock Creek above Curtis Arboretum near Philadelphia	8	1.15	1.03	3
01467085	Jenkintown Creek At Elkins Park	6	1.17	1.03	3
01467086	Tacony Creek at County Line	24	16.6	1.75	3
01467087	Frankford Creek at Castor Ave.	21	30.4	1.98	3
01467089	Frankford Creek at Torresdale Ave.	18	33.8	2.02	5

The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N. N is calculated based on watershed area.

Baseflow Separation

Baseflow due to groundwater inflow is the main component of most streams in dry weather. Baseflow slowly increases and decreases with the elevation of the shallow aquifer water table. In wet weather, a stormwater runoff component is added to the baseflow. Estimation and comparison of these two components can provide insights into the relationship between land use and hydrology in urbanized and more natural systems.

Baseflow separation was carried out following procedures similar to those found in the USGS "HYSEP" program. The following text is taken from "HYSEP: A COMPUTER PROGRAM FOR STREAMFLOW HYDROGRAPH SEPARATION AND ANALYSIS U.S. GEOLOGICAL SURVEY Water-Resources Investigations Report 96-4040":

"Hydrograph analysis is a useful technique in a variety of water-resource investigations. Separation of streamflow hydrographs into base-flow and surface-runoff components is used to estimate the ground-water contribution to streamflow. Hydrograph-separation techniques also have been used to quantify the ground-water component of hydrologic budgets and to aid in the estimation of recharge rates. In addition, base-flow characteristics determined by hydrograph separation of hydrographs from streams draining different geologic terrains have been used to show the effect of geology on base flow (Sloto *et al*, 1991, p. 29-33).

"The HYSEP program uses three methods to separate the base-flow and surface-runoff components of a streamflow hydrograph—fixed interval, sliding interval, and local minimum. These methods can be described conceptually as three different algorithms to systematically draw connecting lines between the low points of the streamflow hydrograph. The sequence of these connecting lines defines the base-flow hydrograph. The techniques were developed by Pettyjohn and Henning (1979). Hydrograph separations were performed for the streamflow-measurement station French Creek near Phoenixville, Pa., using three methods. Each method is described below.

The duration of surface runoff is estimated using the empirically-defined relation:

$$N=A^{0.2}$$

where N is the number of days after which surface runoff ceases, and A is the drainage area in square miles (Linsley et al. 1982).

"The interval 2N* used for hydrograph separations is the odd integer between 3 and 11 nearest to 2N (Pettyjohn & Henning 1979). For example, the drainage area at the streamflow-measurement station French Creek near Phoenixville, Pa. (USGS station number 01472157), is 59.1 mi2. The interval 2N* is equal to 5, which is the nearest odd integer to 2N, where N is equal to 2.26. The N and 2N* values used for the six gauges in this analysis were listed in Table 4-5.

"The hydrograph separation begins one interval (2N* days) prior to the start of the date selected for the start of the separation and ends one interval (2N* days) after the end of the selected date to improve accuracy at the beginning and end of the separation. If the selected beginning and (or) ending date coincides with the start and (or) end of the period of record, then the start of the separation coincides with the start of the period of record, and (or) the end of the separation coincides with the end of the period of record.

"The sliding-interval method finds the lowest discharge in one half the interval minus 1 day [0.5(2N*-1) days] before and after the day being considered and assigns it to that day. The method can be visualized as moving a bar 2N* wide upward until it intersects the hydrograph. The discharge at that point is assigned to the median day in the interval. The bar then slides over to the next day, and the process is repeated."

Summary Statistics

The results of the hydrograph decomposition exercise support the relationships between land use and hydrology discussed above. For convenience, the flows in Table 4-6 are expressed as a mean volume divided by drainage area over a one-year time period. For reference, one inch per year is approximately equal to one cubic foot per second per acre. Table 4-6 shows streamflow statistics for French Creek as representative of a minimally impaired stream, compared to the six gauges of the Tookany/Tacony-Frankford Watershed. The degree of urban impact to baseflow and runoff can be seen in this table. The upstream portions of the watershed still show reasonable levels of baseflow, similar to those of French Creek (in the 12-13 inches per year range). In the downstream segments of Frankford Creek, baseflow is significantly reduced due to the high degree of impervious cover. Looking at baseflow as a percentage of total flow, the same pattern is evident, however, the effects of urbanization in the upstream areas is more evident using this way of measuring, because it accounts for the higher unit area total flow of the Tookany/Tacony-Frankford Watershed compared with French Creek. The table also indicates the elevated runoff due to urbanization (as a percentage of total rainfall). Again, runoff is generally higher in the downstream areas, and lower in the upstream areas.

Table 4-6 Annual Summary Statistics for Baseflow and Stormwater Runoff

	Baseflow (in/yr/unit area)				**Runoff (in/yr/unit area)**			
	Mean	**Max**	**Min**	**St.Dev.**	**Mean**	**Max**	**Min**	**St.Dev.**
French Creek 01475127	12.9	20.8	5.8	3.8	7.4	15.4	2.9	3.1
Frankford Creek 01467089	7.9	11.5	3.5	2.1	14.9	21.3	8.0	4.3
Frankford Creek 01467087	7.1	13.0	4.5	2.2	11.4	20.3	6.2	3.5
Tacony Creek 01467086	12.6	18.1	7.5	3.2	9.2	13.2	5.2	2.3
Jenkintown Creek 01467085	14.0	18.6	9.5	4.0	9.0	12.0	5.1	2.7
Rock Creek 01467084	12.6	17.0	9.4	3.0	14.9	20.5	10.2	3.6
Tacony Creek 01467083	13.5	18.0	10.8	2.9	10.3	13.6	6.7	2.6

	Baseflow (% of Annual Rainfall)				Runoff (% of Annual Rainfall)			
	Mean	Max	Min	St.Dev.	Mean	Max	Min	St.Dev.
French Creek 01475127	31%	44%	15%	7%	17%	30%	7%	5%
Frankford Creek 01467089	18%	24%	9%	4%	34%	46%	21%	7%
Frankford Creek 01467087	18%	25%	11%	4%	29%	39%	17%	6%
Tacony Creek 01467086	29%	40%	19%	6%	21%	27%	13%	3%
Jenkintown Creek 01467085	32%	38%	19%	8%	20%	23%	15%	3%
Rock Creek 01467084	28%	36%	19%	6%	33%	41%	21%	7%
Tacony Creek 01467083	31%	36%	22%	6%	24%	31%	20%	5%

	Baseflow (% of Annual Total Flow)				Runoff (% of Annual Total Flow)			
	Mean	Max	Min	St.Dev.	Mean	Max	Min	St.Dev.
French Creek 01475127	64%	75%	53%	5%	36%	47%	25%	5%
Frankford Creek 01467089	35%	48%	27%	5%	65%	73%	52%	5%
Frankford Creek 01467087	38%	49%	26%	6%	62%	74%	51%	6%
Tacony Creek 01467086	58%	67%	48%	5%	42%	52%	33%	5%
Jenkintown Creek 01467085	61%	68%	50%	7%	39%	50%	32%	7%
Rock Creek 01467084	46%	61%	36%	7%	54%	64%	39%	7%
Tacony Creek 01467083	57%	63%	51%	5%	43%	49%	37%	5%

As expected, the quantity of stormwater runoff on a unit-area basis follows patterns of impervious cover in the drainage area. The French Creek watershed, the least developed, has the smallest amount of stormwater runoff both as an annual mean quantity (7.4 in/yr/unit area) and as an annual mean percent of rainfall (17%). As expected, the more highly-developed downstream Frankford Creek has the most runoff both as an annual mean quantity (14.9 in/yr/unit area) and as an annual mean percent of rainfall (34%). Mean runoff from Frankford Creek is twice the mean runoff in the French Creek basin. The more upstream gauges in the Tacony and Tookany have intermediate quantities of stormwater runoff.

Expressing runoff as a percent of annual rainfall as in Table 4-6 provides an estimate of the upper bound of directly connected impervious area (DCIA), that portion of impervious surfaces that are hydraulically connected to the drainage system. In other words, percent DCIA may be less than this number but is no greater. Runoff from impervious surfaces that are not directly connected may ultimately infiltrate or evaporate rather than contributing to stormwater runoff. It is interesting to note that compared to the land use-derived estimates of total impervious cover presented in Section 4 (ranging from 32% to 47% impervious cover as calculated for each municipality), estimated DCIA is generally more than 90% of total impervious area in the watershed. These estimates are calculated as the long-term mean runoff, as a percentage of rainfall, divided by the impervious cover estimate listed in Section 4. For example, runoff in Frankford Creek is 46% of rainfall on an annual mean basis, and impervious cover for the Philadelphia is estimated at 47%. Therefore about 98% of impervious cover appears to be directly connected.

Example Time Series Graphs

Figures 4-8 through 4-10 provide some idea of trends in unit-area flow, baseflow, and runoff from year to year. Although there is considerable variability between years, flows at the six gauges generally follow the same patterns. For example, the Frankford Creek gauges at Castor Avenue and at Torresdale Avenue have the lowest unit-area baseflows and the highest stormwater runoff volumes almost every year of the period of record. This agreement between gauges suggests that the conclusions drawn from long-term mean flows in the previous section are valid for most individual years.

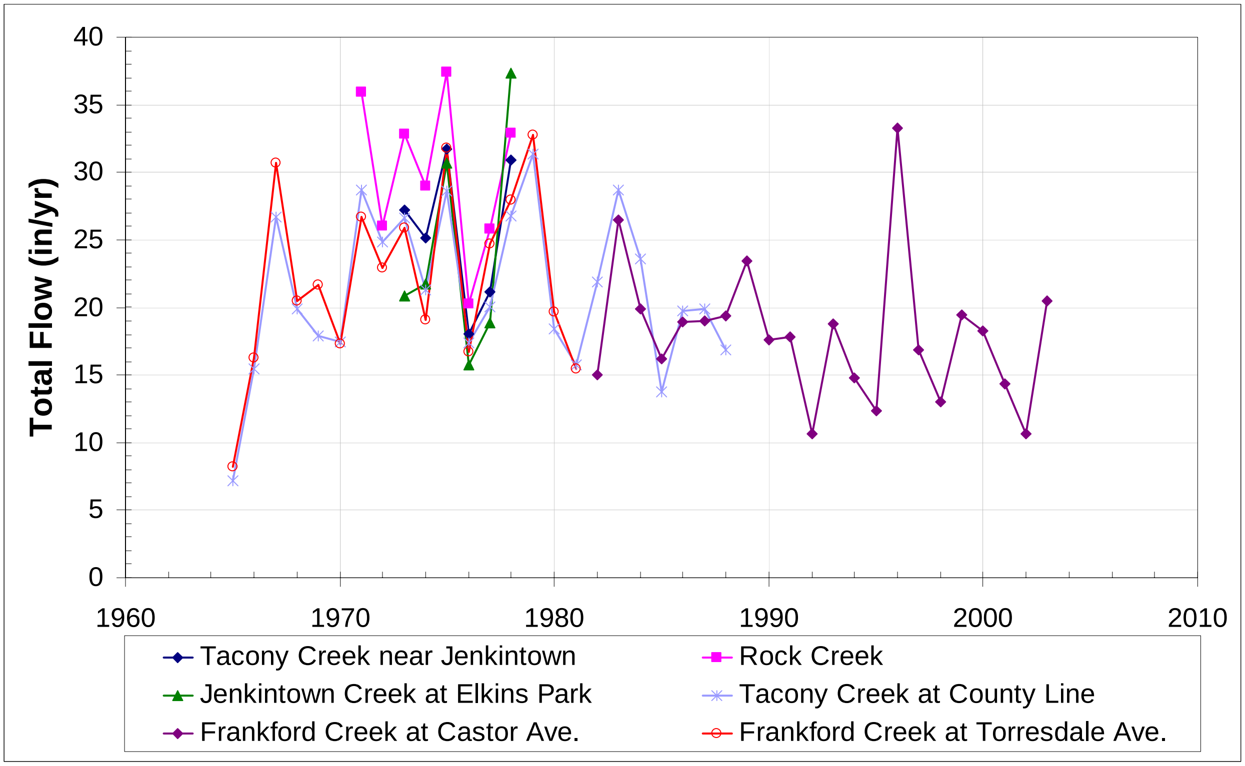


Figure 4-8 Total Flow (in/yr/unit area) Observed at six USGS Gauges in Tookany/Tacony-Frankford Watershed.

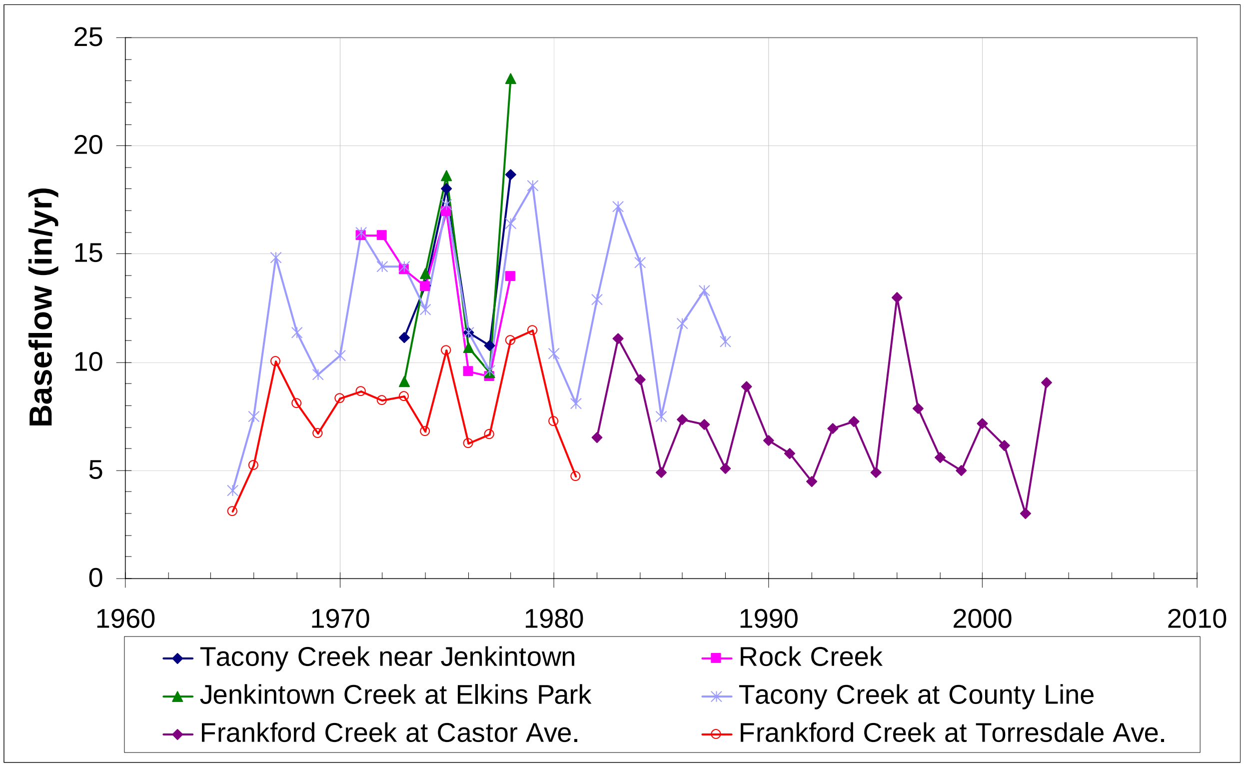


Figure 4-9 Calculated Total Baseflow (in/yr/unit area) at six USGS Gauges in Tookany/Tacony-Frankford Watershed.

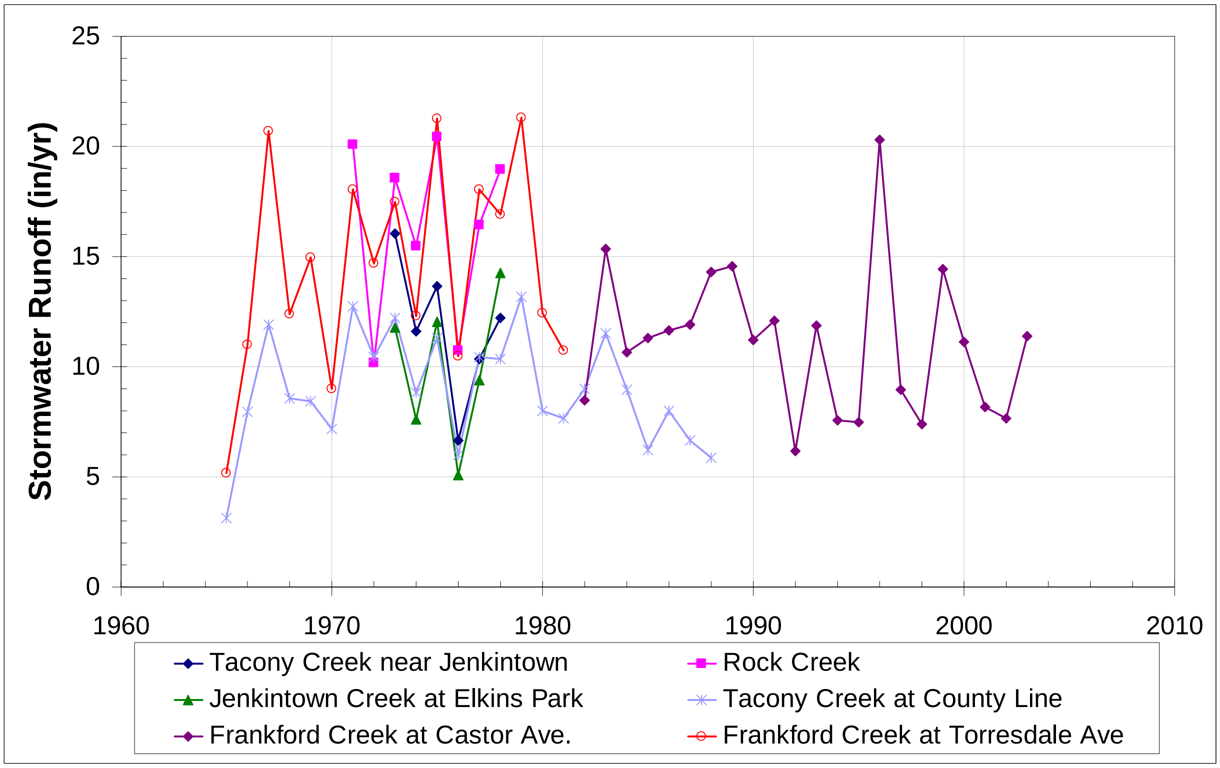


Figure 4-10 Calculated Total Stormwater Runoff (in/yr/unit area) at six USGS Gauges in Tookany/Tacony-Frankford Watershed.

Cumulative Distribution

The cumulative distribution of average daily flow at Tacony Creek near County Line (site TF620/680) and Frankford Creek at Castor Ave. (site TF280) provides more evidence that the Frankford Creek gauge experiences greater extremes of flow. The graph shows the percent of daily flow observations (horizontal axis) that are equal to or less than a given value (on the vertical axis). For example, Figure 4-11 indicates that average daily flow on a unit area basis at the Frankford Creek gauge was less than 0.1 inches on about 90% of days observed. Frankford Creek experiences greater extremes of flow than at the Tacony Creek gauge. On approximately 92% of days, flow at the Frankford Creek gauge is less than flow at the Tacony Creek gauge on a unit-area basis. On the wettest 8% of days, flow at the Tacony Creek gauge is greater than flow at the Frankford Creek gauge on a unit-area basis. These observations strengthen the evidence that downstream reaches of the creek (Frankford Creek) are more influenced by stormwater runoff than upstream reaches (Tacony Creek).

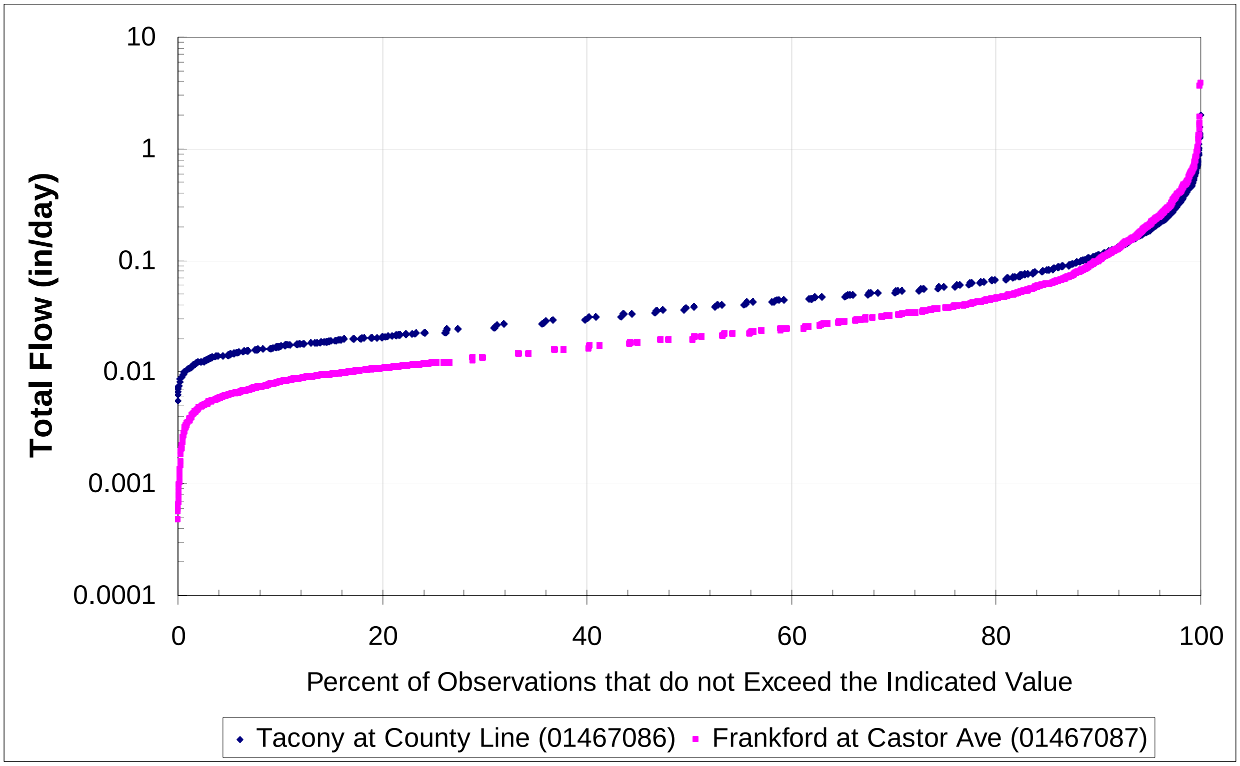


Figure 4-11 Cumulative Distribution Plot of Total Flow at two USGS Gauges in Tookany/Tacony-Frankford Watershed

Characterization of Wet and Dry Weather Sampling Periods

The evaluation of water quality data began with the segregation of water quality observations into wet and dry weather periods. This classification was based upon rainfall. To characterize samples as wet or dry, rainfall for the previous 48 hours was summed and if the total exceeded 0.05 inches the sample was flagged as wet. All samples not meeting this criterion were flagged as dry.

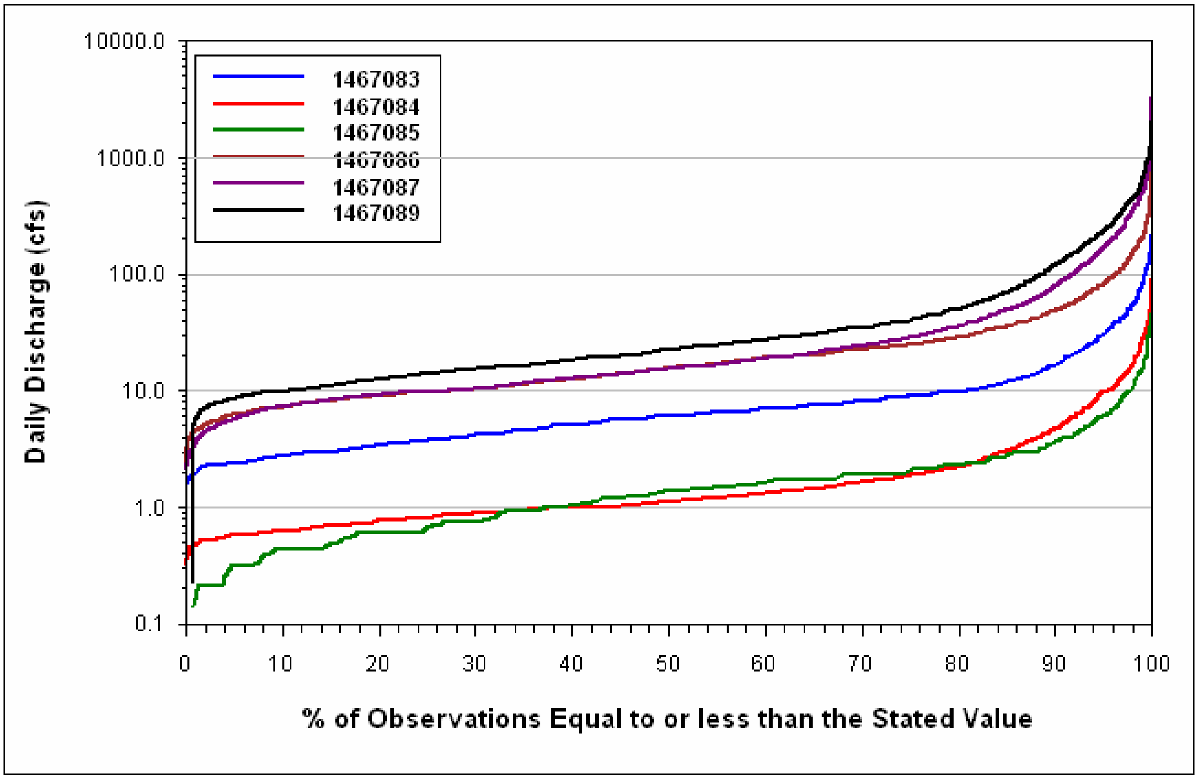


Figure 4-12 Cumulative Distribution Plot of Daily Discharge at six USGS Gauges in Tookany/Tacony-Frankford Watershed

Table 4-7 Wet Weather/Dry Weather Flow Estimates for Historical USGS Gauge Data

Gauge Name	Gauge Number	Season	Q3 (75%) (cfs)
Tacony Creek near Jenkintown	1467083	Annual	9
Tacony Creek near Jenkintown	1467083	Fall	6.7
Tacony Creek near Jenkintown	1467083	Spring	10
Tacony Creek near Jenkintown	1467083	Summer	8.2
Tacony Creek near Jenkintown	1467083	Winter	9.7
Rock Creek by Curtis Arboretum	1467084	Annual	1.9
Rock Creek by Curtis Arboretum	1467084	Fall	1.5
Rock Creek by Curtis Arboretum	1467084	Spring	2.3
Rock Creek by Curtis Arboretum	1467084	Summer	1.8
Rock Creek by Curtis Arboretum	1467084	Winter	1.8
Jenkintown Creek at Elkins Park	1467085	Annual	2.1
Jenkintown Creek at Elkins Park	1467085	Fall	1.5
Jenkintown Creek at Elkins Park	1467085	Spring	2.55
Jenkintown Creek at Elkins Park	1467085	Summer	2
Jenkintown Creek at Elkins Park	1467085	Winter	2.3
Tacony Creek at County Line	1467086	Annual	26
Tacony Creek at County Line	1467086	Fall	18
Tacony Creek at County Line	1467086	Spring	33
Tacony Creek at County Line	1467086	Summer	23
Tacony Creek at County Line	1467086	Winter	26
Frankford Creek at Castor Ave.	1467087	Annual	29
Frankford Creek at Castor Ave.	1467087	Fall	18
Frankford Creek at Castor Ave.	1467087	Spring	40
Frankford Creek at Castor Ave.	1467087	Summer	28
Frankford Creek at Castor Ave.	1467087	Winter	27
Frankford Creek at Torresdale Ave.	1467089	Annual	41
Frankford Creek at Torresdale Ave.	1467089	Fall	28.5
Frankford Creek at Torresdale Ave.	1467089	Spring	52
Frankford Creek at Torresdale Ave.	1467089	Summer	42
Frankford Creek at Torresdale Ave.	1467089	Winter	39

An example of trends in rainfall and corresponding CSOs can be observed in Figures 4-13 and 4-14. Figure 4-13 shows rainfall and CSO data for three CSO outfalls for the period April 12 to 16, 2004. A total of 4.09 inches of rain occurs during the period and CSOs are active. Because CSOs are observed at multiple points in the system, it can be inferred that sampling sites throughout the system are impacted by CSO and stormwater. The discrete sampling conducted during this period would be called wet days. Figure 4-16 shows rainfall and CSO data for the period June 7 to June 11, 2004. This period is classified as dry because neither rainfall nor CSO occurs. Table 4-8 shows the wet or dry categorization of sampling periods when discrete samples were collected. Table 4-9 lists the wet dates in the continuous monitoring or Sonde deployment periods.

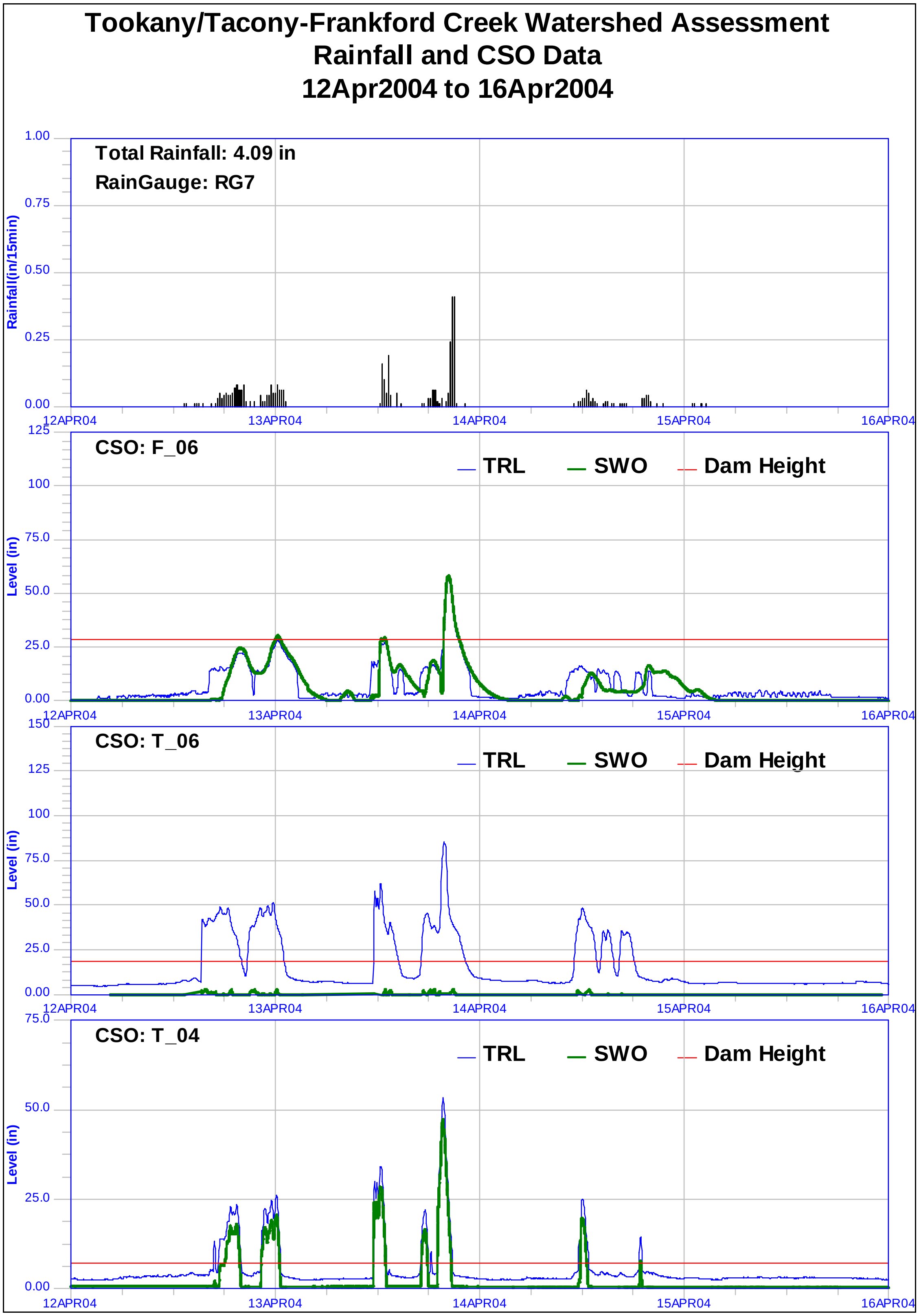


Figure 4-13 Rainfall and CSO plot for a wet period

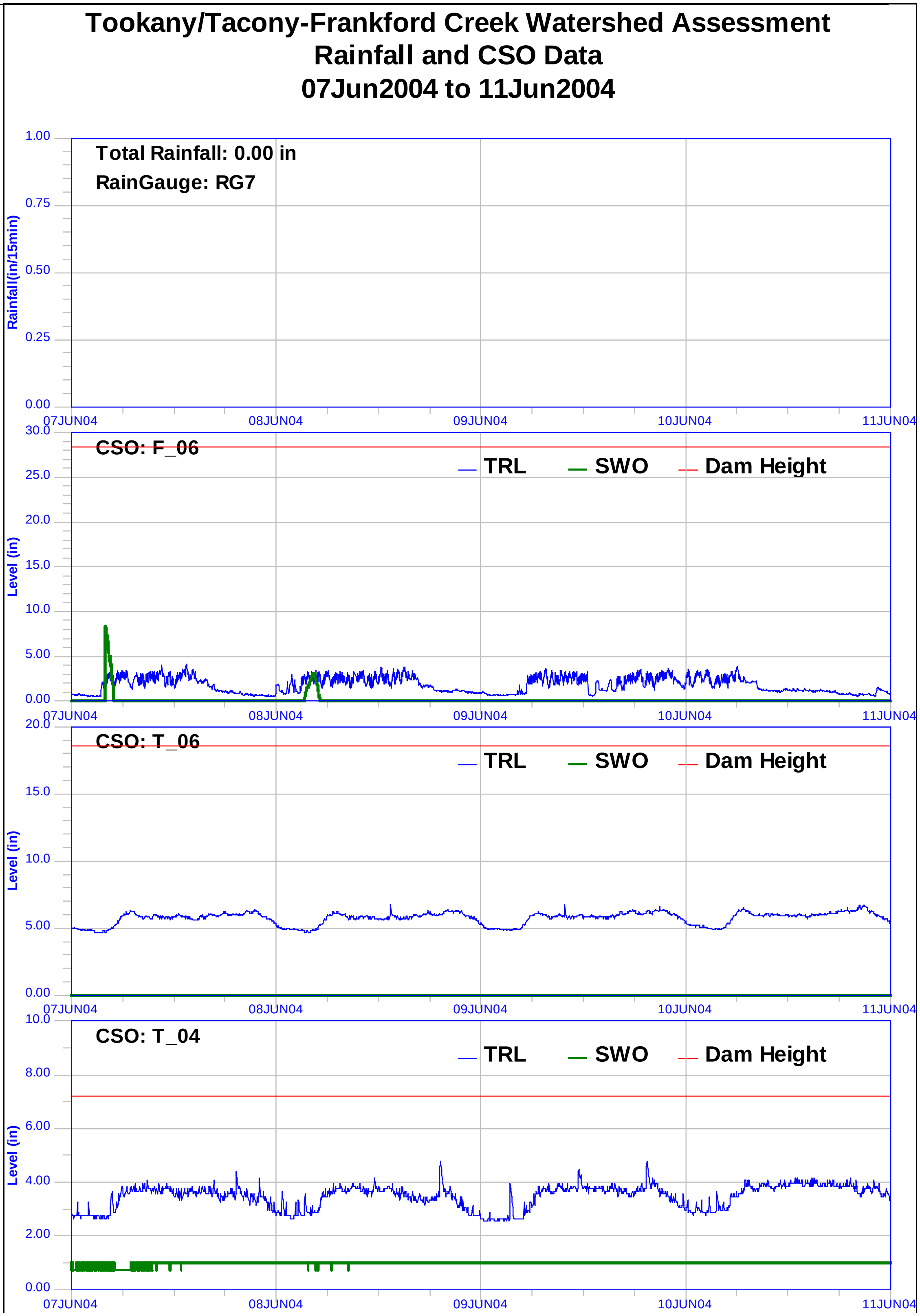


Figure 4-14 Rainfall and CSO plot for a dry period

Table 4-8 Wet and Dry Period Characterization

Date/Period	Weather Status	Sampling Type
6/29/2000	WET	Discrete
7/6/2000	DRY	Discrete
7/20/2000	WET	Discrete
8/10/2000	DRY	Discrete
8/31/2000	WET	Discrete
9/14/2000	WET	Discrete
9/27/2000	WET	Discrete
9/28/2000	WET	Discrete
10/12/2000	DRY	Discrete
10/26/2000	WET	Discrete
11/9/2000	DRY	Discrete
3/19/2001	WET	WETW
3/21-23/2001	WET	WETW
5/21-24/2001	WET	WETW
6/29/2001	DRY	Special
8/17/2001	DRY	Special
10/24/2001	DRY	Special
11/29/2001	DRY	Discrete
2/7/2002	DRY	Discrete
3/7/2002	DRY	Special
5/22/2002	WET	Special
8/1/2002	DRY	Special
8/15/2002	DRY	Special
10/15-18/2002	WET	WETW
10/18-29/2002	WET	WETW
10/24/2002	DRY	Discrete
11/12-14/2002	WET	WETW
1/15/2003	DRY	Discrete
2/12/2003	WET	Discrete
3/4-7/2003	WET	WETW
3/12/2003	DRY	Discrete
3/26-27/2003	WET	Special
4/21/2003	DRY	Discrete
5/1-4/2003	WET	WETW
5/5-7/2003	WET	WETW
5/7-9/2003	WET	WETW
5/15-17/2003	WET	WETW
6/10/2003	DRY	Discrete
6/24/2003	DRY	Discrete
7/9-11/2003	WET	WETW
7/18/2003	DRY	Discrete
9/22-24/2003	WET	WETW
10/3/2003	DRY	Special
10/14-16/2003	WET	WETW
1/15/2004	DRY	Discrete
1/22/2004	DRY	Discrete
1/29/2004	DRY	Discrete
2/5/2004	WET	Discrete
4/21/2004	DRY	Discrete
4/29/2004	WET	Discrete
5/6-13/2004	WET	Discrete
7/7-9/2004	WET	WETW
7/12/2004	WET	Discrete
7/27/2004	WET	Discrete
7/28/2004	WET	Special
7/29/2004	WET	Special
7/30/2004	WET	Special
8/5/2004	WET	Discrete
8/12/2004	WET	Discrete
8/19/2004	DRY	Discrete
8/23/2004	WET	Chlorophyll
8/26/2004	DRY	Discrete
8/30/2004	DRY	Discrete
8/30-9/1/2004	WET	WETW
9/2/2004	DRY	Discrete
9/8/2004	WET	Chlorophyll
9/13/2004	DRY	Chlorophyll
9/17/2004	WET	Chlorophyll
9/18/2004	WET	Special
9/28/2004	WET	Special

WETW = Series of samples taken during a wet weather hydrograph, but the first sample is taken in dry weather before the forecast storm.

Table 4-9 Wet Weather Days of Continuous Sampling Periods

Date/Period			Wet Weather Dates
03/20/01	To	03/26/01	3/21, 3/22, 3/23, 3/26
05/03/01	To	05/17/01	--
05/21/01	To	06/04/01	5/21, 5/22, 5/23, 5/24, 5/26, 5/27, 5/28, 5/29, 5/30, 5/31, 6/1, 6/2, 6/3, 6/4
05/22/01	To	06/05/01	5/22, 5/23, 5/24, 5/26, 5/27, 5/28, 5/29, 5/30, 5/31, 6/1, 6/2, 6/3, 6/4
08/17/01	To	08/29/01	8/19, 8/20, 8/21, 8/22, 8/23, 8/24, 8/25, 8/27, 8/28, 8/29
08/16/01	To	08/29/01	8/19, 8/20, 8/21, 8/22, 8/23, 8/24, 8/25, 8/27, 8/28, 8/29
06/26/01	To	07/03/01	7/1, 7/2, 7/3
07/13/01	To	07/18/01	7/18/2005
11/19/02	To	12/06/02	11/19, 11/21, 11/22, 11/23, 11/24, 11/27, 11/28, 11/29
09/25/02	To	10/09/02	9/25
10/23/02	To	11/05/02	10/25, 10/26, 10/27, 10/28, 10/29, 10/30, 10/31, 11/1
11/19/02	To	12/06/02	11/19, 11/21, 11/22, 11/23, 11/24, 11/27, 11/28, 11/29
09/10/02	To	09/25/02	9/14, 9/15, 9/16, 9/17, 9/24, 9/25
10/04/02	To	10/23/02	10/4, 10/5, 10/10, 10/11, 10/12, 10/13, 10/16, 10/17, 10/18
10/29/02	To	11/19/02	10/29, 10/30, 10/31, 11/1, 11/5, 11/6, 11/7, 11/8, 11/11, 11/12, 11/13, 11/14, 11/15, 11/16, 11/17, 11/18, 11/19
10/23/02	To	11/05/02	10/25, 10/26, 10/27, 10/28, 10/29, 10/30, 10/31, 11/1
11/19/02	To	12/06/02	11/19, 11/21, 11/22, 11/23, 11/24, 11/27, 11/28, 11/29
09/25/02	To	10/08/02	9/25, 9/26, 9/27, 9/28, 9/29, 9/30, 10/3, 10/4, 10/5
10/29/02	To	11/19/02	10/29, 10/30, 10/31, 11/1, 11/5, 11/6, 11/7, 11/8, 11/11, 11/12, 11/13, 11/14, 11/15, 11/16, 11/17, 11/18, 11/19
09/10/02	To	09/25/02	9/14, 9/15, 9/16, 9/17, 9/24, 9/25
10/04/02	To	10/23/02	10/4, 10/5, 10/10, 10/11, 10/12, 10/13, 10/16, 10/17, 10/18
03/04/03	To	03/12/03	3/4, 3/5, 3/6, 3/7, 3/8, 3/9
03/18/03	To	03/21/03	3/20, 3/21
04/01/03	To	04/15/03	4/1, 4/2, 4/3, 4/7, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14
04/15/03	To	04/29/03	4/25, 4/26, 4/27, 4/28
04/29/03	To	05/13/03	5/2, 5/3, 5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11
05/13/03	To	05/20/03	5/16, 5/17, 5/18, 5/19
05/15/03	To	05/18/03	5/16, 5/17, 5/18
05/30/03	To	06/12/03	5/30, 5/31, 6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/9
06/17/03	To	06/23/03	6/17, 6/18, 6/19, 6/20, 6/21, 6/22
07/08/03	To	07/14/03	7/8, 7/9, 7/10, 7/11, 7/12, 7/13, 7/14
03/25/03	To	03/27/03	3/26, 3/27
04/01/03	To	04/15/03	4/1, 4/2, 4/3, 4/7, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14
04/15/03	To	04/29/03	4/25, 4/26, 4/27, 4/28
04/29/03	To	05/08/03	5/2, 5/3, 5/4, 5/5, 5/6, 5/7, 5/8
05/13/03	To	05/20/03	5/16, 5/17, 5/18, 5/19
05/30/03	To	06/12/03	5/30, 5/31, 6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/9
07/08/03	To	07/14/03	7/8, 7/9, 7/10, 7/11, 7/12, 7/13, 7/14
04/01/03	To	04/15/03	4/1, 4/2, 4/3, 4/7, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14
04/15/03	To	04/29/03	4/25, 4/26, 4/27, 4/28
04/29/03	To	05/13/03	5/2, 5/3, 5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11
05/13/03	To	05/20/03	5/16, 5/17, 5/18, 5/19
05/30/03	To	06/12/03	5/30, 5/31, 6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/9
07/08/03	To	07/14/03	7/8, 7/9, 7/10, 7/11, 7/12, 7/13, 7/14

Date/Period			Wet Weather Dates
04/01/03	To	04/15/03	4/1, 4/2, 4/3, 4/7, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14
04/15/03	To	04/18/03	--
04/29/03	To	05/13/03	5/2, 5/3, 5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11
05/13/03	To	05/20/03	5/16, 5/17, 5/18, 5/19
07/08/03	To	07/14/03	7/8, 7/9, 7/10, 7/11, 7/12, 7/13, 7/14
03/18/03	To	03/21/03	3/20, 3/21
09/22/03	To	09/25/03	9/23, 9/24, 9/25
09/25/03	To	10/15/03	9/27, 9/28, 9/29, 9/30, 10/4, 10/5, 10/6, 10/14, 10/15
08/06/03	To	08/13/03	8/6, 8/7, 8/8, 8/9, 8/10, 8/11, 8/12
09/17/03	To	09/25/03	8/6, 8/7, 8/8, 8/9, 8/10, 8/11, 8/12
09/25/03	To	10/15/03	9/27, 9/28, 9/29, 9/30, 10/4, 10/5, 10/6, 10/14, 10/15
09/17/03	To	09/25/03	9/17, 9/18, 9/19, 9/20, 9/21, 9/23, 9/24, 9/25,
09/25/03	To	10/15/03	9/27, 9/28, 9/29, 9/30, 10/4, 10/5, 10/6, 10/14, 10/15
09/17/03	To	09/25/03	9/17, 9/18, 9/19, 9/20, 9/21, 9/23, 9/24, 9/25,
09/25/03	To	10/15/03	9/27, 9/28, 9/29, 9/30, 10/4, 10/5, 10/6, 10/14, 10/15
10/16/03	To	10/23/03	10/16, 10/17, 10/18, 10/19, 10/20, 10/22, 10/23
10/16/03	To	10/30/03	10/16, 10/17, 10/18, 10/19, 10/20, 10/22, 10/23, 10/24, 10/26, 10/27, 10/28, 10/29, 10/30
10/30/03	To	11/13/03	10/30, 10/31, 11/5, 11/6, 11/7, 11/8, 11/12, 11/13
11/13/03	To	11/26/03	11/13, 11/14, 11/19, 11/20, 11/21, 11/22, 11/24, 11/25, 11/26
03/26/04	To	04/04/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/14/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12, 6/13
06/03/04	To	06/12/04	6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/12/04	To	03/23/04	3/16, 3/17, 3/18, 3/19, 3/20, 3/21, 3/22, 3/23
03/26/04	To	04/03/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/14/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12, 6/13
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/26/04	To	04/06/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4, 4/5, 4/6
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/11/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/26/04	To	04/06/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4, 4/5, 4/6
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18

Date/Period			Wet Weather Dates
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
05/19/04	To	06/01/04	5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/26/04	To	04/07/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4, 4/5, 4/6
04/07/04	To	04/21/04	4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/21/04	To	05/06/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4, 5/5, 5/6
05/06/04	To	05/19/04	5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18, 5/19
05/19/04	To	06/01/04	5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/14/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12, 6/13
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
03/12/04	To	03/23/04	3/16, 3/17, 3/18, 3/19, 3/20, 3/21, 3/22, 3/23
03/26/04	To	04/06/04	3/27, 3/28, 3/29, 3/30, 3/31, 4/1, 4/2, 4/3, 4/4, 4/5, 4/6
04/06/04	To	04/20/04	4/6, 4/8, 4/9, 4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16
04/20/04	To	05/04/04	4/23, 4/24, 4/25, 4/26, 4/27, 4/28, 4/29, 5/3, 5/4
05/04/04	To	05/18/04	5/4, 5/5, 5/6, 5/7, 5/8, 5/9, 5/10, 5/11, 5/12, 5/15, 5/16, 5/17, 5/18
05/18/04	To	06/01/04	5/18, 5/19, 5/20, 5/21, 5/25, 5/26, 5/27, 5/31, 6/1
06/01/04	To	06/14/04	6/1, 6/2, 6/3, 6/4, 6/5, 6/6, 6/7, 6/8, 6/11, 6/12, 6/13
06/14/04	To	06/29/04	6/14, 6/15, 6/16, 6/17, 6/18, 6/19, 6/22, 6/23, 6/24, 6/29
06/29/04	To	07/15/04	6/29, 6/30, 7/1, 7/2, 7/3, 7/5, 7/6, 7/7, 7/8, 7/9, 7/12, 7/13, 7/14, 7/15
07/02/04	To	07/15/04	7/2, 7/3, 7/5, 7/6, 7/7, 7/8, 7/9, 7/12, 7/13, 7/14, 7/15, ,
06/29/04	To	07/15/04	6/29, 6/30, 7/1, 7/2, 7/3, 7/5, 7/6, 7/7, 7/8, 7/9, 7/12, 7/13, 7/14, 7/15,
07/15/04	To	07/30/04	7/15, 7/16, 7/18, 7/19, 7/20, 7/21, 7/22, 7/23, 7/24, 7/25, 7/26, 7/27, 7/28, 7/29, 7/30
07/30/04	To	08/12/04	7/30, 8/1, 8/2, 8/3, 8/4, 8/5, 8/6, 8/11, 8/12
08/12/04	To	08/20/04	8/12, 8/13, 8/14, 8/15, 8/16, 8/17, 8/18
08/20/04	To	09/08/04	8/21, 8/22, 8/23, 8/30, 8/31, 9/1, 9/2, 9/8
07/30/04	To	08/12/04	7/30, 8/1, 8/2, 8/3, 8/4, 8/5, 8/6, 8/11, 8/12
08/12/04	To	08/20/04	8/12, 8/13, 8/14, 8/15, 8/16, 8/17, 8/18
08/20/04	To	09/08/04	8/21, 8/22, 8/23, 8/30, 8/31, 9/1, 9/2, 9/8
07/30/04	To	08/12/04	7/30, 8/1, 8/2, 8/3, 8/4, 8/5, 8/6, 8/11, 8/12
08/12/04	To	08/20/04	8/12, 8/13, 8/14, 8/15, 8/16, 8/17, 8/18
08/20/04	To	09/08/04	8/21, 8/22, 8/23, 8/30, 8/31, 9/1, 9/2, 9/8
09/08/04	To	09/22/04	9/8, 9/9, 9/10, 9/11, 9/15, 9/16, 9/17, 9/18, 9/19, 9/20
09/22/04	To	10/05/04	9/28, 9/29, 9/30, 10/1, 10/2

4.4 Flooding

4.4.1 Introduction

A stormwater management plan has been initiated in this watershed by the Philadelphia Water Department in partnership with the watershed municipalities in Montgomery County under Pennsylvania's Act 167, the Storm Water Management Act of 1968. The Act 167 planning process and report will identify any "trouble spots" that may exist within the watershed area.

According to the Tookany Creek Watershed Management Plan, "there are several low-lying areas within the watershed that have experienced frequent flooding with damage to homes and businesses. It appears that dwellings were built over time in the floodplain without recognizing the value of the floodplain in attenuating floodwaters. Compounding the problem is the gradual addition of impervious surfaces over decades to the watershed's creeks, thus causing less on-site infiltration and more direct volume flowing quickly into the creeks."

The Tookany Creek Watershed Management Plan additionally discusses the role of floodplains and riparian areas in flood control: "The 100-year floodplain affects the health, safety and welfare of residents. While much of the time the floodplain may be dry, during storms the floodplain stores and conveys large quantities of water. Development within the floodplain reduces the carrying capacity and increases the height and destructive ability of floodwater. In addition to carrying flood waters, the floodplain and stream corridor serve other important functions. The condition of the stream corridor is important in minimizing erosion and water pollution, protecting water quality (temperature and velocity) and providing animal habitat and recreation opportunities."

Frequent damaging flooding does not appear to be a major concern within the study area. However, frequent smaller events of flooding occur in some locations, and damaging flooding has occurred during very large storms.

FEMA Floodplains and Flood Insurance Rate Maps

Information on floodplain extents, historical flooding events, and flood insurance rates is available from FEMA and provides an idea of flood hazards in the study area. The flood insurance rate map (Figure 4-15) provides a quick idea of the areas in the watershed that may experience flooding. As summarized in Table 4-10, Zones A and AE are areas where flooding is likely (1% or greater annual chance of occurrence) and zones X and X500 are areas where flooding is unlikely (less than an annual 1% chance due to elevation or flood protection structures).

Table 4-10 National Flood Insurance Program Zone Designations

Zone	Description
A	Zone A is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no base flood elevations or depths are shown within this zone. Flood insurance is generally mandatory in these zones.
AE	Zone AE is the flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by detailed methods. In most instances, whole-foot base flood elevations derived from detailed hydraulic analyses are shown at selected intervals within this zone. Flood insurance is generally mandatory in these zones.
X and X500	Zone X is the flood insurance rate zone that corresponds to areas outside the 500-year floodplain, areas within the 500-year floodplain but not the 100-year floodplain (X500), and to areas of 100-year flooding where average depths are less than 1 foot, areas of 100-year flooding where the contributing drainage area is less than 1 square mile, and areas protected from the 100-year flood by levees. No base flood elevations or depths are shown within this zone. Flood insurance is generally not mandatory in these zones.

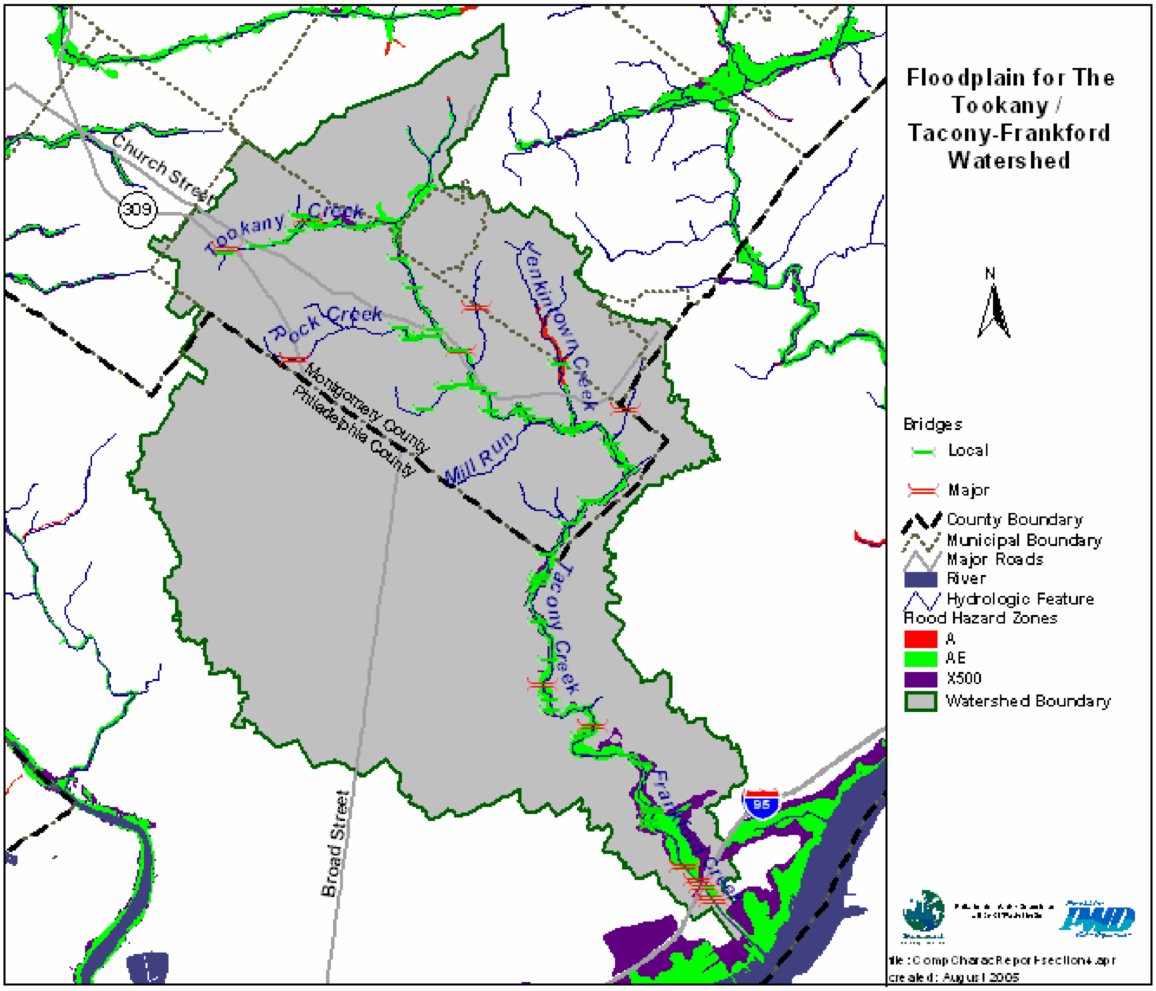


Figure 4-15 FEMA Flood Insurance Rates and Possible Flooding Areas

Table 4-11 Potential Flooding Locations Identified by County FEMA Studies

County	Sheet	Creek	River Mile (ft)	Road Crown/Bridge Deck Below 50-Yr Flood Elevation
Philadelphia	42P	Tacony-Frankford	1,300	Conrail (Partially in 10-yr)
Philadelphia	42P	Tacony-Frankford	1,900	Conrail (Partially in 10-yr)
Philadelphia	42P	Tacony-Frankford	6,400	Conrail
Philadelphia	42P	Tacony-Frankford	6,650	Aramingo Avenue
Philadelphia	43P	Tacony-Frankford	8,670	Conrail
Philadelphia	43P	Tacony-Frankford	9,820	Frankford Avenue
Philadelphia	43P	Tacony-Frankford	10,100	Torresdale Avenue
Philadelphia	43P	Tacony-Frankford	13,800	Wingohocking Street
Philadelphia	45P	Tacony-Frankford	19,980	"I" Street (Fully within 10-yr)
Philadelphia	46P	Tacony-Frankford	26,680	Tabor Road
Philadelphia	47P	Tacony-Frankford	31,220	Adams Avenue
Montgomery	280P	Tacony		Footbridge
Montgomery	280P	Tacony		Central Avenue
Montgomery	280P	Tacony		Footbridge
Montgomery	280P	Tacony		Footbridge
Montgomery	280P	Tacony		Jenkintown Road
Montgomery	281P	Tacony		Mill Road
Montgomery	281P	Tacony		High School Road
Montgomery	281P	Tacony		Church Road
Montgomery	282P	Tacony		Footbridge
Montgomery	282P	Tacony		Footbridge
Montgomery	282P	Tacony		Footbridge (within 10-year floodplain)
Montgomery	282P	Tacony		Conrail (within 10-year floodplain)
Montgomery		Jenkintown		Tookany Creek Parkway
Montgomery		Jenkintown		Footbridge

Floodplains and Flooding in the Tookany/Tacony-Frankford Watershed

FEMA's Flood Insurance Study for Philadelphia (FEMA, 1996) indicates that low-lying portions of the greater Philadelphia area have experienced damaging flooding in the past during major tropical events, including Hurricanes Connie and Dianne in August 1955 and Hurricane Agnes in June 1972. A major problem, as the data indicate, is that so much of the

Tookany/Tacony-Frankford Watershed has been developed before the emergence of any floodplain regulations, the most notable of which are the Federal Emergency Management Agency (FEMA) set of minimum floodplain standards, which were modified and made more rigorous in the mid-1990s.

The following text is taken from the Tacony-Frankford Watershed River Conservation Plan:

"Increases in residential development in the upper portion of the watershed, combined with the level topography of the coastal plain, assured that land adjacent to the watershed's streams would experience frequent and devastating floods. Public outcry demanded that the city government address flooding from the Tacony-Frankford Creek and to do something about the deplorable state of the water quality in the stream. Response to this threat to human health and safety resulted in the encapsulation of over half of the watershed into combined sewers that would carry raw sewage and increasing stormwater run-off from the watershed."

According to the Tookany Creek Watershed Management Plan, "In the early 1950s, the PA DEP built a levee along the Tookany Creek to contain the floodwaters to prevent damage to the surrounding homes. This has decreased the severe damage the area once experienced, but the surrounding area roads and some homes continued to flood. In 1978, a pump house was built on Rices Mill Road in Glenside, to curtail the more serious flood events. The Keswick area has experienced flooding as a result of inadequate storm sewer capacity. Many of the storm drains cannot capture and divert the flows in time to prevent flooding in the intersections. Many of the creeks also overflow their banks, causing localized flooding. Abington Township has recently completed a major flood attenuation project in the Baeder Creek sub-watershed due to ongoing and repeated damage."

Section 5
Characterization of Water Quality

5.1 PWD/USGS Cooperative Program (Water Quality and Flow Data)

The purpose of the PWD/USGS study conducted from 1971 to 1980 (described in section 3.4.4) was to quantify the pollutant loads in some of Philadelphia's streams and possibly relate the degradation in water quality to urbanization. Using six stations in the Tookany/Tacony-Frankford Watershed: 01467089 Frankford Creek at Torresdale Ave, 01467087 Frankford Creek at Castor Ave, 01467086 Tacony Creek at County Line, 01467085 Jenkintown Creek at Elkins Park, 01467084 Rock Creek above Curtis Arboretum near Philadelphia, and 01467083 Tacony Creek near Jenkintown (Figure 3-3), monthly "snapshots" of water quality samples were collected and analyzed for conductivity, BOD_5, total phosphate, ammonia, nitrite, nitrate, and fecal coliform.

5.1.1 Qualitative Discussion of PWD/USGS Data

Table 5-1 qualitatively summarizes water quality data collected by the PWD/USGS Cooperative Program. Tables 5-2 and 5-3 present a quantitative summary of this data.

The PWD/USGS Cooperative Program data indicate that total dissolved solids, pH, and nitrite did not appear to have been parameters of concern. Dissolved oxygen concentrations reported represent instantaneous daytime concentrations. This sampling method is not likely to have identified low DO conditions that would have typically occurred in the early morning. Fecal coliform bacteria concentrations often exceeded current standards with mean counts of 10^3 to 10^5 and maximum counts of 10^4 to 10^6. The highest coliform counts were found located furthest downstream at site 9, which correlates with site TF280.

Table 5-1 Qualitative Summary of Water Quality Data Collected 1970-1980

Parameter	Period of Observation	Comments
Discharge	1970-1980	Discharge at the upstream and downstream sites follow the same pattern, with discharge increasing downstream.
Temperature	1970-1980	Water temperature goes through a seasonal cycle and differs very little between cross-sections.
pH	1970-1973	All pH values fall between 6.5 and 8.5.
Specific Conductance	1970-1980	For most measurements, specific conductance was greatest along the mainstem both in and out of the City.
Dissolved Oxygen	1970-1980	Approximately one-quarter of all measurements fell below 6 mg/L in 1970, 1971, 1977, 1978, and 1979. Concentrations at the downstream site were generally lower for all years (the plot from 1980 is based on a small sample size), suggesting that urbanization had an observable affect on dissolved oxygen concentrations during the period. There may have been a slight downward trend in mean concentrations over time.
BOD	1970-1980	Most upstream BOD loads are less than 5 mg/L. Downstream BOD is higher and the mean is around 10 mg/L.
COD	1970-1973	COD concentrations range from about 5 to 37 mg/L at the downstream site and from about 7 to over 200 mg/L at the upstream site.
TOC	1970-1973	TOC concentrations range from about 1 to 11 mg/L at the upstream site and from about 3 to 54 mg/L at the downstream site.
Suspended Solids	1970-1973	Suspended solids are greatest in the downstream location, ranging as high as 800 mg/L. Upstream suspended solids are generally less than 10 mg/L.
Total Dissolved Solids	1970 – 1980	Mean TDS at all sampling sites with data were greater than 230 mg/L.
Organic Nitrogen	1972	The small number of data points available for organic nitrogen concentrations show relatively constant values at all sites with values ranging between 0 .07 and 0.88 mg/L.
Ammonia as Nitrogen	1970-1980	Most ammonia measurements are less than 2 mg/L though downstream peaks have reached as high as 10 mg/L, Downstream values are greater than upstream values for almost all measurements.
Nitrite as Nitrogen	1970-1980	Except for a few peaks, nitrite concentrations were less than 0.1 mg/L at the all locations. Concentrations at downstream locations were higher and reached a maximum of 1 mg/L.
Nitrate as Nitrogen	1970-1980	Nitrate concentrations were greatest at upstream locations with very few exceptions.
Total Phosphate	1970-1980	Concentrations at Site 9 (downstream) are considerably greater than those at Site 8 (upstream), suggesting a considerable input of phosphorus between the two stations. Concentrations at Site 8 appear to have been higher from 1970 to 1972 than later in the decade, with a maximum in 1971 of close to 30 mg/L.
Fecal Coliform	1970-1980	Coliform counts clearly increase from upstream to downstream for all years samples were taken. Upstream counts typically lie between 10^2 and 10^4 col/100 mL, while downstream counts lie between 10^3 and 10^6 col/100 mL. There may have been a slight downward trend over the course of the decade, but very few of the measurements would meet the current standard of 200 mg/L.

Parameter	Period of Observation	Comments
Aluminum	1970-1973	Few samples of aluminum taken at each location, shows a range of 0.1 to 0.34 mg/L.
Beryllium	1970-1973	All beryllium concentrations measured were less than 0.01 mg/L. (Only 1 sample was available per sampling location)
Cadmium	1970-1973	All cadmium concentrations at the upstream and downstream locations are less than 0.03 mg/L. The upstream samples were greater than the downstream peaks.
Calcium	1970-1973	The upstream and downstream concentrations follow the same pattern. The furthest downstream concentrations are greatest.
Chromium	1970-1973	Upstream and downstream concentrations range from 0.01 to 0.9 mg/L. In 1971, samples from the most downstream location have the highest values. In 1972 and 1973, the upstream location generally has the highest values.
Cobalt	1970-1973	All cobalt concentrations are less than 0.001 mg/L except for one value at the most downstream location of 0.05 mg/L.
Copper	1970-1973	Most of the copper concentrations are less than 0.05 mg/L. The downstream location reached about 0.5 mg/L for one sample.
Iron	1970-1973	All the measured iron concentrations at Sites 7 and 8 are less than 0.6 mg/L except in April 1973. The downstream concentrations are greater than upstream concentrations and reached over 2 mg/L.
Lead	1970-1973	All the measured lead concentrations at Sites 7 and 8 are less than 0.07 mg/L. The downstream concentrations are greater than upstream concentrations and reached 0.7 mg/L.
Magnesium	1970-1972	The concentrations vary between approximately 10 and 18 mg/L. The downstream and upstream concentrations have similar shapes.
Manganese	1972-1973	The upstream concentrations of manganese are generally greater than the downstream concentrations.
Nickel	1970-1973	Measured nickel concentrations are less than 0.01 mg/L (plotted as half the detection limit) during the study period.
Silver	1970-1973	Only 1 silver concentration was measured at each location, all were less than 0.001 mg/L. These values were not graphed.
Zinc	1970-1973	Other than a few peaks at Sites 7 and 8, downstream concentrations of zinc are greatest.

Table 5-2 Statistical Summary of Water Quality Parameters 11/9/70-1/7/80

Site	Statistic	Flow (cfs)	Temp. (°C)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TOC (mg/L)	Spec. Cond. (mhos)	TDS (mg/L)	TSS (mg/L)	pH	TP (mg/L)	ON (mg/L)	NH_3 (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	Fecal Col. (col/100 mL)
7	N	55	54	55	52	36	30	52	13	35	33	55	2	54	55	55	55
7	MIN	0.49	0	7	0.4	4.6	1	171	175	1	6.4	0.05	0.11	0.04	0.01	0.18	4.00E+01
7	MAX	17.4	23	16.8	17.7	36.6	11	1230	276	47	8.3	4.96	0.72	1.64	0.23	5.16	2.20E+05
7	MEAN	2.09	12.5	10.4	2.74	13.2	5.1	421	239	6.46	7.44	0.51	0.42	0.33	0.042	3.15	9.52E+03
7	STD	3.05	6.69	2.19	2.65	7.43	2.26	162	29.9	10.3	0.48	0.67	0.43	0.32	0.038	1.23	3.13E+04
8	N	106	106	109	97	35	30	106	13	35	33	107	2	104	108	108	106
8	MIN	0.95	0	2.5	0.2	4	1	131	150	0	6.4	0.06	0.08	0.01	0.006	0.73	1.00E+02
8	MAX	1150	26	17.2	9.8	26.8	10	924	299	166	8.8	2.77	0.6	5.71	1	6.03	5.30E+04
8	MEAN	34.6	12	10.8	2.77	11.7	5.3	408	243	11.8	7.62	0.34	0.34	0.31	0.037	2.75	5.57E+03
8	STD	114	7.56	2.4	1.88	6	2	134	51.8	31	0.59	0.36	0.37	0.76	0.097	0.95	1.02E+04
9	N	106	106	104	97	36	30	104	13	35	32	106	2	102	105	106	104
9	MIN	3	0	0	0.6	7.2	3	118	137	2	6.4	0.07	0.07	0.03	0.014	0.15	2.50E+01
9	MAX	1210	27.5	15.1	80.4	217	54	1160	461	807	8.3	27.2	0.88	9.8	0.29	5.94	2.58E+06
9	MEAN	50.7	12.9	8.91	10.2	49.8	13.5	439	286	52.7	7.51	2.04	0.48	1.19	0.073	2.02	1.46E+05
9	STD	132	7.89	2.93	11.6	52.8	12.1	163	89.1	162	0.47	3.48	0.57	1.71	0.055	1.05	4.04E+05
18	N	20	20	20	17	0	0	18	0	0	0	20	0	19	20	20	20
18	MIN	0.1	0	7.5	0.6	N/A	N/A	62	N/A	N/A	N/A	0.02	N/A	0.03	0.006	0.5	2.00E+01
18	MAX	91	23.5	13.9	7.3	N/A	N/A	313	N/A	N/A	N/A	0.69	N/A	0.4	0.031	7.04	7.10E+04
18	MEAN	11.3	11.2	10.8	2.65	N/A	N/A	231	N/A	N/A	N/A	0.18	N/A	0.12	0.016	3.08	7.00E+03
18	STD	25.7	6.96	2.16	1.89	N/A	N/A	57	N/A	N/A	N/A	0.18	N/A	0.11	0.006	1.28	1.82E+04
19	N	20	20	20	17	0	0	18	0	0	0	20	0	19	20	20	20
19	MIN	0.9	0	7.5	0.5	N/A	N/A	247	N/A	N/A	N/A	0.05	N/A	0.06	0	1.3	1.00E+02
19	MAX	53	23.5	15.7	14.8	N/A	N/A	619	N/A	N/A	N/A	0.74	N/A	1.03	0.066	8.34	2.80E+04
19	MEAN	9.51	10.9	10.9	3.41	N/A	N/A	435	N/A	N/A	N/A	0.2	N/A	0.2	0.028	3.33	2.94E+03
19	STD	11.8	7.15	2.4	3.37	N/A	N/A	117	N/A	N/A	N/A	0.16	N/A	0.23	0.016	1.53	6.25E+03

Notes

- N = number of samples; STD = standard deviation
- Spec. Cond. = specific conductance; TP = total phosphorus; ON = organic nitrogen
- N/A indicates that no samples were collected.

Table 5-3 Statistical Summary of Metals Concentrations 11/9/70-10/1/73

Site	Statistic	Zn (mg/L)	Ca (mg/L)	Mg (mg/L)	Fe (mg/L)	Ni (mg/L)	Cd (mg/L)	Cu (mg/L)	Cr (mg/L)	Co (mg/L)	Mn (mg/L)	Pb (mg/L)	Be (mg/L)	Al (mg/L)	Ag (mg/L)
7	N	34	7	7	19	6	26	33	35	7	18	28	1	4	1
7	MIN	0.01	14	11	0.05	0.005	0.0005	0.005	0.005	0.005	0.08	0.0005	0.005	0.1	0.0005
7	MAX	0.46	37	18	0.82	0.005	0.02	0.03	0.51	0.005	4.02	0.07	0.005	0.22	0.0005
7	MEAN	0.097	31.6	14.3	0.27	0.005	0.0022	0.0068	0.049	0.005	0.48	0.012	0.005	0.16	0.0005
7	STD	0.099	7.98	2.29	0.17	0	0.004	0.0046	0.1	0	0.9	0.014	N/A	0.049	N/A
8	N	32	8	8	19	5	25	32	35	7	18	27	1	4	1
8	MIN	0.02	19	10	0.07	0.005	0.0005	0.005	0.005	0.005	0.05	0.0005	0.005	0.12	0.0005
8	MAX	0.9	40	17	1.68	0.005	0.02	0.02	0.12	0.005	0.79	0.05	0.005	0.21	0.0005
8	MEAN	0.12	32.4	14.3	0.34	0.005	0.006	0.0072	0.019	0.005	0.21	0.013	0.005	0.15	0.0005
8	STD	0.16	7.67	2.19	0.37	0	0.0056	0.0046	0.028	0	0.19	0.013	N/A	0.042	N/A
9	N	34	7	7	19	6	26	34	36	7	18	28	1	4	1
9	MIN	0.02	27	11	0.37	0.005	0.0005	0.005	0.005	0.005	0.09	0.0005	0.005	0.14	0.0005
9	MAX	0.75	44	17	2.2	0.005	0.029	0.5	0.85	0.05	0.85	0.68	0.005	0.34	0.0005
9	MEAN	0.17	36.9	14.6	0.68	0.005	0.0074	0.029	0.053	0.011	0.3	0.094	0.005	0.23	0.0005
9	STD	0.16	5.52	2.23	0.47	0	0.0073	0.085	0.15	0.017	0.21	0.16	N/A	0.1	N/A

Notes

- Concentrations below the detection limit were most likely reported as equal to the detection limit, resulting in a standard deviation of zero for some parameters.
- N/A indicates that the sample size was too small to calculate a standard deviation.

5.1.2 PWD Water Quality Monitoring Program

To supplement historical data, PWD's Office of Watersheds (OOW) conducted an extensive sampling and monitoring program to characterize the current conditions of the Tookany/Tacony-Frankford Watershed. The program was designed to document the condition of aquatic resources, provide information for the planning process needed to meet regulatory requirements imposed by EPA and PA DEP, and monitor long term trends as implementation of the TTFIWMP proceeds.

Two types of water quality sampling were carried out by PWD in the Tookany/Tacony-Frankford Creek, including discrete sampling before and during wet weather events, and continuous sampling. Figure 5-1 presents the locations of each sampling site and the subshed area draining to that monitoring location. Discrete sampling was performed from June 2000 through December 2004. Wet weather sampling involved the collection of discrete samples before and during a wet weather event, allowing the characterization of water quality responses to stormwater runoff and sanitary and combined sewer overflows. From March 2001 through October 2003, PWD captured data for 12 wet weather events. The second type of sampling to be conducted was continuous water quality monitoring, carried out by introducing YSI 6600 and 600XLM Sondes, shallow depth continuous water quality monitors, and probes that record dissolved oxygen, pH, and turbidity readings. The equipment was deployed to three locations periodically for a number of days to collect continuous data samples and observe water quality fluctuations. The Sonde data for the Tookany/Tacony-Frankford Watershed included over 80 deployments.

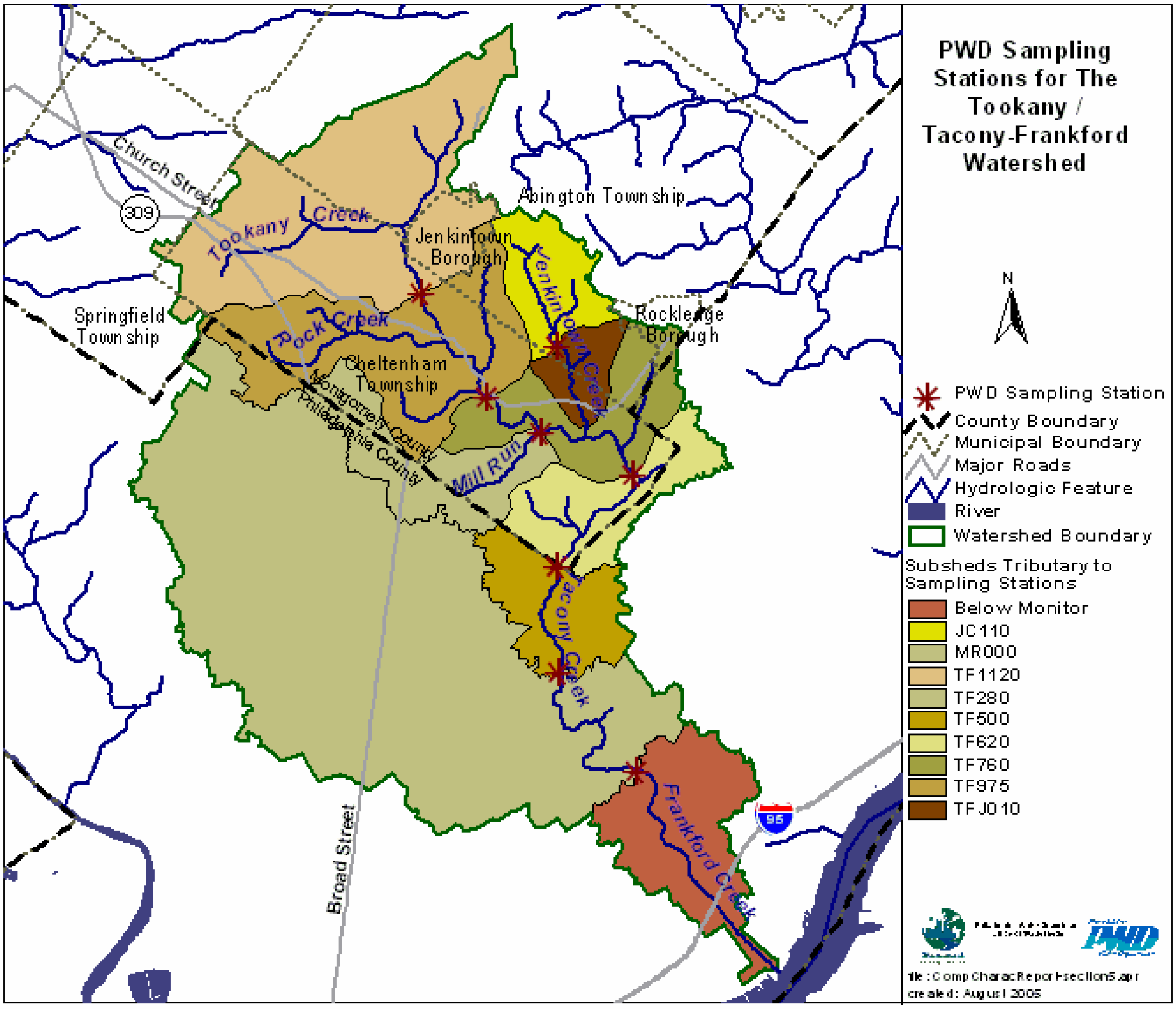


Figure 5-1 Eight Water Quality Monitoring Locations the Tookany/Tacony-Frankford Watershed (Area below monitor represents tidal unassessed portion of the creek)

5.2 Water Quality Analysis for Data Collected from 2000-2004

From 2000 through 2004, PWD has collected water quality data for sampling locations in the Tookany/Tacony-Frankford Watershed. Tables 5-4 thru 5-6 provide a basic, statistical profile of the data from this recent water quality monitoring program. Tables 5-4 and 5-5 provide data from the discrete monitoring program and table 5-6 provides data from the continuous monitoring program. Sample results were compared to relevant PA DEP general water quality criteria to provide an initial impression of which parameters might need further investigation. Applicable relevant standards include water uses to support a potable water supply, recreation and fish consumption, human health, and aquatic life to support warm water fishes.

In addition to the basic statistical profile, Tukey plots of water quality parameters from the 1970s USGS/PWD study and the more recent data are provided in Appendix A.

Table 5-4 Dry Weather Water Quality Summary - Parameters with Standards

Parameter	Standard	Target Value	Units	No. Obs.	Percentiles						No. Exceeding	% Exceeding
					0	25	50	75	90	100		
Al	Acute Maximum	0.75	mg/L	149	0	0.02	0.04	0.06	0.098	0.57	0	0
Al	Chronic Maximum	0.087	mg/L	149	0	0.02	0.04	0.06	0.098	0.57	15	10.1
Alk	Minimum	20	mg/L	130	21	65	72	77	81	89	0	0
BOD_{30}	No Standard	--	mg/L	98	2	3.41	4.15	5.24	8.1	100	0	0
BOD_5	No Standard	--	mg/L	130	0.3	2	2	2	2.185	20.4	0	0
Chl-*a* (water column)	Maximum	3	ug/L	30	0.63	1.12	3.04	6.65	38.576	127.92	15	50
Diss Cd	Acute Maximum	* 0.0043	mg/L	83	0	0	0	0	0.001	0	0	0
Diss Cd	Chronic Maximum	* 0.0022	mg/L	83	0	0	0	0	0.001	0	0	0
Diss Cd	Human Health Maximum	0.001	mg/L	83	0	0	0	0	0.001	0	0	0
DissCr	Acute Maximum	0.0015	mg/L	46	0	0	0	0	0.001	0	0	0
Diss Cr	Chronic Maximum	0.001	mg/L	46	0	0	0	0	0.001	0	0	0
Diss Cu	Acute Maximum	* 0.013	mg/L	74	0	0	0.01	0.01	0.006	0.02	0	0
Diss Cu	Chronic Maximum	* 0.0090	mg/L	74	0	0	0.01	0.01	0.006	0.02	1	1.4
Diss Cu	Human Health Maximum	1	mg/L	74	0	0	0.01	0.01	0.006	0.02	0	0
Diss Fe	Maximum	0.3	mg/L	110	0.02	0.05	0.05	0.08	0.133	0.59	3	2.7
Diss Pb	Acute Maximum	* 0.065	mg/L	65	0	0	0	0	0.001	0	0	0
Diss Pb	Chronic Maximum	* 0.025	mg/L	65	0	0	0	0	0.001	0	0	0
Diss Pb	Human Health Maximum	0.005	mg/L	65	0	0	0	0	0.001	0	0	0
Diss Zn	Acute Maximum	* 0.120	mg/L	73	0	0.01	0.01	0.02	0.022	0.24	2	2.7
Diss Zn	Chronic Maximum	* 0.120	mg/L	73	0	0.01	0.01	0.02	0.022	0.24	3	4.1
Diss Zn	Human Health Maximum	5	mg/L	73	0	0.01	0.01	0.02	0.022	0.24	0	0
DO **	Instantaneous Minimum	4	mg/L	133	2.45	8.78	10.08	13.01	14.46	16.21	2	1.5
DO **	Minimum Average	5	mg/L	133	2.45	8.78	10.08	13.01	14.46	16.21	3	2.3
E. coli	No Standard	--	/100mL	144	10	145	290	500	1800	36000	0	0
F	Maximum	2	mg/L	130	0.08	0.1	0.11	0.13	0.168	416	1	0.8
Fe	Maximum	1.5	mg/L	161	0.03	0.08	0.13	0.26	0.513	1.58	1	0.6
Hardness	No Standard	--	mg/L	86	32.4	164	178	191.66	200	214	0	0
Mn	Maximum	1	mg/L	161	0	0.02	0.04	0.06	0.084	0.17	0	0
NH_3T	Maximum	(pH dependent)	mg/L	103	0.1	0.1	0.1	0.1	0.2	1.13	0	0
NO_2	No Standard	--	mg/L	133	0.01	0.05	0.05	0.05	0.05	0.29	0	0

Parameter	Standard	Target Value	Units	No. Obs.	Percentiles						No. Exceeding	% Exceeding
					0	25	50	75	90	100		
NO23	Maximum	10	mg/L	204	0.4	2.06	2.45	2.8	3.239	3.54	0	0
NO_3	Human Health Maximum	10	mg/L	133	0.28	2.11	2.49	2.85	3.283	3.59	0	0
pH **	Maximum	9	dimensionless	132	6.85	7.35	7.52	7.64	7.76	8.03	0	0
pH **	Minimum	6	dimensionless	132	6.85	7.35	7.52	7.64	7.76	8.03	0	0
Phenolics	Maximum	0.005	mg/L	37	0.03	0.03	0.03	0.03	0.04	0.04	0	0
PO_4	No Standard	--	mg/L	133	0.04	0.1	0.1	0.1	0.1	0.21	0	0
Sp Cond **	No Standard	--	mg/L	142	227	411	507.5	605	697	1225	0	0
TChl	No Standard	--	mg/L	33	0.75	1.35	1.79	3.96	5.99	12.77	0	0
TDS	Maximum	750	mg/L	92	160	273	317.5	380.5	441	643	0	0
Temp C **	Maximum	(varies)	Deg C	129	0.1	5.5	16.1	20.2	21.8	27.6	9	7
TKN ***	Maximum	0.675	mg/L	124	0	0.3	0.35	0.5	0.616	1.83	11	8.9
TOC	No Standard	--	mg/L	8	1.23	1.3	1.58	1.84	1.99	1.99	0	0
Total Nitrogen ***	Maximum	4.91	mg/L	124	0.87	2.21	2.5	2.91	3.082	3.98	0	0
TP ***	Maximum	0.14	mg/L	138	0	0.05	0.05	0.09	0.163	0.69	14	10.1
TSS	Maximum	25	mg/L	104	1	1	1	2	3	24	0	0
Turbidity ***	Maximum	8.05	NTU	129	0.21	0.52	0.67	1.14	2.38	7.76	0	0

* *Water quality standard requires hardness correction; value listed is water quality standard calculated at 100* mg/L *CaCO3 hardness.*
** *These values are hand probe readings taken at the time of grab sampling.*
*** *Reference values from EPA 822-B-00-019*

Table 5-5 Wet Weather Water Quality Summary - Parameters with Standards

Parameter	Standard	Target Value	Units	No. Observations	Minimum	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	No. Exceeding	% Exceeding
Al	Acute Maximum	0.75	mg/L	552	0.00167	0.071	0.17125	0.5855	2.158	19.346	120	21.74
Alk	Minimum	20	mg/L	562	14	43	56.5	70	77	91	7	1.25
BOD_{30}	No Standard	--	mg/L	150	1.96	4.57	6.29	10.9	21.34	125.4	0	0.00
BOD_5	No Standard	--	mg/L	567	1.95	2	3.45	6.62	14.4	147.3	0	0.00
Chl-*a* (Water Column)	Maximum	3	ug/L	62	0.55	1.44	2.645	4.5	16.04	75.62	27	43.55
Diss Cd	Acute Maximum	* 0.0043	mg/L	194	0.001	0.001	0.001	0.001	0.001	0.001	0	0.00
Diss Cd	Human Health Maximum	0.001	mg/L	194	0.001	0.001	0.001	0.001	0.001	0.001	0	0.00
Diss Cr	Acute Maximum	0.0015	mg/L	76	0.001	0.001	0.001	0.001	0.001	0.001	0	0.00
Diss Cu	Acute Maximum	* 0.013	mg/L	81	0.002	0.005	0.007	0.008	0.011	0.015	6	7.41
Diss Cu	Human Health Maximum	1	mg/L	81	0.002	0.005	0.007	0.008	0.011	0.015	0	0.00
Diss Fe	Maximum	0.3	mg/L	199	0.024	0.064	0.097	0.156	0.229	0.701	11	5.53
Diss Pb	Acute Maximum	* 0.065	mg/L	76	0.001	0.001	0.001	0.001	0.001	0.003	0	0.00
Diss Pb	Human Health Maximum	0.005	mg/L	76	0.001	0.001	0.001	0.001	0.001	0.003	0	0.00
Diss Zn	Acute Maximum	* 0.120	mg/L	56	0.003	0.0065	0.011	0.017	0.026	0.263	1	1.79
Diss Zn	Human Health Maximum	5	mg/L	56	0.003	0.0065	0.011	0.017	0.026	0.263	0	0.00
DO**	Minimum Average	4	mg/L	232	1.99	8.06	9.21	11.335	13.13	17.29	6	2.59
DO**	Instantaneous Minimum	5	mg/L	232	1.99	8.06	9.21	11.335	13.13	17.29	4	1.72
E. coli	No Standard	--	/100mL	628	0	1500	4700	20000	69000	1820000	0	0.00
F	Maximum	2	mg/L	564	0.0675	0.098	0.104	0.121	0.151	0.888	0	0.00
Fe	Maximum	1.5	mg/L	610	0.0403	0.224	0.419	1.269	4.195	50	139	22.79

Parameter	Standard	Target Value	Units	No. Observations	Minimum	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	No. Exceeding	% Exceeding
Hardness	No Standard	--	mg/L	468	0.71	94.1	127	162	182.394	282	0	0.00
Mn	Maximum	1	mg/L	611	0.0076	0.037	0.071	0.139	0.283	3.054	13	2.13
NH_3T	Maximum	(pH dependent)	mg/L	196	0.1	0.1	0.113	0.205	0.398	2.98	0	0.00
NO_2	No Standard	--	mg/L	604	0.01	0.05	0.05	0.05	0.076	0.366	0	0.00
NO23	Maximum	10	mg/L	670	0.089	1.0045	1.6635	2.15	2.423	3.22	0	0.00
NO_3	Human Health Maximum	10	mg/L	604	0.249	1.023	2.1855	1.6545	2.47	3.27	0	0.00
pH**	Maximum	9	dimensionless	238	6.61	7.23	7.39	7.53	7.64	8.01	0	0.00
pH**	Minimum	6	dimensionless	238	6.61	7.23	7.39	7.53	7.64	8.01	0	0.00
Phenolics	Maximum	0.005	mg/L	117	0.03	0.03	0.04	0.04	0.042	0.187	14	11.97
PO_4	No Standard	--	mg/L	603	0.04	0.1	0.1	0.1	0.1	0.423	0	0.00
Sp Cond**	No Standard	--	mg/L	243	76	249	381	516	658	1897	0	0.00
TChl	No Standard	--	mg/L	76	0.66	1.435	2.37	4.925	17.06	83.25	0	0.00
TDS	Maximum	750	mg/L	184	56	158.5	230.5	307.5	398	1054	2	1.09
Temp C**	Maximum	varies	degC	238	0.5	8	13.9	19.8	21.7	24.7	6	2.52
TKN ***	Maximum	0.675	mg/L	524	0.154	0.5	0.752	1.21	2.97	15.9	295	56.30
TOC	No Standard	--	mg/L	5	1.35	1.51	1.54	1.82	1.832	1.832	0	0.00
Total Nitrogen ***	Maximum	4.91	mg/L	524	0.056	2.087	2.5705	3.0575	4.269	17.136	35	6.68
TP ***	Maximum	0.14	mg/L	601	0.001	0.067	0.1137	0.2549	0.557	3.45	242	40.27
TSS	Maximum	25	mg/L	188	1	1	2.6	10	54.5	408	30	15.96
Turbidity ***	Maximum	8.05	NTU	564	0.182	1.775	4.66	12.35	37.6	379	180	31.91

**Water quality standard requires hardness correction; value listed is water quality standard calculated at 100 mg/L CaCO3 hardness*
*** These values are hand probe readings taken at the time of grab sampling.*
**** Reference values from EPA 822-B-00-019*

Table 5-6: Sonde Data Meeting/Exceeding Standards

Parameter	Standard	Type	Period	No. Obs.	No. Exceed	% Exceeding	% Meeting
Sonde DO ave	Minimum Average		03/20/01 - 10/05/04	1540	29	1.88	98
Sonde DO min	Minimum		03/20/01 - 10/05/04	1540	104	6.75	93
Sonde Temp C	Maximum		03/20/01 - 10/05/04	177208	23350	13.18	87
Sonde pH mean	Maximum		03/20/01 - 10/05/04	2003	1	0.05	100
Sonde pH mean	Minimum		03/20/01 - 10/05/04	2003	1	0.05	100

5.3 Data Analysis and Water Chemistry

The PWD/USGS Cooperative program recorded a baseline of existing water quality that can now be compared with data collected by PWD from 2000-2004. Sample collection and laboratory techniques were comparable between the two data sets. This comparison allows for a more comprehensive analysis of water quality and the impacts of urbanization on the Tookany/Tacony-Frankford Watershed over the past 30 years.

