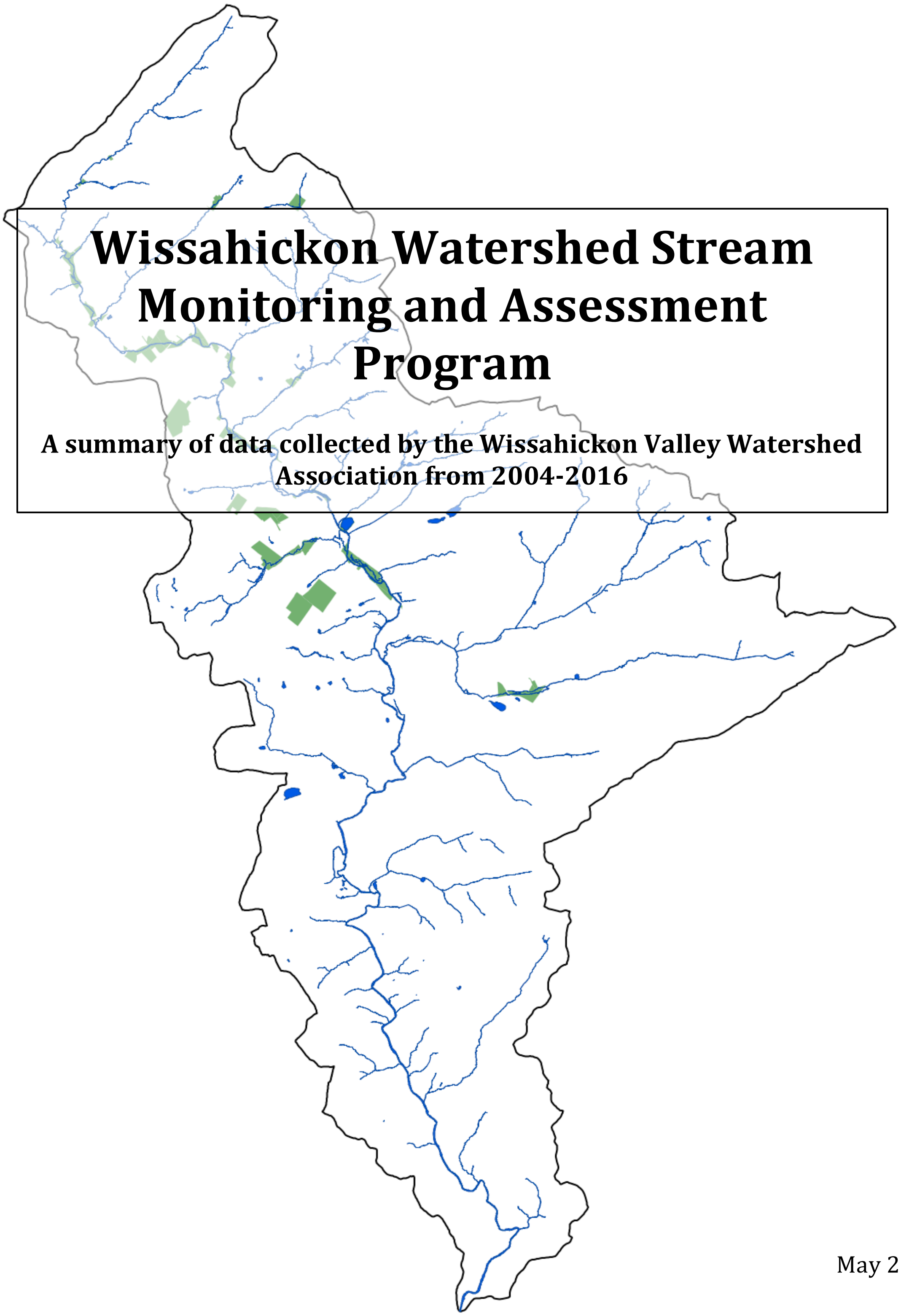
Wissahickon Watershed Stream Monitoring and Assessment Program

A summary of data collected by the Wissahickon Valley Watershed Association from 2004-2016



May 2017

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SECTION ONE: EXECUTIVE SUMMARY

The Wissahickon Watershed is in Southeastern Pennsylvania and is home to nearly a quarter million people. The Stream Monitoring and Assessment Program (Stream MAP) was started by the Wissahickon Valley Watershed Association in 2004 to better understand the Wissahickon Watershed through monitoring. The program sought to identify spatial trends, changes over time, and areas with water quality or habitat impairments.

This report compiles the findings from data collected between 2004 and 2016 for Stream MAP. Collected data includes macroinvertebrate surveys (Section Four), habitat assessments (Section Five), and water quality sampling (Section Six). Overall, Stream MAP results indicated that the Wissahickon Watershed has impairments that are commonly associated with developed landscapes and impervious cover over 10%.

The WVWA conducted macroinvertebrate surveys for Stream MAP from 2011 to 2015. The Wissahickon Watershed macroinvertebrate community was impaired with little diversity within or between sites, and little change over the study period. A single species frequently dominated the macroinvertebrate community. The average Pennsylvania index of biotic integrity for the Wissahickon Watershed was less than 20%. The Pennsylvania index of biotic integrity is on a scale from 0-100% where anything below 50% is considered impaired.

The WVWA conducted habitat assessments from 2011 to 2016. The stream and riparian habitat throughout the Wissahickon Watershed was classified as marginal or suboptimal. Habitat assessments indicated a degree of impairment, typically associated with long-term erosion patterns, at each site. Several habitat parameters used for habitat assessments were suboptimal or optimal. These included vegetative protection, riparian buffer areas, and channel alteration. This validates the importance of preserved open space, including the Green Ribbon Preserve along the Wissahickon Creek. The habitat assessment scores would likely be lower without this preserved land.

Water quality sampling was conducted for Stream MAP since the beginning of the program in 2004. Water quality data indicated that while phosphorus concentrations remained high across the watershed, concentrations have decreased since 2008 at four Wissahickon Creek sites, but increased at one Sandy Run site. The lowest nutrient concentrations in the watershed were found above wastewater treatment plants and on small drainage areas. Conversely, chloride and total dissolved solid concentrations have increased since 2011 at several sites, possibly from runoff and road salt applications. Flow was not measured during Stream MAP and additional study is needed to determine if the nutrient, chloride, and total dissolved solids loading also changed at these sites.

Overall the Wissahickon Watershed has impaired water quality, low diversity and impaired macroinvertebrate communities, and reduced habitat quality due to development in the watershed. Stream MAP also found decreasing phosphorus concentrations at several sites, but overall concentrations are still high, likely driven by development and discharge from wastewater treatment plants. Additionally, the Stream MAP habitat assessment results highlighted the importance of historical open space preservation on mitigating the effect of development. Wissahickon Watershed would benefit from additional actions that mitigate the impacts of development, including widespread green infrastructure implementation, wastewater treatment plant upgrades, low impact development, stormwater best management practices, preserving open space, and restoring the tree canopy and riparian buffers where needed.

SECTION TWO: CHARACTERISTICS OF THE WISSAHICKON WATERSHED

The Wissahickon Creek is an iconic waterbody north of Philadelphia, Pennsylvania with a rich history in the industrial revolution. Throughout the revolution numerous mills were built along the banks of the Wissahickon, leaving behind a legacy of development that still seen today. The Wissahickon Creek also has a history of open space preservation. In the 1860s the city of Philadelphia developed the Wissahickon Valley Park covering the last 7.3 km^2 (1800 acres) of the Wissahickon Valley.

Today, the Wissahickon Creek flows into the Schuylkill River near the Schuylkill River uptake for the Queen Lane Water Treatment Plant. The Queen Lane Water Treatment Plant provides drinking water to 350,000 Philadelphia residents (PDW, 2002). It is estimated that 11 - 28% of the water treated at the Queen Lane Water Treatment Plant is from the Wissahickon Creek (PDW, 2002).

Background information

The Wissahickon Watershed is located in Southeastern Pennsylvania, beginning near the Montgomeryville Mall in Montgomeryville, PA and ending at its confluence with the Schuylkill River in Philadelphia, PA. The Wissahickon Watershed covers 165 km^2 (63.7 mi^2) and has 296.8 km (114.6 mi) of streams, with 70 km (27 mi) on the mainstem of the Wissahickon Creek (PWD, 2007). It is a subwatershed to the Delaware River Watershed, which extends from New York, New Jersey, Pennsylvania, to Delaware. The Wissahickon Watershed has a starting elevation of 148 m (488 feet) and a final elevation of 3.7 m (12 feet).

The watershed can be broken up into two distinct areas that are commonly referred to as the 'Upper Watershed' and the 'Lower Watershed' with Fort Washington, PA as the transition between the two sections. The 'Upper Watershed' is characterized as gradual slopes and low rolling hills, sedimentary bedrock, and soils with poor infiltration rates, known as Group C soils (PWD, 2007). The Lower Watershed has dramatic land features including the Wissahickon Valley Park in Philadelphia. This area is dominated by soils with moderate infiltration rates (Group B soils), and bedrock that includes sedimentary, metamorphic, and igneous components (PWD, 2007).

The Upper Wissahickon is a classified as a 'losing stream,' because under certain flow conditions the surface water infiltrates into the ground water, instead of ground water adding to the surface flow (USEPA, 2003a). Unlike the Upper Wissahickon, the Lower Wissahickon has more ground water inputs that contribute to the surface flow and is classified as a 'gaining stream.' One sizeable input is the Plymouth Meeting Quarry, formally Corson's Quarry, that pumps ground water from the quarry into the Lorraine Run in Fort Washington State Park (USEPA, 2003b).

The Wissahickon Watershed is dominated by an urban and suburban landscape throughout Montgomery County (84% of the watershed, 15 municipalities) and Philadelphia County (16% of the watershed) (Temple University, 2014). Approximately 221,000 people reside in the Wissahickon Watershed as of the 2010 United States Census data, and the landscape has been altered to support these communities. Land use includes 51% residential, 7%

commercial, industrial, and parking, 17% as woodlands, 7% as agriculture, 8% as recreational spaces, and 10% as transportation and utilities (Temple University, 2014).

Natural spaces, including woodlands and some recreational spaces, adjacent to streams are vital for protecting aquatic ecosystems as the nearby land acts as a natural sponge that buffers the freshwater system from man-made impacts. The WVWA has prioritized the preservation of natural spaces along the Wissahickon Creek, including the Green Ribbon Preserve and Trail that extends from Upper Gwynedd to the Wissahickon Valley Park in Philadelphia.

Environmental stressors

Urban and suburban landscapes need infrastructure to support the surrounding communities including roads, parking lots, utilities, and wastewater treatment plants. This man-made environment can alter the flow, water quality, habitat, and biological communities of freshwater systems.

Impervious cover and the impacts

High amounts of impervious cover are common in an urban and suburban environment. Impervious cover is anything that prevents the infiltration of rainwater into the ground, including parking lots, roads, buildings and other structures. Impervious cover is a well-documented environmental stressor on aquatic systems that causes negative impacts, known as the 'urban stream syndrome (Meyer et al., 2005).' Some impacts of the urban stream syndrome include increased nutrient loading, changes in the morphology of the stream, and changes in chemical processing (Figure 2-1) (Welsh et al., 2005).

The urban stream syndrome occurs because impervious cover increases the amount of rainwater running off of the landscape and into a nearby stream. In a natural environment most of the rainfall is either intercepted by plants or infiltrated into the ground, while only a small amount runs off of the landscape and into a nearby stream. In a developed system rain is unable to infiltrate into the ground and can cause local reductions in ground water. With fewer plants and trees in developed systems, less rainwater is intercepted by vegetation and a larger portion of precipitation becomes runoff, know as stormwater. Commonly, the resulting stormwater is directed into a storm drain and piped to the nearest stream or river without treatment (Walsh et al., 2005).

Stormwater increases the volume and speed of stream flow during a rain event and can cause flash floods, stream bank erosion, unstable environments for biological communities, and increased nutrients in the stream (Welsh et al., 2005). Overtime, continued erosion widens the streambed and the stream habitat becomes more homogenous with reduced bends, shallower pools, and fewer riffle areas. As the stream bank erodes the released sediment settles onto the streambed and fills in vital microhabitats for small fish and macroinvertebrates, further reducing habitat suitability.

Increased streambed width has negative impacts on biological communities. A wider streambed allows the stream flows to spread out across a larger surface area and reduces the water depth in the stream. More sunlight is able to reach the streambed because shade trees are set further away from the stream. This increased sunlight coupled with increased nutrients from stormwater inputs enables prolific algae growth that can reduce habitat suitability for fish and macroinvertebrates. The shallower water is also able to warm up faster, which can have deleterious impacts on aquatic biological communities that rely on cool oxygen-rich water. Warm waters can hold less dissolved oxygen and can be further reduced in systems with abundant algae growth by algae respiration at night.

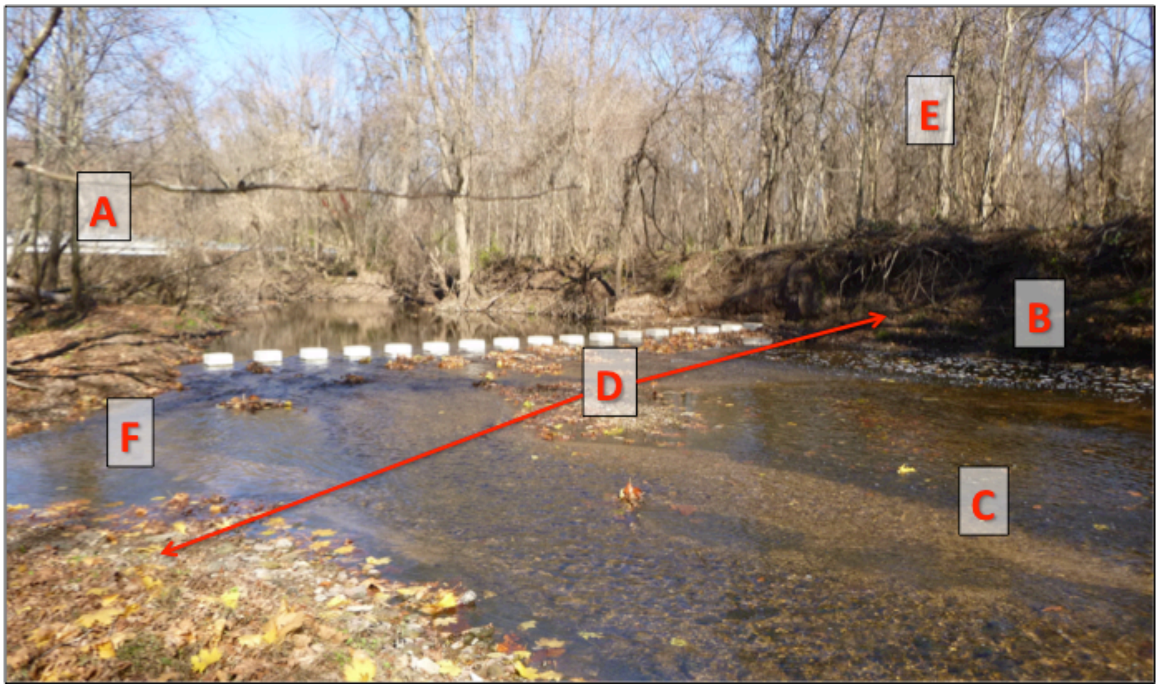

Figure 2- 1. Impacts of the urban stream syndrome. This picture of Stream MAP site WISS550 captures many of the physical impacts of the urban stream syndrome, even in a protected area of the watershed. (A) The road in this picture is an example of an impervious surface in the watershed. In a natural system, rainwater is captured by plants, infiltrates into the ground, and the remaining runoff drains into a creek. In an urban/suburban system, rainfall becomes stormwater as it travels across impervious surfaces where it picks up fertilizers, nutrients, litter, oil and grit from roads, and is commonly piped into a nearby waterbody without any filtering or treatment. This pulse of stormwater reaches the creek sooner and with more volume than in a natural system where most of the rainwater would be intercepted before making it into the waterbody. (B) The large volume of stormwater causes erosion to occur. The marked erosion in the picture is around 10 feet in height. (C) The released sediment from the on site and upstream erosion will eventually settle to the bottom of the streambed, filling in the spaces between the rocks on the streambed. This reduces available habitat for the aquatic organisms that rely on these spaces. (D) As erosion continues overtime, the streambed will widen, stream depth will decrease, and the diversity of flow patterns will decrease. (E) As the streambed widens, trees that provided shade to the streambed are set further away and sunlight can now reach the streambed. The sunlight and shallowness of the stream results in a warmers stream temperatures as shallow water warms up faster than deeper waters. (F) Increased sunlight and nutrients, from stormwater runoff and bank erosion, enable increased algae growth. Prolific algae growth reduces available habitat for pollution sensitive macroinvertebrates and causes large swings in the dissolved oxygen concentrations between the daytime, when algae are photosynthesizing, and nighttime, when algae are respiring and using up the available oxygen.

Urban stream syndrome and the Wissahickon Watershed

The impact of impervious cover and urban stream syndrome is consistently documented in watersheds with high percent impervious cover. The impervious cover model is commonly cited as predicting that watersheds with > 10% impervious cover are potentially impacted and watersheds with >25% are potentially non-supporting for many aquatic species (Center for Watershed Protection, 2003).

The Wissahickon Watershed has 29% impervious cover (PDW, 2007), indicating that this watershed is susceptible to urban stream syndrome conditions. Additionally, much of the watershed was developed before building codes included stormwater management, so most stormwater is directed into the municipal separate storm sewer system storm drains and piped into the Wissahickon Creek without treatment.

Wastewater treatment plants

Like impervious cover, wastewater treatment plants are necessary to support communities in urban and suburban settings. Wastewater treatment plants pipe treated effluent into streams and may alter the water quality of the streams. The impact of each wastewater treatment plant depends on the level of technology used to treat the wastewater and the volume of effluent that is released into the stream. During periods of low flow, particularly in warm summer months, the Upper Watershed is dominated by flow from point sources, primarily the wastewater treatment plants (USEPA, 2003b). Currently, four wastewater treatment plants discharge into the Wissahickon Watershed in Upper Gwynedd, Ambler, Abington, and Upper Dublin (Figure 2-2). In July 2013, a fifth treatment plant in North Wales was closed and the discharge was diverted to the Upper Gwynedd Wastewater Treatment Plant.

The combination of impervious cover and wastewater treatment plants alters the natural flow in the Wissahickon Watershed. The PWD estimates that runoff accounts for 68% of the annual flow at the Fort Washington (USGS gage: 01474000) and 61% of the flow at the mouth of the Wissahickon (USGS gage: 01473900) (PWD, 2007). Ground water accounts for the remainder of the flow at these stations. In a natural system the ratio is typically flipped with a third of the flow from run off and two-thirds from ground water.

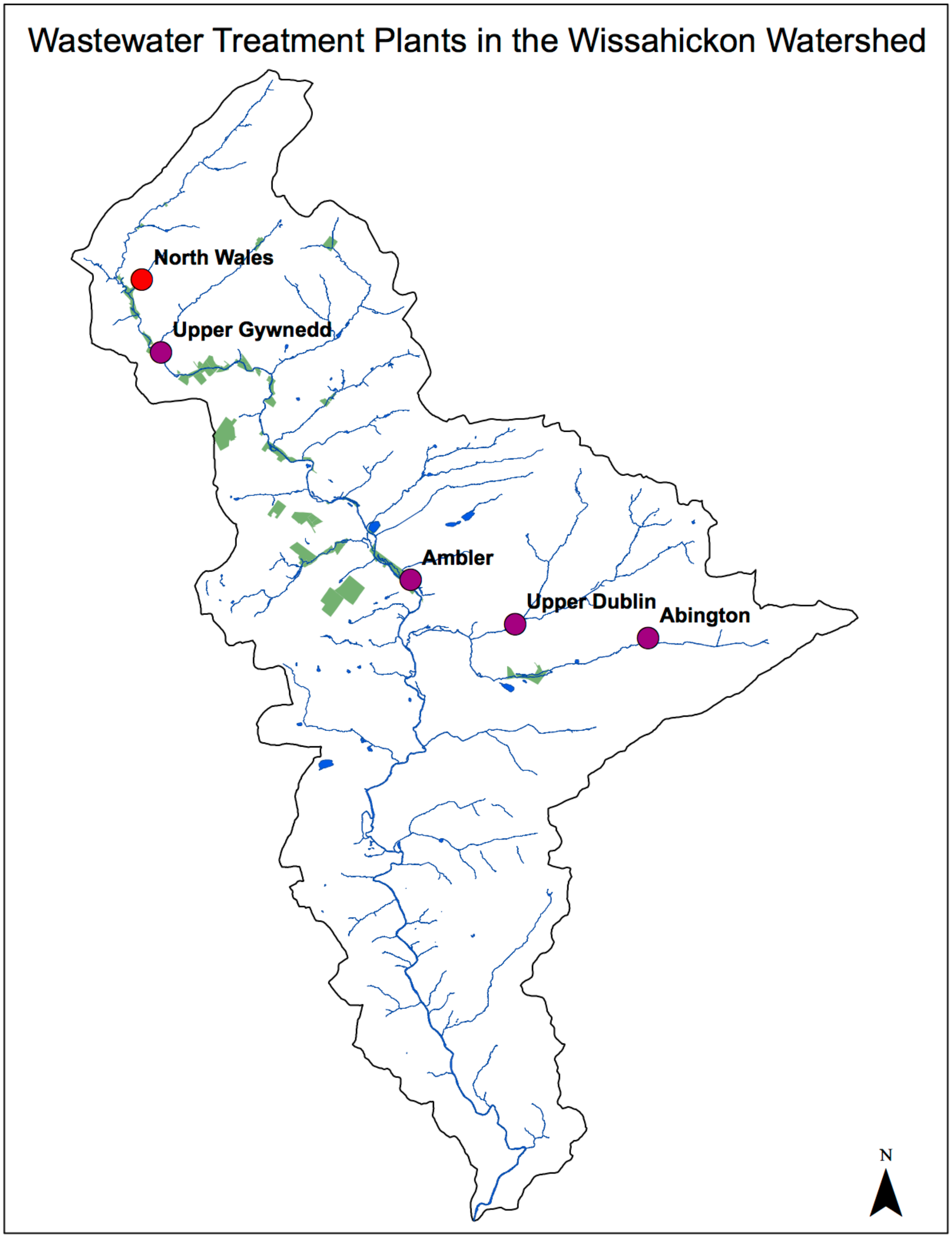

Figure 2- 2. A map of the wastewater treatment plants in the Wissahickon Watershed with currently operating wastewater treatment plants in purple and a closed wastewater treatment plant in red. The North Wales Wastewater Treatment Plant was closed in July 2013.

Wissahickon Creek status

The Wissahickon Watershed is challenged as an urban and suburban system due to impervious cover and wastewater treatment plants. In 1996 the Wissahickon Watershed was listed as impaired on the Commonwealth of Pennsylvania's impaired waterbody list because 83% of stream miles in the watershed did not meet water quality standards for a Trout Stocking Fishery (Temple University, 2014), the stream classification of the Wissahickon Creek.

The Wissahickon Watershed is listed as impaired due to sediment and nutrients. In 2003 the EPA created Total Maximum Daily Loads (TMDL) for the Wissahickon Watershed for sediment and nutrients (USEPA, 2003b). TMDLs determine the maximum amount of pollutant (e.g. nitrate) that can be released into that waterbody and have the waterbody meet water quality standards. TMDLs are created to improve the water quality so the waterbody can be removed from the impaired waterbody list. In 2015, the EPA released a draft total phosphorus TMDL as the 2003 TMDL standards improved the dissolved oxygen concentrations in the watershed, but was not enough to remove the Wissahickon Creek from the impaired streams list (USEPA, 2015 a).

SECTION THREE: STREAM MONITORING AND ASSESSMENT PROGRAM

The Wissahickon Valley Watershed Association launched the Stream Monitoring and Assessment Program (Stream MAP) in 2004 to better understand the Wissahickon Watershed. Objectives of Stream MAP include the following (WVWA, 2012):

- Monitor water quality, habitat, and biological communities throughout the watershed
- Compile and analyze the monitoring data including seasonal changes (e.g. summer compared to winter), over time (e.g. year to year), and spatially (across sampling sites)
- Use these monitoring results to determine areas of concern in the Wissahickon Watershed or areas of improvement from restoration activities
- Share the results with regional partners and use the findings to educate members of the public on the state of the Wissahickon Watershed

The purpose of this report is to summarize all of the Stream MAP data collected since 2004 for all interested stakeholders including, members of the public, partner organizations, government partners, municipal leaders, and others. This section of the report briefly describes Stream MAP and the sites used from 2004 to 2016. Sections Four through Six provide details on sampling methods, dates, and sites used for macroinvertebrate surveys (2011-2015), habitat assessments (2011-2016), and water quality monitoring (2004-2016).

Stream MAP set up

Stream MAP started in the summer of 2004 with quarterly water chemistry samples collected in the summer, fall, and spring at six sites on the Wissahickon Creek until 2006. No samples were collected in 2007. In 2008 the program was revamped and sites were added in the Sandy Run, the Wissahickon Creek's largest tributary. In 2011 the program expanded to two new sites on the Wissahickon Creek and winter sampling was added. Additionally in 2011, macroinvertebrate surveys and habitat assessments were added to the program to provide a more holistic long-term assessment on the state of the watershed compared to water quality samples that provide a snapshot view. In the fall of 2013, sampling on two tributaries, Trewellyn and Prophecy, were added to better understand the watershed as a whole. In 2014 the WVWA joined the Delaware River Watershed Initiative (DRWI), a regional effort to improve the water quality of the entire Delaware River Watershed, funded by the William Penn Foundation. This expanded Stream MAP by improving quality assurance and quality control measures, and streamlined collection methods with regional partners. Lastly, in 2015 two new sites were added on the Wissahickon Creek mainstem.