5.3.1 Dissolved Oxygen

Along with temperature, dissolved oxygen (DO) concentration may be the most important factor shaping heterotrophic communities in streams and rivers. As sufficient DO concentration is critical for fish, amphibians, crustacea, insects, and other aquatic invertebrates, DO concentration is used as a general indicator of a stream's ability to support a balanced ecosystem (TTFIWMP Indicator 9). The Pennsylvania Department of Environmental Protection (PA DEP) has established criteria for both instantaneous minimum and minimum daily average DO concentration. Criteria are intended to be protective of the types of aquatic biota inhabiting a particular lake, stream, river, or segment thereof. Tookany/Tacony-Frankford Watershed is considered a Warm Water fishery (WWF) that cannot support salmonid fish year-round. Furthermore, the stream is not considered appropriate for a put-and-take fishery (*i.e.*, stocking trout to provide recreational opportunities). PA DEP water quality criteria require that minimum DO concentration in a WWF not fall below 4.0 mg/L and that daily averages remain at or above 5.0 mg/L.

Continuous water quality monitoring instruments (YSI Model 6600 and 600XLM Sondes) were deployed periodically at eight sites throughout Tookany/Tacony-Frankford Watershed from 2000 to 2004 to collect data in 15-minute intervals. A total of 1540 days, or the equivalent of over four years of DO data were collected from these monitoring locations. Installing, servicing, and repairing these instruments in an urban environment presented many challenges, as DO membranes were subject to fouling during and after storm events. A protocol for evaluating and rejecting data from intervals when probe failure occurred was developed (Appendix B). Intervals during which probe failure occurred are summarized in Appendix C. Quality of recovered data generally improved as procedures for cleaning and replacing sondes were developed and refined over the course of four years of study (Table 3-12).

When interpreting continuous DO data, one must keep in mind that *in situ* DO probes can only measure dissolved oxygen concentration of water in direct contact with the probe membrane. Furthermore, to obtain accurate measurements, DO probes should be exposed to flowing water or probes themselves must be in motion. Conditions found in urban areas (*e.g.*, severe flows, infrastructure effects, debris accumulation, vandalism, etc.) complicated installation and it was not always possible to situate instruments in ideal locations. Local microclimate conditions surrounding probes and biological growth on probes themselves probably contributed to errors in measurement. It was possible for Sondes situated in subtly different areas of the same stream site to exhibit marked differences in DO concentration due to flow, shading, and local microclimate differences.

DO concentration in Tookany/Tacony-Frankford Watershed was found to be highly variable, both seasonally and spatially, but in general, DO was controlled by temperature, natural community metabolism and inputs of combined sewage and untreated stormwater. As cold water has a much higher capacity for DO than warm water, DO violations were generally restricted to the warmer months. Most serious effects occurred at site TF280, but DO suppression was also observed at sites TF500 and TF620/680 (Table 5-7). Pronounced diurnal fluctuations in DO concentration were observed at sites TF280, TF1120, and TF620/680; most other sites showed only moderate fluctuation due to biological activity. Effects of stream metabolism on DO concentration are addressed in section 5.4-Stream Metabolism.

Site	Parameter	Standard	Reference	Dry Weather			Wet Weather			Comments
				No. Obs.	No. Exceed	% Exceed	No. Obs.	No. Exceed	% Exceed	
TF280	Sonde DO	5mg/L daily avg. 4mg/L min		15072	316	2.10	11439	530	4.63	Potential Problem
	Sonde Turb		8.05 NTU	5192	1045	20.13	7074	3563	50.37	Problem
TF500	Sonde DO	5mg/L daily avg. 4mg/L min		5126	0	0.00	3259	150	4.60	Potential Problem
	Sonde Turb		8.05 NTU	2579	10	0.39	1647	396	24.04	Problem
TF620	Sonde Turb		8.05 NTU	5298	244	4.61	7083	1727	24.38	Problem
	Sonde pH	6-9 inclusive		19380	598	3.09	20510	155	0.76	Potential Problem
TF760	Sonde Turb		8.05 NTU	3623	732	20.20	2710	1411	52.07	Problem
TF975	Sonde Turb		8.05 NTU	9328	360	3.86	9333	2972	31.84	Problem
TF1120	Sonde Turb		8.05 NTU	8972	561	6.25	8862	2722	30.72	Problem
TFJ110	Sonde Turb		8.05 NTU	550	0	0.00	894	251	28.08	Problem
TFM006	Sonde Turb		8.05 NTU	2412	40	1.66	3191	863	27.04	Problem
7th and Cheltenham	Sonde Turb		8.05 NTU	963	1	0.10	182	37	20.33	Problem

5.3.2 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand is an empirical test that measures depletion of oxygen within a water sample over a period of time due to respiration of microorganisms as well as oxidation of inorganic constituents (*e.g.*, sulfides, ferrous iron, nitrogen species) (Greenberg *et al*. 1992). Inhibitors may be used to prevent nitrification in a Carbonaceous Biochemical Oxygen Demand (CBOD) test, and the test may be carried out over the course of thirty or more days to yield ultimate BOD. The BOD_5 test, in which depletion of DO is measured over a five day period, was applied most consistently to water samples from sites in Tookany/Tacony-Frankford Watershed. BOD is one of the most important input parameters for computer simulation of oxygen demand in water quality models. As warm stream water has a limited capacity for DO, excess BOD may preclude warm water streams from meeting WQ criteria despite re-aeration due to diffusion and algal production of DO.

Tookany/Tacony-Frankford Watershed is not affected by municipal wastewater treatment plants or other permitted discharges that would introduce BOD to the stream. Elevated BOD_5 is thus a good indicator of the presence of organic material in stream water that may exert oxygen demand independently of natural stream metabolism. CSO and SSO discharges were believed to be the most important sources of wet weather BOD loading to Tookany/Tacony-Frankford Watershed. Elevated dry weather BOD_5 values were observed frequently at site TF280, and occasionally at sites TF975 and TFM006, suggesting the presence of sewage in dry weather. These results corroborate other sewage indicators observed at these sites (*e.g.*, fecal coliform bacteria, ammonia). Activities recommended to meet target A of the TTFIWMP will address these high priority sources.

Evaluation of BOD_5 results in a watershed where most sources exhibit spatial and temporal variability is difficult. The BOD_5 test provides little information when samples are dilute (MRL= 2mg/L), which is often the case in dry weather samples from streams lacking point source discharges or other sources of organic enrichment (87% of dry weather samples and 28% of wet weather samples had BOD_5 concentration below reporting limits). Analysts must also determine an appropriate series of dilution ratios without *a priori* knowledge of the sample's potential to deplete oxygen. For this reason, 4% of samples were reported as minimum values (*i.e.*, actual values were known to be greater than the value reported but the dilution sequence did not allow computation of an actual value); all samples in which BOD_5 concentration were reported as minimum values were collected in wet weather.

As BOD_5 concentration data were affected by a large number of imprecise values, nonparametric statistics were used in comparing between sites and evaluating wet weather effects. In the latter analysis, data from all sites were combined, non-detects were included as half the method reporting limit (MRL), and minimum values were included as if they were actual values. BOD_5 concentration was found to be significantly greater in wet weather than in dry weather (Mann-Whitney U test, $Z_{2,689} = -7.27$, $p<0.001$), and there was a significant effect of site in wet weather (Kruskal-Wallis ANOVA, $H_{8,565}= 73.32$, $p<0.001$, (Figure 5-2), which is likely due to frequent CSO discharge at site TF280 (mean wet weather BOD_5 11.79±18.22). Though sampling effort was not equal across sites, mean wet weather BOD_5 data suggest CSO discharge at site TF620/680 (5.98±6.55) and occasional SSO discharge or other sources of organic enrichment at sites TFM006 (7.21±7.84), TF975 (4.95±5.74) and TF1120 (4.13±3.89).

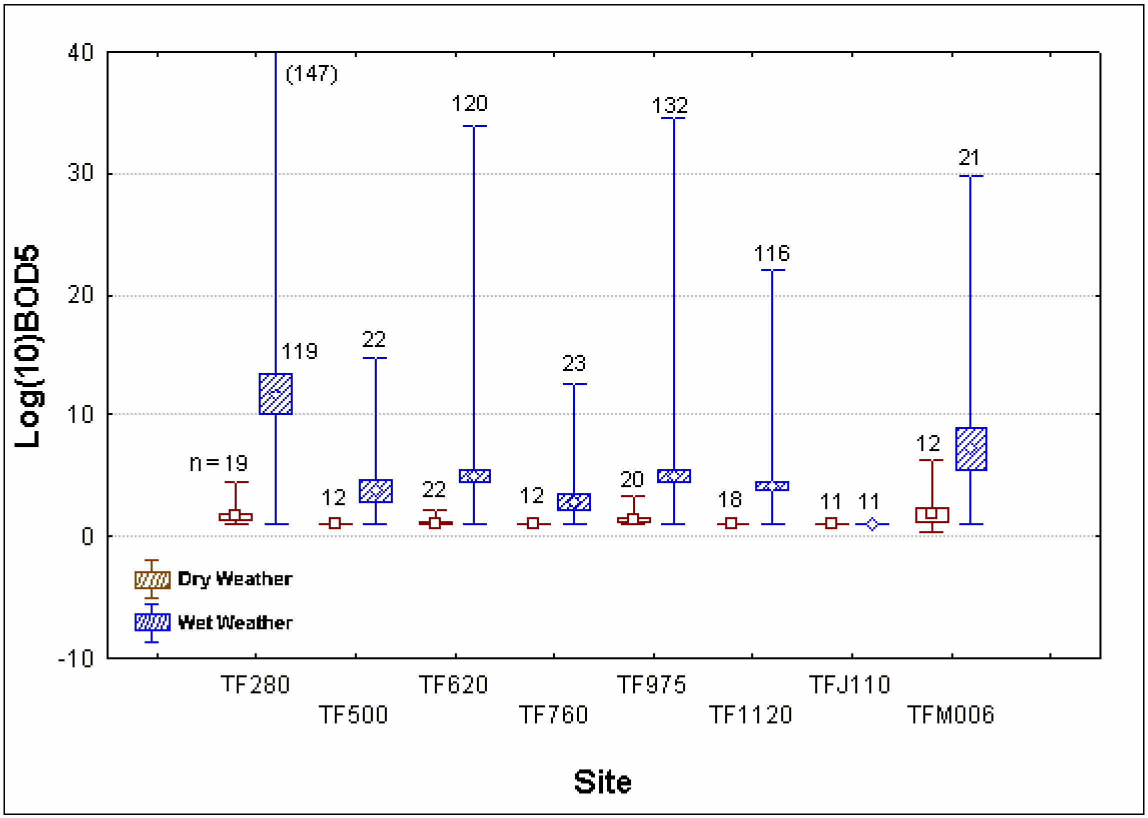


Figure 5-2 Five Day Biological Oxygen Demand of samples collected from 8 sites in Tookany/Tacony-Frankford Watershed in Dry and Wet Weather.

5.3.3 pH

Water quality criteria established by PA DEP regulate pH to a range of 6.0 to 9.0 in Pennsylvania's freshwater streams (Commonwealth of Pennsylvania, 2001). Direct effects of low pH on aquatic ecosystems have been demonstrated in streams affected by acid mine drainage (Butler *et al*. 1973) and by acid rain (Sutcliff and Carrick 1973). Aquatic biota may also be indirectly affected by pH due to its influences on other water quality parameters, such as ammonia. As pH increases, a greater fraction of ammonia N is present as un-ionized NH_3 (gas). For example, ammonia is approximately ten times as toxic at pH 8 as at pH 7. Extreme pH values may also affect solubility and bioavailability of metals (*e.g.*, Cu, Al), which have individually regulated criteria established by PA DEP.

Continuous pH data show that pH fluctuations most often occur at highly productive sites with abundant periphytic algae (Figure 5-3). Pronounced diurnal fluctuations in pH were observed at site TF620, and occasionally at site TF280. These sites occasionally violated water quality criteria by exceeding pH 9.0; minimum pH standards were rarely violated (Table 5-6). pH at shadier sites (*i.e.*, TF500 and sites upstream of site TF680) was probably less strongly influenced by metabolic activity and fluctuations in pH appeared noticeably damped as a result. Algal densities and stream metabolism effects on stream pH are discussed further in section 5.4 Stream Metabolism.

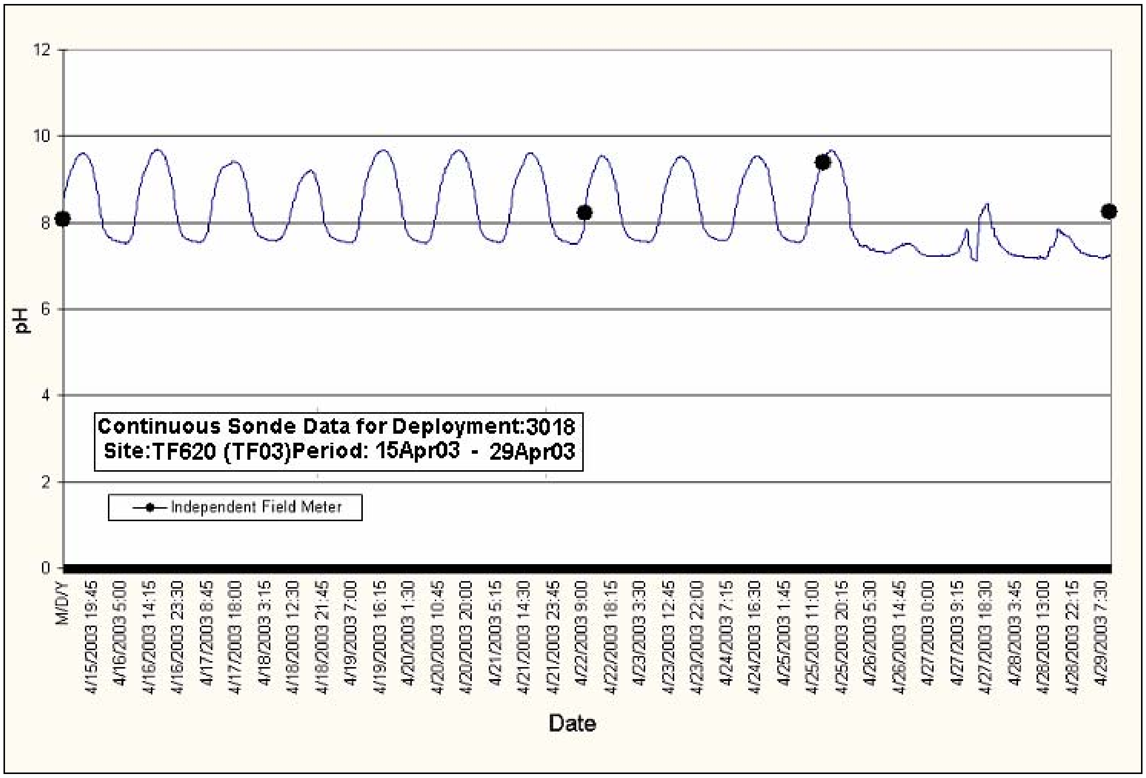


Figure 5-3 Example of pH fluctuations at site TF620, April 2003

Tookany/Tacony-Frankford Watershed is not known to be directly affected by anthropogenic inputs of acids or bases (*e.g.*, acid mine drainage, industrial discharge) that would tend to change stream pH independently of the natural bicarbonate buffer system. Accordingly, the TTFIWMP does not specifically address pH as a separate problem independent of stream eutrophication. Furthermore, as pH problems in Tookany/Tacony-Frankford Watershed are tied closely to DO problems, remediation efforts intended to decrease the frequency and geographic extent of low DO concentrations should generally decrease the severity of pH problems as well. One important caveat, however, is that pH problems may occur at any time of the year when algal production is high. It is possible to have severe fluctuations in DO that do not violate water quality standards due to the greater DO capacity of colder water. While there is a small compensatory effect of lower temperatures on pH toxicity, in general, pH effects may be present under high productivity conditions whenever they occur.

5.3.4 Fecal Coliform and *E. coli* Bacteria

Fecal coliform and *E. coli* bacteria concentrations are positively correlated with point and non-point contamination of water resources by human and animal waste and are used as indicators of poor water quality (Indicator 7, TTFIWMP). PA DEP has established a maximum limit of 200 colony forming units, or "CFU," per 100mL sample during the period 1May - 30Sept, the "swimming season" and a less stringent limit of

2000CFU/100mL for all other times. It should be noted that state criteria are based on the geometric mean of a minimum of five consecutive samples each sample collected on different days during a 30-day period (Commonwealth of Pennsylvania, 2001). As bacterial concentrations can be significantly affected by rain events and otherwise may exhibit high variability, individual samples are not as reliable as replicate or multiple samples taken over a short period.

Based on data from numerous sources (*e.g.*, EPA, USGS, USDA-NRCS, volunteer monitoring organizations, etc.), it appears likely that many, if not most, southeastern PA streams would be found in violation of water quality criteria for fecal coliform bacteria concentration during the swimming season given sufficient sampling effort. PWD has expended considerable resources toward documenting concentrations of fecal coliform bacteria and *E. coli* in Philadelphia's watersheds. The sheer amount of data collected allows for more comprehensive analysis and a more complete picture of the impairment than does the minimum sampling effort needed to verify compliance with water quality criteria. In keeping with the organizational structure of the watershed management plan, fecal coliform bacteria analysis has been separated into dry (Target A) and wet weather (Target C) components, defined by a period with at least 48 hours without rain as measured at the nearest gauge in PWD's rain gauge network.

5.3.4.1 Dry Weather Fecal Coliform Bacteria (Target A)

The geometric mean of 63 fecal coliform bacteria concentration samples collected from Tookany/Tacony-Frankford Watershed in dry weather during the non-swimming season from 2000-2004 did not exceed 2000CFU/100mL (Table 5-8). Only one sample, collected from site TF280, exceeded 2000CFU/100mL (estimated fecal coliform concentration 2100CFU/100mL). In contrast, dry weather geometric mean fecal coliform concentration exceeded water quality criteria of 200CFU/100mL during the swimming season at all sites except TFJ110 (Table 5-9). An improvement in mean fecal coliform concentration can be seen in both swimming and non-swimming season when data from 2000-2004 is compared to historical data from 1970-1980 (t-test $F_{2,140}$= 5.6, p <0.05; $F_{2,163}$ =3.76,p <0.05 respectively)

Table 5-8 Fecal Coliform Concentration (CFU/100mL) Dry Weather Non-swimming Season (1 Oct. - 30 Apr.)

	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
TF280	9	600	286	290	30	2100	777
TF500	8	468	226	330	10	1500	500
TF620	10	259	187	225	30	550	187
TF760	8	139	83	105	10	390	129
TF975	9	408	312	450	90	900	276
TF1120	9	229	186	200	40	410	131
TFJ110	6	55	42	65	10	90	34
TFM006	4	293	231	210	100	650	244

Table 5-9 Fecal Coliform Concentration (CFU/100mL) Dry Weather Swimming Season (1 May - 30 Sept.)

	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
TF280	12	1474	773	425	190	4800	1591
TF500	6	2655	2003	2300	800	6900	2261
TF620	15	833	700	700	340	2700	644
TF760	5	562	514	440	300	1000	275
TF975	13	1620	1130	860	450	6000	1652
TF1120	11	632	541	450	260	1500	409
TFJ110	4	175	173	185	130	200	31
TFM006	8	447	354	365	90	900	298

Collectively, mean fecal coliform bacteria concentration of sites in the City of Philadelphia were significantly higher during the swimming season than during the non-swimming season ($F_{2,68}$= 1.48, p=.000016). Sites in Montgomery County follow the same temporal pattern and have a significantly higher mean during the swimming season ($F_{2,64}$=1.83, $p<0.05$). This could be due to higher temperatures during the swimming season. Increased temperatures may allow bacteria to persist longer in the water column and in sediments. Additionally, bacteria load may increase in warmer weather as a result of wildlife and dog walking activity. Drought and decreased storm duration/intensity during summer months may also partially explain temporal variability in mean fecal coliform concentration. Greater amounts of rain and snow melt during the non-swimming season may dilute fecal coliform concentrations.

With the exception of intense sampling upstream and downstream of a point source, surface water grab samples do not usually allow one to determine source(s) of fecal contamination. Research has shown that fecal coliform bacteria may adsorb to sediment particles and persist for extended periods in sediments (VanDonsel *et al.* 1967, Gerba 1976). At sites where dry weather inputs of sewage are not indicated, presence of persistent background concentrations of bacterial indicators in dry weather may thus more strongly reflect past wet weather loadings than dry weather inputs (Dutka and Kwan, 1980). Clearly, there exist several possible sources of fecal coliform bacteria within the watershed, all or combinations of which may be acting within different spatial and temporal dimensions. PWD is piloting a Bacterial Source Tracking (BST) program that may eventually be useful in identifying the sources of fecal coliform bacteria collected in dry weather. Of particular interest is the relative proportion of the total bacterial load from human sources vs. domestic and wildlife animal sources.

5.3.4.2 Wet Weather Fecal Coliform Bacteria Concentration (Target C)

Wet weather fecal coliform concentration of 480 samples collected during the swimming season (*i.e.*, 5/1 - 9/30) and 140 samples collected during the non-swimming season were estimated. Geometric mean fecal coliform concentration of all samples collected in wet weather during the swimming season exceeded the 200 CFU/100mL water quality criterion (table 5-10, figure 5-4). All sites except TFJ110 had geometric mean fecal coliform concentration greater than $3x10^3$ CFU/100mL. Sites TF280 and TFM006 showed evidence of severe wet weather sewage impacts (estimated geometric mean fecal coliform concentration 23,773 and 13,787 CFU/100mL respectively).

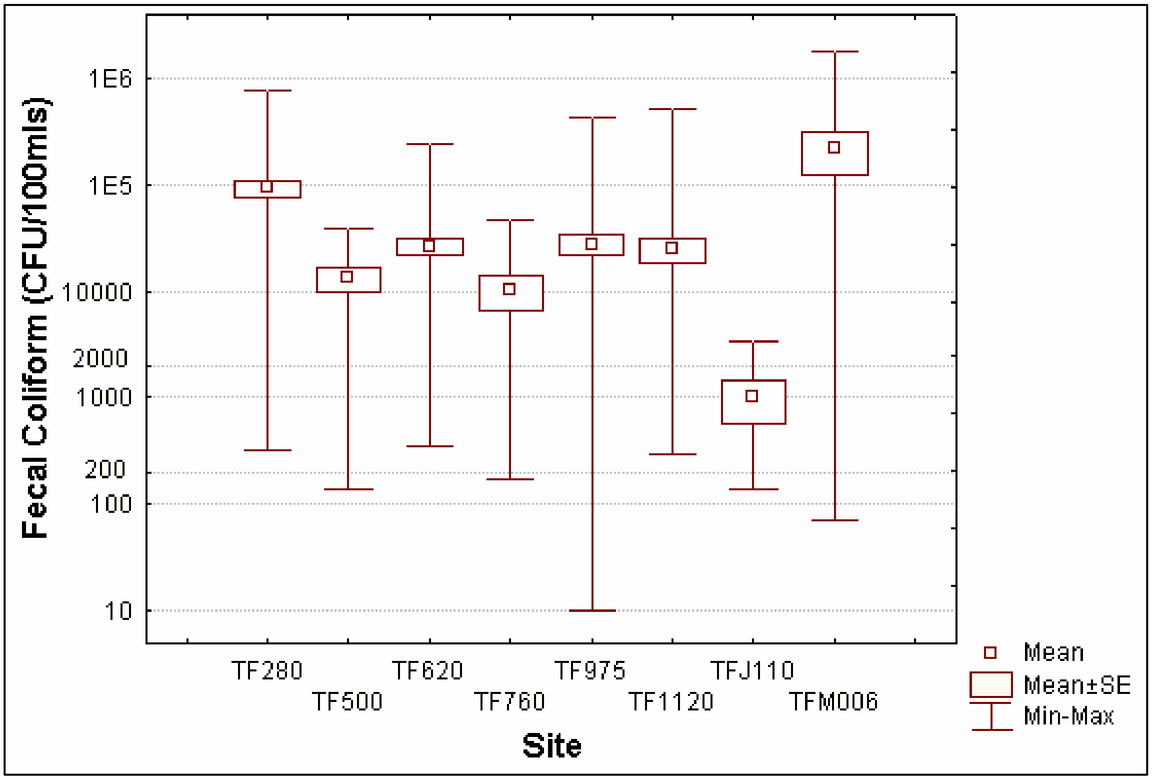


Figure 5-4 Fecal Coliform Bacteria Concentrations of Samples Collected from 8 sites in Tookany/Tacony Frankford Watershed in Wet Weather during the Swimming Season, 2000-2004.

The latter site is located on Mill Run, a historic stream with a drainage area of ca 1mi^2, 52% of which is estimated to be impervious surface. This stream is encapsulated in a storm sewer in Philadelphia, and presently surfaces at stormwater outfall T-88. From 1994 to 1995 PWD investigated 3500 homes within the Mill Run collection area for crossed connections and defective sanitary lateral pipes; although 130 problems were identified and corrected, sewage problems continued. In 2002, PWD sewer maintenance crews installed 6 slot regulators to allow contaminated baseflow in branch storm sewers to be routed to the sanitary sewer. Though subsequent outfall samples collected by PWD's Industrial Waste Unit showed reduced dry weather concentrations of fecal coliform bacteria, large sewage discharges are still reported periodically at the site.

Table 5-10 Fecal Coliform Concentration (CFU/100mL) Wet Weather, Swimming Season (1 May - 30 Sept.)

	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std. Dev.
TF280	104	95132	23774	32000	320	780000	163153
TF500	14	13766	6199	8500	140	40000	13323
TF620	98	27064	8808	8250	350	250000	44437
TF760	14	10446	3357	2950	170	48000	14147
TF975	107	28750	7275	6500	10	430000	61335
TF1120	110	25256	5503	4850	290	520000	66313
TFJ110	8	1004	580	455	140	3500	1219
TFM006	27	223534	15049	11200	70	1820000	497239

Surface water samples collected at site TFM006 in dry weather (n=6) do not indicate severe problems, however, results from a targeted wet weather sampling event 8/30/04-9/1/04 suggest that sewage impacts in wet weather are still a serious problem at this stormwater outfall (Figure 5-5). Source(s) of these sewage inputs remain unknown. PWD's Waterways Restoration Team (WRT) completed a streambank restoration project at this outfall in 2005, and removal of a large plunge pool was one component of the restoration design. It is hoped that reduction of stagnant water will reduce the influence of small wet weather sewage impacts on dry weather fecal coliform concentrations.

Mean wet weather fecal coliform concentration during the swimming season was significantly greater than that of the non-swimming season both within the City of Philadelphia ($F_{2,316}$= 1.11, p <0.05) and in Montgomery County ($F_{2,302}$= 1.35, p= 0.002). However geometric mean fecal coliform concentrations during the non-swimming season exceeded 2,000 CFU/100mL at sites TF280, TF500, TF620, TF975 and TF1120 (tables 5-10 and 5-11 and Figure 5-5). Although few samples were collected in wet weather during the non-swimming season, Sites TFM006 (geometric mean 137, n=2) and TFJ110 (geometric mean 51, n=3) did not exceed water quality standards. Improvements in mean fecal coliform concentration were observed in both the swimming (historical n=22, modern n=482) and non-swimming season when data from 2000-2004 was compared with historical data from 1970-1980 (t-test $F_{2,502}$=1.08, p=.004 and $F_{2,164}$=1.24, p=.002 respectively).

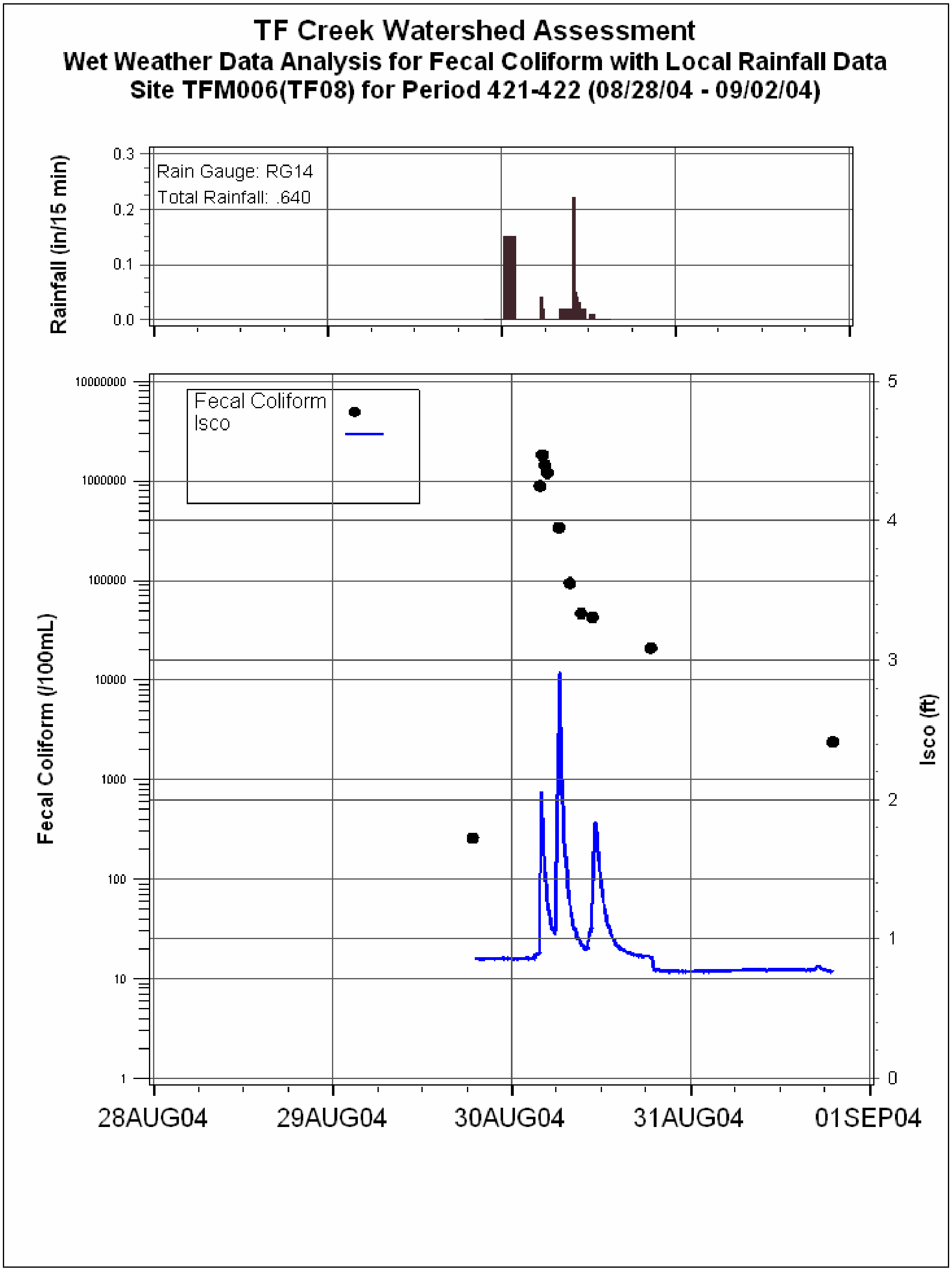


Figure 5-5 Fecal coliform analysis for wet weather event on August 30, 2004 at TFM006

Table 5-11 Fecal Coliform Concentration (CFU/100mL) Wet Weather, Non-swimming Season (1 Oct. - 30 Apr.)

	Valid N	Mean	Geometric Mean	Median	Minimum	Maximum	Std.Dev.
TF280	30	19959	4439	13150	20	70000	22417
TF500	9	14734	2439	3800	140	91000	29570
TF620	34	9038	3397	4000	110	35000	11028
TF760	9	4721	1311	3100	100	22000	6992
TF975	34	10361	3785	4750	100	49000	13111
TF1120	19	11272	3189	6200	50	47000	13559
TFJ110	3	60	51	40	30	110	44
TFM006	2	170	137	170	70	270	141

5.3.5 Temperature

Temperature has a very strong influence on the structure of aquatic communities, determining the saturation concentration of dissolved oxygen and the rate of many biological and physicochemical processes. Though aquatic organisms generally have enzymes capable of working over a range of temperatures, thermal preferenda and tolerance values determine, to a large degree, the range of many species' distributions. This effect is especially true of larger vertebrates, such as fish. Thermal WQ criteria for Tookany/Tacony-Frankford are based on the warm water fishery (WWF) designation, and reflect the fact that the watershed is not expected to have appropriate habitat for maintenance of self propagating populations of coldwater fish (*e.g.*, trout species).

Maximum temperature criteria for WWF vary temporally, but require stream temperatures below 87°F (30.5°C) for the warmest months of the year (*i.e.*, July through August). Heated wastes, such as industrial cooling waters, can neither cause stream temperature to exceed the maximum temperature criterion for a given time period, nor can they result in an increase of 2°F (~1.1°C) over one hour. Continuous water quality monitoring results suggest that temperatures in Tookany/Tacony-Frankford rarely exceed maximum WQ criteria, but increases of 2°F over a one hour period are common due to natural temperature fluctuations (Table 5-6). Flow modifications have probably reduced the influence of groundwater on baseflow water temperature. Dam construction and riparian buffer removal have also probably resulted in enhanced solar heating of stream water. Effects of temperature on fish populations are also discussed briefly in section 8.3 Fish Habitat Indices.

5.3.6 Other Physicochemical Parameters

5.3.6.1 Total Suspended Solids

Sediment transport in small streams is dynamic and difficult to quantify. Numerous factors can affect a stream's ability to transport sediment, but generally sediment transport is related to streamflow and sediment particle size. Stable streams are generally capable of maintaining equilibrium between sediment supply and transport, while unstable streams may be scoured of smaller substrate particles or accumulate fine sediments. The latter effect is particularly damaging to aquatic habitats. PA DEP has identified the cause of impairment in Tookany/Tacony-Frankford to be a combination of "Water/Flow

Variability", "Flow Alterations", and "Other Habitat Alterations". "Siltation" was not listed as a cause of impairment, but the effects of sediment deposition, where and when they occur, are probably addressed by "Other Habitat Alterations".

Water sampling techniques that are adequate to characterize most water quality parameters (*e.g.*, grab samples, automated sampling) are not generally appropriate for evaluating sediment transport in fluvial systems (Edwards and Glysson 1988); errors related to sampling technique should preclude computation of sediment transport during severe storm events that mobilize large streambed particles. TSS concentration (Log transformed) was significantly greater in wet weather than in dry weather ($F_{2,286}$= 8.72, p<0.001).

Maximum daily TSS concentration (log transformed) was found to be significantly positively correlated to average daily streamflow at site TF280 ($r_{(33)}$= 0.85, p<0.001, (Figure 5-6) and instantaneous TSS concentration (log transformed) was positively significantly correlated with instantaneous discharge at all gauged sites in the PWD Historical water quality database (unpublished data). These comparisons of TSS concentration to stream discharge supported the use of TSS concentration as a surrogate measure of the intensity of streamflow and the presence of eroded soil and streambed particles for the purpose of comparing concentrations of certain water quality parameters (*i.e.*, Phosphorus, Nitrate, toxic metals) with intensity of streamflow and soil erosion at stations where USGS gauges have been eliminated.

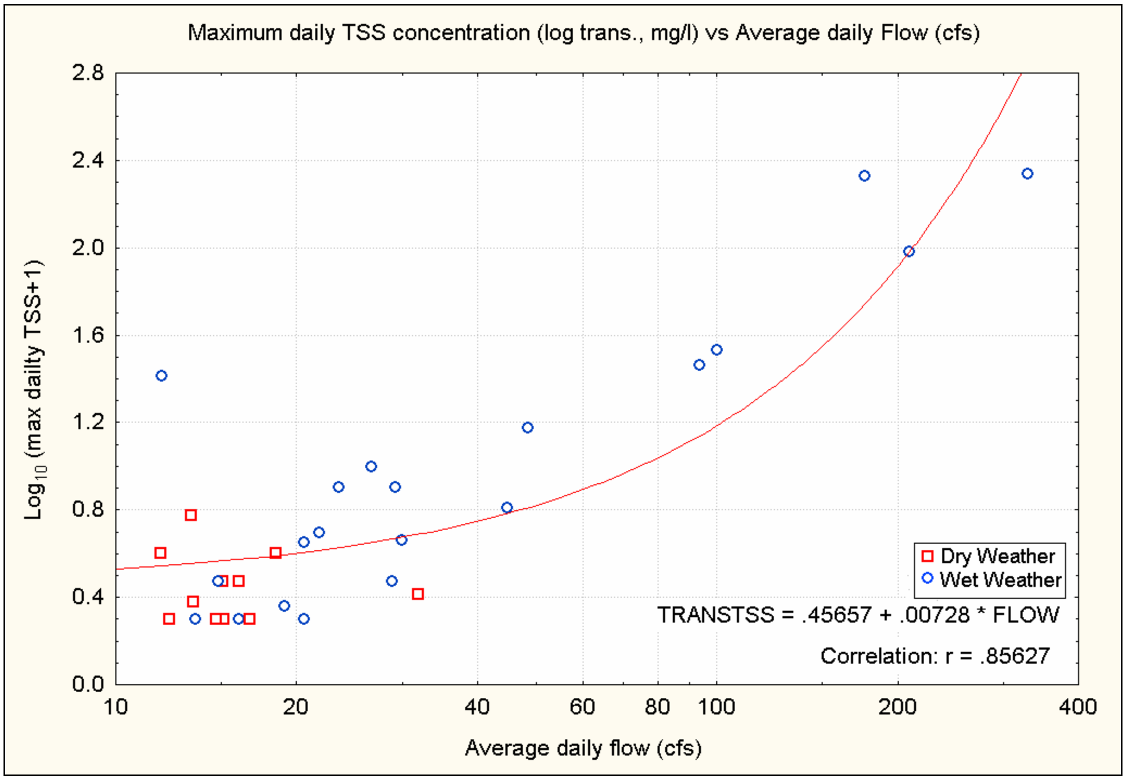


Figure 5-6 Maximum Daily Total Suspended Solids Concentration and Corresponding Average Daily Flow at site TF280.

5.3.6.2 Turbidity

Turbidity is a measure of the light scattering properties of particles suspended in water. In streams, turbidity can come from many sources, but the chief cause of increased turbidity is suspended sediment. While a correlation between turbidity and TSS certainly exists, the relationship between turbidity and TSS may differ between water bodies and even among different flow stages/seasons in the same water body due to sediment characteristics. Consistently turbid waters often show impairment in aquatic communities. Light penetration is reduced, which may result in decreased algal production; suspended particles can clog gills and feeding apparatus of fish, benthic invertebrates, and microorganisms. Feeding efficiency of visual predators may also be reduced.

PA DEP has not established numeric WQ criteria for turbidity, though General Water Quality Criteria (Title 25, Section 93.6) specifically prohibit substances attributable to any point or non-point source in concentrations inimical or harmful to aquatic life. Discharge of substances that produce turbidity are also specifically prohibited. As turbidity may vary considerably from stream to stream, the TTFIWMP uses a reference value of 8.05 NTU to define excess turbidity, based on an analysis of turbidity data from reference reaches in EPA Region IX, subregion 64. All sites in Tookany/Tacony-Frankford were determined to have excess turbidity in wet weather, and many sites were determined to potentially have problems with turbidity in dry weather as well (Table 5-7), though construction activities along SEPTA railroad tracks and within a restoration site in Cheltenham may have contributed excess turbidity in dry weather.

5.3.6.3 Conductivity and Total Dissolved Solids

Conductivity and Total Dissolved Solids (TDS) are measures of the concentration of ions and solids dissolved in water. TDS is an empirical laboratory procedure in which a water sample is filtered and dried to yield the mass of dissolved solids, while conductivity is a measure of the ability of water to conduct electricity over a given distance, expressed as microsiemens/cm (corrected to 25°C, reported as Specific conductance) (Greenberg *et al.* 1993). With sufficient data, a good relationship between conductivity and TDS can be established. Waters containing large relative proportions of organic ions (*e.g.*, bog or wetland samples containing organic acids) generally have less conductivity for equivalent TDS concentration than waters containing primarily inorganic ions.

Dissolved ion content is perhaps most useful in determining the start of wet weather events at ungauged water quality monitoring stations. Conductivity probes are generally simple in design, robust, and very accurate. They are extremely sensitive to changes in flow, as stormwater (diluent) usually contains smaller concentrations of dissolved ions than stream baseflow. A notable exception to this rule concerns the application of ice melt chemicals to roads (primarily Sodium, Magnesium, and Potassium salts). When present in runoff or snowmelt, these substances can cause large increases in ionic strength of stream water. Though some formulations may increase levels of Chloride, PA DEP WQ criteria for Chloride (maximum 250mg/L) are intended to protect water supplies, and aquatic life effects have not been reliably demonstrated at moderate levels typically experienced in streams.

5.3.6.4 Hardness

Hardness is a calculated water quality parameter. Separate determinations of concentrations of Calcium (Ca) and Magnesium (Mg), which are the two primary cations in surface waters, are combined using the formula 2.497[Ca]+4.118[Mg], the result expressed as an equivalent concentration of $CaCO_3$ in mg/L. Waters of the Commonwealth of Pennsylvania must contain 20mg/L minimum $CaCO_3$ hardness concentration, except where natural conditions are less. No samples collected from Tookany/Tacony-Frankford had hardness concentration below this WQ criterion. Hardness is important in the calculation of WQ criteria for toxic metals (Commonwealth of Pennsylvania, 2001), as toxicity of most metals is inversely proportional to hardness concentration. Potential violations of water quality criteria for some toxic metals (*e.g.*, Cadmium) could not be determined, as hardness concentrations were small enough to decrease WQ criteria below reporting limits for the ICP-MS technique (*i.e.*, less than 1μg/L). These samples are discussed in greater detail in section 5.3.7.

5.3.6.5 Iron and Manganese

Iron (Fe) and Manganese (Mn) are generally not toxic in streams, but are regulated in waters of the Commonwealth of Pennsylvania for public water supply (PWS) protection (Commonwealth of Pennsylvania, 2001) because excess concentrations of these metals can cause color, taste, odor, and staining problems in drinking water and industrial applications. Both elements are essential nutrients for all life and relatively abundant in the soils and surface geology of the Tookany/Tacony-Frankford Watershed. Iron is particularly abundant (at approximately 5% of the Earth's crust it is second only to Aluminum in abundance among metals) and was detected in 746 of 761 samples collected from the Tookany/Tacony-Frankford Watershed. Manganese was less abundant but nevertheless detected in 745 of 762 samples. Presence of these metals in surface water samples may be natural- related to weathering of rock and soils- or due to stormwater runoff and ferrous materials in contact with the stream (*e.g.*, pipes and metal debris).

Violations of total recoverable Fe water quality criteria were frequent in wet weather and Mn criteria were exceeded in a small number (~2%) of samples (Table 5-5). However, neither Fe nor Mn is toxic to aquatic life at concentrations observed, and these constituents cannot be responsible for observed impairments in aquatic communities. Unlike toxic metals (*e.g.*, lead, cadmium and copper), Fe and Mn are not regulated by Pennsylvania Code Title 25, Chapter 16-Toxic Substances Criteria. Scientists from PWD's Bureau of Laboratory Services conducted a large scale case study of Fe and Mn concentrations in Tookany/Tacony-Frankford in 2000 and 2002, results of which are being prepared for publication.

5.3.7 Toxic Metals

Toxic metals have been recognized as having the potential to create serious environmental problems even in relatively small concentrations (Warnick and Bell 1969, LaPoint *et al*. 1984, Clements *et al*. 1988). As such, their presence in waters of the Commonwealth, treatment plant effluents, and other permitted discharges is specially regulated by Pennsylvania Code Title 25, Chapter 16-Toxic Substances Criteria. Considerable research over the past two decades has been directed at understanding the ecotoxicology of heavy metals (*e.g.*, biological pathways, physical and chemical mechanisms for aquatic toxicity, thresholds for safe exposure both acute and chronic, roles of other water quality constituents in bioavailability of toxic metals, etc.).

It is now widely accepted that dissolved metals best reflect the potential for toxicity to organisms in the water column, and many states, including PA, have adopted dissolved metals criteria (40 CFR 22227-22236). As many metals occur naturally in various rocks, minerals, and soils, storm events can expose and entrain soil and sediment particles that naturally contain metals. These inert particles are removed when samples are filtered for dissolved metals analysis (Greenberg *et al*. 1992). Total recoverable metals samples are digested and acidified to liberate organically-bound and complexed metals, but this process may also solubilize metals in inorganic and particulate states that are stable and inert under normal stream conditions, overestimating the potential for toxicity.

However, since it is not possible to filter samples collected with automatic sampling equipment immediately after collection, PWD has collected a greater number of total metals samples than dissolved metals samples. In order to ensure an adequate number of dissolved samples, particularly in wet weather, samples were collected from site TF280 during wet weather on two dates in summer 2004. Samples were collected manually by pumping through the automatic sampling tubing and apparatus and filtered immediately after collection. Site TF280 was sampled to conservatively direct sampling effort to the drainage that would be expected to contain the most potential sources of urban wet weather runoff pollution.

Analysis of paired dissolved/total metals concentration data suggests that most metals are generally found in considerably greater concentrations when total metals are measured, particularly in wet weather. Since dissolved metals concentrations are usually small or undetectable in both dry and wet weather, the potential for heavy metal toxicity in Tookany/Tacony-Frankford, at least for water column organisms, is believed to be low. Sediment and pore water conditions may result in greater concentrations or otherwise contribute to increased potential for toxicity to benthic organisms within stream sediment microhabitats, but these effects remain poorly defined and are difficult to measure. Total recoverable metals results and comparisons to discontinued total metals water quality criteria are included herein as a reference measure of the potential for sediment metal loading and metals loading to the Delaware estuary from Philadelphia's urban stormwater; though it is believed that, for at least some metals, samples more closely reflect natural soil and geologic features than water pollution.

With the exception of Aluminum and hexavalent Chromium, PA WQ criteria are based on hardness (as $CaCO_3$), to reflect inverse relationships between hardness and toxicity that exist for most metals (Figure 5-7). While these criteria are much improved over simple numeric criteria, they fail to describe the complex interactions between dissolved metals and other water constituents and physicochemical properties (*e.g.*, Dissolved Organic Carbon, pH, temperature, and ions other than Ca and Mg,). Hardness-based criteria may represent an intermediate step between simple numeric criteria and criteria based on more complex water quality models (*i.e.*, Biotic Ligand Model), drafts of which have been recently been presented by EPA.

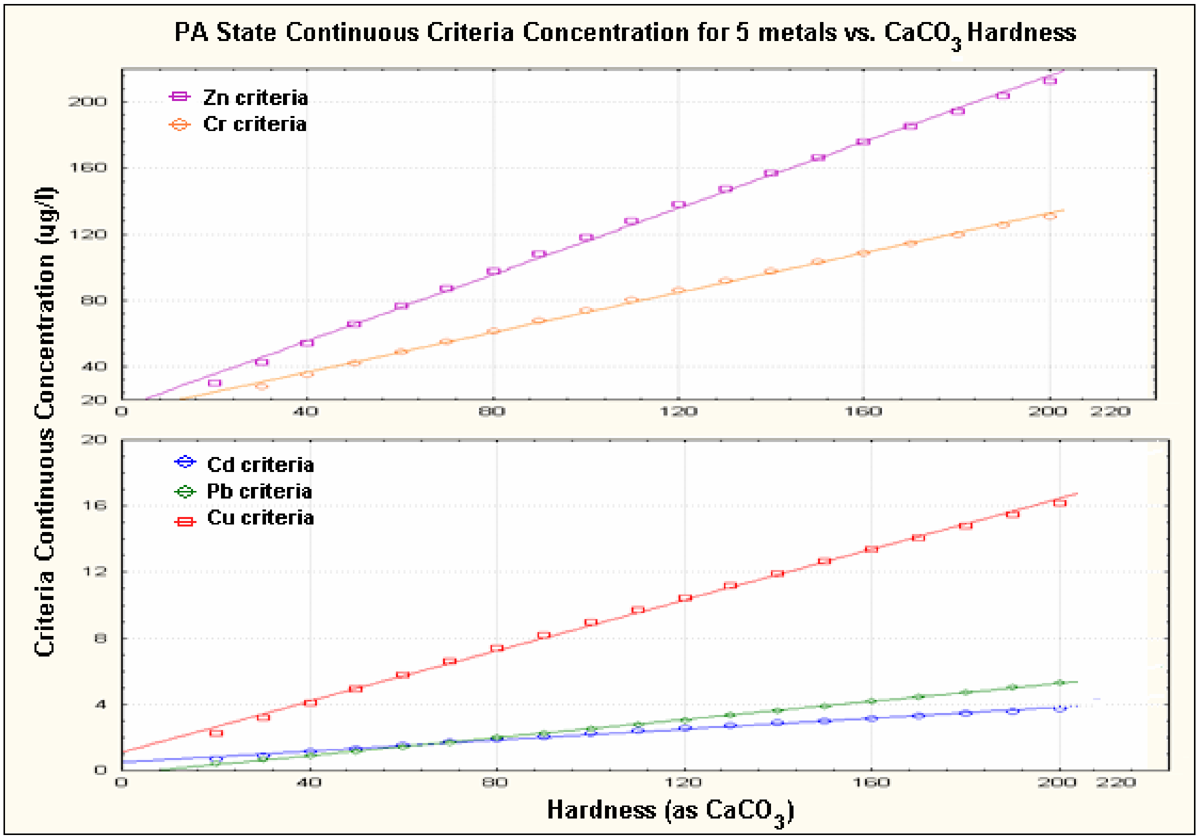


Figure 5-7 PA DEP Hardness-based Criteria Continuous Concentrations for 5 toxic metals.

5.3.7.1 Aluminum

Aluminum (Al) is the most abundant metal in the Earth's crust at approximately 8.1% by mass. As Al is a component of many rocks and minerals, particularly clays, weathering of rocks and soil erosion contribute Al to all natural waters. Water column Al concentrations were significantly higher in wet weather than in dry weather (Mann-Whitney test $Z_{2,699}$= -13.28, p<.05), which may be due to both natural and anthropogenic sources. Examination of paired dissolved and total recoverable Al concentrations from 45 samples collected from Tookany/Tacony-Frankford shows that while total recoverable Al concentrations may often exceed 100ug/L in wet weather, dissolved Al is rarely present in similar concentrations (Figure 5-8). This finding suggests that most Al is present in particulate form.

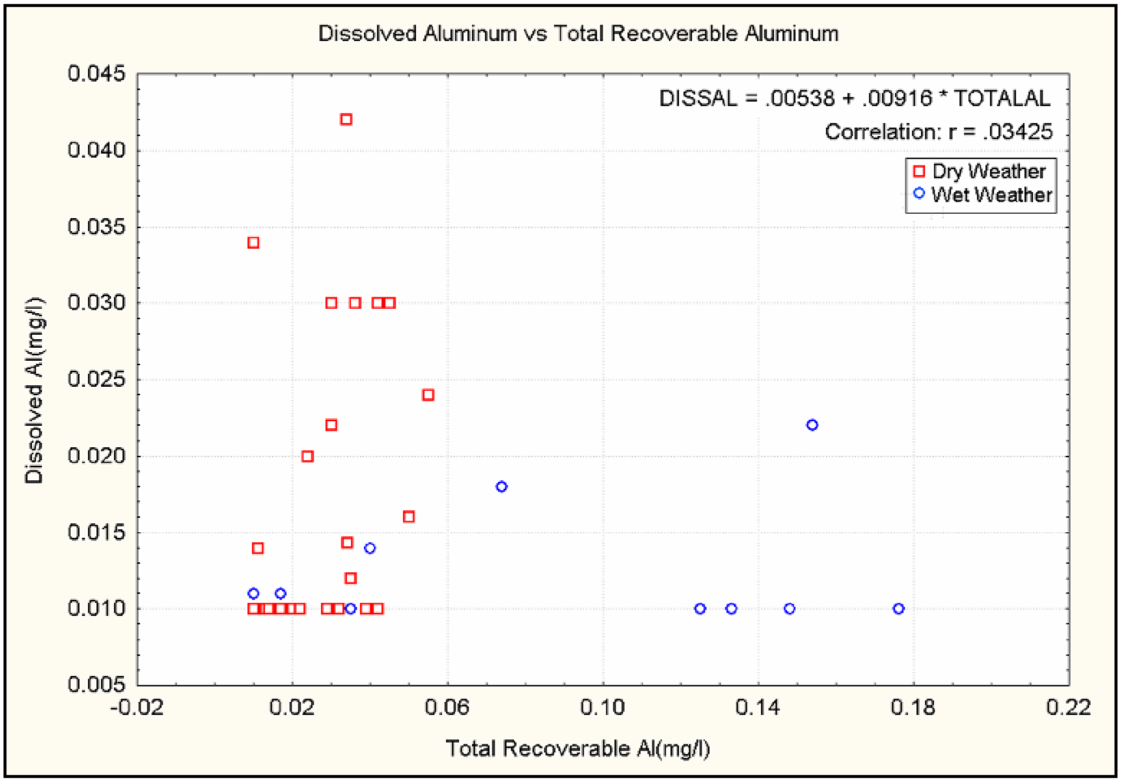


Figure 5-8 Scatterplot of Paired Dissolved Aluminum and Total Recoverable Aluminum Concentrations of Samples collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

Al was detected in 643 of 701 samples from Tookany/Tacony-Frankford (Table 5-12). Though 120 of 135 samples found to be in violation of water quality criteria were collected in wet weather, violations occurred with similar relative frequency in dry and wet weather because wet weather samples were much more numerous overall and dry weather criteria are far more stringent than wet weather criteria (87µg/L and 750µg/L, respectively).

Table 5-12 Summary of Toxic Metals Samples Collected in Dry and Wet Weather and Corresponding Number of Samples Found to have Concentrations Below Reporting Limits

Parameter	Number of Dry Samples	Number of Dry Non-Detects	Number of Wet Samples	Number of wet Non-Detects
Total Aluminum	149	22	552	36
Dissolved Aluminum	55	26	12	7
Total Cadmium	129	129	605	560
Dissolved Cadmium	83	83	194	194
Total Chromium	102	82	548	267
Dissolved Chromium	46	45	76	76
Total Copper	154	0	609	0
Dissolved Copper	74	0	81	0
Total Lead	146	113	605	123
Dissolved Lead	65	65	76	59
Total Zinc	143	8	528	6
Dissolved Zinc	66	12	56	6

The strong correlation between Al and TSS (Figure 5-9) suggests that most of the Al present in wet weather water samples may be due to suspended particulate Al. However, wet weather suspended solids loads consist of a mixture of urban stormwater, eroded upland soils, and streambank particles. It is impossible to determine individual Al contributions of these sources. State water quality criteria for Al are based upon total recoverable fractions rather than dissolved, partially because under experimental conditions, Brook Trout (*Salvelinus fontinalis*) experienced greater mortality with increased total Al concentration despite constant levels of dissolved Al (the form of particulate Al present in this experiment was Aluminum hydroxide, and experimental pH was low). Furthermore, EPA has documented HQ waters that exceed WQ standards for Al (63FR 68353-68364). Al found in natural streams may be predominantly mica and clays, which are inert under normal stream conditions. As the Tookany/Tacony-Frankford Watershed is rich in both mica and clay soils, and rarely experiences pH < 6.0, other factors should probably be ruled out before attributing biological impairment to Al toxicity.

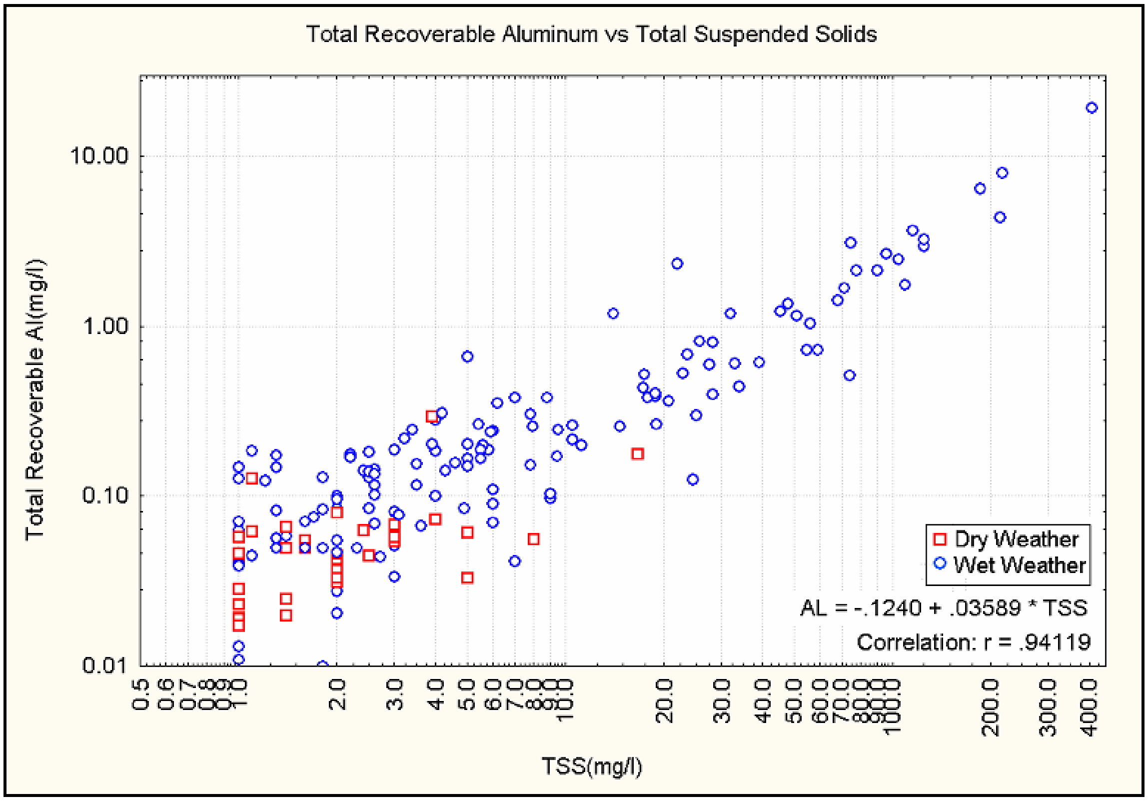


Figure 5-9 Scatterplot of Paired Total Recoverable Aluminum and Total Suspended Solids concentrations of samples collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

5.3.7.2 Cadmium

Cadmium (Cd) is a heavy metal that is widely but sparsely distributed in the earth's crust. Cd is often associated with Zinc (Zn), but may also be found with other metals such as Copper (Cu) and Lead (Pb). For this reason, smelting and other industrial uses of nonferrous metals may be sources of Cd pollution. Other industrial sources include battery, pigment, and plastics manufacturing. Atmospheric deposition and some types of agricultural fertilizers may also contribute Cd to the environment. Cd has no known biological function, and may be toxic in very small concentrations. In aquatic environments, toxicity is assumed to be due to uptake of dissolved Cd, so PA DEP WQ criteria are based on dissolved concentrations.

Cd was rarely detected in water samples from Tookany/Tacony-Frankford Watershed. Though concentrations were nearly always below reporting limits, WQ criteria for Cd reflect the fact that this metal may be toxic in small concentrations. WQ criteria for Cd are calculated based on hardness and Cd concentrations less than 1ug/L may be a violation of water quality criteria in very soft water. Dissolved Cd was detected in only one of 277 samples (Table 5-12); there were no violations of state WQ criteria, but 4 of 276 samples in which Cd concentration was below reporting limits had sufficiently soft water (hardness < 34mg/L in dry weather or <26.5mg/L in wet weather) to lower the sample WQ criterion below the reporting limit.

Total recoverable Cd was only detected in 45 of 734 samples, and only in wet weather (Table 5-12). Of these samples, 15 would have exceeded the former total recoverable WQ criteria that were discontinued in 2001. An additional 14 samples would have had sufficiently soft water (hardness < 34mg/L in dry weather or <26.5mg/L in wet weather) to lower discontinued WQ criteria below the reporting limit. Although sediments and sediment pore water Cd concentrations may be a concern given observed increases in total recoverable Cd during wet weather, dissolved Cd concentrations were always small, and it is unlikely that Cd toxicity is responsible for observed biological impairment in Tookany/Tacony-Frankford.

5.3.7.3 Chromium

Chromium (Cr) is commonly used in alloys of stainless steel and, as Chromate salts, in other metallurgical and industrial applications. Of the two predominant naturally occurring forms, only hexavalent Chromium (Cr[VI]) is toxic, while trivalent Cr (Cr[III]) is an essential trace nutrient; Separate WQ standards exist for Cr[III] and Cr[VI]. Toxic Cr[VI] is much more soluble at normal stream pH than Cr[III] (Rai *et al*. 1989), so at the extremes, dry weather dissolved Cr samples probably more closely reflect actual water column concentrations of Cr[VI], while wet weather total recoverable Cr samples will contain a much greater proportion of insoluble, nontoxic Cr[III]. Despite the influence of other water quality constituents on the speciation and bioavailability of Cr, WQ criteria for Cr[VI] are absolute (CCC=10µg/L, CMC=16µg/L, dissolved fraction only).

Determinations of Cr described herein were obtained with ICP-MS equipment following acid digestion, a method that does not allow for speciation of Cr in either dissolved or total recoverable samples; concentrations were conservatively assumed to be Cr[VI], though the ratio of Cr[III] to Cr[VI] is very likely to be much greater in total recoverable samples as well as in wet weather samples. Dissolved Cr was detected in only one of 122 samples (Table 5-12), and there were no violations of WQ criteria (Table 5-5). Approximately 31 of 650 total recoverable Cr samples would have violated WQ criteria discontinued in 2001.

5.3.7.4 Copper

Copper (Cu) occurs naturally in numerous forms and is present to some degree in most soils and natural waters. Cu is also used industrially for electric wires and coils, as well as in building materials such as roofing and pressure-treated lumber. Cupric Ion (Cu^{2+}) is the bioavailable form of Cu in aquatic systems and its mode of toxicity involves ligand bonding with the gill surface of fish or similar structures of invertebrates. As such, WQ criteria are based on dissolved Cu concentration, which is a better predictor of Cu toxicity than total recoverable metal concentration. Dissolved concentrations are usually much smaller than total recoverable concentrations in natural waters, as Cu forms complexes and ligand bonds with other water column constituents (Morel & Hering, 1993). Cu can also be present in particulate form or be adsorbed to large particles that are trapped by filtering the sample.

Cu was always detectable in Tookany/Tacony-Frankford; all of the 763 samples collected had Cu concentration above reporting limits. Basic statistics for Total Cu and Dissolved Cu appear in (Table 5-12) and outliers excluded from subsequent analyses are tabulated in Appendix D (Contamination was suspected in two samples where the ratio of dissolved to total Cu exceeded 2:1, and also in a dry weather sample at site TF500 where Total Cu concentration was 102µg/L.). Some samples lacked hardness data, so conservative hardness values were substituted for the purpose of comparing observed dissolved Cu to WQ criteria. These substitute hardness values were mean hardness minus one standard deviation, calculated separately for dry and wet weather (hardness data aggregated for all sites and dates).

In 2004, PWD reinstated separate determinations of total and dissolved fractions on metals samples collected as part of the discrete interval sampling program. PWD also conducted two rounds of intensive metals sampling during wet weather at site TF280, which is believed to be the most chemically impaired non-tidal site in the watershed. As of May 2005, 152 paired dissolved and total copper results were available. The ratio of dissolved Cu to total recoverable Cu was significantly higher in dry weather samples than in wet weather samples (t-test, $F_{(2,148)}=2.809$, $p=.000039$). Furthermore, there was no strong relationship between dissolved and total recoverable Cu in wet weather samples (Figure 5-10). Despite total recoverable concentrations that ranged up to 200µg/L, maximum observed concentration of dissolved Cu was 22µg/L.

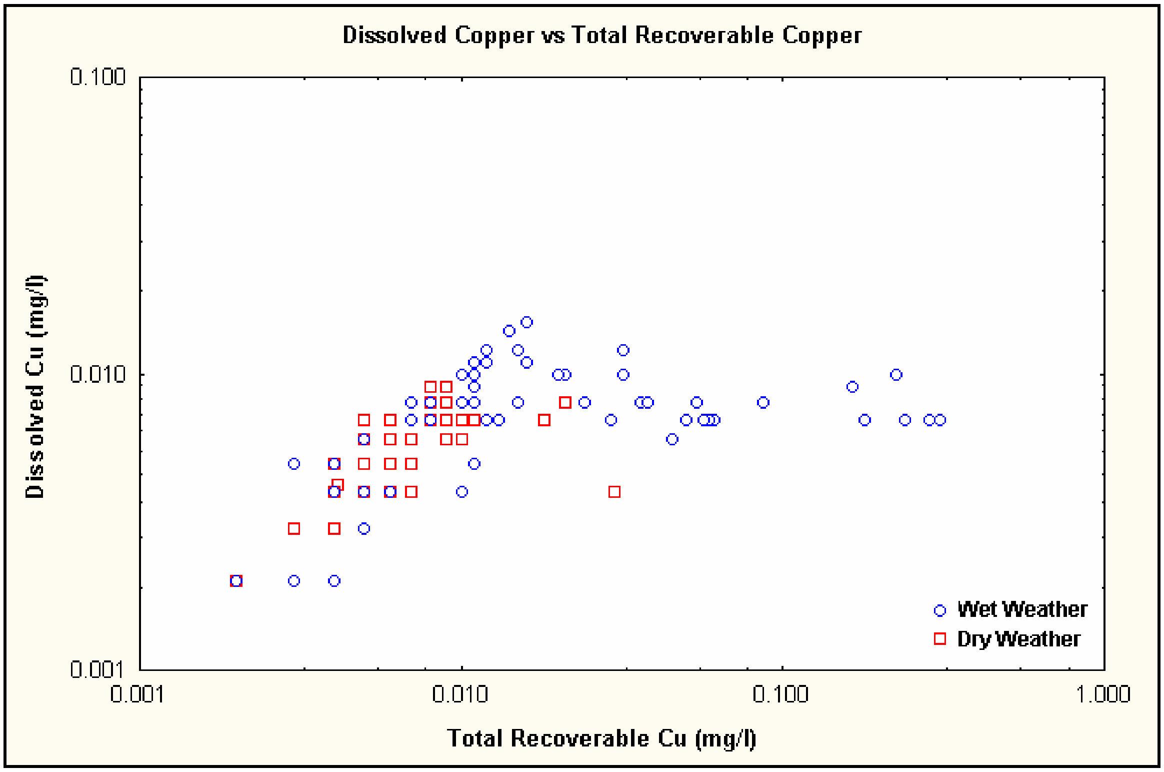


Figure 5-10 Paired Dissolved and Total Recoverable Copper Concentration of Samples Collected from 8 Sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

As Cu strongly associates with sediment, pore water/sediment toxicity should not be ignored as a potential stressor to benthic invertebrates. The only sensitive taxa that were consistently collected throughout the watershed (though densities were low) were tipulid larvae; these relatively large larvae are shredders, and enshroud themselves in leaf packets. A diet and microhabitat rich in organic acids may confer resistance to heavy metal pollution. Mayflies, on the other hand, have been characterized as very sensitive to metals pollution (Clements *et al.* 1988, Clements *et al.* 1990) and the obvious disparity between Tookany/Tacony-Frankford sites and reference sites with respect to number and abundance of mayfly taxa may be attributable to heavy metal pollution. Sediment metals concentrations and reference site chemistry data are needed before any conclusions can be drawn.

Cu toxicity was also investigated using the Biotic Ligand Model (BLM) (DiToro *et al.* 2001). Data were lacking for some model input parameters, so conservative values were substituted. Many water chemistry parameters can affect Cu toxicity, particularly other ions and organic molecules that tend to compete with gill ligand bonding sites for available Cu. Figure 5-11 illustrates the effects of pH and temperature on Cu bioavailability and toxicity. BLM data were used only to determine whether Cu toxicity could affect the biology of Tookany/Tacony-Frankford Watershed, not to develop alternative water quality criteria. EPA is in the process of developing new WQ criteria for Cu incorporating the BLM with appropriate margins of safety for protecting aquatic life.

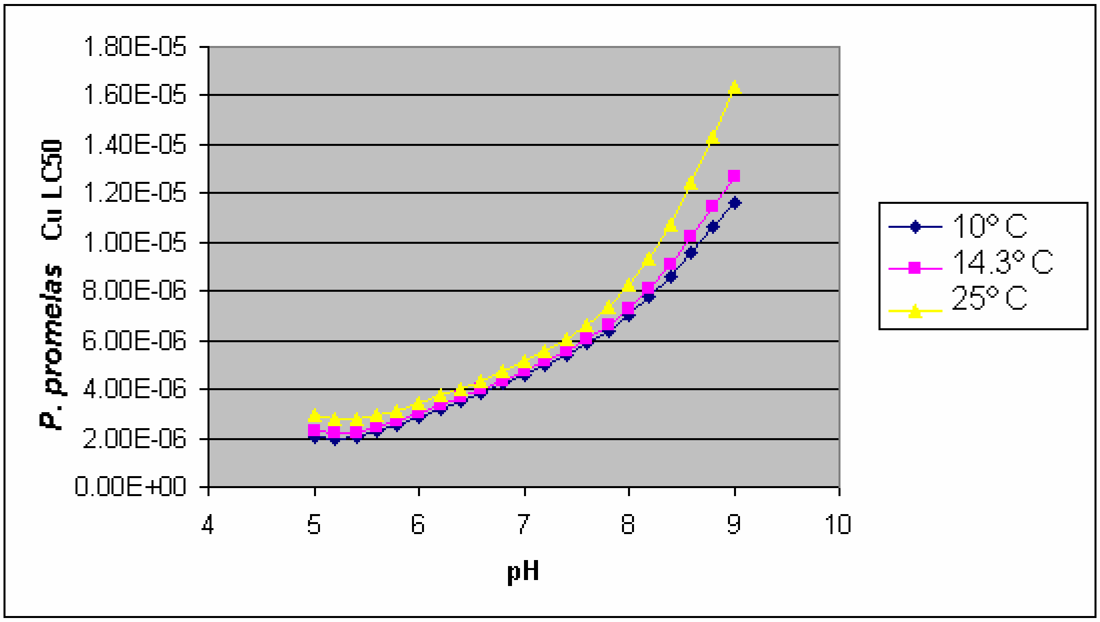


Figure 5-11 Effects of pH and Temperature on Copper Toxicity to Fathead Minnows.

The BLM was used to determine the LD50 of dissolved copper to Fathead Minnow (*Pimephales promelas*), and two cladoceran microcrustaceans (*Ceriodaphnia dubia*, and *Daphnia pulex*). For most parameters data entered into the model came from samples collected from Tookany/Tacony-Frankford Watershed. Data from each sample were entered into the model as a separate case and the LD50 of Cu was determined for each case. When data from Tookany/Tacony-Frankford Watershed were not available estimates from nearby streams were used. Parameters for which estimates were used included: DOC, Percent of DOC contributed by Humic Acids, Potassium, and Chloride. DOC competes for Cu with gill ligand sites and is positively correlated to the LD50 of Cu, therefore a conservative estimate of 2.9 mg/L from French Creek was used in place of 5.4 mg/L , an estimate given for PA streams (EPA document #822-B-98-005). Due to the lack of DOC characterization data, ten percent was used for the relative proportion of DOC made up by Humic acids as recommended by the model documentation (DiToro *et al.* 2001). Model input values for Potassium (K) were estimated by averaging potassium values from Pickering Creek, Trout Creek, and Wissahickon Creek, though K currently has no direct effect on metal toxicity in the BLM. Chloride model input values were calculated by averaging values from Pickering Creek and Trout Creek. When comparing dissolved Cu concentrations from Tookany/Tacony-Frankford Watershed to predicted LD50, the predicted LD50 concentration was reduced by an order of magnitude (margin of safety). Even with this margin of safety, no sample had dissolved Cu concentration above the LD50 for any of the target organisms

5.3.7.5 Lead

Lead (Pb) is a toxic heavy metal that was once commonly used in paints (as recently as 1978) and in automotive fuels (until being phased out in the 1980s). Pb is still used industrially in solder and batteries. Some areas have banned the use of lead in shotgun pellets and fishing weights, as chronic toxicity results when these items are ingested by waterfowl. Acute toxicity of Pb to aquatic life is considerably less than chronic toxicity, as evidenced by the large difference in CCC and CMC criteria (2.5 and 65µg/L, respectively, at 100mg/L $CaCO_3$ hardness). Dissolved Pb was only detected in 17 of 141 samples collected in Tookany/Tacony-Frankford; no violations of WQ criteria were found (Table 5-5). When compared to discontinued total recoverable metals criteria, 70 of 712 samples would have been violations.

5.3.7.6 Zinc

Zinc (Zn) is a common element present in many rocks and in small concentrations in soil. Zn is a micronutrient needed by plants and animals, but when present in greater concentrations in surface water, it is moderately toxic to fish and other aquatic life. Toxicity is most severe during certain sensitive (usually early) life stages. Zn is a component of common alloys such as brass and bronze and is used industrially for solders, galvanized coatings, and in roofing materials. Zn is usually present in surface waters of Tookany/Tacony-Frankford; only 14 of 671 individual total recoverable Zn samples and 18 of 122 dissolved Zn samples from Tookany/Tacony-Frankford had Zn below reporting limits (Table 5-5), though concentrations were relatively small.

Contamination was suspected in four sets of samples collected in 2004, where dissolved concentrations were consistently greater that total recoverable concentrations in 30 of 32 samples (Figure 5-12). Dates and sample information for these sample dates are summarized in Appendix D. Of 15 dissolved Zn samples exceeding WQ criteria, 14 are likely to have been affected by contamination. If these samples are ignored, dissolved Zn/total recoverable Zn ratios more closely mirror those of other metals (*i.e.*, higher in dry weather than in wet weather, Figure 5-12).

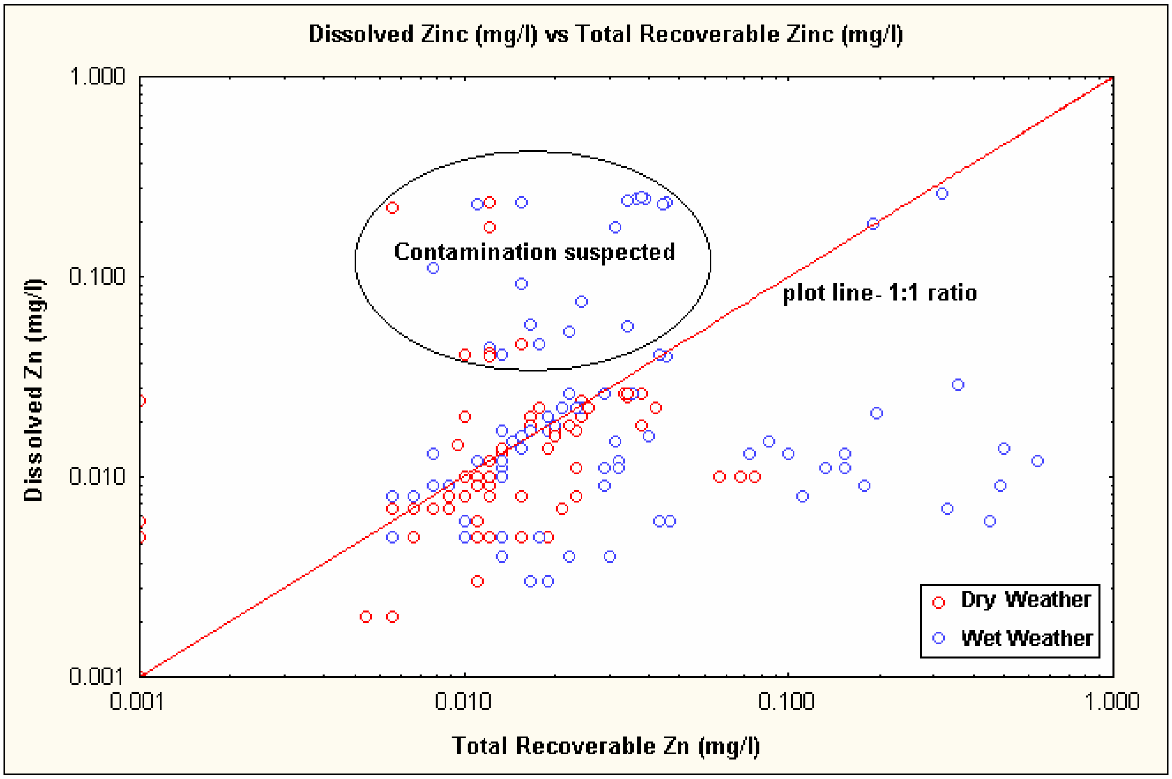


Figure5-12 Paired Total Recoverable and Dissolved Zinc Concentrations of Samples collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

Discrepancies occurred with both dry and wet weather samples. Bench sheets did not indicate any problems with samples or the instrumentation, and all QC checks were passed. As samples were preserved and stored, the PWD Bureau of Laboratory Services (BLS) was able to re-analyze these samples, obtaining similar results. The analyst visually confirmed the presence of settled solids in sample containers used for total recoverable metal, while sample containers used for dissolved metals were visually clear. A series of subsequent filter blank trials showed filters used to prepare dissolved metals samples may have leached Zn, but the magnitude of the difference in total and dissolved concentrations was much too great to be explained by filter contamination. The source of contamination remains unknown.

The BLM was used to estimate the toxicity of dissolved Zn to fathead minnows (*Pimephales promelas*), rainbow trout (*Oncorhynchus mykiss*), and a cladoceran (*Daphnia magna*). Input data were compiled or estimated in the same manner as dissolved copper model input data. An order of magnitude safety factor was applied to the LD_{50} concentrations generated by the model and the resulting concentration was compared with dissolved zinc data collected from the Tookany/Tacony-Frankford Watershed. Even with this safety margin, no observed dissolved zinc concentrations exceeded the calculated LD_{50} for the studied organisms.

5.3.8 Nutrients

5.3.8.1 Phosphorus

Phosphorus (P) concentrations are often correlated with algal density and are used as a primary indicator of cultural eutrophication of water bodies. N:P ratio analysis strongly suggests that P is the limiting macronutrient in the Tookany/Tacony-Frankford Watershed. Readily available dissolved orthophosphate (PO_4) was only detected in 5 of 129 total samples collected in dry weather, and in 55 of 584 wet weather samples, so nutrient analyses considered only total P concentrations (TP). TP includes some smaller fraction of P that is considered to be bioavailable, or readily usable by stream producers. Bioavailable P (BAP) includes soluble reactive P (SRP) and, depending on other factors, some portion of particulate inorganic P. Furthermore, some producer taxa can produce endogenous alkaline phosphatases and obtain P that is not normally available.

The Tookany/Tacony-Frankford Watershed has not been listed by PA DEP as impaired due to nutrients, and no WQ criteria exist for TP or OPO_4. For the TTFIWMP, TP concentrations were evaluated using a frequency distribution approach. Data were compiled for reference reaches in EPA Ecoregion IX, subregion 64 (median of 75th percentile value for each of four seasons=140µg/L) from EPA (822-B-00-019). This reference value is considerably greater than the mesotrophic/eutrophic boundary for TP suggested by Dodds *et al.* (1998) (*i.e.*, 75µg/L). Dry weather TP concentrations were usually below both reference values.

Total P concentration was below reporting limits in 58 of 135 samples collected in dry weather, but in only 87 of 555 wet weather samples. Elevated dry weather TP concentration was observed at sites TF280 and TFM006, probably due to dry weather sewage inputs. Log-transformed Mean TP concentration was significantly greater in wet weather than in dry weather ($F_{2,183}$=1.55, p=0.008), so stream producers in the Tookany/Tacony-Frankford Watershed are generally exposed to somewhat constant TP concentrations punctuated with episodic inputs of greater TP concentration due to runoff and erosion. Point sources of P include CSO and SSO discharges, contributing large amounts of phosphorus where and when they occur.

Phosphorus readily adsorbs to soil and sediment particles and is generally less mobile in soils than nitrogen compounds. Potential non-point sources of P are decomposing organic matter in or near the stream, runoff from industrial parks, golf courses, agriculture and residential areas, and inorganic P adsorbed to soil particles that are washed into the stream by erosive forces. In fact, soil erosion may be the greatest source of P in separate-sewered portions of Tookany/Tacony-Frankford. TP concentration was significantly positively correlated with TSS concentration, (Log transformed, $r_{(183)}$=0.60, p<0.001) (Figure 5-13). Wet weather phosphorus inputs, however, are coupled with physical disturbances (*e.g.*, hydraulic shear stress, other abrasive forces, reduced light availability). These stressors respond to changes in flow in a non-linear fashion. Some taxa have the ability to store intercellular reserves of inorganic nutrients ("luxury consumption") when concentrations exceed immediate demands. It is thus very difficult to estimate P concentrations available to stream producers and draw conclusions about stream trophic status. This topic is addressed in greater detail in Section 5.4.

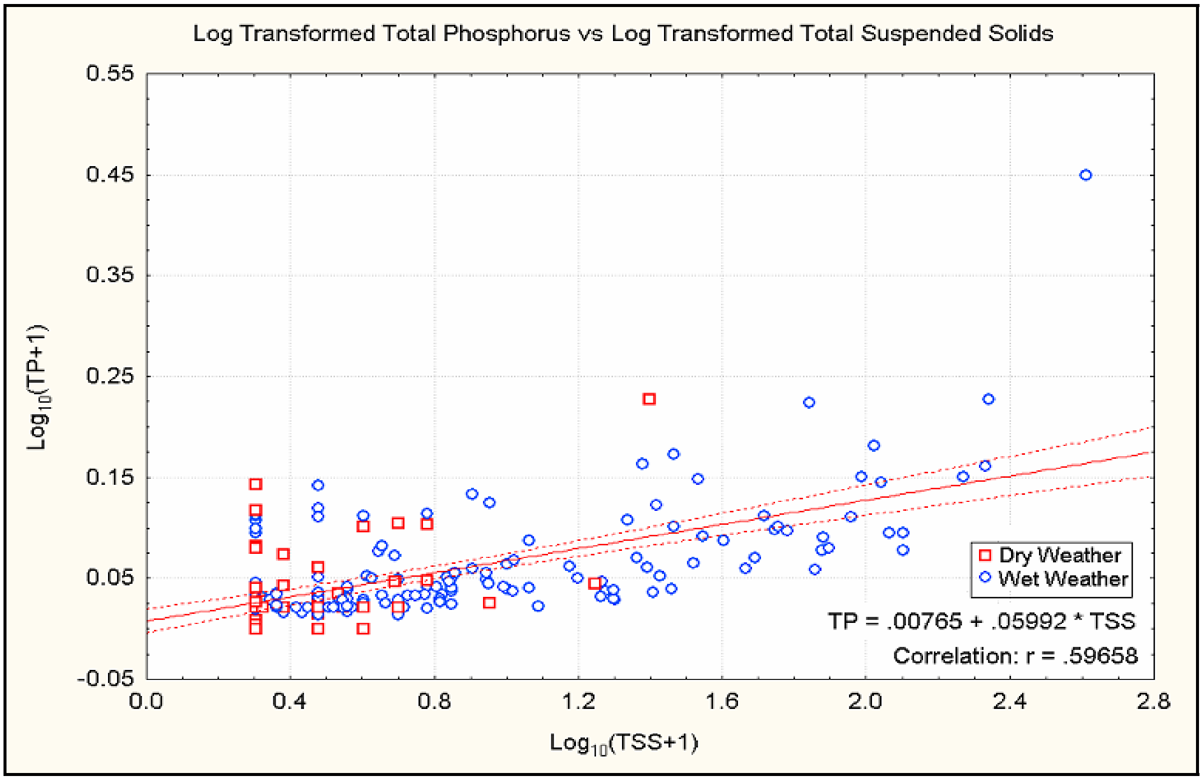


Figure 5-13 Scatterplot of Paired Total Phosphorus and Total Suspended Solids Concentrations of Samples Collected from 8 Sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

5.3.8.2 Ammonia

Ammonia, present in surface waters as un-ionized ammonia gas (NH_3), or as ammonium ion (NH_4^+), is produced by deamination of organic nitrogen-containing compounds, such as proteins, and also by hydrolysis of urea. In the presence of oxygen, NH_3 is converted to nitrate (NO_3) by a pair of bacteria-mediated reactions, together known as the process of nitrification. Nitrification occurs quickly in oxygenated waters with sufficient densities of nitrifying bacteria, effectively reducing NH_3, although at the expense of increased NO_3 concentration. PA DEP WQ criteria for NH_3 reflect the relationship between stream pH, temperature, and ammonia speciation/dissociation. Ammonia toxicity is inversely related to hydrogen ion [H+] concentration; an increase in pH from 7 to 8 increases NH_3 toxicity by approximately an order of magnitude. At pH 9.5 and above, even background concentrations of NH_3 may be toxic.