Site descriptions

This section of the report will describe each of the monitoring site locations, the reason they were selected as a sampling location, and years sampled (Table 3-1, Figure 3-1). The details of what was monitored at each site will be described in later sections. The distance downstream from the start of the Wissahickon Creek was measured using ArcMap and the drainage area was calculated using USGS StreamStats (USGS, 2016). Sites are listed in increasing distances from the start of the Wissahickon Creek in Montgomeryville, PA.

Table 3- 1. Stream MAP station names, descriptions, coordinates, sampling years, distance downstream from the start of the Wissahickon Creek, and drainage area. No samples were collected in 2007.

Station	Description	Latitude	Longitude	Years sampled	Distance	Drainage
Wissahickon Creek Sites						
WISS850	West Point Pike, pedestrian bridge	40.2093	-75.2932	2015-16	6.3 (km)/ 3.9 (mi)	10.3 (km^2)/ 3.9 (mi^2)
WISS800	West Point Pike - Moyer Blvd	40.2064	-75.2949	2011-16	6.8 (km)/ 4.2 (mi)	10.4 (km^2)/ 4.0 (mi^2)
WISS750	Evans - Mumbower Mill	40.1867	-75.2790	2004-16	9.8 (km)/ 6.1 (mi)	20.1 (km^2)/ 7.8 (mi^2)
WISS700	Mather's Rd, WVWA property	40.1599	-75.2404	2015-16	16.6 (km)/ 10.3 (mi)	46.1 (km^2)/ 17.8 (mi^2)
WISS600	Rotary Bridge, Butler Pike	40.1501	-75.2285	2004-16	18.5 (km)/ 11.5 (mi)	56.0 (km^2)/ 21.6 (mi^2)
WISS550	Lafayette Ave, stepping stones	40.1322	-75.2226	2004-16	21.4 (km)/ 13.3 (mi)	71.2 (km^2)/ 27.5 (mi^2)
WISS500	Mather Mill	40.1240	-75.2197	2004-16	22.4 (km)/ 13.9 (mi)	105.2 (km^2)/ 40.6 (mi^2)
WISS400	Morris Arboretum	40.0910	-75.2308	2004-16	27.7 (km)/ 17.2 (mi)	129.0 (km^2)/ 49.8 (mi^2)
WISS250	Valley Green Inn	40.0550	-75.2178	2011-16	33.5 (km)/ 20.8 (mi)	145.8 (km^2)/ 56.3 (mi^2)
WISS150	Lincoln Drive	40.0225	-75.1992	2004-16	38.9 (km)/ 24.2 (mi)	164.2 (km^2)/ 63.4 (mi^2)
Sandy Run and Tributary Sites						
SR300	Sandy Run, Roslyn Park	40.1287	-75.1275	2008-13		1.8 (km^2)/ 1.1 (mi^2)
SR200	Sandy Run Middle School	40.1264	-75.1706	2008-16		11.1 (km^2)/ 6.9 (mi^2)
SR100	Sandy Run, Bethlehem Pike	40.1334	-75.2141	2008-16		32.1 (km^2)/ 20.0 (mi^2)
PR100	Pine Run	40.1135	-75.1847	2014		8.4 (km^2)/ 5.2 (mi^2)
T100	Trewellyn Creek	40.1919	-75.2402	2013		7.0 (km^2)/ 4.3 (mi^2)
T400	Prophecy Creek	40.1507	-75.2291	2013-16		6.3 (km^2)/ 3.9 (mi^2)

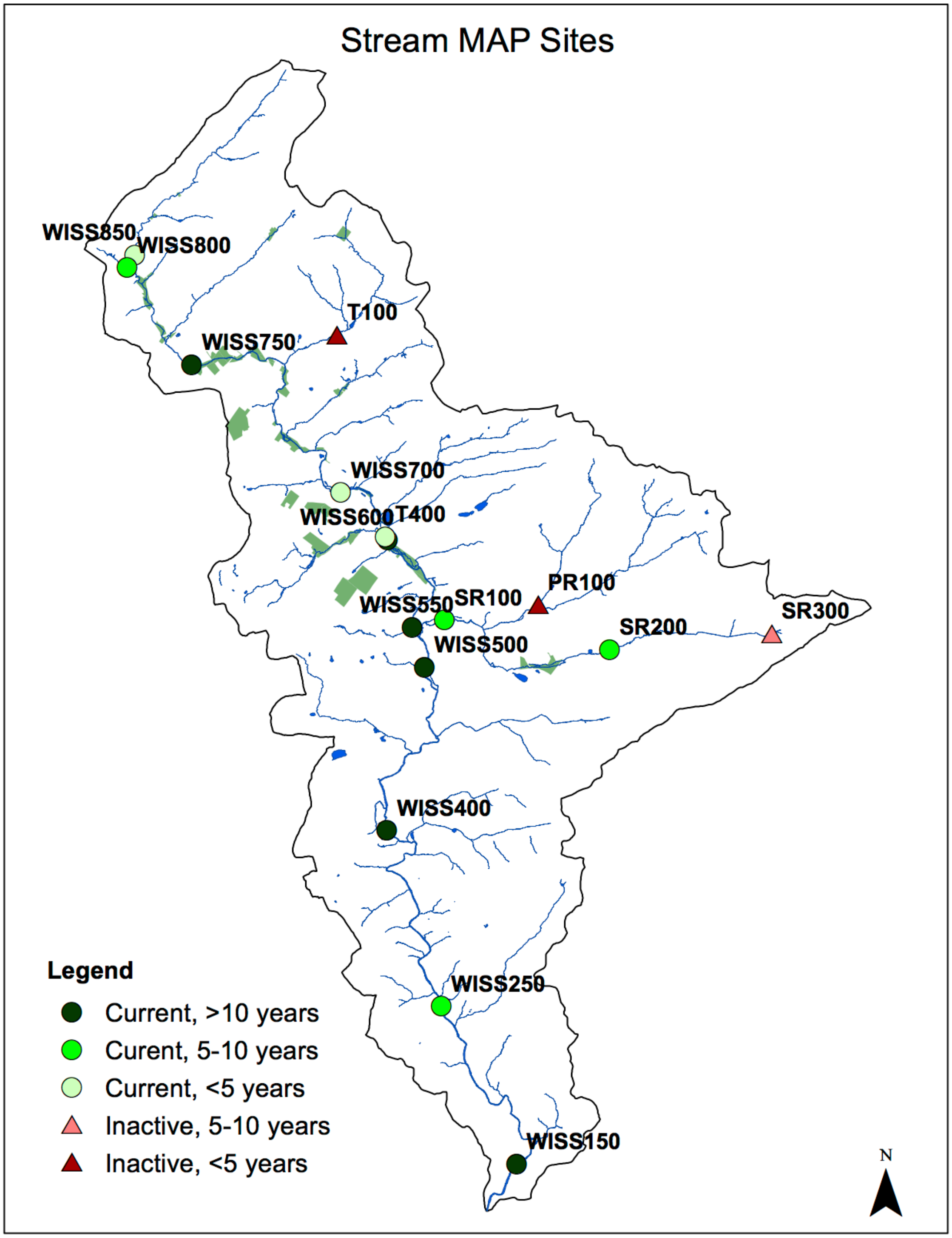

Figure 3- 1. A map of the Stream MAP sampling locations from 2004 to 2016. The circles represent sites that are currently sampled and triangles represent sites that are no longer sampled. Dark green circles were sampled all 12 years, green circles were sampled between 5 and 10 years, and light green circles were sampled for less than five years. Light red triangles were sampled between 5 to 10 years and dark red triangles were sampled for less than five years.

Wissahickon mainstem sites

WISS850: WISS850 is the uppermost site at just 6.3 km (3.9 mi) downstream from the start of the Wissahickon Creek in Montgomeryville, PA and was added in 2015. WISS850 has a drainage area of 10.3 km^2 (3.9 mi^2), or in other words the runoff from rain events from 10.3 km^2 (3.9 mi^2) of land drains to this sampling point. This site is at a footbridge that connects West Point Pike to the Green Ribbon Trail. The Green Ribbon Trail is managed by the WVWA and extends from Upper Gwynedd to Fort Washington, PA. WISS850 was selected because it is upstream of a section of the Wissahickon Creek that is proposed for stream morphology restoration due to extensive erosion along the stream banks.

WISS800: WISS800 is 6.8 km (4.2 mi) from the start of the Wissahickon Creek, and has a drainage area of 10.4 km^2 (4.0 mi^2). This site was added to Stream MAP in 2011, is the first site with continuous flow, and is downstream of an in-stream restoration site that would reconnect the eroded streambed with the floodplain. The site is protected in the PECO right of way and is near the Green Ribbon Trail.

WISS750: This site is 9.8 km (6.1 mi) from the start of the Wissahickon, is downstream of the Haines Run confluence, and has a drainage area of 20.1 km^2 (7.8 mi^2). Monitoring at WISS750 started in 2004, but did not become a constant site until 2008. WISS750 is at the Evans-Mumbower Mill, along the Green Ribbon Trail, and is downstream from the Upper Gwynedd Wastewater Treatment Plant that discharges into the Wissahickon Creek.

WISS700: This site is 16.6 km (10.3 mi) downstream from the start of the Wissahickon Creek, has a drainage area of 46.1 km^2 (17.8 mi^2). WISS700 was added in 2015 to reduce an 8.7 km (5.4 mi) gap between WISS750 and WISS600. WISS700 is downstream of Cedarbrook Country Club and Wissahickon confluences with Willow Run East, Willow Run West, and Trewellyn Creek.

WISS600: WISS600 is 18.5 km (11.5 mi) downstream from the start of the Wissahickon Creek, has a drainage area of 56.0 km^2 (21.6 mi^2), and is one of the original sites from 2004. This site is at the Rotary Bridge on the Green Ribbon Trail of the Four Mills Reserve near the WVWA Headquarters. This site is downstream of the Rose Valley Creek confluence with the Wissahickon Creek, the asbestos Superfund sites in Ambler, PA, and just upstream of the Prophecy Creek confluence.

WISS550: WISS550 is 21.4 km (13.3 mi) downstream from the start of the Wissahickon Creek, has a drainage area of 71.2 km^2 (27.5 mi^2) and is one of the original sites from 2004. This site is just upstream of the confluence with the Sandy Run and downstream of the Ambler Wastewater Treatment Plant that discharges into the Wissahickon Creek. This site is along the Green Ribbon Trail and has stepping stones at the site to allow trail users to cross the creek.

WISS500: WISS500 is 22.4 km (13.9 mi) downstream from the start of the Wissahickon Creek, has a drainage area of 105.2 km^2 (40.6 mi^2) and is one of the original sites from 2004. This site is just downstream of the confluence with the Sandy Run, which has two wastewater treatment plants that discharge into it. WISS500 is at Mather's Mill, along the Green Ribbon Trail, and has the United States Geological Survey (USGS) Fort Washington gage (#01473900) just downstream of it.

WISS400: WISS400 is 27.7 km (17.2 mi) downstream from the start of the Wissahickon Creek, has a drainage area of 129.0 km^2 (49.8 mi^2), and is one of the original sites from 2004. WISS400 is at Morris Arboretum near a historical mill and a pronounced rock outcrop that creates turbulent flows at the site. This site is just downstream of the Whitemarsh Valley Country Club.

WISS250: WISS250 is 33.5 km (20.8 mi) downstream from the start of the Wissahickon Creek, has a drainage area of 145.8 km^2 (56.3 mi^2), and is one of the original sites from 2004. The site is in the Wissahickon Valley Park of Philadelphia and is near the Valley Green Inn.

WISS150: WISS150 is 38.9 km (24.2 mi) downstream from the start of the Wissahickon Creek, has a drainage area of 164.2 km^2 (63.4 mi^2), and is one of the original sites from 2004. This site is in the Wissahickon Valley Park of Philadelphia and boarders Lincoln Drive with an armored bank. A USGS station for the Wissahickon Creek mouth is at this site (#01474000), is upstream of the dam near Ridge Avenue, and the last site on the Wissahickon Creek mainstem.

Sandy Run and tributary sites

SR300: SR300 has a small drainage area of 1.8 km^2 (1.1 mi^2) and monitoring on this site began 2008. SR300 is in Roselyn Park, just after the section of the Sandy Run that is channelized in Abington, PA. SR300 was the most upstream sampling site in the Sandy Run until monitoring of this site ended in 2013 due to limited access.