Historic data comparisons show that, in the watershed overall, NH_3 concentrations have decreased significantly compared to samples collected from 1970 to 1980 ($F_{2,1001}=6.18$, $p<0.001$). Dry weather NH_3 concentrations, in particular, have improved dramatically. For example, in samples collected from 1970 to 1980, there was no significant difference in NH_3 concentrations between dry and wet weather samples at site TF280 ($F_{2,99}=1.19$, $p=0.77$), suggesting that sewage inputs or anoxic conditions were common at this site regardless of weather.

Though no dry weather samples collected from the Tookany/Tacony-Frankford Watershed from 2000-2004 contained NH_3 concentration in excess of 0.8mg/L and there were no violations of WQ criteria, 20 of 87 samples were above reporting limits, suggesting occasional inputs of untreated sewage, anoxic conditions, or the presence of other decomposing organic material. Site TF280 was responsible for most of these observations, and is believed to be the site most seriously affected by dry weather sewage inputs and anoxic conditions. Target A of the TTFIWMP is directed at further reducing dry weather sewage inputs through source track-down and infrastructure repair/improvements.

NH_3 concentration of sites within Tookany/Tacony-Frankford Watershed (log-transformed, all sites combined) was significantly higher in wet weather than in dry weather ($F_{2,710}$=2.30, p=.0047). NH_3 concentration was above detection limits in 211 of 436 total wet weather samples, though all samples with concentrations greater than 0.8mg/L were collected at site TF280.

There were no violations of WQ criteria due to the fact that pH remained near neutrality at the time samples were taken. Algal activity was observed to cause pH fluctuations, particularly at site TF620 in spring 2003. When severe, these fluctuations in pH caused NH_3 WQ criteria to decrease to within the range of values observed at other times. The NH_3 sampling regime was not ideal for identifying possible violations of WQ standards as discrete interval grab samples were collected in the morning, while daily pH maxima were typically reached in afternoon/early evening hours.

5.3.8.3 Nitrite

As an intermediate product in the oxidation of organic matter and ammonia to nitrate, nitrite (NO_2) is seldom found in unimpaired natural waters in great concentrations provided that oxygen and nitrifying bacteria are present. For this reason, NO_2 may indicate sewage leaks from illicit connections, defective laterals, or storm sewer overflows and/or anoxic conditions in natural waters. NO_2 was detected in only 14 dry weather samples collected from the Tookany/Tacony-Frankford Watershed; most of these observations were at site TF280 and most were collected prior to 2004. Comparison to data collected from 1970-1980 showed that the incidence of Nitrite detections in dry weather has been drastically reduced, suggesting fewer dry weather sources of sewage and/or reduced severity of anoxic conditions.

NO_2 concentrations were greater than reporting limits more frequently in wet weather (129 of 585 total samples) than in dry weather, but contribution of NO2 to total inorganic nitrogen was usually small and concentrations of many samples were estimated to be half the detection limit for the purpose of evaluating nutrient ratios. Large numbers of samples below detection limits prevented the use of parametric statistical methods to evaluate weather effects. Mann-Whitney U test analysis showed significantly greater NO2 concentration (log transformed, samples below MRL included as half the MRL) in wet weather than in dry weather ($Z_{2,717}$ = -2.75, p<0.005).

5.3.8.4 Nitrate

Concentrations of nitrate (NO_3) are often greatest in watersheds impacted by (secondary) treated sewage and agricultural runoff, but elevated NO_3 concentrations in surface waters may also be attributed to runoff from residential and industrial land uses, atmospheric deposition and precipitation (*e.g.*, HNO_3 in acid rain) and decomposing organic material of natural or anthropogenic origin. Nitrate is a less toxic inorganic form of N than ammonia and serves as an essential nutrient for photosynthetic autotrophs. Availability of inorganic N can be a growth-limiting factor for producers, though usually only in oligotrophic (nutrient-poor) lakes and streams or acidic bogs.

PA DEP has established a limit of 10mg/L for oxidized inorganic nitrogen species (NO_3 + NO_2) (Commonwealth of Pennsylvania, 2001). This limit is based on public water supply use and intended to prevent methemoglobinemia, or "blue baby syndrome", not prevent eutrophication of natural water bodies. Waters of the Commonwealth that have been determined to be impaired due to excess nutrients have Waste Load Allocations (WLA) determined through the Total Maximum Daily Load (TMDL) process; Tookany/Tacony-Frankford Watershed has not been listed as impaired due to nutrient enrichment. For the TTFIWMP, NO_2 +NO_3 concentrations were evaluated using a frequency distribution approach. Data were compiled for reference reaches in EPA Ecoregion IX, subregion 64 (75th percentile of observed data=2.9mg/L). This reference value is considerably greater than the mesotrophic/eutrophic boundary for Total N suggested by Dodds *et al.* (1998) (*i.e.*, 1.5 mg/L TN).

Dry weather NO_3 concentrations in the Tookany/Tacony-Frankford Watershed are almost always found between the two aforementioned reference points (*i.e.*, between 1.5mg/L and 2.9mg/L). NO_3 concentrations typically decreased in wet weather. Mean NO_3 concentration (log transformed, all sites combined) was significantly lower in wet weather than in dry weather ($F_{2,180}$=1.70, p<0.001), and NO_3 was significantly negatively correlated with Log transformed TSS concentration (r(182)= -0.55, p<0.001, Figure 5-14). This relationship demonstrates dilution by stormwater and is the reverse of the phenomenon observed with P concentration. However, other forms of N (*i.e.*, TKN, NH_3, NO_2) tended to increase in concentration in wet weather. Nutrient dynamics and relationships to autotrophic community production are addressed in greater detail in section 5.4.

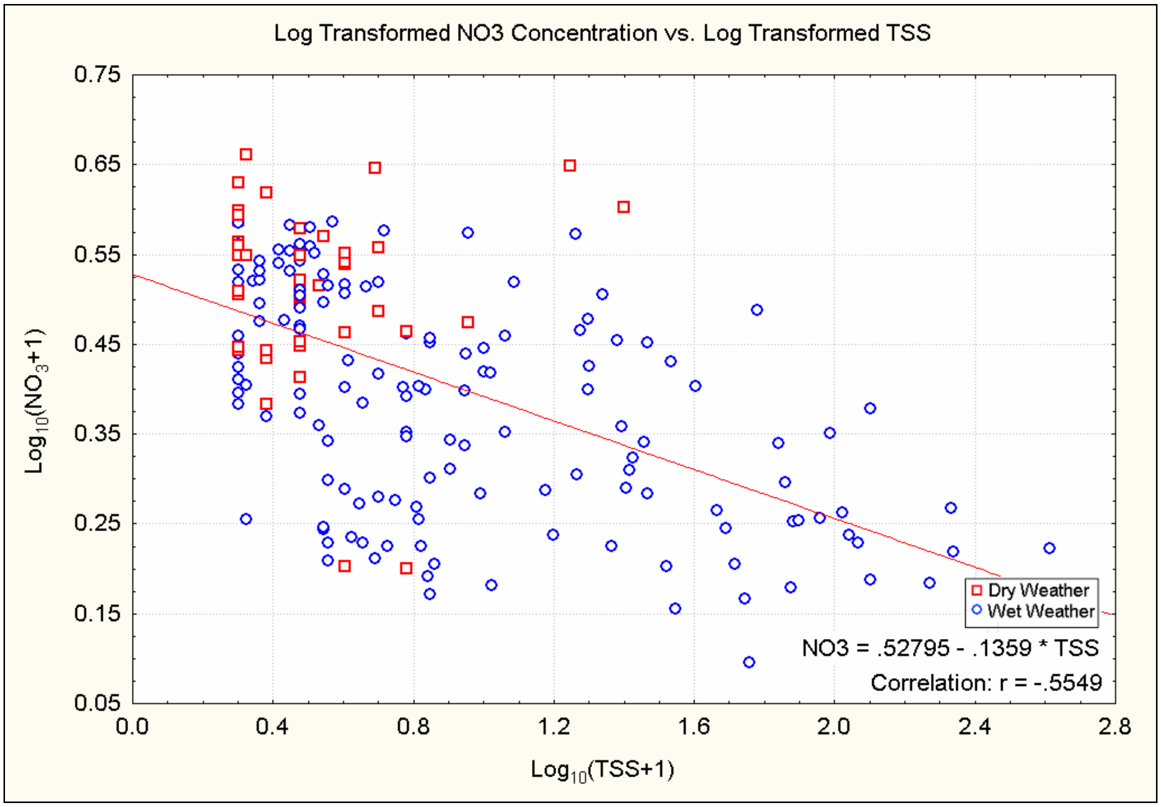


Figure 5-14 Scatterplot of Paired Nitrate and Total Suspended Solids Concentrations of Samples Collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

Unusual dry weather samples were collected from site TF280 on July 7, 2004 and TFM006 on August 30, 2004 in which NO_3 concentration seemed diluted compared to most other dry weather baseflow samples. In the first case, accompanying data showed increases in TKN and NO_2, as would be expected with under anoxic conditions, but DO suppression could not be verified due to probe failure. In the second case, TKN was slightly elevated for a dry weather sample, but NO2 was below reporting limits and no DO data were available.

5.3.8.5 Total Kjeldahl Nitrogen

The Total Kjeldahl Nitrogen (TKN) test provides an estimate of the concentration of organically-bound N, but actually measures all N present in the trinegative oxidation state. Ammonia must be subtracted from TKN values to give the organically bound fraction. TKN analysis also does not account for several other N compounds (*e.g.*, azides, nitriles, hydrazone); these compounds are rarely present in significant concentrations in surface waters. Sampling results strongly suggest the most important source of organic N is sewage inputs from CSO and SSO discharge. Log-transformed Organic N concentration was significantly greater in wet weather than in dry weather ($F_{2,654}$=14.04, p<0.001). Organic N was also significantly positively correlated with fecal coliform bacteria concentration, r(647)=0.70, p<0.001 (Figure 5-15). As most organic N loadings to the watershed occur in wet weather, this N is probably transported out of the system and into the Delaware estuary before exerting nitrification DO demand or becoming available for uptake by algae.

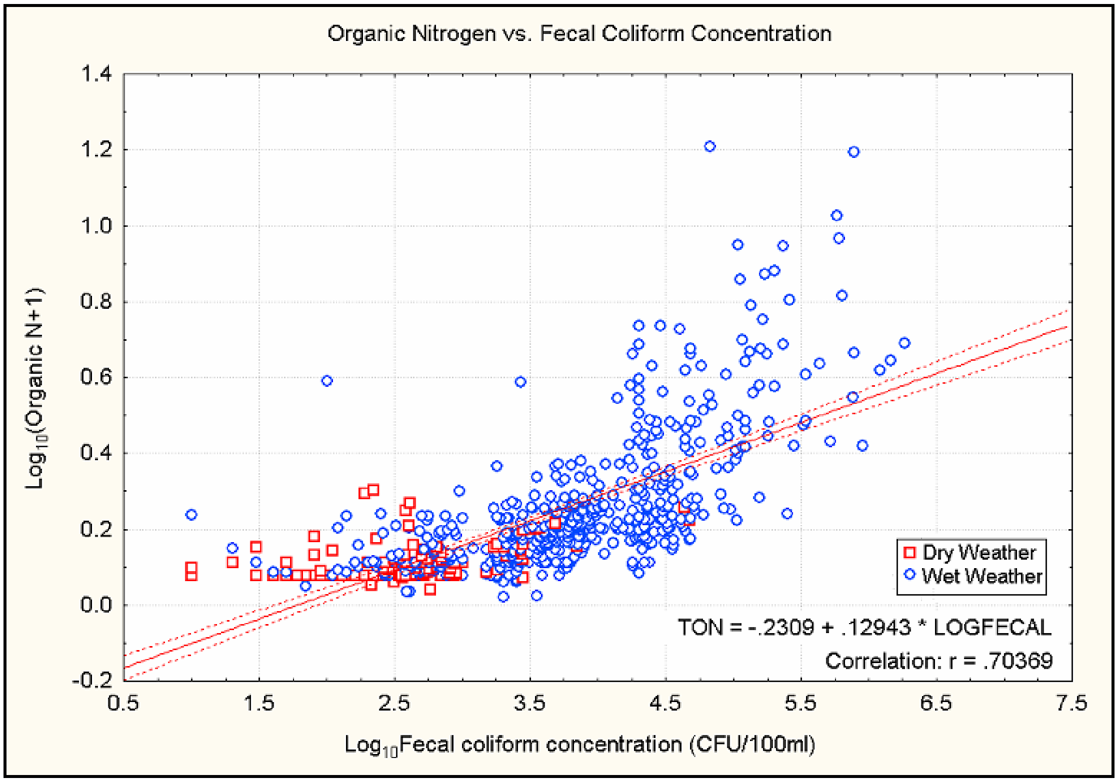


Figure 5-15 Scatterplot of Organic Nitrogen and Fecal Coliform Bacteria Concentrations of Samples Collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

5.4 Stream Metabolism

Stream Metabolism is a measure of the basic ecosystem processes of primary productivity and community respiration. Primary productivity measures the total energy fixed by plants in a community by photosynthesis, and community respiration quantifies the use of reduced chemical energy by autotrophs as well as heterotrophs (Odum 1956). Benthic algae are important primary producers in aquatic systems and are often the greatest source of energy in mid-order streams with less than complete tree canopy. Where abundant, periphyton communities may strongly influence water column dissolved oxygen, pH and inorganic carbon speciation.

Continuous water quality data indicated that certain sites in Tookany/Tacony-Frankford experience pronounced diurnal fluctuations in DO and pH that can be reduced in magnitude following storm events (Figure 5-16). These fluctuations sometimes result in short-lived violations of state water quality standards, frequently so within 3 miles of the confluence with the Delaware River. As Tookany/Tacony-Frankford Watershed was not found to have large dry weather concentrations of chlorophyll in the water column that would be indicative of suspended phytoplankton, it was hypothesized that these pronounced fluctuations were due largely to periphytic algae.

Supporting this conclusion are observed reductions in the magnitude of fluctuations during and immediately after storm events (Figure 5-16) and increases in water column chlorophyll-a during storm events observed at some sites. The latter effect is difficult to characterize, as the degree to which chl-*a* increased in wet weather is believed to have been affected by algal density, predominant growth form, and stream velocity. To address these hypotheses, a study was carried out at sites TF280 and TF680 to determine the biomass of benthic algae in terms of chlorophyll-*a* (chl-*a*), spatial variation in biomass within and between sites, scouring effects of high flows, and algal accrual rates following a high flow event.

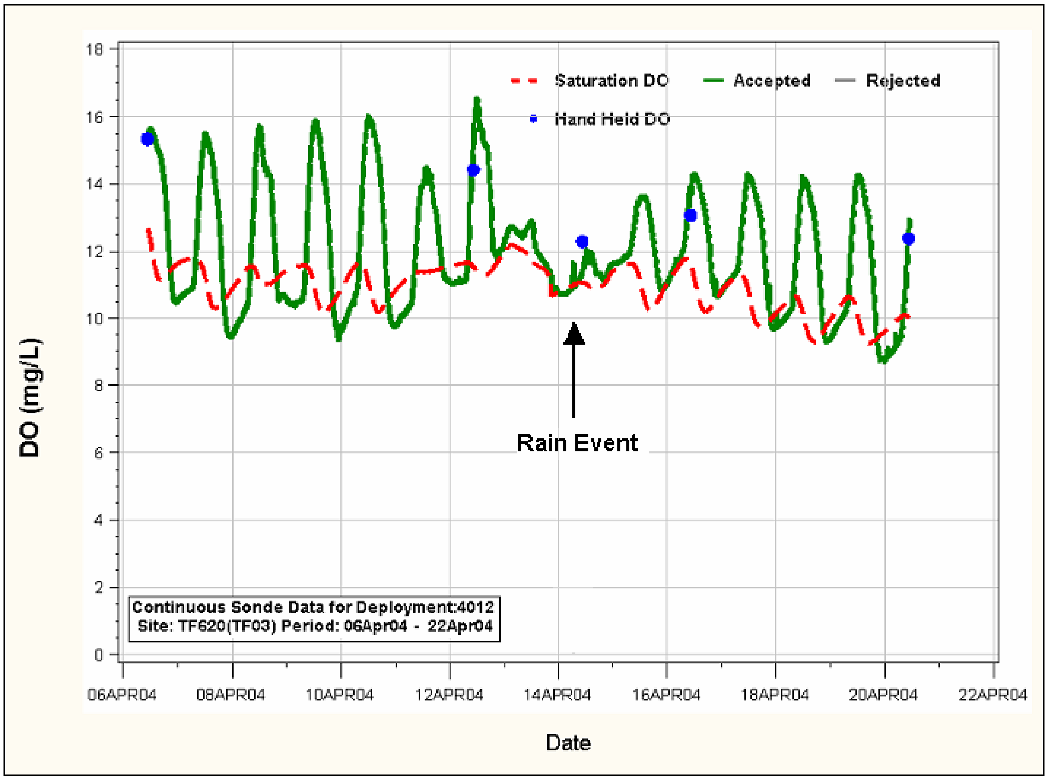


Figure 5-16 Continuous Plot of Water column Dissolved Oxygen Concentration at site TF620, April 2004.

Chlorophyll-*a* concentrations were consistently significantly greater at TF680 than at TF280 with mean concentrations ranging from 29.8 (±3.79) to 88.5 (±11.0) mg/m^2 at TF280, and from 108.5 (±14.8) to 127.9 (±12.8) mg/m^2 at TF680 (Figure 5-16). Mean chl-*a* at the TF680 site on 8 September 2004 was significantly lower (49.8 ± 6.5 mg/m^2) than on other sampling dates. This is possibly due to seasonal changeover in benthic algal community structure (summer die-off).

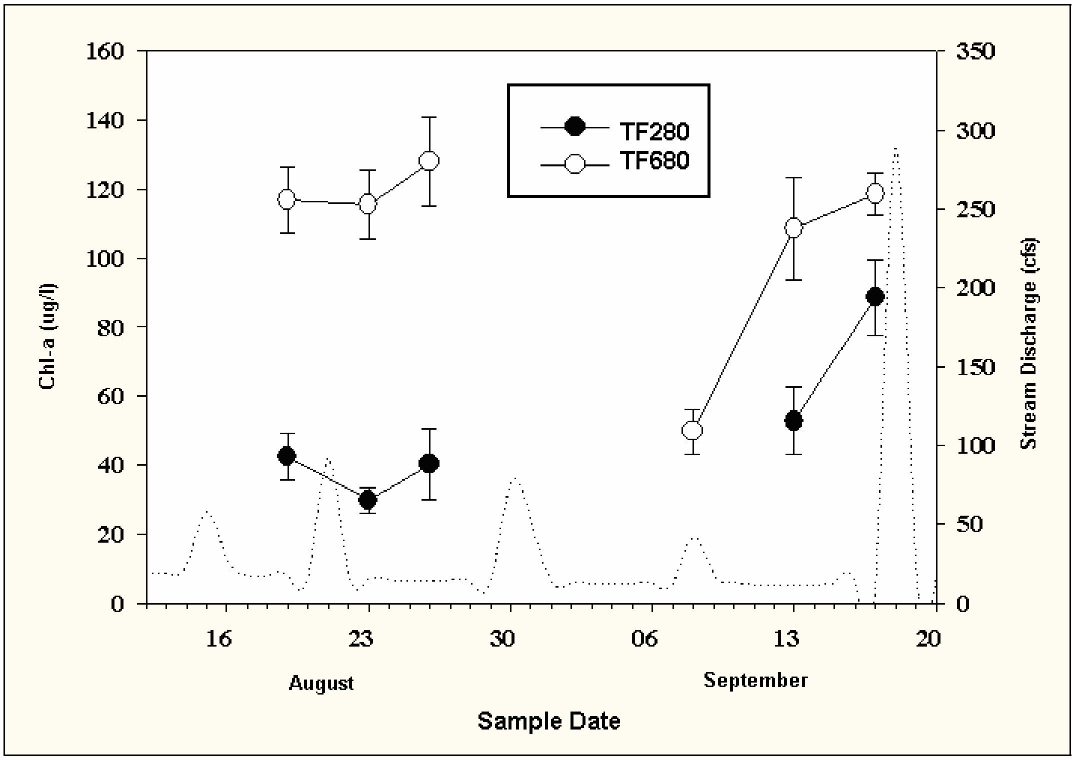


Figure 5-17 Chlorophyll-*a* Density on Natural and Artificially Scoured Substrates at sites TF 280 and TF620, September 2004

Algal accrual rates during the first 5 days following an artificial scouring experiment were similar to accrual rates on non-scoured rocks for each site (Figure 5-18). The average daily accrual rate for TF280 and TF620 was 8.36 ±1.30 mg/m^2 and 16.7 ± 4.34 mg/m^2, respectively. The accrual rate at TF03 of non-scoured rocks was 11.7 mg/m^2. During days 5-9 of the experiment, both sites lost biomass with an average daily loss rate of 1.73 (± 0.99) mg/m^2 at TF01 and 4.56 (± 1.31) mg/m^2 at TF620. The mean daily accrual rate of non-scoured rocks at TF01 during this time period was 8.96 mg/m^2 and 2.48 mg/m^2 at TF620.

Grazing, nutrients, current velocity, and scouring disturbances are likely the most important in driving algal communities in Tookany/Tacony-Frankford watershed. Differences in algal community structure between the two sites are likely the result of differential nutrient conditions, grazing pressures, and disturbance regimes. Light may also play a factor in explaining site differences (Triska *et al*. 1983, Hill and Knight 1988, Everett 1998).

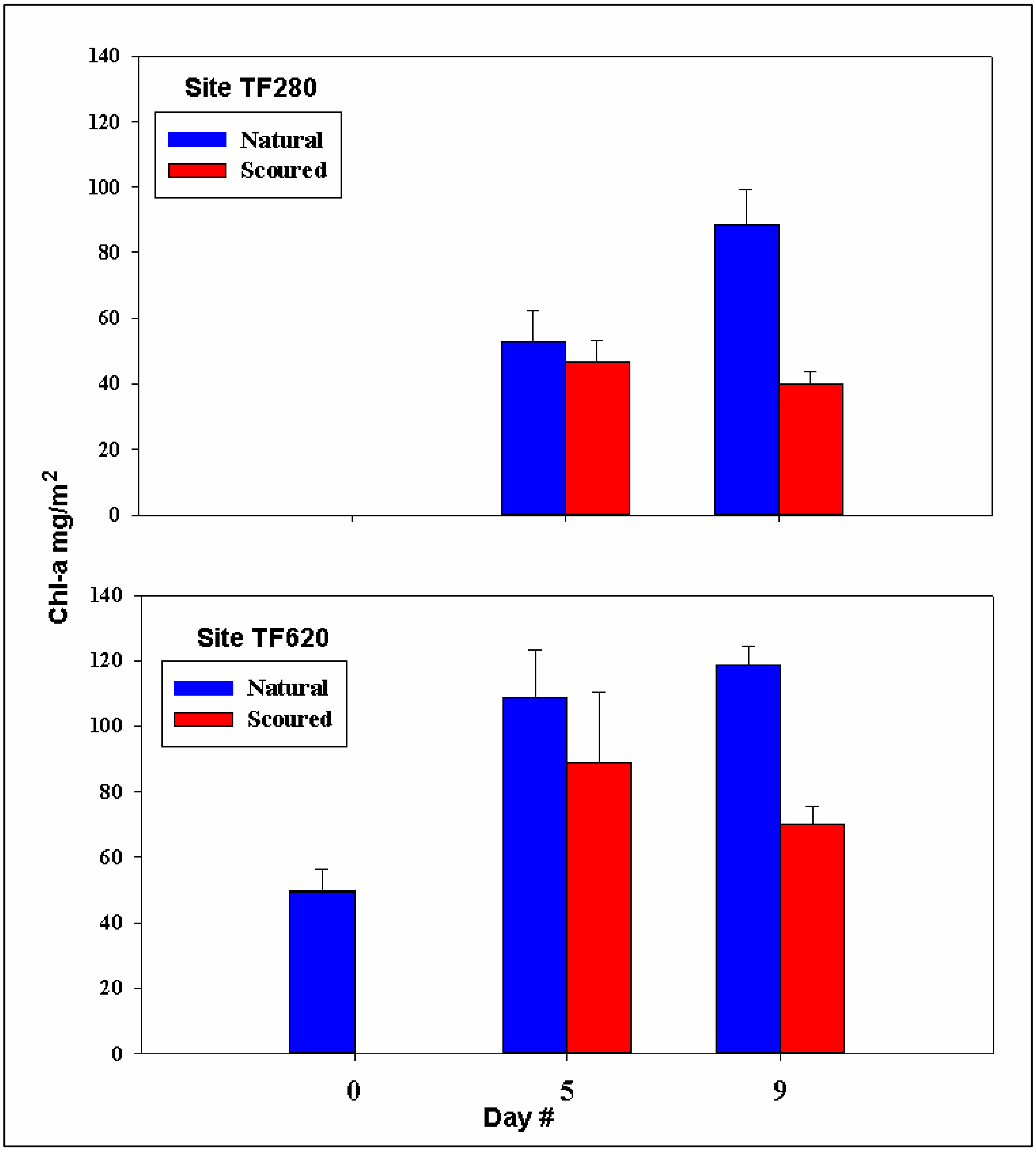


Figure 5-18 Chlorophyll-a Density on Natural and Artificially Scoured Substrates at sites TF280 and TF620, September 2004.

5.4.1 Relation of Algal Activity to Dissolved Oxygen Concentration

DO concentrations often strongly reflect autotrophic community metabolism and in turn, affect the heterotrophic community structure as a limiting factor for numerous organisms. Stream sites that support abundant algal growth often exhibit dramatic diurnal fluctuations in dissolved oxygen concentration. Algal photosynthesis infuses oxygen during the day (often to the point of supersaturation), while algae and heterotrophic organisms remove oxygen throughout the night. Diurnal fluctuations are more pronounced in the summer months than the autumn and winter months as colder water has a greater capacity for DO and biological metabolic activity is generally regulated by temperature.

Mainstem sites on Tookany/Tacony-Frankford Creek experience pronounced diurnal fluctuations in dissolved oxygen (DO) concentrations. When biological activity is high, DO concentrations may fall below the state-regulated limit of 4.0 mg/L. Violation of these standards is generally limited to the stretch of river within 6 miles of the confluence with the Delaware River and common within the lower three miles of the confluence (*i.e.*, downstream of site TF500). Dry weather dissolved oxygen suppression tends to occur at night and is likely caused by respiration of algae and microbial decomposition of algae and other organic constituents in the absence of additional photosynthetic oxygen production.

Following storm events, amplitude of daily DO fluctuations was reduced. DO concentrations may decrease sharply upon increase in stage, but it was difficult to determine how much of these instantaneous decreases were due to DO probe membrane fouling (Figure 5-19). It was hypothesized that anoxic effluent from storm sewers contributes to a sudden reduction in water column DO, but modeling of CSO discharge DO concentrations indicated that the discharge alone could not account for the observed DO reductions. BOD and SOD may have increased due to organic matter present in sewage. Mean BOD_5 was substantially higher at TF280 than at TF620 (Figure 5-2), although numerous samples were below reporting limits. Additionally, the scouring effect of high flows reduces algal biomass, and the oxygen produced through photosynthesis and consumed through respiration is reduced. As algal biomass accrues following scouring events, peak DO concentrations and range of diurnal fluctuations return to pre-flow conditions (Figure 5-20).

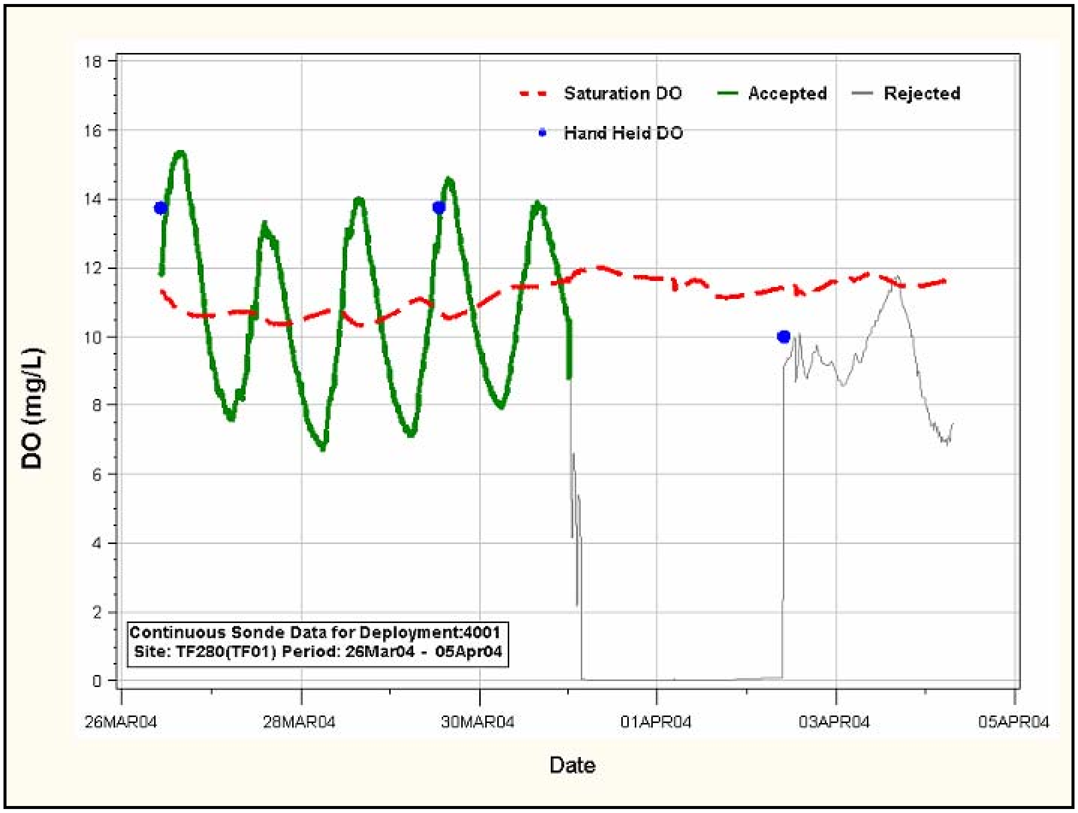


Figure 5-19 Continuous plot of Dissolved Oxygen Concentration at site TF280 Showing DO Probe Failure.

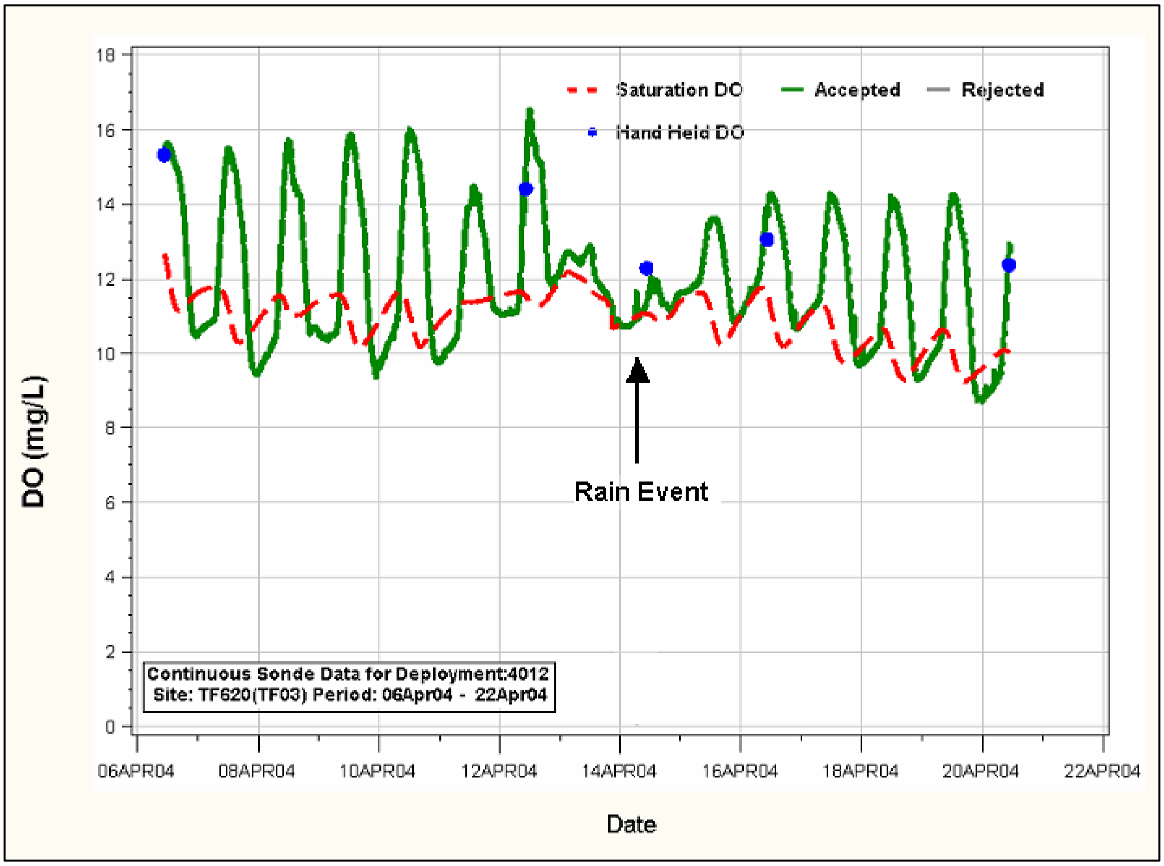


Figure 5-20 Continuous plot of Dissolved Oxygen Concentration at site TF280 returning to pre-flow conditions

Algal biomass at site TF280 was lower than at site TF620 further upstream. However, TF620 exhibits a higher mean DO and less pronounced diurnal fluctuations suggesting that the relationship between biomass and primary production is not straightforward. It is hypothesized that in dry weather the algae in combination with the residual effects of anoxic effluent, BOD and SOD accounts for the greater fluctuations in DO at site TF280. Further confounding the interpretation of this data is the fact that the sonde at site TF280 is located within a stagnant pool, the only location offering enough depth to allow the instrument to remain submerged at baseflow. Conversely, sonde locations at site TF620/680 are exposed to more streamflow, which replenishes the water surrounding the DO probe more frequently and helps keep the DO membrane itself from accumulating algae and debris. Microclimate conditions surrounding the DO probe membrane probably partially explain the difference in DO fluctuations observed between these two sites.

5.4.2 Relation of Algal Activity to stream pH

Fluctuations in pH can occur in freshwater systems as a result of natural and anthropogenic influences. Interplay between inorganic carbon species, known as the bicarbonate buffer system, generally maintains pH within a range suitable for aquatic life.

The bicarbonate buffer system describes the equilibrium relationship between carbon dioxide (CO_2) and carbonic acid (H_2CO_3), as well as bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions. In natural waters, the predominant source of hydrogen ions is carbonic acid. Biochemical metabolism of carbon throughout the day continually shifts the equilibrium equation, causing fluctuations in pH. As plants and algae consume carbon dioxide during photosynthesis, carbonic acid dissociates to replenish the CO_2 and maintain equilibrium. Decreasing carbonic acid concentrations cause elevated pH. As photosynthetic rates decline after peak sunlight hours, respiratory activities of aquatic biota replenish carbon dioxide to the system, decreasing pH. pH in Tookany/Tacony-Frankford Watershed is chiefly determined by this metabolic activity; the watershed is not heavily influenced by bedrock composition, groundwater sources or anthropogenic inputs, such as acid mine drainage.

Comparison of diurnal fluctuations of pH at sites TF280 and TF680 found that TF680 has greater variability between daytime and nighttime pH. This finding is attributed to the greater benthic algae biomass found at this site. pH affects aquatic biota directly, and also influences ionization of NH_3 and solubility/bioavailability of toxic metals. Severe fluctuations in pH driven by algal activity thus have the potential to exacerbate toxic conditions or even create toxic conditions where none previously existed.

5.4.2.1 Nutrient Limitation Effects on Primary Production

Nutrients are arguably the most important factor dictating algal standing crop, primary production, and community composition with examination of the nutrient-algae relationship requiring both an autecological and community-level approach (Borchardt 1996).

Nutrients can be a limiting factor to algal growth. In any given scenario, only one nutrient can limit algal growth for a given species at a time, although, at the community level, this rule does not apply where different species might be limited by different nutrients. Growth rates are not affected by nutrient concentrations alone. Light and temperature can affect nutrient uptake rates (*e.g.,*Falkner *et al*. 1980, Wynne and Rhee 1988), and more nutrients are often needed when light and temperature conditions are less than ideal (Goldman 1979, Rhee and Gotham 1981a,b, Wynne and Rhee 1986, van Donk and Kilham 1990). Additionally, nutrient uptake rates can vary depending on nutrient conditions. In steady-state growth conditions, the rate of nutrient uptake is equivalent to the rate at which nutrients are used in growth. However, cells may take up fewer or greater amounts of nutrients (for example, during nutrient pulses) and alter the nutrient ratios within the cell (Borchardt 1996).

The relationship between nutrients and algal biomass is complicated by numerous factors and findings are not consistent across ecoregions and water body types. Typically, nutrient enrichment stimulates periphyton growth in lotic systems and many studies have shown strong relationships between nutrient concentrations and algal biomass (*e.g.,* Jones *et al*. 1984, Welch *et al*. 1988, Kjeldsen 1994, Chetelat *et al*. 1999, Francouer 2001). However, other studies have shown no relationship between biomass and nutrient concentration (Biggs and Close 1989, Lohman *et al*. 1992). Periphyton standing crop can be highly variable (Morin and Cattaneo 1992) and other factors (described in subsequent sections) may override nutrient effects.

Of the necessary components for algal growth, nitrogen and phosphorus are likely to be growth-limiting in aquatic systems (Wetzel 2001) although carbon (Fairchild *et al.* 1989, Fairchild and Sherman 1993), trace metals (Winterbourn 1990), organic phosphorus (Pringle 1987) and silicates (Duncan and Blinn 1989) have also been implicated in limiting algal growth. Based on periphyton-nutrient studies, phosphorus is typically the limiting nutrient in the northern US (see Borchardt 1996 for review) while nitrogen has been shown to be limiting in the southwest (Grimm and Fisher 1986, Hill and Knight 1988a, Peterson and Grimm 1992) and Ozark (Lohman *et al.* 1991) regions.

In an effort to develop a practical system of stream classification based on nutrient concentrations similar to those used for lakes, Dodds *et al.* (1998) examined the relationship between chl-*a* (mean and maximum benthic chl-*a* and sestonic chl-*a*) and total nitrogen (TN) and total phosphorus (TP) in a large, global dataset. They defined the oligotrophic-mesotrohpic boundary by the lower third of the distribution of values with mean and maximum benthic chl-*a* concentrations of 20 mg/m^2 and 60 mg/m^2, respectively; and TN and TP concentrations of 700 µg/L and 25 µg/L, respectively. The mesotrophic-eutrophic boundary was represented by the upper third of the distribution of values with mean and maximum benthic chl-*a* concentrations of 70 mg/m^2 and 200 mg/m^2, respectively; and TN and TP concentrations of 1500 µg/L and 75 µg/L, respectively. Other recent studies examining specific chl-*a*-nutrient relationships include Dodds *et al.* (1997), Biggs (2000), Francouer (2001), Dodds *et al*. (2002a, b), Kemp and Dodds (2002).

N:P Ratio

Although nitrogen and phosphorus are the nutrients commonly limiting algal growth, the concentrations required to limit growth are less clear. Concentrations of phosphorus ranging 0.3-0.6 µg PO_4-P/L had been shown to maximize growth of benthic diatoms (Bothwell 1988) but higher concentrations have been needed in filamentous green algal communities (Rosemarin 1982), and even higher concentrations (25-50 µg PO_4-P/L) as algal mats develop (Horner *et al*. 1983, Bothwell 1989). Nitrogen has been shown to limit benthic algal growth at 55 µg NO_3-N/L (Grimm and Fisher 1986) and 100 µg NO_3-N/L (Lohman *et al.* 1991). In the past, the Redfield ratio (Redfield 1958) of cellular carbon, nitrogen, and phosphorus at 106:16:1 has been used to determine nutrient limitation. In benthic algae studies, ambient N:P ratios greater than 20:1 are considered phosphorus limited whereas those less than 10:1 are considered nitrogen limited. Nutrient limitation analysis was focused on steady state (*i.e.*, dry weather) conditions because these are the conditions under which limitation is most likely to affect periphyton communities.

Combining the above frameworks, most samples collected from sites in the Tookany/Tacony-Frankford Watershed in dry weather would be considered P-limited, mesotrophic with respect to TP, and eutrophic with respect to TN. A small number of samples would be considered not strongly limited by N or P and eutrophic with respect to both macronutrients. Sites TF500, TFJ110, and TF1120 were P-limited and never had TP concentrations exceeding the mesotrophic/eutrophic boundary of .075mg/L. TF620 was P-limited and not eutrophic for all but one sample which was considered co-limited and eutrophic. TF760 was always P-limited and did not have eutrophic concentrations of P in all but one sample. Two sites, TF280 and TFM006, were P-limited and had TP concentrations above the eutrophic boundary more often than not. The latter two sites also had other indicators of sewage (*e.g.*, fecal coliform bacteria) elevated in concentration in dry weather.

Sites TF280 and TF620 had similar mean TN values (2.59 ±0.49mg/L and 2.77± 0.45mg/L respectively), but mean dry weather TP concentration at site TF280 was significantly greater than at site TF620 ($F_{(47)}$= 9.35 p=0.0002). Given the greater TP concentration, one might expect greater algal biomass at site TF280. However, observed biomass was consistently smaller at site TF280 than at site TF620, which indicates that other parameters such as light, disturbance, grazing and scouring are controlling algal biomass.

5.4.2.2 Flow Effects on Stream Nutrient Concentrations

Stream nutrient concentrations in Tookany/Tacony-Frankford are dynamic. Macronutrients of greatest concern exhibited different responses to wet weather. NO_3 concentrations were relatively stable and adequate for abundant algal growth during dry weather and diluted in wet weather (mean NO_3 concentration 2.37mg/L ±0.65, and 1.49mg/L ±0.70, respectively). Conversely, other forms of N (*i.e.*, NH_3, NO_2, TKN) generally increased in concentration during wet weather, which is likely due to CSO and SSO discharge as well as presence of other organic constituents in stormwater runoff. Nitrate (NO_3) and ammonium ions NH_4^+ forms are generally bioavailable, but other forms are not available for algal growth. Total organic nitrogen concentration (TON; calculated as TKN minus NH_3) showed a significant positive correlation with fecal coliform concentration, suggesting that sewage is a primary source of organic loading to the watershed ($r_{(648)}$=0.70, p<0.001, Figure 5-15).

P concentration followed a pattern similar to NH_3 and TON, increasing in wet weather (Figure 5-13). This increase was likely due to CSO and SSO discharge, runoff, and soil erosion. Particle size mobilization and transport, traditionally related to flow by entrainment velocity curves (*i.e.* Shields curve), may determine the effective P loading for a given sediment load. Smaller particles, due to their greater relative surface area, can adsorb relatively more P than larger particles. Smaller particles are also generally more readily eroded and entrained in stormwater flow than larger particles.

Smaller storm events in Tookany/Tacony-Frankford thus probably contribute more to eutrophication than larger events. For example, if smaller sediment particles adsorb more P than larger particles as has been suggested, P loading becomes less efficient as larger particles are entrained in runoff. As shear stresses increase, streambank materials comprise a greater proportion of the sediment load. These particles are likely more similar to the soil parent material (*i.e.*, lower in P concentration) than more superficial soils layers that tend to incorporate more organic material. Furthermore, NH_3 showed a significant positive correlation with TSS ($r_{(380)}=0.46$, $p<0.001$), but the greatest concentrations of NH_3 were observed accompanying moderate TSS concentrations, suggesting that NH_3 concentration increases immediately due to sewage inputs but is diluted by stormwater in larger, more severe storm events (Figure 5-21).

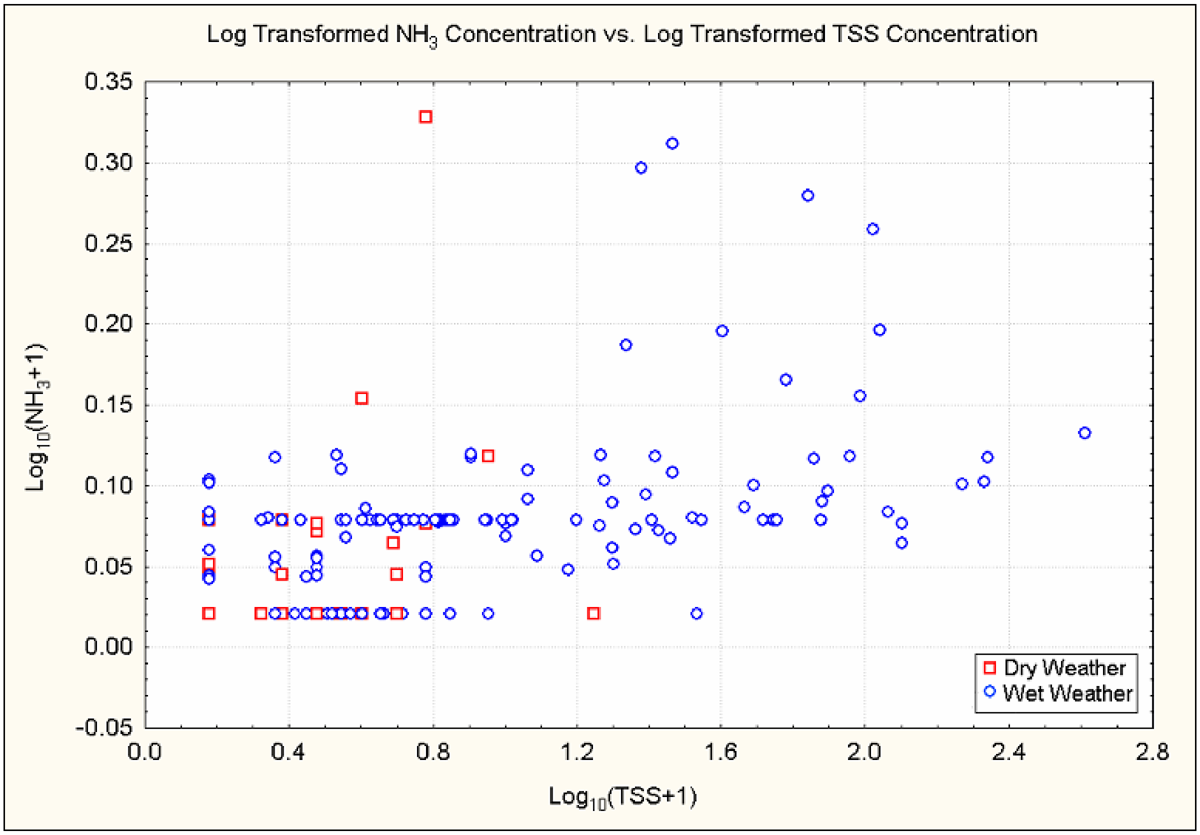


Figure 5-21 Scatterplot of log-transformed Ammonia and Total Suspended Solids Concentration of Samples Collected from 8 sites in Tookany/Tacony-Frankford Watershed, 2000-2004.

In addition to the decrease in relative bioavailability that accompanies high flows, physical stressors probably impose limits on the degree to which stream producers can take advantage of these increased concentrations. As flows increase, a greater proportion of the total nutrient load is transported out of the system, a greater proportion of the total load is inaccessible to producers, and much of the photosynthetic biomass (filamentous green algae and their associated epiphytes in particular) may be sloughed away and transported out of the system.

In areas served by combined sewers, the relative impact of small, intense storms is magnified. CSO discharge is minimally diluted by stormwater in the initial overflow phase, or "first flush". If nutrients present in these overflows can become deposited along with sediment or rapidly taken up by stream producers, discharges of short duration, particularly in which shear stresses do not result in major sloughing of algal communities, may have far-reaching consequences for stream nutrient dynamics and aquatic biota. A greater benefit may result from reducing frequency, number, and volume of small CSO discharges rather than attempting to capture releases from larger events.

Section 6
Biological Characterization

6.1 Historical and Existing Information

The Tookany/Tacony-Frankford Watershed was extensively developed as early as the 19th century. While under the control of the US Army Corps of Engineers from 1799 to 1940, the Tacony-Frankford creek channel was extensively modified, dammed, and channelized. Many businesses built mill races for hydropower and used the creek for waste disposal. With the exception of 302 acres acquired by Fairmount Park in 1915 and 1939, the remainder of the Philadelphia portion of the watershed was nearly built out in a construction boom that followed WWII. Major tributaries, including Little Tacony Creek, Wingohocking Creek, and Rock Run were buried in storm sewers both to protect people from what had essentially become open sewers, and to enable development consistent with the city's grid system. Likewise, suburban development consumed much of the Montgomery County portion of the watershed by the 1970s. Philadelphia Water Department Historian Adam Levine has amassed a collection of photographs, maps, and newspaper clippings documenting changes in Tookany/Tacony-Frankford Watershed brought about by urbanization. (More information is available on the internet at http://www.Phillyh2o.org/).

There is scant historical information about aquatic life in Tookany/Tacony-Frankford Watershed. In a 1998 report submitted to the Fairmount Park Commission (FPC), researchers from the Philadelphia Academy of Natural Sciences (ANS) reviewed existing information, citing macroinvertebrate surveys of Tookany and Baeder Creeks in Montgomery County by the Pennsylvania Department of Environmental Protection (PA DEP) in 1973, 1974, 1981, and 1998 (Fairmount Park Commission, 1999). According to ANS, most of these investigations were related to permits or spill responses, so results are probably not reflective of water quality throughout the basin.

A team of researchers from ANS conducted macroinvertebrate sampling at one site and collected fish at another site within Tacony Creek Park in 1998, documenting 8 benthic macroinvertebrate taxa and 9 species of fish. In 1999, PA DEP collected macroinvertebrates and surveyed habitats as part of the Unassessed Waters program, listing Tookany/Tacony-Frankford Watershed as impaired due to habitat alterations, flow variability and flow alterations (PA DEP, 2004 Integrated List of Waters). Philadelphia Water Department conducted a preliminary bioassessment of the watershed in 2000-2001, collecting macroinvertebrates and fish from 7 and 4 sites, respectively (Butler, *et al.* 2001). Sites sampled and collection methods were similar to the present study, allowing rough comparisons to be made.

Results of all historical studies have been consistent and unambiguous; impairment was evident in both macroinvertebrate and fish communities, whether measured as taxa richness, ecosystem function, or various numeric criteria used to evaluate aquatic communities (*e.g.*, Hilsenhoff Biotic Index, EPT index, Fish MIwb, etc.). The present study, however, is the first to integrate extensive physical habitat and chemical information.

When assessing an urban stream system that has been impaired for a long time, particularly one that lies at the center of a region of widespread impairment, it may be difficult to determine whether observed effects are the result of antecedent or ongoing impairments. There have been numerous improvements in water quality over the past 30 years, but the stream generally remains impaired.

6.2 Preliminary Documentation on the Biological Assessment of the Tookany/Tacony-Frankford Watershed

Though Tookany/Tacony-Frankford Watershed fish and benthic macroinvertebrate data suggest that many taxa have been extirpated or nearly extirpated in the past century, historical information to support these findings is generally lacking. There are simply no data to indicate what the biological communities of Tookany/Tacony-Frankford Watershed looked like prior to changes wrought by man. While some measures of community structure (*e.g.*, diversity indices) may provide meaningful information alone, conclusions of most analyses and metrics are enhanced by, or require, comparison to an unimpaired reference site. These unimpaired reference sites are often difficult to identify in southeast Pennsylvania due to extensive development and agricultural land uses. The most robust application of the reference site approach is a pair of sites located upstream and downstream of a suspected source of impairment. The downstream site in this scenario can be assumed to have a rather constant source of colonists, or "drift" from the upstream site, and all life stages of fish and macroinvertebrates are prone to displacement from the upstream site to the downstream site.

As applied to Tookany/Tacony-Frankford Watershed, reference site-based biological indexing methods assume that all similar habitats within a given ecoregion will have similar communities (absent major stressors) and that recovery of biological communities, particularly benthic macroinvertebrate communities, will occur quickly once stressors are removed. However, in regions where impairments occur watershed-wide and most first order streams have been eliminated, one cannot assume that study sites have a constant upstream source of colonists. Therefore, the most likely means of colonization of Tookany/Tacony-Frankford Watershed by rare or extirpated macroinvertebrate taxa is by winged adults, and the most likely means of re-colonization by rare or extirpated fish taxa is by passive dispersal (*i.e.*, purposeful or incidental inter-basin transfer by man).

Factors affecting re-colonization by macroinvertebrate taxa include:

1.) Geographic factors (*e.g.*, number and relative size of undisturbed first order tributaries within the watershed, distance to sources of colonists, predominant land cover and topological features separating target sites from sources of colonists, prevailing winds and climatic factors, natural and anthropogenic barriers to passive and active dispersal),
2.) Life history strategies (*e.g.*, propensity of the taxon to actively disperse, behaviors that increase the likelihood of passive dispersal, seasonal timing of oviposition and propensity to disperse prior to oviposition, duration of life cycle stages that are more prone to passive dispersal),

3.) Population factors (*e.g.*, stability of local populations representing potential colonists), and
4.) Miscellaneous factors, such as natural and anthropogenic mechanisms of passive dispersal.

Tookany/Tacony-Frankford Watershed is at the center of a region of widespread impairment due to urbanization (Figure 6-1). Some areas of the watershed may have water quality suitable for re-establishment of sensitive EPT taxa, but these taxa are generally much more abundant west of the Schuylkill River than in the Philadelphia region. PWD supports reintroduction of macroinvertebrates combined with stream restoration and stormwater BMPs for these areas.

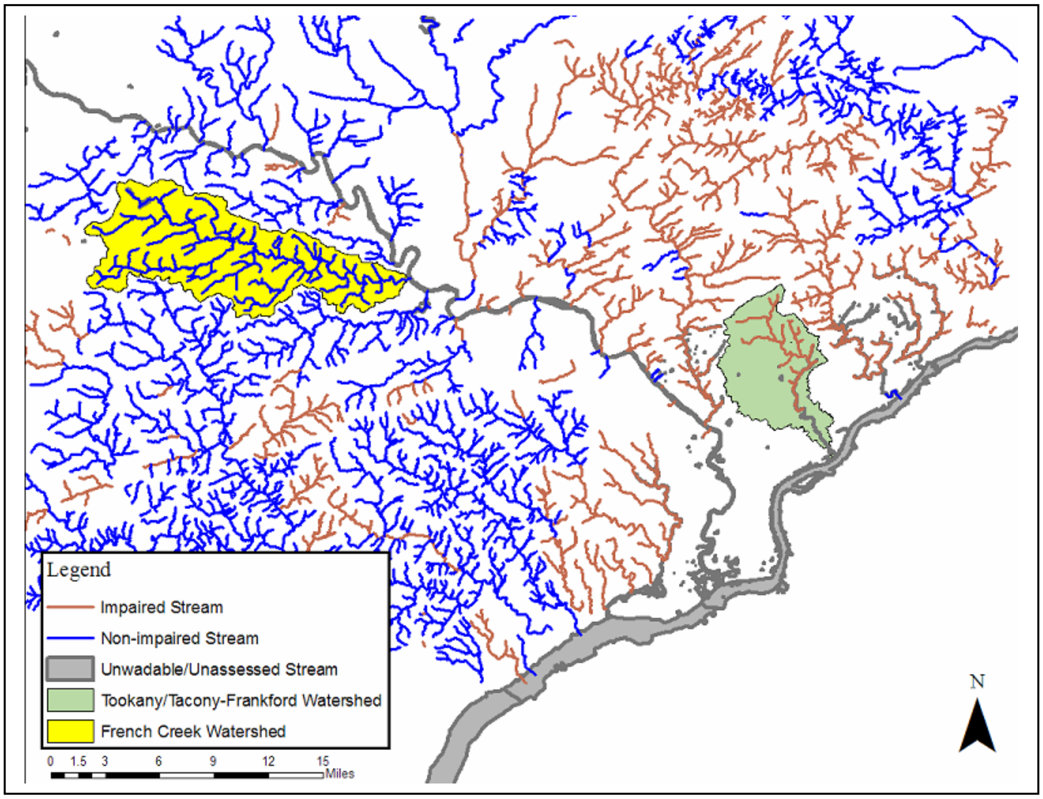


Figure 6-1 Southeastern PA stream segments in Tookany/Tacony-Frankford Watershed, French Creek watershed, and the surrounding region showing attainment status from PA DEP 2004 List of Waters (formerly 303d list).

The set of factors affecting recolonization by fish is simpler, as fish generally require water for all life stages and cannot disperse through the air. Poor water quality and physical impediments to upstream migration (*i.e.*, dams) probably prevent recolonization of non-tidal portions of Tookany/Tacony-Frankford Watershed via the Delaware River for most taxa, though American Eels are a noteworthy exception. The watershed is not actively stocked by the Pennsylvania Fish and Boat Commission (PAFBC), does not support game fish, and does not appear to be greatly affected by angling or similar activities that might result in releases of non-indigenous fish or aquatic life (*e.g.*, bait bucket release). Most of the common native fish species of southeast Pennsylvania are tolerant or moderately tolerant of water pollution.

Intolerant and non-game native fish species are unlikely to become established or re-established within the watershed other than by stocking, and PWD supports the efforts of ANS and FPC to reintroduce species such as tessellated darter and native minnows for which habitat in Tookany/Tacony-Frankford Watershed is appropriate. However, all restoration efforts should be well documented among watershed stakeholder communities so that progress can be tracked and results of subsequent ecological investigations are not jeopardized. Re-establishment of coastal plain wetlands and reintroduction of associated fish fauna (*e.g.*, Eastern mudminnow, sticklebacks, *Enneacanthus* spp.) is highly desirable, but probably not feasible in the watershed due to extensive development along the Delaware River.

Sites in Tookany/Tacony-Frankford Watershed were compared to reference sites on French Creek and Rock Run in Chester County, PA (Appendix F). Reference sites were chosen to represent a range of stream drainage areas, yet extensive impervious cover in portions of Tookany/Tacony-Frankford Watershed complicates these comparisons. Due to baseflow suppression, piping of tributaries, exaggerated storm flows and widespread erosion, sites in this urbanized watershed are difficult to categorize according to traditional frameworks (*e.g.*, stream order, link magnitude, drainage area, geomorphological attributes). These details are addressed in greater detail in Section 7.1 Habitat Assessment. Tookany/Tacony-Frankford Watershed is only linked to the tidal Delaware River and is considered a warmwater stream, while the reference sites have better connectivity and are classified as trout stocking fisheries or high quality trout stocking fisheries.

6.3 Fish

During the 2004 Tacony-Frankford Watershed fish assessment, PWD collected a total of 9774 individuals representing 17 species in 7 families (Table 6-1). Blacknose dace (*Rhinichthys atratulus)* and mummichog (*Fundulus heteroclitus),* two taxa extremely tolerant of poor stream conditions, were most abundant and comprised over half (56%) of all fish collected. Other common species included white sucker (*Catostomus commersoni*), satinfin shiner (*Cyprinella analostana*), banded killifish (*Fundulus diaphanus*), and swallowtail shiner (*Notropis procne*). Of 17 species collected in the watershed, four species comprised over 80% of the entire fish assemblage. Similarly, five species made up greater than 80% of the total fish biomass, with redbreast sunfish (*Lepomis auritus*) and American eel (*Anguilla rostrata*) contributing 42% of the biomass. American eel, blacknose dace, and satinfin shiner were found at all sites while bluegill sunfish (*Lepomis macrochirus*) and green sunfish (*L. cyanellus*) were each only found at one site and represented by a single individual. Two individual tessellated darters (*Etheostoma olmstedi*) were collected at two different sites (TF500, TF620) in the watershed; however, scientists from the Academy of Natural Sciences of Philadelphia likely stocked these fish as part of a reintroduction effort. The presence of only one tessellated darter at each site suggests that they have not become established and therefore were not included in the scoring criteria for the Index of Biotic Integrity. Overall, the non-tidal Tookany/Tacony-Frankford Watershed displayed the lowest fish diversity (*i.e.*, species richness) of all the watersheds in Philadelphia.

Table 6-1 Summary of Fish Species Collected at 7 Sites in Tookany/Tacony-Frankford Watershed, Summer 2004

Common Name	Scientific Name	TF396	TF280	TF500	TF620	TF760	TF975	TF1120
American eel	*Anguilla rostrata*	1	2	32	12	20	6	8
Banded killifish	*Fundulus diaphanus*	33	5	231	169	10	5	0
Blacknose dace	*Rhinichthys atratulus*	15	1	114	433	352	1662	847
Bluegill sunfish	*Lepomis macrochirus*	0	0	0	0	0	1	0
Brown bullhead	*Ameiurus nebulosus*	8	0	12	0	0	0	0
Common shiner	*Luxilus cornutus*	0	0	53	87	8	12	0
Creek chub	*Semotilus atromaculatus*	0	0	0	4	2	24	116
Green sunfish	*Lepomis cyanellus*	0	0	0	1	0	0	0
Hybrid sunfish	*Lepomis cyanellus x Lepomis gibbosus*	0	0	0	0	1	0	0
Mummichog	*Fundulus heteroclitus*	1101	800	179	0	0	0	0
Pumpkinseed sunfish	*Lepomis gibbosus*	0	0	1	1	0	12	0
Redbreast sunfish	*Lepomis auritus*	1	0	87	129	99	0	0
Satinfin shiner	*Cyprinella analostana*	52	4	667	763	257	27	1
Spotfin shiner	*Cyprinella spiloptera*	1	0	5	18	2	0	0
Spottail shiner	*Notropis hudsonius*	0	0	2	4	0	6	0
Swallowtail shiner	*Notropis procne*	3	0	366	345	0	0	0
Tessellated darter	*Etheostoma olmstedi*	0	0	1	1	0	0	0
White sucker	*Catostomus commersoni*	0	1	13	83	106	340	8
	TOTAL	**1215**	**813**	**1763**	**2050**	**858**	**2095**	**980**

Trophic composition evaluates quality of the energy base and foraging dynamics of a fish assemblage. This is a means to evaluate the shift towards more generalized foraging that typically occurs with increased degradation of the physicochemical habitat (Barbour, *et al.*, 1999). For example, the Tacony-Frankford fish assemblage was dominated by generalist feeders (69%) with insectivores composing 30% and top carnivores at less than 1% (Figure 6-2). Generalists become dominant and top carnivores become rare when certain components of the food base become less reliable (Halliwell *et al.*, 1999). Relative abundance of insectivores decreases with degradation in response to availability of the insect supply, which reflects alterations of water quality and instream habitat (Daniels, *et al.* 2002). The near absence of insectivores in the two upstream-most sites illustrates this point. Trophic composition was poor compared to reference sites. Though community composition varied between sites, the fish assemblage in Tookany/Tacony-Frankford Watershed was highly skewed towards a pollution tolerant, generalist feeding community.

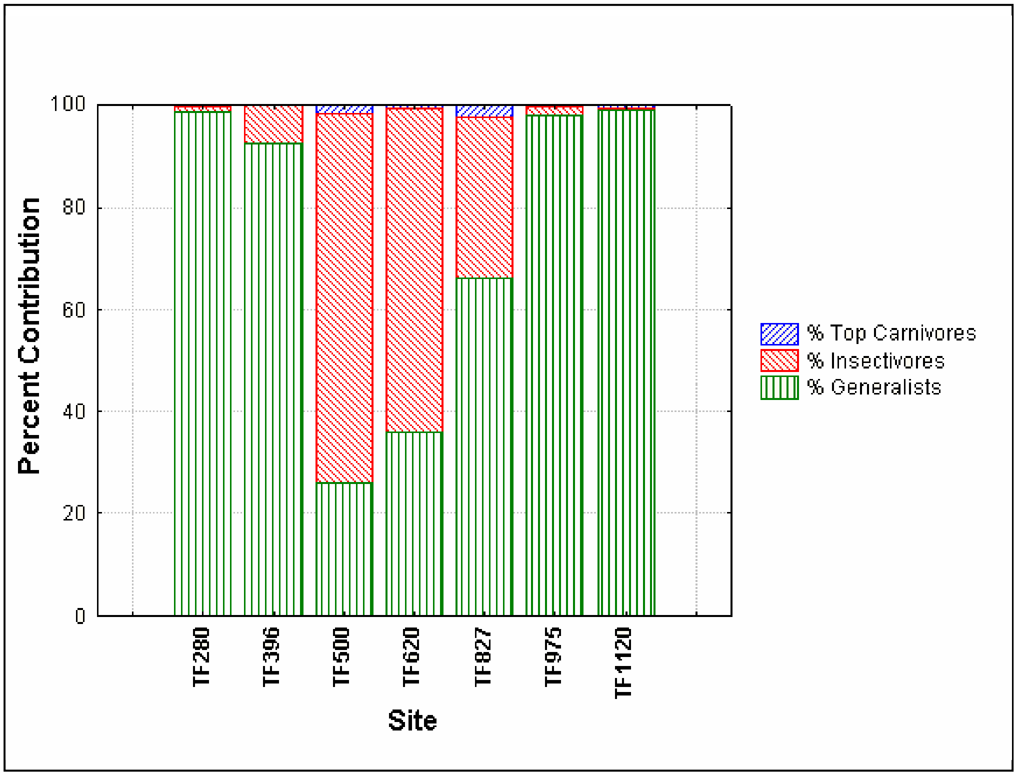


Figure 6-2 Fish Trophic Composition of the Tookany/Tacony-Frankford Watershed

Tolerance designations describe the susceptibility of a species to chemical and physical perturbations. Intolerant species are typically first to disappear following a disturbance (Barbour, *et al.*, 1999). For example, at least 70% of the fish collected at each monitoring station in Tookany/Tacony-Frankford Watershed were classified as "tolerant", and no "intolerant" species were collected (Figure 6-3). Moderately tolerant individuals were absent from the lowermost (TF280) and uppermost (TF1120) stations, and represented less than one percent (TF396) to 29% (TF500) of the assemblage at the remaining five sites. Furthermore, with approximately 91% of the fish assemblage composed of tolerant individuals, this watershed had the greatest percentage of fishes tolerant of poor stream conditions in all of Philadelphia's watersheds.

Figure 6-3 Fish Tolerance Composition of the Tookany/Tacony-Frankford Watershed

The Index of Biotic Integrity (IBI) is useful in determining long-term effects and coarse-scale habitat conditions because fish are relatively long-lived and mobile. A site with high integrity (*i.e.* high score) is associated with communities of native species that interact under natural ecosystem processes and functions (Karr, 1986). Since biological integrity is closely related to environmental quality, assessments of integrity can serve as a surrogate measurement of health (Daniels, *et al.* 2002). The mean IBI score for Tacony-Frankford Watershed was 21 (out of 50), placing it in the “poor” category for biotic integrity (Table 6-2). Low diversity, absence of benthic insectivorous species, absence of intolerant species, skewed trophic structure dominated by generalist feeders, high percentage of individuals with disease and anomalies, and high percentage of dominant species are characteristics of a fish community with "poor" biotic integrity. Spatial trends showed that only two sites received a "fair" IBI score, both centrally located within the watershed. Similar spatial trends were seen in Modified Index of Well-Being and Shannon Diversity Index values, which are measures of diversity and abundance. These indices were lowest in the lower and upper monitoring stations and highest in the middle of the watershed. This was to be expected because diversity is typically lower in upstream/smaller reaches of southeast Pennsylvania (Fairmount Park Commission 1999, W. Fairchild, personal communication). Overall, monitoring stations in the central portion of the watershed had higher biological integrity than downstream and upstream stations.

Table 6-2 Fish Community Attributes, Sampling Information, and Metric Scores for 7 Sites in Tookany/Tacony-Frankford Watershed and 3 reference sites in French Creek watershed

Metric	FC472	FC1310	FCR025	TF324	TF396	TF500	TF620	TF827	TF975	TF1120	Avg(TF)
Total Number of Fish Species*	22	18	18	6	9	13	12	9	10	5	9
Number of Benthic Insectivorous Species**	5	4	3	0	0	0	0	0	0	0	0
Number of Water Column Species	3	5	2	2	4	6	5	3	3	1	3
Number of Intolerant/Sensitive Species	3	4	3	0	0	0	0	0	0	0	0
Percent White Sucker	7.50	11.39	2.90	0.12	0.00	0.74	4.00	12.35	16.23	0.80	5
Percent Generalists	34.58	53.42	57.56	98.65	92.59	26.08	36.00	66.20	97.90	99.08	74
Percent Insectivores	37.56	35.02	38.77	1.11	7.33	72.11	63.41	31.47	1.81	0.10	25
Percent Top Carnivores	27.86	11.56	3.67	0.25	0.08	1.81	0.59	2.33	0.29	0.82	1
Percent Individuals with Disease and Anomalies	6.97	2.83	14.54	2.34	4.36	3.57	4.49	5.71	8.78	8.98	5
Percentage of Dominant Species	14.40	14.98	29.70	98.40	90.62	37.81	37.22	41.00	79.33	86.50	67
IBI Score	**Reference Streams**			16	20	34	30	22	14	14	21
Integrity Class				POOR	POOR	FAIR	FAIR	POOR	POOR	POOR	POOR
Area (m^2)	1420.14	1192.50	400.00	1972.71	1123.52	1046.19	1208.14	1327.33	1163.05	630.81	1210
Density (# Individuals/m^2)	0.28	0.98	1.70	0.41	1.08	1.69	1.70	0.65	1.80	1.55	1
Number Of Individuals	402.00	1168.00	681	813.00	1215.00	1763.00	2050.00	858.00	2095.00	980.00	1396
Total Biomass (g)	17612.56	9413.91	5040	4917.13	1219.66	13267.95	16001.37	9939.68	11270.18	7183.74	9114
Biomass per m^2	12.40	7.89	12.60	2.49	1.09	12.68	13.24	7.49	9.69	11.39	8
Modified Index Of Well-Being (MIwb)	12.21	12.21	11.37	0.00	2.71	10.22	10.58	9.37	6.75	0.00	6
Shannon-Weiner Diversity Index (H')	2.84	2.51	2.10	0.10	0.44	1.29	1.41	1.45	0.70	0.46	1
Number of Cyprinid Species	9	10	8	2	4	7	7	5	5	3	5
Percent Resident Species	92.54	100.00	99.12	100.00	100.00	100.00	99.95	99.88	99.95	100.00	100
Percent Introduced/Exotic Species	7.46	0.00	0.88	0.00	0.00	0.00	0.05	0.12	0.05	0.00	0
Percent Tolerant Fish	35.32	29.45	45.23	100.00	99.67	71.09	72.34	87.53	98.57	100.00	90
Percent Moderately Tolerant Fish	48.76	61.30	24.82	0.00	0.33	28.91	27.66	12.47	1.43	0.00	10
Percent Intolerant Fish	15.92	9.25	29.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Total Electrofishing Time (min)	62.28		77.23	77.43	61.68	61.44	67.87	50.62	61.76	42.32	60
Catch per Unit Effort (# Individuals/min)	6.45		8.82	10.50	19.70	28.71	30.21	16.95	33.92	23.16	23
Stream Order	4	3	2	3	3	3	3	3	3	3	

*"Total # of fish species" metric excluded non-resident fish and tessellated darter (recently introduced)

**"Number of benthic insectivorous species" metric excluded tessellated darter (recently introduced)
excluded from MIwb were brown bullhead, American eel, white sucker, satinfin shiner, spotfin shiner, green sunfish, bluegill sunfish, blacknose dace, banded killifish, mummichog, and common shiner.

Site TF324

A total of 813 individuals representing six species yielded a biomass of 5 kg during 77 minutes of electrofishing. This site had the lowest abundance (*i.e.* number of fish) and second lowest diversity in the watershed. Based on the site's estimated stream surface area of 1973 m^2, density and standing crop were estimated at 0.41 fish per m^2 and 2.5 grams per m^2 (g/m^2), respectively. This was the lowest density and second lowest standing crop in the watershed. Similarly, this site had the lowest catch per unit effort (CPUE) at 10.5 fish per minute of electrofishing (Table 6-2). Of the six species collected at site TF324, mummichog (*F. heteroclitus)*, a species extremely tolerant of high pollution levels and low dissolved oxygen, composed 98% of all fishes collected and 85% of the total biomass. There were neither intolerant or moderately tolerant taxa nor benthic insectivorous species collected at this location. Furthermore, the trophic structure of this assemblage was almost exclusively made up of generalist feeding taxa (98%).

Site TF324 received an Index of Biotic Integrity (IBI) score of 16 (out of 50), representing a "poor" quality fish assemblage and therefore, poor environmental health. To further support this characterization, the Modified Index of Well-Being (0.0) and Shannon Diversity Index (0.1) values, which are measures of diversity and abundance, were not only the worst in the watershed, but in all of Philadelphia's watersheds surveyed by PWD. These fish assemblage characteristics are symptomatic of a severely degraded stream system suffering from multiple chemical and physical stressors.

Site TF396

In 1123 m^2 of stream surface area, a total of 1215 individuals representing nine species were collected during 62 minutes of electrofishing. This site had the smallest total biomass (1.2 kg) and standing crop (1.1 g/m^2) in the watershed, with a density of 1.1 fish/m^2 and catch per unit effort of 19.7 fish/minute (Table 6-2). Intolerant taxa, benthic insectivorous species, and white suckers (*C. commersoni*) were not collected. As observed at the previous site, mummichog (*F. heteroclitus)*, a species extremely tolerant of high pollution levels and low dissolved oxygen, accounted for 91% of all fishes collected and 78% of total biomass. Three of the nine species collected at this site were represented by a single individual. Pollution tolerant taxa accounted for greater than 99% of the fish assemblage and generalist feeders (93%) dominated the trophic structure. This highly unbalanced community structure of generalist feeding, tolerant taxa, dominated by a single species, exemplifies a stream with inadequate environmental quality.

The IBI score of 20 (out of 50) was typical of a fish assemblage with "poor" biotic integrity. Disease, tumors, fin damage, and other anomalies were prevalent at site TF396 (4.4% of fish affected). The Modified Index of Well-Being (2.71) and Shannon Diversity Index (0.44) values were second lowest in the watershed and corroborate the IBI designation. These values represent 22% and 18% comparability, respectively, to reference stream conditions. Principal causes of impairment are probably low dissolved oxygen concentration and habitat modification (instability promoted by urbanized hydrology).

Site TF500

TF500 contained the most diverse fish assemblage in the watershed with 1763 individuals representing 13 species. The single tessellated darter (*Etheostoma olmstedi*) specimen collected at this site was assumed to have been recently stocked as part of a reintroduction program, and was thus excluded from calculations and metrics. The presence of only one individual tessellated darter suggests that the species has not, and may not, become established at this site and thus was not considered members of the fish assemblage. This site had the greatest number of water column species (n=6), which is directly comparable to reference conditions, however, there were no benthic insectivores or intolerant species. Satinfin shiner (*C. analostana*), swallowtail shiner (*N. procne*), and banded killifish (*F. diaphanus*), three pollution tolerant species, composed approximately 72% of all fishes collected (Table 6-1). Despite this, TF500 had the lowest percentage of tolerant individuals and the greatest percentage of moderately tolerant individuals (Table 6-2). TF500 had the most relatively balanced trophic structure in the watershed with 72% insectivores, 26% generalists, and almost 2% top carnivores; representing the greatest percentage of the fish assemblage as insectivores and smallest percentage of generalists. This was one of only two sites in which the percentage of insectivores was greater than the percentage of generalist feeders. This shift toward specialized feeding typically occurs in response to a stabilizing insect supply, which reflects possible improvements of water quality and instream habitat. However, benthic macroinvertebrate survey results were poor.

In addition to positive scores for abundance, diversity, and trophic structure indices, TF500 had the second lowest percentage of individuals with disease, tumors, fin damage, or other anomalies. As a result, this site received the highest IBI score in the watershed (34 out of 50), characteristic of a fish assemblage with "fair" biotic integrity. This was one of only two sites that obtained a "fair" IBI score, with the rest of the watershed scoring poor for biotic integrity. Similarly, the Modified Index of Well-Being (10.22) and Shannon Diversity Index (1.29) values were the second and third highest values, respectively, in the watershed and further support the IBI classification.

Site TF620

A total of 2050 fishes representing 12 species were collected in 1208 m^2 of stream surface area in 68 minutes of electrofishing. This site had the greatest total biomass (16 kg) and standing crop (13.2 g/m^2), as well as the second greatest number of individuals (n=2050), density (1.7 $fish/m^2$), and catch per unit effort (30.2 fish/minute) in the watershed (Table 6-2). These relatively high abundance and diversity values, indicative of the quality of the fish assemblage, produced the best Modified Index of Well-Being (10.58) and second-best Shannon Diversity Index (1.41) values in the watershed. This was the only site in the watershed where a green sunfish (*Lepomis cyanellus*) was collected. Though diverse and abundant, the fish assemblage at TF620 lacked pollution sensitive taxa and benthic insectivorous species. Also, of the 12 species collected, three pollution-tolerant species composed 75% of all individuals collected and four species contributed 79% of the biomass. This unbalanced assemblage is symptomatic of degraded stream conditions.

Trophic composition also displayed unbalanced characteristics with less than 1% top carnivores, 36% generalist feeders, and 63% percent insectivores. Furthermore, approximately 4.5% of all fishes had some type of disease, tumors, fin damage, or other anomalies. Regardless of this unevenness and prevalence of anomalies, TF620 was one of only two sites with more insectivores than generalists and at least 25% moderately tolerant individuals, which helped elevate the IBI score. With positive scores for abundance, diversity, and trophic structure, this monitoring location received the second highest IBI score (30 out of 50) in the watershed and was considered to have a "fair" quality fish assemblage.

Site TF827

As the first monitoring station upstream of the Philadelphia county line, TF827 marks a transition in the trophic structure from an insectivore-dominated community, to generalist feeders (66%), with insectivore abundance decreasing relative to generalist feeders (Table 6-2). Likewise, pollution tolerant individuals increased in abundance (88%) while moderately tolerant (12%) individuals decreased. Of 9 species collected at this site, blacknose dace, satinfin shiner, and white sucker composed approximately 84% of the assemblage. This was the only location where a hybrid sunfish (*L. cyanellus* x *L. gibbosus*) was identified. Redbreast sunfish (*Lepomis auritus*), American eel (*Anguilla rostrata*), and white sucker made up over 75% of total fish biomass (~10 kg) (Table 6-1). This site had the second smallest abundance (n=858), density (0.65 fish/m^2), and catch per unit effort (17 fish per minute) in the watershed.

The Modified Index of Well-Being (9.37) was above average and the Shannon Diversity Index (1.45) was best in Tookany/Tacony-Frankford Watershed. Since 9 species were collected at a site with low abundance, the Shannon Diversity Index is high. However, with over 5% of the fish assemblage affected by disease, tumors, fin damage, or other anomalies; numerous white suckers; and absence of intolerant species and benthic insectivores, this site received a "poor" IBI score of 22 out of 50. Habitat modification, particularly effects of infrastructure, may be responsible for observed poor qualities of the fish assemblage at this site.

Site TF975

This site contained the greatest number of fish (n=2095), density (1.8 fish/m^2), and catch per unit effort (34 fish /minute) in Tookany/Tacony-Frankford Watershed (Table 6-2). However, greater than 95% of all fish collected were blacknose dace (79%) and white sucker (16%), species highly tolerant of poor water quality and degraded habitat. These two species also accounted for 79% of fish biomass (11 kg) collected at site TF975. Of 10 species collected, there were no intolerant species, no benthic insectivores, three water column species, and five cyprinid species. This was the only site where a bluegill sunfish (*L. macrochirus*) was collected. Trophic structure of the fish assemblage at this site was dominated by generalist feeders (98%), with very few insectivores and top carnivores. Likewise, pollution tolerant taxa made up 98% of the fish assemblage.

The large percentage of white sucker (16%) may be indicative of degradation as this species typically shows increased distribution or abundance despite historical disturbances and they shift from incidental to dominant in disturbed sites (Barbour, *et al.*, 1999). This site had the second highest percentage (8.8%) of fishes with disease, tumors, fin damage, or other anomalies, which is symptomatic of an impacted assemblage downstream of point source pollution or in areas where toxic chemicals are concentrated (Barbour, *et al.*, 1999). Taking into account the aforementioned problems, TF975 received an IBI score of 14 (out of 50), placing it into the "poor" classification for biotic integrity. The IBI score for this site was tied for worst in the watershed. Modified Index of Well-Being (6.75) and Shannon

Diversity Index (0.70) values were low and represented 55% and 28% comparability, respectively, to reference conditions.

Site TF1120

The fish assemblage at TF1120 contained only five species, least for this watershed and all of Philadelphia's watersheds surveyed by PWD using RBPV protocols. Blacknose dace constituted 86% of all fish collected at this location and one species (*C. analostana*) was represented by a single individual (Table 6-1). This site was devoid of intolerant taxa and benthic insectivorous species, and only contained one water column species. With 99% generalist feeders, this was the most highly skewed trophic structure in all of Philadelphia's watersheds surveyed by PWD. This site contained only pollution tolerant species and had the highest percentage (9%) of individuals with disease, tumors, fin damage, or other anomalies in this watershed. These are excellent measures of the subacute effects of chemical pollution and aesthetic value of nongame fishes (Barbour, *et al.*, 1999). The Modified Index of Well-Being (0.0) and poor IBI score (14 out of 50) were tied for worst in Tookany/Tacony-Frankford Watershed (with TF324) and in all of Philadelphia's watersheds monitored by PWD. Low species richness and trophic composition metrics combined with poor abundance and condition metrics reflect severely degraded stream quality.

6.4 Benthic Macroinvertebrates

A total of 2,137 individuals from 19 taxa were identified during the 2004 benthic macroinvertebrate survey of Tookany/Tacony-Frankford Watershed (Table 6-3). The average taxa richness of the watershed was 7 (Figure 6-4). Overall, moderately tolerant (91%) and generalist feeding taxa (96%) dominated the watershed. The average Hilsenhoff Biotic Index (HBI) of all assessment sites was 6.16. Pollution sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa were absent throughout the watershed (Table 6-4). One site had one modified EPT taxon present. Modified EPT taxa are EPT taxa with Hilsenhoff Biotic Index score less than or equal to four. Seven of 12 sites included in the present study were sampled by PWD in November 2000 using the same protocols, allowing some rough comparisons to be made. Most sites had reduced taxa richness and metric scores compared to year 2000 samples.

Table 6-3 Summary of Benthic Macroinvertebrates Collected at 12 sites in Tookany/Tacony-Frankford Watershed, Spring 2004

Taxon	**HBI score**	**TF324**	**TF396**	**TF500**	**TF620**	**TF827**	**TF975**	**TF1120**	**TF1270**	**TFU010**	**TFM006**	**TFR064**	**TFJ013**
Turbellaria (Flatworms)													
Cura	**7**	0	0	0	0	0	0	1	0	3	0	0	0
Oligochaeta (Worms)													
Lumbriculidae	**8**	0	1	0	1	0	1	0	0	2	1	1	0
Tubificidae	**10**	**114**	3	0	0	0	0	0	0	0	0	0	0
Hirudinea (Leeches)													
Erpobdellidae	**7**	4	1	0	0	0	0	2	1	0	0	0	0
Gastropoda (snails)													
Ancylidae	**7**	0	0	0	0	0	0	1	0	0	0	0	0
Physidae	**8**	0	0	0	0	0	0	0	0	0	0	1	0
Planorbidae	**6**	0	0	0	0	0	0	0	0	0	0	1	0
Bivalvia (Clams)													
Corbicula	**4**	0	3	0	0	0	0	0	0	0	0	0	0
Amphipoda (Scuds)													
Crangonyx	**6**	0	0	1	0	1	0	0	0	2	0	0	0
Isopoda (Sowbugs)													
Caecidotea	**6**	2	4	0	0	0	3	0	0	0	0	2	1
Ephemeroptera (Mayflies)													
Baetis	**6**	0	0	0	0	0	0	0	2	0	0	3	2
Trichoptera (Caddisflies)													
Cheumatopsyche	**6**	0	6	0	0	0	0	0	0	0	0	0	0
Chimarra	**4**	0	0	0	0	0	0	0	0	0	0	0	13
Hydropsyche	**5**	2	47	2	10	2	7	0	4	3	1	1	5
Coleoptera (Beetles)													
Stenelmis	**5**	0	1	0	0	7	0	0	0	0	0	0	48
Ectopria	**5**	0	0	0	0	0	0	0	0	0	0	0	1
Diptera (True flies)													
Hemerodromia	**6**	2	1	1	0	0	2	0	1	0	1	0	1
Simulium	**6**	0	0	0	0	0	3	0	0	1	0	0	0
Antocha	**3**	0	5	0	1	1	1	0	2	1	3	3	1
Tipula	**4**	0	1	0	1	1	1	1	1	1	0	1	3
Chironomidae	**6**	34	**126**	**129**	**321**	**239**	**147**	**108**	**123**	**176**	**130**	**108**	**129**
Total		**158**	**199**	**133**	**334**	**251**	**165**	**113**	**134**	**189**	**136**	**121**	**204**

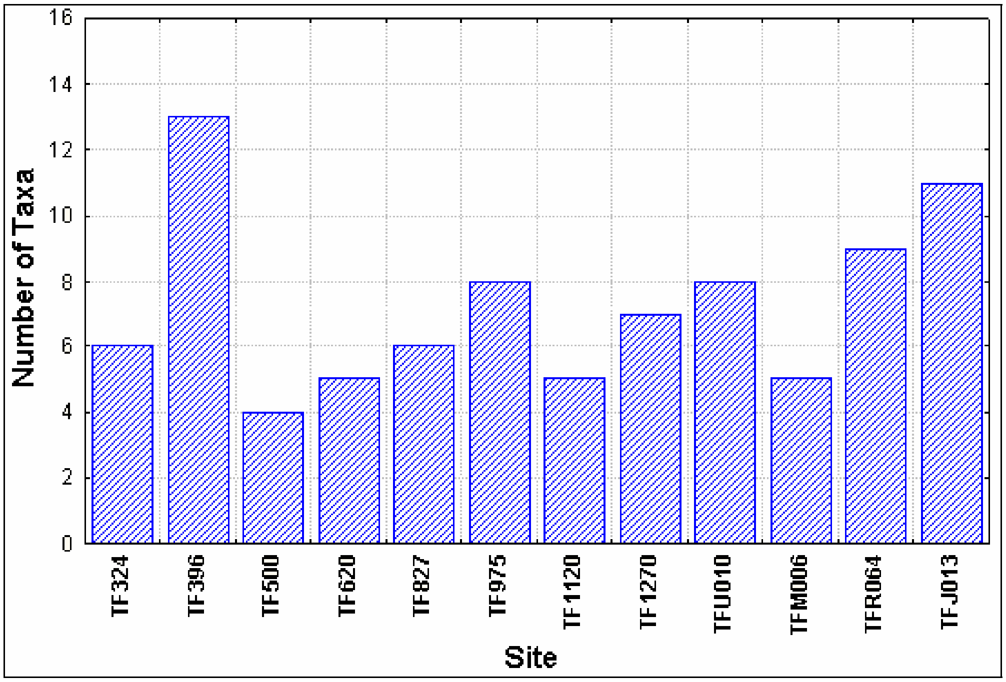


Figure 6-4 Benthic Macroinvertebrate Taxa Richness at 12 sites in Tookany/Tacony-Frankford Watershed, Spring 2004

Chironomidae (midges) dominated the benthic macroinvertebrate communities within the watershed (percent contribution ranged from 63% to 97%). Net-spinning caddisflies (Hydropsychidae), isopods, amphipods, tipulids, gastropods, and oligochaetes were also present throughout the watershed but in very low abundance (Table 6-3). Benthic macroinvertebrate communities of Tookany/Tacony-Frankford Watershed are thoroughly dominated by midges, suggesting stressors are affecting survival of more sensitive taxa.

Table 6-4 Summary of Benthic Macroinvertebrate Metric Scores from 12 sites in Tookany/Tacony-Frankford Watershed and Reference Sites in French Creek Watershed, Spring 2004

Site	Taxa Richness	Modified EPT Taxa	Hilsenhoff Biotic Index (modified)	Percent Dominant Taxon	Percent Modified Mayflies	Biological Quality (%)	Biological Assessment	Habitat Quality (%)	Habitat Assessment
TF324	6	0	8.92	72.15 (Tubificidae)	0.00	0.00	Severely Impaired	31.84	Non-Supporting
TF396	13	0	5.79	63.31 (Chironomidae)	0.00	0.00	Severely Impaired	74.53	Supporting
TF500	4	0	5.98	96.99 (Chironomidae)	0.00	0.00	Severely Impaired	62.03	Partially Supporting
TF620	5	0	5.96	96.11 (Chironomidae	0.00	0.00	Severely Impaired	72.41	Partially Supporting
TF827	6	0	5.94	95.22 (Chironomidae)	0.00	0.00	Severely Impaired	58.25	Non-Supporting
TF975	8	0	5.94	89.09 (Chironomidae)	0.00	0.00	Severely Impaired	54.95	Non-Supporting
TF1120	5	0	6.04	95.58 (Chironomidae)	0.00	0.00	Severely Impaired	58.02	Non-Supporting
TF1270	7	0	5.91	91.79 (Chironomidae)	0.00	0.00	Severely Impaired	48.03	Non-Supporting
TFU010	8	0	5.99	93.12 (Chironomidae)	0.00	0.00	Severely Impaired	48.46	Non-Supporting
TFM006	5	0	5.94	95.59 (Chironomidae)	0.00	0.00	Severely Impaired	38.60	Non-Supporting
TFR064	9	0	5.93	89.25 (Chironomidae)	0.00	0.00	Severely Impaired	64.69	Partially Supporting
TFJ013	11	1	5.57	63.24 (Chironomidae)	0.00	20.00	Moderately Impaired	60.53	Partially Supporting
FCR025	25	10	4.47	42.24 (Chironomidae)	27.44	Reference Sites			
FC1310	21	9	3.69	21.60 (*Hydropsyche*)	13.59				

Feeding measures describe functional feeding groups and provide information on the balance of feeding strategies in the benthic macroinvertebrate community (Barbour *et al.* 1999). The trophic composition of the watershed was skewed toward generalist feeding gatherer collectors (greater than 90%) (Figure 6-5). Particularly notable was the general lack of moderately tolerant filterer collector taxa (*e.g.*, Hydropsychidae, Simuliidae) which are often abundant in organically enriched streams. These taxa were generally present in moderate numbers at all sites studied in 2000, so their reduced abundance is disturbing. This may reflect severe water quality and habitat degradation or perhaps a lack of fine particulate organic matter (FPOM). Food source limitation may also impair survivability of other specialized feeders, such as cranefly larvae that rely on accumulated leaf material. Other shredders, and sensitive taxa in general, were not encountered. Specialized taxa are generally more sensitive to perturbation than generalist feeders.

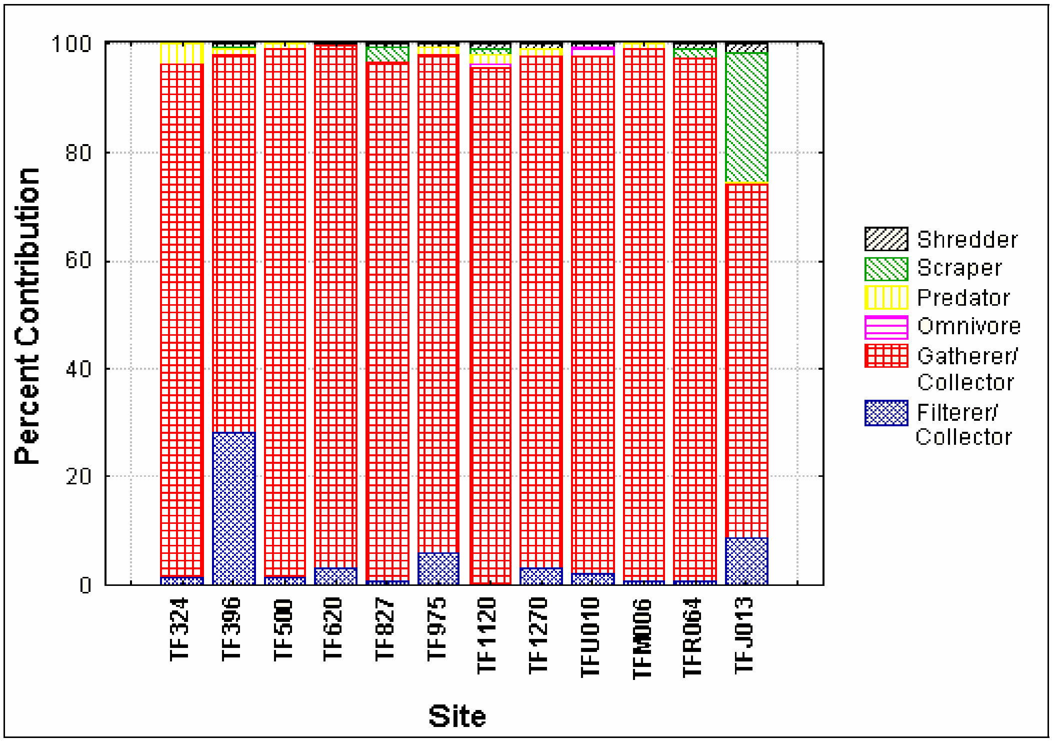


Figure 6-5 Benthic Macroinvertebrate Community Trophic Composition at 12 sites in Tookany/Tacony-Frankford Watershed, Spring 2004

Tolerance/intolerance measures are intended to be representative of relative sensitivity to perturbation and may include numbers of pollution tolerant and intolerant taxa or percent composition (Barbour *et al.* 1999). Moderately tolerant individuals (91%) dominated macroinvertebrates communities of Tookany/Tacony-Frankford Watershed. Sensitive taxa were poorly represented (2%), suggesting watershed-wide perturbation (Figure 6-6).

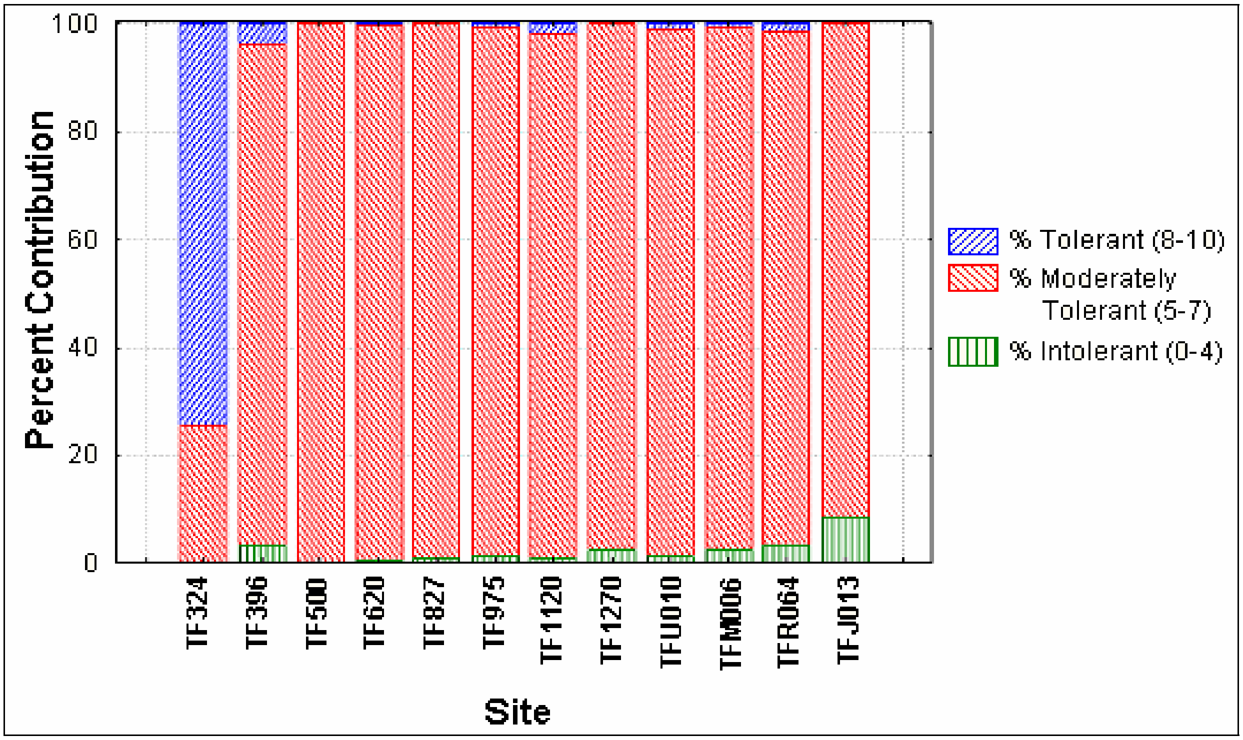


Figure 6-6 Tolerance Designations of Benthic Macroinvertebrate Communities at 12 sites in Tookany/Tacony-Frankford Watershed

The Hilsenhoff Biotic Index (HBI) is a metric used to determine the overall pollution tolerance of a site's benthic macroinvertebrate community. The HBI is oriented toward the detection of organic pollution. The HBI can range from zero (very sensitive) to ten (very tolerant). Differences in HBI score between reference and assessment sites greater than 0.71 indicate impairment. Mean HBI score of sites within Tookany/Tacony-Frankford Watershed was 6.16 (Figure 6-7). Dominance by moderately tolerant individuals and general lack of pollution-sensitive taxa contributed to the elevated HBI. In comparison, mean reference site HBI score was 4.08. When compared to reference conditions, Tookany/Tacony-Frankford Watershed mean HBI exceeded reference site mean HBI by 2.08, indicating severe impairment overall.

While HBI is very effective in determining whether a site is impaired relative to a reference site, HBI scores are not very useful in comparing impaired urban sites to one another, as these systems typically have one to three dominant taxa with similar HBI scores. For example, 90% of benthic macroinvertebrate samples collected by PWD in urban streams had HBI scores between 5 and 6. This lack of resolution is exacerbated when chironomids are not identified beyond the family level, as has been PWD practice.

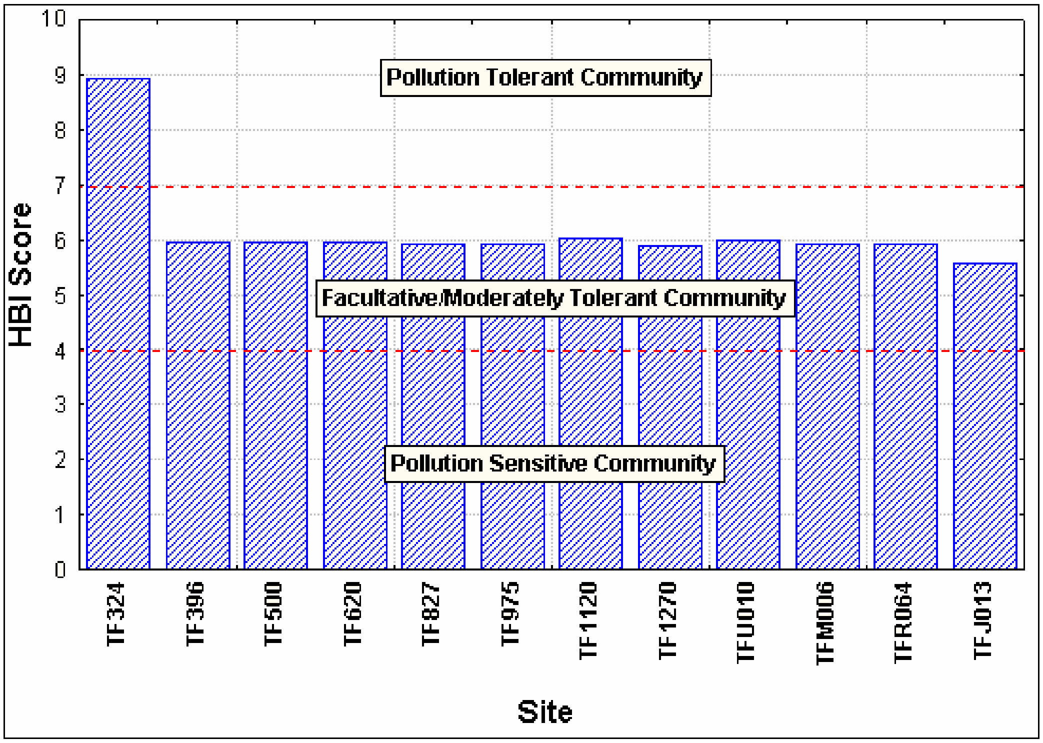


Figure 6-7 Hilsenhoff Biotic Index of Benthic Macroinvertebrate Communities at 12 sites in Tookany/Tacony-Frankford Watershed

Site TF324

Site TF324 received a total metric score of zero (0) out of a possible 30. The site was designated "severely impaired". Impairment is based primarily on low taxa richness (n=6) and the highest HBI score in the watershed (8.92) (Figures 6-4 and 6-7). This was the highest HBI score of any site assessed by PWD using RBPIII protocols. Despite a history of sampling sites below wastewater treatment plant discharge and in heavily urbanized stream systems, no other sites scored higher than 7. Tubificid worms dominated the benthic assemblage (72%) which accounts for the high HBI score. Tolerant individuals (75%) dominated the benthic assemblage at TF324 and there were no intolerant taxa collected. Generalist feeders (96%) also dominated the feeding structure of the site with predators being the only specialized feeders present (4%). The two specialized feeder taxa collected at TF324 were not pollution-sensitive.

Ten taxa were collected at this site during the 2000 survey, and tubificid worms were not collected. If the shift in benthic macroinvertebrate composition between these two subsamples reflects actual stream community changes, this site has become much more severely impaired over the past five years. Samples were collected in different seasons, and there were numerous natural disturbances (*e.g.*, floods and drought) over this period. It is assumed that water quality had been consistently poor at this site throughout the interval represented by these samples.

Site TF396

The assessment site at TF396 received a total metric score of zero (0) of 30 possible points. The site was designated "severely impaired". TF396 had the highest taxa richness (n=13) of all assessment sites and the lowest HBI (5.79) of mainstem assessment sites (Figures 6-4 and 6-7). Generalist feeders (98%) and moderately tolerant individuals (93%) dominated the site. TF396 scored substantially better in taxa richness, percent dominant taxon, and HBI than the other mainstem assessment sites. Site TF396 was the only mainstem site in which filterer collector taxa were well represented. A shift in community composition toward chironomid midges has been associated with water quality degradation, such as toxic metals contamination (Clements *et al.* 1988), but data from site TF396 are inconsistent with this explanation -- site TF396 had the best benthic macroinvertebrate community scores in mainstem Tacony-Frankford Creek despite frequent insults to water quality from CSO discharge and urban stormwater. Higher scores at this assessment location can probably be attributed to superior instream habitat and other site specific features that allow filterer collectors and other rare taxa to survive and/or recover from perturbations.

Site TF500

The total metric score at TF500 was zero (0) out of 30, which designated the site as "severely impaired". TF500 had the lowest taxa richness (n=4) of all assessment sites. TF500 also had an elevated HBI (5.98) and a very unbalanced trophic structure with 99% generalist feeders. Midge larvae (Chironomidae 97%) dominated the site. Like site TF324, 2004 metric scores and attributes of the benthic macroinvertebrate subsample were considerably worse than scores from 2000; relative abundance of filterer collector taxa decreased from 25% to <2%, and taxa richness decreased from 10 to 4. Researchers from ANS (Fairmount Park Commission, 1999) reported 63% chironomid relative abundance and 6% filterer-collector relative abundance in a quantitative benthic macroinvertebrate sample collected in winter 1998 near site TF500.

Site TF620

The total metric score at TF620 was zero (0) out of 30. The site was designated "severely impaired" when compared to the reference condition at FC1310. The site was dominated by Chironomidae (96%) and had a high HBI score (5.96). Generalist collector-gatherers (97%) dominated the feeding structure of the assemblage. When the 2000 subsample was compared to the 2004 subsample, relative abundance of filterer collector taxa decreased from 34% to 3%, and taxa richness decreased from 11 to 6. Again, if comparisons between single subsamples are representative of actual changes in benthic macroinvertebrate community structure, this site has become more severely impaired.

Site TF827

TF827 received a total metric score of zero (0) out of a possible 30. The site was designated as "severely impaired". The macroinvertebrate sample was dominated by chironomids (95%) and had low taxa richness (n=6) and an HBI score of 5.94. Generalist feeders (97%) and moderately tolerant individuals (99%) dominated the assemblage.

Site TF975

The assessment site at TF975 received a total metric score of zero (0) out of 30. The site was designated "severely impaired". Impairment was based primarily on low taxa richness (n=8) and an elevated HBI (5.94). Similar to other assessment sites, generalist feeders (98%) and moderately tolerant individuals (98%) dominated the assemblage. Chironomids composed 89% of the sub-sampled sorted for identification.

Site TF1120

The macroinvertebrate assemblage at TF1120 scored zero (0) out of 30. The site was deemed “severely impaired” when compared to the reference condition at FC1310. TF1120 had an elevated HBI score (6.04) and very low taxa richness (n=5). TF1120 was the only site surveyed where net-spinning caddisflies (Hydropsychidae) were not identified. Chironomids (96%) dominated the assemblage. When this site was sampled in 2000, filterer collectors were much more abundant, trophic and overall community composition was more even compared to results from the present study.

Site TF1270

The total biological score at TF1270 was zero (0), which designated the site as “severely impaired”. TF1270 was the most upstream mainstem assessment site sampled during the 2004 survey. Similar to other assessment sites, there was an elevated HBI (5.93), low taxa richness (n=7) and abundance of chironomids (92%). Moderately tolerant individuals (98%) dominated the assemblage.

Site TFU010

TFU010 received a total metric score of zero (0) out of a possible 30. The site was designated as “severely impaired”. TFU010 had an elevated HBI (5.99) and low taxa richness (n=8). The assemblage consisted mostly of chironomids (93%) and moderately tolerant individuals (98%). Although most feeding groups were represented, generalist feeders (98%) dominated the assemblage.

Site TFM006

The assessment site at TFM006 received a total metric score of zero (0) out of 30. The site was designated “severely impaired”. The site had very low taxa richness (n=5) and a high HBI score (5.94). Similar to other assessment sites, generalist feeders (99%) and moderately tolerant individuals (97%) dominated the assemblage. Chironomidae (96%) dominated the benthic community and all metrics were scored as zero. Water quality in Mill Run was generally poor, with indicators of sewage present in dry and wet weather.

Site TFR064

The total metric score at TFR064 was (0) out of 30. The site was designated “severely impaired” when compared to the reference condition at FCR025. Resembling the rest of the watershed, TFR064 had an elevated HBI (5.93) and low taxa richness (n=9). Midge larvae composed 89% of the sub-sampled sorted for identification. Generalist feeders (97%) and moderately tolerant individuals (95%) dominated the assemblage.

Site TFJ013

The total biological score at TFJ013 was six (6) out of a possible 30. The site was designated as “moderately impaired”. The metric score for TFJ013 was between two condition categories. The site was listed as “moderately impaired” because TFJ013 was the only site with a modified EPT taxon (*Chimarra*) present. The site was impaired primarily for low taxa richness (n=11) and an elevated HBI (5.57) score. Similar to other assessment sites, generalist feeders (74%) and moderately tolerant individuals (92%) dominated the assemblage. Compared to the rest of the watershed, the site had the smallest relative proportion of the dominant taxon (Chironomidae, at 63%). PWD 2000 survey data suggest that sensitive *Chimarra* caddisflies may have been more abundant at this site than presently. Furthermore, two additional sensitive caddisfly taxa (*i.e.*, *Glossosoma*, *Dolophilodes*) were collected in 2000 but not in 2004.

6.5 Periphyton

Periphyton communities were sampled from a limited number of sites, chiefly to assess the role of periphyton regulating stream metabolism (Section 5.4). Several samples were preserved for taxonomic identification, but these analyses have not been completed. As most water chemistry parameters (*e.g.*, nutrients, BOD, etc.) have been fully characterized through extensive sampling, there is little need to use periphyton communities to infer an ecological condition. The ratio of water column chlorophyll-*a* to periphyton chlorophyll-*a* in dry weather and observed increases in concentrations of water column chlorophyll-*a* in wet weather suggest that attached algal communities are the dominant primary producers in Tookany/Tacony-Frankford Watershed and that storm events tend to scour and remove algal biomass.

Chlorophyll-*a* concentrations (± Standard Error (SE)) at sites TF324 and TF680 are shown in Section 5.4, (Figure 5-16). Although temporal patterns of chl-*a* were similar at both sites, chl-*a* concentrations were consistently significantly greater at site TF680 than at site TF324 ($F_{5,50}$= 14.27, p<0.05). Mean chl-*a* at site TF680 was significantly lower (49.8 ± 6.5 mg/m^2) on 9/08/2004 than on other sampling dates ($F_{4,50}$= 2.66, p= 0.043). Mean chl-*a* concentration at the TF02 site sampled 19 August 2004 (not shown in Figure) was 34.9 (± 6.9) mg/m^2.

An artificial scouring experiment was conducted to examine differences in accrual rates with respect to site and non-scoured substrates. As with the monitoring program, there were significant site differences in algal biomass with TF680 having greater chl-*a* concentrations than TF324 ($F_{2,32}$= 14.96, p <0.05). Algal accrual rates for each site were positive for the first 5 days of the study period with TF324 having an average daily accrual rate (8.36 ±1.30 mg/m^2) approximately half that of TF680 (16.7 ± 4.34 mg/m^2). During days 5-9 of the experiment, both sites lost biomass with an average daily loss rate of 1.73 (± 0.99) mg/m^2 at TF324 and 4.56 (± 1.31) mg/m^2 at TF680. The mean daily accrual rate of non-scoured rocks at TF324 during days 5-9 was 8.96 mg/m^2 (accrual rates could not be calculated for the first 5 days because of insufficient data). At TF680, the mean daily accrual rate of non-scoured rocks was 11.7 mg/m^2 and 1.98 mg/m^2 during days 0-5 and 5-9, respectively.

Algal samples for water column chl-*a* analyses were collected from sites on mainstem Tookany/Tacony-Frankford Creek during 2000-2002, and for benthic chl-*a* analyses during 2003. These data are presented in Appendix I to amalgamate all available chl-*a* data for the Tookany/Tacony-Frankford Watershed into a single document. Suspended water column samples were collected as grab samples at all Tookany/Tacony-Frankford Watershed sites on multiple occasions. In 2003, algal samples were collected from TF324, TF500, TF680, and TF760 on 16 October. Algal samples were processed and analyzed in the same manner as samples collected for the present study.

Water column (*i.e.*, suspended) chl-*a* concentrations are typically below 5 mg/L at all sites although concentrations at TF324 tend to be more variable (Table 5-7). The large spikes in chl-*a* concentrations are likely the result of scouring and suspension of benthic algae due to high flow events. Large river phytoplankton communities (potamoplankton) are typically prolific and can reach concentrations of 250 µg/L (Reynolds 1988), but Tookany/Tacony-Frankford Watershed is a relatively small, shallow stream. Given the baseflow concentrations observed, it is likely that the source of water column chl-*a* is suspended benthic algal material.

Benthic chl-*a* collected during 2003 showed a similar spatial pattern to that of this study. Chlorophyll-*a* concentrations at TF324, TF500, TF680, and TF760 were 114 mg/m^2, 222 mg/m^2, 167 mg/m^2, and 116 mg/m^2, respectively. As with the current study, it would be expected that chl-*a* concentrations would be greater at TF324 than at upstream sites because of the observed diurnal DO fluctuations. It appears that other factors such as disturbance, light, or grazing may be limiting accrual at TF324 and that the relationship between biomass and production is not as clear-cut as expected.

6.6 Summary of Biology by Reach

Site TF280/324

Site TF 324 is one of the most severely degraded aquatic habitats in the City of Philadelphia. Approximately one third of the watershed land area, roughly representing the drainage area of the former Wingohocking Creek, drains directly to the combined sewer outfall located just upstream of this site (Figure 7-1). This outfall is responsible for combined sewer overflows of 2 billion gallons per year on average. Due to stormwater collection system efficiency and the sheer size and imperviousness of its drainage area, it is assumed that even small storm events may cause discharge of combined sewage from this outfall. Sewage that is constantly present in the system is minimally diluted by stormwater in these small events, and the large scour pool downstream of this outfall is capable of storing many gallons of mixed discharge. One component of PWD's CSO long term control plan is construction of a Pelican gate within this outfall that will allow for storage and capture of combined sewer flows; this project is in the conceptual design stage. It is estimated that once completed, this gate will reduce the number of overflows from 69 to 51 per year on average at this site. It is hoped that this gate will capture small rain events and provide many benefits to dry weather water quality.

As evidenced by comparison to water quality data from the 1970s in which fecal coliform concentration was elevated in both wet and dry weather at this site (Appendix A), much improvement has been made with regard to controlling and managing this combined sewer, but tracking down and fixing sources of dry weather discharge is still a high priority. This site had the most severe wet weather loading of organic material (mean BOD_5 and TKN) in Tookany/Tacony-Frankford Watershed. Dissolved oxygen suppression due to the breakdown of organic matter is probably limiting the success of most taxa at this site. Saprobic conditions are further indicated by the dominance of tubificid worms and mummichogs, two taxa known to be tolerant of anoxia; the presence of black, reduced sediments and hydrogen sulfide odors which were commonly encountered here; and the fact that periphyton biomass was smaller at TF280 than upstream sites that do not typically experience frequent DO suppression.

Site TF396

Site TF396 is located only 0.7 mi upstream of site TF324, and was chosen to enable an assessment of effects from the large CSO outfall at site TF324. While nearly all attributes of this site were much improved over site TF324, this site is still considered severely impaired. Water quality and hydrologic impairment are assumed to be co-limiting factors. This site had excellent habitat relative to other sites in the watershed, and without the influence of combined sewer overflows and untreated stormwater it might be expected to have much better biological communities. While upstream of the former Wingohocking Creek, based on computer simulation this site is still subject to the effects of over 1 billion gallons per year of combined sewer overflows.

Dominance of the fish community by *H. heteroclitus* shows that these fish will ascend into non-tidal waters to exploit suitable habitats and further suggests that anoxic conditions at this site may limit the success of less tolerant fish taxa. Conversely, the macroinvertebrate community at site TF396 showed significant improvement over that of TF324, with the highest taxa richness and lowest HBI score on mainstem Tacony Creek. This finding suggests that long, extensive riffles with large, relatively stable, non-embedded substrate can partially offset effects of stormwater on a local scale. However, few of the macroinvertebrate taxa present at this site are considered sensitive to organic pollution, and sensitive taxa that were present (*i.e.*, tipulids) were found in small numbers.

Extensive riparian buffers on both banks fail to ameliorate the hydrologic effects of a 22mi^2 drainage area with 60% impervious surface, and stream segments just upstream and downstream of this site have severe habitat impairments as well. This site is exceptional and not representative of habitat south of Roosevelt Blvd. Surface geology and the sharp bend at the upstream limit of the sampling site allow for more stormwater flow energy dissipation and the left bank of this site (outside meander) has been protected by extensive large boulder rip rap revetments. A large stand of Japanese knotweed was the only vegetation present along this bank.

Site TF500

With drainage area of approximately 17 mi^2, site TF500 should be large and stable enough to support complex native fish and macroinvertebrate communities. Water quality, and to a more limited extent, habitat stability tend to generally improve from downstream to upstream within the City of Philadelphia. While fecal coliform counts were elevated at all city sites downstream of CSO outfalls, Site TF500 had smaller dry weather concentrations of NO_2, BOD_5, TKN and NH_3 than site TF280 (Appendix A). Continuous water chemistry results indicated that anoxic conditions were also less frequent than at site TF280 (Table 5.6); these findings correlate well with an increase in fish species richness, though not with macroinvertebrate taxa richness, which was lowest in the watershed.

North of site TF396, riparian zones of Tacony Creek Park are consistently wider and more densely forested than downstream portions that are narrower or have more mown lawn and golf course area. The mainstem of Tacony Creek North of Whitaker Avenue is a nearly continuous band of forested parkland (Figure 6-8). However, riparian buffers do not protect the stream from stormwater erosion effects, as only a small portion of stormwater flow reaches the stream as surface runoff. Effects of erosion and destabilization were very apparent – Site TF500 and other stream segments in its vicinity have been severely overwidened and straightened by exaggerated storm flows (Appendix F in preparation). The fish assessment site was bisected at its upstream limit by a large channel bar, and the downstream left bank had extensive deposits of fine sediment that were black in color and odorous.

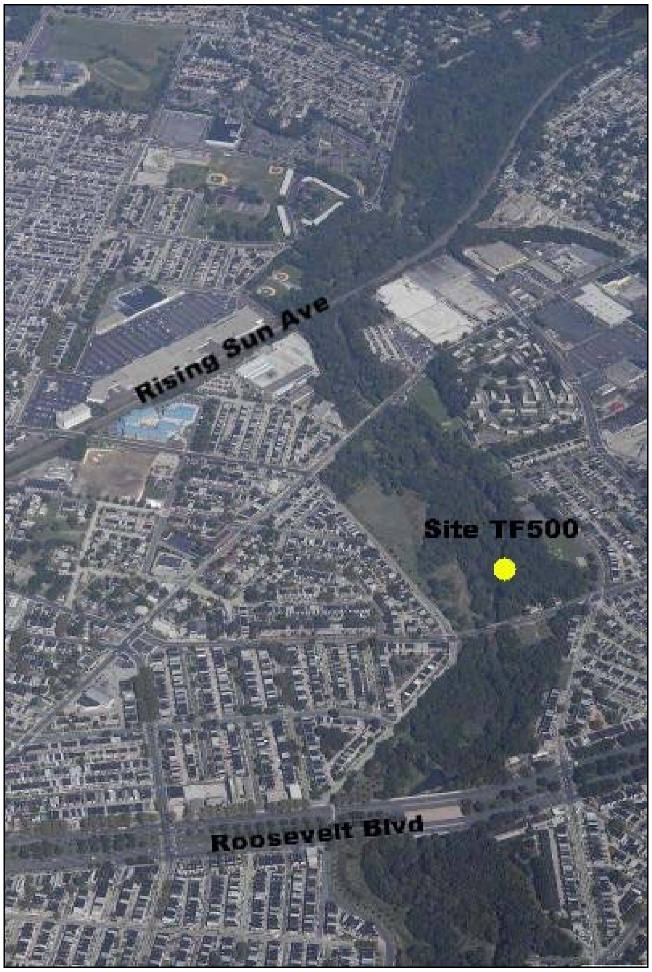


Figure 6-8 Oblique Aerial Photograph of site TF500 and Vicinity

Though mainstem Tacony Creek in Tacony Creek Park is disconnected from its floodplain, abandoned floodplains are generally wide and undeveloped, offering many opportunities for stormwater wetland creation. In a 1998 report to the Fairmount Park Commission, scientists from the Philadelphia Academy of Natural Sciences (ANS) recommended the creation of a wetland just downstream from site TF500 in a ballfield that has been largely abandoned due to frequent inundation. This site was also identified as having wetland creation potential in a wetland inventory performed by PWD in 2001. Another important task is maintenance of the steep slopes that drain directly to the stream at this point.

Erosion in gullies and along trails may introduce sediment to the stream. ATV use has been reduced since metal gates were installed in 2003.

Despite obvious habitat impairments, fish community metrics at site TF500 were substantially improved over site TF396, especially species richness and evenness. These improvements can be largely attributed to an increase in the number and relative abundance of insectivorous minnow taxa that feed in the water column (*i.e.*, *Cyprinella* and *Notropis* spp.). As these fish feed opportunistically on drifting food items, including terrestrial insects, increased abundance may be partially due to an increase in the availability of terrestrial insects which might be expected to accompany increased canopy cover and riparian zone vegetation. Substrates at site TF500 were typically much smaller than at sites TF396 and TF324, perhaps an important factor for species that spawn over sand and gravel substrates. Many species classified as pollution tolerant were present at site TF500 but not downstream, which corroborates the findings of water quality data (*i.e.*, poorer water quality downstream).

Site TF500 was located approximately 0.5mi downstream of the site where ANS collected fish in a 1998 survey of fish in Philadelphia Parks (Fairmount Park Commission, 1999 Volume III). While the fish community in the 1998 sample was generally similar to the 2004 sample, certain changes were noted. For example, ANS scientists collected 118 Spotfin shiners (*C. spiloptera*), but did not collect Satinfin shiners (*C. analostana*). The investigators concluded that *C. analostana* was not present in the basin, possibly due to interspecific competition, and recommended against its introduction. However, PWD did not record *C. spiloptera* from the basin in a 2000 assessment. In 2004, *C. analostana* was found at each assessment site, greatly outnumbering its congener. Though these results come from a small number of sites only, it appears that either a major shift in relative abundance has occurred since 1998, or the 1998 record is in error. The relative abundance of *Notropis* spp. was also interesting, with ANS collecting 183 *N. procne* and 117 *N. hudsonius*. In 2004, *N. procne* still appeared to be abundant in the basin, but *N. hudsonius* was rarely caught (12 individuals). In this case, however, intermediate (2000) sample data seem to support the hypothesis that a change in relative abundance has taken place (91*N. procne* and 57 *N. hudsonius* individuals collected in 2000). No specific explanation is offered for the observed change in relative abundance, but water quality and habitat modification, along with biotic interactions (*e.g.*, predation, competition) are possible factors.

Site TF620/680

Much like site TF500, site TF620 lies in a continuous belt of riparian forested parkland in Tacony Creek Park where canopy cover and width of riparian vegetated zone were considered good. Like all sites in Philadelphia served by combined sewer systems, this site shows elevated dry weather fecal coliform concentration (Tables 5-4 and 5-5), but most other dry weather water quality constituents were similar to site TF500 or improved slightly at site TF620 compared to downstream sites. Dissolved oxygen concentration, in particular, seems to be much improved over downstream locations, as site TF620 marks the upstream-most limit of the area in which DO concentration is considered to be a problem (Table 5-6). Sites for water chemistry monitoring and biological monitoring were not identical, and the water chemistry monitoring site was moved 0.5mi upstream in 2003 due to recurrent vandalism at the site 200m upstream of Adams Avenue.

Two dams separate site TF620 from site TF500. The first dam, located upstream of Rising Sun Avenue, is only about 3ft high, and creates a total water surface drop of approximately 1ft. The dam at Adams Avenue, however, is much larger and creates an impoundment of slower, deeper water where sediment deposition is high. Furthermore, site TF620 had the smallest percentage of boulder substrate in Tookany/Tacony-Frankford Watershed. Like most other sites, TF620 is in a region where most stream segments are extensively destabilized due to stormwater and urbanized hydrology. Because PWD protocols result in direct sampling of the richest habitat in an area, fish and macroinvertebrate sites probably score much higher for habitat metrics than would more typical stream segments upstream and downstream. The 100m segment chosen for fish sampling at TF620 was the only segment in this area where adequate pool and riffle habitats could be found.

The dam at Adams Avenue probably has other effects on aquatic biota other than increased sediment deposition and habitat homogeneity upstream. Over five feet in height, this dam is assumed to be an impediment to upstream migration of most fishes other than eels (*A. rostrata*), though eel abundance and biomass decreased from site TF500 to site TF620. Though stream size and drainage area no doubt are influential, and species richness is expected to be greatest in medium-sized streams, dams may be partially responsible for the absence or decreased abundance of certain species from downstream to upstream (*e.g.*, *A. nebulosus*). Furthermore, habitat between the sampling reach and the dam at Adams Avenue is a homogeneous run with sand and gravel substrates due to deposition caused by the dam. Sand and gravel are needed by many native species for spawning, a factor that may partially explain the increased number of native minnow species at sites TF620 and TF500 relative to sites with coarser substrates. The natural forested floodplain also probably provides more roots, coarse woody debris and snags of the type used by crevice spawners (*e.g.*, *Cyprinella* spp.).

Site TF760/827

Site TF 760 is the first assessment site within Montgomery County and this area marks numerous changes that have implications for water quality and biological communities. Most importantly, stormwater is collected in a separate sewer system which discharges directly to the stream, unlike downstream reaches which are served by combined sewers that discharge to the stream only when the receiving capacity is exceeded. Along mainstem Tookany Creek in Montgomery County, riparian buffer zone width becomes more variable and riparian zones are increasingly maintained as lawn. Predominant land use drastically changes from multi-family residential to single-family residential housing (Figure 2-7). The frequency and amount of stream area impacted by bridges, culverts, and channelized sections increases compared to the non-tidal portions of Tookany/Tacony-Frankford Watershed (especially within Tacony Creek Park upstream of Whitaker Avenue). Much of the land abutting streams is privately owned and maintained as lawn. Erosion control structures are often built by private landowners, and these structures vary widely in design, effectiveness and impacts to stream stability.

Site TF760 is another example of a site where the biological assessment points were shifted upstream from the location where water chemistry samples were taken. This change was necessary to find adequate habitat, as the chemical sampling point was located within a channelized section. The confluence of an unnamed tributary with a drainage area of 0.6 mi^2 was located between the biological assessment sites and the chemical monitoring site. Nearly 3000 ft of streambank restoration have been completed in Tookany Creek along Tookany Creek Parkway in Cheltenham Township as of May 2005. Restoration techniques used at this site followed a semi- naturalized revetment approach, incorporating live willow stakes and branch bundles. Telephone poles were trenched and pinned to the streambank and the toe of slope was reinforced with boulders. Construction activities at this restoration site and along railroad tracks in the vicinity of site TF1120 may have impacted the results of chemical samples and biological assessments. For example, continuous water quality monitoring probes recorded turbidity >8NTU during 20% of all dry weather observations (373 days of combined dry weather monitoring from 2000-2004, (Table 5-7).

Substrate at this site was much coarser than at site TF620, and the site was lacking pools, factors that contribute to decreased HSI scores for some species. Lack of pool habitat may partially explain the low abundance of Swallowtail Shiners and absence of Creek Chubs at this site. These fish are regarded as pool species and were found to be more numerous in sites with greater pool volume downstream and upstream of site TF760, respectively. This site also had many Redbreast sunfish, a species that was not found again in any upstream Tookany Creek sites. Decreased species richness at this site relative to site TF620 may be partially due to construction disturbances within the stream restoration area upstream of the assessment site. There are also 2 dams between site TF620 and TF760 which may impair upstream migration of fish.

Many fish require sand and gravel substrates for spawning, and fish assessments were conducted during the spawning season for many native species. The paucity of appropriate spawning substrates at sites TF760 and TF975 relative to site TF620 may help explain the decreased abundance of these species. Urbanized stormwater flows are exacerbated by extensive channelization and scour the streambed of sand and gravel substrates. A decrease in the proportion of sand and gravel substrates might be expected to correlate with an increase in overall health of the benthic macroinvertebrate community, as cobbles and larger substrates are more stable, but this site had one of the worst assemblages in Tookany/Tacony-Frankford Watershed. Again, construction disturbances may be partially to blame. While crayfish were not collected or enumerated, biologists observed them to be very abundant at this site while electrofishing. Increased crayfish abundance is probably also related to the increased substrate size.

Site TFJ013

Though impaired compared to reference sites on French Creek, site TFJ013 exemplifies some of the best conditions within Tookany/Tacony-Frankford Watershed. This sub-watershed was among the lowest in impervious cover (28%), and fewer Jenkintown Creek stream segments were channelized and culverted compared to many other tributaries in Montgomery County (Appendix F in preparation). Decreased impervious surface, combined with fewer infrastructure impacts, probably helps ameliorate the effects of urbanized hydrology. Jenkintown Creek has the best Baseflow characteristics in the watershed, as evidenced by USGS gauge data analysis (Table 4-6), so drought effects may be lessened compared to tributaries with smaller drainage area. Jenkintown Creek may serve as an example of changes one would hope to find once more severely degraded reaches in the watershed are restored.

Substrates in Jenkintown creek were generally coarser than in mainstem sites (Appendix F to be added at a later date), and most habitat attributes related to substrate and riffle stability for macroinvertebrates were rated suboptimal. Site TFJ013 had the best benthic macroinvertebrate community of all Tookany/Tacony-Frankford Watershed sites. Certain sensitive EPT taxa appear to have become less numerous or extirpated completely, based on comparison to 2000 PWD survey data, but there appears to be a population of *Chimarra* remaining. Repeated sampling or sampling at additional locations would enable us to draw stronger conclusions about whether this site has become more severely impaired since 2000. Water quality data do not indicate serious physicochemical stressors, so hydrologic modification is the most likely explanation for increased degradation, if the site is indeed continuing to degrade.

Jenkintown Creek is shallow and was not selected for fish sampling, but it is likely that Jenkintown Creek has many of the same species of fish as site TF1120 (*i.e.*, Blacknose Dace and Creek Chubs). A northern water snake was observed eating a small sunfish in Jenkintown Creek. A small instream pond located north of Indian Creek Road may support greater diversity of fish life.

Site TF975
Biological communities at site TF 975 showed signs of severe impairment, as benthic macroinvertebrate and fish species known to be tolerant of poor water quality were nearly completely dominant. This site had the greatest proportion of white suckers within the watershed and the second greatest proportion of blacknose dace and fish with deformities, lesions and tumors in the watershed. This site experienced water quality criteria exceedances frequently in both dry and wet weather. Indicators of dry weather sewage inputs (*e.g.*, fecal coliform bacteria concentration, *E.coli*) were highest among sites upstream of combined sewer outfalls (Appendix A). However, site TF975 is located within a small park in Cheltenham Township, so dog feces must be considered a potential source of indicator bacteria.

Numerous infrastructure impacts are present in the vicinity of this site. Bridge culverts and a dam located at High School Road promote instability and the semi-natural revetments installed along the right bank to curb erosion are beginning to deteriorate. Dams located downstream of the site (n=3) may partially explain the decreased fish species evenness relative to downstream sites. Upstream of High School Road, the stream has been extensively channelized, particularly along the left bank (20% of the left bank of Tookany Creek is channelized between site TF1120 and TF975). Stormwater outfalls (n=20) with combined cross sectional area 180ft^2 discharge to the stream between site TF1120 and site TF975, the greatest relative impact of stormwater outfall density outside the City of Philadelphia's Combined sewer system (Appendix F, in preparation). Like site TF827, habitat attributes associated with streambanks and riparian zone management scored poorly, despite the fact that these sites are located within parkland (Table 7-2).

Site TF1120

Site TF1120 is located just downstream of a straightened and recently channelized portion of Tookany Creek that runs parallel to SEPTA Railroad tracks. Gabion baskets were installed in 2004 to reinforce the railroad bed. Cheltenham Township also replaced many water mains in the vicinity of this site. Though sediment bags were used in combination with coffer dams and trash pumps, construction disturbance often caused the Creek to appear turbid throughout the course of work. Signs of hydrologic instability were very evident at this site, especially within the fish assessment site located immediately downstream of Washington Lane Bridge. Bedrock outcrops have been scoured of smaller substrates and the inside meander bar was observed to increase in size dramatically since 2000. Near the lower end of the fish assessment site, the stream is channelized along the right bank where the creek adjoins Chelten Hills Drive. The portion of Tookany Creek between site TF1270 and TF1120 has 24 stormwater outfalls with combined cross sectional area greater than 185ft^2.

Tree canopy was nearly complete throughout most of the site and algae were not observed to grow to nuisance densities. Continuous water quality data do not indicate DO stress at this site (Table 5-7) and there were few violations of WQ criteria at this site overall (Tables 5-4 and 5-5). It is believed that hydrologic modification and construction disturbances are responsible for the poor benthic macroinvertebrate and fish communities observed at this site. In addition to channelization and peak flow modification, four dams separate site 1120 from site TF975, probably limiting upstream migration of fish species, other than minnows that are known to have an affinity for smaller streams (*i.e.*, blacknose dace, creek chubs)

Section 7
Physical Habitat Characterization

7.1 Habitat Assessment

Tookany/Tacony-Frankford is an urban stream system that has been adversely affected by development and land use practices over the past century. Impervious cover is estimated at 40.9% of the watershed in total and 53.6% within the city of Philadelphia. More than 55% of the watershed, particularly the portion representing the former Wingohocking Creek, has been encapsulated and does not flow to natural surface waters, but to a combined sewer system. (Figure 7-1) Impervious cover, especially directly connected impervious cover, decreases groundwater recharge and the percent of annual streamflow represented by baseflow. Tookany/Tacony-Frankford streams are extremely "flashy"- increases in streamflow and erosive forces occur almost immediately following the onset of storm events. Both maximum discharge and total runoff volume are increased compared to an undeveloped watershed (Figure 7-2).

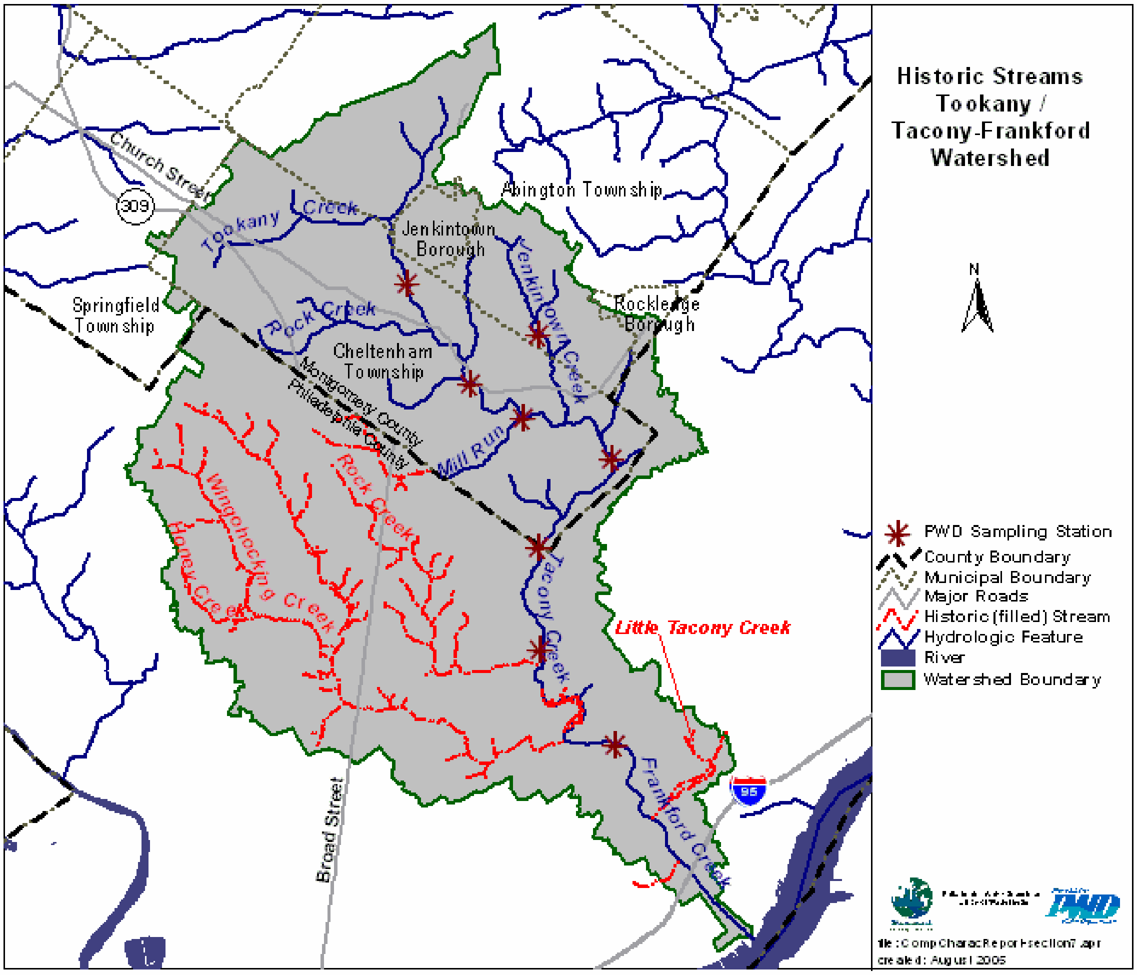


Figure 7-1 Historic and present day streams of the Tookany/Tacony-Frankford Watershed

Changes in hydrology have resulted in de-stabilization of much of the watershed. Urbanization promotes a cumulative, self-reinforcing pattern of streambank erosion. As stream channels become physically larger and further disconnected from their historic floodplains, more stormwater forces are restricted to the stream channel, where compromised, heavily eroded banks are least suited to dissipate them. These overwidened stream segments deficient in baseflow make very poor habitats for all but the most tolerant generalist species. Signs of habitat impairment were present in the watershed's biological communities; Tookany/Tacony-Frankford Watershed is nearly devoid of sensitive macroinvertebrates and fish taxa, while unstable stream banks have been extensively colonized by invasive species, especially Japanese knotweed (*Polygonum cuspidatum*).

Other habitat effects include widespread sedimentation in runs and pools as well as along channel and lateral bars. With few exceptions, historic first order tributaries and wetlands within the watershed have been filled in and/or piped into storm sewers. Erosion has exposed, threatened, and in some cases, destroyed valuable infrastructure and private property. Unfortunately, traditional solutions for addressing erosion and flooding problems may increase instability overall, exacerbating problems they are intended to solve. The Tookany/Tacony-Frankford Watershed Management Plan (TTFIWMP) outlines several options for detaining, infiltrating, and treating stormwater to reduce stream channel impacts. Healthy ecosystems require healthy habitats, and healthy habitats cannot be restored without addressing stormwater impacts.

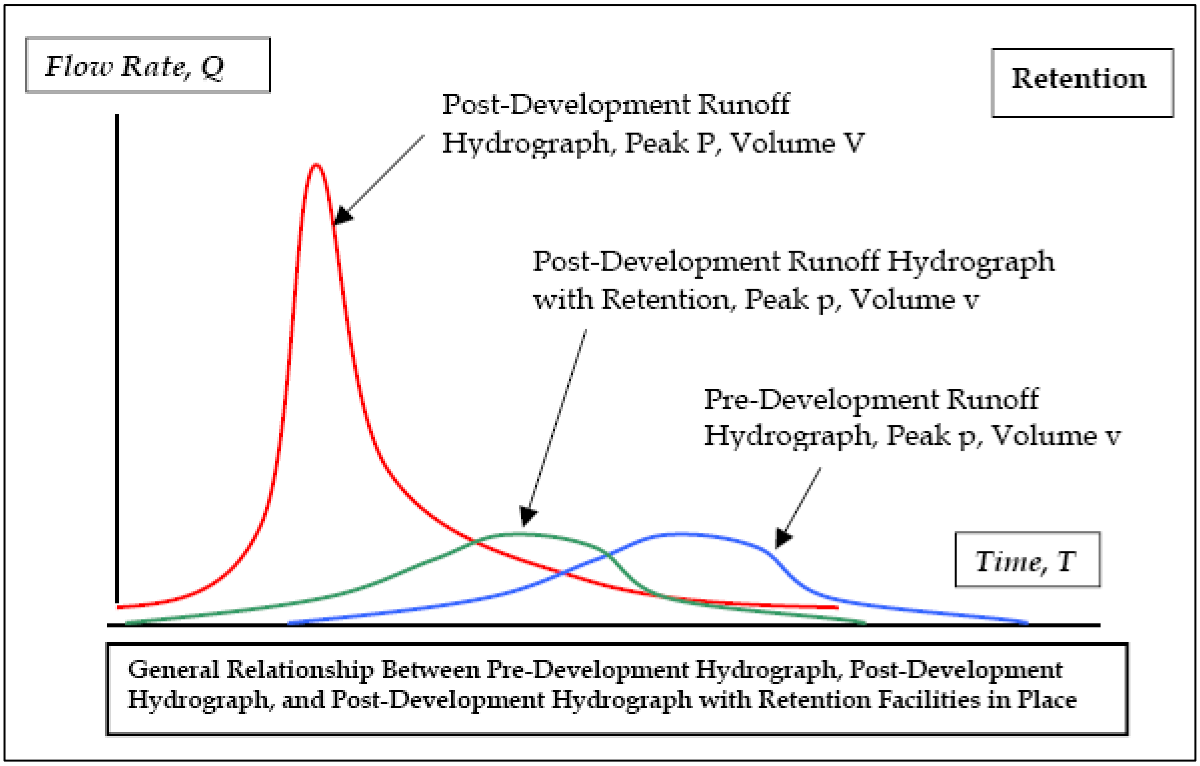


Figure 7-2 Typical Hydrographs for Developed and Natural Streams. (Source: Portland Bureau of Environmental Services, Stormwater Management Manual, 2004)

7.2 EPA Habitat Assessment Results

Comparison to Reference Sites

Habitat features at twelve Tookany/Tacony-Frankford Watershed sites were compared to those of the reference sites located in nearby Chester County. Mainstem and third order tributary sites were compared to French Creek reference sites, located in Coventry Township, Chester County, PA. Tributary sites, second order or less, were compared to Rock Run, a tributary to French Creek located in Coventry Township, Chester County, PA (Appendix F). In general, habitat was determined to be very poor, with seven of twelve sites designated "non-supporting" of the watershed's designated uses (Figure 7-3). Five sites, including three in Tacony Creek Park in the City of Philadelphia, had slightly better scores and were designated "partially supporting". Habitat degradation was considered to be the most important impairment in Tookany/Tacony-Frankford Watershed, corroborating the results of biotic indexing. Table 7-1 summarizes the results of habitat assessment using EPA habitat assessment protocols.

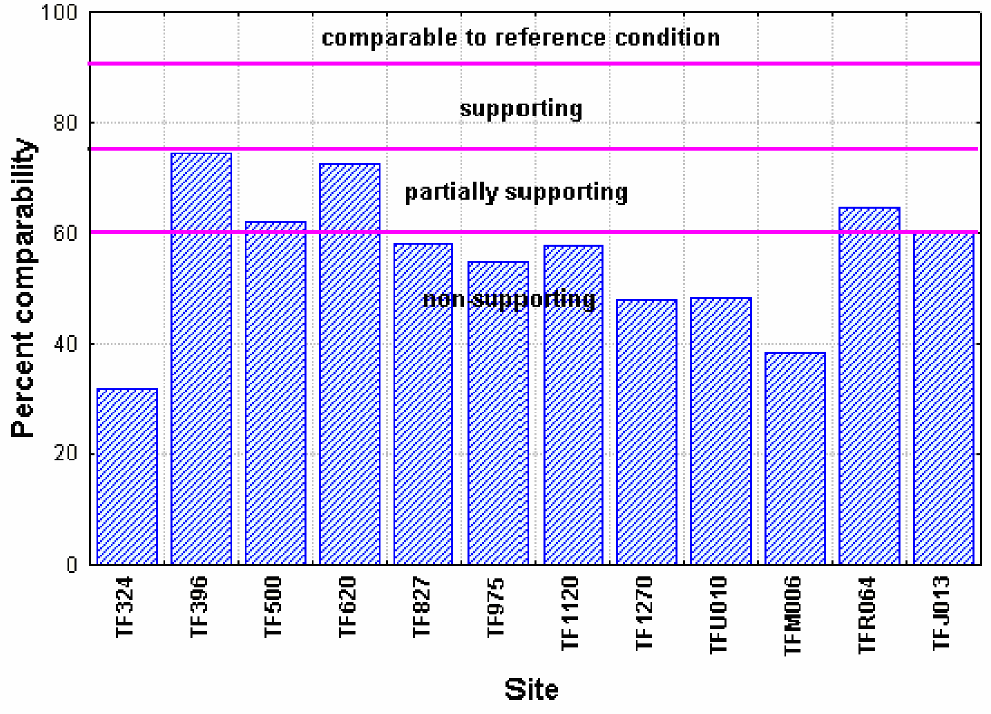


Figure 7-3 USEPA Habitat Assessment Percent Comparability to Reference Sites.

Table 7-1 EPA Physical Habitat Assessment Results for 12 sites in Tookany/Tacony-Frankford Watershed, Spring 2004

	Scores by Site											
Attribute	**TF324**	**TF396**	**TF500**	**TF620**	**TF827**	**TF975**	**TF1120**	**TF1270**	**TFJ013**	**TFM006**	**TFR064**	**TFU010**
Epifaunal Substrate/Available Cover	3	12.5	9.5	11	8.5	8	10	6.5	10.5	5	7.5	6
Pool Substrate	3	11	9.5	10.5	9	8.5	7	6.5	9	6	6	6
Pool Variability	4.5	11.5	9	9.5	8.5	6.5	10	5	12	2.5	4.5	2
Sediment Deposition	12	9	7	8	10	10	7.5	6.5	11	5.5	13.5	9
Channel Flow Status	8.5	11	7.5	12	9	9.5	7	8.5	11	7.5	8	7.5
Channel Alterations	1.5	16.5	12.5	16	10	9.5	8	11.5	6.5	6.5	14.5	12.5
Sinuosity	1	13	9	10.5	9.5	10.5	12	8.5	13.5	7.5	10	6.5
Bank Stability (Left Bank)	4	6	6.5	6	6	6.5	6	7.5	5	6	7.5	6.5
Bank Stability (Left Bank)	1.5	5	6	5.5	1	3.5	6	6	4	6.5	5	3.5
Vegetative Protection (Left Bank)	3.5	4.5	4.5	6	5	6	5	5	5.5	2	7.5	6.5
Vegetative Protection (Right Bank)	3	7	4	5.5	2	4	5	5	4	2	7.5	3.5
Riparian Zone Width (Left Bank)	1.5	5	5	7.5	3	3	4.5	4	4	2	8	5
Riparian Zone Width (Right Bank)	3.5	9	5	7.5	6	3.5	2	4.5	4	2	4.5	3.5
Embeddedness	3.5	11.5	9	14	9	10	8.5	8	12	8	15	9.5
Velocity/Depth Regime	8.5	13	16	14	14	8	13	8.5	13.5	8	12	8
Frequency of Riffles/Bends	5	12.5	11.5	10	13	9.5	11.5	8	12.5	11	16.5	15
Total	**67.5**	**158**	**131.5**	**153.5**	**123.5**	**116.5**	**123**	**109.5**	**138**	**88**	**147.5**	**110.5**

TF324

The mean habitat score at TF324 was 67.5, and the habitat was designated as "non-supporting" (31.84% comparison). All condition categories were scored as "marginal" or "poor" except sediment deposition (Table 7-1). Sediment deposition was scored as "suboptimal" because of a large CSO outfall upstream of the assessment site that routinely scours the area. The channel of the creek is relatively straight and there is extensive alteration of both banks. Pools were almost absent and epifaunal substrate was very inadequate. The riparian zone on both banks was reduced and both banks were unstable with poor vegetative protection. Both stream banks were highly eroded.

TF396

TF396 received a mean habitat score of 158.0. The site had a 74.53% comparison to the reference condition and was designated as "supporting" (Table 7-1). TF396 is located in an undisturbed area behind Friends Hospital, and the site had the highest mean habitat score of all assessment sites. The site had an even distribution of morphology types and substrate components. Most condition categories were scored as "suboptimal" or high "marginal". Highest scores were for channel alteration and riparian vegetative zone width on the right bank. The assessment site is one of the few areas within the watershed that has not had the surrounding land impacted by urbanization.

TF500

Site TF500 received a mean habitat score of 131.5 and was deemed "partially supporting" (62.03% comparison, Table 7-1). The site had an even distribution of morphology types and substrate components. Most habitat attributes were scored as "marginal". Most notable at the site was a large mid-channel bar at the upstream limit of the assessment site. The riparian zone on both banks was reduced and both banks were moderately stable with poor vegetative protection. Field observations included heavy erosion on both banks.

TF620

The mean habitat score at TF620 was 153.5 and the habitat was designated as "partially supporting" (72.41% comparison) (Table 7-1). The substrate of the assessment site was dominated by sand (40%) and run dominated the stream morphology (45%). Riffles composed 20% of the stream reach. The channel had a normal pattern and alteration was absent. TF620 is located in Tacony Park and the riparian zone at the assessment location was well preserved. Although sand was the dominant substrate, embeddedness was scored as suboptimal. The higher scores for embeddedness were most likely due to periodic surges of storm water that scour and redeposit sediment through out the assessment site.

TF827

TF827 had a mean habitat score of 123.5, which was 58.25% comparison to the reference site ("non-supporting" designation) (Table 7-1). Overall the habitat scored mostly as "marginal" and "poor". In particular, the right bank was very unstable with long stretches that were highly eroded. The right bank also had very poor vegetative protection. The instream morphology and substrate was evenly distributed, but the stream was channelized both upstream and downstream of the assessment site.

TF975

Site TF975 received a mean habitat score of 116.5 and was deemed “non-supporting” (54.95% comparison) (Table 7-1). The substrate of the stream reach was well distributed, but the morphology type of the stream was dominated by run (50%). Most condition categories were scored as “marginal”. A dam is present upstream of the assessment site, and the stream is channelized downstream of the assessment location. The riparian zone at the site is highly reduced. The surrounding land use is residential with maintained lawns dominating the riparian vegetation.

TF1120

The mean habitat score at TF1120 was 123.0, which was a 58.02% comparison to the reference condition at FC1310 (“non-supporting” designation) (Table 7-1). Most habitat attributes were scored as “marginal”. The substrate of the site was well distributed with a large portion of bedrock (15%) and a sizeable portion of sand (30%). A large bedrock outcropping comprised a substantial portion of the left bank of the assessment site. The riparian vegetative zone width of the right bank scored low because of an electrical/railroad access road and vehicle roadway.

TF1270

TF1270 had a mean habitat score of 109.5, which was 48.03% comparison to the reference site (“non-supporting” designation) (Table 7-1). The inorganic substrate of the site was dominated by sand (40%), and the morphology of the assessment reach was predominantly run (60%). A majority of the condition categories were scored as “marginal”. Pool variability was scored low with pools comprising 10% of the stream morphology. The riparian zone on both banks was reduced and both banks had decreased vegetative protection.

TFU010

Site TFU010 received a mean habitat score of 110.5 and was deemed “non-supporting” (48.46% comparison) (Table 7-1). Most habitat attributes were scored as “marginal". The site had a disproportionate percentage of riffles (75%) and sand and gravel (35% each) dominated the substrate. Pools were almost absent and epifaunal substrate was less than desirable. TFU010 is located in a residential neighborhood with moderate erosion. The right bank was moderately unstable with a reduced riparian zone.

TFM006

The mean habitat score at TFM006 was 88.0, which was a 38.60% comparison to the reference condition at FCR025 (“non-supporting” designation) (Table 7-1). Most habitat attributes were scored as “marginal" or “poor”. The site is located within a golf course and the riparian zone and vegetative protection were both poor. The channel is extensively armored or channeled and is relatively straight. Sand and gravel (35% each) dominated the substrate and pools were almost absent (5%). There were also large, thick mats of filamentous algae at the time of macroinvertebrate sampling/habitat assessment.

TFR064

TFR064 had a mean habitat score of 147.5, which was 64.69% comparison to the reference site ("partially-supporting" designation) (Table 7-1). The inorganic substrate of the site was predominately boulder and cobble (35% each). Riffle (40%) and run (50%) dominated the morphology of the stream reach. Pools were either shallow or absent throughout the site. Most condition categories were scored as "suboptimal" or "marginal". The higher gradient and number of riffles at the site increased scores for sediment deposition, embeddedness, and frequency of riffles.

TFJ013

Site TFJ013 received a mean habitat score of 138.0, and was designated as "partially-supporting" (60.53% comparison) (Table 7-1). The site had an even distribution of morphology types and substrate components. All habitat attributes were scored as either "suboptimal" or "marginal". The surrounding land use at TFJ013 is residential and there is heavy erosion throughout the assessment reach. Both banks were moderately unstable and the riparian zone on both banks was reduced. Rip-rap has been used on both banks in an attempt to reduce erosion.

7.3 Fish Habitat Suitability Indices (HSI)

7.3.1 HSI Model Selection

HSI models for seven species were selected for Tookany/Tacony-Frankford Watershed. Models were chosen to reflect the range of habitat types and attributes needed to support healthy, naturally-reproducing native fish communities and provide recreational angling opportunities in non-tidal portions of the watershed (Table 7-2). Two centrarchid fish, redbreast sunfish (*Lepomis auritus*), and smallmouth bass (*Micropterus dolomieu*), were included in the analysis. These species are tolerant of warmer water temperatures and require extensive slow, relatively deep water (*i.e.*, pool) habitats with appropriate cover or structure to achieve maximum biomass.

While black basses (*M. dolomieu* and its congener *M. salmoides*) are not native to Southeast Pennsylvania, they occupy the top carnivore niche and are among the most sought-after freshwater game fish in water bodies where they occur. Moreover, the only other large bodied piscivores known to occur in non-tidal portions of Tookany/Tacony-Frankford Watershed are American eels, native catadromous fish for which no HSI have been developed. Salmonid HSI models were available but inappropriate because coldwater fish generally cannot establish and maintain reproducing populations in warmwater streams, and PFBC does not stock salmonids in Tookany/Tacony-Frankford Watershed.

Five native minnow species were selected for HSI analysis: blacknose dace (*Rhinichthys atratulus*), common shiner (*Luxilis cornutus*), creek chub (*Semotilus atromaculatus*), fallfish (*Semotilus corporalis*), and longnose dace (*Rhinichthys cataractae*). Of these, *R. cataractae* and *S. corporalis* are not known to occur in Tookany/Tacony-Frankford Watershed. However, the former species' known affinity for stable, high quality riffle habitats and the substrate requirements of the latter species are reflected in HSI models, prompting inclusion in the analysis as indicators of riffle habitats and stream stability. The longnose dace HSI may be considered a surrogate indicator of habitat suitability for other native riffle species (*e.g.*, margined madtom) for which no HSI are available.

Table 7-2 HSI Data Summary

HSI Model Variable Matrix	**Variable Type**	**Blacknose Dace**	**Common shiner**	**Creek Chub**	**Fallfish**	**Longnose Dace**	**Redbreast Sunfish**	**Smallmouth Bass**
Total number of HSI variables		**16***	**9**	**20**	**6**	**6**	**10**	**13***
Avg. Temperature during growing season (May-Oct.)	**temperature**	X						X
Average Temperature in spawning season**		X	X		X		X	X
Maximum temperature sustained for 1 week			X			X	X	
Average Summer Temperature (Jul-Sep)				X	X			
Average temperature during spring (May-Jun)				X				
Average Turbidity (JTU)***	**water quality**	X	X	X	X		X	X
Average yearly pH value			X					X
Least suitable pH value (instantaneous)							X	
pH fluctuation classification				X				
Minimum dissolved oxygen concentration				X			X	X
Minimum dissolved oxygen conc. during spring				X				
Percent instream cover during average summer flow	**general stream characteristics**			X		X	X	X
Instream cover classification					X			
Percent shading of stream between 1000 and 1500 hrs.		X		X				
Percent vegetative cover							X	
Availability of thermal refugia (winter) (Y/N)				X				
Stream gradient (m/km)		X		X				X
Average stream velocity during average summer flow				X		X		
Dominant substrate characterization					X		X	
Stream width		X		X			X	
Mode of stream depth during average summer flow					X			
Water level fluctuations								X
Stream margin substrate characterization (Y/N)		X						
Average velocity along stream margins		X		X				
Stream margin vegetation characterization				X				
Substrate food production potential				X				
Percent riffles	**riffles**					X		
Riffle substrate characterization		X	X	X		X		
Average velocity in riffles		X	X	X				
Average depth of riffles		X						
Average maximum depth of riffles						X		
Percent pools	**pools**	X	X	X			X	X
Pool substrate characterization		X						X
Pool classification			X	X				
Average depth of pools				X				X
Average velocity at 0.6 depth in pools		X	X					

* Some variables used more than once, applied to different life stages
**Spawning season varies by species. Common Shiner and Fallfish use a Y/N index.
*** Turbidity relationships developed using Jackson candle units; cannot be converted to NTU values

7.3.2 Smallmouth Bass HSI Model

Smallmouth bass were not collected from Tookany/Tacony-Frankford Watershed in 2004, and there is insufficient data to determine whether black basses (*Micropterus* spp.) ever established reproducing populations in non-tidal portions of the watershed. The smallmouth bass HSI model identified several habitat attributes that would be detrimental to bass. Like most centrarchids, smallmouth and largemouth basses are able to acclimate to brief periods of suboptimal dissolved oxygen concentration. However, continuous water chemistry analysis indicated DO concentrations at sites TF324, TF396, and TF620 may drop below 3mg/l for extended periods, yielding HSI scores of zero (Table 7-3). DO suppression at these sites is likely due to sewage inputs.

Site TF1120 had HSI score 0.90, and may have good habitat for smallmouth bass, but one might not expect bass to occur in large numbers at a site so near the headwaters (Drainage area ca. 5sq mi), especially considering the baseflow reduction that often accompanies increased impervious cover. It may be more feasible to establish/restore populations of other native centrarchids (e.g. redbreast sunfish and rock bass) in upper watershed sites. All other sites appear to be limited by the size and frequency of pools with appropriate cover, especially site TF760, which lacked pool habitats and received an HSI score of zero (Table 7-3).

Stream restoration activities that increase the amount of instream and overhanging cover, or activities that create, expand or improve pool habitats probably will result in increased habitat suitability for smallmouth bass. Re-meandering of the stream channel, installation of flow diverters such as rock vanes and J-hooks, as well as the creation of bank habitat through log sill cribbing and cantilevered banks should also enhance habitat for smallmouth bass, and other centrarchids, and forage fish. Infrastructure assessments, inspections, and dry weather pollution source trackdown activities will likely reduce the severity and frequency of water quality (*i.e.*, DO and pH related) impacts at some sites, particularly downstream of TF620. It is unlikely that habitat impairment due to frequent water level fluctuations and effects of erosion and sedimentation will be ameliorated in the near future without significant investments in streambank restoration and basin-wide implementation of stormwater BMPs.

Table 7-3 Smallmouth Bass HSI Data Table

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Substrate type category	C	1.00	C	1.00	A	0.20	C	1.00	C	0.00	B	0.30	C	1.00
Percent pools	19.30	0.32	24.18	0.43	25.75	0.46	22.48	0.39	0.00	0.00	16.23	0.25	55.21	1.00
Avg. pool depth	0.48	0.40	0.56	0.46	0.36	0.30	0.37	0.31	0.00	0.00	0.27	0.22	0.48	0.40
Percent cover	70.00	0.84	45.00	1.00	15.00	0.60	5.00	0.20	60.00	0.92	20.00	0.80	50.00	1.00
Average pH	7.30	0.96	7.30	0.96	7.39	0.98	7.59	0.99	7.32	0.96	7.43	0.98	7.18	0.94
Dissolved Oxygen	0.24	0.00	0.24	0.00	0.10	0.00	6.21	0.98	5.19	0.70	6.61	0.98	6.22	0.98
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Temperature (adult)	19.81	0.84	19.81	0.84	20.47	0.87	18.56	0.78	16.80	0.67	16.20	0.64	16.35	0.65
Temperature (embryo)	19.16	1.00	19.16	1.00	22.50	1.00	17.87	1.00	16.34	1.00	15.97	1.00	15.89	1.00
Temperature (fry)	19.81	0.82	19.81	0.82	20.47	0.86	18.56	0.74	16.80	0.63	16.20	0.58	16.35	0.59
Temperature (juvenile)	19.81	0.86	19.81	0.86	20.47	0.88	18.56	0.78	16.80	0.70	16.20	0.64	16.35	0.67
Water fluctuations	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30	A	0.30
Stream Gradient	3.81	1.00	5.27	0.91	1.37	1.00	1.29	1.00	4.22	1.00	7.01	0.60	4.67	1.00
Food component		0.64		0.75		0.38		0.43		0.00		0.39		1.00
Cover component		0.64		0.72		0.39		0.47		0.23		0.39		0.85
Water Quality component		0.73		0.73		0.74		0.90		0.80		0.84		0.84
Reproduction component		0.00		0.00		0.00		0.67		0.00		0.68		0.84
Other component		1.00		0.91		1.00		1.00		1.00		0.60		1.00
H S I score		**0.00**		**0.00**		**0.00**		0.66		**0.00**		0.56		0.90
Abundance		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**
Biomass		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**

7.3.3 Redbreast Sunfish HSI Model

As a generalist species, redbreast sunfish (*Lepomis auritus*) are adaptable to a range of habitat attributes and may feed opportunistically upon a variety of prey types. Most suitability index (SI) variable expressions in this species' HSI include a large range of highly suitable values (or large area "under the curve"). HSI scores (Table 7-4) did not correlate well with observed *L. auritus* abundance or biomass (the correlation was, in fact, negative). Limiting factors included vegetative cover, temperature, and substrate-related variables, but the discriminatory power of the HSI was probably limited by lack of variability and marginal habitat available at all sites. pH limitation was difficult to identify due to differences in data collection methods between sites. Though pH fluctuations due to algal activity occasionally result in pH >9.0, the Redbreast sunfish HSI model was not designed to be used with the least suitable value picked from a continuous database. Because fish can avoid areas of unsuitable pH when they occur infrequently, model input was modified to exclude the worst 5% of pH values.

Table 7-4 Redbreast HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Percent cover	70.00	1.00	45.00	1.00	15.00	0.76	5.00	0.52	60.00	1.00	20.00	0.88	50.00	1.00
Vegetated cover	5.00	0.50	5.00	0.50	5.00	0.50	5.00	0.50	5.00	0.50	5.00	0.50	10.00	0.60
Spawning temperature (summer)	20.33	1.00	20.33	1.00	22.18	1.00	19.78	0.40	18.23	0.40	16.85	0.40	16.82	0.40
Percent slow pools	19.30	0.43	24.18	0.49	25.75	0.72	22.48	0.47	0.00	0.20	16.23	0.39	55.21	0.91
Percent sand/gravel	16.00	0.39	36.00	0.94	65.00	1.00	52.00	1.00	14.00	0.37	25.00	0.50	29.00	0.66
Least suitable pH observed	8.52	0.99	8.52	0.99	8.37	1.00	9.03	0.81	8.01	1.00	8.48	1.00	8.36	1.00
Minimum DO (category)	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00	A	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Max temp growing season	27.28	1.00	27.28	1.00	26.55	1.00	26.09	1.00	24.54	0.80	22.43	0.80	24.59	0.80
Stream width	19.73	1.00	11.24	1.00	10.46	1.00	12.08	1.00	13.27	1.00	11.63	1.00	6.31	1.00
H S I score		**0.39**		**0.49**		**0.50**		**0.40**		**0.20**		**0.39**		**0.40**
Abundance		**0.00**		**1.00**		**87.00**		**129.00**		**99.00**		**0.00**		**0.00**
Biomass		**0.00**		**2.70**		**2214.05**		**3808.70**		**2525.69**		**0.00**		**0.00**

correlations	**r^2 value**
HSI: biomass/unit vol	**-0.21562**
HSI :abundance/unit vol	**-0.23605**

Likewise, summer temperature during spawning may poorly reflect habitat suitability for this species. The HSI was designed to be used throughout the species' range; temperature parameters should not be expected to be "optimal" in the temperate northeast. Fish may spawn at warmer downstream locations or in sunnier, sandy backwaters that are not accounted for in HSI model input. Observations made during electrofishing surveys suggested that Redbreast sunfish (and congeneric sunfishes) are most frequently found associated with cover, which can be difficult to measure quantitatively.

For example, site TF760 scored well for percent cover, due to the presence of many large boulders that were not exposed (Figure 7-4). Though this site was limited by a lack of pools and received a final HSI score of 0.2, it had the second greatest Redbreast sunfish abundance in Tookany/Tacony-Frankford Watershed. Fish collected were generally small (mean TL= 10.3 ±2.4; only four of 99 total individuals were >15cm). These findings reflect the fact that habitat requirements for a given species change over an individual's lifetime (as fish age they may require larger habitats for foraging) or even seasonally (such as specific substrate types and/or flow scenarios required during spawning). With more large, deep pool habitats, site TF 760 might support larger fish.

Figure 7-4 Instream Habitat at Cheltenham Restoration Site.

7.3.4 Longnose Dace

The longnose dace HSI model was applied to Tookany/Tacony-Frankford Watershed despite the fact that this species was not collected from the watershed in the 2004 fish survey. Longnose dace are, however, present in the nearby Pennypack and Wissahickon watersheds. This species is considered a riffle specialist, feeding and spawning in fast water in higher gradient, clear and cool streams. This species has good indicator potential, as hydrologic effects of urbanization tend to cause over-widening of stream channels, reduce baseflow and baseflow velocities, increase stream temperature, and generally make habitat unsuitable for this species.

High longnose dace HSI scores indicate favorable riffle conditions, not only for this species, but for a variety of other riffle dwellers such as margined madtoms and sensitive macroinvertebrate bioindicator taxa. High longnose dace scores might suggest that a site is appropriate for re-introduction, but scores in Tookany/Tacony-Frankford Watershed were marginal, reflecting general habitat unsuitability and stream instability caused by urbanized hydrology (Table 7-5). Stream restoration projects that are based in fluvial geomorphological (FGM) principles should help correct the problem of riffle substrate exposure due to overwidening (a universal problem in urbanized watersheds), while stormwater BMPs and infiltration projects could eventually begin to restore historic baseflow levels and mitigate the effects of scouring and sedimentation exhibited by streams with extensive impervious cover.

Table 7-5 Longnose Dace HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Average stream velocity	25.00	0.56	31.00	0.76	30.00	0.72	22.00	0.47	21.00	0.43	20.00	0.39	13.00	0.18
Maximum depth in riffles	0.29	1.00	0.31	1.00	0.25	0.95	0.23	0.92	0.27	1.00	0.15	0.69	0.15	0.69
Percent riffles	52.38	1.00	28.57	1.00	42.86	1.00	19.05	0.76	14.29	0.57	28.57	1.00	23.81	0.95
Percent of substrate >5cm	28.00	0.56	30.00	0.60	20.00	0.40	32.00	0.64	31.00	0.62	44.00	0.88	27.00	0.54
Spring/Summer maximum temp.	21.28	0.58	21.28	0.58	20.34	0.87	20.73	0.83	20.37	0.86	18.35	1.00	18.63	1.00
Percent Cover	70.00	1.00	45.00	1.00	15.00	0.60	5.00	0.20	60.00	1.00	20.00	0.80	50.00	1.00
H S I Score		**0.56**		**0.58**		**0.40**		**0.20**		**0.43**		**0.39**		**0.18**
Abundance		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**
Biomass		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**

7.3.5 Fallfish

Fallfish was the third species for which an HSI model was applied despite an apparent absence of the species within the watershed. Fallfish have many attributes that make them suitable as indicator species. They are long-lived, and the largest native minnow that occurs in Southeast PA, capable of attaining lengths over 30 cm (1ft.). Fallfish also build large gravel mounds over which to spawn, and bury their eggs within for protection. Changes in several factors that typically accompany increased urbanization may be implicated in fallfish habitat loss or decreased suitability (*e.g.*, range of substrate materials available for use in constructing spawning mounds, stability and sufficiency of baseflow depth, sediment oxygen state, and frequency of hydrologic disturbance).

The fallfish HSI model was too simplistic, incorporating only four variables as modified for Tookany/Tacony-Frankford Watershed, and final scores did not reflect decreased habitat suitability caused by urbanization (Table 7-6). For example, nearly all mainstem stream reaches are overwidened, riffles substrates are coarsened, and dry weather (*i.e.*, baseflow) flow characteristics (particularly depth) are poor. Pools and runs generally are affected by sedimentation and may not have stable substrate of appropriate size for fallfish nest building in combination with the appropriate flow regime. Sediments may be poorly oxygenated or even anoxic, especially in lower reaches of the watershed. This is an unsuitable condition for not only fallfish, but other egg-burying cyprinid species (*e.g.*, cutlips minnow, creek chub) and benthic macroinvertebrates. Frequent severe scouring flows may also scour away or bury and stifle eggs and various aquatic macroinvertebrate life stages. To be useful in an urban setting, the fallfish HSI model would have to be modified to account for some of these effects.

Table 7-6 Fallfish HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Temperature	22.24	0.73	22.24	0.73	21.50	0.82	20.92	0.89	22.38	0.71	18.72	1.00	19.26	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Mode of stream depth	0.32	0.96	0.20	0.86	0.11	0.79	0.15	0.82	0.26	0.91	0.15	0.82	0.18	0.84
Favorable spawning temperature Y/N	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00
Substrate category	E	0.10	D	0.40	C	1.00	C	1.00	E	0.10	D	0.40	D	0.40
Cover category	C	0.40	C	0.40	C	0.40	C	0.40	C	0.40	C	0.40	B	0.70
Water quality component		0.86		0.86		0.91		0.94		0.85		1.00		1.00
Reproduction component		0.34		0.52		0.68		0.69		0.33		0.51		0.62
H S I score		**0.60**		**0.69**		**0.79**		**0.82**		**0.59**		**0.75**		**0.81**
Abundance		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**
Biomass		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**		**0.00**

7.3.6 Blacknose Dace HSI Model

The blacknose dace HSI model was modified to suppress the influence of two limiting variables (gradient and stream margin substrate) because limitation by these factors is not evident in fish collections from Philadelphia area streams. Geography and topographic features undoubtedly influenced blacknose dace distribution, but the relationship between stream gradient SI scores and blacknose dace abundance was weak. Similarly, there was no strong relationship between stream margin substrate SI scores and blacknose dace abundance. While most sites generally had coarser margin substrates than would be desirable, shallow low velocity habitats that could be used as "nursery habitat" by immature fish were present at all sites but TF324.

Once modified, the HSI model was a fair predictor of blacknose dace abundance and biomass (Table 7-7). SLR analysis of HSI score with observed abundance and biomass yielded r^2 values of 0.62 and 0.67, respectively. The blacknose dace is classified as a "tolerant" fish. In fact, along with *C. commersoni*, *A. rostrata*, and *Fundulus* spp., blacknose dace is one of the most common fish in degraded streams in southeast PA. Blacknose dace appears to be an "upstream" species, abundance and biomass increased in an upstream direction. The stream gradient factor in the HSI model probably addresses this aspect of the species' ecology. Life history strategies and morphological features that allow blacknose dace to exploit upstream reaches of natural streams may partially explain its dominance of streams that are hydrologically impaired due to urbanization.

Blacknose dace is a stocky fish, moderate in body form and somewhat rounded (dorsoventrally flattened) in comparison to vertically compressed minnows. Hydrodynamics may contribute adaptability to a variety of flow conditions and, in part, explain its abundance at degraded sites that are periodically exposed to intense scouring flows. Over-widening of channels and coarsening of stream substrate are typical of streams that are exposed to extremes in hydrology. Blacknose dace appear resilient to these factors. Other minnow species may not be as well adapted for these effects.

Table 7-7 Blacknose Dace HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Percent shaded	15.00	0.61	50.00	1.00	50.00	1.00	70.00	1.00	20.00	0.77	90.00	0.83	95.00	0.67
Percent Pools	19.30	0.74	24.18	0.80	25.75	0.82	22.48	0.78	0.00	0.50	16.23	0.70	55.21	1.00
Stream gradient*	6.15	1.00	2.46	1.00	4.20	1.00	2.74	1.00	3.27	1.00	7.47	1.00	4.13	1.00
Stream Width	19.73	0.15	11.24	0.55	10.46	0.64	12.08	0.46	13.27	0.34	11.63	0.51	6.31	1.00
Temperature (growing season)	26.00	0.43	26.00	0.43	25.60	0.49	24.95	0.58	24.41	0.66	22.09	0.99	22.73	0.90
Turbidity (growing season)	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle substrate category	E	0.40	D	0.60	D	0.60	C	1.00	E	0.40	D	0.60	D	0.60
Riffle depth	19.60	1.00	23.53	1.00	15.24	1.00	14.48	1.00	18.12	1.00	10.67	1.00	10.16	1.00
Velocity in riffles	33.60	1.00	55.46	0.48	46.18	0.94	23.11	1.00	33.70	1.00	38.10	1.00	30.48	1.00
Temperature (spawning seas.)	19.86	1.00	19.86	1.00	22.50	1.00	18.90	1.00	16.33	1.00	16.85	1.00	16.35	1.00
Pool substrate category (adult habitat)	E	0.20	E	0.20	A	0.80	C	1.00	E	0.20	D	1.00	A	0.80
Velocity in pools (adult)	11.94	1.00	15.49	1.00	27.77	1.00	16.26	1.00	0.00	1.00	12.00	1.00	8.26	1.00
Riffle substrate category (juvenile Habitat)	E	0.30	D	0.50	D	0.50	C	1.00	E	0.30	D	0.50	D	0.50
Velocity in riffles (Juvenile)	33.60	1.00	55.46	0.38	46.18	0.60	23.11	1.00	33.70	1.00	38.10	0.90	30.48	1.00
Stream margins substrate (fry habitat)*	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00
Velocity in stream margins (fry)	3.05	1.00	7.62	1.00	10.67	1.00	6.10	1.00	6.10	1.00	6.10	1.00	6.10	1.00
Food/Cover component		0.15		0.84		0.86		0.81		0.34		0.76		0.92
Water quality component		0.57		0.57		0.62		0.69		0.75		0.99		0.93
Reproduction component		0.40		0.80		0.93		1.00		0.40		0.94		0.94
Adult component		0.20		0.20		0.89		1.00		0.20		1.00		0.89
Juvenile component		0.30		0.38		0.55		1.00		0.30		0.67		0.71
Fry component		1.00		1.00		1.00		1.00		1.00		1.00		1.00
H S I Score		**0.15**		**0.20**		**0.62**		**0.83**		**0.20**		**0.78**		**0.80**
Abundance	1.00		15.00		114.00		433.00		352.00		1662.00		847.00	
Biomass	0.08		36.79		332.81		1111.24		970.62		3768.12		3016.21	

Correlations	r^2 **value**
HSI: biomass/unit vol	0.67476
HSI: abundance/unit vol	0.62861

7.3.7 Creek Chub HSI Model

The creek chub HSI model produced good results overall. HSI score was correlated with creek chub abundance and biomass (SLR, r^2= 0.78 and 0.72, respectively). Furthermore, sites where no fish were collected had the lowest HSI scores in the watershed and the site with the highest HSI score had the greatest abundance and biomass in the watershed (Table 7-8). The HSI model scale of resolution was greatly compacted. Only two creek chubs were collected from four sites that were deemed unsuitable (HSI=0). The limiting factor in these cases was identified as low dissolved oxygen, which corroborates results of continuous water quality monitoring (Table 5-6). However, USFW scientists did not have access to continuous water quality data when building the model so it may be inappropriate to choose the lowest value from a continuous database.

Though creek chubs and blacknose dace share some habitat associations and both tended to be more numerous in upstream reaches, creek chubs generally showed a stronger affinity for narrower streams with abundant pools and overhead cover. For example, creek chub biomass increased almost tenfold from site TF975 to TF1120, while blacknose dace biomass decreased between these sites which differ greatly in width, percent pools, and surface to volume ratio. Blacknose dace biomass seemed more closely tied to stream surface area, while creek chub biomass seemed more attuned to volume, which may reflect the latter species' stronger association with pool habitats (Jenkins and Burkhead, 1993).

A similar effect was noted at site TF760, which was wide and lacked pool habitats. While blacknose dace biomass was reduced at site TF760 relative to the two upstream sites, creek chubs were nearly absent. Unlike creek chubs, blacknose dace did not show a strong association with pools. This site also had the most violations of daily minimum DO of all Montgomery County sites, which reinforces the view that blacknose dace are more tolerant of low DO than creek chubs.

With 20 habitat and water quality variables and 5 life requisite components, the creek chub HSI model was most complex of the models used (Table 7-2). As many water quality variables returned optimum suitability values (*i.e.*, SI= 1.0, Table 7-8), and most had limited discriminatory power, the model could be made simpler without sacrificing predictability. It is likely that if a smaller number of critical habitat variables were focused on, the model could have better resolution over a larger scale of final HSI scores.