SR200: SR200 has a drainage area of 11.1 km^2 (6.9 mi^2) and monitoring began on this site in 2008 and has continued into 2016. This site is at the Sandy Run Middle School, downstream of the Abington Wastewater Treatment Plant, and is between LuLu Country Club and Manufacturer's Golf and Country Club. After the Sandy Run exits Manufacturer's Golf and Country Club it enters Piszek Preserve, which is managed by the WVWA.

SR100: SR100 is 1.2 km (0.7 mi) upstream of the confluence between the Wissahickon Creek and the Sandy Run and has a drainage area of 32.1 km^2 (20.0 mi^2). Monitoring at SR100 began in 2008 and has continued into 2016. This site is downstream of where Pine and Rapp Run enter the Sandy Run. The Bucks County Water and Sewer Authority wastewater treatment plant in Upper Dublin, PA discharges into the Pine Run.

PR100: PR100 has a drainage area of 8.4 km^2 (5.2 mi^2) and was monitored in 2014 only. PR100 is on the Pine Run, a tributary to the Sandy Run, This site is upstream of the Bucks County Water and Sewer Authority wastewater treatment plant in Upper Dublin, PA.

T100: T100 has a drainage area of 7.0 km^2 (4.3 mi^2) and was sampled from the fall of 2013 to the fall of 2014. T100 is on the Trewellyn Creek after the Trewellyn Creek leaves the Treweryn Farm Trail Park in Lower Gwynedd, PA.

T400: T400 is on Prophecy Creek near Butler Pike in Ambler, PA and has a drainage area of 6.3 km^2 (3.9 mi^2). Monitoring at this site began in in the fall of 2013. The Prophecy Creek watershed is the least developed subwatershed in the Wissahickon Watershed and is considered to be the least impacted subwatershed. This site is just before the Prophecy Creek enters the Wissahickon Creek near the Green Ribbon Trail.

SECTION FIVE: MACROINVERTEBRATE SURVEYS

Macroinvertebrate surveys indicate long-term ecological conditions compared to water quality sampling that captures a snapshot in time and may miss periods of high stress (e.g. low dissolved oxygen concentrations at night). Macroinvertebrate communities are ideal for indicating the ecological condition of a site because they (1) are present in all systems, even degraded systems, (2) have varying tolerances to stressors and can be assigned a pollution tolerance value, (3) are relatively sedentary, and (4) are long lived.

Methods

Macroinvertebrates were collected from 2011 - 2013 in the Spring and Fall. Surveys were conducted at eight sites on the Wissahickon Creek and three sites on the Sandy Run. In the fall of 2013 SR300 was not surveyed and two tributary sites, Trewellyn and Prophecy, were added to investigate differences between the Wissahickon mainstem and the tributaries.

URS conducted targeted riffle macroinvertebrate surveys on 30 – 50 m reach at the same location as the Stream MAP water quality sites. One site, WISS600, lacked a riffle area and samples were collected in a glide instead. All samples were collected with a Surber sampling net (500 μm) by disturbing a 0.25 m^2 quadrate in front of the sampling net. At each site three samples were collected, totaling 0.75 m^2 of collected substrate (URS, 2011). Samples were preserved in the field using ethanol. Samples were returned to the laboratory and the first 200 organisms were counted using random subsampling with a gridded tray. Entire subsamples were counted to reduce bias. Macroinvertebrates were identified to genus, when possible. Pennsylvania index of biotic integrity was calculated for each site using the community composition and abundance values (PADEP, 2012).

In 2014 the WVWA discontinued the fall sampling survey and adjusted the macroinvertebrates sampling methods to comply with the Quality Assurance Project Plan of the Delaware River Watershed Initiative (ANS, 2014). The new methods included collecting eight random samples from riffle areas in the stream reach using a Surber sampling net (0.09 m^2, 250 μm). The collected samples were composited into four sampling jars (two samples/jar), preserved with ethanol in the field, and returned to the laboratory. In 2014 one site, WISS800 was counted by Stroud Water Research Center and in 2015 Cole Ecological, Inc. counted WISS850, WISS800, and WISS250. The first 200 organisms were counted using subsampling and were identified to family (2014) or genus (2015).

Pennsylvania index of biotic integrity

The Pennsylvania's index of biotic integrity (IBI) is the combination of six metrics including (1) Total Taxa Richness, (2) EPT Taxa Richness, (3) Modified Beck's Index, (4) Hilsenhoff Biotic Index, (5) Shannon Diversity Index, and (6) Percent Sensitive Individuals (PADEP, 2012). The IBI is a single score for a site that can be compared across Pennsylvania and is on a scale from 0 - 100% with higher values indicating a macroinvertebrate community that is more similar to a non-disturbed site. Any values below 50% are considered impaired (PADEP, 2012).

Descriptions of the six metrics are used to calculate the IBI:

- Total Taxa: The number of different taxa at a site. A higher number indicates more macroinvertebrate species diversity

- EPT Taxa Richness: The number of taxa that are in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), or Trichoptera (caddisflies) that have pollution tolerance values (PTV) between 0 – 4. In general, most mayflies, stoneflies, and caddisflies have lower pollution tolerances than other insect orders
- Beck's Index (version 3): Calculates a score for the amount of pollution tolerance taxa, from any insect order (Beck's Index= $3(n_{PTV0taxa})+2(n_{PTV1taxa})+1(n_{PTV2taxa})$)
- Hilsenhoff Biotic Index: Calculated using both the number of organisms and their PTV (0 - 10, 10 = most tolerant) in the community
- Shannon Diversity Index: Measures the community richness and evenness. For example, a macroinvertebrate community that is primarily one species would have a low value
- Percent Sensitive Individuals: Measure the portion of the macroinvertebrate community with a PTV of 0-3

Results

The macroinvertebrate survey results were investigated for (1) trends overtime (2) patterns in individual components of the IBI, and (3) patterns in functional feeding groups.

Watershed wide trends

The IBI was used to understand the overall trends of the surveyed macroinvertebrate community throughout the Wissahickon Watershed. The Wissahickon Creek and Sandy Run sites all had an IBI below 26% for all sampling events, indicating all sites were impaired. Overall there was little variability throughout the watershed or over the study years (Figure 4-1). WISS400 consistently had a higher IBI, possibility from the large rock outcrop at the site that creates turbulent flow and increases oxygen concentration in the water at the site. WISS600 had the most consistent and lowest IBI score, likely a reflection of sampling on a glide instead of a riffle. Lastly, the 2014 and 2015 results indicated similar IBI values as the previous surveys.

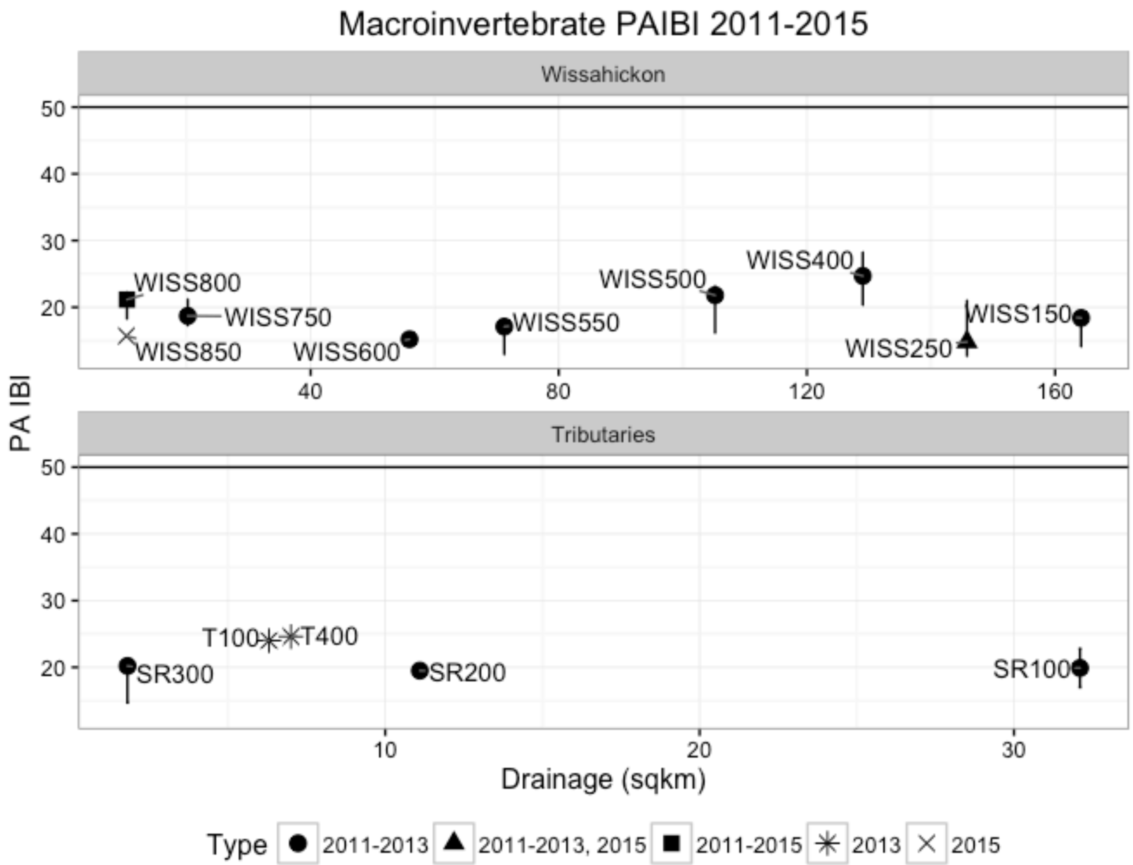

Figure 4- 1. Macroinvertebrate surveys were conducted from 2011 to 2015. The circles represent the median IBI at sites that were surveyed from 2011 - 2013. The triangles represent the median IBI for the site that was surveyed from 2011 – 2013 and 2015. The square is a site that was surveyed from 2011 – 2015. The stars are sites that were surveyed in 2013 only. The x is a site that was surveyed in 2015 only. The error bars indicate the 25th and 75th percentiles of all assessments at each site. The solid line is the cut of between impaired and non-impaired macroinvertebrate communities. Anything below 50% IBI is considered impaired.

IBI components of interest

A few individual components of the IBI are worth highlighting, including percent sensitive individuals and Shannon Diversity Index. The percent sensitive individuals indicated that there were no pollution sensitive individuals upstream of WISS550, 21.4 km (13.3 mi) downstream from the start of the Wissahickon, for any of the sampling events. The Sandy Run site SR100, closest to the Wissahickon, typically had more sensitive species than the two upstream Sandy Run sites, but at times there were no sensitive individuals at any of the Sandy Run sites.

The Shannon Diversity Index was low for all sites and sampling events. The Shannon Diversity Index was low because the macroinvertebrate communities in the Wissahickon are typically dominated by one taxon, Chironomidae. Chironomidae, commonly known as midges, had a median abundance of 68.3% across all sampling events and was more than 90% of the total abundances at many sites.

Functional feeding groups

Macroinvertebrate functional feeding groups (FFG) are expected to occupy different areas in a watershed based on the food that is available. Though it is not uniform for all streams, the River Continuum Concept is commonly used as a reference for the proportion of FFGs that should be found in the upstream, midstream, and downstream section of a watershed. The Wissahickon Watershed is not large enough to have a true downstream section as referred to in the concept but the River Continuum Concept still provides a good framework.

The major FFGs are predators, grazers, shredders, and collectors. Each FFG has an expected area and proportion of the macroinvertebrate community that they are likely to be found in (Table 4-1). Investigating the FFGs throughout the Wissahickon and Sandy Run sites indicated several missing feeding groups and an overall homogenous community. Collectors dominated the systems, leaving lower than expected levels of grazers and predators with nearly absent shedders in the system (Figure 4-2). Shredders and piercers, a type of grazer, may be absent in the Wissahickon Creek due to limited food availability from frequent flash floods that push decomposing plant matter downstream and absent aquatic vegetation at the sampling locations. At most sites, collectors were more than 90% of the macroinvertebrate community and at times were 100% of the macroinvertebrate community. This pattern was consistent in 2014 and 2015 sampling events.

Table 4- 1. The diet of each functional feeding group, their expected location in a watershed, and what was found in the Wissahickon and Sandy Run sites.

FFG	Diet	Expected prevalence	In the Wissahickon
Predators	Animal tissue	10-20% of a normal macroinvertebrate community found throughout all areas	<5% abundance throughout the system
Grazers	Living plant tissue, including aquatic plants and algae (periphyton)	Lower numbers in the headwaters, higher numbers in the midsection, and absent in the downstream	Nearly uniform throughout the system at lower than expected abundances. Piercers, a subset of grazers that consume aquatic plants, were absent from the system.
Shredders	Living and decomposing plant tissue (e.g. tree leaves that wash into a stream)	High abundances in the headwaters (where leaf litter washes into the stream from the forest), lower abundances in the midsection, and absent from the downstream section.	Nearly absent from the system
Collectors	Decomposing fine particulate organic matter	Throughout the stream, but predominantly in the downstream sections. As a whole, collectors tend to be the most pollution tolerant feeding group.	Nearly the entire macroinvertebrate community is collectors, indicating that fine particulate organic matter is the primary food source in the system.