Table 7.8 Creek Chub HSI Data

HSI Variable	TF324	SI	TF396	SI	TF500	SI	TF620	SI	TF760	SI	TF975	SI	TF1120	SI
Percent pools	19.30	0.58	24.18	0.72	25.75	0.77	22.48	0.67	0.00	0.20	16.23	0.48	55.21	1.00
Pool class (category)	B	0.60	A	1.00	C	0.30	C	0.30	C	0.30	C	0.30	B	0.60
Percent cover	70.00	1.00	45.00	1.00	15.00	0.22	5.00	1.00	60.00	1.00	20.00	0.59	50.00	1.00
Winter thermal cover	Y	0.90	Y	1.00	Y	0.57	Y	0.79	Y	0.59	Y	0.64	Y	100
Stream gradient	6.15	0.96	2.46	0.37	4.20	0.71	2.74	0.43	3.27	0.53	7.47	1.00	4.13	0.70
Stream width	19.73	0.21	11.24	0.46	10.46	0.53	12.08	0.42	13.27	0.37	11.63	0.44	6.31	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
pH (category)	B	0.80	B	0.80	B	0.80	C	0.40	A	1.00	B	0.80	B	0.80
Vegetation index	112.50	1.00	160.00	1.00	120.00	1.00	155.00	1.00	110.00	1.00	172.00	1.00	95.00	1.00
Substrate food index	C	0.50	B	0.70	C	0.50	C	0.50	B	0.70	B	0.70	B	0.70
Average summer water temp.	22.24	1.00	22.24	1.00	21.50	1.00	20.92	1.00	22.38	1.00	18.72	1.00	19.26	1.00
Minimum summer DO conc.	0.19	0.00	0.19	0.00	0.06	0.00	6.20	1.00	0.47	0.00	7.20	1.00	6.85	1.00
Average velocity (0.6 depth)	25.00	1.00	31.00	1.00	30.00	1.00	22.00	1.00	21.00	1.00	20.00	1.00	13.00	1.00
Average spring water temp	16.55	1.00	16.55	1.00	15.08	1.00	16.51	1.00	16.33	1.00	14.60	1.00	14.53	1.00
Minimum spring DO conc.	1.20	0.01	1.20	0.01	5.87	0.92	6.93	1.00	5.80	0.91	6.46	0.98	5.90	0.92
Average spring riffle velocity	33.60	1.00	55.46	1.00	46.18	1.00	23.11	1.00	33.70	1.00	38.10	1.00	30.48	1.00
Riffle substrate index	102.00	1.00	125.00	1.00	115.00	1.00	123.00	1.00	114.00	1.00	114.00	1.00	92.00	1.00
Average stream margin velocity	3.05	1.00	7.62	1.00	10.67	0.81	6.10	1.00	6.10	1.00	6.10	1.00	6.10	1.00
Percent summer shade	15.00	0.28	50.00	0.80	50.00	0.80	70.00	1.00	20.00	0.33	90.00	1.00	95.00	1.00
Average maximum depth	0.37	0.91	0.42	0.97	0.33	0.85	0.31	0.83	0.30	0.81	0.21	0.61	0.39	0.94
Food component		0.75		0.85		0.75		0.75		0.85		0.85		0.85
Cover component		0.82		0.95		0.53		0.74		0.57		0.62		0.92
Water quality component		0.00		0.00		0.00		0.40		0.00		0.95		0.95
Reproduction component		0.01		0.01		0.98		1.00		0.98		1.00		0.98
Other component		0.69		0.60		0.70		0.56		0.57		0.68		0.88
H S I score		**0.00**		**0.00**		**0.00**		**0.40**		**0.00**		**0.80**		**0.91**
Abundance	0.00		0.00		0.00		4.00		2.00		24.00		116.00	
Biomass	0.00		0.00		0.00		23.10		9.40		116.53		1105.20	

Correlations	**r^2 value**
HSI :biomass/unit vol	0.728771
HSI: abundance/unit vol	0.787745

7.3.8 Common Shiner HSI Model

Common shiner HSI model results were fair. The model performed well in identifying unsuitable conditions in the lower watershed, but did not help explain the absence of common shiners from site TF1120, which had the highest HSI score in the watershed (Table 7-9). Due almost entirely to this site, SLR coefficients between HSI score and common shiner abundance and biomass were lowered: r^2= 0.45 and 0.48, respectively (However, if site TF1120 were ignored, r^2 values increased to 0.92 and 0.93, respectively). The HSI score at site TF760 was zero, due to a lack of pools, and though the species was collected at site TF760, abundance and biomass were reduced compared to mid-watershed sites with more pool habitat available.

Common shiners were most abundant in Tacony Creek in the City of Philadelphia at sites TF500 and TF620. These sites had the best diversity, fish index of biological integrity (IBI), and modified index of well-being (MIWB) scores in the watershed Table 7-9. Much like the redbreast sunfish model, SI variables used are general in nature, and contain a large range of suitable values (redbreast sunfish and common shiners are both considered generalist species). Interspecific competition, low productivity, water quality and hydrologic perturbations are among the possible explanations for low common shiner abundance in upstream segments of Tookany/Tacony-Frankford Watershed.

Table 7-9 Common Shiner HSI Data

HSI Variable	**TF324**	**SI**	**TF396**	**SI**	**TF500**	**SI**	**TF620**	**SI**	**TF760**	**SI**	**TF975**	**SI**	**TF1120**	**SI**
Max. summer temperature	26.00	0.29	26.00	0.29	25.60	0.33	24.95	0.43	24.41	0.50	22.09	0.96	22.73	0.82
Least suitable pH throughout year	8.52	0.99	8.52	0.99	8.37	1.00	9.03	0.88	8.01	1.00	8.48	1.00	8.36	1.00
Turbidity	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00	25.00	1.00
Riffle substrate category	E	0.20	D	0.80	D	0.80	C	1.00	E	0.20	D	0.80	D	0.80
Percent pools	19.30	0.35	24.18	0.53	25.75	0.56	22.48	0.46	0.00	0.00	16.23	0.23	55.21	0.99
Velocity in pools	3.66	0.85	4.57	0.90	8.53	0.99	4.88	0.91	0.00	0.00	12.50	1.00	2.44	0.80
Pool class	B	1.00	B	1.00	C	0.60	C	0.60	C	0.60	C	0.60	B	1.00
Adequate spring temp (spawning)	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00	Y	1.00
Riffle velocity	33.60	0.37	55.46	0.00	23.09	0.87	23.11	0.87	33.70	0.37	38.10	0.22	30.48	0.52
Food/Cover component		0.20		0.81		0.74		0.74		0.00		0.23		0.90
Water quality component		0.29		0.29		0.33		0.72		0.80		0.99		0.94
Reproduction component		0.20		0.00		0.86		0.97		0.20		0.22		0.76
H S I Score		**0.20**		**0.00**		**0.33**		**0.80**		**0.00**		**0.22**		**0.86**
Abundance	0.00		0.00		53.00		87.00		8.00		12.00		0.00	
Biomass	0.00		0.00		305.58		625.91		93.11		80.58		0.00	

Correlations	**r^2 value**
HSI: biomass/unit vol	0.485461
HSI: abundance/unit vol	0.479658

7.4 Sensitivity Analysis

A pseudo-Monte Carlo approach was used with all HSI models to determine which habitat attributes were most sensitive, and thus influential in the final HSI score. Data for all variables was compiled and basic statistics (*i.e.*, mean, standard deviation, range) were computed. Most physicochemical variables were found to most closely fit a normal (Gaussian) distribution, while other parameters (*e.g.*, stream width, percent shade) best fit an even distribution, so two separate random number generators (Microsoft Excel and Statistica) were used to obtain an array of values for model input. Each case in the array was a combination of random values within the range of values that might have come from a stream in Tookany/Tacony-Frankford Watershed. In combining the randomly generated results, variables were considered completely independent, so some combinations of random input values were less realistic than others (*e.g.*, very low average yearly temperature and very high growing season temperature; very wide stream with 100% shade; severe DO fluctuations and stable pH). To be sure, Interdependencies exist between some variables, but these relationships were difficult to quantify and build into the Monte Carlo procedure. It was assumed that the influence of these unlikely combinations would be suppressed by using a large number of iterations.

The habitat attribute input array for each HSI model was used with the model to compute the final HSI score for each case in ten trials of 1000 iterations each, for a total of 100,000 iterations in total for each model. Values for the input array were re-computed between trials, and the correlation of each variable with final HSI score was computed after each trial. After ten trials were completed, habitat attributes were ranked according to the mean of their correlation scores. In interpreting sensitivity analysis results, it should be noted that many variables were almost always completely suitable (*i.e.*, SI=1) and not found to be important in determining the HSI score for a given species. Those variables that have a limiting effect are thus more likely to influence the score than variables that tend to maintain the total score at or near complete suitability (*i.e.*, HSI=1). If the situation was reversed and many habitat variables were influential and less suitable, a variable or variables that tended to increase scores would be more influential.

Blacknose Dace

Sensitivity analysis showed that stream width was the most important attribute in determining habitat suitability for blacknose dace (Table 7-10). This corroborates results of the 2004 fish assessment, and other records in the PWD bioassessment database which have shown the species to be more abundant in upstream reaches. Stream gradient would likely have ranked high in HSI influence, had the model been adequately calibrated to the range of stream gradient values present in Tookany/Tacony-Frankford Watershed, as mainstem sites were generally found to have milder slopes than upstream and tributary sites. During the infrastructure assessment procedure in which PWD biologists walked entire segments of the stream, blacknose dace were observed in very small tributaries that originate in stormwater pipes, in some cases even in small disconnected pools left by intermittent streams. Blacknose dace is assumed to be a fast colonizer of these small tributaries, feeding primarily on dipteran larvae (*e.g.*, chironomids, mosquitoes).

Table 7-10 Blacknose Dace HSI Model Sensitivity Analysis

HSI Variable	*r* value	*r*²	rank
Stream Width	0.60	0.36	1
Pool Substrate Category (adult habitat)	0.29	0.09	2
Riffle Substrate Category (juvenile habitat)	0.23	0.05	3
Riffle Substrate Category	0.15	0.02	4
Velocity in Riffles (juvenile)	0.04	0.00	
Temperature (growing season)	0.03	0.00	
Percent pools	0.02	0.00	
Percent shaded	0.01	0.00	
Velocity in Riffles	0.01	0.00	

Common Shiner

Common shiner is described as primarily a pool shiner (Jenkins and Burkhead 1993, Trial and Nelson 1983), and "percent pools" was found to be the second most influential variable in final HSI score (Table 7-11). It was unusual, however, that riffle attributes were found to be so influential in final HSI score. Exceptional sites such as TF396 that were steep in gradient and not overwidened tended to have greater velocity in riffles. Habitat at sites such as TF396, while highly desirable overall and good for a majority of indicator species, is actually not as suitable for common shiners as more degraded sites. So, in this case, riffle velocity and substrate had an important influence on total HSI score. Common shiners do not appear to exploit small streams and upstream reaches, as do blacknose dace and creek chubs; rather they show a preference for larger, mid-watershed stream segments with a mix of pool habitats, especially if large, slow pools are present.

Table 7-11 Common Shiner HSI Model Sensitivity Analysis

HSI Variable	r value	r²	rank
Riffle Velocity	0.58	0.34	1
Percent pools	0.37	0.14	2
Riffle Substrate Category	0.19	0.04	3
Pool Class	0.08	0.01	
Max. Summer Temperature	0.07	0.01	
Velocity in Pools	0.02	0.00	

Creek Chub

As mentioned previously, the creek chub HSI model includes a large number of habitat attribute input variables (n=20), many of which nearly always scored perfect suitability (SI=1). A small number of variables were very powerful in the analysis, and seemed to perform well in estimating habitat suitability (Table 7.8). In the original HSI analysis of Tookany/Tacony-Frankford Watershed data, minimum oxygen concentration in spring and summer limited suitability at all sites in Philadelphia and site TF760.

When the sensitivity analysis was initially run using a simple random number generator that limited the output values to a range with even distribution, DO variables were very important, accounting for a majority of the variance in HSI total score (Table 7.12). However, when the sensitivity analysis was performed using randomly generated, normally distributed minimum oxygen values, the influence of spring DO concentration was reduced and summer DO concentration was almost negligible (Table 7.12). The pH habitat suitability factor was an ordinal variable (only three categories were valid input values as applied to the Tookany/Tacony-Frankford Watershed) and thus very influential on the total HSI score once DO input variables were converted to an array of values fitting the normal distribution. As pH and oxygen fluctuations are inter-related, it may be sufficient to say that downstream sites that exhibit problems with either variable will be generally unsuitable for creek chubs.

Table 7-12 Creek Chub HSI Model Sensitivity Analysis

HSI Variable	**r value**	**r^2**	**rank**
Minimum spring DO conc.	0.614072	0.377201	1
Minimum summer DO conc.	0.503348	0.253712	2
pH (category)	0.165738	0.02763	3
Percent summer shade	0.031921	0.001353	
Average maximum depth	0.030484	0.001102	
Pool class (category)	0.030215	0.001136	
Average stream margin velocity	0.026425	0.001058	
Substrate food index	0.024913	0.000768	
Stream width	0.024608	0.000931	
Stream gradient	0.02374	0.000919	
Percent pools	0.021388	0.000684	
Winter thermal cover	0.019738	0.000553	
Percent cover	0.012689	0.000379	

Table 7-13 Creek Chub HSI Model Modified Sensitivity Analysis

HSI Variable	**r value**	**r^2**	**rank**
pH (category)	0.867203	0.752314	1
Minimum spring DO conc.*	0.199296	0.040377	2
Winter thermal cover	0.08947	0.009113	3
Percent pools	0.07437	0.006729	
Stream width	0.066559	0.004954	
Percent summer shade	0.05645	0.003858	
Substrate food index	0.047608	0.002867	
Pool class (category)	0.039874	0.003218	
Stream gradient	0.034031	0.002056	
Percent cover	0.03317	0.001707	
Minimum summer DO conc.	0.013052	0.001139	
Average maximum depth	0.005239	0.001379	
Average stream margin velocity	0.002902	0.000752	
*Dissolved oxygen values randomly generated to fit normal distribution			

Fallfish

Sensitivity analysis performed with the fallfish HSI model suggested that substrate and temperature variables had the most influence on total HSI score (Table 7-14). The model was very simple, and since the species was not collected from Tookany/Tacony-Frankford Watershed, there was no opportunity to compare model output with observed fish data.

Table 7-14 Fallfish HSI Model Sensitivity Analysis

HSI Variable	r value	r^2	rank
Substrate Category	0.537861	0.318505	1
Favorable Spawning Temperature Y/N	0.484223	0.25853	2
Temperature	0.279436	0.086915	3
Mode of Stream Depth	0.027016	0.001389	
Cover category	2.85E-15	1.06E-12	

Longnose Dace

The longnose dace HSI model was similar to the fallfish model in that it did not appear to have a sufficient number of input variables to estimate habitat suitability for the species. Results of sensitivity analysis suggested that the longnose dace model was very sensitive to stream velocity (Table 7-15). Many sites in Tookany/Tacony-Frankford Watershed probably do not have the swift flowing riffles with moderate depth during baseflow that this species needs in order to thrive. Unfortunately, the one site that appeared to have adequate physical habitat, TF396, probably could not support a population of longnose dace due to water quality problems.

Table 7-15 Longnose Dace HSI Model Sensitivity Analysis

HSI Variable	r value	r^2	rank
Average Stream Velocity	0.870711	0.758267	1
Percent Cover	0.164372	0.027557	2
Percent of Substrate >5cm	0.150228	0.022929	3
Maximum Depth in Riffles	0.012016	0.001503	
Percent Riffles	0.011341	0.000912	

Redbreast Sunfish

The redbreast sunfish HSI model used an ordinal (*i.e.*, categorical) variable for minimum dissolved oxygen concentration, and suggested that habitat suitability for this species is not adversely affected at 5.0 mg/l and is still moderately suitable (SI=0.70) at 3.0mg/l (Aho, *et al.* 1986). Results were very similar to the creek chub model. In the absence of influence from DO concentration, pH was very influential, overshadowing the other variables (Table 7-16). As mentioned previously, pH and DO fluctuations are interrelated, and sites that exhibit severe fluctuations in either DO or pH will be less suitable habitat for redbreast sunfish and fish in general.

Table 7-16 Redbreast Sunfish HSI Model Sensitivity Analysis

HSI Variable	r value	r^2	rank
Least suitable pH observed	0.830002	0.68896	1
Spawning temperature (summer)	0.107977	0.000726	2
Percent slow pools	0.098623	0.001564	3
Percent sand/gravel	0.020353	0.000987	
Vegetated cover	0.009163	0.001039	
Percent cover	0.00622	0.000543	
Max temp growing season	0.00385	0.000558	

Smallmouth Bass

The smallmouth bass HSI model was considered to be the most comprehensive and refined of all HSI models used. One explanation for this is the fact that Smallmouth bass are large predators and economically important. All factors appear to have been considered and included in the model, yet there are few extraneous factors. The only shortcoming was the number of variables defined by ordinal data.

When minimum DO concentration values were generated for sensitivity analysis input as a range of values with an even distribution, low DO values appeared frequently in the input array and the influence of DO concentration on final HSI score was the most important factor (Table 7-17). When minimum DO input values were fitted to a normal distribution, the incidence of low DO concentrations was much less and the overall influence of DO on the final HSI score decreased and physical habitat features became much more influential. Unfortunately, no smallmouth bass were collected from Tookany/Tacony-Frankford Watershed, so further interpretation of the model output was not possible. Factors the model suggested were influencing habitat suitability (*i.e.*, substrate type, percent pools and DO) were considered to be limiting for other indicator species as well.

Table 7-17 Smallmouth Bass HSI Model Sensitivity Analysis

HSI Variable	***r* value**	**r^2**	**rank**
Dissolved O_2	0.55121	0.304095036	1
Percent pools	0.342683	0.117847336	2
Substrate type category	0.14563	0.021791216	3
Percent cover	0.063263	0.004417092	4
Gradient	0.031777	0.002482453	5
Avg. pool depth	0.01208	0.00074076	
Temperature (juvenile)	0.005166	0.001810854	
Temperature (adult)	0.001128	0.001648207	
Average pH	0.001279	0.000938872	
Temperature (fry)	0.007792	0.00155506	

Table 7-18 Smallmouth Bass HSI Model Modified Sensitivity Analysis

HSI Variable	***r* value**	**r^2**	**rank**
Percent pools	0.658775	0.434124162	1
Substrate type category	0.252076	0.06438798	2
Percent cover	0.127203	0.016691022	3
Gradient	0.089035	0.00852654	4
Dissolved O_2*	0.066097	0.004928978	5
Temperature (adult)	0.022228	0.001333032	
Temperature (juvenile)	0.020963	0.001260527	
Temperature (fry)	0.018387	0.002537125	
Avg. pool depth	0.010251	0.000591149	
Average pH	0.004575	0.000323035	
***Dissolved oxygen values randomly generated to fit normal distribution**			

Section 8
Indicator Status Update

Overview

An important component of the Comprehensive Characterization Report is a concise update on the biological, chemical and physical conditions within the Tookany/Tacony-Frankford Watershed. Indicator status updates derived within this report will be used as a tool for identifying spatial and temporal trends of a particular stream reach or for the entire watershed. Moreover, indicators defined in the Tookany/Tacony-Frankford Integrated Watershed Management Plan (TTFIWMP) will serve as benchmarks for future restoration projects. The indicators addressed in this section are:

- Indicator 3: Stream Channels and Aquatic Habitat
- Indicator 5: Fish
- Indicator 6: Benthos
- Indicator 7: Effects on Public Health (Bacteria)
- Indicator 8: Effects on Public Health (Metals and Fish Consumption)
- Indicator 9: Effects on Aquatic Life (Dissolved Oxygen)

8.1 Indicator 3: Stream Channels and Aquatic Habitat

Indicator 3 of the TTFIWMP stresses the importance of physical habitat features that will support healthy fish and benthic communities. As described in Section 3.8.1, thirteen habitat variables, ranging from instream parameters to riparian zone width and quality were compared against reference conditions to obtain an overall habitat integrity score.

In 2004, PWD staff biologists surveyed habitat at 12 sites throughout the Tookany/Tacony-Frankford Watershed. Monitoring locations along the mainstem of Tookany Creek (Montgomery County) received uniform scores of “Non-Supporting”, indicating a region of severe habitat degradation (Figure 8-1). In general, upstream reaches in Tookany Creek lacked habitat heterogeneity, possessed poor riparian zones, and experienced high levels of channelization. Moreover, poor bank stability and exaggerated levels of sediment deposition also contributed to the poor aquatic habitat in the upper portions of the watershed.

Habitat values in the middle portion of Tacony Creek varied among sites, ranging from “Non-Supporting” to “Supporting” (*i.e.*, good). With the exception of site TF 396, a site with exceptional habitat for an urbanized stream, assessment sites in Tacony Creek possessed the same attributes as the upstream reaches (erosion, poor bank stability, reduced riparian zones and heavy sediment deposition).

Rock Creek and Jenkintown Creek sites, the two surveyed upstream tributaries, both were rated as partially supporting, indicating slightly better habitat conditions relative to the mainstem.

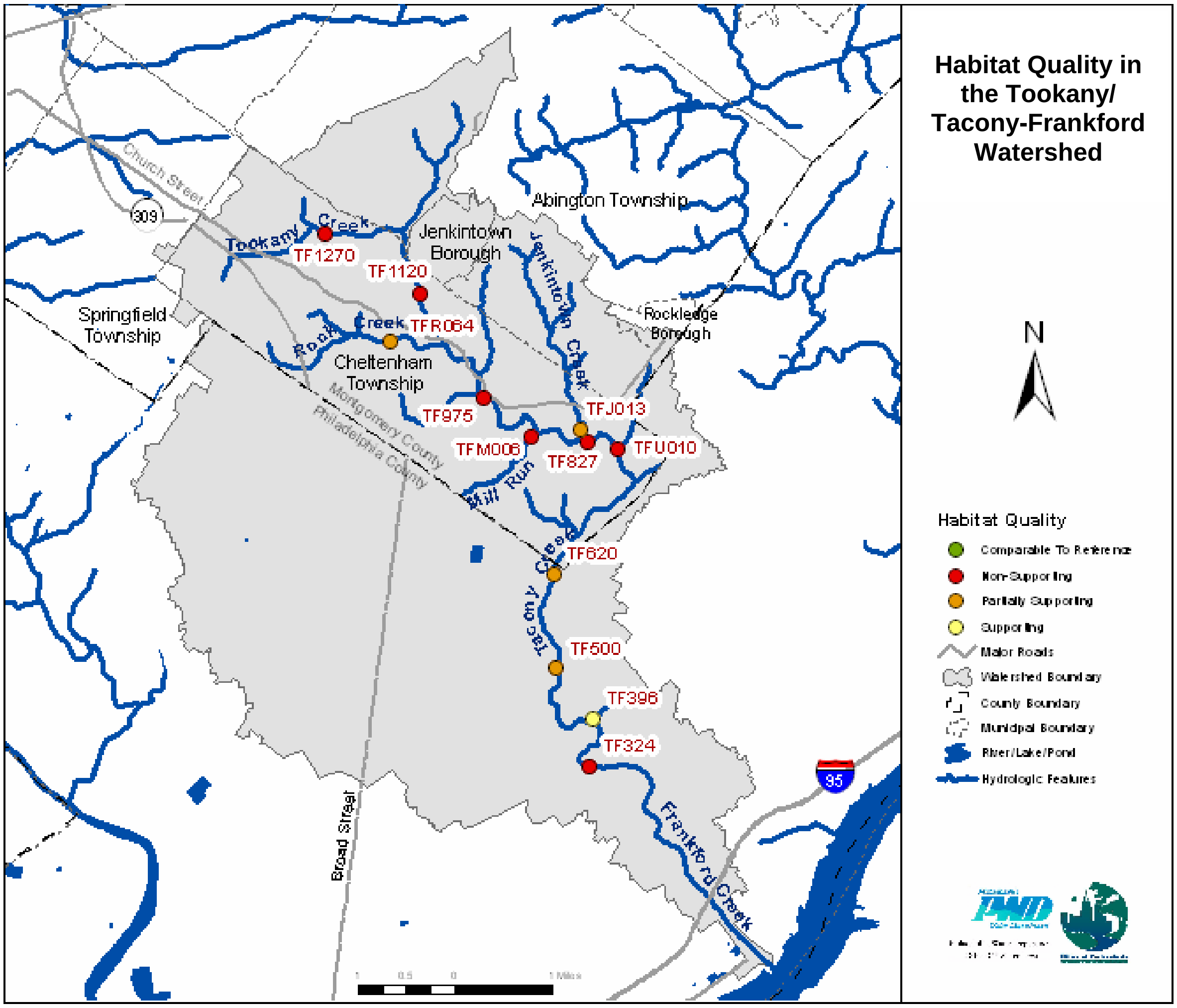


Figure 8-1 Tookany/Tacony-Frankford Watershed Habitat Quality Indicator Status Update.

8.2 Indicator 5: Fish

During 2000, three surrogate indicators were used to define the integrity of fish communities in the Tookany/Tacony-Frankford Basin. Relative abundance (*i.e.*, density), pollution tolerance, and number of native species provided a semi-quantitative measurement of fish assemblage health. With the development of ecoregion-specific metrics, PWD replaced these early indicators in 2004 with the Index of Biological Integrity (IBI), a multi-metric approach that characterizes fish community health at a particular stream reach or at the watershed scale (Section 3.6).

Fisheries data revealed a mean IBI score of 21 (out of 50), placing the Tookany/Tacony-Frankford Watershed in the “poor” category for fish community health (Figure 8-2). Low diversity, absence of benthic insectivorous species, absence of intolerant species, skewed trophic structure dominated by generalist feeders, high percentage of individuals with disease and anomalies, and high percentage of dominant species are characteristics of a fish community with "poor" biotic integrity. Spatial trends showed that only two sites received a "fair" IBI score, both located in Tacony Creek Park in the City of Philadelphia. Similar spatial trends revealed that Modified Index of Well-Being (MIWB) and Shannon Diversity Index values, which are measures of diversity and abundance, were lowest in the lower and upper monitoring stations and highest in the middle of the watershed, mirroring the habitat indicator results. Overall, monitoring stations in the central portion of the watershed had higher biological integrity and thus environmental quality, than either downstream or upstream stations.

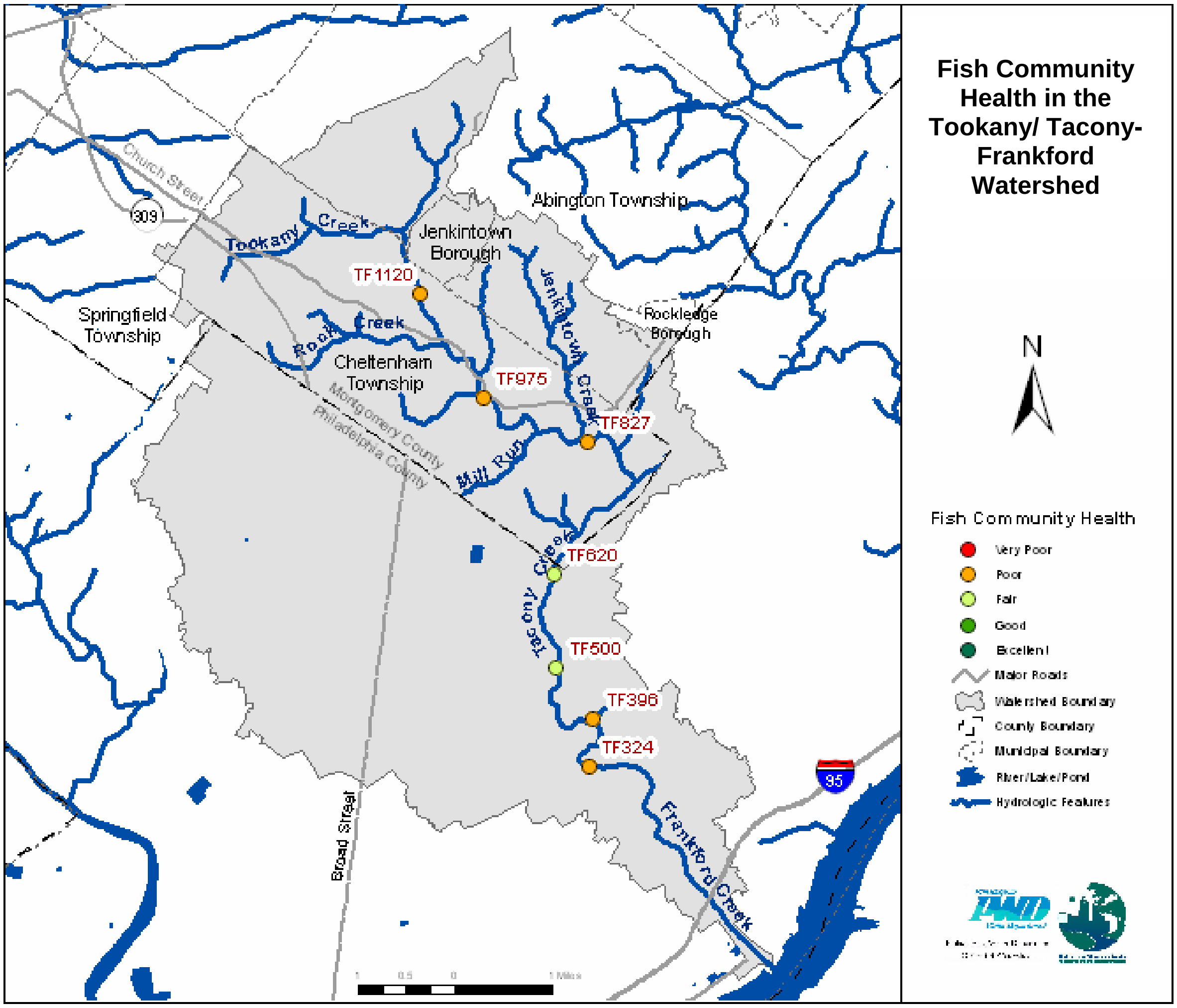


Figure 8-2 Tookany/Tacony-Frankford Watershed Fish Indicator Status Update

8.3 Indicator 6: Benthos

Benthic macroinvertebrate monitoring occurred at 12 sites in Tookany/Tacony-Frankford Watershed during 2004. Similar to the 2000 sampling effort, Rapid Bioassessment Protocol III (RBP III) was chosen as the approved method for assessing the condition of the macroinvertebrate community in Tookany/Tacony-Frankford Watershed.

The assessment conducted in 2004 reconfirmed earlier findings of the Pennsylvania Department of Environmental Protection (PA DEP) and Philadelphia Water Department (PWD). Benthic impairment in Tookany/Tacony-Frankford Watershed was omnipresent;

with the exception of Jenkintown Creek, all stream segments were designated "severely impaired" (Figure 8-3).

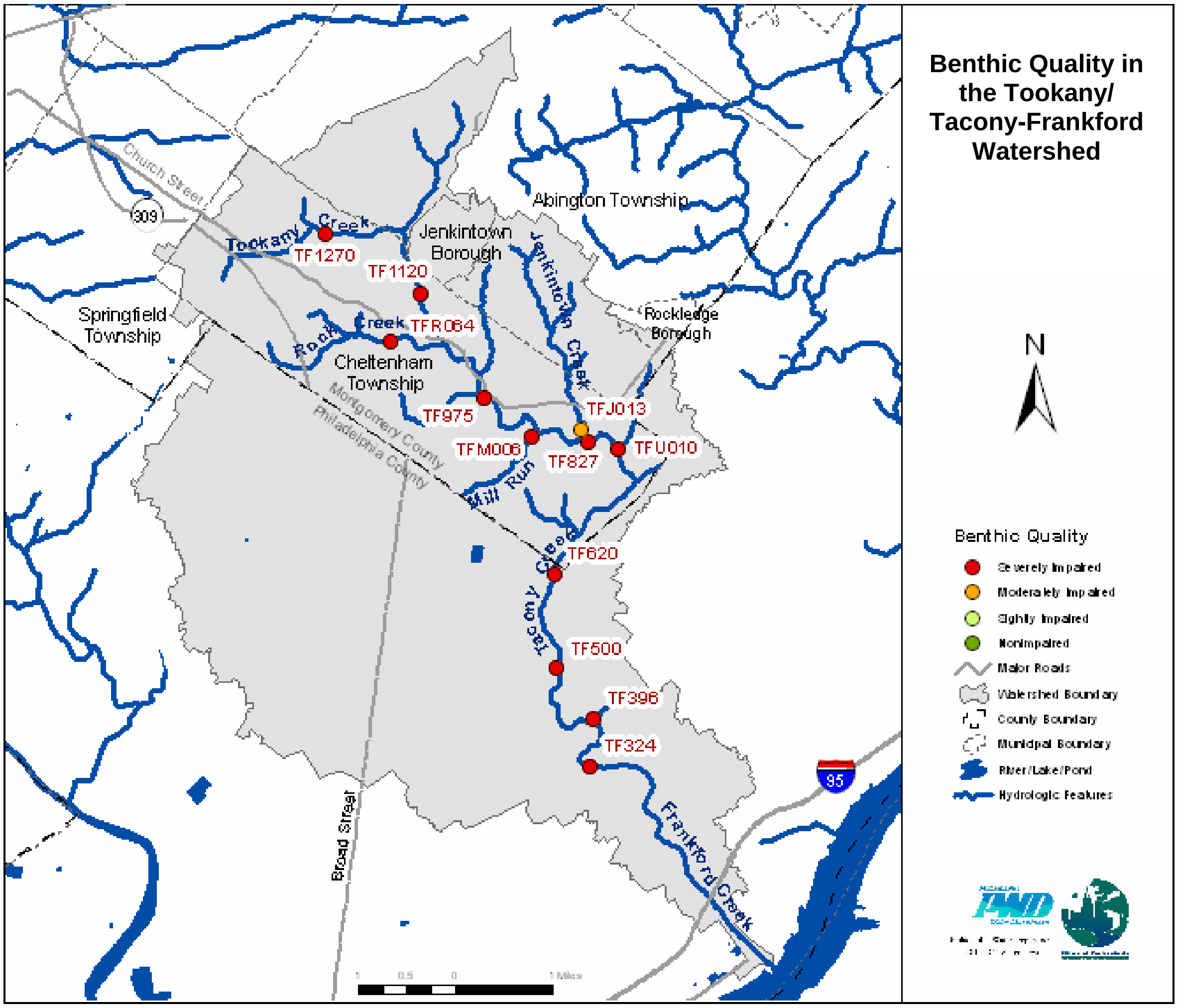


Figure 8-3 Tookany/Tacony-Frankford Watershed Benthic Indicator Status Update.

The severity of impairment throughout Tookany/Tacony-Frankford Watershed suggests that attaining healthy benthic communities in mainstem localities and associated tributaries is not a feasible option at this time. Habitat restoration, flow attenuation and possibly, active re-introduction (*i.e.*, "invertebrate seeding") may be the only solutions to ensure a viable benthic community within this watershed.

8.4 Indicator 7: Public Health Effects (Bacteria)

Based on Pennsylvania's water quality criteria, the maximum fecal coliform concentration during the swimming season (*i.e.*, May 1 through September 30) shall not exceed a geometric mean of 200 colony forming units (CFU) per 100 ml for five non-consecutive samples. During the remainder of the year, the maximum fecal coliform concentration should be equal to or less than a geometric mean of 2000 CFU per 100 ml based on five samples collected on different days.

Discrete chemical samples taken at ten sites (n=10) in Tookany/Tacony-Frankford Watershed between 2000 and 2004 were used to calculate the percentage of samples meeting the appropriate standard (*i.e.*, swimming vs. non-swimming seasons) during wet and dry periods.

During dry weather, fecal coliform concentrations from May 1st through September 30th were placed in the "red" category (met standards less than ninety percent of the time) at all sites in Tookany/Tacony-Frankford Watershed (Figure 8-4). Between 91.1% - 100% of samples at all sites along Tookany-Tacony/Frankford mainstem did not meet the water quality standard of 200 CFU/100 ml during dry weather. Conversely, all sites with the exception of TF 280 met the non-swimming standard (2000 CFU/100 ml) greater than ninety-eight percent of the time during dry periods (Figure 8-4).

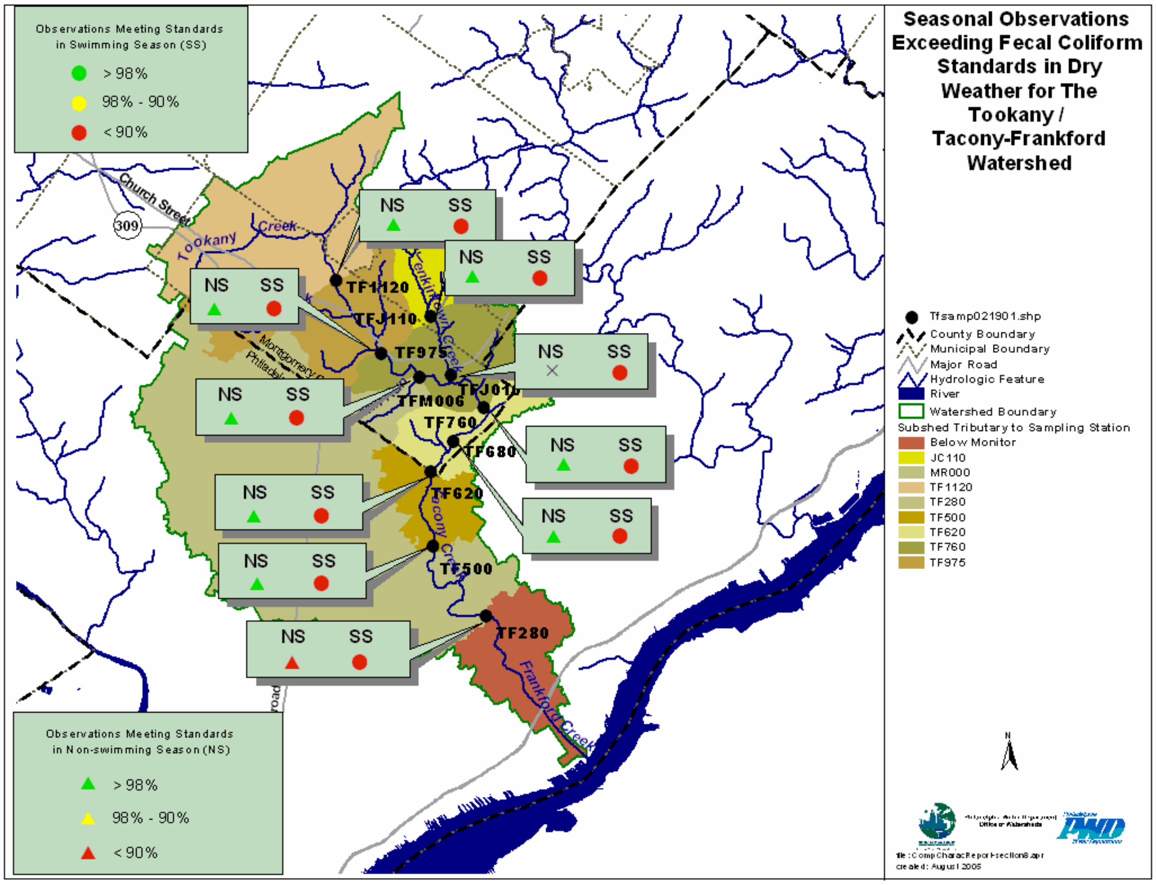


Figure 8-4 Fecal Coliform Samples Meeting Standards in Dry Weather during the Swimming and Non-Swimming Seasons.

Wet weather sampling results showed concentrations of fecal coliform exceeding water quality standards at all mainstem sites in Tookany/Tacony-Frankford Watershed during swimming and non-swimming seasons (Figure 8-5). Approximately 87.5% to 100 % of samples taken during the swimming season at the mainstem sites exceeded standards. Samples taken during the non-swimming period showed similar results with exception of the two major tributaries, Mill Run and Jenkintown Creek. Samples taken at these localities met the water quality standards greater than 98% of the time (Figure 8-5).

Figure 8-6 depicts the relationship (*i.e.*, magnitude of departure) between the geometric mean of fecal coliform concentrations and the appropriate standard at each site during dry and wet weather conditions. During the swimming season, concentrations of fecal coliform exceeded the standard at all locations along mainstem Tookany and Tacony Creeks in dry and wet weather. Most pronounced were sites TF500 and TF975, with fecal coliform levels exceeding the standard by a factor of 5 (*i.e.*, >1000 CFU/100 ml) during dry periods. Other sites along the continuum ranged between 1 to 4 times the standard during dry weather. All sites, with the exception of TFJ110, showed concentrations greater than five times the standard during wet weather.

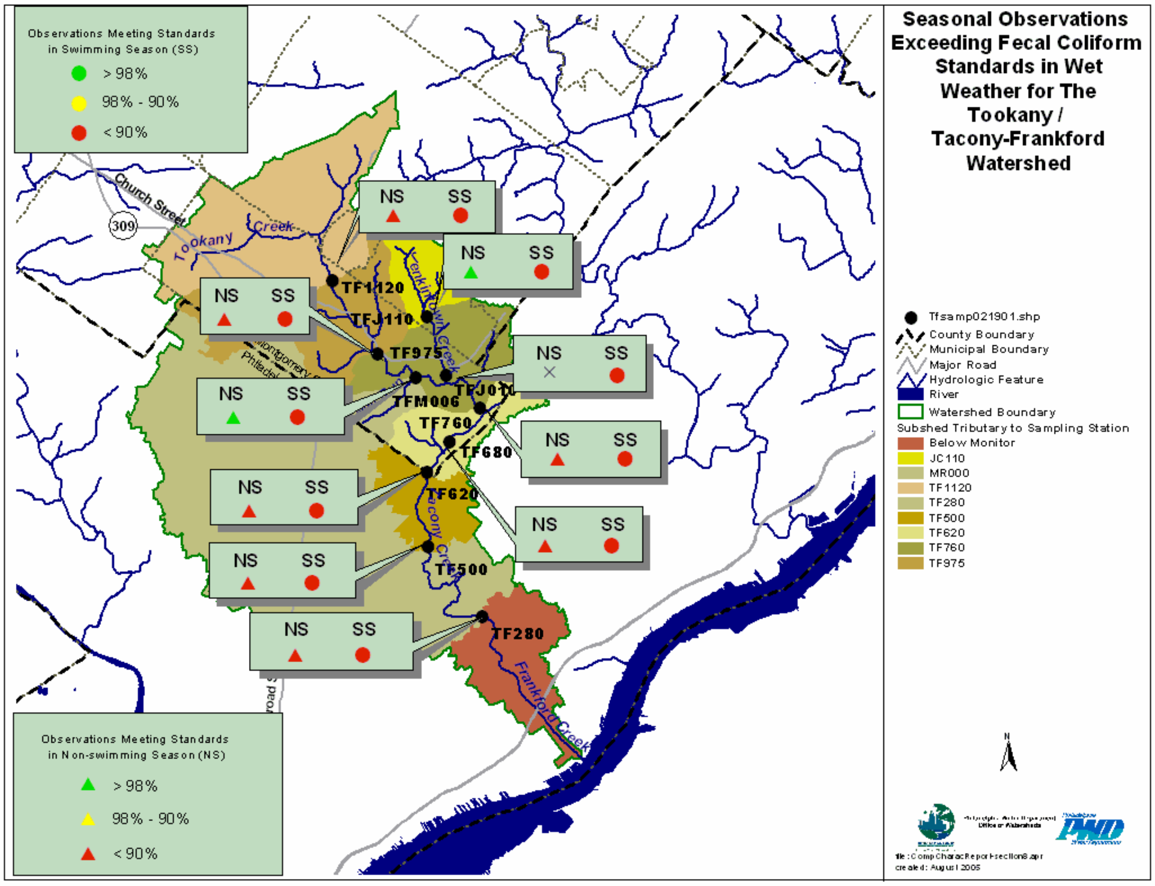


Figure 8-5 Fecal Coliform Samples Meeting Standards in Wet Weather during the Swimming and Non-Swimming Seasons.

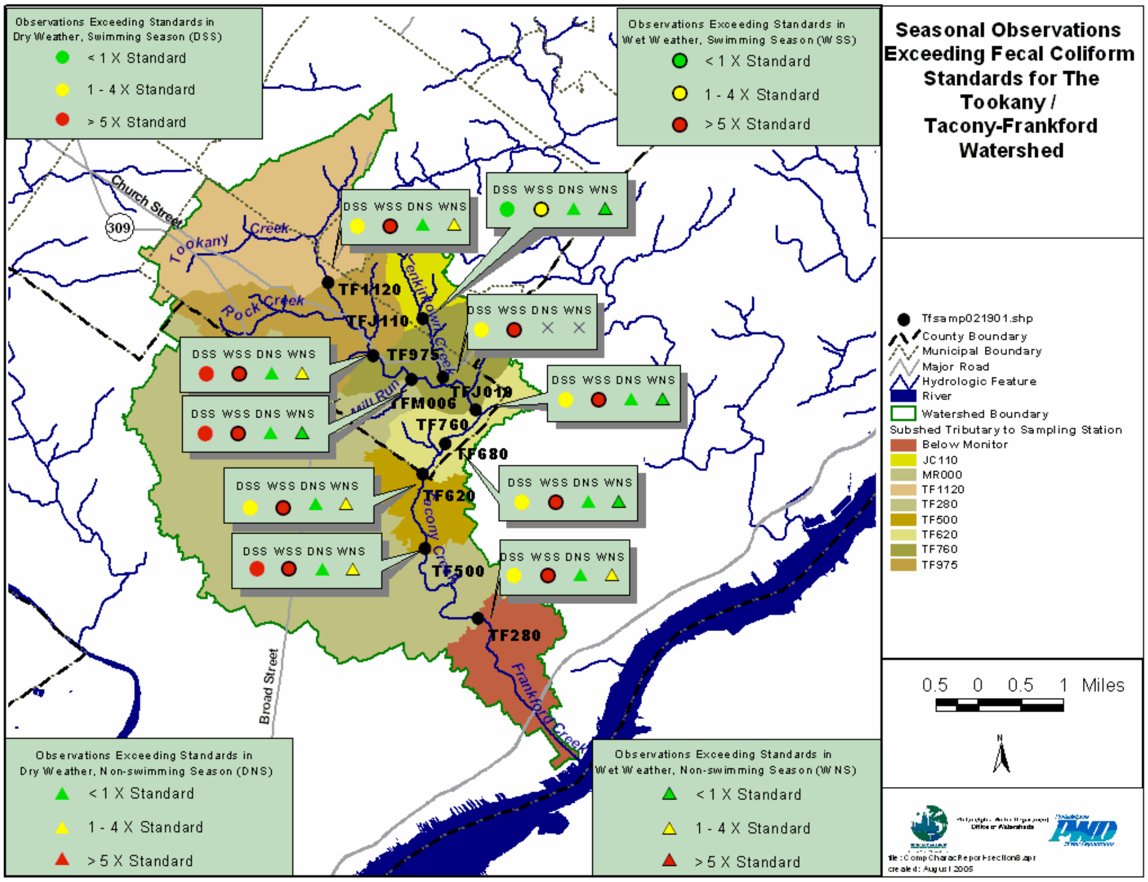


Figure 8-6 Seasonal Observations Exceeding Fecal Coliform Standards during Dry and Wet Weather

8.5. Indicator 8: Public Health Effects (Metals and Fish Consumption)

Relatively small amounts of certain toxic compounds can kill aquatic life through acute poisoning, while chronic levels may be harmful to developmental stages of fish and macroinvertebrates. For example, bioaccumulation of toxins in fish may have a profound effect on fecundity and may also pose a threat to humans who regularly consume fish. The established indicator measures the percent of aluminum, cadmium, chromium, copper, lead and zinc samples meeting state standards at various sites in Tookany/Tacony-Frankford Watershed.

Results suggest acute standards intended to protect aquatic life were met at all locations during dry-weather, while concentrations for aluminum exceeded chronic standards at most localities (Figures 8-7 and 8-8, respectively). Similarly, concentrations of aluminum exceeded acute standards regularly during wet conditions (Figure 8-7). In addition, copper generally exceeded acute standards during wet weather more than 10 % of the time at sites TFM006, TF620 and TF280.

Figure 8-9 represents observations of samples exceeding human health standards for toxic metals. As shown, all sites met standards greater than 98% of the time during dry and wet conditions.

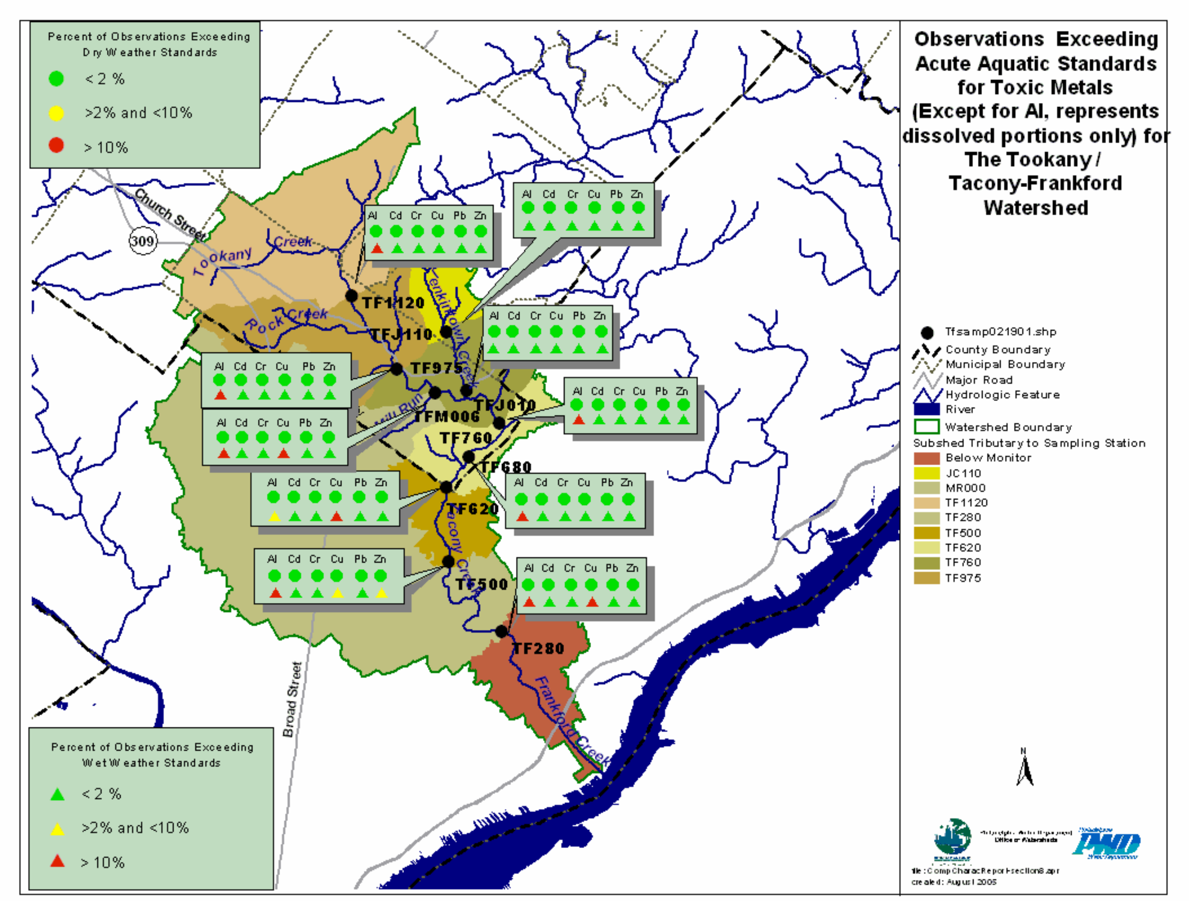


Figure 8-7 Acute Aquatic Standards for Toxic Metals during Wet and Dry Conditions.

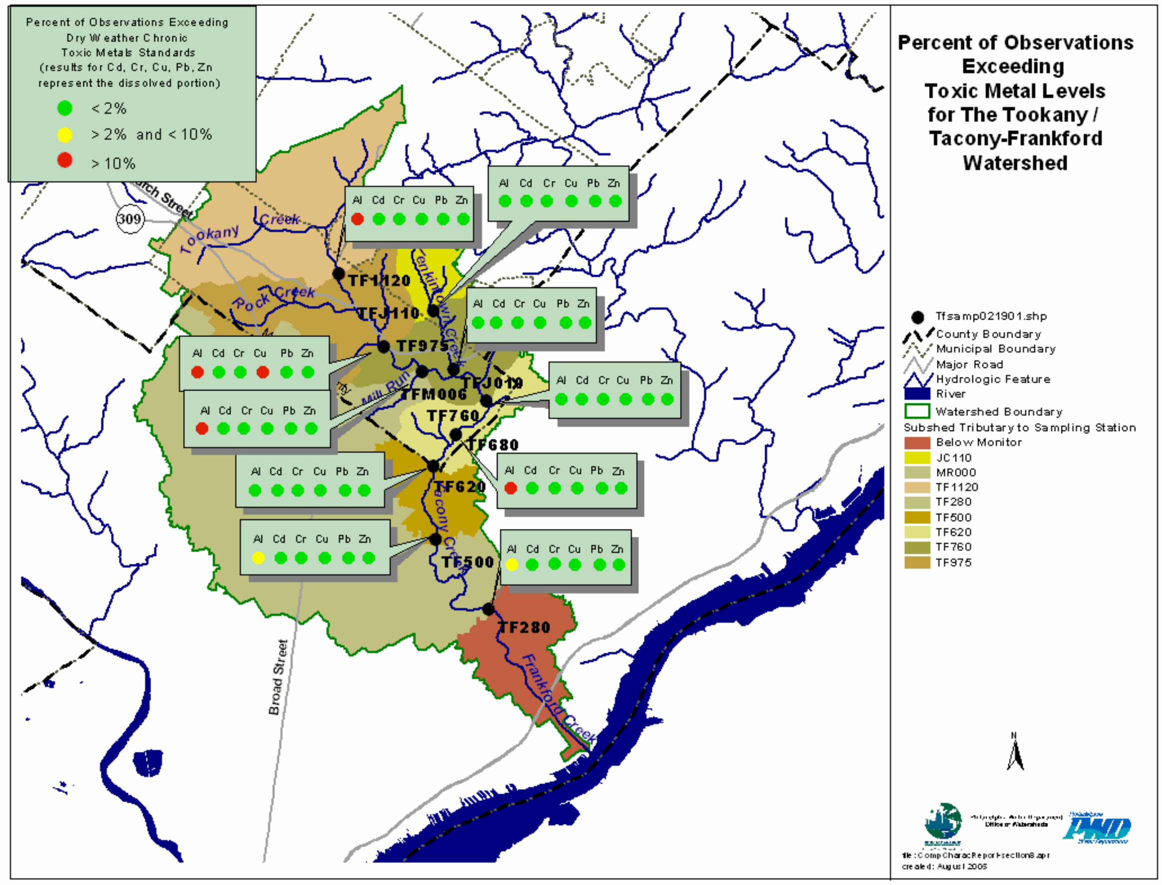


Figure 8-8 Percent Exceedance of Dry Weather Chronic Toxic Metals Standards.

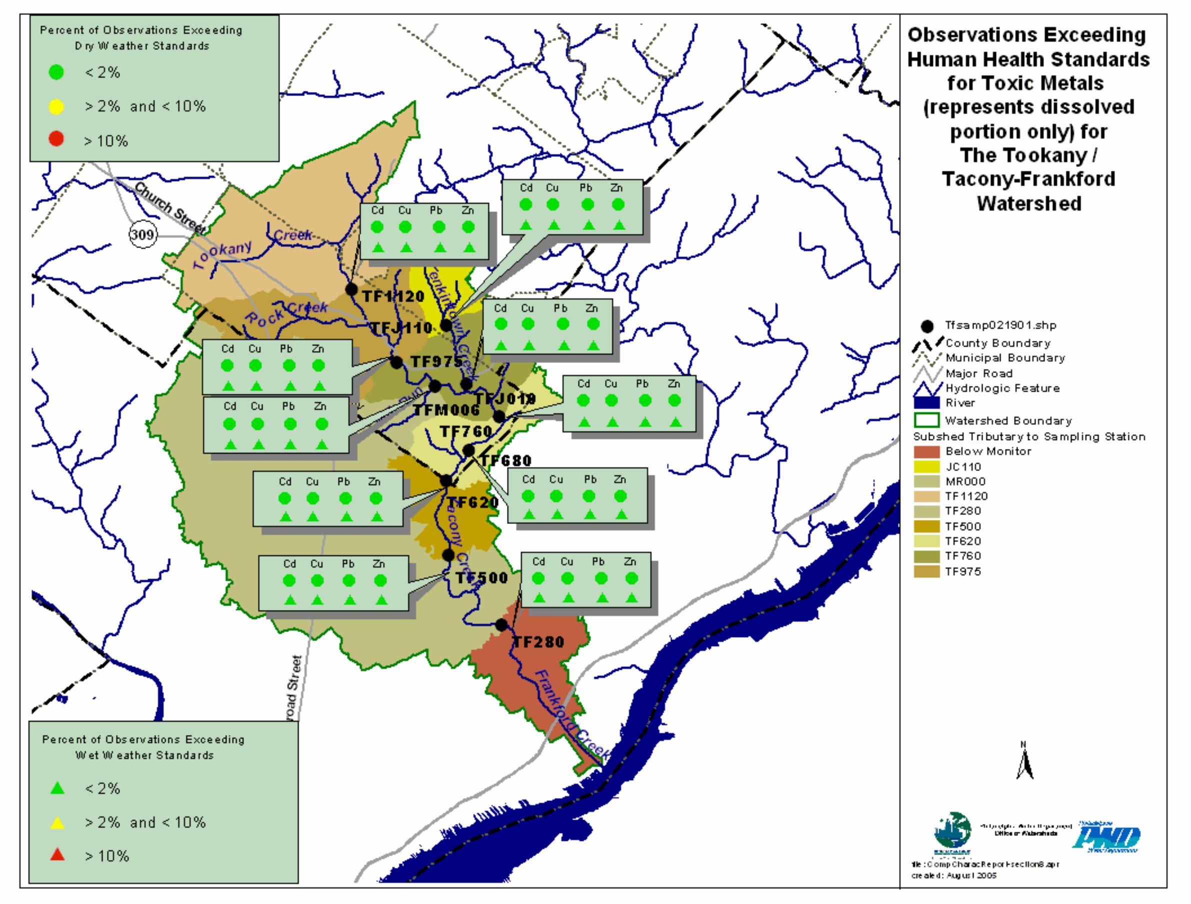


Figure 8-9 Observations Exceeding Human Health Standards for Toxic Metals in Wet and Dry Weather.

8.6. Indicator 9: Aquatic Life Effects (Dissolved Oxygen)

Automated water quality monitors (*i.e.*, Sondes) were deployed in Tookany/Tacony-Frankford Watershed at seven locations along the mainstem and three locations in major tributaries between 2000 and 2004. Sondes were deployed for approximately two-week periods, recording dissolved oxygen concentrations (mg/L) every 15 minutes. Upon completion of a cycle, Sondes were retrieved from the stream and exchanged for a reconditioned unit.

Continuous data from the mainstem sites indicated that daily average DO concentrations met minimum standards (daily average >5 mg/L of O_2,) greater than 90% of the time (Figure 8-10), with some locations meeting standards greater than 98% of the sampling period. Similar results were observed in Mill Run and Jenkintown Creek. Daily minimum standards for dissolved oxygen (instantaneous minimum 4 mg/L of O_2), however, indicate a potential problem in the downstream portion of the watershed. Site TF280 met minimum daily standards less than 90% of the sampling period while all other locations met the daily minimum standard between 90% and 100 % of the time.

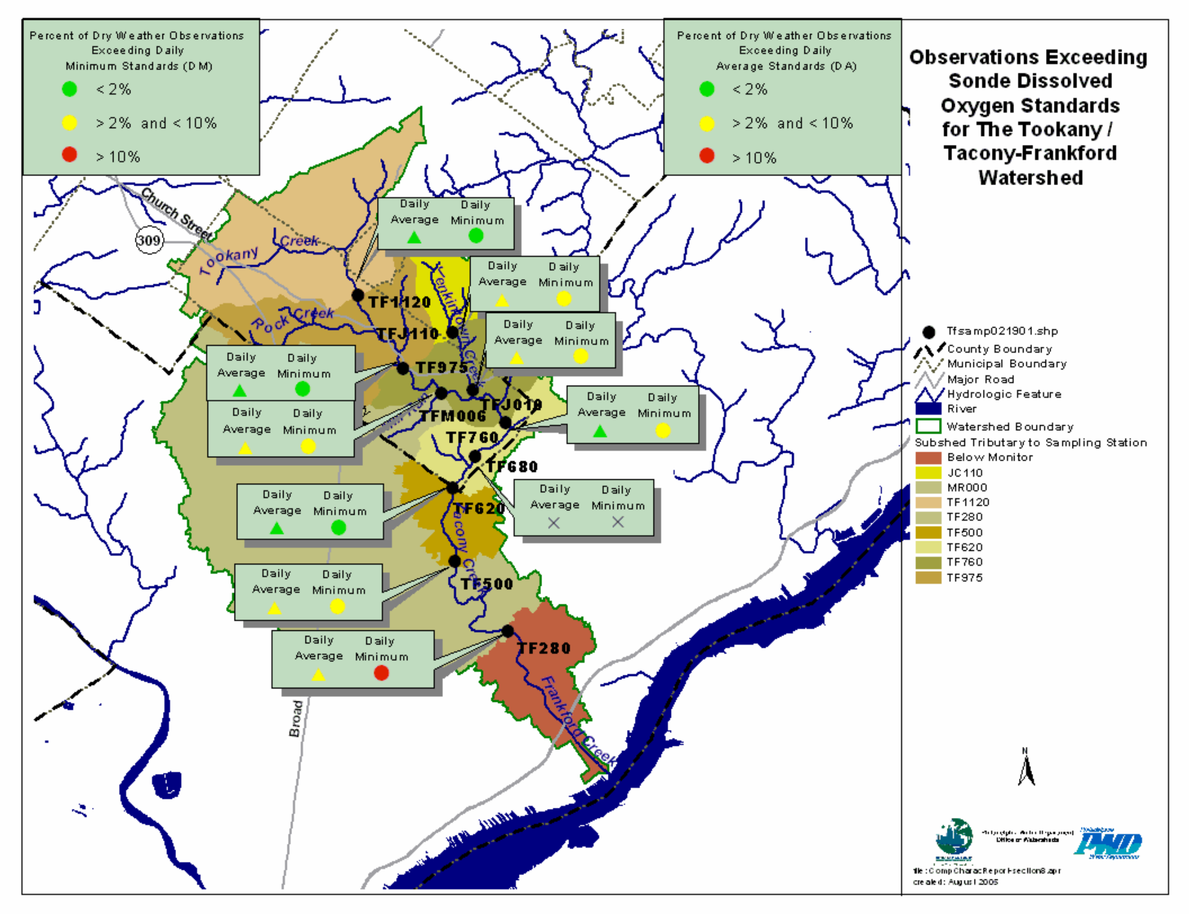


Figure 8-10 Observations Exceeding Dissolved Oxygen Standards.

Section 9
Active and Potential Sources of Water Quality Constituents

9.1 Model Description and Data Sources

9.1.1 Introduction

This subsection summarizes the results of a preliminary estimate of loading rates of various pollutants to Tookany/Tacony-Frankford Creek and tributaries. The waters in the drainage area receive point source discharges including CSO and other urban and suburban stormwater, sanitary sewer overflows, and limited industrial storm, process, and cooling waters. Combined sewers service approximately 47% of the watershed. Nonpoint sources in the basin include atmospheric deposition, limited direct overland runoff from urban and suburban areas, and limited individual on-lot domestic sewage systems discharging through shallow groundwater. Results for the Tookany/Tacony-Frankford Watershed were obtained using the detailed Storm Water Management Model (SWMM).

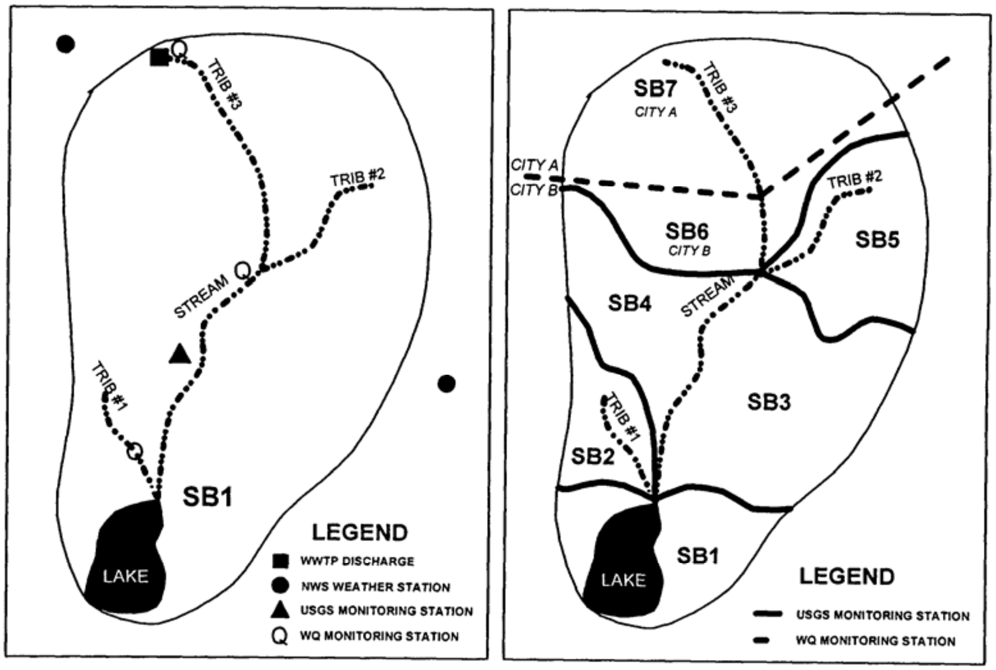
9.1.2 The Storm Water Management Model (SWMM)

The U.S. EPA's Storm Water Management Model (SWMM) was used to develop the watershed-scale model for the Tookany/Tacony-Frankford Watershed. The major components of the SWMM model used in the development of the Tookany/Tacony-Frankford Watershed model were the RUNOFF and EXTRAN modules.

The RUNOFF module was developed to simulate both the quantity and quality of runoff in a drainage basin and the routing of flows and contaminants to sewers or receiving body. The program can accept an arbitrary precipitation (rainfall or snowfall) hyetograph and performs a step by step accounting of snowmelt, evapo-transpiration losses, infiltration losses in pervious areas, surface detention, overland flow, channel flow, and water quality constituents leading to the calculation of one or more hydrographs and/or pollutographs at a certain geographic point such as a sewer inlet. The driving force of the RUNOFF module is precipitation, which may be a continuous record, single measured event, or artificial design event.

The EXTRAN module was developed to simulate hydraulic flow routing for open channel and/or closed conduit systems. The EXTRAN module receives hydrograph inputs at specific nodal locations by interface file transfer from an upstream module (*e.g.* the RUNOFF module) and/or by direct user input. The module performs dynamic routing of stormwater flows through storm drainage systems and receiving streams.

9.1.3 Planning Areas/Units (Subsheds)



A. Map of Watershed and Location of Potential Data Sources B. Delineation of Subbasins by Drainage and Jurisdiction

Figure 9-1 Conceptual Framework for Delineation of Model Units

Model subsheds were delineated differently in areas with separate storm sewers and areas with combined sewers. In areas with separate storm sewers, a digital elevation model was used to delineate topographic drainage areas to points along the stream. Figure 9-1 illustrates this delineation conceptually. The points chosen were locations where a fluvial geomorphological analysis of the stream was conducted as part of a related study. In areas with combined sewers, model subsheds coincided with sewersheds, or topographic areas draining to individual regulator structures. Model subsheds were further refined in two ways. First, subsheds extending across the county boundary were separated into two areas to allow pollutant loads to be summed individually. Second, subsheds were delineated at a finer scale in some areas with known flooding problems, such as the Wingohocking area in the northwest portion of the drainage area within Philadelphia. The model was not optimized for the loading analysis; rather, a model was created to adequately serve multiple purposes such as pollutant loading analyses, combined sewer infrastructure studies, flood management studies, and water quality studies.

The planning areas or jurisdictional sub-watersheds range in size from less than 1 acre to greater than 1400 acres. The mean size of the planning areas is about 430 acres with a median size of about 71 acres. The largest planning area is located in the City, and drains to CSO regulator T14. The smallest basin also is located in the City and contributes to CSO regulator T14. Eighty percent of the planning areas are between 5 and 1000 acres.

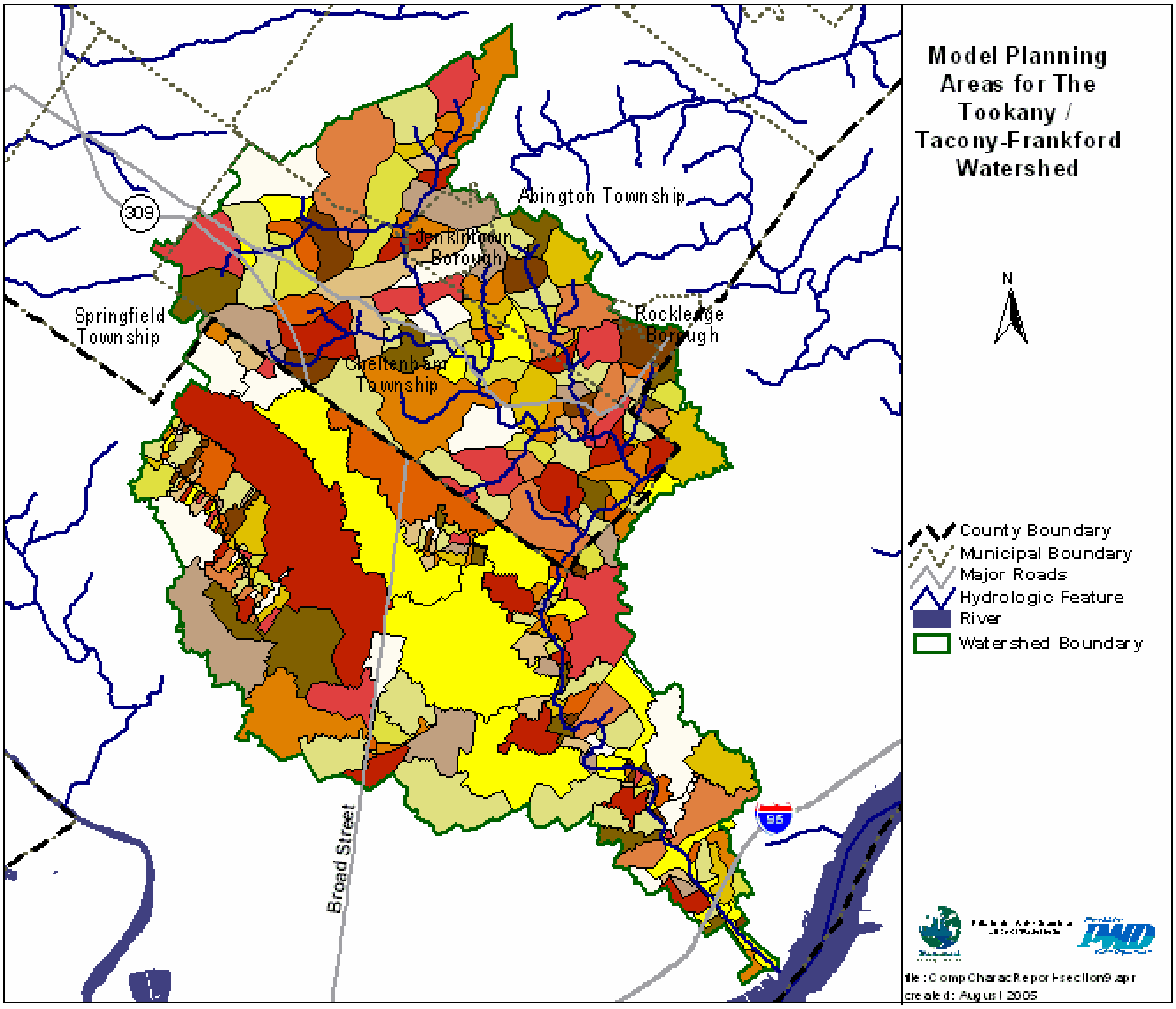


Figure 9-2 Planning Areas or Model Units in the Tookany/Tacony-Frankford Watershed

9.1.4 Land Use

Data used to define the land uses by planning area were compiled by the Delaware Valley Regional Planning Commission (DVRPC) and are shown in Figure 2-6.

9.1.5 Event Mean Concentrations (EMCs)

Event Mean Concentrations (EMCs) are defined as the total mass load of a chemical parameter yielded from a site during a storm divided by the total runoff water volume discharged from the site during the storm. The EMC is widely used as the primary statistic for evaluations of stormwater quality data and as the stormwater pollutant loading factor in analyses of pollutant loads to receiving waters.

Use of EMCs in Loading Analyses: Nonpoint source pollution loading analyses typically consist of applying land use- specific stormwater pollution loading factors to land use scenarios in the watershed under study. Loading rates of urban stormwater pollution (nutrients, metals, BOD, fecal coliform) are determined by the quantity of runoff from the land surface. Thus, they are closely related to the imperviousness of the land use type.

Runoff volumes are computed for each land use category based on percent imperviousness of the land use and annual rainfall. These runoff volumes are multiplied by the land use specific EMC load factor (mg/L) to obtain nonpoint source pollutant loads by land use category. This analysis can be performed on a subarea or watershed-wide basis, and the results can be used to perform load allocation studies, to evaluate pollution control alternatives, or as input into a riverine water quality model.

The model calculates pollutant loads based upon nonpoint source pollution loading factors (expressed as lb/acre/year) that vary by land use and the percent imperviousness associated with each land use. The pollution loading factor M_L is computed for each land use L by the following equation:

$$M_L = EMC_L * R_L * K$$

where:

M_L = loading factor for land use L (lb/acre/year)
EMC_L = event mean concentration of runoff from land use L (mg/L); EMCs may vary by land use and pollutant
R_L = total average annual surface runoff from land use L (in/yr); and
K = 0.2266, a unit conversion constant.

By multiplying the pollutant loading factor by the acreage per land use and summing for all land uses, the total annual pollution load from a sub-basin can be computed. The EMC coverage is typically not changed for various land use scenarios within a given study watershed.

In areas drained by separate storm sewers, applying EMCs to calculated runoff volumes provides reasonable estimates of stormwater pollutant loadings to surface water. In areas drained by combined sewers, this approach estimates the pollutant load entering the sewer system; additional analysis is required to estimate the pollutant load to the receiving water.

History and Sources of EMCs: Once point source discharges from treatment plants and industrial facilities were addressed in the 1970s and 1980s, more attention was focused on stormwater runoff from urban areas as a source of water quality degradation. As pollution from stormwater and urban drainage began to be investigated, studies focused on the types of pollution and methods to reduce the loads. However, these investigations did not consider the achievable level of improvement of receiving water bodies with the mitigation of stormwater pollution. In addition, many research studies concluded that additional and more comprehensive information was needed to make such assessments. This need led to the development of the Nationwide Urban Runoff Program, also known as NURP.

The goals of NURP were to develop and provide information to local decision makers, the States, EPA, and other parties for use in assessing the impacts of stormwater and urban runoff on water quality. The information collected also was intended to aid in the development of water quality management plans and provide a foundation for local, State and Federal policy decision making about water quality issues.

The NURP studies investigated 10 standard water quality constituents to characterize urban runoff. As a result of data collected through the NURP program, EMCs for these and other pollutants were developed from over 2,300 station-storms at more than 81 urban sites located in 28 different metropolitan areas. These studies greatly increased the knowledge of the characteristics of urban runoff, its effects upon the designated uses of receiving water bodies, and the performance efficiencies of various control measures. Pertinent conclusions from the NURP Program include:

- The variance of the EMCs, when data from sites are grouped by land use type or geographic region, is so great that differences in measures of central tendency among groups are not statistically significant.

- Statistically, the entire sample of EMCs and the medians of all EMCs among sites are log-normally distributed.

EMCs often are used in screening-level models. The pollutant loads (L_i) are estimated as the product of the area of urban land (A_U), the rainfall-runoff depth as estimated by a modified rational formula approach (d_r), and a constant pollutant concentration (C_i), usually estimated from the EMCs reported by NURP (i.e., $L_i = C_i A_u d_r$).

Since the conclusion of the NURP Program in the 1980's, additional urban runoff quality monitoring data has been collected. One large effort conducted by the United States Geological Survey resulted in the collection of urban runoff data for over 1,100 station-storms at 97 urban sites in 21 metropolitan areas. Additionally, EPA required many major cities to collect urban runoff quality data as part of the application requirements for stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES). Data from 800 station-storms from 30 cities was gathered and incorporated into a database by CDM. CDM analyzed the data collected from NURP, USGS, and NPDES to assess if additional EMC observations (more degrees of freedom) would uncover statistically significant differences in EMCs among various land uses. While the resulting EMCs from the combined data sets did not indicate statistical differences in water quality among land uses, the pooled EMCs were significantly different than the NURP EMCs for several parameters (*e.g.*, TSS, Cu, and Pb) and would produce different loading rates for urban areas. Table 9-1 illustrates the EMCs used in the Tookany/Tacony-Frankford Watershed Study and the source of each EMC value.

Table 9-1 Event Mean Concentrations

Land Use	**Mean EMCs, mg/L**											**Source (Equivalent Category)**
	BOD	**COD**	**TSS**	**TP**	**DP**	**TKN**	**NO2+ NO3**	**Pb**	**Cu**	**Zn**	**Fecal**	
Agriculture/Pasture	14.1	40.0	70.0	0.121	0.026	0.965	0.543	0.0300	0.0135	0.195	30000	EPA 1982 Chesapeake Bay Program
Commercial	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Community Services	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Industrial/ Light Manufacturing	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Military	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Utility	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Transportation	24.0	103	141	0.430	0.129	1.82	0.830	0.5270	0.052	0.367	30000	FHA, 1990.
Parking	24.0	103	141	0.430	0.129	1.82	0.830	0.5270	0.052	0.367	30000	FHA, 1990.
Water/Wetlands (Atmospheric Input)	1	1	1	0.064	0.02	1.022	0.571	0.00266	0.0022	0.0652	1	EPA 1982 Chesapeake Bay Program
Residential Single-Family	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Residential Multi-Family	14.1	52.8	78.4	0.315	0.129	1.73	0.658	0.0675	0.0135	0.162	30000	Smullen, J. T., *et al*. 1999
Wooded	14.1	52.8	40.5	0.145	0.129	0.505	0.245	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Parks	14.1	52.8	78.4	0.145	0.129	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Cemetery	14.1	52.8	407	0.75	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Urban Recreation	2.00	52.8	60	0.188	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Vacant	2.00	52.8	60	0.188	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program
Golf Courses	14.1	52.8	407	0.75	0.100	3.19	1.0100	0.0675	0.0135	0.162	30000	EPA 1982 Chesapeake Bay Program

Note: All metals data are from Smullen (1999), except Highway. Atmospheric contributions are included in these values. The EMC for fecal coliform is based on NURP data as reported in NOAA (1987).

9.1.6 Baseflows

Most streams exhibit dry weather flow due to groundwater infiltration. As discussed in Section 4, baseflows for the individual planning areas were determined using USGS streamflow gauging data.

Baseflow due to groundwater inflow is the main component of most streams in dry weather. Baseflow slowly increases and decreases with the elevation of the shallow aquifer water table. In wet weather, a stormwater runoff component is added to the baseflow. Estimation and comparison of these two components can provide insights into the relationship between land use and hydrology in urbanized and more natural systems. For a more detailed explanation of the baseflow separation techniques used, see Section 4.3.

9.1.7 Constituent Source Types

For a watershed or TMDL study, an inventory of pollutant sources to the receiving water bodies must be compiled. The various types of sources usually considered are listed below. Note that urban stormwater runoff has some attributes of both point and nonpoint sources.

- Point (industrial and municipal dischargers, CSOs, SSOs);
- Nonpoint (stormwater, urban drainage, leaking septic systems);
- Background (instream, baseflow); and
- Atmospheric.

Stormwater and Urban Drainage: Stormwater from areas with separate storm sewers contributes to water body impairment in highly urbanized, impervious catchments. Pollutants most frequently associated with stormwater include sediment, nutrients, bacteria, oxygen demanding substances, oil and grease, heavy metals, other toxic chemicals, and floatables. The primary sources of these pollutants include automobiles, roadways (pavement, bridges), housekeeping and landscaping practices, industrial activities, construction, non-storm connections to drainage systems, accidental spills and illegal dumping. Calculations used to estimate pollutant loads in stormwater are described in Section 9.1.5.

Combined Sewer Overflows (CSOs): In many cities throughout the United States, stormwater runoff and sanitary wastewater are collected in the same sewer (a combined sewer). In dry-weather conditions, all flows are conveyed to and treated at a local or regional wastewater treatment plant. In wet-weather conditions, the capacity of the combined sewer system can be exceeded and discharges of mixed sanitary and stormwater then occur to receiving waters. The fraction of sanitary sewage in discharges varies from storm to storm, but is typically on the order of 10% over the long term, while the remaining 90% is untreated stormwater. For constituents where sanitary sewage and untreated stormwater concentrations are the same order of magnitude (*e.g.*, TSS, nutrients), concentrations in CSO are similar or slightly higher than when compared to stormwater. For constituents where sanitary concentrations are typically lower (*e.g.*, metals such as Pb, Cu, Zn), concentrations in CSO are slightly lower than in untreated stormwater. For bacteria and other pathogens, concentrations in CSO are one or more orders of magnitude higher than those found in stormwater.

Estimating loads to surface waters from an area served by a combined sewer requires three steps.

1. Stormwater flow and load entering the sewer system are estimated by the methods described in Section 9.1.5.
2. A hydraulic simulation of the sewer system predicts the portion of flow that is captured and sent to a wastewater treatment plant, the portion of flow that overflows to the receiving water (CSO), and the fractions of CSO made up of sanitary sewage and stormwater.
3. Using known volumes and pollutant concentrations of sanitary sewage and stormwater reaching the receiving water (step 2), the total pollutant load reaching the receiving water is estimated.

Municipal and Industrial Process Water Discharges: A search of federal and state NPDES permit databases was performed to identify permitted dischargers within the Tookany/Tacony-Frankford Watershed. Table 9-2 presents the list of dischargers and the information found for each point source.

Sanitary Sewer Overflows (SSOs): SSOs result in discharges of untreated wastewater that can affect stream quality and occasionally back up into basements and city streets. The USEPA has found that SSOs represent a significant threat to health and the environment in areas where they occur frequently. Frequent SSOs may indicate that the capacity of the collection system is insufficient to convey the flows introduced or that the system is in need of maintenance or repair. Potential causes of excess flow include infiltration and inflow, illegal connections, population growth, and under-design. Problems requiring maintenance or repair may include broken or cracked pipes, tree roots, poor connections, and settling. Proper maintenance can help prevent problems or identify them before they become extremely costly to repair (USEPA, 2000).

Sanitary Sewer Overflows (SSOs) are a known source of bacterial and other pollution to the Tookany/Tacony-Frankford Watershed. Currently, no inventory of SSOs exists for the area within the two counties that contain the Tookany/Tacony-Frankford Watershed. Since the data collection effort required to obtain SSO load information was beyond the scope of this screening-level study, SSO loads were not considered part of this study. An SSO assessment methodology will be implemented as part of the Phase II efforts.

Septic Tanks: Although there are septic systems in the watershed, most of the population is served by sanitary sewers. The number of septic tanks within the watershed is difficult to accurately quantify; according to 1990 census data there are estimated to be about 1,075 septic tanks present in the watershed, 706 of which are located within the city of Philadelphia. This number is believed to be a high estimate of the actual number.

Compilations of septic tank and on-lot sewer systems have not been completed to date. Detailed assessment of individual municipalities for septic tank and on-lot sewage disposal inventories and/or permits was beyond the scope of the current phase of this study.

Atmospheric Sources: Pollutants from atmospheric deposition on land surfaces are considered to be included in the calculations of stormwater runoff. Direct deposition on water surfaces also is included in these calculations by the use of a water surface land use type. Specifically, precipitation falling on the water surface land use was assigned EMCs of nutrients and metals derived from rainfall data. For this study, the water surface EMCs were taken from the Chesapeake Bay Program literature (EPA, 1982).

Table 9-2 Active Point Sources Permitted Under NPDES

PA NPDES ID.	Site Name	Available Information
PA0010961	SPS Technologies Aerospace Products Division	NPDES Pmt Industrial Wastewater Discharge Minor
PA0024252	Sun Refining & Marketing Co.	NPDES Pmt Industrial Wastewater Discharge Minor
PAR600026	Allegheny Iron Radiation	PAG-03 Discharge of Stormwater Assoc w Industrial Activities
PA0040991	Bayway Refining Company (Inc.)	NPDES Pmt Industrial Wastewater Discharge Minor
PAR800085	Roadway Express	PAG-03 Discharge of Stormwater Assoc w Industrial Activities
PAR800064	BFI Waste Systems of North America	PAG-03 Discharge of Stormwater Assoc w Industrial Activities
PAR600024	S D Richman Sons Incorporated	PAG-03 Discharge of Stormwater Assoc w Industrial Activities
PAR230045	Sunoco Incorporated Frankford Plant	PAG-03 Discharge of Stormwater Assoc w Industrial Activities

9.2 Results: Estimated Annual Constituent Loads

Figures 9-3 through 9-11 show estimated loading rates for stormwater runoff and CSO. Table 9-3 breaks load estimates into two geographic regions, the upper and lower Tookany/Tacony-Frankford. The loads are estimates of the total input to the stream system. For example, the surface runoff listed for lower Tookany/Tacony-Frankford (an area serviced by combined sewers) is relatively low because it does not include the volume that is captured, treated, and discharged outside the system. With some exceptions, higher pollutant loading rates are found in the lower Tookany/Tacony-Frankford Watershed, in and near the densely populated areas of Philadelphia. Loads from areas with combined sewers are higher for some constituents because a portion of the discharge is made up of sanitary sewage. In these areas, the pollutant load is a function both of pollutants washed from the land surface and pollutants added to the sewer system directly by residences and businesses. Thus, areas of higher loading shown in the figures do not necessarily indicate that stormwater from those areas is more polluted.

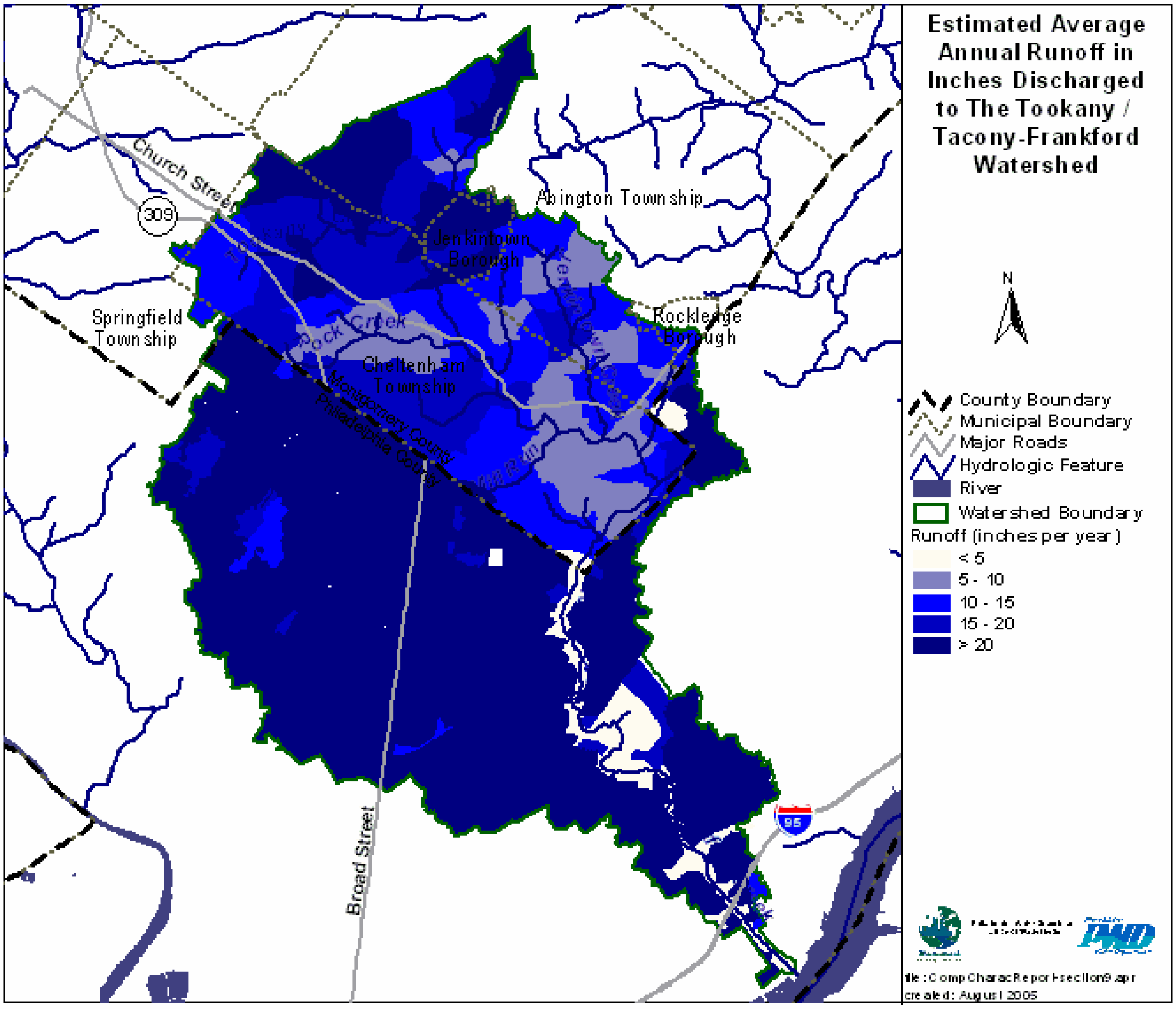


Figure 9-3 Estimated Annual Runoff for Tookany/Tacony-Frankford Watershed

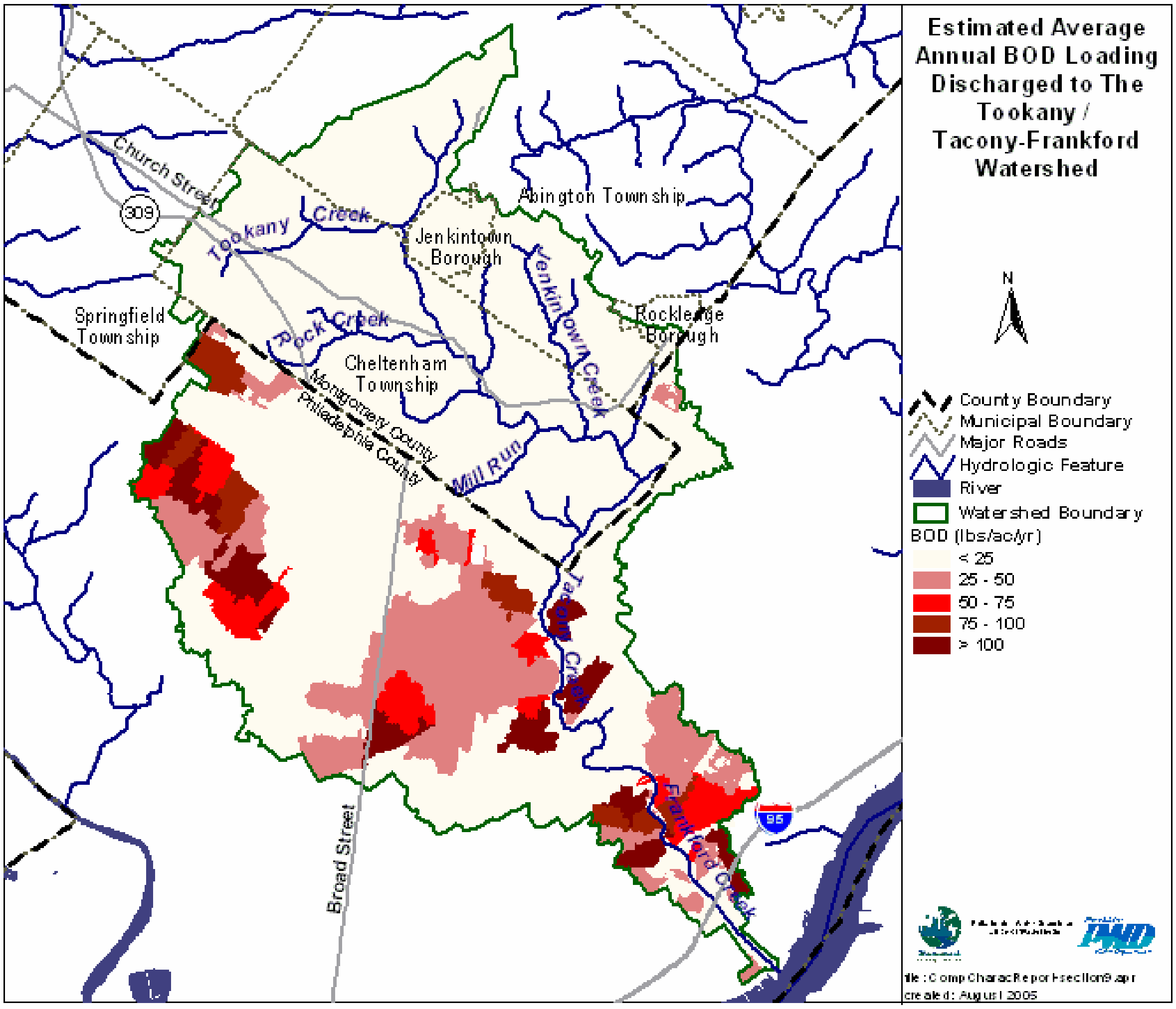


Figure 9-4 Estimated Annual Loading Rate for BOD for Tookany/Tacony-Frankford Watershed

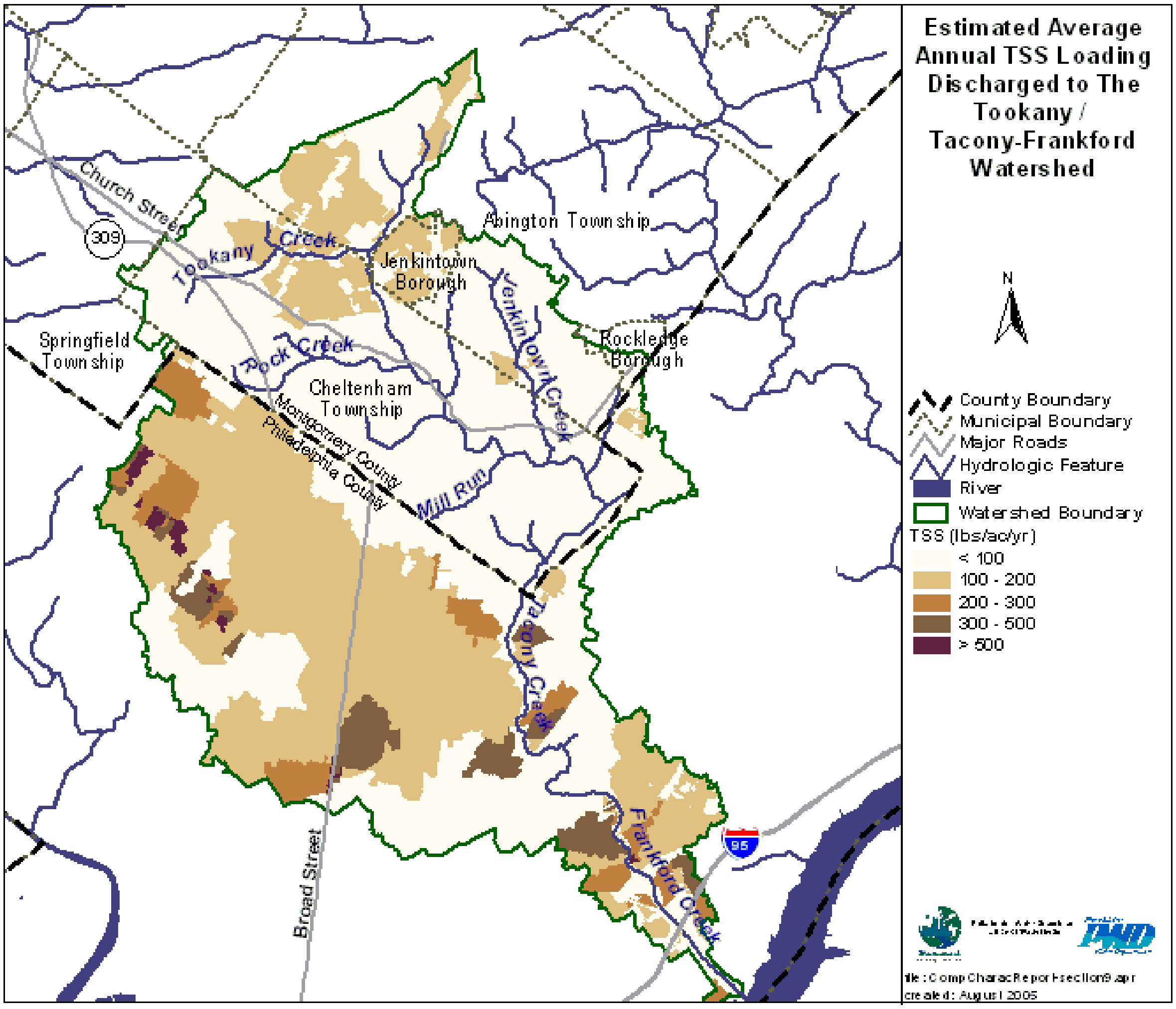


Figure 9-5 Estimated Annual Loading Rate for TSS for Tookany/Tacony-Frankford Watershed

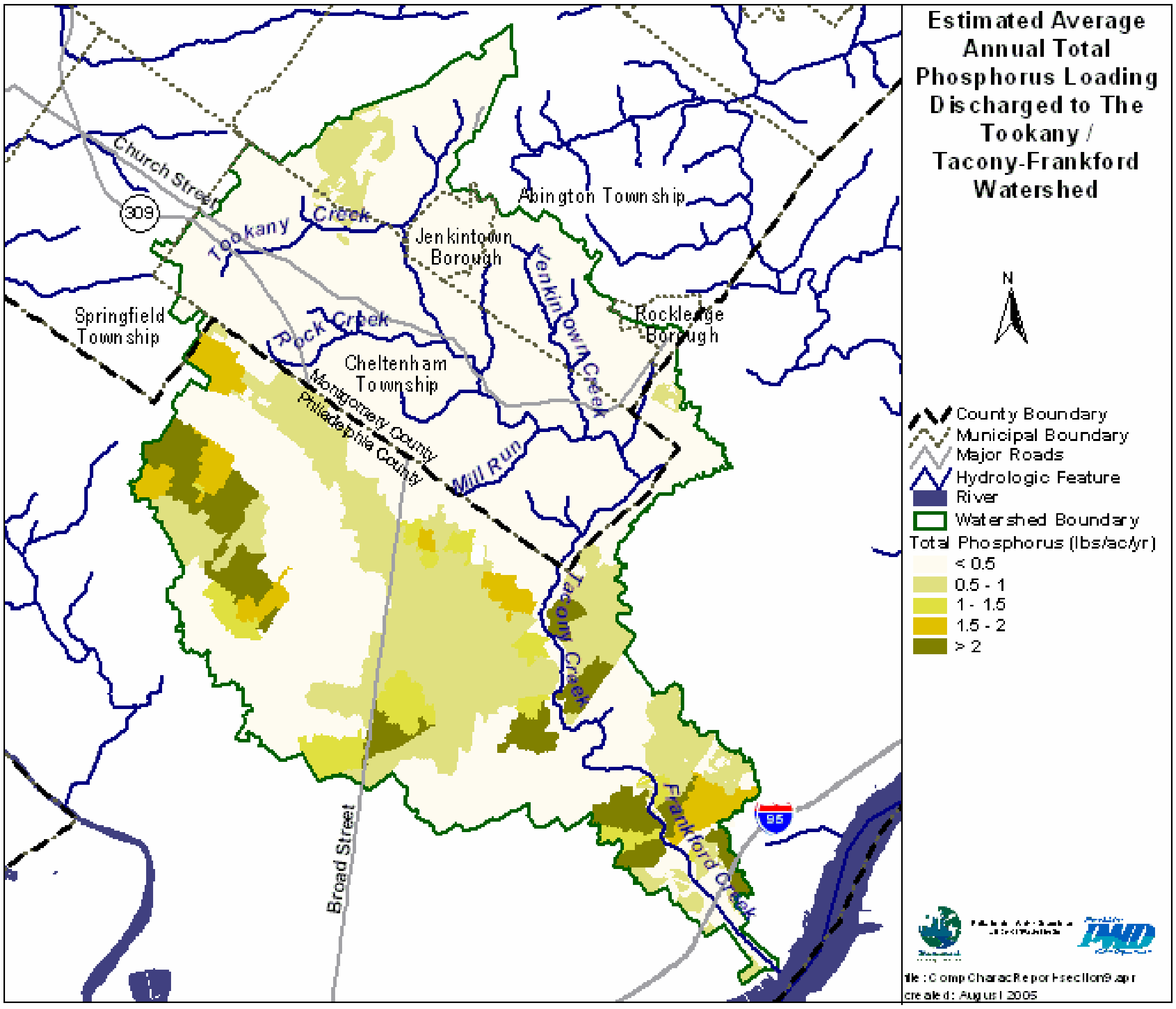


Figure 9-6 Estimated Annual Loading Rate for Total Phosphorus for Tookany/Tacony-Frankford Watershed

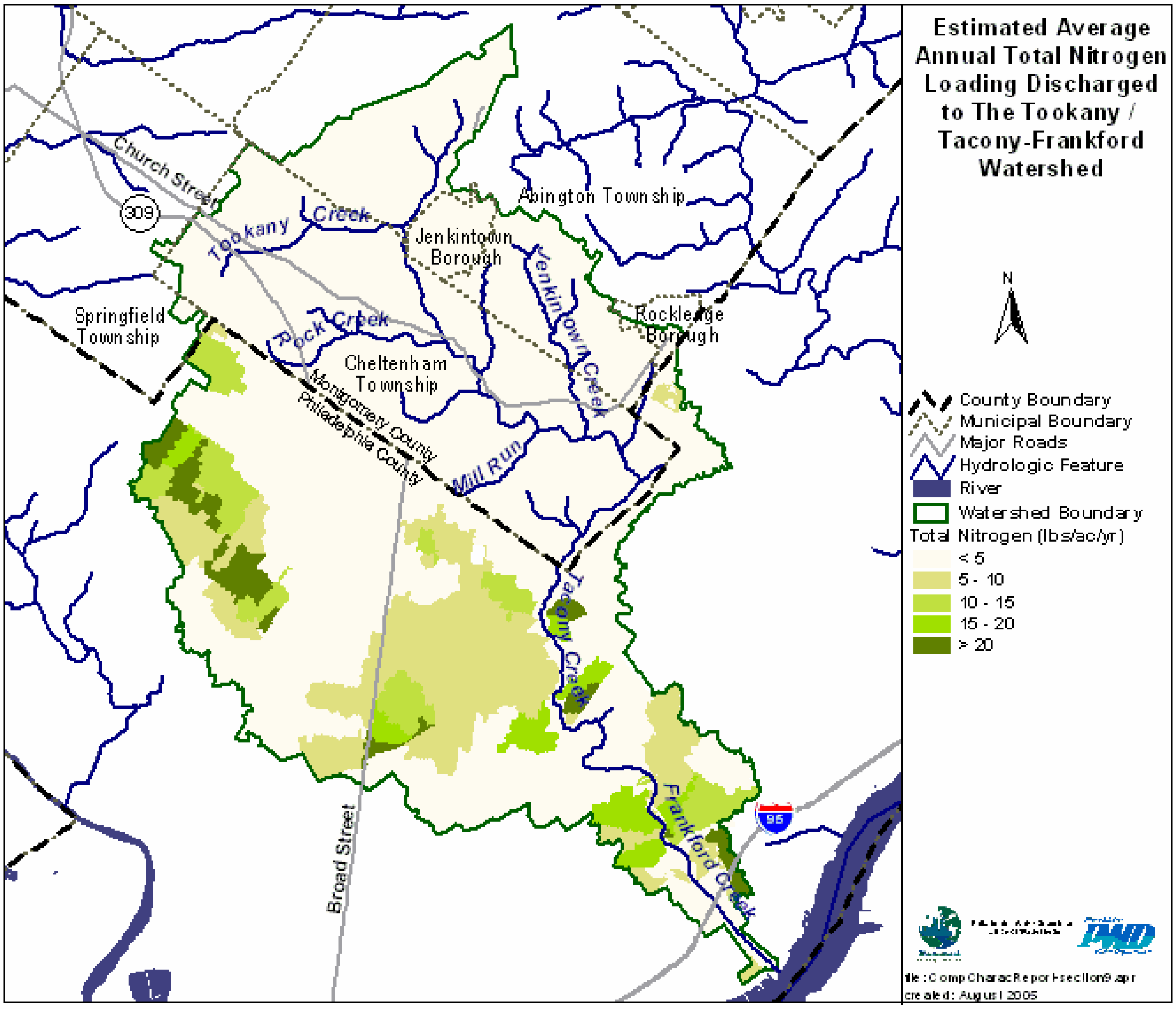


Figure 9-7 Estimated Annual Loading Rate for Total Nitrogen for Tookany/Tacony-Frankford Watershed

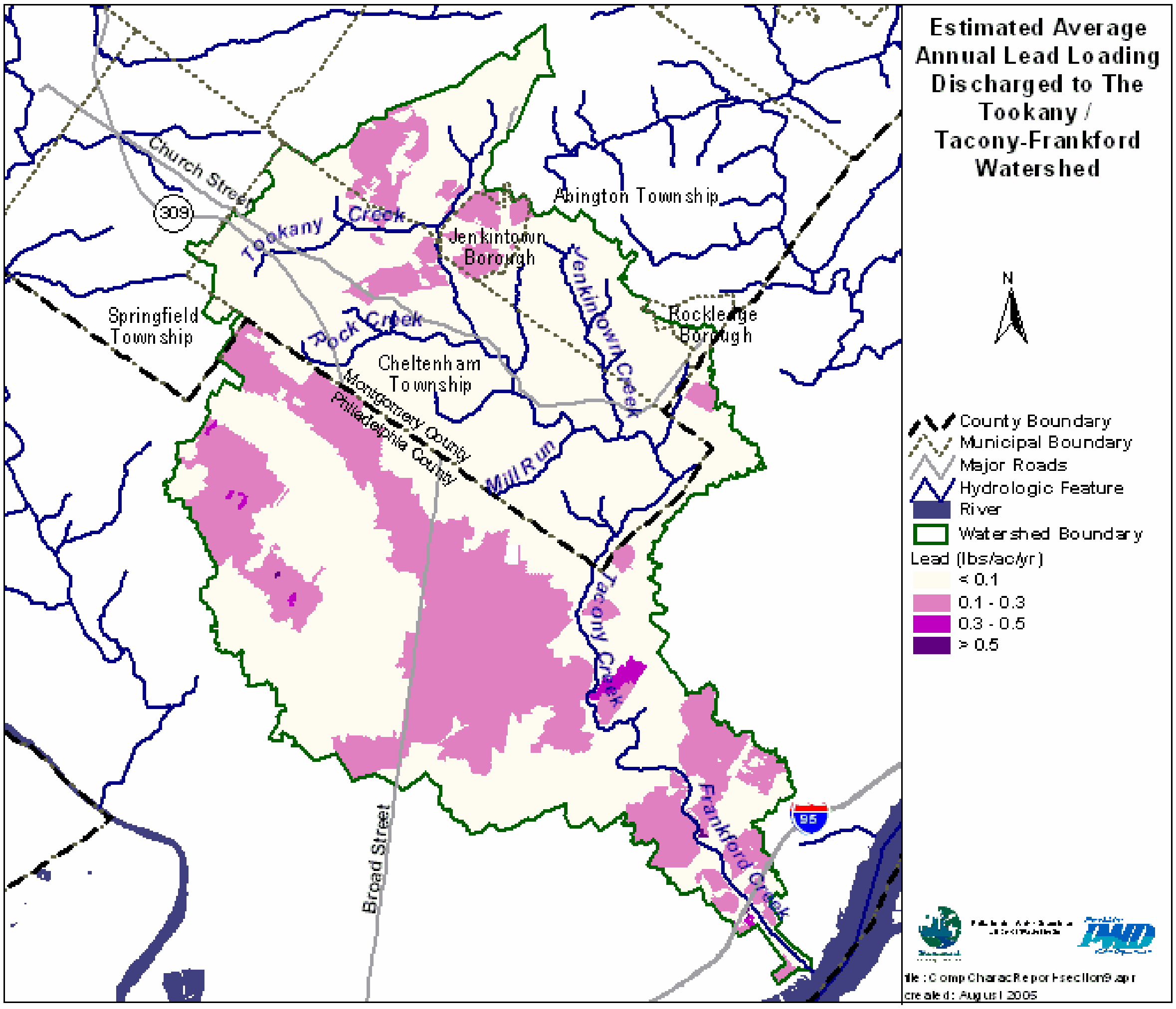


Figure 9-8 Estimated Annual Loading Rate for Lead for Tookany/Tacony-Frankford Watershed

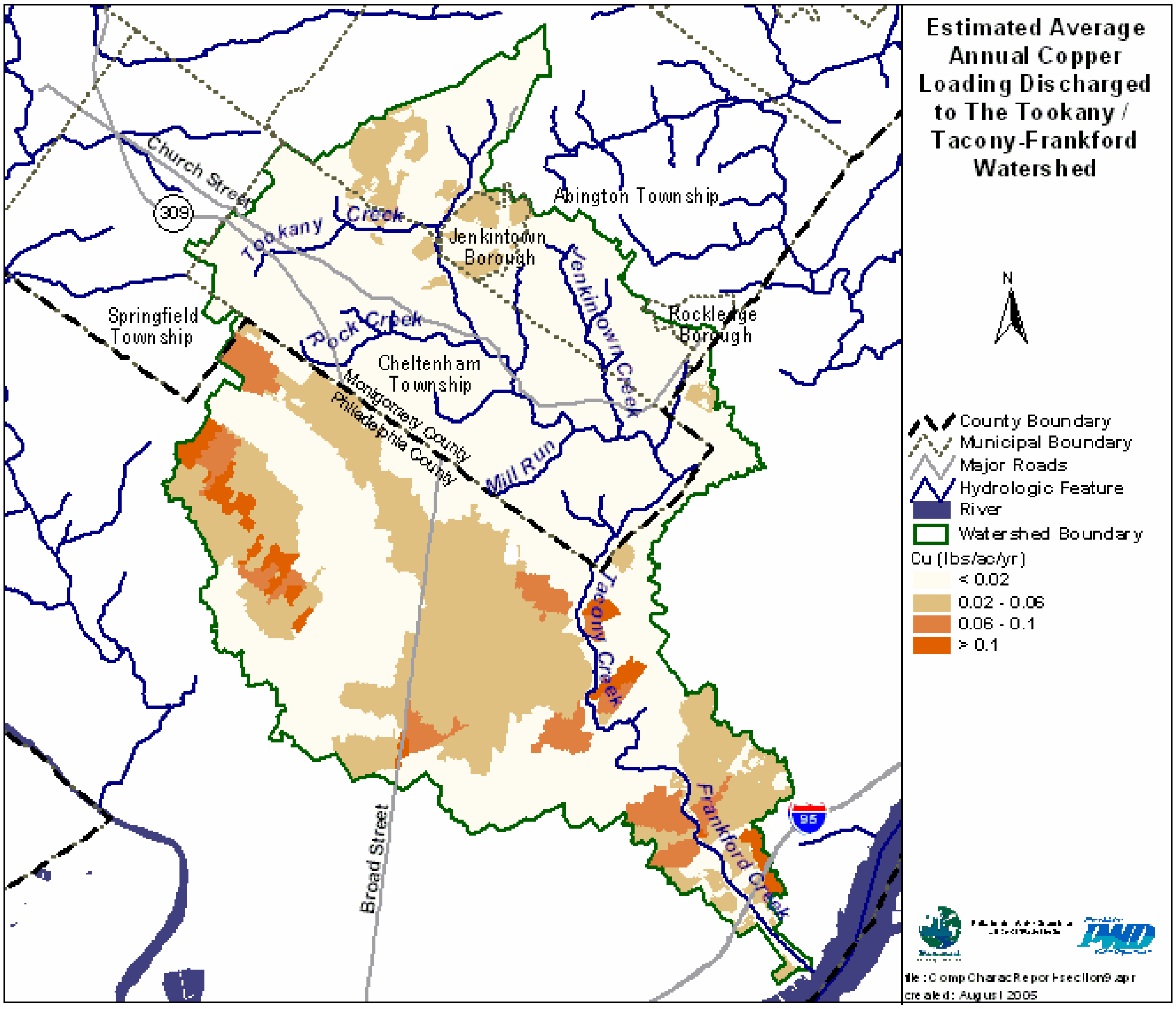


Figure 9-9 Estimated Annual Loading Rate for Copper for Tookany/Tacony-Frankford Watershed

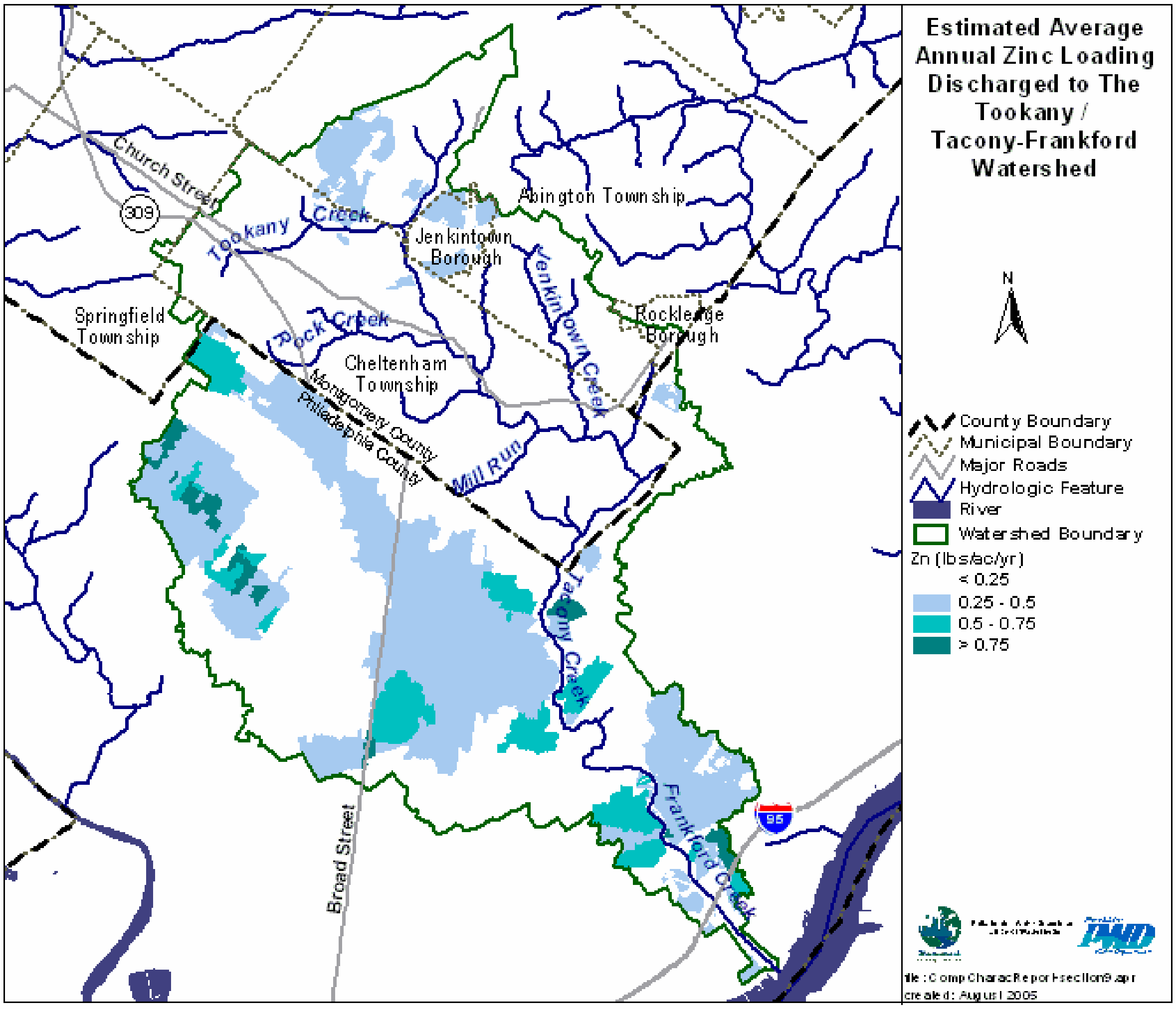


Figure 9-10 Estimated Annual Loading Rate for Zinc for Tookany/Tacony-Frankford Watershed

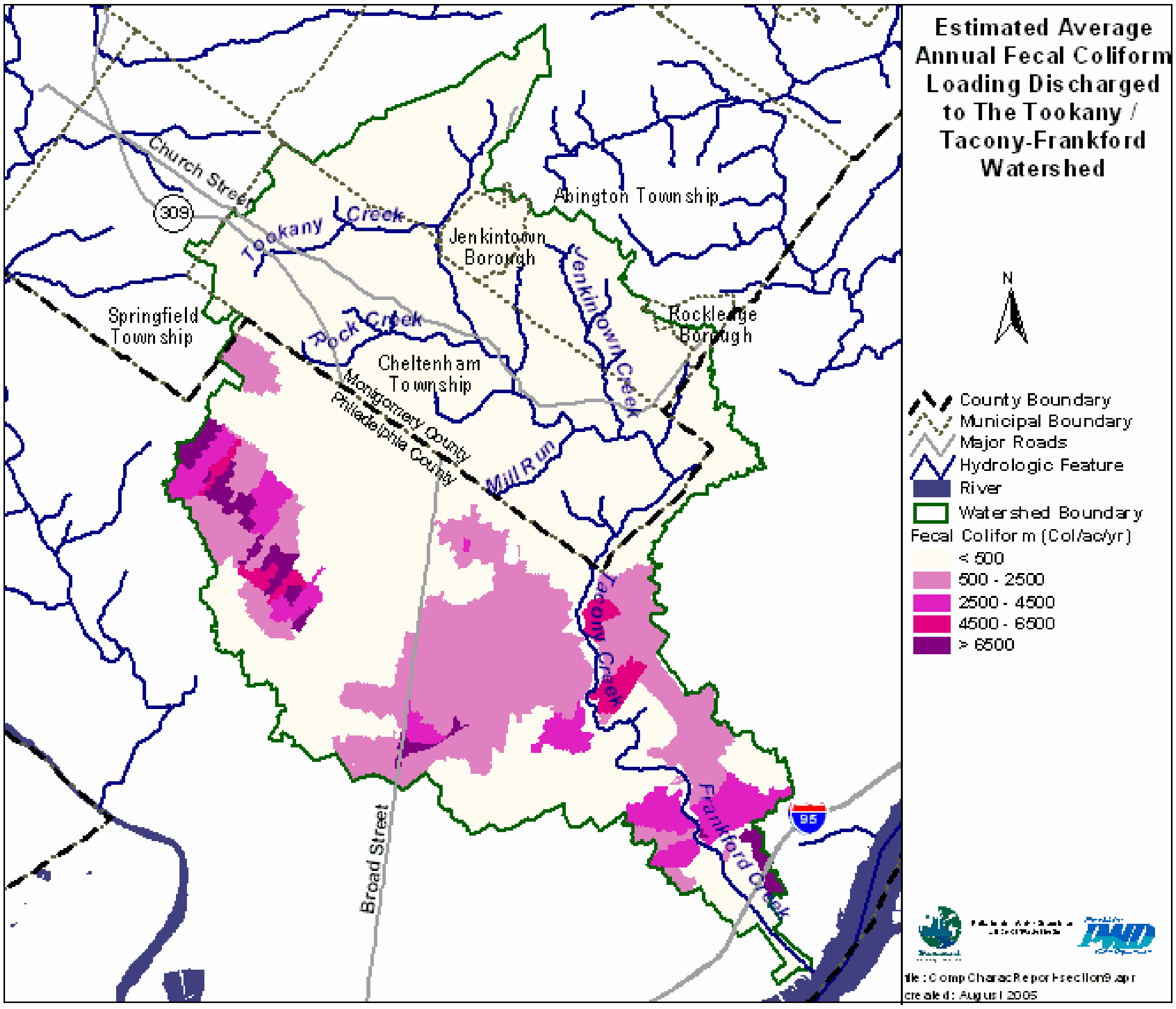


Figure 9-11 Annual Loading Rate for Fecal Coliform for Tookany/Tacony-Frankford Watershed

Table 9-3 Mean SWMM-Estimated Loads by Basins

Watershed	**Area (ac)**	**Surface Runoff (in/yr)**	**Surface Runoff (MG)**	**BOD (ton/yr)**	**TSS (ton/yr)**	**Fecal (col/yr)**	**TN (ton/yr)**	**TP (ton/yr)**	**Cu (ton/yr)**	**Pb (ton/yr)**	**Zn (ton/yr)**
Tookany Creek (outside City)	8,855	6.8	1630	33.0	187	6.5E+14	5.8	0.7	0.03	0.17	0.39
Tacony-Frankford Creek (in City)	12,200	10.4	3460	123	692	2.4E+15	21.1	2.8	0.12	0.62	1.44

9.2.1 Relative Contribution of Source Types

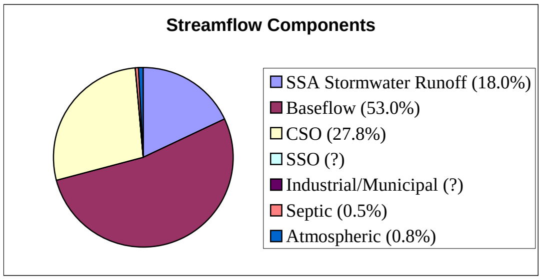
Figure 9-12 presents the approximate relative contribution each source (stormwater runoff from separate sanitary areas, baseflow, CSOs, industrial and municipal point sources, septic tanks, and atmospheric sources) contributes to the total potential load to the Delaware River from the Tookany/Tacony-Frankford Watershed area. As expected in highly urbanized settings, runoff from separate sanitary areas is a significant (over 10%) source of water pollution for most pollutant types except fecal coliform. Baseflow contributes a significant amount of total nitrogen. Separate sanitary overflows (SSOs) may be a significant source of pollutants, but information concerning these sources was insufficient to include in the current analysis. The results indicate that CSOs are a dominant source of the total load for all parameters. The model indicates that almost 90% of the fecal coliform introduced to the system is the result of CSOs; however, this portion may change when future work accounts for the contribution of SSOs. Industrial and municipal point sources are a relatively small source of pollutants. Septic tank loads are significant only for phosphorus and nitrogen. However, the reliability of the data available on septic tanks in the watershed is questionable. Atmospheric inputs, based on wetfall or concentrations within rainfall, are included in the EMCs for all land use types except for wetlands and open water. Atmospheric loads to wetlands and water were small (1% or less) but measurable.

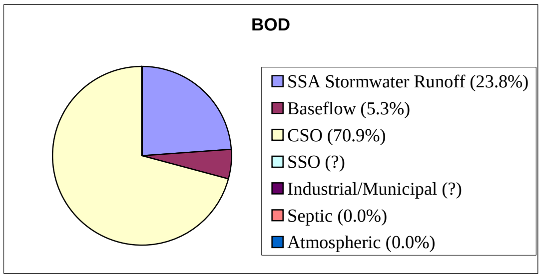
Table 9-4 presents the average areal loads contributed by runoff from separate and combined sewer areas. Areal loads show the intensity of loading rather than total loads. The areal loadings for most parameters are similar for the two sources, but the fecal coliform loads introduced by combined sewer areas are approximately 100 times greater per acre than those introduced by runoff from separate sewer areas. For comparison, the table includes loads for the other sources.

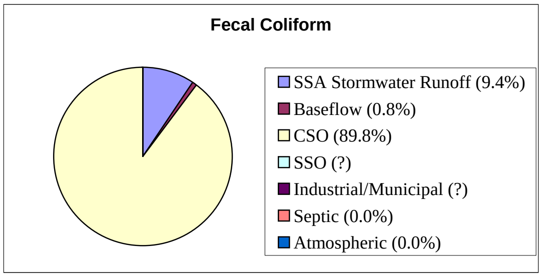
Table 9-4 Estimated Annual Area Loads by Source (lb/ac except as noted)

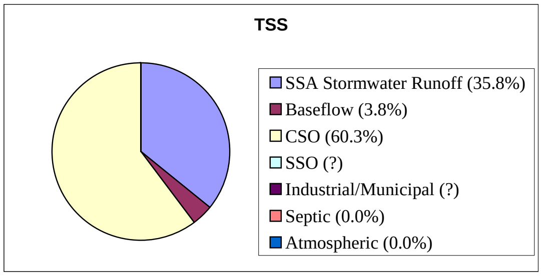
Parameter	SSA Stormwater Runoff (lb/ac)	Baseflow	CSO	Industrial/ Municipal	Septic	Atmospheric
BOD	22.4	2.5	73	0	0	0
TSS	127	6.8	235	0	0	0
Fecal Coliform (col/ac)	2.2E+11	9.8E+9	2.3E+12	0	0	0
Total Nitrogen	3.90	5.9	12.3	0	0.072	0.062
Total Phosphorus	0.50	0.34	1.74	0	0.027	0.002
Copper	0.02	0.015	0.06	0	0	8.5E-05
Lead	0.12	0.002	0.19	0	0	1.0E-04
Zinc	0.27	0.041	0.50	0	0	2.5E-03

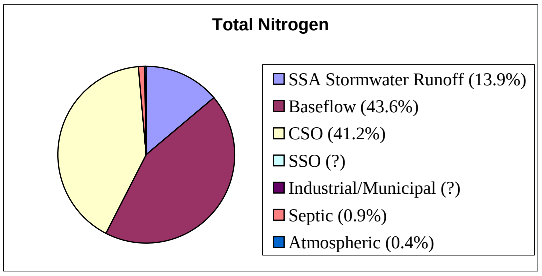
Figure 9-12 –Estimated Annual Relative Contribution of Constituent Sources

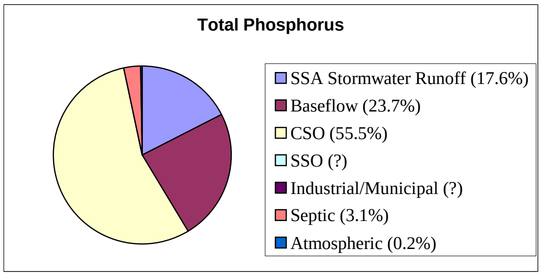


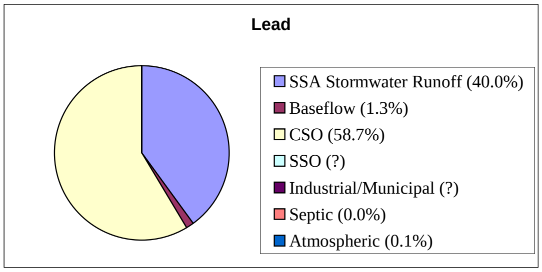


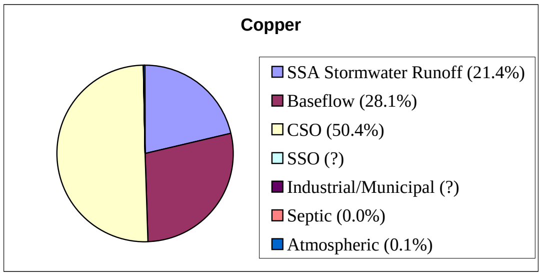


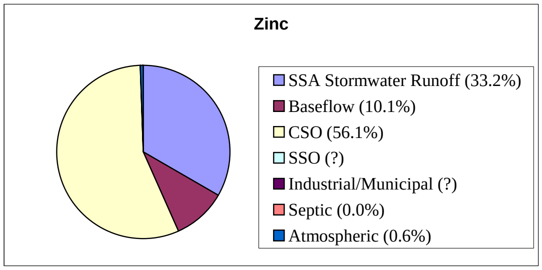












Notes:

- SSA = separate sanitary area runoff
- CSO = combined sewer overflow
- Sanitary sewer overflows (SSOs) were not explicitly included in this analysis.
- The model indicates that direct atmospheric loads to surface water were found to contribute less than 0.4% of the load for any parameter studied. This result is due mainly to the fact that very little area is classified as water or wetlands.

9.2.2 Sources of Uncertainty

Baseflow water quality information is based upon water quality sampling data obtained between 1999 and 2000. The data represents background conditions; if significant dry weather pollutant inputs are present, these will be reflected in the baseflow concentrations.

EMCs are based on literature values. The EMCs used for this study for urban land uses are from Smullen, Shallcross, and Cave (1999). These values represent a compilation of stormwater monitoring data from NURP, the USGS, and NPDES Phase I Municipal Stormwater Monitoring Requirements.

Sanitary sewer overflows (SSOs) are believed to be a significant potential source of bacterial and other pollution in the watershed. For the watershed study, estimates of SSO flows and pollutant loads were not calculated due to lack of readily available information on municipal sewer systems. Future studies may include a more thorough investigation of these sources.

Failures of septic tanks can contribute nutrient and bacterial loads to receiving waters. For this screening level study, the 1990 census data for on-lot septic systems was used to determine the number of septic systems in each drainage area. Although of limited accuracy, the census data indicated that over 1075 septic systems were located within the watershed. Since extensive research into on-lot systems and Act 537 plans for Montgomery Counties will be required, the 1990 census counts of septic systems were used for all portions of the Tookany/Tacony-Frankford Watershed study except Philadelphia.

9.3 Comparison of Load Estimates

Table 9-5 compares several loading rate estimates for Tookany/Tacony-Frankford Creek. These estimates are based on historical water quality monitoring, 2000-2004 water quality monitoring, and SWMM model estimates. The loads from the monitoring data were calculated by applying wet weather and dry weather pollutant concentrations to USGS historical flow data. The resultant loads were averaged over the period of record to determine the average daily load.

Table 9-5 compares the loads of some conventional water quality parameters calculated from the results of the first 50 months of sampling of the PWD/USGS Cooperative Program. Ammonia and nitrate loads were not calculated for the estimate. The loading rates estimated by SWMM are much larger than the instream mass load estimated from the current monitoring data. This difference is not a mistake but a result of the modeling philosophy:

- SWMM loads represent the total potential load to be delivered downstream and do not specifically account for the instream processes that reduce the total load.
- For the screening level study, the loads were used to estimate an overall delivery ratio for each pollutant, rather than estimate delivery ratios for various land uses by pollutant.

- The instream mass loads were based on limited, discrete, wet and dry weather monitoring data in addition to streamflow data from the 1970s.

- Loading is based on national EMCs which are measures of central tendency with significant variance. Local conditions may not be reflected by the national EMCs.

9.4 Delivery Ratios

The delivery ratio represents the fraction of the original pollutant load remaining after a particular pollutant travels downstream and is affected by instream processes. Data available in the literature indicate that the delivery ratio varies with drainage-area size. Some representative values calculated by the USDA for sediment are:

Drainage Area (sq. miles)	Delivery Ratio
0.5	0.33
10	0.18
100	0.10

However, the delivery ratios may vary substantially for any given size of drainage area. Other important factors affecting pollutant delivery include soil texture, relief (slope), types of erosion, sediment transport system, and deposition areas. For instance, a watershed with fine soil texture, high channel density, and high stream gradients would generally have a higher than average delivery ratio for watersheds of similar drainage area. Also, edge-of-field delivery ratios can approach 1.0 while delivery ratios for larger study areas can be less than 0.05. Instream processes also affect the delivery ratio. Such processes include deposition, sediment and water column diagenesis, remineralization, and volatilization. These processes are discussed in the next section.

The delivery ratios were calculated by dividing the runoff loads by the 2000-2004 sampling means, if available. Table 9-5 presents the calculated delivery ratios for two sites along Tookany/Tacony-Frankford Creek (TF620 and TF680). Although delivery ratios might be expected to decrease with distance downstream, the data do not display such behavior. The delivery ratio for most pollutants increases from the upstream to the downstream cross-sections; the delivery ratios for total suspended solids stay about the same. This trend may be largely explained by greater urbanization in the downstream reaches of Tacony-Frankford Creek; much of the loading occurs downstream where less time and distance are available for degradation processes to take place.

Table 9-5 Comparisons of Load Estimates for Tookany/Tacony-Frankford Creek

	Historic Data		2000-2004 Monitoring Data		2000-2004 vs. Historical		SWMM Estimate		Calculated Delivery Ratio	
	Upstr.	Downstr	Upstr.	Downstr	Upstr.	Downstr	Upstr.	Downstr	Upstr.	Downstr
Drainage Area (sq. mi)	16.60	33.80*	16.60	30.40*						
Discharge (cfs)	34.6	50.7	26.5	40.5	-23.4%	-20.1%				
BOD$_5$ (lb/day)	517	2790	405	2668	-21.7%	-4.37%	599	1470	0.68	1.8
TSS (lb/day)	2202	14,413	1455	5255	-33.9%	-63.5%	3403	8318	0.43	0.63
Total N (lb/day)							105	255		
NH$_3$ (lb/day)	57.9	325	21.9	109	-62.2%	-66.5%				
NO$_2$ (lb/day)	6.91	20.0	6.15	14.4	-11.0%	-28.0%				
NO$_3$ (lb/day)	513	552	258	290	-49.7%	-47.5%				
Total P (lb/day)	63.5	558	13.9	95.9	-78.1%	-82.8%	13.5	33.1	1.0	2.9
Fecal Coliform (col/day)	4.7E+12	1.8E+14	4.4E+12	6.7E+13	-6.38%	-62.8%	5.9E+12	1.5E+13	0.75	4.5
Cu (lb/day)	1.34	7.93	1.14	8.30	-14.9%	4.67%	0.60	1.47	1.9	5.6
Cd (lb/day)	1.12	2.02	0.14	0.44	-87.5%	-78.2%				
Cr (lb/day)	3.55	14.5	0.29	1.09	-91.8%	-92.5%				
Fe (lb/day)	63.5	186	50.5	458	-20.5%	146%				
Pb (lb/day)	2.43	25.7	0.43	5.68	-82.3%	-77.9%	3.07	7.55	0.14	0.75
Zn (lb/day)	22.4	46.5	3.29	17.9	-85.3%	-61.5%	7.12	17.4	0.46	1.0

Note: “Upstream” corresponds to station 8 for the historical and Radzuil data, station TF620 for the 2000-04 monitoring data and USGS station 01467086 (Tacony Creek at County Line). “Downstream” corresponds to station 9 for the Historical, station TF280 for the 2000-04 monitoring data, and USGS station 01467089 (Frankford Creek at Torresdale Ave).

* The difference in drainage area at the downstream end is because the recorded drainage area for the USGS station includes the Old Frankford Creek.

Appendix A: Temporal Changes in Water Quality

Tukey plots were used to characterize water quality parameters by comparing load changes as Tookany/Tacony-Frankford Creek passes through Montgomery County and the City. Using the wet/dry flow designations, box plots compared current water quality data with historical (PWD/USGS Cooperative Program 1970-1980) water quality data. Ammonia, total phosphate, and fecal coliform are shown in this section of the report. Figure A-1 shows the schematic of the modified Tukey plots.

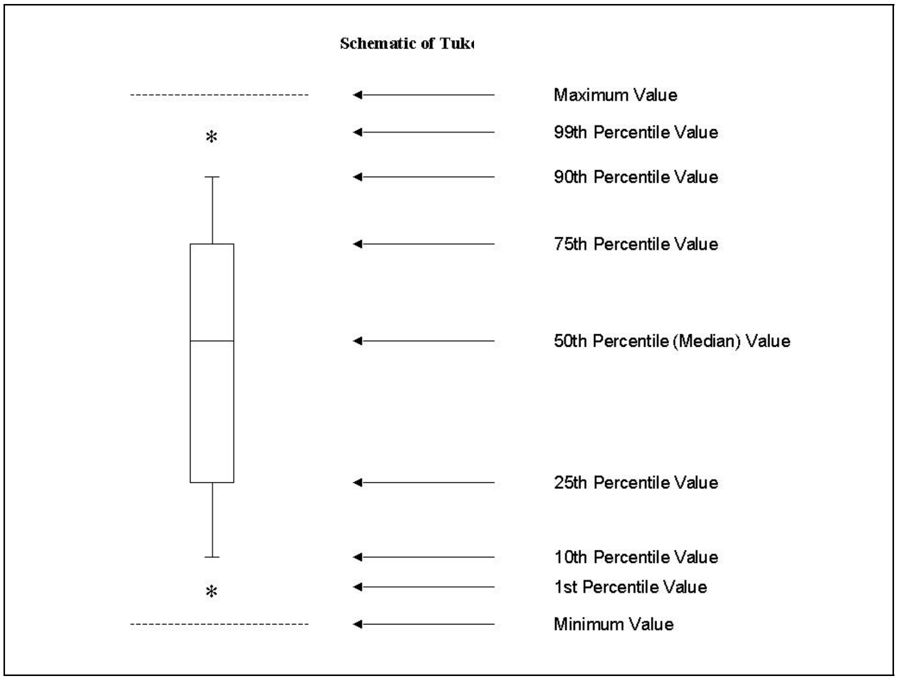


Figure A-1 Schematic Diagram of the Modified Tukey Box Plot

The ammonia, total phosphate, and fecal coliform plots, Figures A-2 through A-23, display an increased concentration from the upstream location at the County Line (TF620, or Site 8) to the downstream location at Castor Avenue (TF280, or Site 9). Malfunctioning regulators and higher loading rates during storm events are the most likely cause. However, other sources of fecal coliform bacteria not previously considered include urban runoff, broken or leaking sewers, failing septic systems, and unanticipated pump station discharges from non-gravity separate sewer systems. For these three constituents, the concentrations have decreased since the historical data collection.

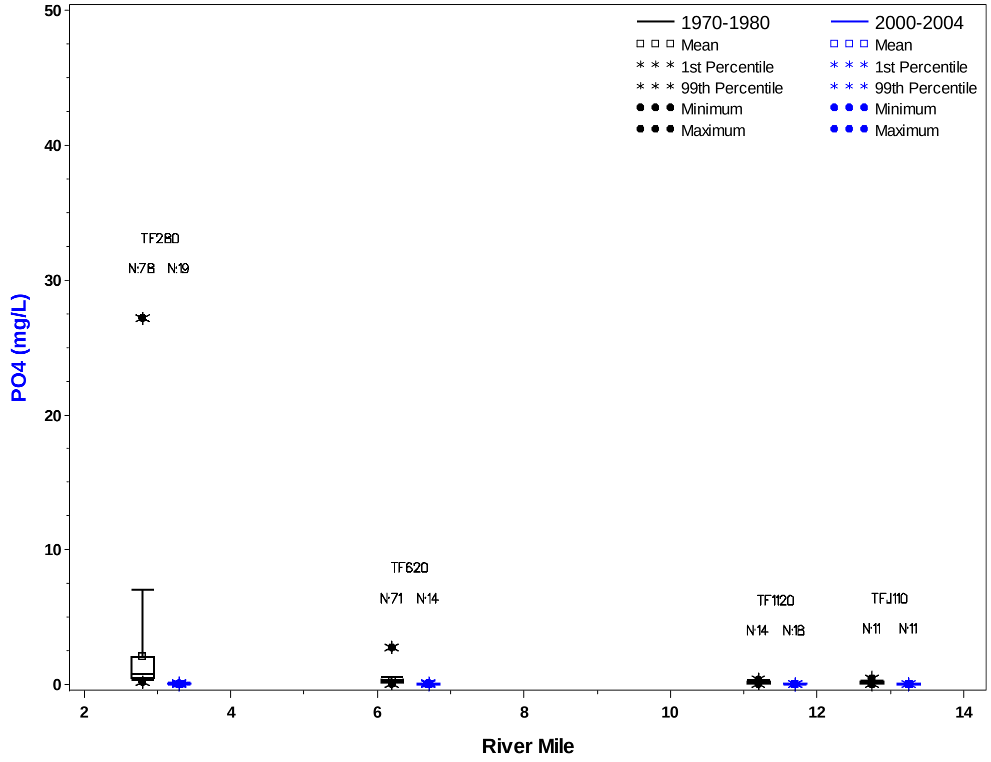


Figure A-2 Paired Modified Tukey Diagrams for Phosphate Dry Weather

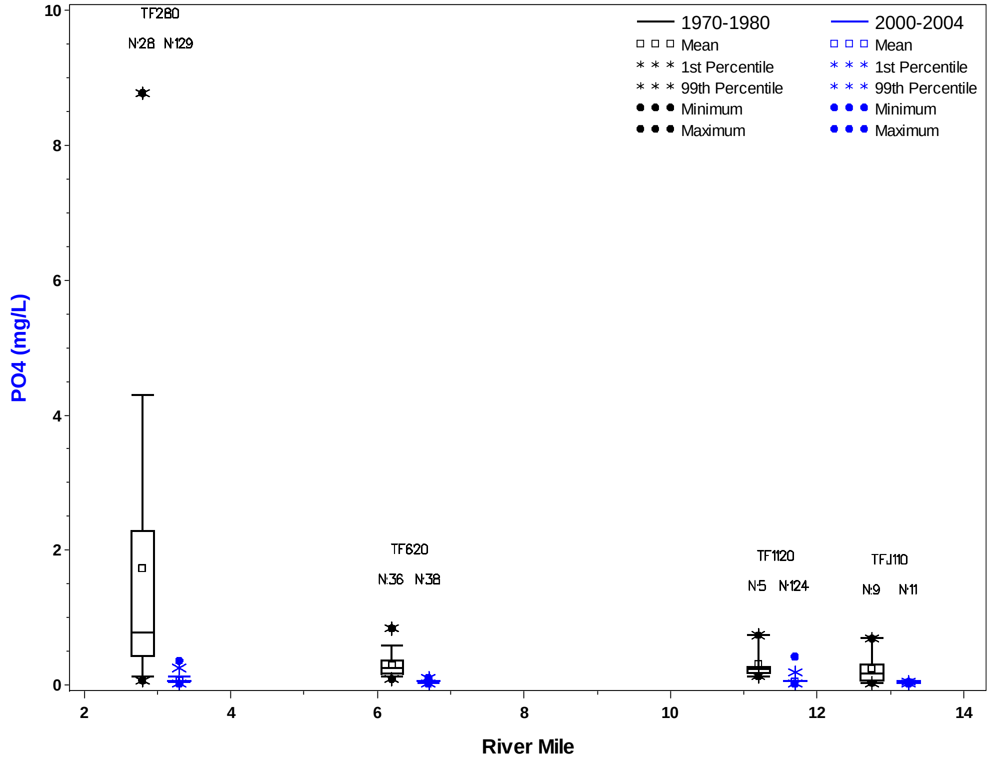


Figure A-3 Paired Modified Tukey Diagrams for Phosphate Wet Weather

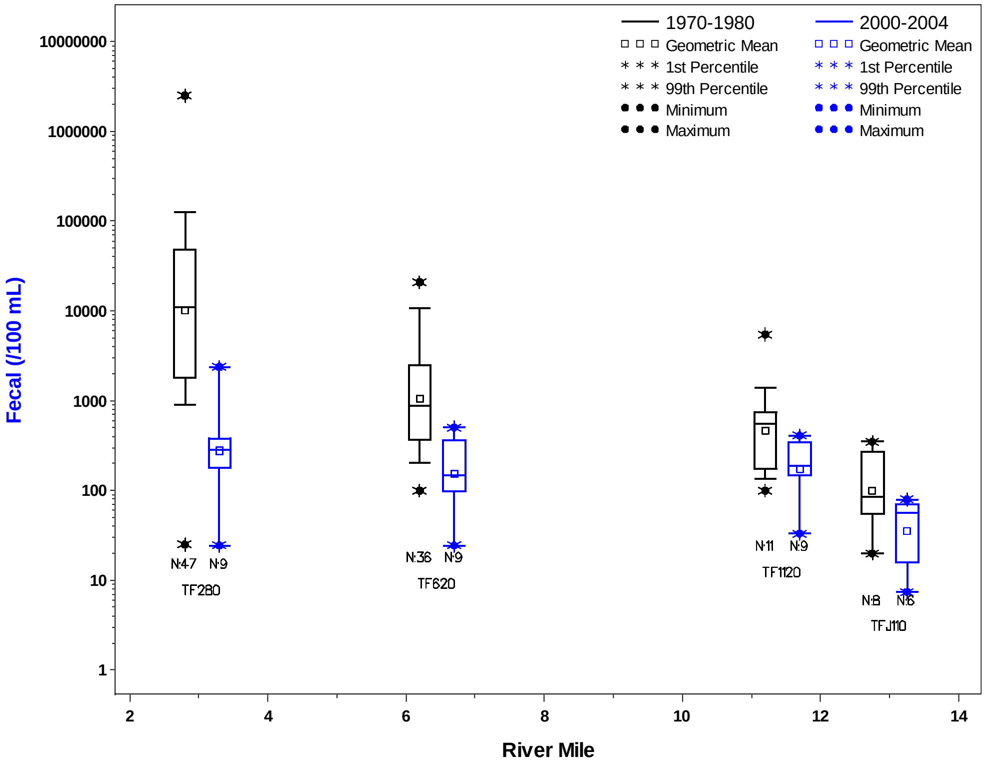


Figure A-4 Paired Modified Tukey Diagrams for Fecal Coliform Non-Swimming Dry Weather

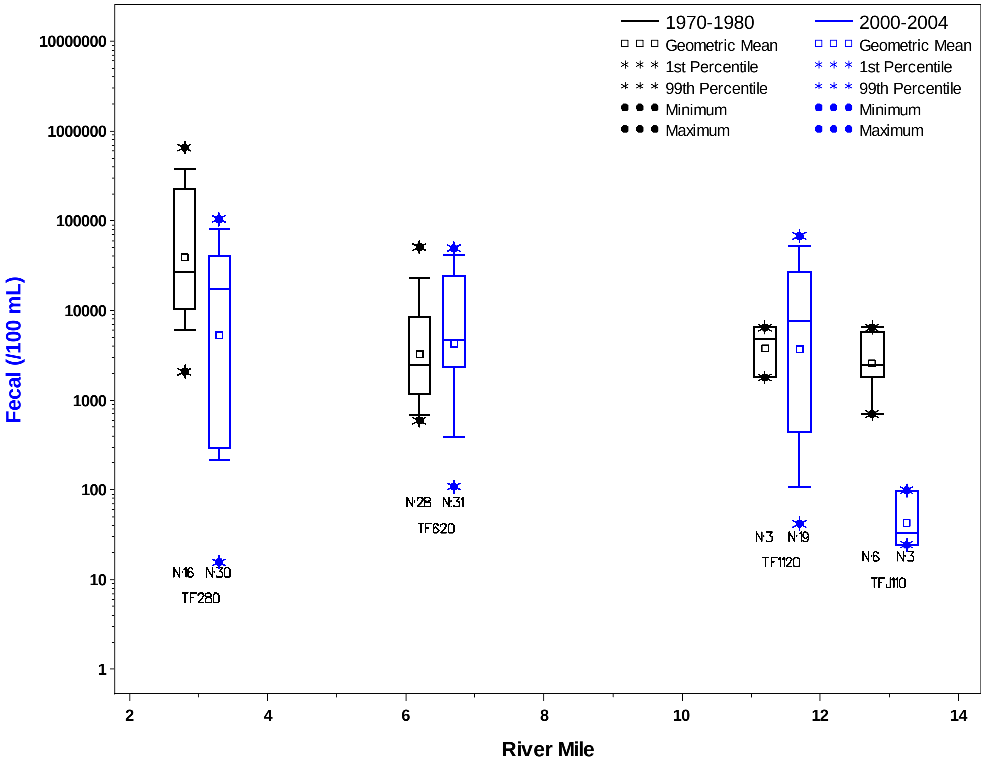


Figure A-5 Paired Modified Tukey Diagrams for Fecal Coliform Non-Swimming Wet Weather

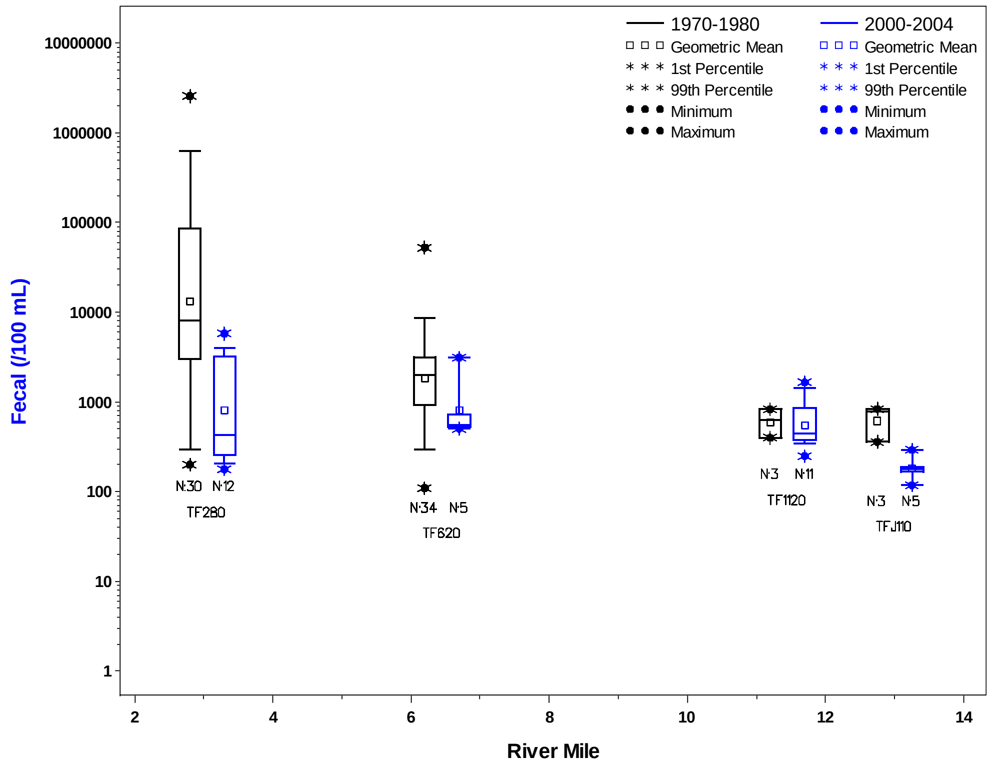


Figure A-6 Paired Modified Tukey Diagrams for Fecal Coliform Swimming Dry Weather

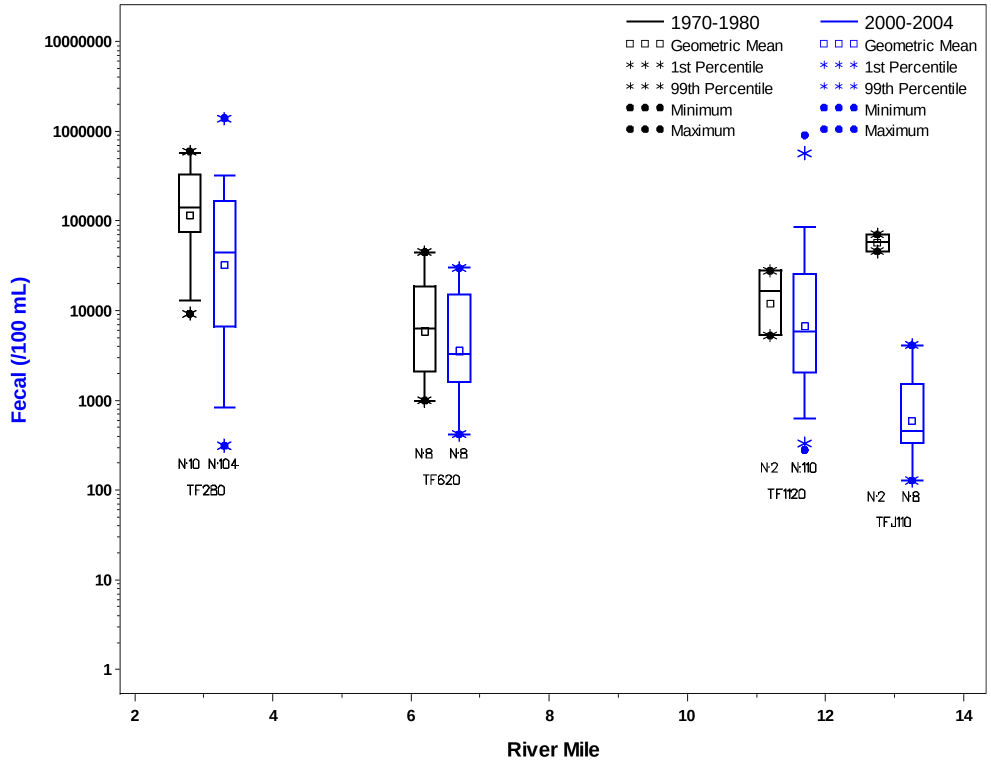


Figure A-7 Paired Modified Tukey Diagrams for Fecal Coliform Swimming Wet Weather

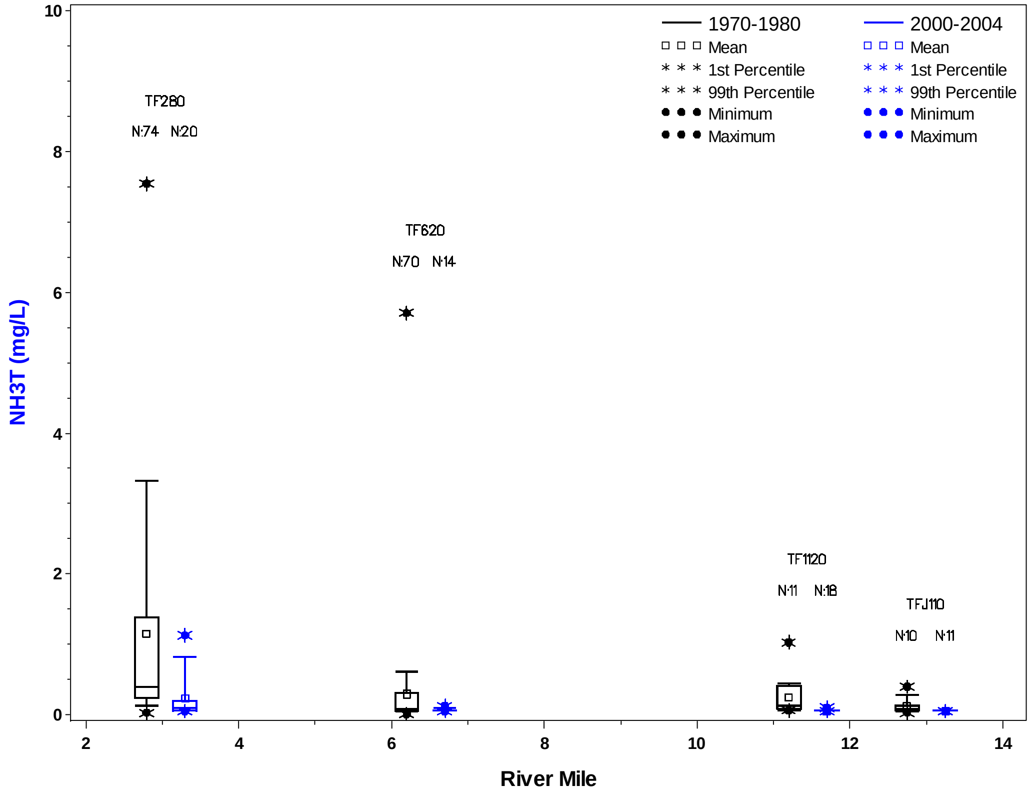


Figure A-8 Paired Modified Tukey Diagrams for Ammonia Dry Weather

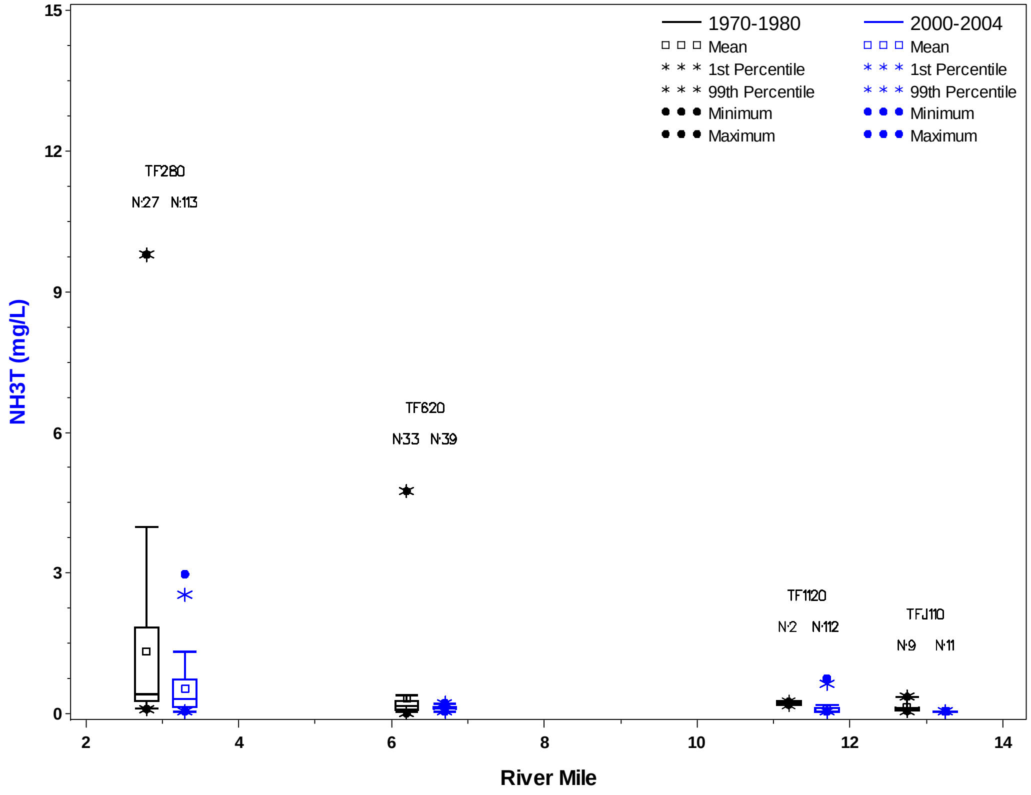


Figure A-9 Paired Modified Tukey Diagrams for Ammonia Wet Weather

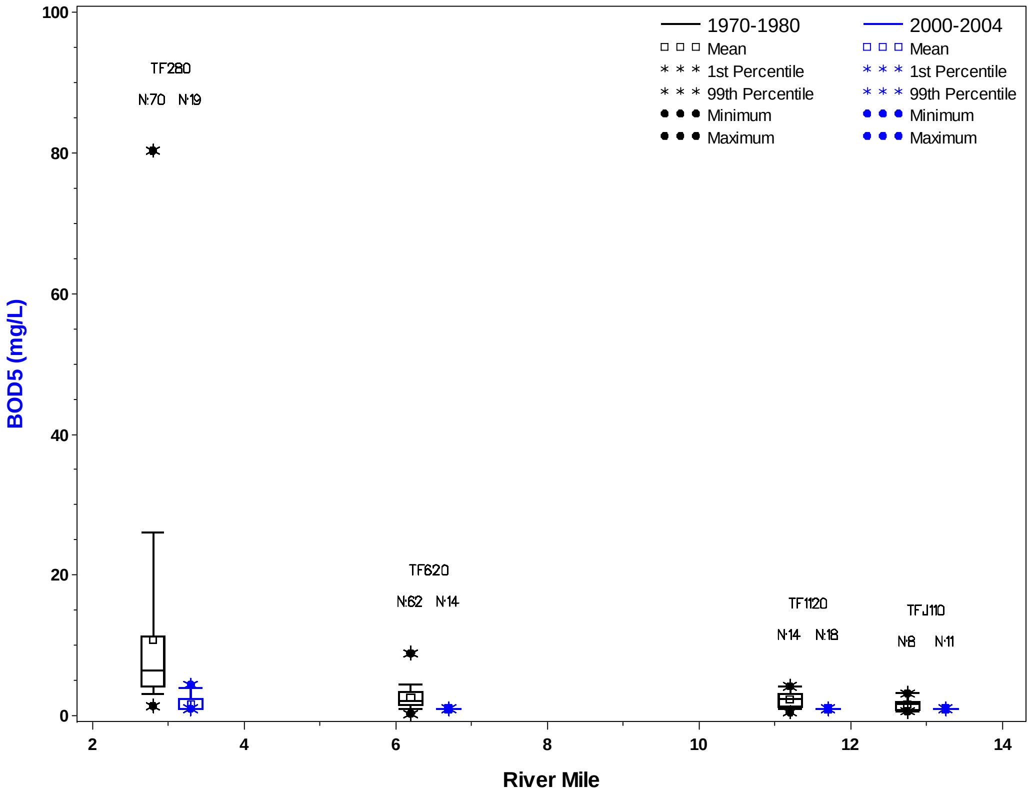


Figure A-10 Paired Modified Tukey Diagrams for BOD5 Dry Weather

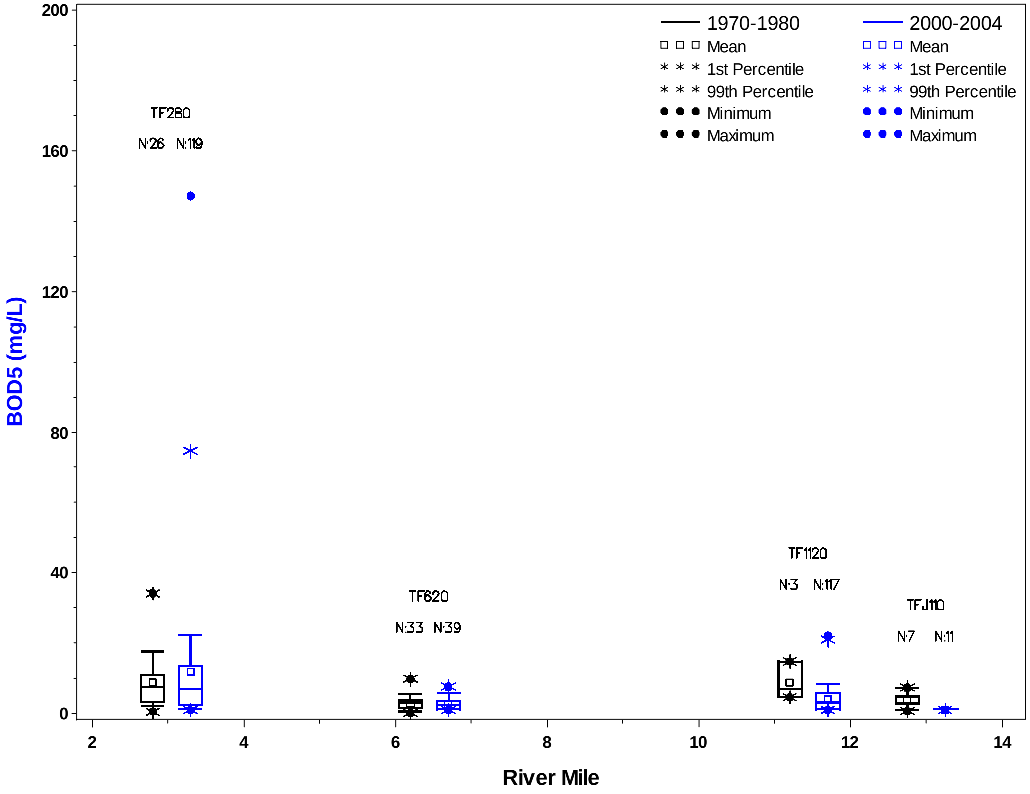


Figure A-11 Paired Modified Tukey Diagrams for BOD5 Wet Weather

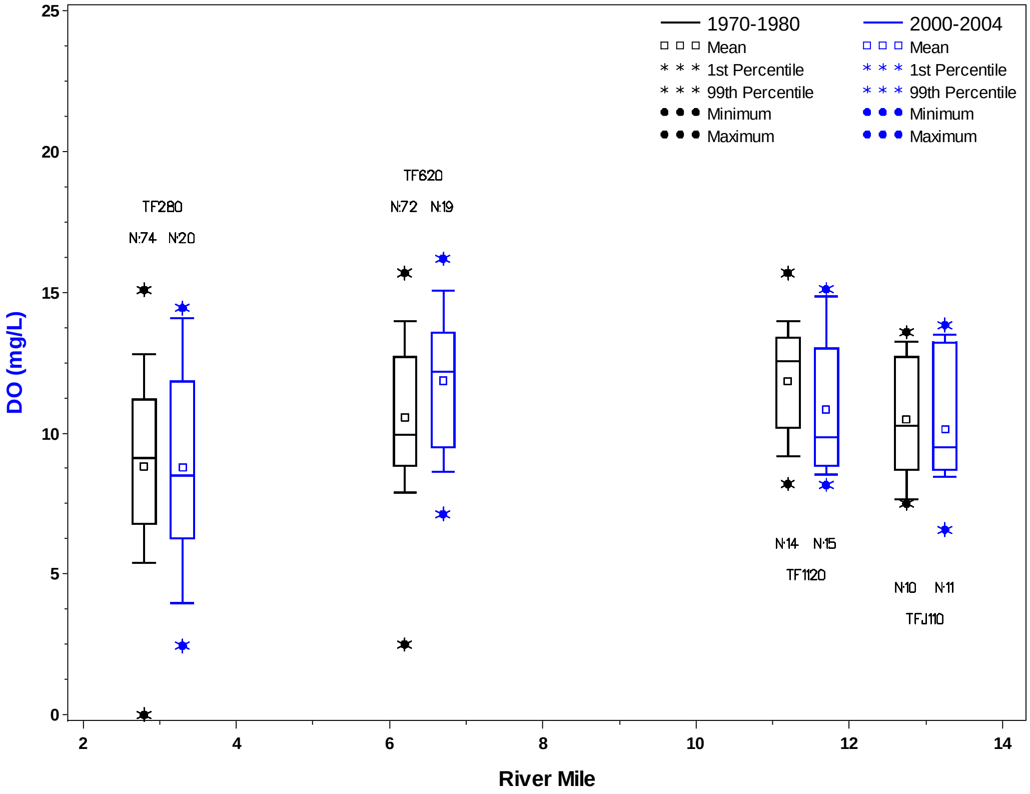


Figure A-12 Paired Modified Tukey Diagrams for Dissolved Oxygen Dry Weather

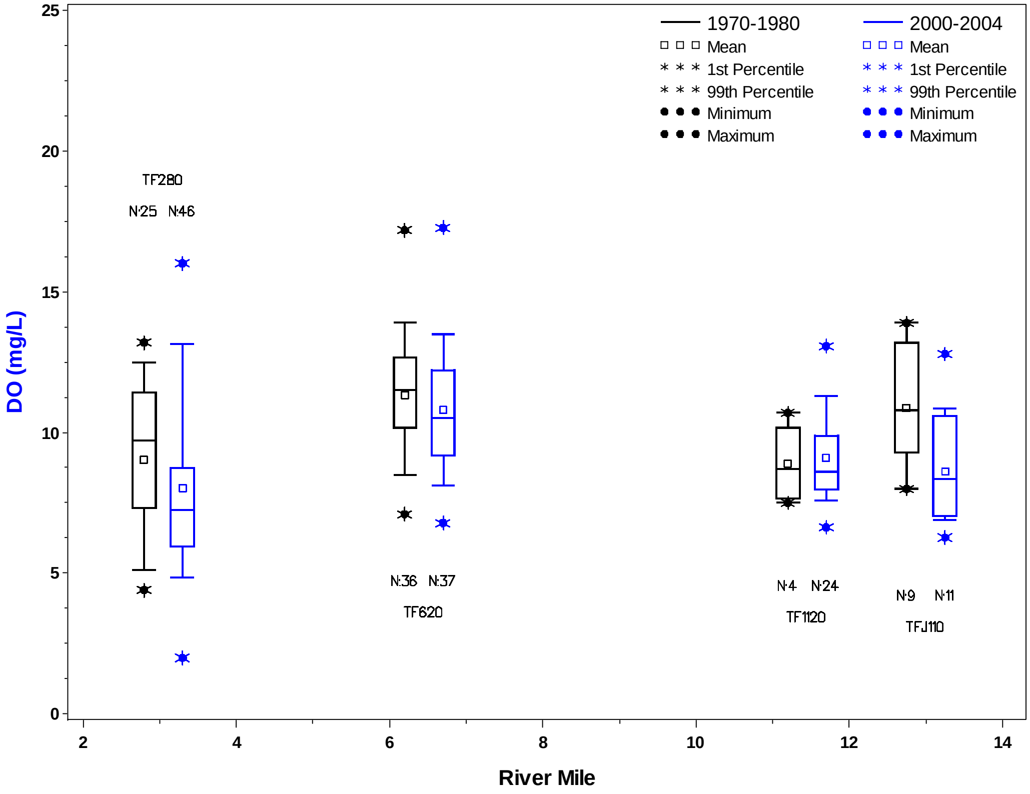


Figure A-13 Paired Modified Tukey Diagrams for dissolved oxygen Wet weather

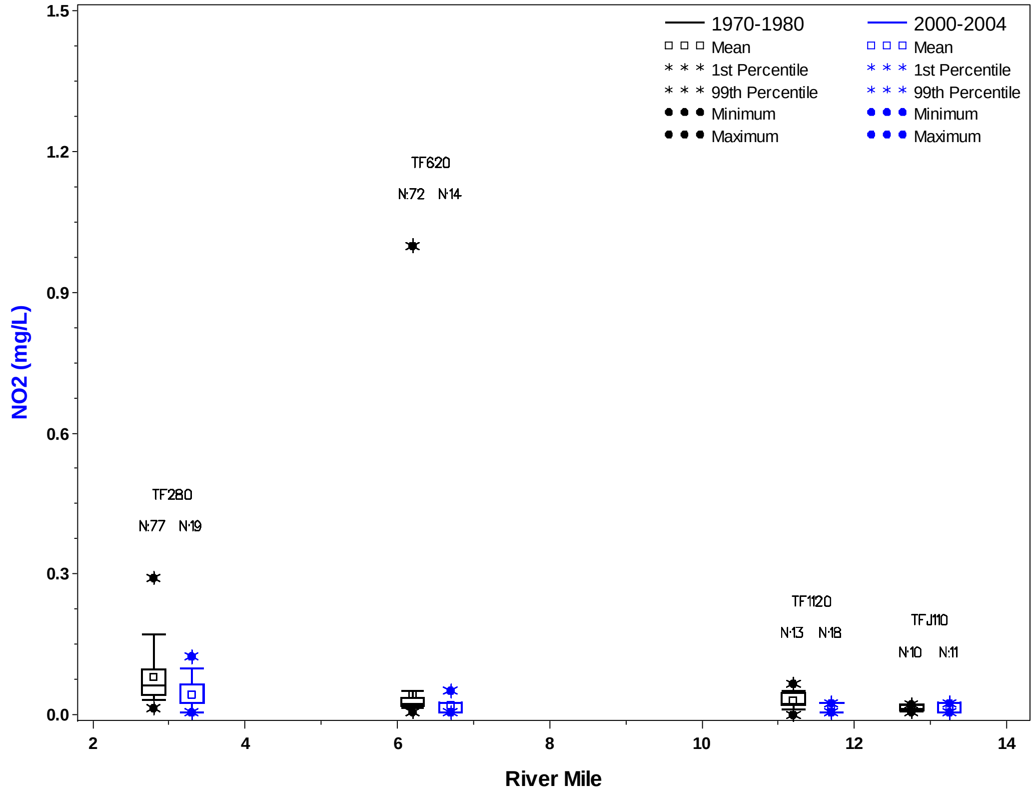


Figure A-14 Paired Modified Tukey Diagrams for Nitrite Dry Weather

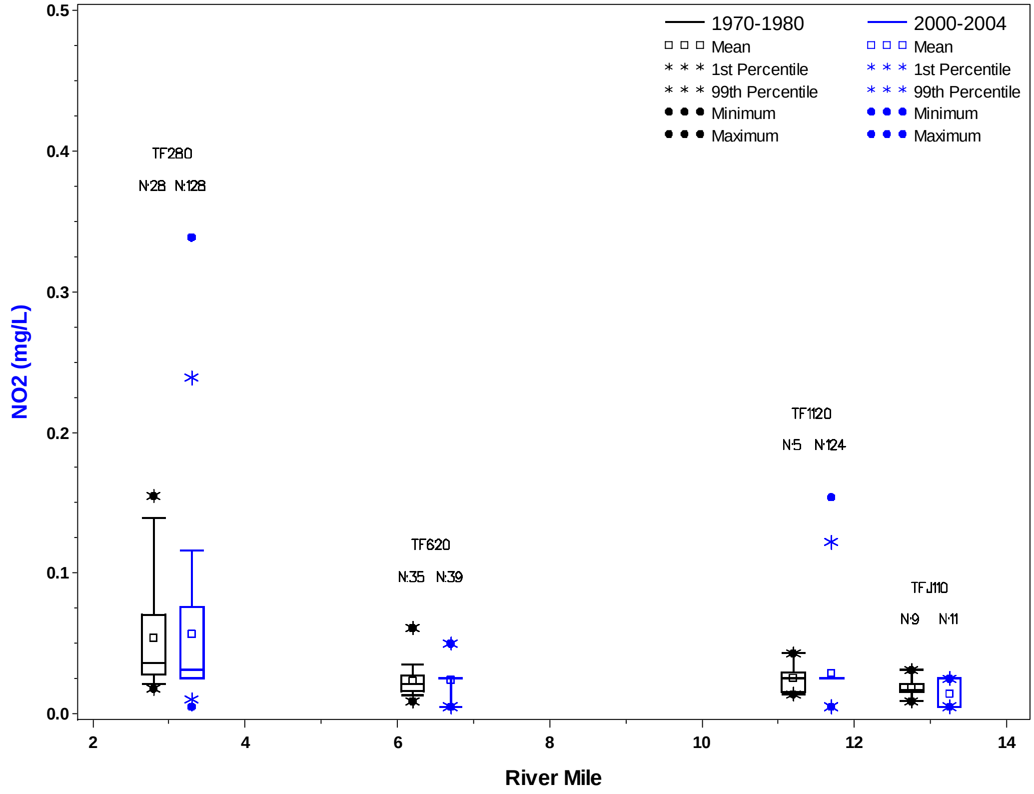


Figure A-15 Paired Modified Tukey Diagrams for Nitrite Wet Weather

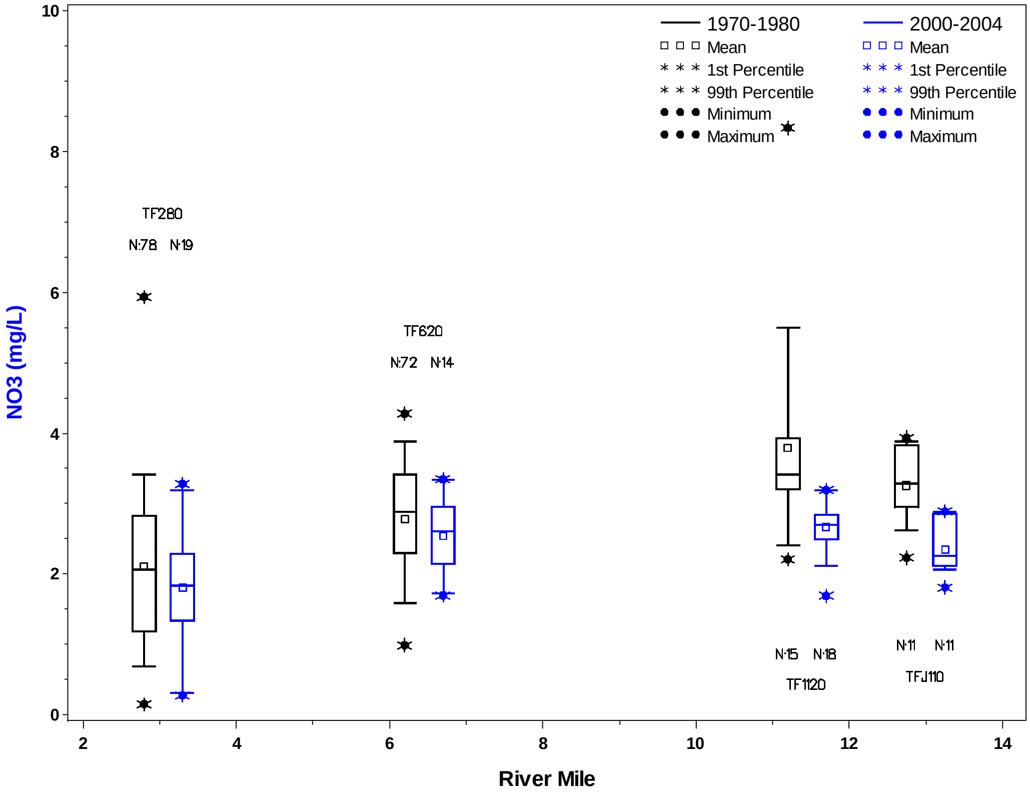


Figure A-16 Paired Modified Tukey Diagrams for Nitrate Dry Weather

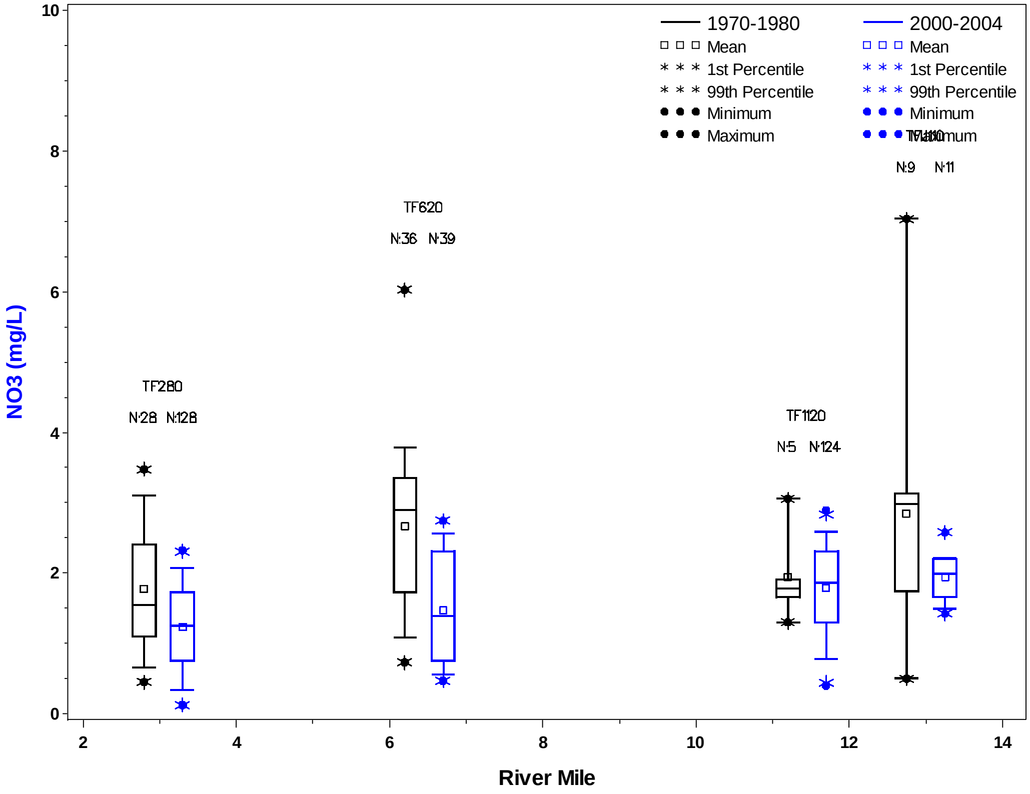


Figure A-17 Paired Modified Tukey Diagrams for Nitrate Wet Weather

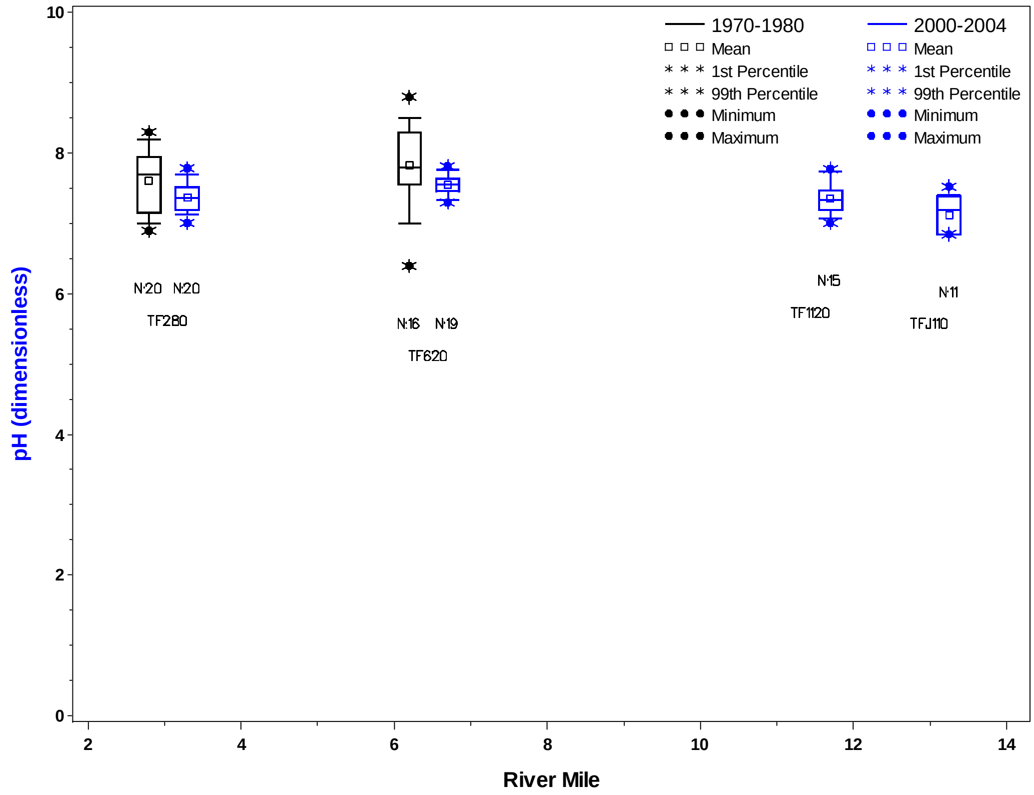


Figure A-18 Paired Modified Tukey Diagrams for pH Dry Weather

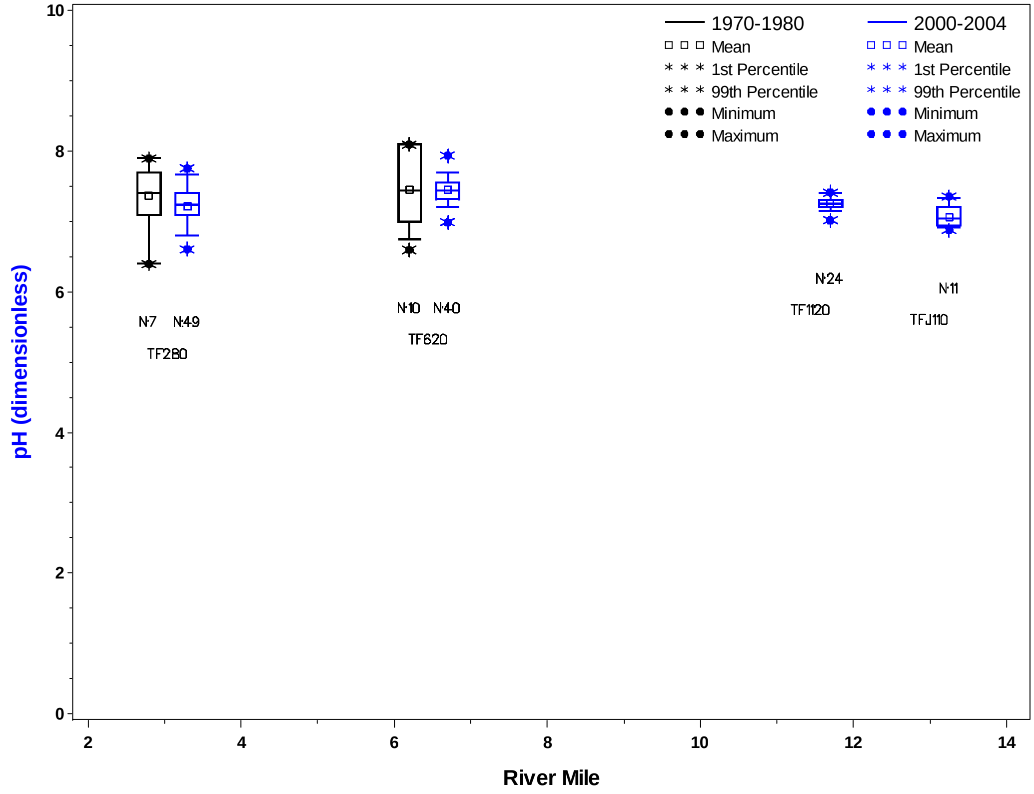


Figure A-19 Paired Modified Tukey Diagrams for pH Wet Weather

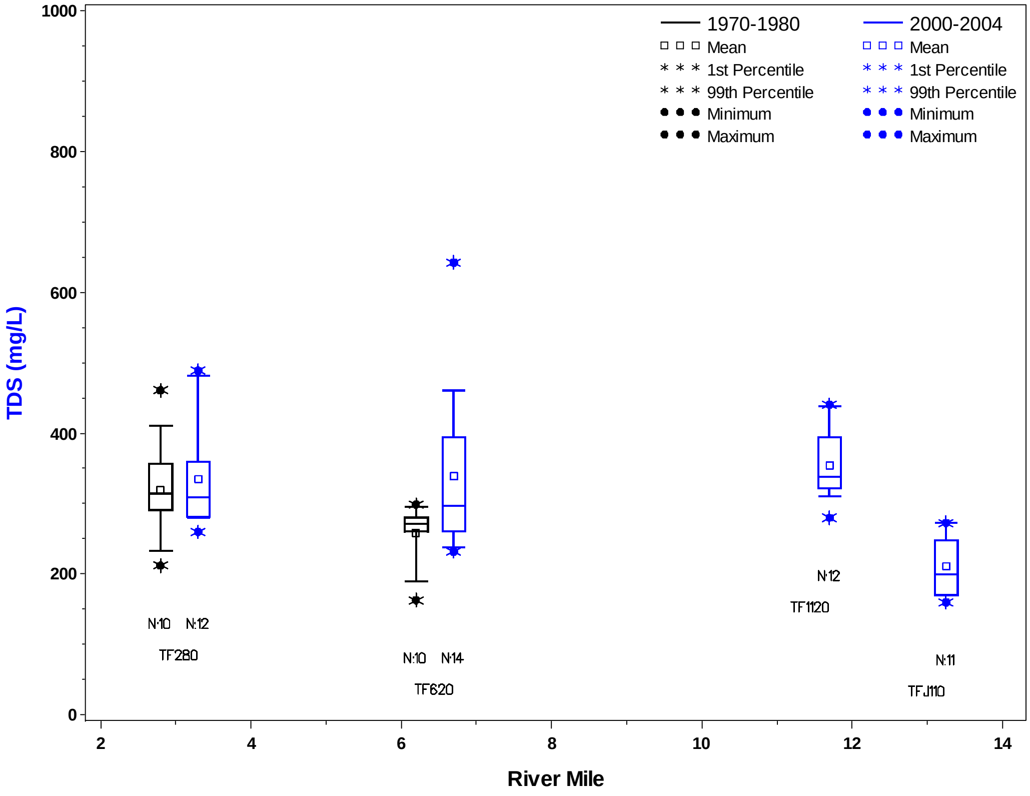


Figure A-20 Paired Modified Tukey Diagrams for Total Dissolved Solids Dry Weather