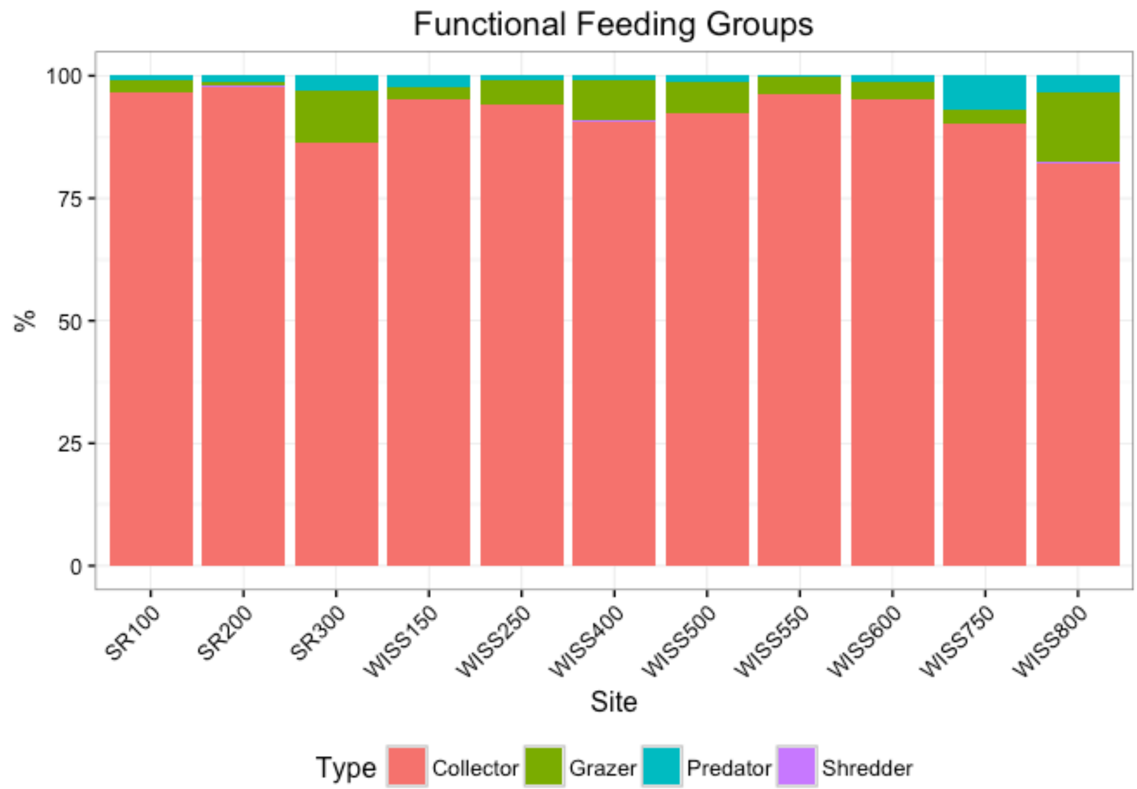

Figure 4- 2. Macroinvertebrate surveys from 2011 to 2013 were used to determine the proportion of the community that was represented by four functional feeding groups. Red indicates the percentage of the macroinvertebrates at each site that were collectors, green indicates grazers, blue indicates predators, and purple indicates shedders.

Tributaries (Fall 2013)

The Trewellyn and Prophecy Creek tributaries were sampled once in the fall of 2013. The IBI for Trewellyn was 24.0% and Prophecy was 24.6%, both slightly above the Wissahickon Watershed's average IBI for the fall of 2013 of 21.5%, but still impaired. The FFGs were more balanced in the tributaries than in the Wissahickon Creek and Sandy Run sites with collectors as 55.8% at Trewellyn and 67.6% at Prophecy, grazers as 8.3% and 16.2%, predators as 35.9% and 16.2%, and no shredders at either site.

WVWA results compared with other studies

Other organizations have conducted macroinvertebrate surveys in the Wissahickon Watershed, including the Philadelphia Water Department (PWD) in 2005 throughout the watershed, Stroud Water Research Center at one site from 1996-2007, and others.

The PWD Creek Characterization Report (CCR) included macroinvertebrates surveys from 2005, predominately in Philadelphia County, using a kick-net (PWD, 2007). This is a different method than the WVWA uses, but both methods are widely accepted. The CCR indicated that the Wissahickon Watershed macroinvertebrate community was impaired and had low species diversity. The CCR also reported that the macroinvertebrate community was predominately collectors, particularly Chironomidea. The Hilsenhoff Biotic Index (HBI), a component of the PA IBI, ranged from 5.79 to 6.07 at the Wissahickon sites in the CCR, while the WVWA survey had an average HBI at the Wissahickon sites from 2011 to 2013 of

6.46. Overall, the results in the CCR were very similar to the WVWA results and both surveys found impaired macroinvertebrate communities in the Wissahickon Watershed.

Conclusion

Stream MAP macroinvertebrate surveys found that the macroinvertebrate communities throughout the Wissahickon Watershed are impaired with an average IBI score of 18.8% across all sites and sampling events, well below the indicator of impairment at 50%. Investigating the FFGs indicated that the macroinvertebrate communities were homogenous, dominated by collectors, and at times missing entire FFGs, typically shredders. Lastly, two tributaries were sampled in the Fall 2013 and were determined to also be impaired, but with slightly higher IBIs (~24%) and more complex FFGs. These findings are expected in a stream with urban stream syndrome. Urban stream syndrome is common with watersheds with >10% of impervious cover (Center for Watershed Protection, 2003) and the Wissahickon Watershed has 29% impervious cover.

Take-away points and summary map

A few take away points from macroinvertebrate surveys in the Wissahickon Watershed from 2011 to 2015:

- The macroinvertebrate community in the Wissahickon Watershed was impaired at all sites and all sampling events. Trewellyn and Prophecy Creek tributaries were slightly better, but still impaired (Figure 4-3).
- The Wissahickon Watershed has low macroinvertebrate taxa diversity.
- The collector functional feeding group dominates the macroinvertebrate community in the Wissahickon Watershed, typically with the family Chironomidae. The shredder functional feeding group was nearly absent in the Wissahickon Watershed, possibly due to frequent disturbances (e.g. flash floods).

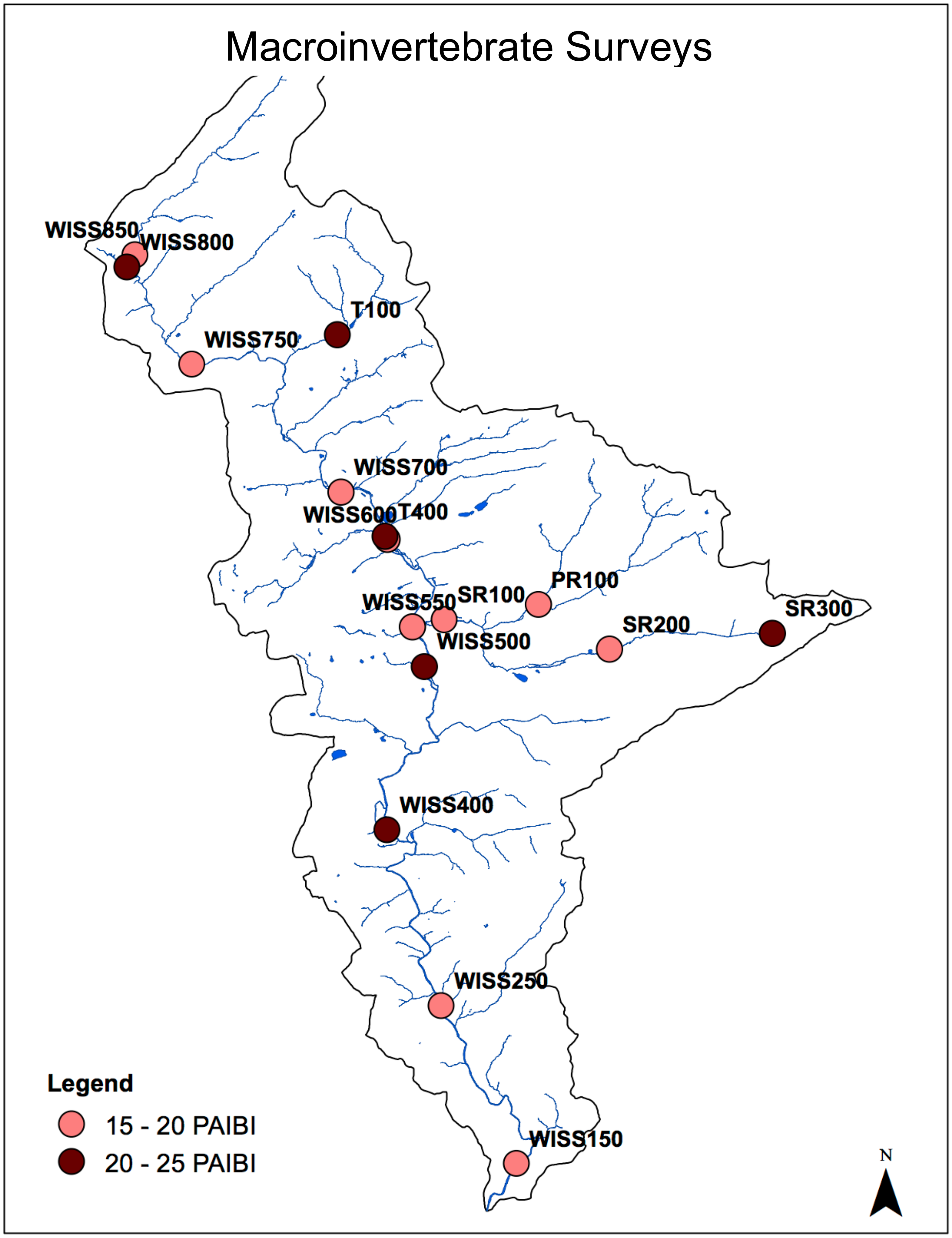

Figure 4- 3. A map of the Wissahickon Watershed and the macroinvertebrate survey sites from 2011 - 2015. All sites were impaired. Sites in light red had a median PAIBI of 15 – 20% and dark red had a median PAIBI of 20-25%. All sites were not surveyed from 2011 to 2015.

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SECTION FIVE: HABITAT ASSESSMENTS

Habitat assessments are a method for quantifying the habitat diversity, extent of human impact, and the likelihood of disturbance at the site. The WVWA's Stream Monitoring and Assessment Program (Stream MAP) includes habitat assessments because the quality of available habitat is known to influence the aquatic biological community species diversity (Gorman and Karr, 1978; Maddock, 1999).

Methods

Site habitat scores are determined by evaluating the condition of ten habitat parameters (Table 5-1) in a section of a stream, known as a reach. The WVWA used the Rapid Bioassessment Protocols developed by the USEPA for habitat assessments (Barbour et al., 1999) where each site is scored from 0 - 200 with a higher score indicating a better habitat condition. Parameters are independently scored between 0 – 20 (poor= 0 - 5, marginal= 6 - 10, suboptimal= 11 - 15, optimal= 16 - 20) and then are added together for a single site score, ranging between 0 - 200 (poor <60, marginal 60 - 109, suboptimal 110 - 159, optimal 160 - 200).

Stream MAP has included habitat assessments from 2011 to 2016 at 16 sites. A consultant, URS, conducted three years of habitat assessments in June 2011, Nov 2012, and Nov 2013. The WVWA started preforming the assessments after 2014 and performed the next three assessments in Aug 2014, Sept 2015, and Aug 2016. Both URS and WVWA used the high gradient stream assessment method (Barbour et al., 1999) for consistency. Variability in the site habitat scores between years is expected due to variation in the dates of the assessment and assessors.

Habitat assessments were conducted on the same sites as macroinvertebrate surveys and water quality monitoring. Habitat assessments included the same 30 - 50 m section the stream, known as a reach, that was included in macroinvertebrate sampling. Riffle areas were targeted when selecting a stream reach for macroinvertebrate surveys.

Table 5- 1. The parameters used in habitat assessments and a description of each parameter.

Parameter	Description
Epifaunal Substrate/ Available Cover	Amount and diversity of in stream structures that provide habitat for aquatic organisms needs (e.g. hiding and spawning)
Embeddedness	Amount of sand or silt covering or filling in spaces between rocks, cobble, or snags. This reduces the area and habitat available for aquatic organisms
Velocity/Depth Combinations	Diversity of velocity (slow or fast) and depths (swallow and deep)
Sediment Deposition	Amount of sediment that has been relocated and created point bars and islands, or filled in pools and areas behind boulders
Channel Flow Status	The extent that the channel is full of water with ideally all available habitat submerged for aquatic organism use
Channel Alteration	Structural changes to a stream either through artificial structures, damming, or channel straightening
Frequency of Riffles (or bends)	Frequency of riffles throughout the stream reach, which provide more diverse habitat for organisms
Bank Stability	State of current erosion or erosion potential on each bank, scored individually
Bank Vegetative Protection	Amount and quality of vegetation covering the stream banks, including if all vegetative types are accounted for (trees, shrubs, herbaceous cover)
Riparian Vegetative Zone Width	The width of the riparian vegetation along the stream and the amount of human impact within the vegetative zone

Results

The habitat assessment results from 2011 to 2016 are organized into (1) trends throughout the watershed including upstream/downstream trends and changes over time, (2) descriptions of findings at individual sites, and (3) the WVWA results compared to other studies.