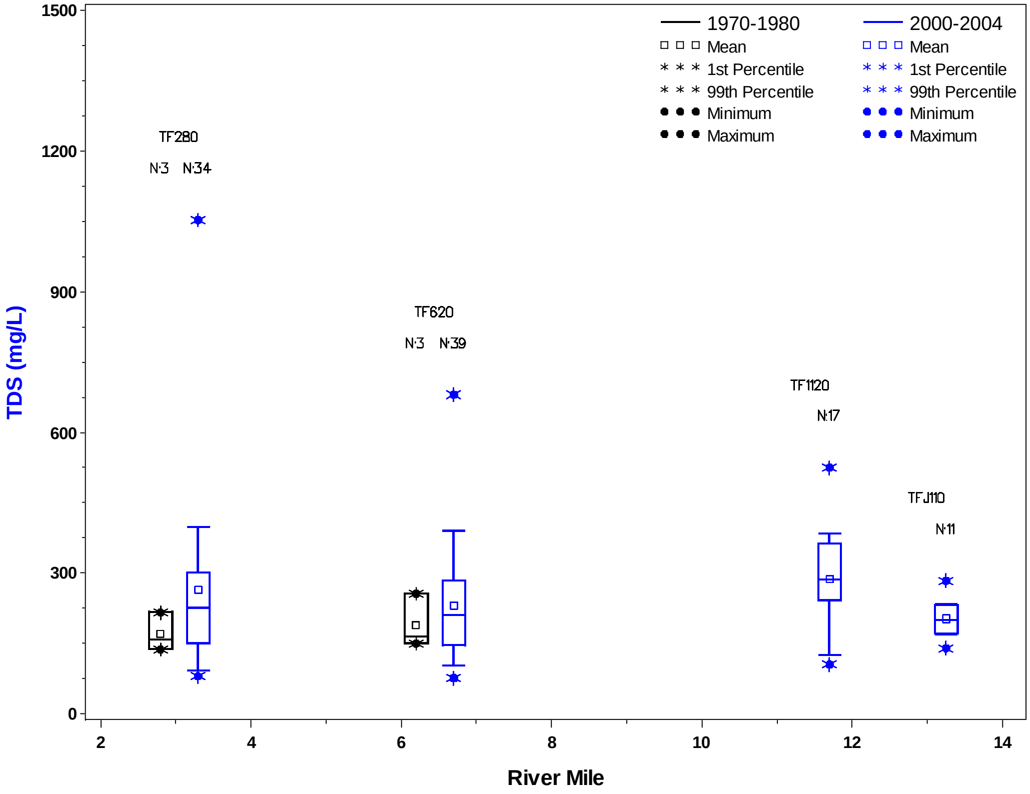


Figure A-21 Paired Modified Tukey Diagrams for Total Dissolved Solids Wet Weather

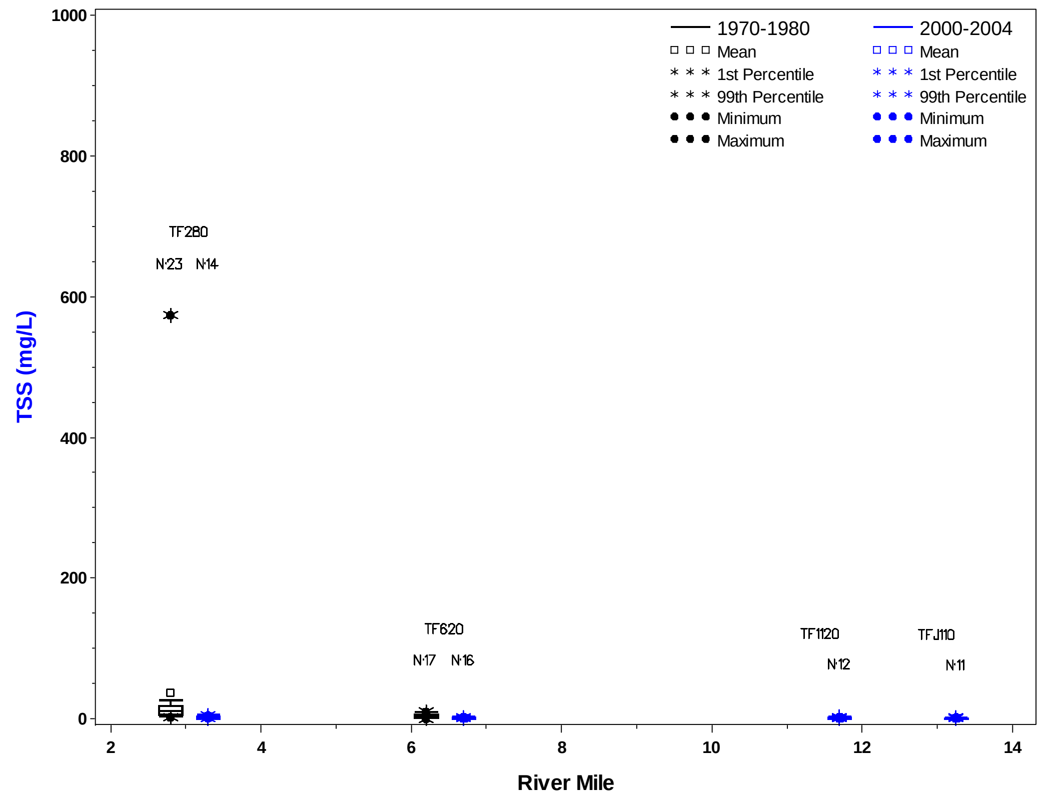


Figure A-22 Paired Modified Tukey Diagrams for Total Suspended Solids Dry Weather

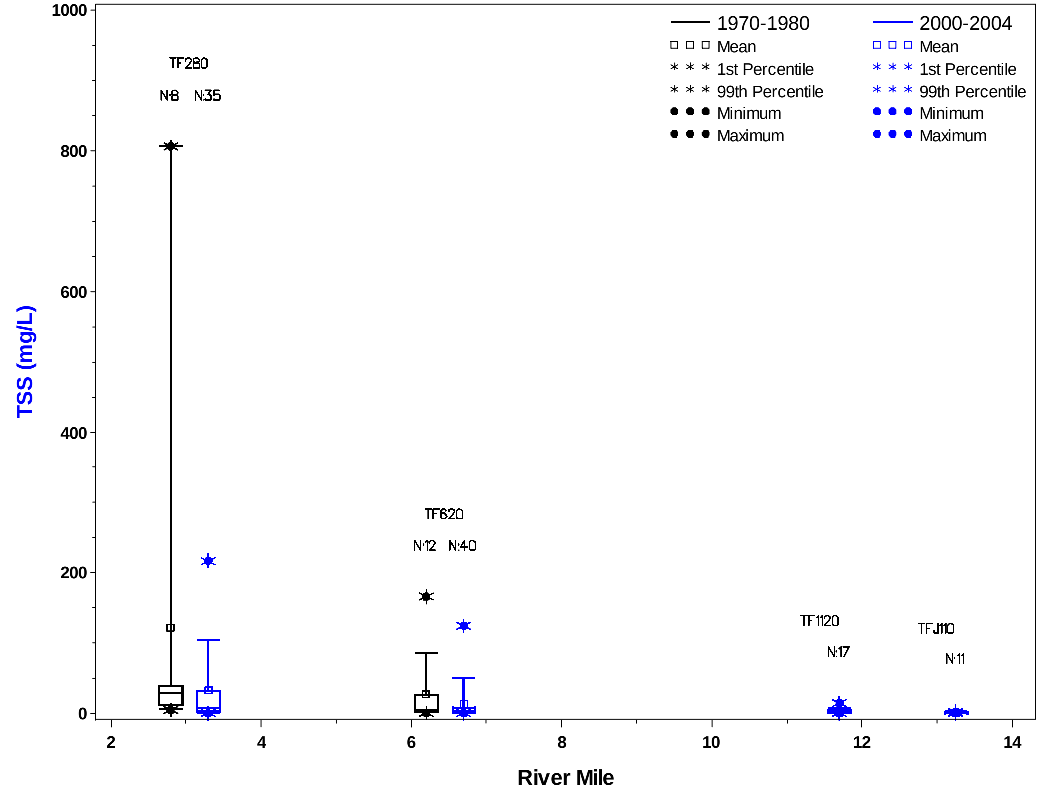


Figure A-23 Paired Modified Tukey Diagrams for Total Suspended Solids Wet Weather

Appendix B: Sonde Data Protocol for the Tookany/Tacony-Frankford Creek

DO Acceptance:

The large number of measurements made by the continuous sampling equipment serves to characterize DO throughout the diurnal cycle under a range of flow conditions. The equipment produces 96 observations of DO every 24 hours, but cost and quality control are more challenging compared to discrete sampling. A variety of procedures are followed before, during, and immediately after deployment to help insure quality and identify problems that may affect DO data quality. These procedures are outlined in detail in the main body of "YSI 6600 Sondes to Monitor Water Quality in Streams" and are summarized below.

- Pre-deployment and post-deployment laboratory validation checks are performed on all parameters. The probes are tested in solutions of known concentrations as established by standard laboratory testing procedures. Instruments are deployed and data is initially accepted if probe measurements are within a certain tolerance of the standards.

- Field personnel fill out standardized forms to note conditions and events that may have an effect on data quality. Examples include debris or sediment obstructing the probe, debris obstructing free flow of water around the instrument, or instrument failure such as a battery failure.

- Beginning in the fall of 2001, field measurements are taken of DO, pH, and specific conductance at deployment and retrieval. Measurements are taken as close to the probe locations as possible, and the data is added to the pre- and post-deployment validation checks when determining whether data is initially accepted.

- BLS personnel prepare time series plots and make preliminary determinations of whether data fall within reasonable ranges and patterns. BLS staff recommends acceptance of data at this point provided they pass the criteria discussed above.

These four items represent initial screens for poor quality data; they identify instances where probes do not accurately measure conditions in the immediate vicinity of the instrument. However, suspended sediment, debris, and biofouling can all affect the microenvironment in the immediate vicinity of the instrument, causing data to be collected that does not represent overall conditions in the water column. For this reason, additional procedures are needed to distinguish data that is sufficiently representative to be included in analyses from data that is not representative.

Table B-1 summarizes a system that assigns points to data based on the presence of characteristics that are indicative of reliable data. Data analysis suggests that conditions that lead to unreliable data are present primarily during and after wet weather and depend on the intensity of the runoff event. For this reason, the continuous data is biased toward dry weather conditions although they do represent some wet weather events.

Table B-1 Criteria Applied to Determine Sonde DO Data Reliability

CRITERIA (Accept data with 5 or more points.)	**CHARACTERISTICS OF Chapter 1 HIGHER RELIABILITY DATA**	↔	**CHARACTERISTICS OF LOWER RELIABILITY DATA**
VALIDATION CHECKS	The data pass all field and laboratory validation checks within 1.0 mg/L. PROCEED TO NEXT STEP.	Does not apply.	The data do not pass one or more validation checks. REJECT THE DATA.
PROBE FAILURE	The data never drop to zero for two or more days. PROCEED TO NEXT STEP.	The data drop to zero for two days or more, but recover later in the deployment. PROCEED TO NEXT STEP.	The data drop abruptly to zero and remain there for the duration of the deployment. REJECT THE DATA.
SITE CONDITIONS	Field notes do not document any conditions that may cause instrument failure. (+2 POINTS)	Field notes indicate light to moderate obstruction by debris, sediment, and/or biofouling. (+1 POINT)	Field notes indicate moderate to extensive obstruction by debris, sediment, and/or biofouling. (+0 POINTS)
NOISE	The data pattern is smooth, without sudden and erratic changes. (+2 POINTS)	Data are slightly to moderately noisy, but the underlying pattern is readily apparent. (+1 POINT)	The data are extremely noisy. (+0 POINTS)
IF diurnal pattern is evident…	The diurnal pattern is relatively constant in dry weather and has an amplitude of less than 4 mg/L. (+2 POINTS)	The diurnal amplitude is less than 4 mg/L, but it changes over the course of the deployment by a factor of 2 or more. This may indicate algae accumulation. (+1 POINT)	The diurnal amplitude is greater than 4 mg/L. (+0 points)
IF redundant observations are available…	Both sets of data are similar and display characteristics of high quality data. (+2 POINTS for one data set; discard the other).	Only one data set displays multiple characteristics of low quality data. (+1 POINTS for the higher quality data set; discard the other).	Both data sets display multiple characteristics of low quality data. (+0 POINTS)

Explanation of acceptance/rejection:
The primary objective in this part of the update is to identify which data is usable and which is not. The most important comment that can be made is that we are not trying to reject data that doesn't seem to fit the "usual" pattern (diurnal). Instead we are trying to reject data that seems to have been caused by mechanical failure. Therefore it is important to realize exactly what is usable and what is useless. The first place to look for this is in the original excel file that supplied the data. Check the charts that are in the file and look for any red comments about mechanical failure. If this is the case, then the data should be rejected in those regions. The Excel file "TF_Acceptance_Criteria.xls" has a series of worksheets which help decide if the data should be rejected or not. Looking at the plot, decide on an appropriate number of sections that are needed. For example, if there seems to be a section of questionable data between 2 sections of good data, you would need 3 sections. Make a copy of one of the templates depending on the sections required and rename the sheet for the respective deployment. Complete the sheet to help gauge if the data should be rejected or not.

How to select which regions to reject:
- Open the TaconyFrankford Database :"**TaconyFrankford.mdb**".
- Open the sheet called **"RejectedDates"**.
- For each region you wish to reject, enter the deployment, start dtime to reject and end dtime to stop rejecting.
- For single point rejections, enter the same dtime for start and stop.
- For multiple rejection ranges for the same deployment, use the same deployment number and add a new record with more rejection times.
- Update the "**TF_Acceptance_Criteria**" worksheet. Add a new worksheet for each new deployment using the template sheets in the front. For 2 rejection regions use Template2, for 3 use Temp3 etc.
- Fill in the proper point values as was described above.

DO Flagging:

Program 5 – "update do flag optimized.vb" - Module inside database
- This program takes the rejected date ranges and flags the TF_Sonde table accordingly.
- Run the module, if there are any errors, read the comments in the program. You may comment out the **fillw1** query.
- Export the table **"TF_Sonde"** with the export query. Output is **"TF_Export_Sonde.csv".**
- Rerun the program **DOPlots.sas.** Output will be several graphics files.

Check the graphs for consistency

Appendix C: Rejected Continuous DO Monitoring Data Intervals

Site	Start Date/Time	End Date/Time
TF280	3/21/2001 14:30	3/26/2001 15:30
TF760	5/3/2001 11:00	5/17/2001 14:00
TF1120	5/21/2001 16:00	6/4/2001 16:00
TF760	5/22/2001 11:30	6/5/2001 11:30
TF1120	8/20/2001 1:00	8/29/2001 10:45
TF280	8/19/2001 20:15	8/29/2001 10:15
TF500	8/19/2001 20:15	8/29/2001 9:45
TF620	8/20/2001 1:45	8/29/2001 10:30
TF760	8/20/2001 1:45	8/29/2001 9:30
TF1120	6/26/2001 14:45	7/3/2001 10:45
TFM000	7/13/2001 12:00	7/18/2001 14:00
TFM000	11/22/2002 1:30	12/1/2002 13:30
TF280	9/25/2002 10:00	10/9/2002 9:00
TF500	10/26/2002 0:45	10/30/2002 12:15
TF500	11/21/2002 22:31	11/26/2002 15:31
TF500	9/14/2002 20:15	9/25/2002 14:00
TF620	10/11/2002 9:31	10/17/2002 11:46
TF620	11/5/2002 18:30	11/8/2002 7:45
TF620	11/11/2002 0:15	11/19/2002 8:00
TF760	10/26/2002 2:16	10/29/2002 14:31
TF760	9/27/2002 7:31	10/1/2002 15:01
TF975	11/10/2002 16:16	11/19/2002 8:01
TF975	9/14/2002 16:31	9/25/2002 15:16
TF1120	10/11/2002 21:01	10/17/2002 11:46
TF1120	3/4/2003 10:30	3/4/2003 11:45
TF280	3/6/2003 12:15	3/7/2003 11:45
TF280	3/20/2003 20:15	3/21/2003 11:00
TF280	4/9/2003 0:01	4/15/2003 11:46
TF280	4/11/2003 0:15	4/15/2003 11:30
TF280	4/26/2003 0:15	4/29/2003 12:30
TF280	4/29/2003 12:45	5/3/2003 17:45
TF280	5/6/2003 18:15	5/9/2003 11:45
TF280	5/13/2003 0:15	5/13/2003 11:45
TF280	5/6/2003 0:15	5/9/2003 13:45
TF280	5/13/2003 0:15	5/13/2003 11:45
TF280	5/16/2003 15:15	5/18/2003 5:45
TF280	5/20/2003 0:15	5/20/2003 11:15
TF280	5/30/2003 14:30	6/12/2003 14:00
TF280	5/30/2003 14:00	6/2/2003 11:45
TF280	6/7/2003 12:15	6/7/2003 21:45
TF620	6/17/2003 16:15	6/18/2003 11:45
TF620	6/20/2003 0:15	6/20/2003 13:45
TF620	6/17/2003 19:00	6/18/2003 11:45
TF620	6/20/2003 0:15	6/20/2003 13:45
TF620	7/8/2003 15:31	7/8/2003 15:31

TF620	7/9/2003 13:16	7/11/2003 15:31
Site	**Start Date/Time**	**End Date/Time**
TF620	7/12/2003 17:01	7/14/2003 13:16
TF975	7/9/2003 15:45	7/11/2003 13:30
TF975	7/12/2003 17:15	7/14/2003 13:15
TF975	4/11/2003 0:15	4/15/2003 9:30
TF975	4/27/2003 0:15	4/29/2003 10:15
TF975	5/2/2003 18:15	5/3/2003 12:45
TF975	4/11/2003 0:15	4/15/2003 10:00
TF1120	4/26/2003 0:15	4/29/2003 11:15
TF1120	5/5/2003 12:01	5/13/2003 10:46
TF1120	4/9/2003 0:01	4/10/2003 11:46
TF1120	4/11/2003 9:01	4/15/2003 10:31
TF1120	5/2/2003 12:01	5/3/2003 11:46
TF280	9/27/2003 14:15	9/30/2003 11:00
TF280	10/14/2003 20:15	10/15/2003 16:30
TF280	10/14/2003 18:15	10/15/2003 16:45
TF280	11/5/2003 18:15	11/10/2003 12:45
TF620	11/12/2003 3:15	11/13/2003 14:45
TF620	11/13/2003 12:15	11/13/2003 15:15
TF620	11/13/2003 12:01	11/13/2003 15:46
TF975	11/13/2003 12:15	11/13/2003 16:00
TF975	3/31/2004 0:46	4/4/2004 7:16
TF1120	4/12/2004 18:46	4/15/2004 5:46
TF1120	4/26/2004 0:46	4/27/2004 8:46
TF280	5/3/2004 1:31	5/4/2004 9:00
TF620	5/9/2004 22:31	5/10/2004 13:16
TF975	5/15/2004 23:16	5/18/2004 11:01
TF1120	5/18/2004 11:16	6/1/2004 13:31
TF280	6/5/2004 8:16	6/7/2004 9:46
TF620	6/15/2004 18:01	6/17/2004 9:31
TF975	6/22/2004 18:46	6/29/2004 9:31
TF1120	6/15/2004 18:01	6/17/2004 9:31
TF280	6/22/2004 18:46	6/29/2004 9:16
TF620	5/15/2004 20:01	5/18/2004 11:31
TF975	6/28/2004 0:16	6/29/2004 9:46
TF1120	3/31/2004 12:16	4/2/2004 11:01
TF280	5/10/2004 0:00	5/10/2004 14:00
TF280	5/15/2004 23:00	5/18/2004 12:00
TF280	5/31/2004 17:31	6/1/2004 14:16
TF280	6/14/2004 14:46	6/29/2004 10:16
TF280	4/13/2004 0:16	4/15/2004 7:01
TF280	6/1/2004 11:46	6/14/2004 16:01
TF280	6/14/2004 16:01	6/29/2004 10:45
TF280	5/12/2004 19:31	5/12/2004 19:31
TF280	6/14/2004 15:31	6/29/2004 11:01
TF620	3/20/2003 9:00	3/21/2003 11:00
TF620	6/29/2004 9:30	7/15/2004 13:15

TF620	6/29/2004 9:31	7/15/2004 13:16
Site	**Start Date/Time**	**End Date/Time**
TF620	7/12/2004 8:16	7/15/2004 14:01
TF620	7/10/2004 5:31	7/10/2004 5:31
TF620	7/18/2004 11:31	7/18/2004 14:46
TF620	7/28/2004 21:31	7/30/2004 9:46
TF620	7/27/2004 16:16	7/28/2004 1:16
TF975	7/23/2004 13:31	7/27/2004 21:46
TF975	8/1/2004 7:46	8/5/2004 9:31
TF975	7/29/2004 0:00	8/13/2004 0:00
TF975	8/16/2004 8:16	8/17/2004 14:16
TF975	8/21/2004 14:46	8/24/2004 14:30
TF975	8/31/2004 5:00	9/1/2004 10:31
TF975	7/29/2004 0:00	8/13/2004 0:00
TF1120	8/11/2004 19:31	8/12/2004 9:31
TF1120	9/8/2004 10:01	9/15/2004 10:01
TF1120	9/17/2004 22:16	9/20/2004 10:31
TF1120	9/8/2004 9:31	9/15/2004 10:46
TF1120	9/18/2004 3:01	9/20/2004 11:01
TF1120		
TF1120		
TFJ110		
TFJ110		
TFJ110		
TFJ110		
TFJ110		
TFJ110		
TFJ110		
TFM000		
TFM000		
TFM000		
TFM000		
TFM000		
TFM000		
TFM000		
TFM000		
TF280		
TF280		
TF500		
TF620		
TF280		
TF500		
TF620		
TF280		
TF280		
TF280		
TF500		
TF500		

TF500		
TF620		
TF620		
Site	**Start Date/Time**	**End Date/Time**
TF620		
TF280		
TF500		
TF620		
TF280		
TF500		
TF620		

Appendix D: Statistical Outliers and samples affected by contamination

Sample_ID	Parameter	Value	Date	Site	Units	Reason
HWQ7126126-3	Total Suspended Solids	574	7/12/1971	TF280	mg/L	Outlier
DW000706-0050	Aluminum	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Calcium	0.06675	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Cadmium	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Chromium	0.00115	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Copper	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Iron	0.0224	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Magnesium	0.01679	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Manganese	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Lead	<.001	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Total Phosphorus	0.01847	7/6/2000	TF620	mg/L	Outlier
DW000706-0050	Zinc	0.01034	7/6/2000	TF620	mg/L	Outlier
DW000706-0051	Cadmium Dissolved	<.001	7/6/2000	TFJ110	mg/L	Outlier
DW000706-0051	Dissolved Iron	0.02335	7/6/2000	TFJ110	mg/L	Outlier
DW000706-0052	Ammonia	<.1	7/6/2000	TF280	mg/L as N	Outlier
DW000706-0052	TKN	<.4	7/6/2000	TF280	mg/L	Outlier
DW040712-0056	Aluminum	<.05	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Calcium	0.121	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Cadmium	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Chromium	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Copper	0.004	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Cadmium Dissolved	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Chromium Dissolved	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Copper Dissolved	0.002	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Iron Dissolved	<.05	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Lead Dissolved	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Zinc Dissolved	0.016	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Iron	<.05	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Hardness	<.71	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Magnesium	<.1	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Manganese	<.01	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Lead	<.001	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Sodium	0.102	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Total Phosphorus	<.05	7/12/2004	TF280	mg/L	Outlier
DW040712-0056	Zinc	0.037	7/12/2004	TF280	mg/L	Outlier
DW040707-0068	Copper Dissolved	0.003	7/7/2004	TFJ010	mg/L	Outlier

Sample_ID	Parameter	Value	Date	Site	Units	Reason
DW040819-0057	Copper Dissolved	0.006	8/19/2004	TF500	mg/L	Outlier
DW040429-0060	Zinc	0.013	4/29/2004	TF280	mg/L	Contamination Suspected
DW040429-0060	Zinc Dissolved	0.041	4/29/2004	TF280	mg/L	Contamination Suspected
DW040429-0061	Zinc	0.011	4/29/2004	TF500	mg/L	Contamination Suspected
DW040429-0061	Zinc Dissolved	0.231	4/29/2004	TF500	mg/L	Contamination Suspected
DW040429-0062	Zinc	0.012	4/29/2004	TF620	mg/L	Contamination Suspected
DW040429-0062	Zinc Dissolved	0.044	4/29/2004	TF620	mg/L	Contamination Suspected
DW040429-0063	Zinc	0.015	4/29/2004	TF760	mg/L	Contamination Suspected
DW040429-0063	Zinc Dissolved	0.234	4/29/2004	TF760	mg/L	Contamination Suspected
DW040429-0065	Zinc	0.032	4/29/2004	TFM006	mg/L	Contamination Suspected
DW040429-0065	Zinc Dissolved	0.057	4/29/2004	TFM006	mg/L	Contamination Suspected
DW040429-0066	Zinc	0.015	4/29/2004	TF975	mg/L	Contamination Suspected
DW040429-0066	Zinc Dissolved	0.093	4/29/2004	TF975	mg/L	Contamination Suspected
DW040429-0067	Zinc	0.023	4/29/2004	TF1120	mg/L	Contamination Suspected
DW040429-0067	Zinc Dissolved	0.075	4/29/2004	TF1120	mg/L	Contamination Suspected
DW040429-0068	Zinc	0.008	4/29/2004	TFJ110	mg/L	Contamination Suspected
DW040429-0068	Zinc Dissolved	0.013	4/29/2004	TFJ110	mg/L	Contamination Suspected
DW040506-0062	Zinc	0.016	5/6/2004	TF280	mg/L	Contamination Suspected
DW040506-0062	Zinc Dissolved	0.058	5/6/2004	TF280	mg/L	Contamination Suspected
DW040506-0063	Zinc	0.021	5/6/2004	TF500	mg/L	Contamination Suspected
DW040506-0063	Zinc Dissolved	0.053	5/6/2004	TF500	mg/L	Contamination Suspected
DW040506-0064	Zinc	0.017	5/6/2004	TF620	mg/L	Contamination Suspected
DW040506-0064	Zinc Dissolved	0.046	5/6/2004	TF620	mg/L	Contamination Suspected
DW040506-0065	Zinc	0.014	5/6/2004	TF760	mg/L	Contamination Suspected

Sample_ID	Parameter	Value	Date	Site	Units	Reason
DW040506-0065	Zinc Dissolved	0.015	5/6/2004	TF760	mg/L	Contamination Suspected
DW040506-0066	Zinc	0.033	5/6/2004	TFM006	mg/L	Contamination Suspected
DW040506-0066	Zinc Dissolved	0.026	5/6/2004	TFM006	mg/L	Contamination Suspected
DW040506-0067	Zinc	0.015	5/6/2004	TF975	mg/L	Contamination Suspected
DW040506-0067	Zinc Dissolved	0.016	5/6/2004	TF975	mg/L	Contamination Suspected
DW040506-0068	Zinc	0.013	5/6/2004	TF1120	mg/L	Contamination Suspected
DW040506-0068	Zinc Dissolved	0.017	5/6/2004	TF1120	mg/L	Contamination Suspected
DW040506-0069	Zinc	0.008	5/6/2004	TFJ110	mg/L	Contamination Suspected
DW040506-0069	Zinc Dissolved	0.009	5/6/2004	TFJ110	mg/L	Contamination Suspected
DW040513-0070	Zinc	0.01	5/13/2004	TF280	mg/L	Contamination Suspected
DW040513-0070	Zinc Dissolved	0.041	5/13/2004	TF280	mg/L	Contamination Suspected
DW040513-0071	Zinc	0.012	5/13/2004	TF500	mg/L	Contamination Suspected
DW040513-0071	Zinc Dissolved	0.042	5/13/2004	TF500	mg/L	Contamination Suspected
DW040513-0072	Zinc	0.012	5/13/2004	TF620	mg/L	Contamination Suspected
DW040513-0072	Zinc Dissolved	0.04	5/13/2004	TF620	mg/L	Contamination Suspected
DW040513-0073	Zinc	0.012	5/13/2004	TF760	mg/L	Contamination Suspected
DW040513-0073	Zinc Dissolved	0.177	5/13/2004	TF760	mg/L	Contamination Suspected
DW040513-0074	Zinc	0.012	5/13/2004	TF975	mg/L	Contamination Suspected
DW040513-0074	Zinc Dissolved	< 0.005	5/13/2004	TF975	mg/L	Contamination Suspected
DW040513-0075	Zinc	0.012	5/13/2004	TF1120	mg/L	Contamination Suspected
DW040513-0075	Zinc Dissolved	0.236	5/13/2004	TF1120	mg/L	Contamination Suspected
DW040513-0076	Zinc	0.015	5/13/2004	TFM006	mg/L	Contamination Suspected
DW040513-0076	Zinc Dissolved	0.046	5/13/2004	TFM006	mg/L	Contamination Suspected
DW040513-0077	Zinc	0.006	5/13/2004	TFJ110	mg/L	Contamination Suspected

Sample_ID	Parameter	Value	Date	Site	Units	Reason
DW040513-0077	Zinc Dissolved	0.223	5/13/2004	TFJ110	mg/L	Contamination Suspected
DW040920-0049	Zinc	0.036	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0049	Zinc Dissolved	0.244	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0050	Zinc	0.029	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0050	Zinc Dissolved	0.176	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0051	Zinc	0.034	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0051	Zinc Dissolved	0.244	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0052	Zinc	0.032	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0052	Zinc Dissolved	0.238	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0053	Zinc	0.035	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0053	Zinc Dissolved	0.249	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0054	Zinc	0.042	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0054	Zinc Dissolved	0.237	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0055	Zinc	0.041	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0055	Zinc Dissolved	0.229	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0056	Zinc	0.181	9/18/2004	TF280	mg/L	Contamination Suspected
DW040920-0056	Zinc Dissolved	0.184	9/18/2004	TF280	mg/L	Contamination Suspected

Appendix E: The diurnal oxygen-curve method for estimating primary productivity and community metabolism in the Tookany-Tacony-Frankford Creek

The diurnal oxygen-curve method for estimating primary productivity and community metabolism in streams (USGS 1987) was applied for single station analysis to TTF using continuous sonde DO, Temperature, and level data. This approach provides an estimate of gross primary productivity and community respiration by estimating the total amount of oxygen produced and consumed over a 24-hour period. It assumes that the daytime respiration rate varies linearly with time from pre-dawn to post-dusk. The net consumption or production of oxygen in the stream is estimated from measured DO concentration changes over time using finite difference methods. The measured DO concentrations and subsequent rates of DO change are adjusted for atmospheric reaeration rates which are estimated to be directly proportional to the DO saturation deficit at the measured temperature. The reaeration rate constant was estimated as a function of average stream cross-sectional velocity and hydraulic radius using the Churchill-Elmore-Buckingham formula (Churchill 1962) given by equation E1.

$$k_2 = 5.026\,(V^{9.69})\,(R^{-1.673}) \qquad \text{(E1)}$$

- V is the average stream cross-sectional velocity (ft/s)
- R is the hydraulic radius (ft)
- k_2 is the reaeration rate constant (day^{-1}) at 20^{o}C

The reaeration rate constant was adjusted for temperature (T) using:

$$K = 1.024^{(T-20)}\,k_2 \qquad \text{(E2)}$$

And, the reaeration rate was estimated by:

$$D_a = K\,(C_s - C_o) \qquad \text{(E3)}$$

- Where Da is the change in DO due to reaeration in mg / l / hour
- C_s is the DO saturation concentration at measured water temperature
- C_o is the measured DO concentration
- K is the temperature adjusted reaeration rate constant from equation (E2)

Note that in shallow turbulent streams the time needed to achieve equilibrium between the atmosphere and water may be too short for the diurnal oxygen-curve method to be used reliably (Britton 1987).

Stream cross-sectional velocity was estimated using rating curves and sonde depth measurements corrected for atmospheric pressure and adjusted for sensor offset based on relative baseflow values at the USGS stream gauge station at Frankford Creek and Castor Avenue. The rating curves were developed by field measurement over the dry weather flow regime at cross-sections near each monitoring location.

Night-time respiration rate was estimated directly from measured changes in DO concentration over time and adjusted for atmospheric reaertion rates as described above. During daytime, however, photosynthesis and respiration together account for observed changes in adjusted DO concentrations over time. Daytime respiration, therefore, was estimated to vary linearly from early morning to late evening and gross productivity determined by difference from changes in measured DO concentrations. Productivity and respiration rates estimated in this manner for site TF280 on April 30 and May 1, 2003 are shown in Figure E1. Gross daily oxygen production and consumption, expressed in mg/l, were determined by numerical integration of these rates over time seen as the area between the curves and the zero rate of DO change line in Figure E1. In addition, net daily productivity and production respiration ratio (P:R) were determined.

Productivity and respiration estimates were determined in this manner using only complete days of accepted sonde data collected to date. Each accepted day was then characterized by the number of days since the last rainfall recorded at any PWD raingage station surrounding the watershed, and only dry days with 2 or more days since the last rainfall were used in further analyses. In addition, “post” and “pre” rainfall days were identified as having either 3 to 5 and more than eight days, respectively, since the last rainfall.

In order to characterize community metabolism and better understand the role of periphytic algae between sites along the TTF creek and across seasons, various statistical analyses of productivity and respiration estimates were performed. The results of these analyses are presented in figures E2 through E5. It can be readily seen that peak metabolism rates occur during the springtime across all sites.

In addition, comparisons of “pre” and “post” storm metabolism were performed across seasons for each site. These results are presented in figures E6 through E21. There appears to be potentially significant reductions in gross productivity, gross respiration, and to a lesser extent P:R ratio between “pre” and “post” storm estimates taken during the fall samplings. Further investigation is needed.

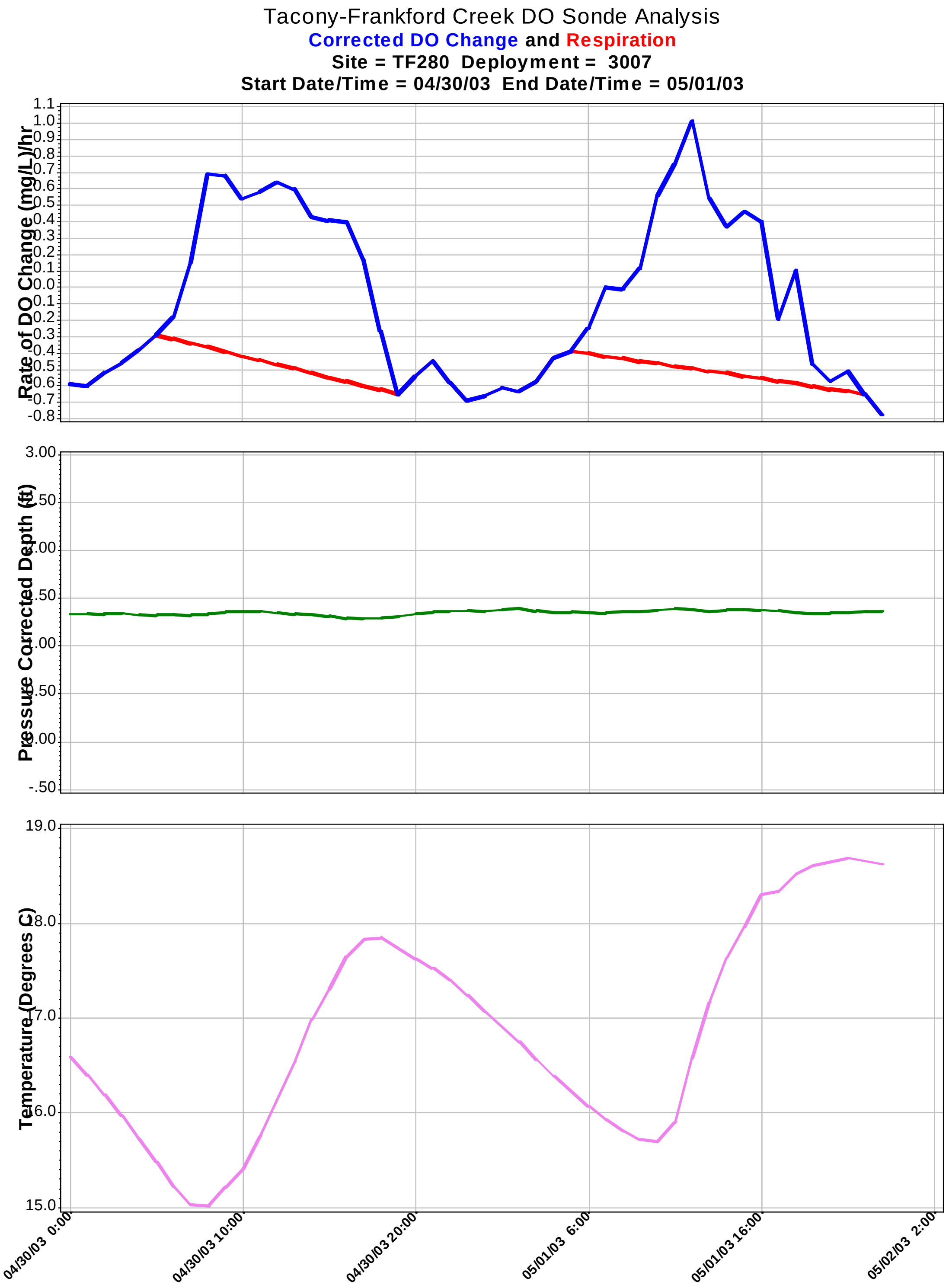
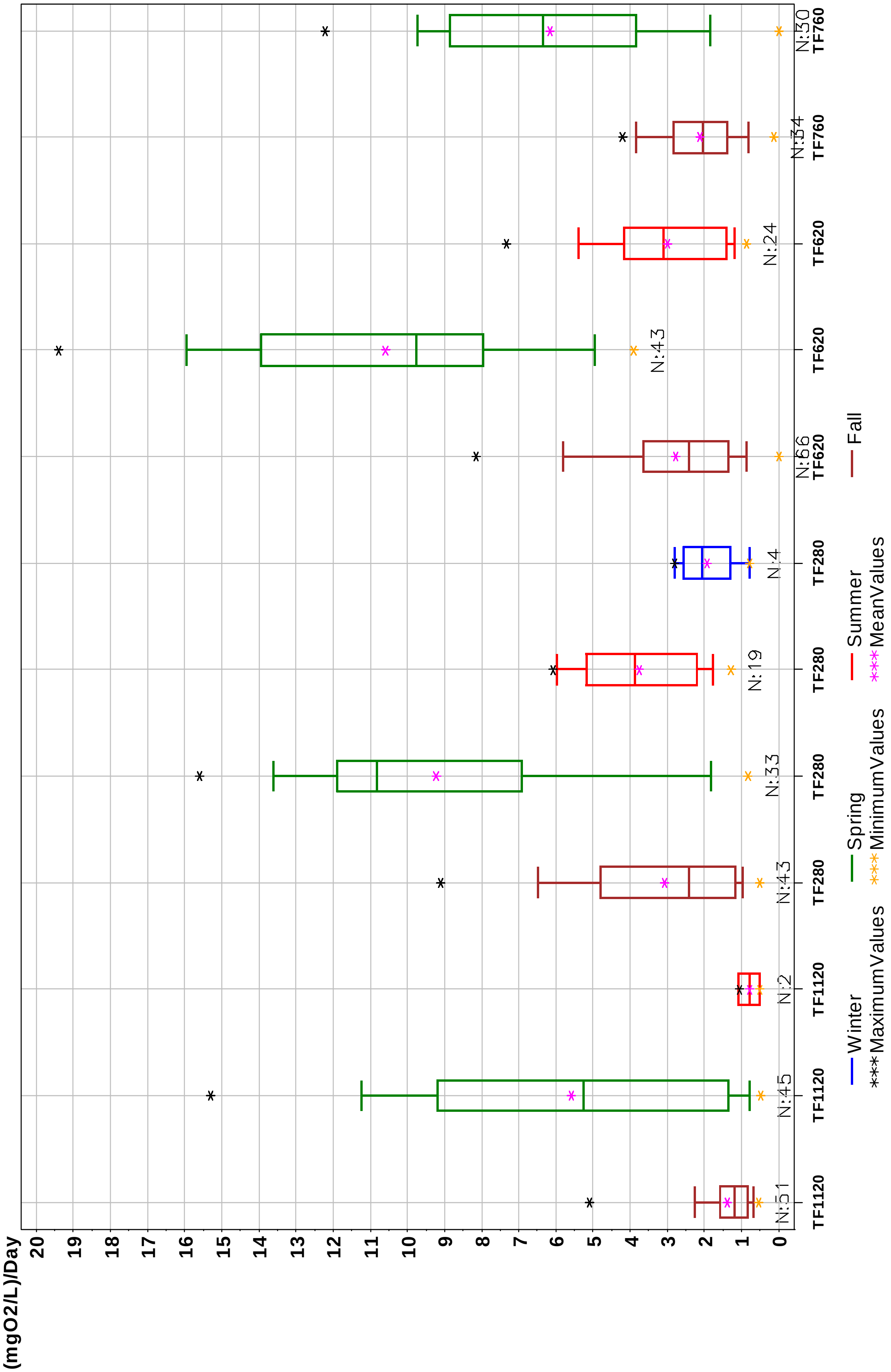


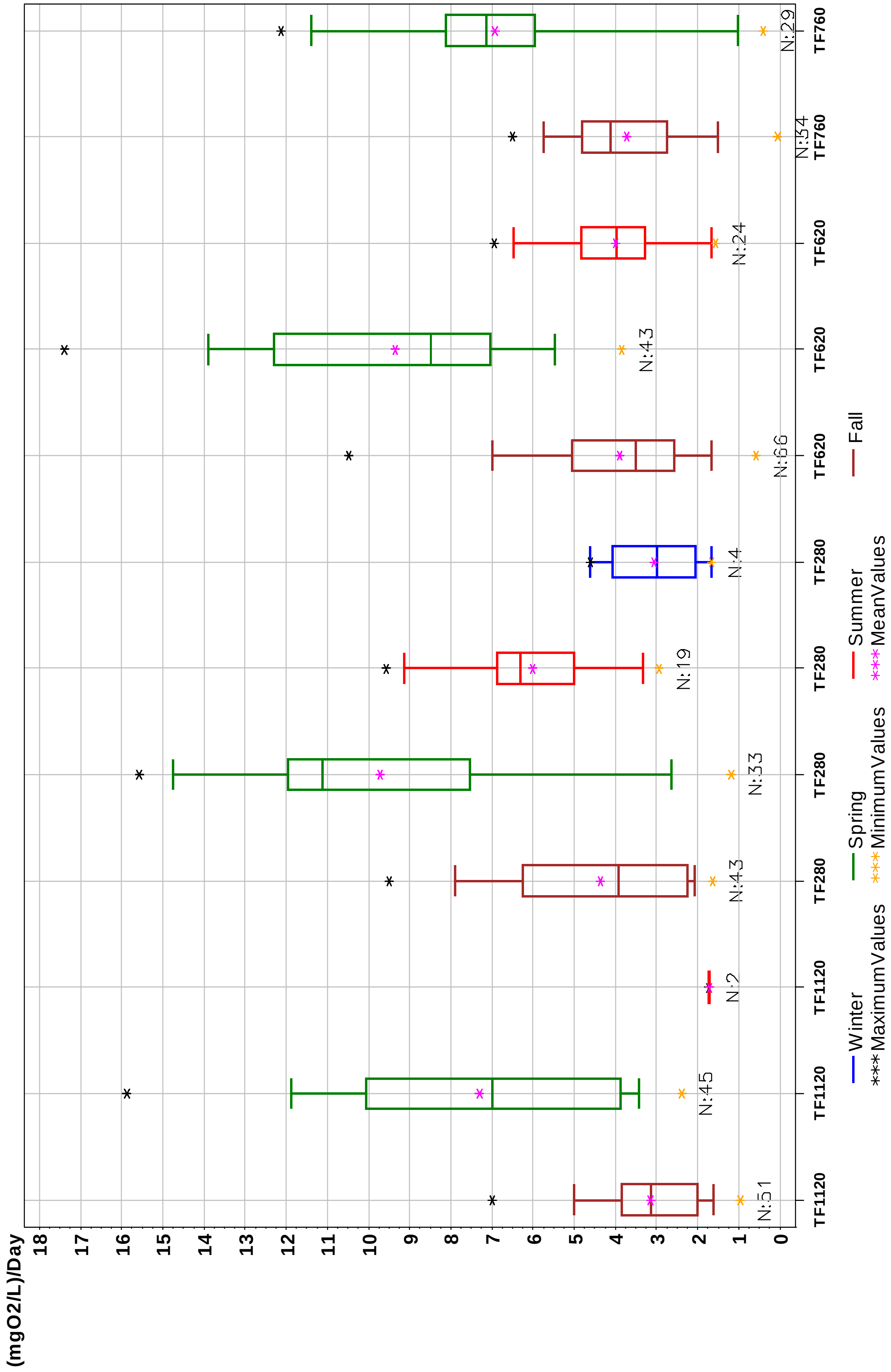
Figure E1: TTF continuous monitoring results at site TF280 for April 30 and May 1, 2003 (Top) Corrected rate of DO change and estimated daytime respiration (Middle) Pressure corrected sonde depth (Bottom) sonde Temperature measurement.

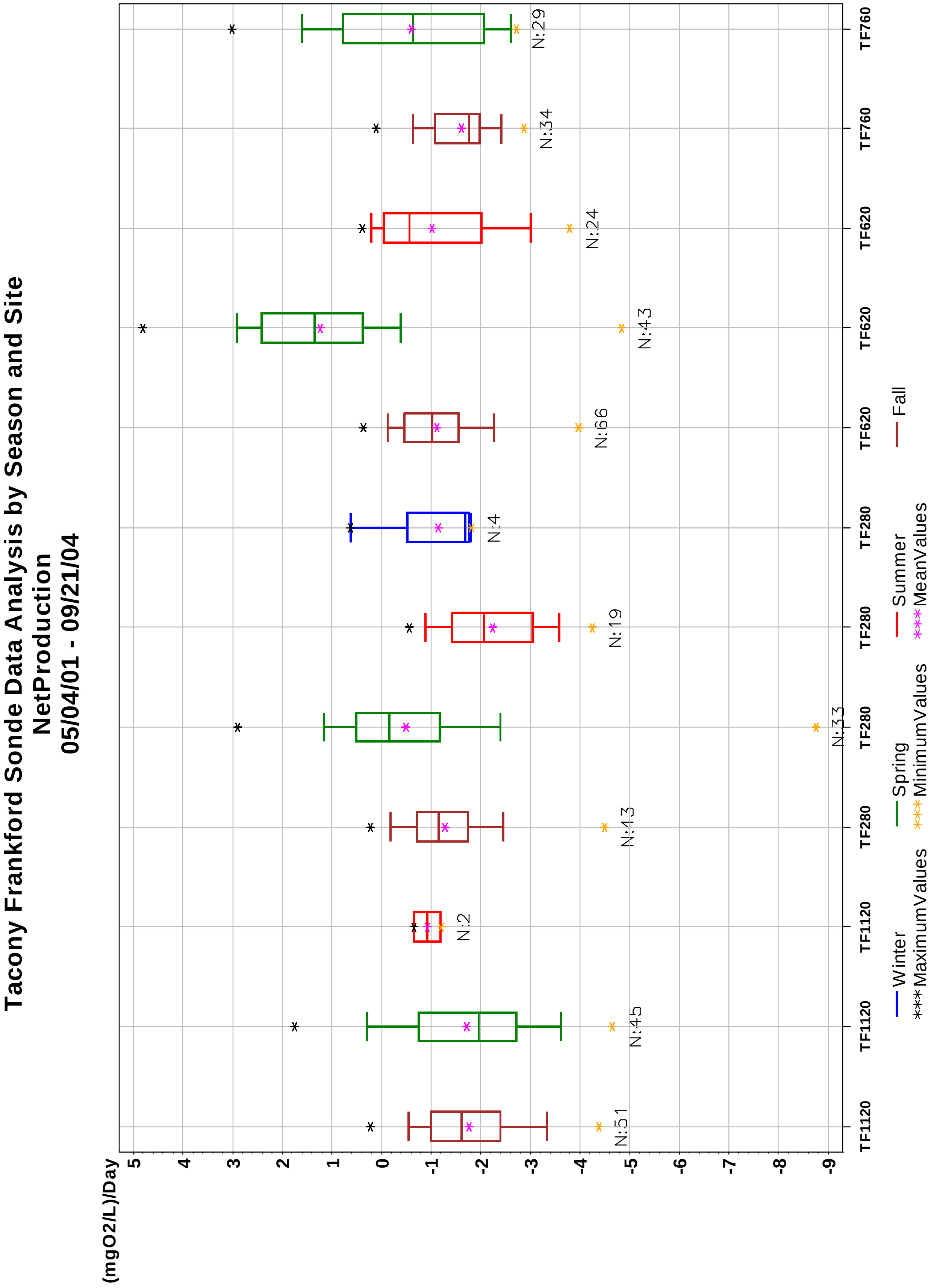
Figures E2 through E5: Comparison of statistical analysis results showing seasonal variations in gross productivity, gross respiration, net productivity, and P:R ratios across TTF monitoring locations.

Tacony Frankford Sonde Data Analysis by Season and Site
GrossProduction
05/04/01 - 09/21/04



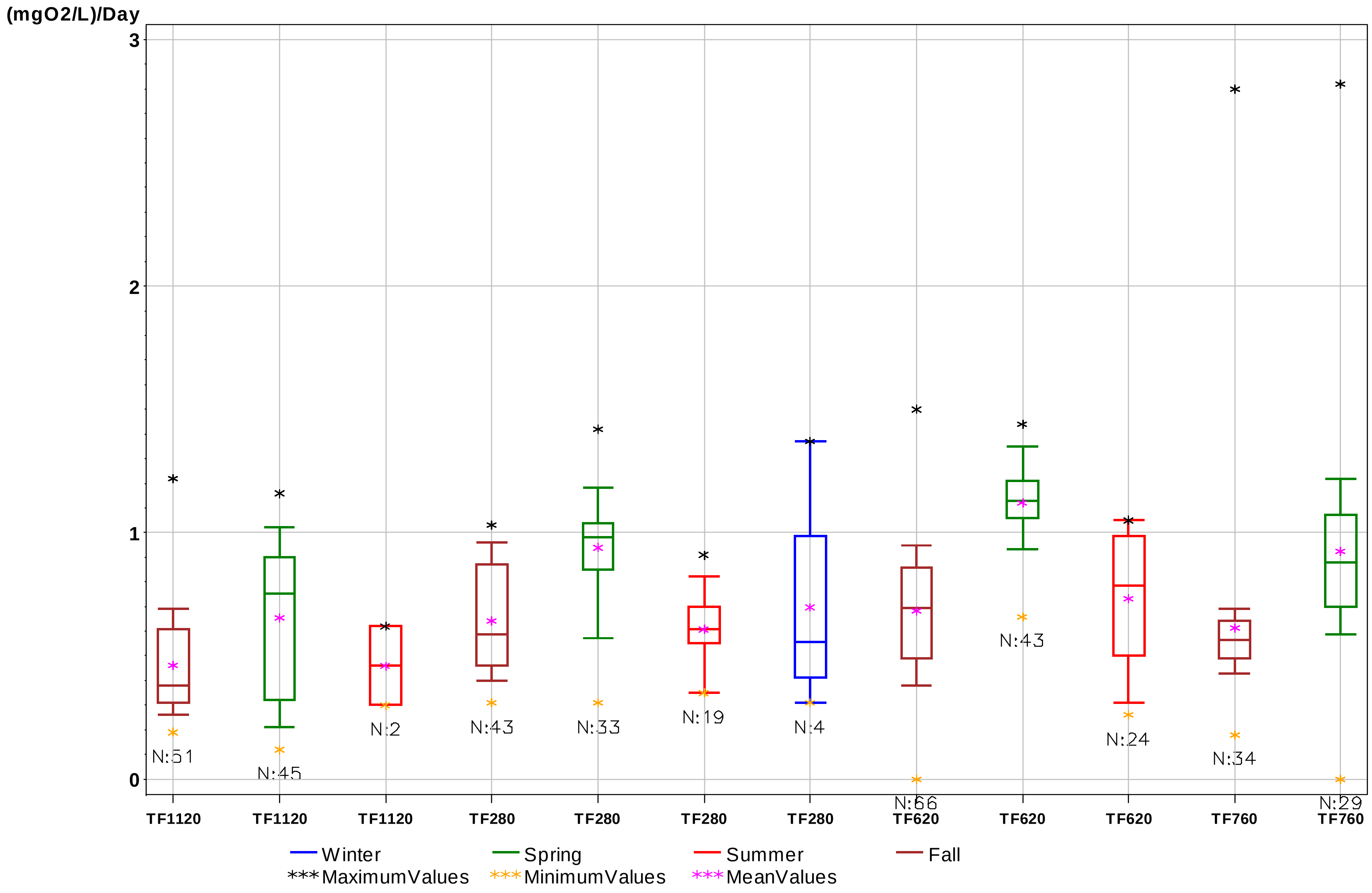
Tacony Frankford Sonde Data Analysis by Season and Site
GrossRespiration
05/04/01 - 09/21/04



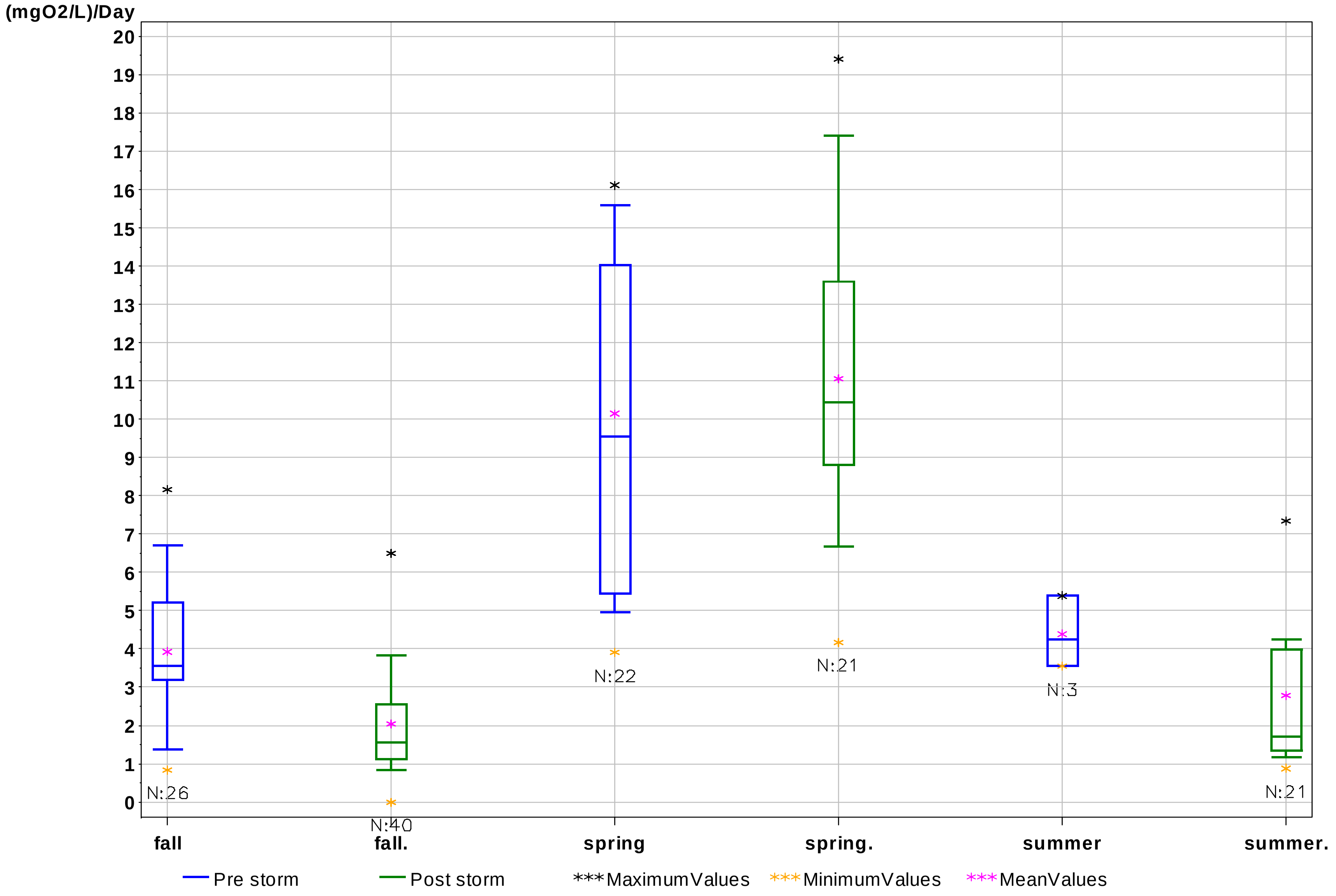


Tacony Frankford Sonde Data Analysis by Season and Site
NetProduction
05/04/01 - 09/21/04

Tacony Frankford Sonde Data Analysis by Season and Site
PRRatio
05/04/01 - 09/21/04

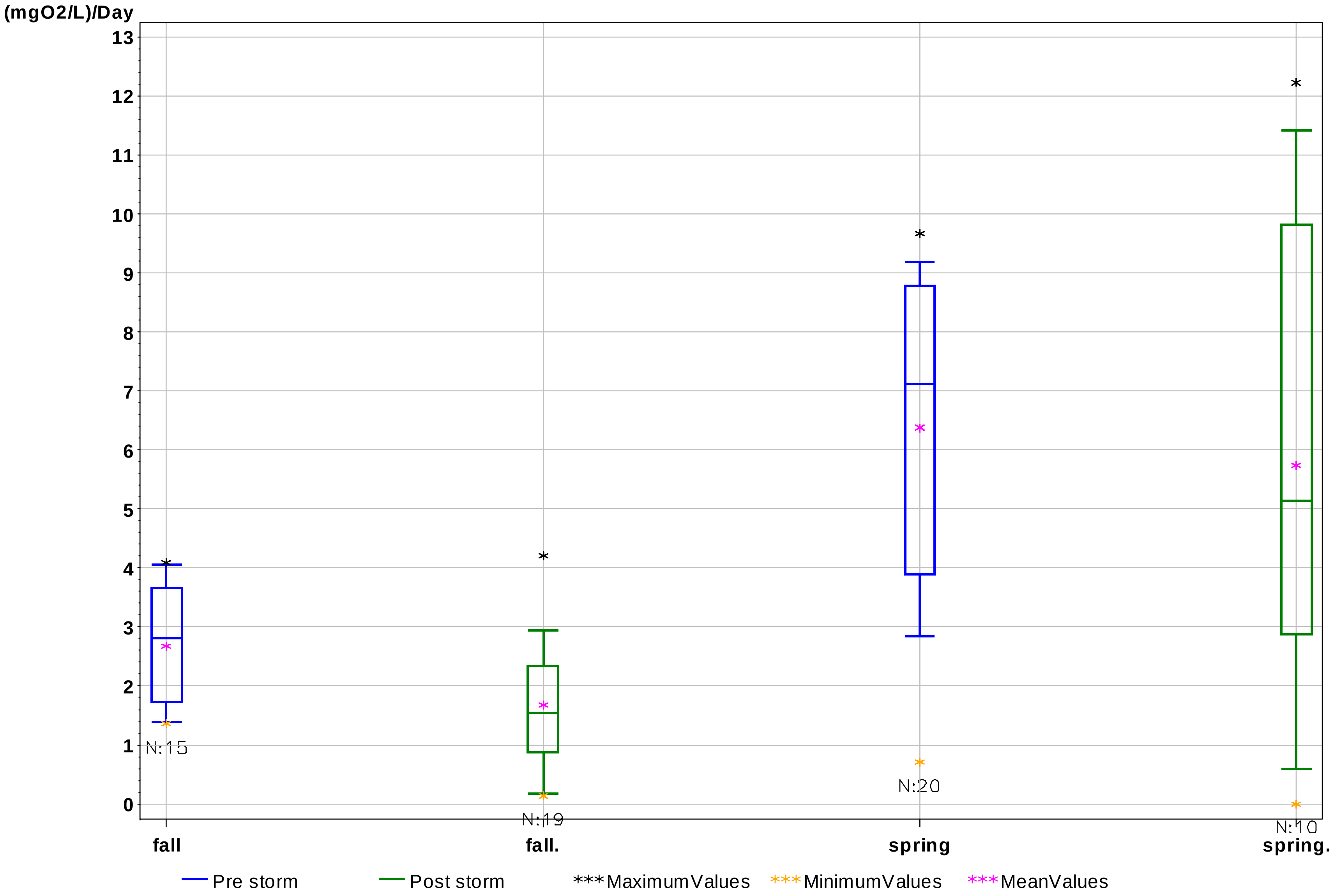


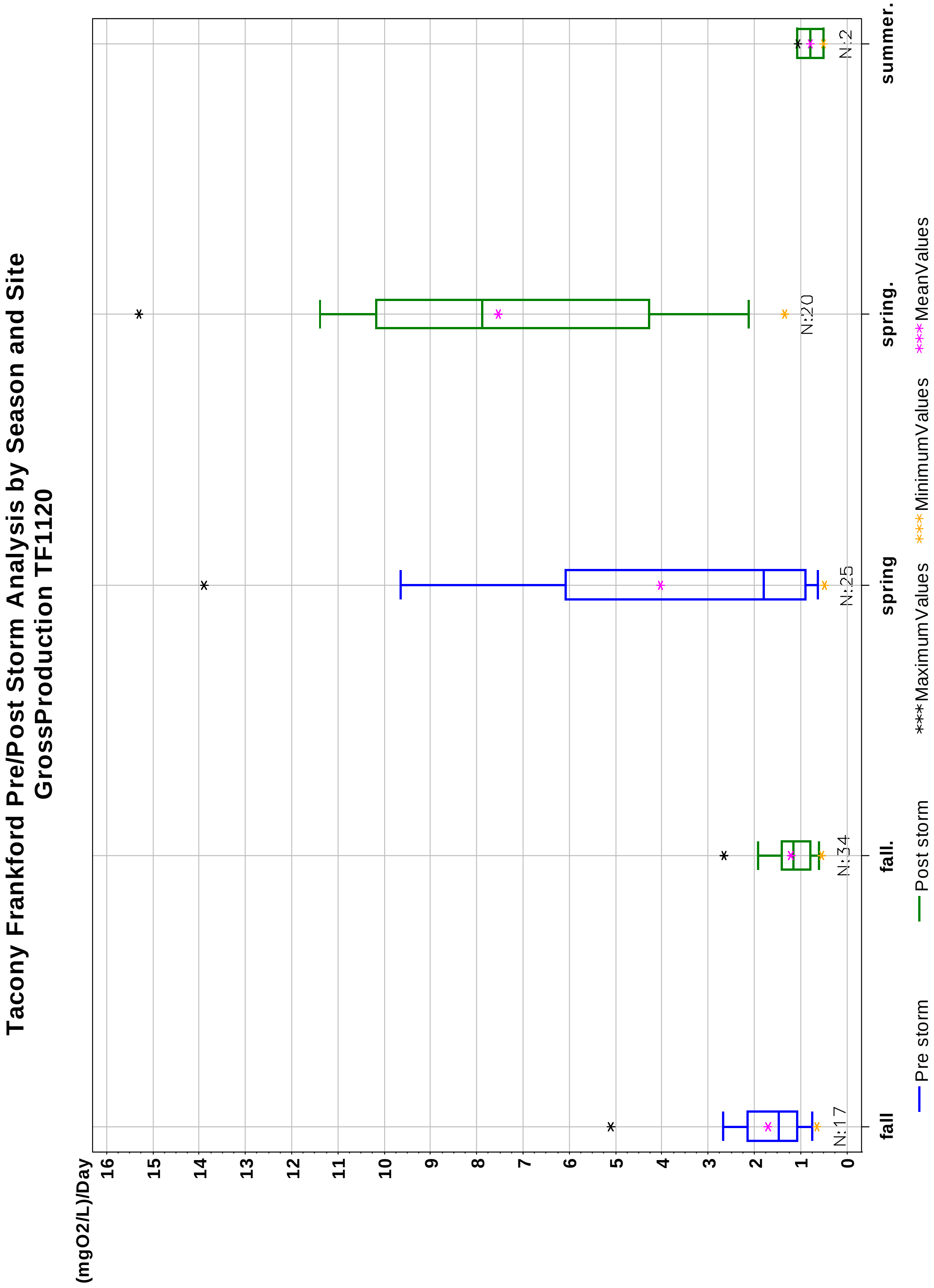
Figures E6 through E21: Comparison of statistical analysis results for “pre” and “post” storm monitoring showing seasonal variations in gross productivity, gross respiration, net productivity, and P:R ratios for each TTF monitoring location.



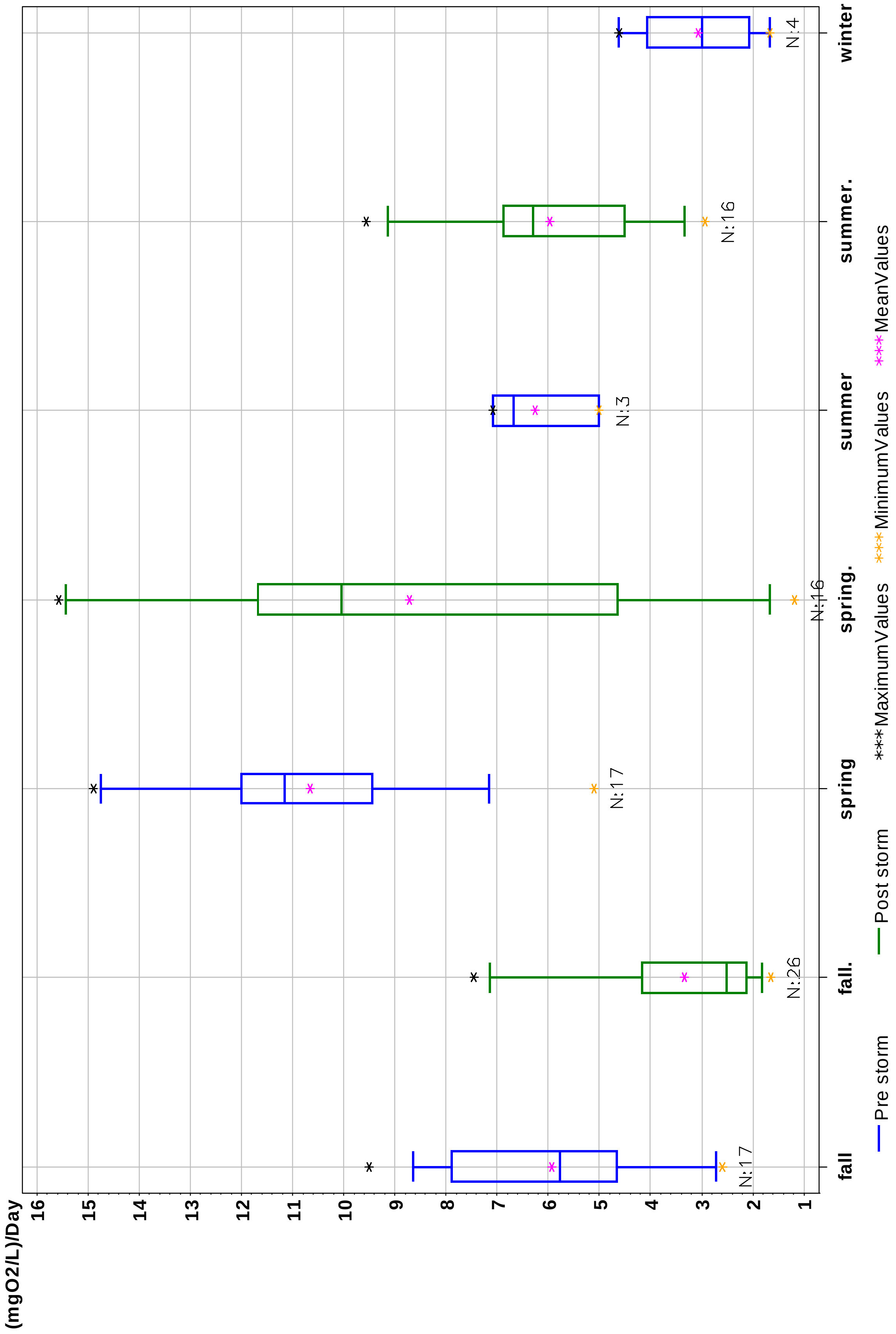
Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossProduction TF620

Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossProduction TF975

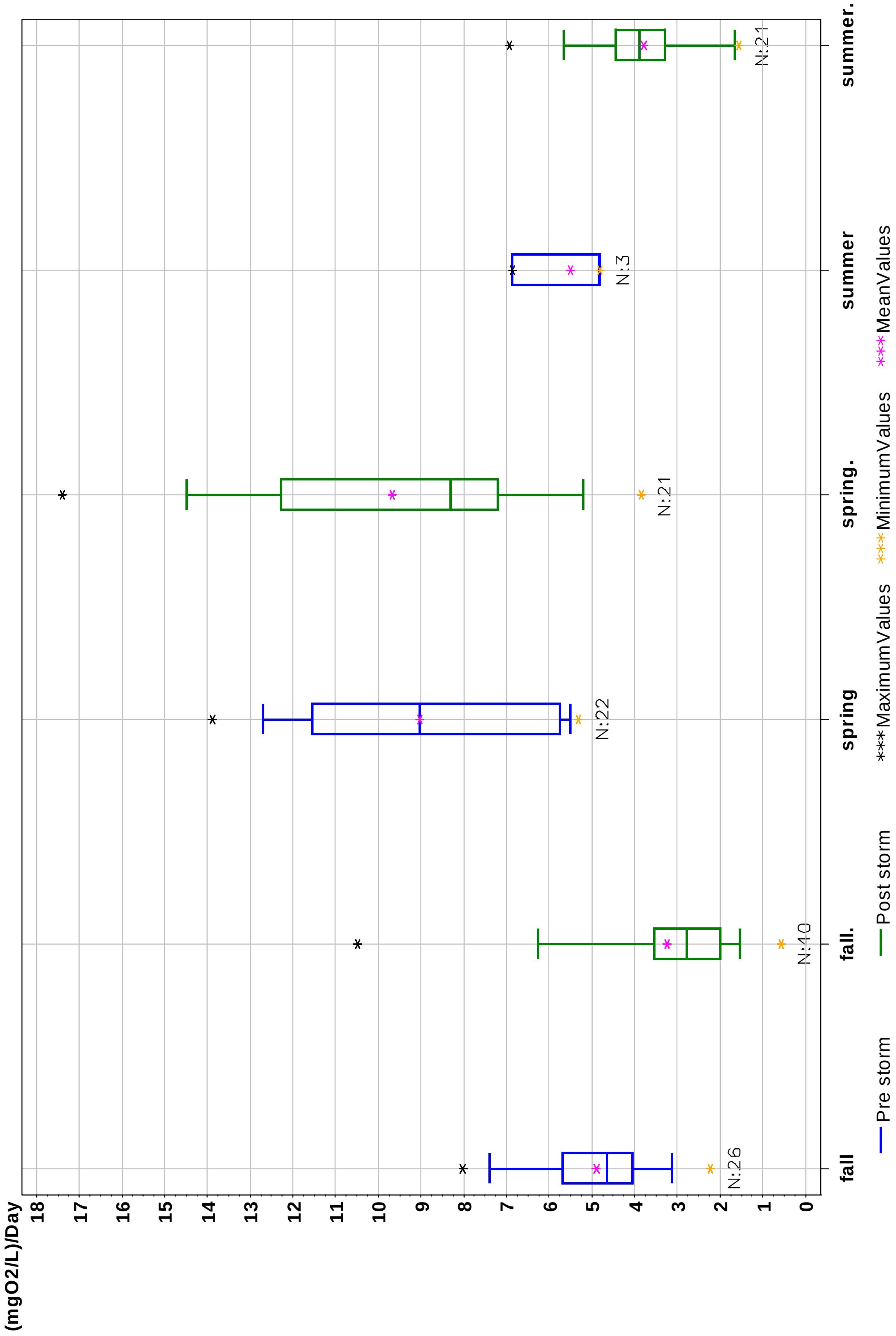


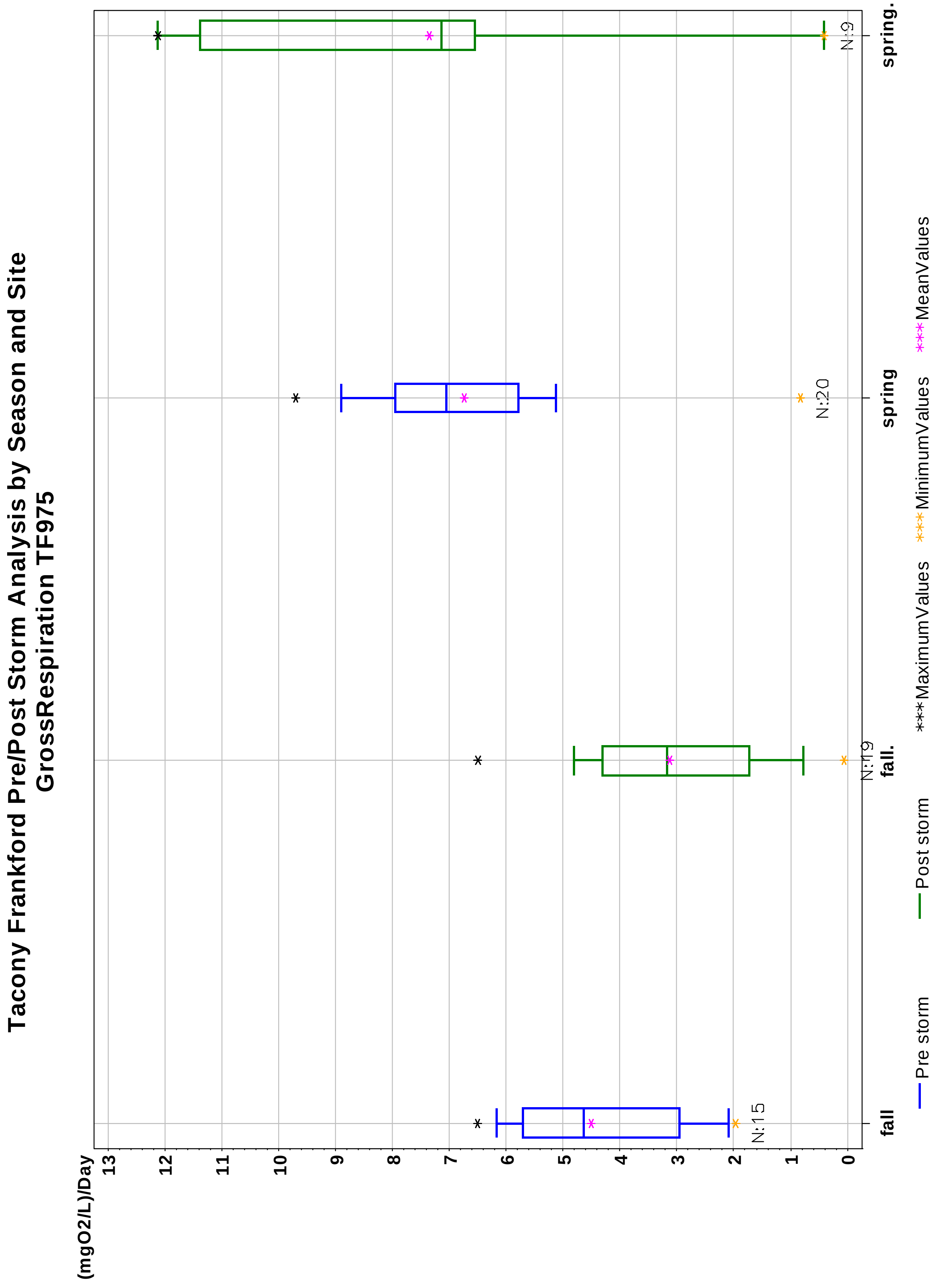

Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossProduction TF1120
(mgO2/L)/Day
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
N:17
N:34
N:25
N:20
N:2
fall
fall.
spring
spring.
summer.
Pre storm
Post storm
***MaximumValues
***MinimumValues
***MeanValues

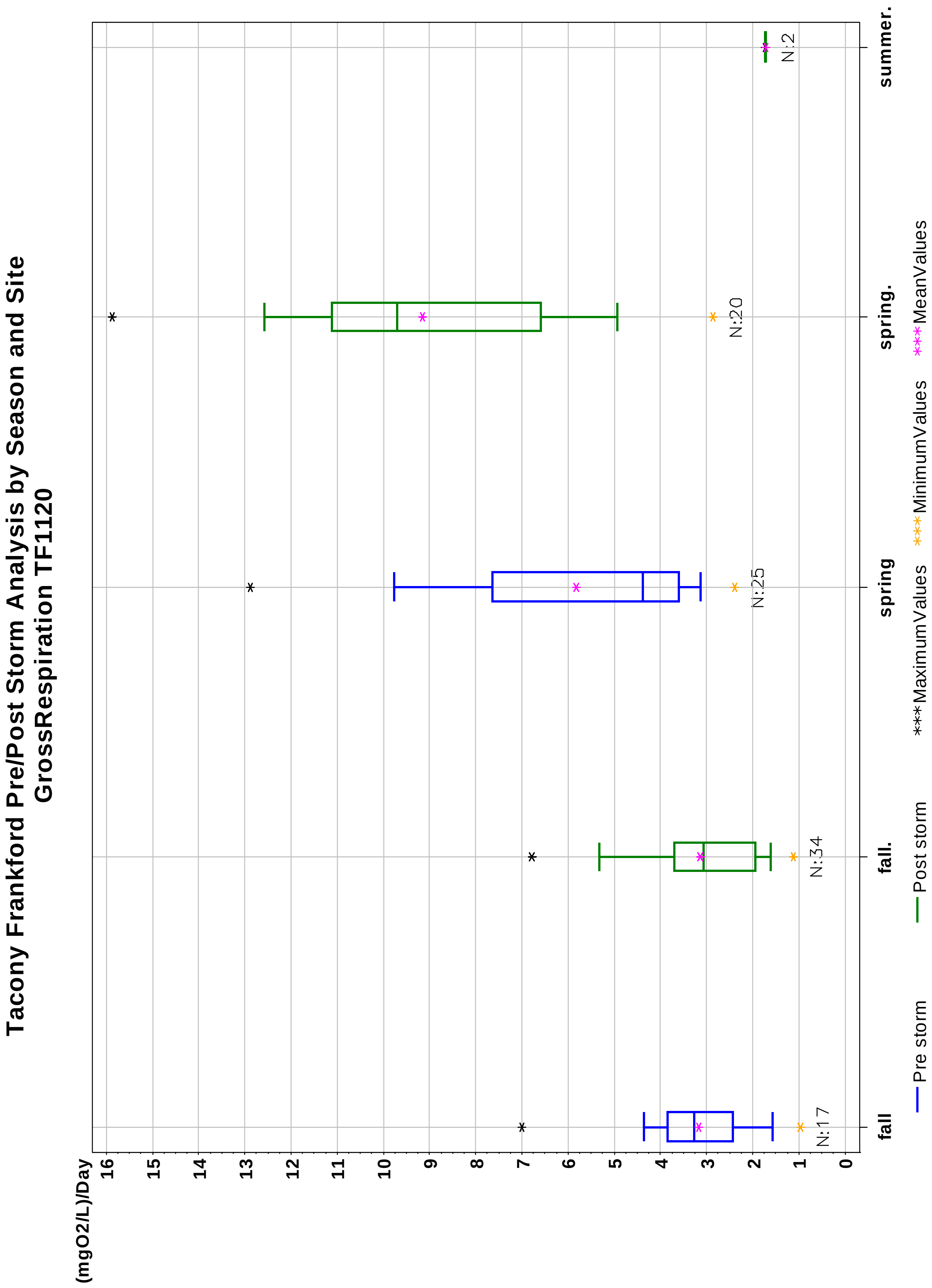
Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossRespiration TF280



Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossRespiration TF620

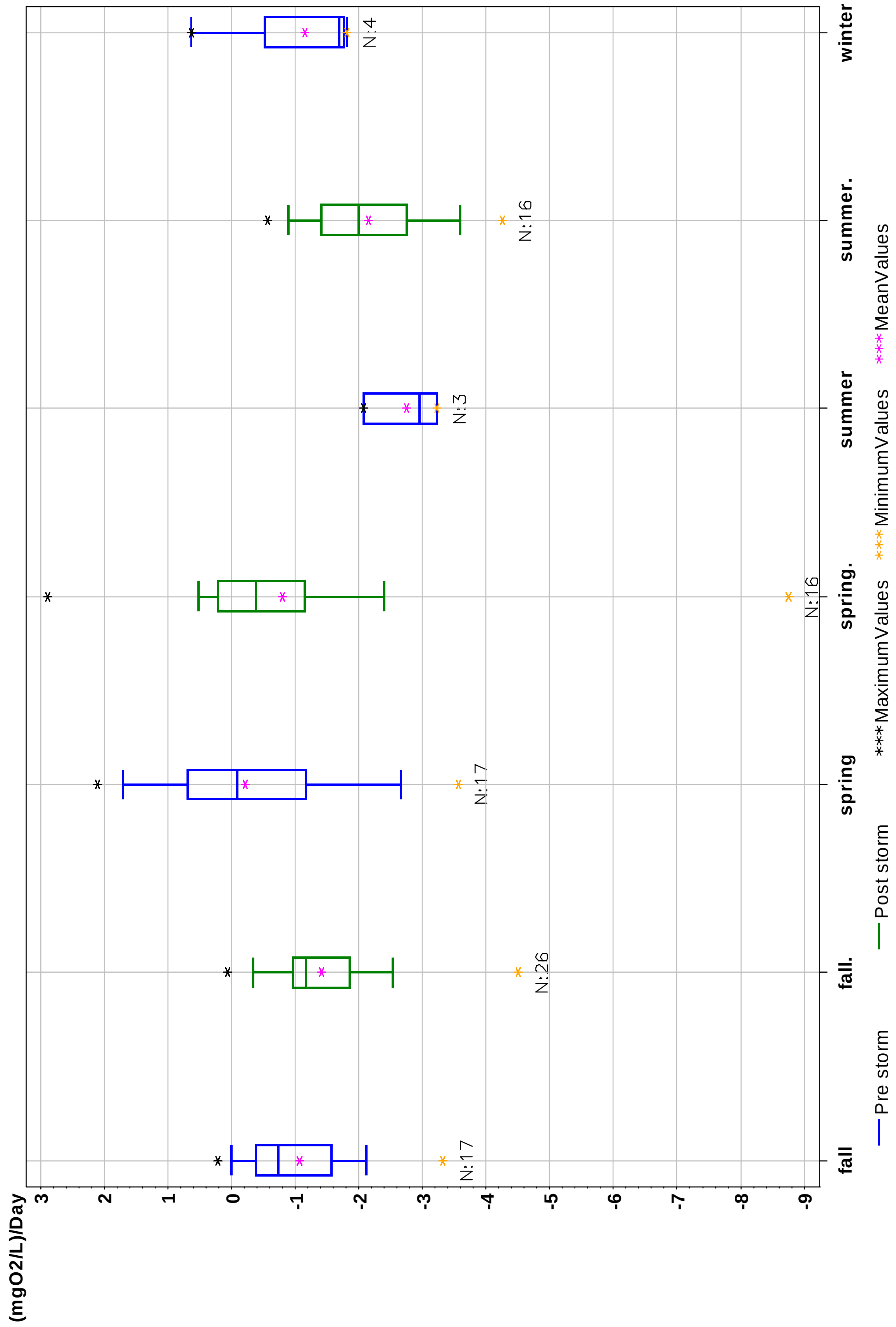


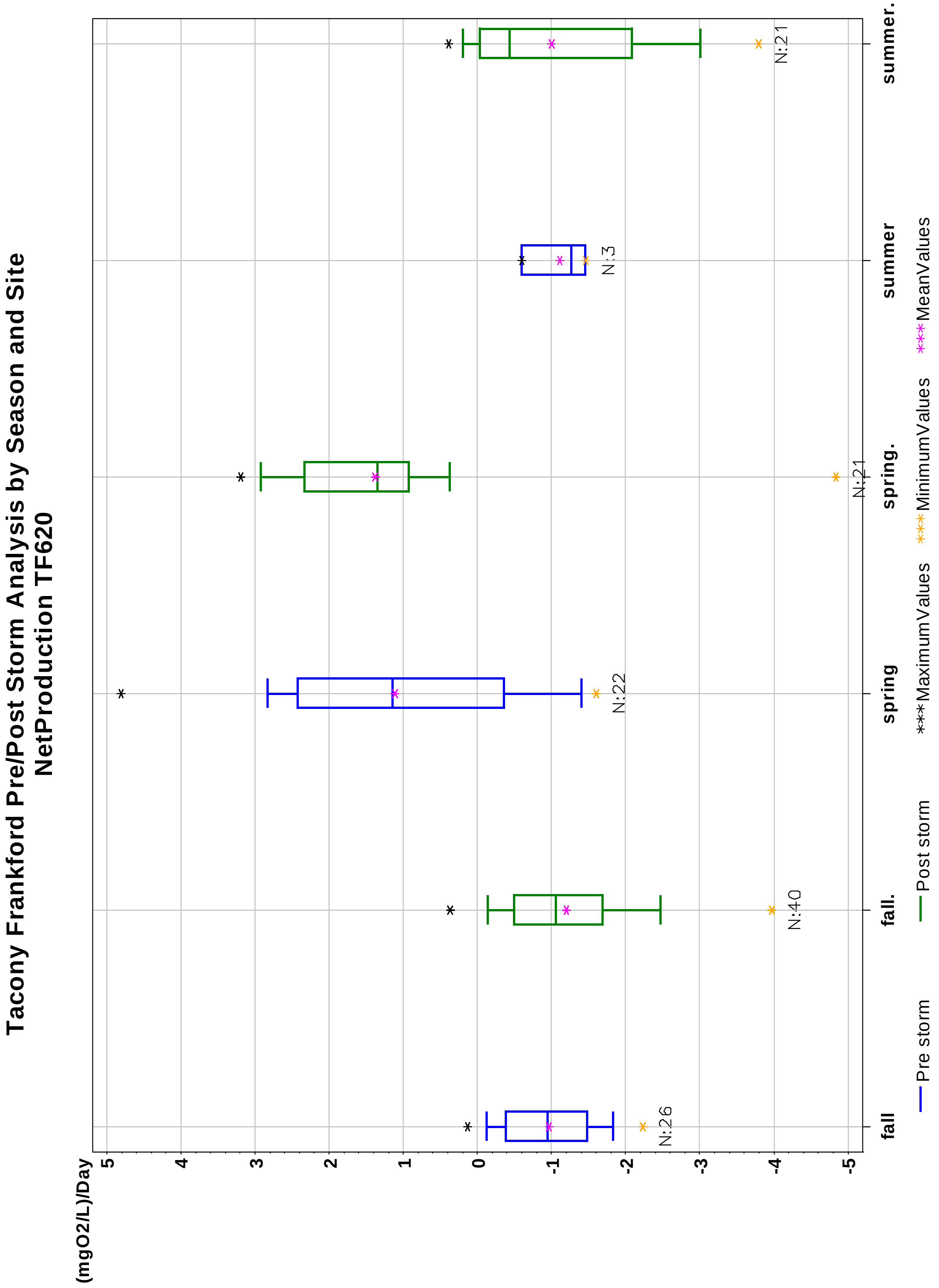

Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossRespiration TF975

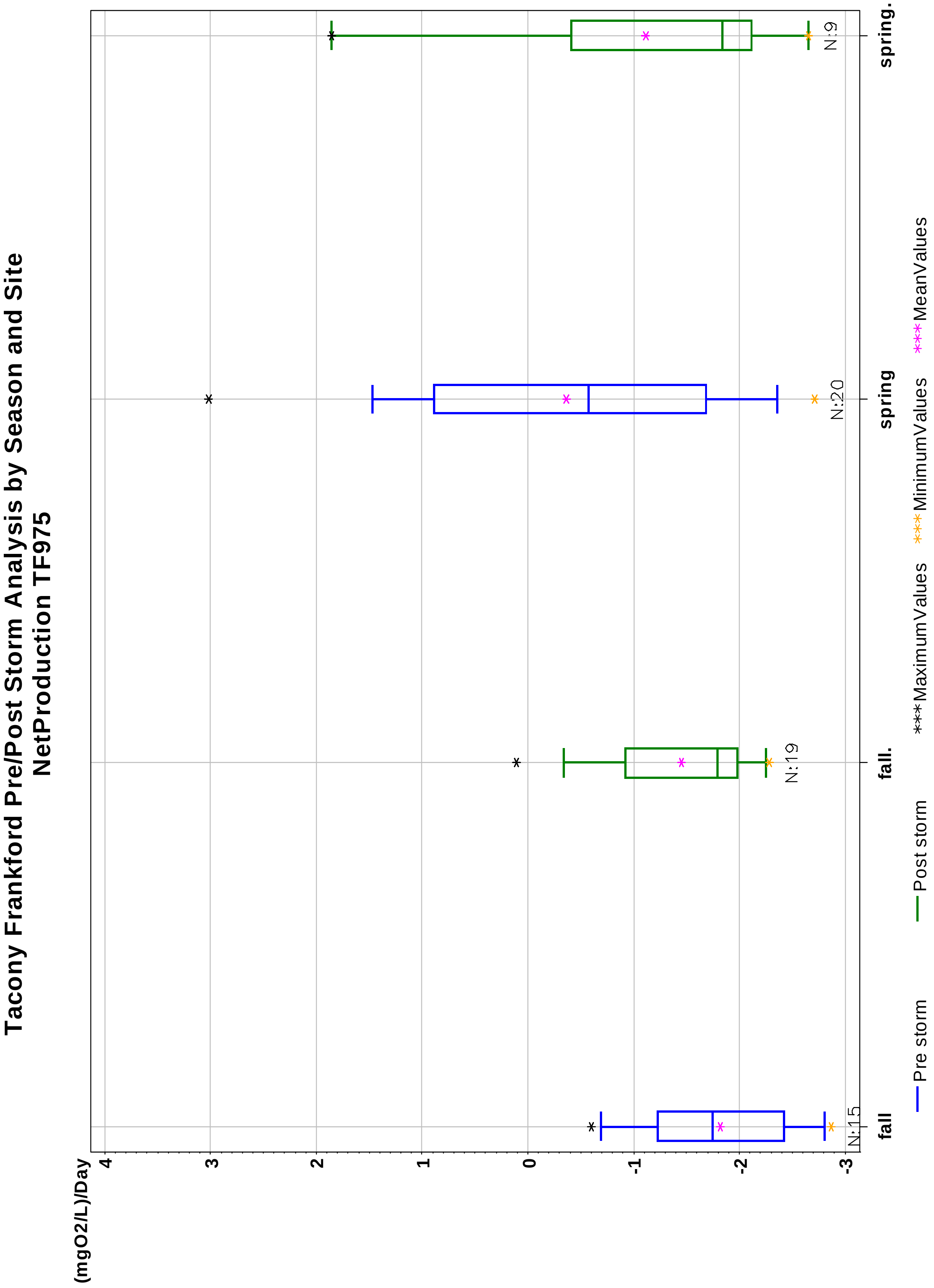


Tacony Frankford Pre/Post Storm Analysis by Season and Site
GrossRespiration TF1120

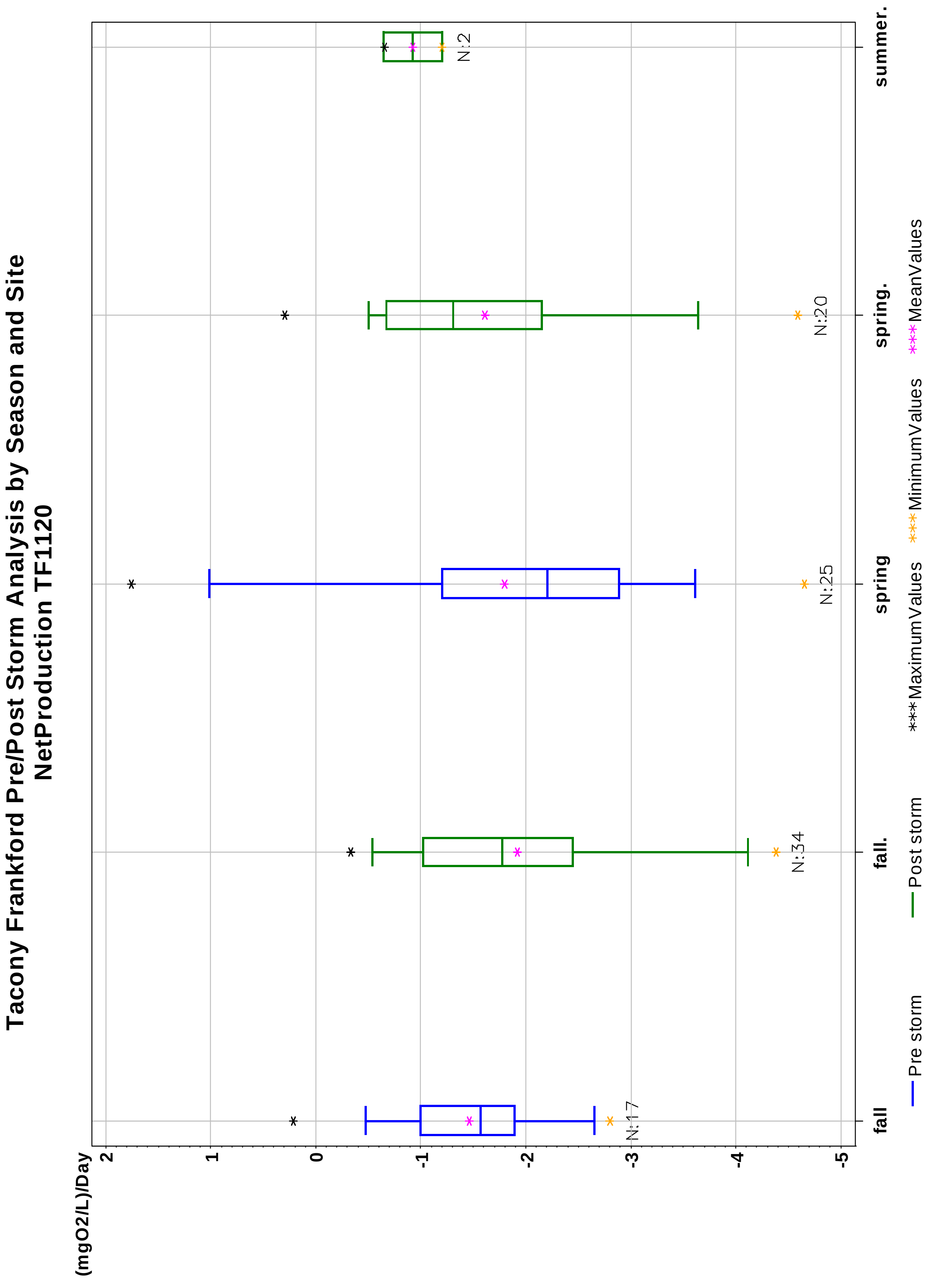
Tacony Frankford Pre/Post Storm Analysis by Season and Site
NetProduction TF280

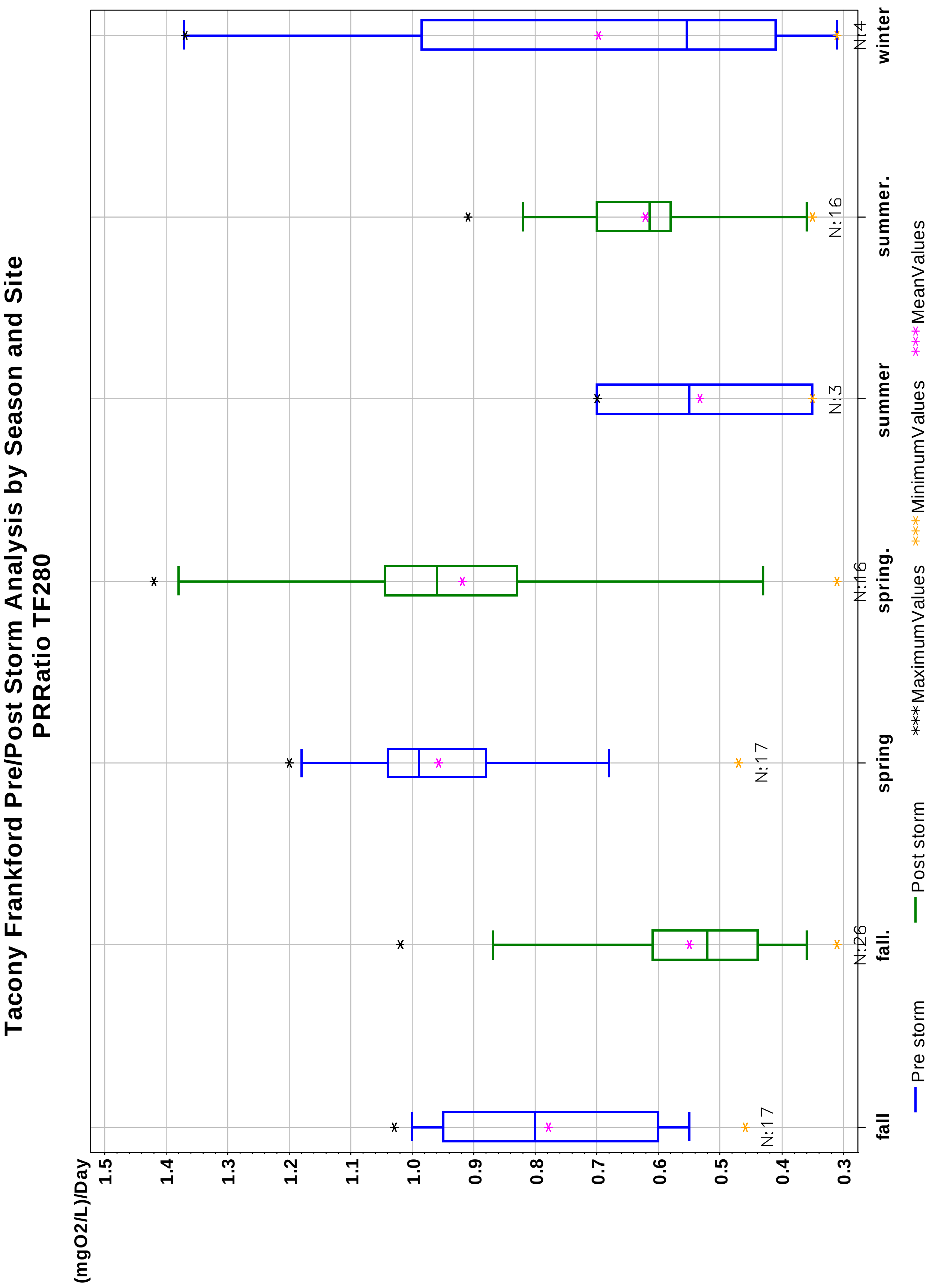



Tacony Frankford Pre/Post Storm Analysis by Season and Site
NetProduction TF620

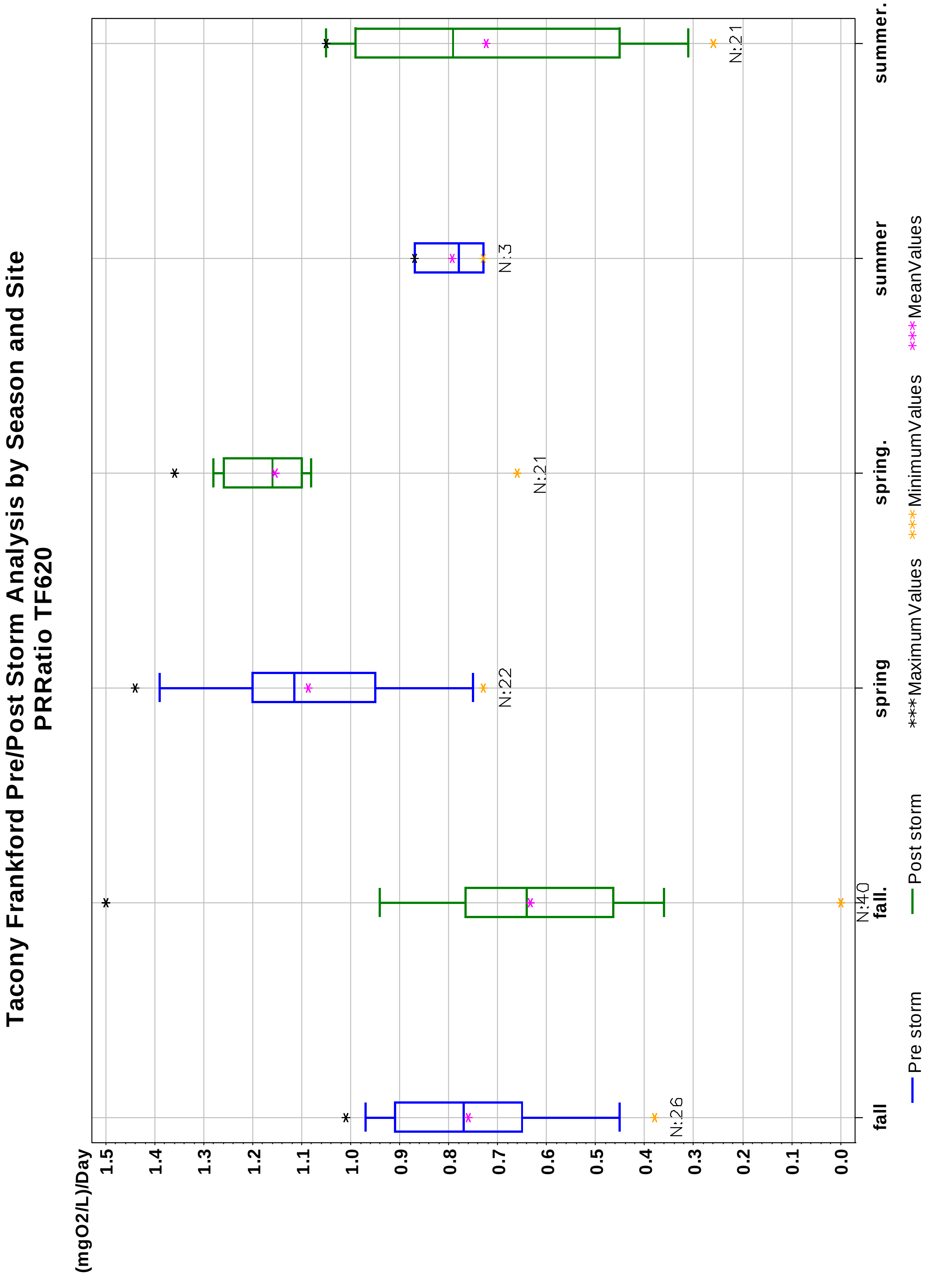


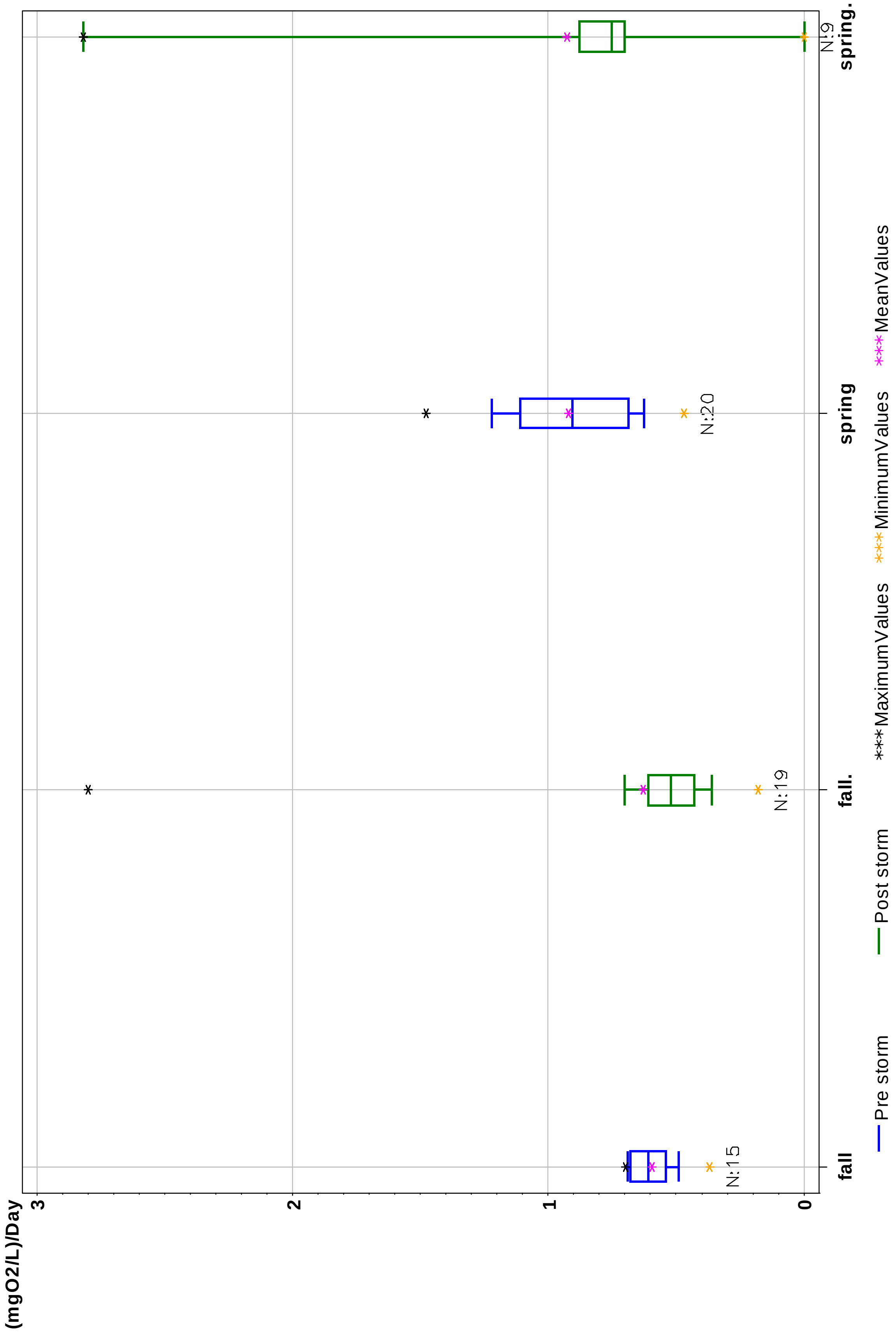
Tacony Frankford Pre/Post Storm Analysis by Season and Site
NetProduction TF975


Tacony Frankford Pre/Post Storm Analysis by Season and Site
NetProduction TF1120



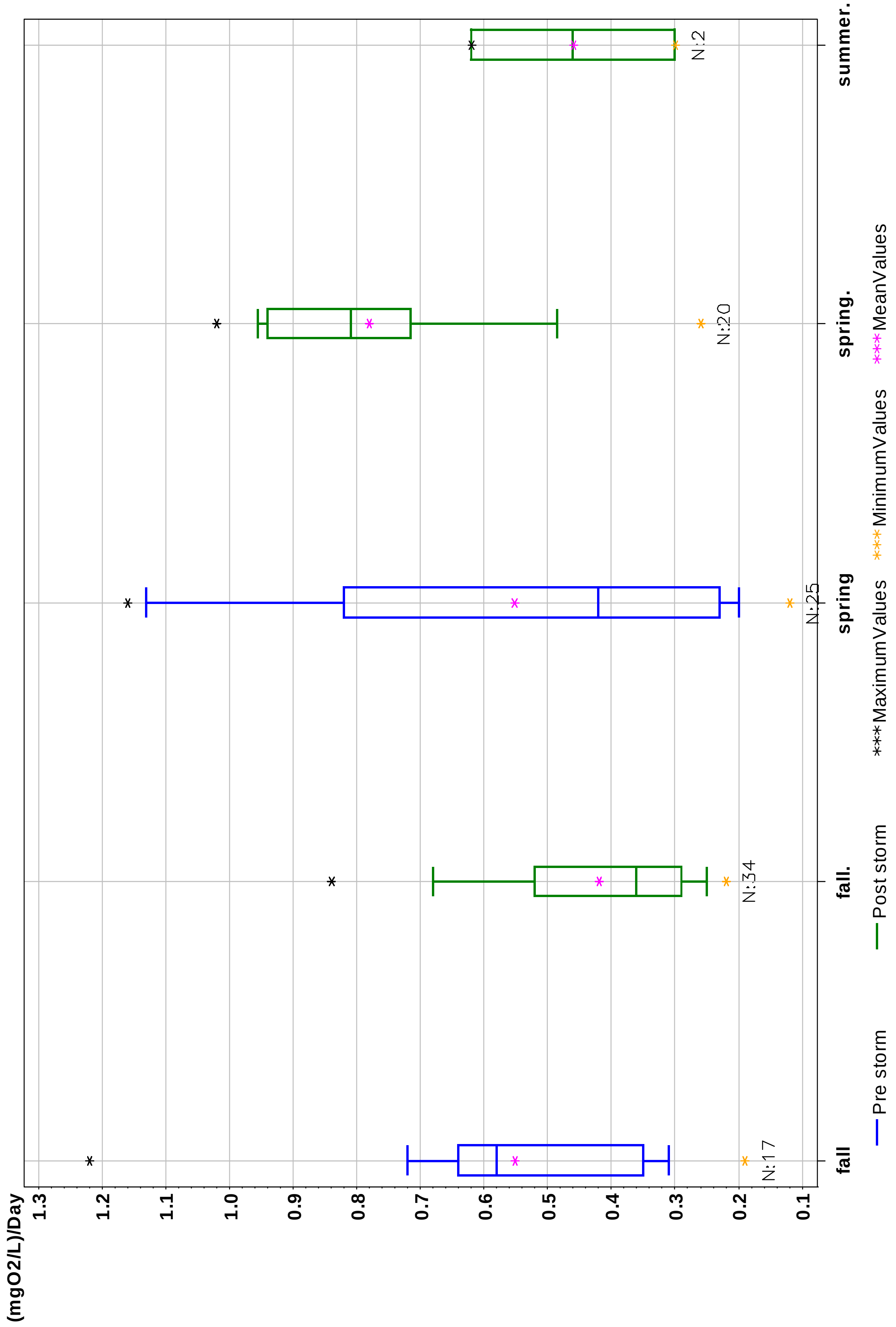
Tacony Frankford Pre/Post Storm Analysis by Season and Site
PRRatio TF280


Tacony Frankford Pre/Post Storm Analysis by Season and Site
PRRatio TF620



Tacony Frankford Pre/Post Storm Analysis by Season and Site
PRRatio TF975

Tacony Frankford Pre/Post Storm Analysis by Season and Site
PRRatio TF1120



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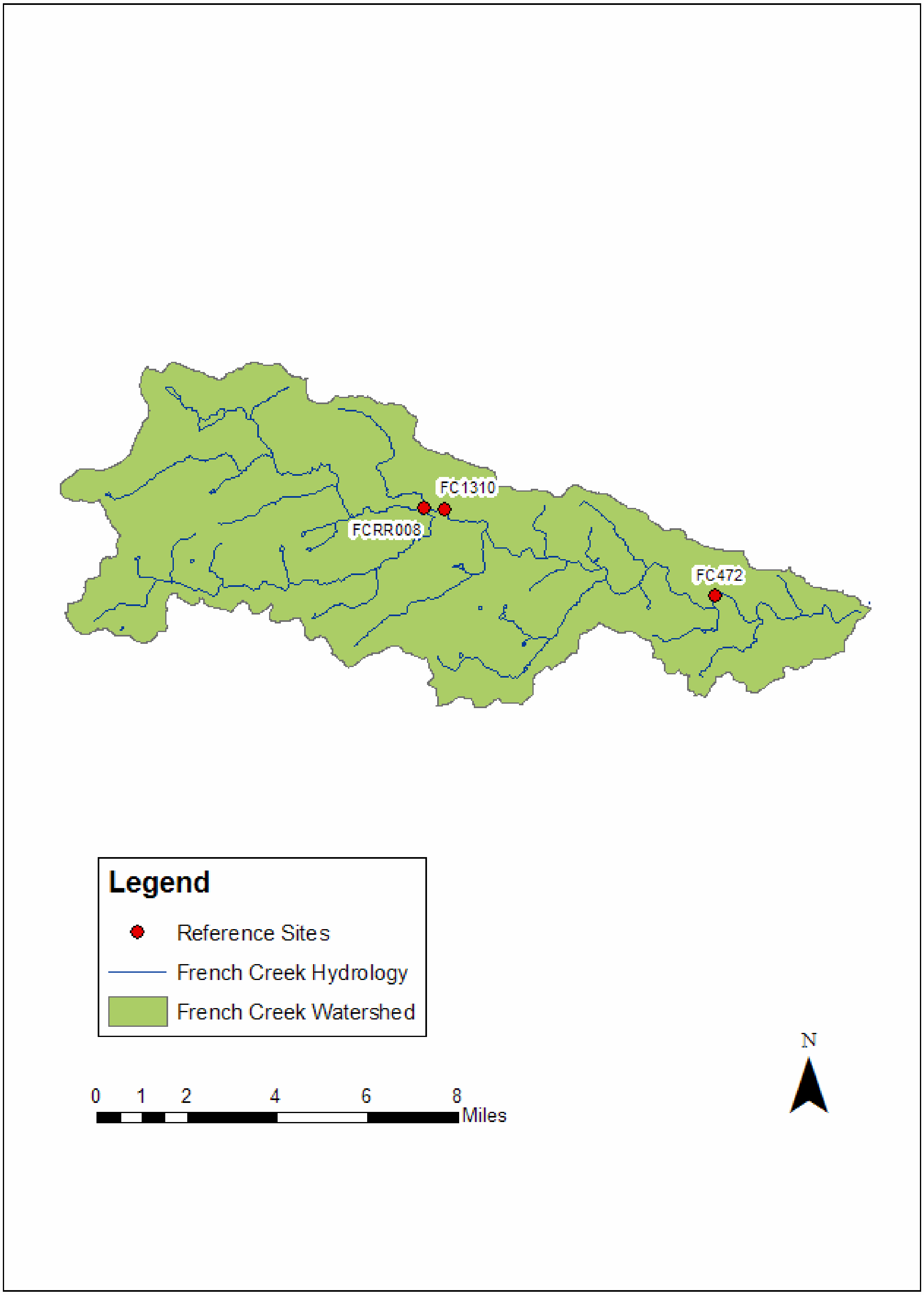
Churchill, M. A., Elmore H. L., Buckingham, R.A., 1962, The prediction of stream reaeration rates, Journal of the Sanitary Engineering Division Proceedings of the American Society of Civil Engineers, v 88, no. SA-4, p 1-46.

O'Connell, Richard L., Thomas, Nelson A., 1965, Effect of Benthic Algea on Stream Dissolved Oxygen, Journal of the Sanitary Engineering Division Proceedings of the American Society of Civil Engineers, no. SA-3, p 1-16.

Appendix F: Reference Site Locations



Appendix I All Chlorophyll data collected from Tookany/Tacony-Frankford Watershed 2000-2005

Samples in **bold font** are periphyton samples

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW000629-0046	6/29/2000 8:40	TF280	Chlorophyll a (approx)	6.23	ug/L	1
DW000629-0050	6/29/2000 8:57	TF975	Chlorophyll a (approx)	3.03	ug/L	1
DW000629-0047	6/29/2000 9:20	TF500	Chlorophyll a (approx)	5.26	ug/L	1
DW000629-0051	6/29/2000 9:30	TF1120	Chlorophyll a (approx)	1.39	ug/L	1
DW000629-0052	6/29/2000 9:57	TFJ110	Chlorophyll a (approx)	1.58	ug/L	1
DW000629-0048	6/29/2000 10:00	TF620	Chlorophyll a (approx)	3.97	ug/L	1
DW000629-0049	6/29/2000 10:30	TF760	Chlorophyll a (approx)	3.72	ug/L	1
DW000706-0043	7/6/2000 8:30	TF280	Chlorophyll a (approx)	10.85	ug/L	0
DW000706-0047	7/6/2000 9:05	TF975	Chlorophyll a (approx)	1.96	ug/L	0
DW000706-0044	7/6/2000 9:10	TF500	Chlorophyll a (approx)	4.06	ug/L	0
DW000706-0048	7/6/2000 9:39	TF1120	Chlorophyll a (approx)	0.71	ug/L	0
DW000706-0045	7/6/2000 9:45	TF620	Chlorophyll a (approx)	3.13	ug/L	0
DW000706-0046	7/6/2000 10:20	TF760	Chlorophyll a (approx)	3.49	ug/L	0
DW000810-00□3	8/10/2000 8:25	TF280	Chlorophyll a (approx)	2.19	ug/L	1
DW000810-0039	8/10/2000 8:40	TF975	Chlorophyll a (approx)	0.84	ug/L	1
DW000810-0044	8/10/2000 9:30	TF500	Chlorophyll a (approx)	2.94	ug/L	1
DW000810-0045	8/10/2000 9:55	TF620	Chlorophyll a (approx)	2.25	ug/L	1
DW000810-0046	8/10/2000 10:25	TF760	Chlorophyll a (approx)	5.13	ug/L	1
DW000831-0044	8/31/2000 8:54	TF975	Chlorophyll a (approx)	2.06	ug/L	0
DW000831-0047	8/31/2000 9:05	TF280	Chlorophyll a (approx)	15.66	ug/L	0
DW000831-0045	8/31/2000 9:30	TF1120	Chlorophyll a (approx)	1.99	ug/L	0
DW000831-0048	8/31/2000 9:50	TF500	Chlorophyll a (approx)	4.99	ug/L	0
DW000831-0049	8/31/2000 10:25	TF620	Chlorophyll a (approx)	4.48	ug/L	0
DW000831-0050	8/31/2000 11:00	TF760	Chlorophyll a (approx)	4.25	ug/L	0
DW000914-0041	9/14/2000 7:55	TF280	Chlorophyll a (approx)	2.87	ug/L	0
DW000914-0038	9/14/2000 8:14	TF975	Chlorophyll a (approx)	1.38	ug/L	0
DW000914-0042	9/14/2000 8:45	TF500	Chlorophyll a (approx)	2.64	ug/L	0
DW000914-0039	9/14/2000 8:55	TF1120	Chlorophyll a (approx)	2.93	ug/L	0
DW000914-0043	9/14/2000 9:20	TF620	Chlorophyll a (approx)	1.94	ug/L	0
DW000914-0040	9/14/2000 9:25	TFJ110	Chlorophyll a (approx)	0.75	ug/L	0
DW000914-0044	9/14/2000 9:50	TF760	Chlorophyll a (approx)	1.88	ug/L	0
DW000928-0042	9/28/2000 8:45	TF280	Chlorophyll a (approx)	0.77	ug/L	0
DW000928-0039	9/28/2000 8:55	TF975	Chlorophyll a (approx)	0.59	ug/L	0
DW000928-0040	9/28/2000 9:30	TF1120	Chlorophyll a (approx)	2.57	ug/L	0
DW000928-0041	9/28/2000 10:10	TFJ110	Chlorophyll a (approx)	0.85	ug/L	0
DW000928-0045	9/28/2000 10:40	TF760	Chlorophyll a (approx)	0.55	ug/L	0
DW001012-0048	10/12/2000 8:40	TF280	Chlorophyll a (approx)	1.17	ug/L	0
DW001012-0049	10/12/2000 9:35	TF500	Chlorophyll a (approx)	1.03	ug/L	0
DW001012-0053	10/12/2000 9:55	TF975	Chlorophyll a (approx)	1.04	ug/L	0
DW001012-0050	10/12/2000 10:10	TF620	Chlorophyll a (approx)	1.02	ug/L	0
DW001012-0054	10/12/2000 10:33	TF1120	Chlorophyll a (approx)	0.85	ug/L	0
DW001012-0051	10/12/2000 10:40	TF760	Chlorophyll a (approx)	1.16	ug/L	0
DW001026-0085	10/26/2000 8:45	TF280	Chlorophyll a (approx)	3.07	ug/L	0
DW001026-0089	10/26/2000 9:25	TF975	Chlorophyll a (approx)	1.14	ug/L	0

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW001026-0090	10/26/2000 9:25	TF1120	Chlorophyll a (approx)	0.57	ug/L	0
DW001026-0086	10/26/2000 9:40	TF500	Chlorophyll a (approx)	2.65	ug/L	0
DW001026-0087	10/26/2000 10:15	TF620	Chlorophyll a (approx)	2.10	ug/L	0
DW001026-0088	10/26/2000 10:40	TF760	Chlorophyll a (approx)	2.02	ug/L	0
DW001109-0054	11/9/2000 8:55	TF280	Chlorophyll a (approx)	4.32	ug/L	0
DW001109-0055	11/9/2000 9:25	TF500	Chlorophyll a (approx)	6.65	ug/L	0
DW001109-0067	11/9/2000 9:57	TF975	Chlorophyll a (approx)	3.34	ug/L	0
DW001109-0056	11/9/2000 10:05	TF620	Chlorophyll a (approx)	3.95	ug/L	0
DW001109-0068	11/9/2000 10:40	TF1120	Chlorophyll a (approx)	9.59	ug/L	0
DW001109-0057	11/9/2000 10:50	TF760	Chlorophyll a (approx)	1.12	ug/L	0
DW001109-0069	11/9/2000 11:18	TFJ110	Chlorophyll a (approx)	0.63	ug/L	0
DW010319-0061	3/19/2001 13:45	TF280	Chlorophyll a (approx)	2.10	ug/L	0
DW010321-0055	3/21/2001 10:35	TF280	Chlorophyll a (approx)	2.93	ug/L	1
DW010321-0057	3/21/2001 12:35	TF280	Chlorophyll a (approx)	4.50	ug/L	1
DW010321-0078	3/21/2001 16:35	TF280	Chlorophyll a (approx)	20.75	ug/L	1
DW010321-0079	3/21/2001 18:35	TF280	Chlorophyll a (approx)	75.62	ug/L	1
DW010322-0038	3/22/2001 8:35	TF280	Chlorophyll a (approx)	4.44	ug/L	1
DW010322-0048	3/22/2001 12:50	TF280	Chlorophyll a (approx)	3.58	ug/L	1
DW010322-0049	3/22/2001 16:35	TF280	Chlorophyll a (approx)	2.80	ug/L	1
DW010323-0052	3/23/2001 9:55	TF280	Chlorophyll a (approx)	2.22	ug/L	1
DW010521-0060	5/21/2001 10:30	TF280	Chlorophyll a (approx)	16.04	ug/L	1
DW010521-0061	5/21/2001 11:25	TF500	Chlorophyll a (approx)	24.88	ug/L	1
DW010521-0062	5/21/2001 11:55	TF760	Chlorophyll a (approx)	18.08	ug/L	1
DW010522-0045	5/22/2001 11:05	TF280	Chlorophyll a (approx)	31.54	ug/L	1
DW010522-0053	5/22/2001 12:14	TF500	Chlorophyll a (approx)	16.72	ug/L	1
DW010522-0056	5/22/2001 12:41	TF760	Chlorophyll a (approx)	5.56	ug/L	1
DW010523-0059	5/23/2001 9:00	TF280	Chlorophyll a (approx)	4.36	ug/L	1
DW010523-0060	5/23/2001 9:42	TF500	Chlorophyll a (approx)	4.80	ug/L	1
DW010523-0061	5/23/2001 10:18	TF760	Chlorophyll a (approx)	3.44	ug/L	1
DW021016-0091	10/16/2002 11:45	TF620	Chlorophyll a (approx)	1.37	ug/L	1
DW021016-0092	10/16/2002 12:20	TF1120	Chlorophyll a (approx)	1.21	ug/L	1
DW021030-0058	10/30/2002 7:45	TF620	Chlorophyll a (approx)	1.35	ug/L	1
DW021030-0055	10/30/2002 8:35	TF500	Chlorophyll a (approx)	1.48	ug/L	1
DW021030-0067	10/30/2002 12:05	TF760	Chlorophyll a (approx)	1.28	ug/L	1
DW021030-0064	10/30/2002 12:30	TF500	Chlorophyll a (approx)	1.44	ug/L	1
DW021031-0053	10/30/2002 16:20	TF760	Chlorophyll a (approx)	2.21	ug/L	1
DW021031-0052	10/30/2002 16:25	TF620	Chlorophyll a (approx)	1.92	ug/L	1
DW021031-0051	10/30/2002 16:50	TF500	Chlorophyll a (approx)	1.26	ug/L	1
DW021031-0054	10/30/2002 16:50	TF975	Chlorophyll a (approx)	3.31	ug/L	1
DW021031-0058	10/31/2002 10:10	TF760	Chlorophyll a (approx)	1.42	ug/L	1
DW021112-0060	11/12/2002 12:00	TF620	Chlorophyll a (approx)	4.73	ug/L	1
DW021112-0061	11/12/2002 12:30	TF975	Chlorophyll a (approx)	11.00	ug/L	1
DW021113-0059	11/13/2002 11:55	TF620	Chlorophyll a (approx)	1.94	ug/L	1
DW040819-0070	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**70.26**	**mg/sqmeter**	**3**
DW040819-0069	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**47.62**	**mg/sqmeter**	**3**
DW040819-0069	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**47.62**	**mg/sqmeter**	**3**
DW040819-0070	**8/19/2004 0:00**	**TF280**	**Chlorophyll a (approx)**	**70.26**	**mg/sqmeter**	**3**

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW040819-0068	8/19/2004 0:00	TF280	Chlorophyll a (approx)	40.53	mg/sqmeter	3
DW040819-0067	8/19/2004 0:00	TF280	Chlorophyll a (approx)	30.06	mg/sqmeter	3
DW040819-0066	8/19/2004 0:00	TF280	Chlorophyll a (approx)	57.93	mg/sqmeter	3
DW040819-0071	8/19/2004 0:00	TF280	Chlorophyll a (approx)	17.39	mg/sqmeter	3
DW040819-0066	8/19/2004 0:00	TF280	Chlorophyll a (approx)	57.93	mg/sqmeter	3
DW040819-0084	8/19/2004 0:00	TF680	Chlorophyll a (approx)	96.38	mg/sqmeter	3
DW040819-0081	8/19/2004 0:00	TF680	Chlorophyll a (approx)	84.20	mg/sqmeter	3
DW040819-0086	8/19/2004 0:00	TF680	Chlorophyll a (approx)	96.58	mg/sqmeter	3
DW040819-0086	8/19/2004 0:00	TF680	Chlorophyll a (approx)	96.58	mg/sqmeter	3
DW040819-0085	8/19/2004 0:00	TF680	Chlorophyll a (approx)	143.71	mg/sqmeter	3
DW040819-0084	8/19/2004 0:00	TF680	Chlorophyll a (approx)	96.38	mg/sqmeter	3
DW040819-0083	8/19/2004 0:00	TF680	Chlorophyll a (approx)	123.68	mg/sqmeter	3
DW040819-0082	8/19/2004 0:00	TF680	Chlorophyll a (approx)	154.40	mg/sqmeter	3
DW040819-0081	8/19/2004 0:00	TF680	Chlorophyll a (approx)	84.20	mg/sqmeter	3
DW040819-0076	8/19/2004 0:00	TF500	Chlorophyll a (approx)	59.94	mg/sqmeter	3
DW040819-0074	8/19/2004 0:00	TF500	Chlorophyll a (approx)	38.26	mg/sqmeter	3
DW040819-0076	8/19/2004 0:00	TF500	Chlorophyll a (approx)	59.94	mg/sqmeter	3
DW040819-0075	8/19/2004 0:00	TF500	Chlorophyll a (approx)	24.92	mg/sqmeter	3
DW040819-0080	8/19/2004 0:00	TF680	Chlorophyll a (approx)	96.73	mg/sqmeter	3
DW040819-0072	8/19/2004 0:00	TF280	Chlorophyll a (approx)	18.97	mg/sqmeter	3
DW040819-0080	8/19/2004 0:00	TF680	Chlorophyll a (approx)	96.73	mg/sqmeter	3
DW040819-0073	8/19/2004 0:00	TF280	Chlorophyll a (approx)	55.51	mg/sqmeter	3
DW040819-0073	8/19/2004 0:00	TF280	Chlorophyll a (approx)	55.51	mg/sqmeter	3
DW040819-0077	8/19/2004 0:00	TF500	Chlorophyll a (approx)	21.75	mg/sqmeter	3
DW040819-0079	8/19/2004 0:00	TF680	Chlorophyll a (approx)	139.24	mg/sqmeter	3
DW040819-0079	8/19/2004 0:00	TF680	Chlorophyll a (approx)	139.24	mg/sqmeter	3
DW040819-0078	8/19/2004 0:00	TF500	Chlorophyll a (approx)	29.48	mg/sqmeter	3
DW040823-0058	8/23/2004 10:45	TF280	Chlorophyll a (approx)	17.88	mg/sqmeter	1
DW040823-0062	8/23/2004 10:45	TF280	Chlorophyll a (approx)	39.19	mg/sqmeter	1
DW040823-0061	8/23/2004 10:45	TF280	Chlorophyll a (approx)	35.82	mg/sqmeter	1
DW040823-0061	8/23/2004 10:45	TF280	Chlorophyll a (approx)	35.82	mg/sqmeter	1
DW040823-0060	8/23/2004 10:45	TF280	Chlorophyll a (approx)	25.40	mg/sqmeter	1
DW040823-0059	8/23/2004 10:45	TF280	Chlorophyll a (approx)	30.73	mg/sqmeter	1
DW040823-0063	8/23/2004 10:45	TF280	Chlorophyll a (approx)	2.78	ug/L	1
DW040823-0069	8/23/2004 12:00	TF680	Chlorophyll a (approx)	151.42	mg/sqmeter	1
DW040823-0068	8/23/2004 12:00	TF680	Chlorophyll a (approx)	92.24	mg/sqmeter	1
DW040823-0067	8/23/2004 12:00	TF680	Chlorophyll a (approx)	117.10	mg/sqmeter	1
DW040823-0066	8/23/2004 12:00	TF680	Chlorophyll a (approx)	112.20	mg/sqmeter	1
DW040823-0066	8/23/2004 12:00	TF680	Chlorophyll a (approx)	112.20	mg/sqmeter	1
DW040823-0065	8/23/2004 12:00	TF680	Chlorophyll a (approx)	104.45	mg/sqmeter	1
DW040823-0065	8/23/2004 12:00	TF680	Chlorophyll a (approx)	104.45	mg/sqmeter	1
DW040823-0070	8/23/2004 12:00	TF680	Chlorophyll a (approx)	2.69	ug/L	1
DW040826-0070	8/26/2004 10:00	TF280	Chlorophyll a (approx)	78.45	mg/sqmeter	0
DW040826-0073	8/26/2004 10:00	TF280	Chlorophyll a (approx)	37.36	mg/sqmeter	0
DW040826-0068	8/26/2004 10:00	TF280	Chlorophyll a (approx)	37.56	mg/sqmeter	0
DW040826-0068	8/26/2004 10:00	TF280	Chlorophyll a (approx)	37.56	mg/sqmeter	0
DW040826-0074	8/26/2004 10:00	TF280	Chlorophyll a (approx)	18.74	mg/sqmeter	0

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW040826-0071	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**28.59**	**mg/sqmeter**	**0**
DW040826-0070	**8/26/2004 10:00**	**TF280**	**Chlorophyll a (approx)**	**78.45**	**mg/sqmeter**	**0**
DW040826-0075	8/26/2004 10:00	TF280	Chlorophyll a (approx)	2.09	ug/L	0
DW040826-0077	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**175.64**	**mg/sqmeter**	**0**
DW040826-0076	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**124.08**	**mg/sqmeter**	**0**
DW040826-0078	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**100.75**	**mg/sqmeter**	**0**
DW040826-0080	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**112.21**	**mg/sqmeter**	**0**
DW040826-0081	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**126.93**	**mg/sqmeter**	**0**
DW040826-0081	**8/26/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**126.93**	**mg/sqmeter**	**0**
DW040909-0067	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**31.64**	**mg/sqmeter**	**1**
DW040909-0068	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**40.59**	**mg/sqmeter**	**1**
DW040909-0067	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**31.64**	**mg/sqmeter**	**1**
DW040909-0066	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**39.19**	**mg/sqmeter**	**1**
DW040909-0074	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**41.55**	**mg/sqmeter**	**1**
DW040909-0073	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**43.89**	**mg/sqmeter**	**1**
DW040909-0072	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**81.97**	**mg/sqmeter**	**1**
DW040909-0070	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**67.68**	**mg/sqmeter**	**1**
DW040909-0073	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**43.89**	**mg/sqmeter**	**1**
DW040909-0071	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**73.89**	**mg/sqmeter**	**1**
DW040909-0070	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**67.68**	**mg/sqmeter**	**1**
DW040909-0069	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**27.43**	**mg/sqmeter**	**1**
DW040909-0068	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**40.59**	**mg/sqmeter**	**1**
DW040909-0071	**9/8/2004 10:30**	**TF680**	**Chlorophyll a (approx)**	**73.89**	**mg/sqmeter**	**1**
DW040913-0081	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**144.74**	**mg/sqmeter**	**0**
DW040913-0080	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**100.86**	**mg/sqmeter**	**0**
DW040913-0079	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**57.86**	**mg/sqmeter**	**0**
DW040913-0082	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**50.93**	**mg/sqmeter**	**0**
DW040913-0076	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**105.72**	**mg/sqmeter**	**0**
DW040913-0075	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**150.77**	**mg/sqmeter**	**0**
DW040913-0077	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**93.84**	**mg/sqmeter**	**0**
DW040913-0078	**9/13/2004 13:00**	**TF680**	**Chlorophyll a (approx)**	**83.93**	**mg/sqmeter**	**0**
DW040913-0068	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**43.09**	**mg/sqmeter**	**0**
DW040913-0072	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**65.13**	**mg/sqmeter**	**0**
DW040913-0066	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**65.34**	**mg/sqmeter**	**0**
DW040913-0071	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**70.75**	**mg/sqmeter**	**0**
DW040913-0070	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**43.97**	**mg/sqmeter**	**0**
DW040913-0069	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**34.81**	**mg/sqmeter**	**0**
DW040913-0074	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**27.08**	**mg/sqmeter**	**0**
DW040913-0073	**9/13/2004 14:00**	**TF280**	**Chlorophyll a (approx)**	**47.77**	**mg/sqmeter**	**0**
DW040917-0085	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**118.93**	**mg/sqmeter**	**0**
DW040917-0086	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**77.10**	**mg/sqmeter**	**0**
DW040917-0087	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**89.27**	**mg/sqmeter**	**0**
DW040917-0088	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**68.71**	**mg/sqmeter**	**0**
DW040917-0084	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**28.42**	**mg/sqmeter**	**0**
DW040917-0083	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**46.49**	**mg/sqmeter**	**0**
DW040917-0081	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**43.72**	**mg/sqmeter**	**0**
DW040917-0082	**9/17/2004 10:45**	**TF280**	**Chlorophyll a (approx)**	**40.93**	**mg/sqmeter**	**0**

Sam_ID	DateTime	Site	Parameter	Value	Units	Wet/Dry
DW040917-0089	9/17/2004 10:45	TF280	Chlorophyll a (approx)	2.81	ug/L	0
DW040917-0095	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**130.06**	**mg/sqmeter**	**0**
DW040917-0097	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**122.21**	**mg/sqmeter**	**0**
DW040917-0094	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**120.29**	**mg/sqmeter**	**0**
DW040917-0096	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**101.43**	**mg/sqmeter**	**0**
DW040917-0090	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**74.32**	**mg/sqmeter**	**0**
DW040917-0091	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**82.73**	**mg/sqmeter**	**0**
DW040917-0092	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**65.95**	**mg/sqmeter**	**0**
DW040917-0093	**9/17/2004 12:00**	**TF680**	**Chlorophyll a (approx)**	**58.40**	**mg/sqmeter**	**0**

Appendix J: List of Terms

a priori	latin, literally "from the former"; describing a hypothesis made without prior knowledge, before experimentation, or based upon assumption
Acute	describing an effect or response, such as toxicity, that is measured or occurs over a relatively short amount of time; not chronic
Adaptive management	Process of continually monitoring progress and adjusting the approach
Algae	any of a number of several groups of single-celled or multi-cellular organisms, all of which lack leaves, roots, flowers, and other organ structures that characterize higher plants.
Ammonia/ Ammonium	a Nitrogen-containing molecule that exists naturally in both gaseous (NH3) and ionized (NH_4+) forms. The gaseous form is corrosive and toxic, while the ionized form is a usable source of nitrogen for plant growth. Ammonia may be produced by decomposition of nitrogen-containing molecules such as proteins.
Amphipoda	an order of small, shrimp-like crustaceans
Anadromous	describes fishes that migrate from salt water to fresh water to spawn or reproduce
Anoxic	lacking oxygen; especially water lacking dissolved oxygen
Anthropogenic	man-made or human in origin; influenced by mankind
Aquatic	relating to water, particularly freshwater
Aquifer	An underground geologic feature containing water
Autotroph/ Autotrophic	Describes organisms that can produce their own food, such as plants, algae or certain specialized bacteria.
Bankfull discharge	The high flow stage of a fluvial system distinguished by the highest stage elevation a stream can reach before spilling over. In fluvial geomorphology, the bankfull stage is used to describe the flow stage that is most important in shaping the stream channel. Often defined as the flow with recurrence interval 1.3-1.5 years on average, but urbanization tends to decrease this interval.
Baseflow	flow in a stream that is not influenced by precipitation
Basic	alkaline; containing oxide or hydroxyl ions; not acidic

Benthic	Used to describe aquatic organisms living at the bottom of a body of water
Benthic macroinvertebrates	Aquatic insect larvae that live on stream bottom. Because of a short lifespan and relative immobility, they reflect the chemical and physical characteristics of a stream and chronic sources of pollution.
Bioaccumulation	describes the condition or process through which living things concentrate substances, such as toxins, in excess of ambient concentrations
Bioassessment	an evaluation technique that uses measures of the structure, condition, or distribution of biological communities
Bioavailable	describes a substance, such as a pollutant, that can be taken up or incorporated by living things.
Bioindicator	an organism that exhibits sensitivity or tolerance of environmental conditions and may be used in assessing an environmental condition, such as water pollution
Biotic	living, relating to life or biology
BMP -	Best Management Practice – Also called a "management option," BMP is a technique, measure, or structural control that addresses one or more objectives (e.g., a detention basin that gets built, an ordinance that gets passed, and an educational program that gets implemented).
BOD	biological or biochemical oxygen demand, an empirical test procedure that measures the ability of a water sample to deplete oxygen
BOD_{30}	a BOD test that is carried out over 30days
BOD_5	a BOD test that is carried out over 5 days
Caddisfly	an insect of the order Trichoptera, a group of insects usually having an aquatic life stage which are generally sensitive to organic pollution. Often used as a bioindicator of organic pollution.
Cadmium	(Cd) a toxic heavy metal element
Calcium	(Ca) a metallic element found in limestone and numerous naturally occurring compounds
$CaCO_3$	Calcium Carbonate
Catadromous	describes fishes that migrate from fresh water to salt water to spawn or reproduce

Cation	a positively charged ion. Common cations in streamwater are Calcium (Ca) and Magnesium (Mg)
Catchment	see Drainage area
CBOD	carbonaceous oxygen demand; a BOD test in which oxidation of nitrogen is inhibited
CCD	County Conservation District(s)
CCTV	Closed Circuit Television
Channelization	the process of modifying the natural course of a stream in order to make it flow into or along a restricted path
Chlorophyll	any of a group of green pigments necessary for photosynthesis, concentrations of which are used as a surrogate measurement of producer biomass
Chl-*a*	chlorophyll-α, a form of chlorophyll that is found universally in autotrophic organisms
Chironomid	a midge; a small fly of the family Chironomidae, many of which are used as bioindicators of water pollution
Chromium	(Cr) a heavy metal element, occurring naturally in trivalent [CrIII] and hexavalent [CrIV] forms. The latter form is highly toxic
Chronic	describing an effect or response, such as toxicity, that occurs or can be measured over a relatively long period of time; not acute
Cladocera/ Cladoceran	an order of microcrustaceans that are common zooplankton in fresh water and used in toxicity testing
Clay	inorganic sediment particles smaller than 0.002mm
CO_3^{2-}	carbonate ion
Cobble	a stream particle with diameter between 64 and 256mm
Coliform	of or relating to the bacilli (bacteria) that inhabit the intestines of warm-blooded animals
Collector-gatherer	a functional feeding group of aquatic organisms characterized by feeding upon particulate matter that is gathered or manipulated rather than filtered from flowing water by specialized appendage or apparatus
Conductance/	a measure of the ability of a water sample to conduct an electric current; a

Conductivity	measure of dissolved ionic strength
Copper	an essential metallic nutrient that can be toxic in relatively small concentrations
Criterion	an established standard, such as concentration of a pollutant, that is limited or regulated by law
Crustacea/ Crustacean	a class of arthropods that includes shrimp, crabs, crayfish and many types of zooplankton
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
Culvert	a metal, concrete, or plastic pipe that allows water to flow under a road or any other obstruction
CWA	Clean Water Act –Federal Amendment that authorizes EPA to implement pollution control programs and set water quality standards for all contaminants in surface waters. "The Act made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions. It also funded the construction of sewage treatment plants under the construction grants program and recognized the need for planning to address the critical problems posed by nonpoint source pollution." (EPA website)
CWA Section 104(b)(3) Program	Promotes the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction and elimination of pollution.
CWA Section 208 Wastewater Planning	Intended to encourage and facilitate the development and implementation of area-wide waste treatment management plans.
CWA Section 319(b) Non-point Source Management Program	Designed to address mine drainage, agricultural runoff, construction/urban runoff, hydrologic and habitat modifications, on-lot wastewater systems, and silviculture.
Daphnia	a genus of small cladoceran; common in ponds/lakes, used in toxicity testing
DCIA	Directly Connected Impervious Area
Deamination	a stage in the decomposition of protein in which amine groups are removed, usually through hydrolysis; produces ammonia

Decomposition	decay; process through which a complex substance, such as dead organic matter, is broken down into smaller molecules
Defective lateral	a plumbing problem in which a lateral pipe is damaged, potentially leading to sanitary waste in a storm sewer and the receiving water body
Designation/ Designated Use	describes the uses a waterbody is intended to support, such as stocking trout for recreational fishing
Detection limit/ Method Detection Limit (MDL)	the smallest amount of a substance that can be measured with a laboratory technique or instrument (see method reporting limit)
Diatom	Single-celled alga of the class bacillariophyceae, having a cell wall composed of silica. Diatoms are primary producers in streams and lakes.
Diffusion	spontaneous, random movement of molecules that tends to result in equalization of concentrations over time as net movement occurs from areas of greater concentration to areas of lower concentration
Diluent/Dilutant	a thinning agent, such as water, which reduces the concentration of a solution. Pollution may be diluted by streamwater.
Dilute/Dilution	the process through which a solution is made less concentrated through the addition of a diluent/dilutant
Discharge	Flow; a measure of the volume of water flowing through a defined area in a given time. Discharge is often abbreviated as Q, and measured in cubic feet per second (cfs)
Dissolve	cause to pass into solution. In laboratory testing, substances may be considered dissolved if they pass through a 0.45µm filter
Diurnal	Relating to or occurring in a 24-hour period; daily.
DO	Dissolved Oxygen
Drainage area	The area of land that drains to a particular body of water or site on a waterbody.
DRBC	Delaware River Basin Commission
DVRPC	Delaware Valley Regional Planning Commission
DWO	Dry-Weather Outlet - connector pipe between a CSO regulator and interceptor sewer.
Dynamic	relating to conditions that change or are in motion; not static

E. coli	a common rod-shaped bacterium that is found in the intestinal tract of warm blooded animals. Used as an indicator of contamination by feces/sewage.
EACs	Environmental Advisory Councils
Ecoregion	a relatively large area of land characterized by a unique set of communities, physical, and climatological characteristics
Ecosystem	a collection of living things and their environment
Ecotoxicology	the study of environmental toxins
Effluent	outflow of liquid waste, such as discharge from a sewage treatment plant
Empirical	of or related to direct observation; not theoretical
Encapsulated	enclosed or covered, such a stream that has been built into a sewer
Endogenous	coming from or produced wholly from within, such as an enzyme produced by bacteria
E.P.A.	United States Environmental Protection Agency
EPT	(Ephemeroptera + Plecoptera + Trichoptera) three insect orders that are generally sensitive to organic pollution and are used to measure stream water quality
Epifaunal	of or relating to stream surfaces upon which attached alga and other living things may grow or find shelter
Epiphyte	a type of plant or algae that grows upon another plant or algae
Equilibrium	a steady state or condition in which opposing influences balance one another out
Erosion	the process by which soil particles are removed or displaced, usually by wind or water
Estuary	a body of water intermediate between an ocean and river, usually tidal and highly productive
ET	Evapotranspiration – the sum of water vapor evaporation from the earth's surface and transpiration from plants.
Eutrophic	characterized by abundant or overabundant life, such as a stream or river that is nutrient enriched and has dense growth of algae or aquatic vegetation

Eutrophication	the process through which a waterbody comes to have an overabundance of life, usually caused by nutrient enrichment
EVAMIX	A multi-criteria evaluation program to help choose objectively between various alternatives
FGM	Fluvial Geomorphology is the study of a stream's interactions with the local climate, geology, topography, vegetation, and land use; the study of how a river carves its channel within its landscape.
Filamentous	characterized by an elongated, sometimes repeating growth pattern, such as that exhibited by some types of green and blue-green algae
Filterer-collector	a functional feeding group of aquatic organisms characterized by feeding upon particulate matter that is filtered from flowing water by specialized appendage or apparatus, such as a silken net
Fluvial	of or relating to flowing waters, especially rivers
Floatables	Waterborne waste material and debris (e.g., plastics, polystyrene, paper) that float at or below the water surface.
Functional feeding group	a group of aquatic organisms defined by a common feeding strategy, such as predation on other living things
Generalist	describes a species that tolerates a broad range of environmental conditions
Geometric mean	A measure of the central tendency of a set of numbers defined as the product of all numbers of the set raised to a power equal to the reciprocal of the total number of members of the set. The geometric mean is always smaller than the Arithmetic mean
GIS	Geographic Information Systems
H_2CO_3	Carbonic acid
Handheld DO	Dissolved oxygen readings taken with a handheld meter.
Hardness	a measure of the concentration of Calcium and Magnesium ions in water
HCO_3-	Bicarbonate ion
Heterotrophic	describes organisms that cannot synthesize their own food through photosynthesis or other chemical means
Hexavalent	having valence number 6, such as hexavalent Chromium, a toxic metal
Hilsenhoff Biotic	A biological index of stream health that employs a scale of sensitivity of

Index (HBI)	macroinvertebrates to organic pollution
HNO_3	nitric acid, a source of atmospheric nitrogen pollution and acid rain
HSI	Habitat Suitability Indices
Humic	derived from decomposing organic matter, such as leaf litter.
Hydraulic	of or relating to forces exerted by a fluid, often water, under pressure
Hydrograph	A graphical representation of the change in stage or discharge of a stream as a function of time
Hydrolysis	a chemical reaction in which water reacts with another molecule, often resulting in new compounds. The breakdown of urea is a hydrolytic reaction
Hyetograph	a graphical representation of rainfall intensity as a function of time
IDD&E	Illicit Discharge, Detection, and Elimination – one of the six minimum control measures required of permittees under the Phase II NPDES Stormwater Regulations. Program steps include developing maps of municipal separate storm sewer system outfalls and receiving waterbodies; prohibiting illicit discharges via PADEP-approved ordinance; implementing an IDD&E Program that includes a field screening program and procedures, and elimination of illicit discharges; conducting public awareness and reporting program. A similar program is being followed by PWD in the Long Term Control Plan (LTCP) for CSOs.
Illicit connection	An illegal sewer connection, particularly connection of a sanitary sewer, household or industrial waste pipe to a storm sewer. Illicit connections may result in sewage or other pollution inputs to receiving waterbodies.
Impairment	weakening, damage, or instability, such as the effects caused by pollution
Impervious	incapable of being penetrated, such as a surface that does not absorb water
in situ	Latin, literally "in place", refers to types of measurements and observations made directly in the natural environment, such as a water quality instrument installed in a stream
Index/Indices	A number, ratio, or value on a scale of measurement that can reveal differences between observations or reveal changes over time. Numerous indices are used to assess the health of aquatic communities, such as the Hilsenhoff Biotic Index or HBI

Infrastructure	The basic system of utilities and services needed to support a society. Structures such as culverts, pipes, bridges, dams, and flood control measures can cause instability of streams and affect aquatic habitats.
Inimical	harmful; injurious
Insoluble	unable to pass into solution
Instantaneous	immediate; occurring, such as a change, quickly. Some continuous water quality parameters are observed instantaneously
Invertebrates	animals, such as insects and crustaceans, that lack backbones (vertebrae)
Ion	an atom or molecule that has lost or gained an electron or electrons, resulting in a charged state
IPM	Integrated Pest Management
Iron	(Fe) a common metallic element; an essential nutrient that may be toxic in relatively large concentrations. Iron can cause problems with taste and color of drinking water.
Kjeldahl nitrogen test	a laboratory procedure for determining the concentration of ammonia and organically-bound nitrogen in a water sample
Kruskal-Wallis ANOVA	a non-parametric test that can be used to compare sample means when the assumptions of parametric statistics are not met
Larva/larvae	Immature life stage of an invertebrate, such as a beetle or fly. Many insects that have aquatic larval stages are used as bioindicators of water pollution.
LD50	in toxicity testing, an endpoint, such as toxin concentration, where 50% of the test organisms die over a specified exposure interval
Lentic	of or relating to still water, such as lakes, ponds, or bogs
LID	Low-Impact Development (similar to "better site design" and "conservation site design")
Ligand	An atom or molecule that can form a bond with a one or more central atoms (usually metals), forming a complex. Naturally occurring ligands compete with gill surface interaction sites for metals and metallic ions, reducing metal toxicity
Lotic	of or relating to flowing water, such as streams and rivers
LTCP	Long-Term CSO Control Plan – part of the EPA's CSO Control Policy for

	regulation of CSOs under NPDES that guides municipalities, state, and federal permitting agencies in reaching full compliance with the CWA.
Macroinvertebrates	Macroinvertebrates are invertebrate animals that can be seen without the aid of a microscope.
Macronutrient	a nutrient, such as nitrogen or phosphorus, needed in relatively large amounts for biological growth
Magnesium (Mg)	a common cation that contributes to hardness in water
Mainstem	the main flow or central channel of a stream drainage network into which tributaries flow
Manganese	a relatively common metallic element; an essential nutrient that may be toxic in relatively large concentrations
Mayfly	Aquatic insect of the order Ephemeroptera. Mayflies are recognized as being generally sensitive to pollution and are used as indicators of water pollution
Mean/ Arithmetic mean	average; a measure of the central tendency of a set of numbers equal to the sum of all members of a set divided by the number of members of the set
Median	In descriptive statistics, the value in a set of numbers for which half the members of the set are greater and half are smaller. In some instances, the median value may be more informative than the arithmetic mean if a small number of extreme values tends to skew the mean
Mesotrophic	characterized by a moderate amount of biological growth; not eutrophic
Metabolism	all the biochemical processes exhibited by a living organism
Methemoglobinemia	A medical condition in which the oxygen carrying capacity of hemoglobin is disrupted by a faulty gene or exposure to toxins. Infants are especially susceptible to methemoglobinemia due to exposure to nitrates, a condition termed “blue baby syndrome”
mhos	A unit of electrical conductance; a measure of the ability to pass electric current. Water itself is an insulator, but dissolved ions increase its ability to conduct electricity
Microcrustacean	A crustacean that is not readily visible to the unaided eye
Microgram (µg)	A unit of mass equivalent to 1/1,000,000 of a gram
Microhabitat	Fine scale habitat, features of which are important to small living things

Micronutrient	A nutrient, such as a trace metal, needed in relatively small concentrations for biological growth. Micronutrients may limit growth if macronutrients are very abundant
Microorganism	An organism, such as a bacterium or alga, that is observable only under magnification
Microsiemen (µS)	A unit of electrical conductance, Microsiemens/cm is a common unit of measure in water chemistry.
Minnow	Any of a number of species of fish, typically small, of the family Cyprinidae. Minnows are an important link in the aquatic ecosystem, consuming invertebrates and being preyed upon by larger fish
Model	A useful representation, such as a computer simulation, that can be used to simplify and study systems and processes
MPC	Municipalities Planning Code
MRL	Method reporting limit, a measure of the accuracy of a laboratory procedure that takes actual test conditions and characteristics of the environmental sample into account. MRLs are always smaller than method detection limits (MDLs) and may change from laboratory to laboratory or from day to day depending upon the actual performance of an instrument or technique
MS4	Municipal Separate Storm Sewer System
NH_3	Ammonia (gaseous, un-ionized)
NH_4+	Ammonium ion
Nitrate (NO_3)	An oxidized form of Nitrogen; an essential plant nutrient. Elevated Nitrate concentration may result in eutrophication of water bodies and in very great concentrations may be toxic (see methemoglobinemia)
Nitrification	Process of converting ammonia to nitrite and nitrate in the presence of oxygen, especially by the action of naturally occurring bacteria
Nitrite (NO_2-)	An oxidized ion of nitrogen; an intermediate form in the reaction that converts ammonia to nitrate. Nitrite is usually not available for plant growth
Nitrogen	A macronutrient needed for biological growth. Inert nitrogen gas makes up a large portion of the Earth’s atmosphere
NLREEP	Natural Lands Restoration and Environmental Education Program (a unit of Philadelphia’s Fairmount Park Commission)

NOAA	National Oceanic and Atmospheric Administration
Nonferrous	not containing iron; especially metals and alloys that do not contain iron
Nonparametric statistics	a collection of statistical analysis tools, used when the data to be analyzed do not meet the assumptions of parametric statistics, such as homogeneity of variances
Non-point source pollution	Pollution that comes from a diffuse source such as atmospheric deposition, stormwater runoff from pasture and crop land, or individual on-lot domestic sewage systems discharging through shallow groundwater.
Non-structural BMPs	These BMPs will require no operation or maintenance. Examples are use of open space and vegetated buffers in development design, minimization of soil disturbance and compaction during construction, and minimization of directly-connected impervious areas.
NPDES	National Pollutant Discharge Elimination System
NPDES Phase I	The stormwater management component of the NPDES program instituted in 1990, which addressed the storm runoff sources most threatening to water quality. Under this phase, industrial activity, and construction sites within large communities (population 100,000 or more) are required to obtain permits for the storm water leaving the site.
NPDES Phase II	Additional stormwater management regulations enacted in 1999, applying to smaller communities and construction sites.
NRCS	Natural Resource Conservation Service
NTU	nephelometric turbidity units; a unit of measure describing the light scattering properties of a water sample
Nutrient	An element or molecule needed for biological growth. When nutrients such as phosphorus are present in great concentrations, biological growth (algae in particular) can become overabundant, causing problems for aquatic ecosystems
Oligotrophic	characterized by a relatively small amount of biological growth
OLDS	On-Lot sewage Disposal Systems
O&M	Operations and Maintenance
OOW	PWD's Office of Watersheds
Orthophosphate	a dissolved, inorganic form of phosphorus, available as a nutrient for

(OPO_4)	plant growth; soluble reactive phosphorus
Outfall	a pipe or other structure that discharges flow, such as treated sewage effluent or stormwater, to receiving waters
Outlier	in statistics, a data point or observation that is far away from the rest of the data. Statistical techniques can be used to identify and remove outliers from a data set, if desired
Oxidation	chemical process in which a molecule or atom reacts with oxygen or generally, a reaction in which an atom loses electrons and increases in valence state; the opposite of a reduction reaction
Oxygen	an element, common in Earth's atmosphere and dissolved in water, necessary for most forms of complex animal and plant life
PA Act 167	Stormwater Management Act
PA Act 537	Sewage Facilities Planning Act
PADCNR	Pennsylvania Department of Conservation and Natural Resources
PADEP	Pennsylvania Department of Environmental Protection
Parameter	A chemical constituent or physical characteristic of water quality (*e.g.*, dissolved oxygen is a chemical constituent, temperature is a physical characteristic)
Parametric statistics	a collection of powerful statistical tools that assume certain qualities of the data being analyzed, such as homogeneity of variances
Parasite	a functional feeding group of aquatic organisms characterized by feeding usually upon bodily fluids of other organisms, rather than direct predation and consumption. The organism that is fed upon need not die due to the effects of feeding
PEC	Pennsylvania Environmental Council
Periphyton	collectively, the algae growing upon stream surfaces; a group or growth form of algae defined by a bottom or surficial growth habit
PFBC	Pennsylvania Fish and Boat Commission
Phenolics	Any of a group of aromatic compounds having at least one hydroxl group. Phenolics in surface waters generally originate from industry and are toxic in relatively small concentrations.
Phosphatases	any of a group of enzymes, such as those produced by some algae, that can convert or liberate phosphorus from an organically bound to soluble, usable form

Phosphate	An oxidized form of phosphorus, which may be organic or inorganic. Inorganic phosphates are generally more likely to be available as nutrients for biological growth
Photosynthesis	A set of chemical reactions in which plants and other organisms, such as blue-green algae, can synthesize their own food using light and inorganic carbon. Photosynthetic activity in water increases dissolved oxygen concentration during daylight hours.
Physicochemical	physical and chemical properties of water; a term used to group water quality parameters of interest
Phytoplankton	collectively, algae suspended in water; a group or growth form of algae defined by passive or active suspension in the water column
PO_4	phosphate
Point source	Pollution discharged from a single point, defined in the CWA as "any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, vessel, or other floating craft from which pollutants are or may be discharged."
Potassium (K)	an elemental macronutrient required for biological growth
POTW	Publicly Owned Treatment Works
PRD	Planned Residential Development
Predator	a functional feeding group of aquatic organisms characterized by actively feeding upon captured prey
Preferenda/ preferendum	a preferred environmental condition, such as the temperature range an organism will tend to occupy when presented with a gradient
Producers	collectively, the components of an ecosystem, predominantly plants and plant-like living things, that make their own food by chemical means from inorganic building blocks; the base of the food chain
Productivity	a measure of the amount of biological growth that occurs in an ecosystem
PWD	Philadelphia Water Department
QA/QC	Quality Assurance/Quality Control
RBP	Rapid Bioassessment Protocol (developed by the EPA) a standard method to assess aquatic health through fish and macroinvertebrate diversity (EPA Website).

RBPIII	(Rapid Bioassessment Protocol III) EPA approved technique for evaluating macroinvertebrate communities of a river or stream
RBPV	(Rapid Bioassessment Protocol V) EPA approved technique for evaluating the fish communities of a river or stream
RCP	PA DCNR's Rivers Conservation Planning Program
Reach	a segment of a stream as defined by the study being undertaken
Recoverable	a substance, such as a metal, that can be removed, dissolved or taken away in a chemical reaction or physical process
Redfield ratio	an approximation of the relative molar concentrations of the most common elements (Carbon, Nitrogen, and Phosphorus) present in organic matter, usually expressed as 106:16:1
Reduction	a reaction in which an atom or molecule gains electrons, decreasing valence state; not oxidation
Reference	A condition or value used for comparison. Many types of biological assessment techniques require comparison to references
Regulator	in sewer infrastructure, a physical gate, valve, or other control structure that routes flow between two or more receiving pipes, usually one of which terminates in a CSO
Replicate	additional sample(s) or observation(s) which can be used to measure the accuracy or repeatability (precision) of an experimental result
Respiration	biological metabolic process in which a large molecule is broken into smaller pieces to yield usable energy. Aerobic respiration, the efficient respiration reaction favored by complex living things, requires oxygen.
Riffle	a reach of stream that is characterized by shallow, fast moving water broken by the presence of rocks and boulders
Riparian	related to, within, or near a river or its banks
Riparian corridor	The area of land along the bank or shoreline of a body of water (EPA website).
Riparian woodlands	Woodlands that grow within the riparian corridor.
RTC	Real Time Control - a dynamic system of hydraulic controls to provide additional storage and reduce overflows from a combined sewer system
Run	a reach of stream that is characterized by smooth flowing water

Runoff	generally, precipitation that is not absorbed by surfaces or evaporated, but allowed to flow over the surface to a receiving body of water
Scraper	a functional feeding group of aquatic organisms characterized by feeding upon living attached material, usually algae, by means of a specialized scraping apparatus or mouthparts
Sediment	particles, especially inorganic soil particles, that settle upon stream surfaces
SEO	Sewage Enforcement Officers (designated by PADEP)
Seston/Sestonic	of or relating to the collection of inorganic and organic particles that settle to the bottom of a body of water; usually used to describe the predominantly organic detrital particles that settle to the bottom of a lake or pond.
Shear	generally, the physical force applied perpendicularly or at an angle to a surface, such as the hydraulic force applied to stream banks and surfaces by flowing water
Shredder	a functional feeding group of stream invertebrates that consume coarse particulate matter, such as leaves
Sinuosity	a measure of the degree to which a stream, viewed from above, deviates from a linear path, expressed as the ratio of stream length between two points divided by the valley length, or point-to-point distance between the same two points
Slough	to scour or remove from a surface, such as the removal of surficial algae by physical hydraulic force
Significant	when describing the results of scientific or experimental study, describes a comparison or relationship that has been determined to be more likely real than related to randomness or chance to a stated degree of confidence
Silt/Siltation	Inorganic sediment particles between 3.9 and 62.5 µm in diameter. also the process of being covered by or embedded in silt
SOD	sediment oxygen demand; a measure of the oxygen depleting capabilities of decomposing organic material and oxidizable inorganic material in sediment, often expressed as a mass of oxygen per unit area over time
Soluble/Solubility	The quality or state of being able to pass into solution. In water chemistry analysis, a substance may be considered soluble or dissolved if it passes through a 0.45µm filter
Sonde	a continuous water quality monitoring instrument

Speciation	the process of distinguishing between different forms of a substance through analytical or chemical means; or the process through which a substance is converted to two or more different forms
Species	the level of biological taxonomic classification at which living things are separated from one another by the ability to reproduce yielding fertile offspring
SRP	soluble reactive phosphorus; see orthophosphate
SSA	Separate-Sewered Area stormwater runoff
SSET	Sewer Scanner and Evaluation Technology
SSMS	Sanitary Sewer Management System
SSO	Sanitary Sewer Overflow
Stage	level of a stream's water surface, as measured on a gauge or reference datum
Stonefly	An insect of the order Plecoptera, a group of insects usually having an aquatic life stage which are generally sensitive to organic pollution. Often used as a bioindicator of organic pollution.
STORET	USEPA's water quality database (STOrage and RETrieval)
Stormwater Management Program Protocol ("Protocol")	PADEP guidance for implementing the requirements of the NPDES Phase II stormwater regulations
Structural BMPs	These BMPS will require proper operation and maintenance. Examples include wet ponds, grassed swales, infiltration basins and bioretention areas.
Substrate	a surface upon which living things grow; commonly, the bottom of a stream or river
Supersaturation	the condition in which a substance, such as dissolved oxygen, is dissolved in a solvent in a concentration exceeding the usual maximum concentration for the solute under given conditions. When algae are very abundant, they may increase dissolved oxygen concentration to the point of supersaturation
SWMM	Storm Water Management Model
Taxon/taxa	a distinct unit of biological taxonomic organization, such as a family or species

TDR	Transfer of Development Rights
Temporal	of or relating to time, such as a change observed over time
TIGER	Topologically Integrated Geographic Encoding and Referencing (U.S. Census database)
Tipulid	cranefly; an insect of the family Tipulidae, of which many secies are aquatic or semi-aquatic as larvae
TMDL program	Total Maximum Daily Load program - EPA/PADEP program for limiting and allocating discharges of a pollutant within a watershed.
TOC	total organic carbon
Toxic/toxicity	describing a substance that is harmful, able to cause injury or death; also the concentration at which a substance may cause injury or death
Transpiration	The process by which water vapor passes through the membrane or pores of plants to the atmosphere.
Trivalent	having valence 3, such as Cr[III], a non toxic, trace nutrient form of Chromium
Trophic	describing or relating to food, food type, or the process through which a living thing acquires food
TSS	Total Suspended Solids
TTFIWMP	The Tookany/Tacony-Frankford Integrated Watershed Management Plan
Turbidity	a measure of the light scattering properties of water
UA	Urban Areas
UAA	Use Attainability Analysis
Unimpaired	natural, unmolested; describing an unaltered or undisturbed state
Urea	a nitrogen-containing breakdown product of protein metabolism
USDA	United States Department of Agriculture
USGS	United States Geological Survey
Velocity	a vector quantity that describes speed in a stated direction or along an axis
Vertebrate	a complex living thing having a backbone (vertebrae)

Violation	an instance or time period during which a regulated water quality parameter was exceeded
Watershed	The area of land draining to a stream, river, or other water body. Watershed boundaries are established where any precipitation falling within the boundary will drain to a single water body. Precipitation falling outside the boundary will drain to a different watershed. These boundaries are typically formed on high elevation ridges. The water bodies formed from the watershed drainage are usually at the lowest elevation in the watershed. Watersheds can also be called drainage basins.
WLA	waste load allocation
WMP	Watershed Management Plan
WQS	Water Quality Standards
WRAS	PADEP's Watershed Restoration Action Strategy

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