Watershed wide trends

Habitat assessments were conducted on 16 sites throughout the Wissahickon Watershed from 2011 - 2016. Nine sites, including seven on the Wissahickon Creek and two on the Sandy Run, were assessed all six years.

The median site habitat score from 2011 to 2016 and site drainage areas (km^2) were plotted for Wissahickon and Sandy Run sites (Figure 5-1). Results indicated that WISS850, an intermittent site, had a lower median site habitat score than WISS800 where flow becomes continuous. WISS800 and WISS750 were suboptimal and had higher site habitat scores. The middle Wissahickon Creek (WISS700, WISS600, WISS550) was marginal with lower site habitat scores. The site habitat scores increased slightly with WISS500 and WISS400, both were suboptimal and have more variable flow patterns than other sites. The lower Wissahickon Creek (WISS250 and WISS150) had marginal scores. WISS600 had the lowest site habitat score throughout the Wissahickon Creek. In the tributaries, the Sandy Run and Trewellyn site habitat scores were marginal. Prophecy Creek, the most protected subwatershed, had suboptimal site habitat score. From 2011 to 2016, the lowest rated parameter was embeddedness while the highest rated parameter was channel alteration and channel flow status.

The site habitat scores improved slightly between 2011 and 2016, particularly from the 2011 – 2013 period and 2014 – 2016 period (Figure 5-2). However the time of the year the site was sampled also varied between these two periods; the 2011 - 2013 assessments were completed in June or November, potentially either before full leaf-out or after some leaf drop and herbaceous die back, while the 2014 - 2016 assessments were conducted in August or September during full vegetation and leaf out. This is reflected in increasing vegetative protection and vegetative buffer zones between 2011 - 2013 and 2014 - 2016.

Between 2011 and 2016, 73 habitat assessments were conducted across 16 sites in the Wissahickon Watershed. Of these assessments, 1 (1.4%) was poor, 37 (50.1%) were marginal, and 35 (48.0%) were suboptimal. No sites were considered optimal indicating impairment throughout the watershed.

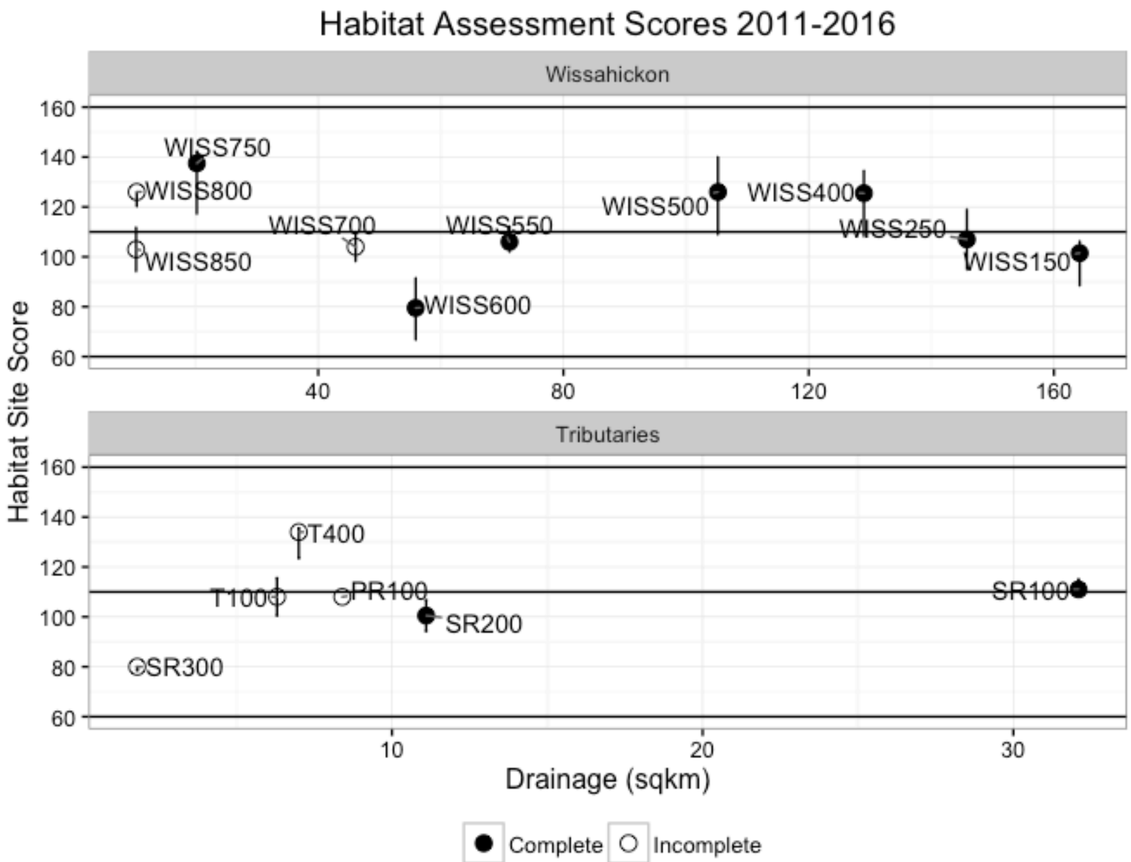

Figure 5- 1. Habitat assessments were conducted from 2011 to 2016. The filled in circles represent the median habitat assessment score for sites that were assessed from 2011 - 2016. The hollow circles are the habitat assessment scores for sites that were not assessed all six years. The error bars indicate the 25th and 75th percentiles of all assessments at each site. The solid lines are the distinctions between poor (>60), marginal (60 and 109), suboptimal (110 and 159), and optimal (>160).

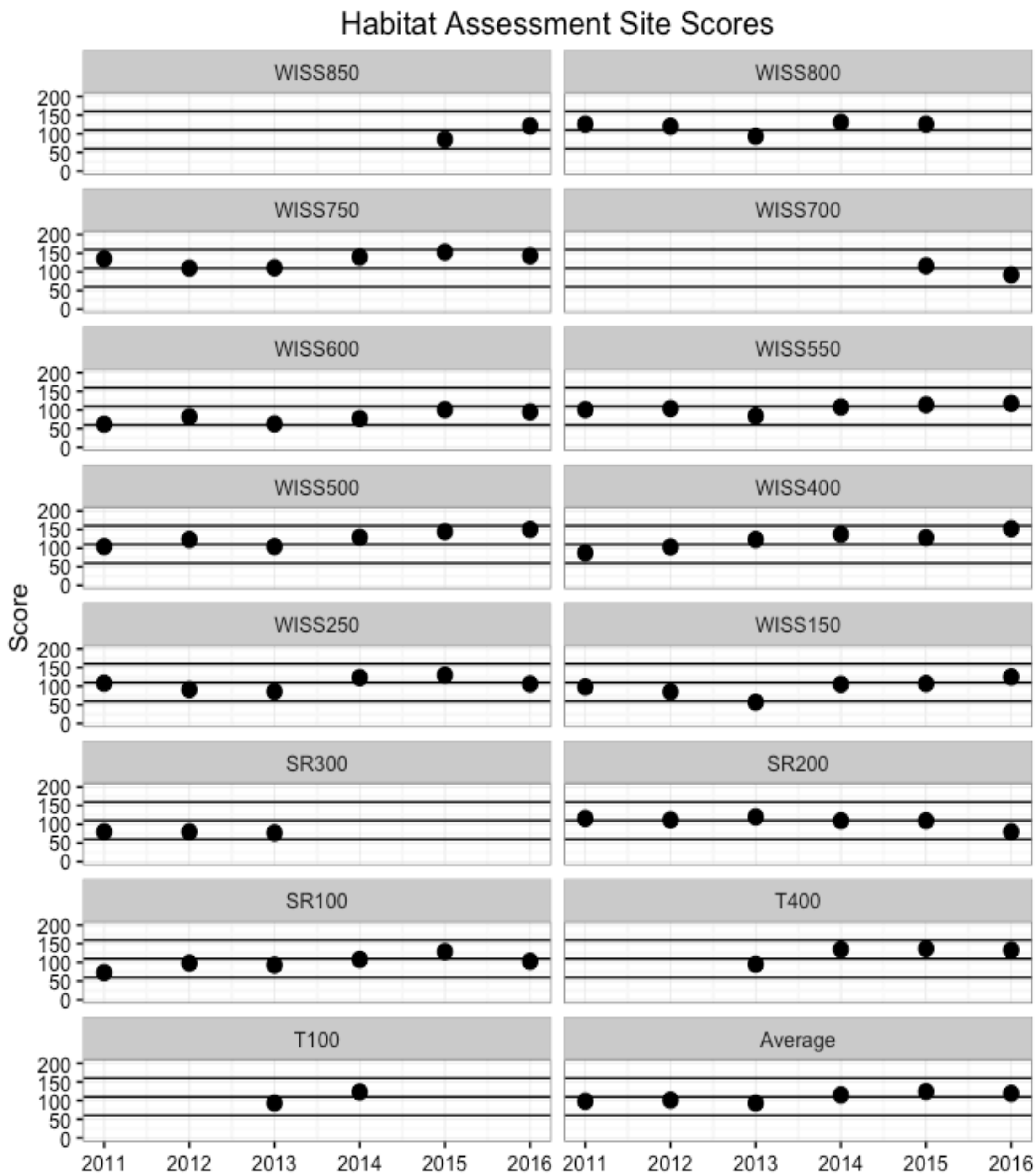

Figure 5- 2. The site habitat scores for all current Stream MAP sites and past sites, SR300 and T100. Site habitat scores range from 0 - 200. PR100 was only assessed one year and was not included in the figure. The solid lines are the distinctions between poor (>60), marginal (60 and 109), suboptimal (110 and 159), and optimal (>160). The last figure, 'Average,' is the average site score of the nine sites that were assessed all six years (WISS750, 600, 550, 500, 400, 250, 150, and SR100, 200).

Results by site

WISS850: WISS850 was analyzed in 2015 - 2016 and was scored as marginal (Table 5-2). The site is above a proposed restoration area and is intermittent. The lowest ranked parameter at the site was velocity/depth regime, reflecting the intermittent nature of the site. The highest ranked parameter was channel alteration, reflecting that the site is in a protected conservation area.

WISS800: WISS800 was analyzed from 2011 - 2015 was suboptimal. WISS800 is in the eroded headwaters of the Wissahickon Creek along the protected PECO right-of-way. There is little human traffic in the area and minimal man-made structural impact, however the site has deep erosion and is disconnected from the adjacent flood plain. The lowest ranked habitat score was embeddedness, closely followed by velocity/depth regime, and sediment deposition, indicating the site is homogenous with excess sediment. The highest score was channel alteration, as expected in the protected conservation area.

WISS750: WISS750 was assessed from 2011 – 2016. WISS750 was suboptimal and the highest scoring site throughout the Wissahickon Watershed. The lowest ranked parameter at the site was epifaunal substrate and the highest ranked parameter was channel alteration. This site is along the Green Ribbon Trail and upstream from the Evans Mumbower Mill, adding to the high channel alteration scores.

WISS700: WISS700 was assessed in 2015 - 2016 and was scored as marginal. The lowest ranked parameters were frequency of riffles. The highest rated parameter was channel flow status. The site is downstream of the Cedarbrook Country Club and has homogenous flow patterns.

WISS600: WISS600 was assessed from 2011 – 2016 and was considered marginal. WISS600 is in the WVWA protected Green Ribbon Corridor near the 'Rotary Bridge' and the asbestos piles in Ambler, PA. The site is significantly altered with a straightened channel and one armored stream bank for asbestos remediation. These conditions were reflected in the poorest scored parameter, frequency in bends or riffles, closely followed by velocity depth regime. The highest rated parameter was channel flow status from the lack of variability in at the site that would highlight channel flow variability. The next highest scored parameter was bank stability, from riprap around the Rotary Bridge and stabilization at the remediated asbestos site.

WISS550: WISS550, along the Green Ribbon Corridor, was assessed from 2011 – 2016 and was considered marginal. The lowest scored parameter was embeddedness. At the site, one stream bank has a large erosion scar along the length of the reach causing the low bank stability score. The highest scored parameters were channel alteration and riparian vegetative zone, as expected in the protected natural area.

WISS500: WISS500 was analyzed from 2011 - 2016 and was considered suboptimal. WISS500 is at Mather's Mill and is protected by the Green Ribbon Trail on one side. The lowest ranked parameter was bank stability and the highest was frequency of riffles. This site has a breached stone dam in the reach that increases the diversity of flow patterns and riffles at the site. However, the site was also missing most of its riparian buffer on one side and has a large erosion scar on one bank.

WISS400: WISS400 was between marginal and suboptimal throughout 2011 - 2016. WISS400 is at Morris Arboretum near the old mill site and has a large rock outcrop. The highest parameter score was channel alteration. The lowest parameter score was riparian vegetative zone width due to a golf course in the stream reach. The site has a large erosional scar on one bank and deposited sediment in and below the rock outcrop.

WISS250: WISS250 was analyzed from 2011 - 2016 and was considered marginal. WISS250 is at the Valley Green Inn in the Wissahickon Valley Park. The highest parameter score was bank stability and the lowest rated parameters were embeddedness and sediment deposition. The low parameters indicate the pattern of erosion upstream of this site, while the high bank stability score reflects the bank stabilization projects at the site.

WISS150: WISS150, along Lincoln Drive in Philadelphia, was scored as marginal between 2011 and 2016. This site has the Wissahickon Valley Park on one site and Lincoln Drive on the other. The highest rating at this site was bank stability, however this was from the armored wall supporting Lincoln Drive. The lowest scores are riparian vegetative zone and followed by vegetative protection, indicating the lack of riparian protection or quality of protection due Lincoln Drive and a multiuse path on the other stream bank.

SR300: SR300 was analyzed from 2011 - 2013 and was considered marginal. The lowest rated parameter was the riparian buffer zone and the highest was the embeddedness.

SR200: SR200 was analyzed from 2011 - 2016 and was considered marginal. SR200 is near the Sandy Run Middle School is just upstream from Manufactures Golf and Country Club. The lowest parameter was the frequency of riffles and the highest was channel flow status. In 2016 there was recent construction at the Manufactures Golf and Country Club causing lower site score compared to the previous five years.

SR100: SR100 was analyzed from 2011 - 2016 and was considered marginal. SR100 is 1.2 km upstream from where the Sandy Run enters the Wissahickon Creek. The lowest rated parameter was embeddedness and the highest was channel alteration.

PR100: PR100 was analyzed in 2014 and was scored as marginal. The lowest ranked parameter was the riparian buffer zone and the highest ranked parameter was the channel flow status.

T400 (Prophecy): T400 was analyzed from 2013 - 2016 and was scored as suboptimal. The lowest rated parameter was the frequency of bends and riffles and the highest rated parameter was the channel flow status. This site is near the Green Ribbon Trail and is in a protected area. T400 had the second highest average site score throughout the Wissahickon Watershed. This is consistent with the Prophecy Creek subwatershed being the most protected and considered the highest quality tributary to the Wissahickon Creek.

T100 (Trewellyn): T100 was analyzed from 2013 - 2014 and was considered marginal. The lowest ranked parameter was sediment deposition and the highest was the velocity and depth regime.

Table 5- 2. The sites, years sampled, average scores, and lowest and highest scored parameter score across the years analyzed. The scores are listed in parentheses with the parameter scored between 0 - 20 (poor= 0 - 5, marginal= 6 - 10, suboptimal= 11 - 15, optimal= 16 - 20) and the site score between 0 – 200 (poor <60, marginal 60 - 109, suboptimal 110 - 159, optimal 160 - 200).

		Average Parameter Score		
Site	**Years**	**Lowest**	**Highest**	**Score**
WISS850	2015-2016	Velocity/Depth (5)	Channel Alteration (16)	Marginal (103)
WISS800	2011-2015	Embeddedness (9.2)	Channel Alteration (14.8)	Sub-Optimal (119)
WISS750	2011-2016	Epifaunal Substrate (11)	Channel Alteration (16.3)	Sub-Optimal (132)
WISS700	2015-2016	Frequency of Riffles (2.5)	Channel Flow Status (17)	Marginal (104)
WISS600	2011-2016	Frequency of Riffles (2.0)	Channel Flow Status (15.2)	Marginal (80)
WISS550	2011-2016	Embeddedness (4.8)	Channel Alteration (15.2)	Marginal (105)
WISS500	2011-2016	Bank Stability (10.5)	Frequency of Riffles (15.8)	Sub-Optimal (126)
WISS400	2011-2016	Riparian Vegetative Zone Width (9.5)	Channel Alteration (16.2)	Sub-Optimal (121)
WISS250	2011-2016	Embeddedness (7.2)	Bank Stability (13.3)	Marginal (107)
WISS150	2011-2016	Riparian Vegetative Zone Width (6.2)	Bank Stability (13.2)	Marginal (96.2)
SR300	2011-2013	Riparian Vegetative Zone Width (4)	Embeddedness (12.7)	Marginal (79)
SR200	2011-2016	Frequency of Riffles (8.7)	Channel Flow Status (14.2)	Marginal (108)
SR100	2011-2016	Embeddedness (5.3)	Channel Alteration (14.3)	Marginal (101)
PR100	2014	Riparian Vegetative Zone Width (5)	Channel Flow Status (16)	Marginal (108)
T400	2013-2016	Bank Stability (10)	Channel Flow Status (15)	Sub-Optimal (125)
T100	2013-2014	Sediment Disposition (7)	Velocity/Depth Regime (13.5)	Marginal (108)

WVWA results compared with other studies

The WVWA results were compared to the Philadelphia Water Department Creek Characterization Report (CCR) of the Wissahickon Watershed, completed in 2007 (PWD, 2007). The reported values in the CCR cannot be directly compared to the WVWA because the CCR used a slightly different method, which has a higher maximum site score (260, instead of 200), but the raw CCR habitat scores could be compared to the WVWA habitat scores.

The overall the habitat values were slightly higher in the CCR compared to the WVWA values, which resulted in more sites considered 'supporting,' instead of 'marginal.' The CCR habitat assessments were completed in 2005, 6 years before the WVWA assessments began, so this may indicate that conditions degraded slightly between 2005 and 2011. The CCR indicated low in-stream variation between upstream and downstream sites. The WVWA found similar results with most sites between marginal and suboptimal in the Wissahickon Creek, except for WISS600. Overall, the results between the WVWA and CCR are similar and indicate that all sites in the Wissahickon Watershed have habitat with some degradation and impairment.

Conclusions

Overall, both the WVWA and the PWD results indicated impairments in the Wissahickon Watershed with no sites listed as optimal. Embeddedness was the lowest ranked parameter throughout the watershed, reflecting erosion as an issue in the Wissahickon Watershed. This is consistent with the urban stream syndrome and the sediment Total Maximum Daily Load for the Wissahickon Watershed. However, the highest scored parameter, channel alteration, indicated the benefits of the preservation efforts by the WVWA and others in the Wissahickon Watershed to create a protective riparian buffer for the Wissahickon Creek.

Take-away points and summary map

A few take away points from habitat assessments in the Wissahickon Watershed from 2011 to 2016:

- 73 habitat assessments were completed from 2011 to 2016. Of the assessments, 1.3% were categorized as poor, 50.7% were marginal, and 48% were suboptimal.
- WISS750 and T400 (Prophecy Creek) were on average the highest scored sites. This is consistent with Prophecy Creek being the most protected and least developed subwatershed in the Wissahickon Watershed. WISS600 had the lowest habitat assessments scores.
- The highest average parameter in the Wissahickon Watershed was channel alteration. This is likely due to the Green Ribbon Preserve that buffers the Wissahickon Creek.
- The lowest average parameter was embeddedness, indicating an issue with erosion. This is consistent with the urban stream syndrome.
- There was variation over time in habitat assessment scores at sites, but these are likely from changes in the time of year habitat assessments were conducted.
- Each site's habitat assessment category across the watershed can be found in Figure 5-3.

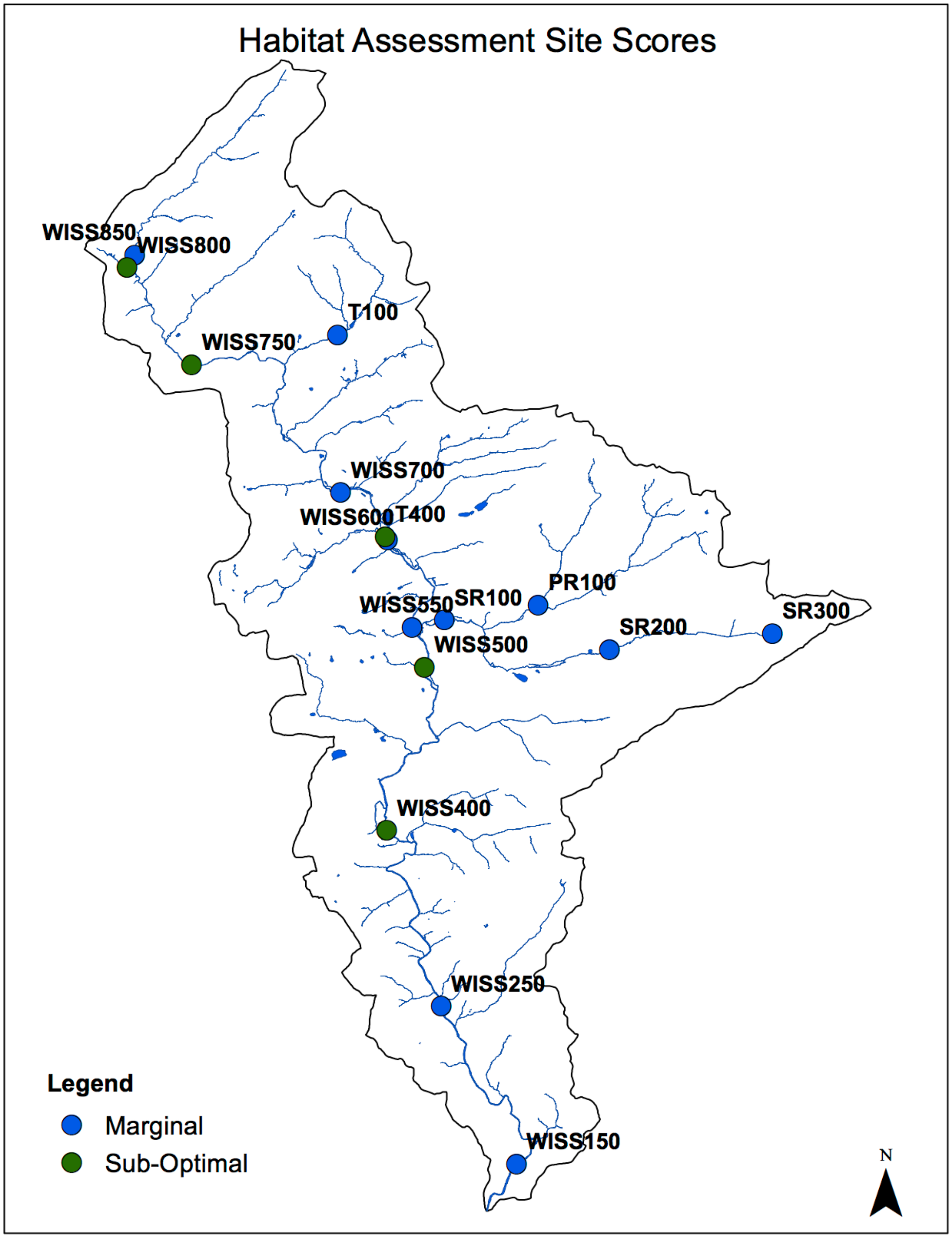

Figure 5- 3. A map of the Wissahickon Watershed and the habitat assessment sites from 2011-2016. Sites in blue were considered marginal and sites in green were suboptimal. All sites were not surveyed from 2011 to 2015.

SECTION SIX: WATER QUALITY

The Stream Monitoring and Assessment Program (Stream MAP) started as a water quality monitoring program in 2004. Water quality monitoring is vital in any ecological monitoring program because it captures what is occurring in the stream, including stressors and pollutants, which cannot be determined visually. These results can then be used to determine the factors that are contributing to the condition of the biological community.

Methods

The sites and frequency of sampling has changed over the life of Stream MAP from the early days of the program with five sites, to the present day with 13 active sites. Table 6-1 details when samples were collected at each site from 2004 to 2016. A few major changes in the program include (1) adding Sandy Run sites in 2008, (2) adding winter season sampling in 2011, (3) adding tributary sites in 2013, and (4) joining the Delaware River Watershed Initiative in 2014.

Table 6- 1. The years and seasons that sites were sampled in the Wissahickon Watershed from 2004 to 2016 for Stream MAP. Quarters refer to the sampling season, starting with (1) for winter, (2) for spring, (3) for summer, and (4) for fall. Areas in grey indicate a standard dry weather sample was collected at that site for the sampling quarter. Dark grey indicates a wet weather sample was collected.

Year	2004		2005				2006				2007	2008				2009				2010				2011				2012				2013				2014				2015				2016			
Quarters	3	4	1	2	3	4	1	2	3	4		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	5	1	2	3	4
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Sampling methods

The parameters that were collected during Stream MAP changed over time and included phosphorus (total and orthophosphate), nitrogen (nitrate, nitrite, and ammonia), total solids (suspended and dissolved), bacteria (fecal coliform, *E. coli*, or total coliform), chloride, sulfate, bromide, alkalinity, hardness, aluminum, iron, and total organic carbon (Table 6-2). Water quality samples were collected by the WVWA and sent to an accredited laboratory for analysis, including QC laboratories (2004 – 2010), HamptonClarke Veritech (2011 – 2012), Test America (2013 – 2015), and Suburban Laboratories (2015 – 2016). Streamside parameters were recorded at each site including temperature, conductivity, and pH using an YSI 63, and dissolved oxygen using a YSI ODO after 2014 and OAKTON DO 6+ prior to 2014.

Water quality samples were collected for Stream MAP as grab samples. From 2004 to 2013 samples were collected either directly from a bankside riffle or by lowering a bucket into the stream and collecting samples from the bucket. In 2014 the WVWA adopted the DRWI Quality Assurance Project Plan (QAPP) and the QAPP method of collecting all samples directly from a riffle area, ideally halfway across the stream channel. Water quality samples were collected in the middle of each season including typically, (1) winter collections in February, (2) spring collections in April, (3) summer collections in August, and (4) fall collections in November. Samples were collected during dry weather with ideally at least three days since the last rainfall. One exception was November 2006, which was a wet weather sampling event. Samples collected from 2011 to 2014 were collected over two days while all other samples were collected in a single day.

Table 6- 2. The water quality parameters collected for Stream MAP from 2004 to 2016. Quarters refer to the sampling season, starting with (1) for winter, (2) for spring, (3) for summer, and (4) for fall. Areas in grey indicate the parameter was included in the sampling event. The quarters that are marked in grey indicate that additional samples were collected for quality assurance and quality control practices

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	3 4	1 2 3 4	1 2 3 4		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Ortho-Phosphate													
Total Phosphorus													
Nitrate													
Nitrite													
Ammonia													
Total Suspended Solids													
Total Dissolved Solids													
Fecal Coliform													
E. Coli													
Total Coliform													
Chloride													
Sulfate													
Bromide													
Total Alkalinity													
Hardness													
Aluminum													
Iron													
Total Organic Carbon													

Quality assurance and quality control

The DRWI QAPP included quality assurance and quality control (QA/QC) practices that the WVWA adopted. QA/QC practices improve data integrity by providing evidence that sampling methods and analysis are executed properly and without contamination. The DRWI QAPP requires the collection of two duplicates and two field blanks for each sampling event. Sample duplicates, two samples collected using the same methods at the same location and time, must be within 15% relative percent difference to be accepted. Field blanks, a sample of purified water that is brought into the field and treated as a sample, must be below twice the method detection limit to be accepted.

Prior to the adoption of the DWRI QAPP, duplicate samples were collected in the summer of 2009 and the winter of 2011. Starting in the winter of 2014 all sampling events included a sample duplicate for QA/QC purposes and starting in the summer of 2014 all sampling events included two sample duplicates and two field blanks to fully comply with the DRWI QAPP. Lastly, a calibration record for streamside sampling probes was established in the summer of 2014 for documenting calibration methods and calibration drift at the end of the day.

Study limitations

Stream MAP was developed with the goal of monitoring the Wissahickon Watershed over time to better understand the watershed, but all study designs have limitations and assumptions that are built into them. Water quality sampling is limited to indicating the condition of a stream only at the moment of sampling because the water at the site is constantly changing. Stream MAP focused on daytime and low-flow periods, which are two factors that influence the concentrations of many water quality parameters. Total suspended solid concentration, a proxy for erosion, is a good example of a parameter that fluctuates by orders of magnitude between low flow time periods, without erosion, and during rain events when erosion is actively occurring. Diurnal patterns are also common. Dissolved oxygen is a good example of a parameter that is elevated during the day when algae are photosynthesizing, but is low at night while algae are respiring. Stream MAP also focused on the concentration of water quality parameters, instead of the loading at the site. This means that a water quality parameter could appear to be improving at a site, but instead sampling occurred during time periods of higher flow and the parameter is more diluted. Overall, though Stream MAP provides a lot of information on what is happening in the Wissahickon Watershed, it is important to recognize that it is limited to when the samples are collected.

The Stream MAP has undergone many changes since the start of the program in 2004, including changes in sites and parameters collected. This means that each site or parameter may not have the full 12 years of data and conclusions on the site or parameter may be limited. Lastly, QA/QC procedures have only been in place after the sampling methods were adjusted for the QAPP in 2014. Samples collected prior to 2014 were with a different sampling method and only two QA/QC samples collected with these methods. This means that samples collected before 2014 should still indicate the trends throughout the Wissahickon Creek, but caution should be used when analyzing this data or looking at individual sampling events and sites.

Results

This section will describe the results for each parameter collected for Stream MAP, including (1) a description of the parameter, (2) when it was sampled for Stream MAP, (3) water quality standards associated with the parameter, (4) QA/QC results, (5) monitoring trends throughout the Wissahickon and over the years of monitoring, and (6) Stream MAP results compared to the PWD CCR for any parameters that were included in the CCR.

Streamside parameters

Streamside parameters collected for Stream MAP included conductivity, dissolved oxygen, temperature, and pH. In 2014 the WVWA adopted the DWRI QAPP that required recording calibration results before and after sampling for QA/QC. This section will include the data collected in 2015 and 2016. These are the two years after the DWRI QAPP was adopted and all probes were serviced or replaced.

Conductivity

Conductivity is the electrical conductance of water across a set distance and was determined using a streamside probe (YSI63). Conductivity is commonly used as a proxy for other water quality parameters, including total dissolved solids and chlorides, which are influenced by point sources, road salt in the winter, stormwater inputs, and the natural geology of a region. There are no Pennsylvania water quality standards (PA WQS) for conductivity.

Conductivity and specific conductivity were both recorded for Stream MAP. Only specific conductivity will be reported here because it is conductivity that is normalized to 25^{0} C and can be used to compare conductivity measurements across temperatures. The patterns in specific conductivity were different between upstream and downstream sites depending on the time of year in 2015 and 2016 (Figure 7.1). Conductivity was higher during winter sampling at all sites, likely due to runoff from road salt. Conductivity was highest at WISS850 and WISS800 in the Wissahickon mainstream and then decreased moving downstream to the mouth of the Wissahickon Creek. During the three other seasons, WISS850 and WISS800 frequently had the lowest conductivity in the Wissahickon mainstream and instead conductivity increased at WISS750 and then decreased moving downstream to the mouth of the Wissahickon Creek. Sites WISS850 and WISS800 are likely the most influenced by changes in runoff because they are upstream of wastewater treatment plants and the Upper Watershed has little ground water input. At the tributary sites, both Sandy Run sites had similar conductivity readings as the Wissahickon mainstem. Prophecy Creek (T400) is the most protected subwatershed and had the lowest conductivity readings throughout the Wissahickon Watershed.

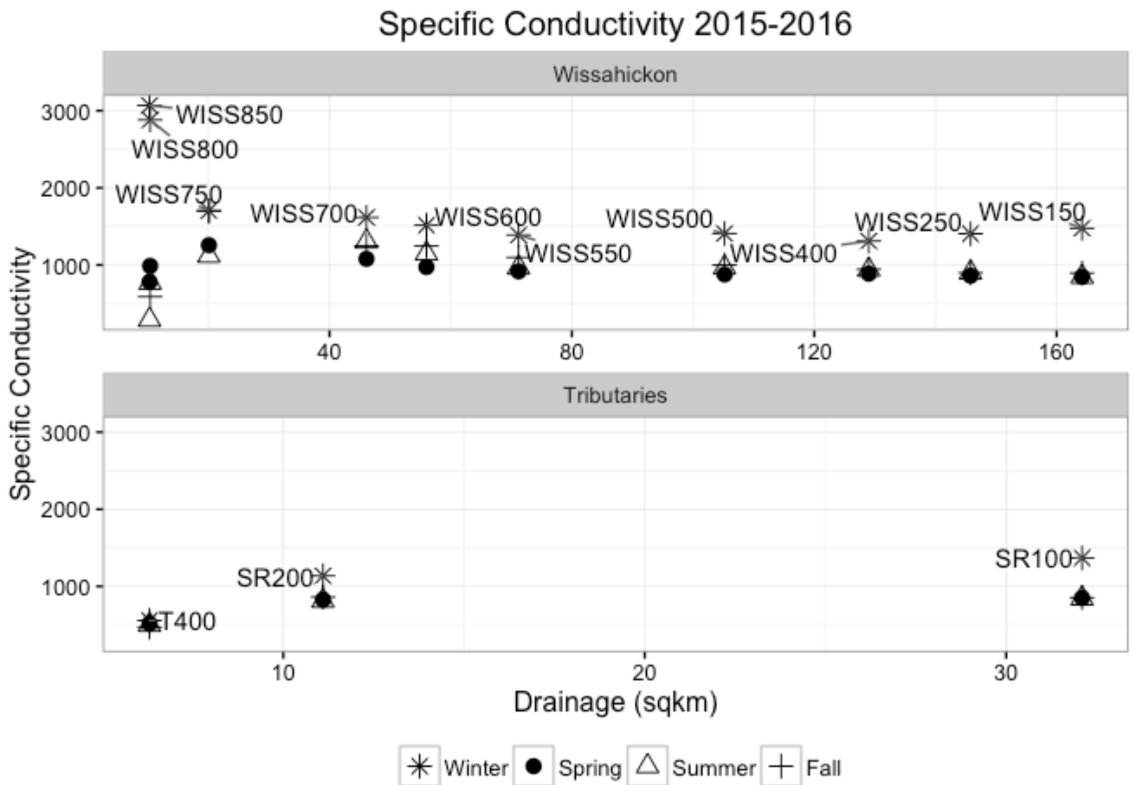

Figure 6- 1. Average seasonal specific conductivity measurements in the Wissahickon Watershed from 2015 to 2016. The symbols are as follows (1) star indicates average specific conductivity in the winter, (2) circle indicates average specific conductivity in the spring, (3) triangle indicates average specific conductivity in the summer, and (4) cross indicates average specific conductivity in the fall

pH

Commonly referred to as 'acidity', pH is the measure of the concentration of hydrogen ions in water. Factors that influence pH in freshwater systems include, geology of a region, non-point and point sources, photosynthesis, and the burning of fossil fuels through acid rain and atmospheric deposition. The PA WQS is pH 6.0 - 9.0 for trout stocking fishery (TSF), the protected water use classification of the Wissahickon Creek, cold-water fisheries, and warm water fisheries (WWF) (PA, 2001). TSF must maintain certain WQS from February 15 to July 31 for the stocked trout and then maintain WWF standards during the rest of the year.

Diurnal patterns are common for pH, particularly in highly productive systems where pH increases as photosynthesis increases. These diurnal patterns are likely to influence the Stream MAP data, since stations were often sampled consecutively throughout the day. Stream MAP results indicated that pH values were typically between 7 and 9, all recordings were above 6.0, and twice pH was above 9.0 in May 2016 at WISS700 and WISS600. These measurements were taken in the middle of the afternoon while photosynthesis is highest. Additionally, WISS700 is downstream of a section that has no tree canopy cover, which increases algae productivity.

The Stream MAP readings were similar to the patterns found in the Wissahickon Creek Watershed Comprehensive Characterization Report (CCR) by the Philadelphia Water

Department (PWD, 2007). Sampling for the CCR found diurnal patterns in pH and any water quality standard violations were pH >9.0 and not pH <6.0.

Temperature

Water temperature is influenced by climate, discharge from point sources and non-point sources into the system, tree canopy cover, and impoundments. Water temperature heavily influences the biological community present at a site as aquatic organisms have a limited range of temperatures they can survive and reproduce in. Additionally, water temperature determines the maximum concentration of dissolved oxygen in the water column, where cooler water can have a higher maximum concentration. Temperature has such a strong influence on aquatic communities that fisheries are grouped into warm water and cool water species. Pennsylvania has a maximum water temperature WQS by date for cool water, warm water, and trout stocked fisheries (PA, 2001).

The maximum stream temperature recorded over the two years was 31.2^{0} C (88.2 F) at WISS700 in summer 2016, exceeding the PA WQS for TSF in August. WISS700 is a slow moving site that is just downstream from a section of the Wissahickon Creek without a tree canopy. Stream MAP does not include a site just upstream of the section without a tree canopy, so there is no way to determine how much the exposed section of the Wissahickon Creek is increasing the stream temperature. Like pH, temperature is also diurnally influenced, and because Stream MAP sampling is conducted one site at a time throughout a day the data cannot be used to determine watershed wide patterns.

Dissolved oxygen

Dissolved oxygen is the concentration of oxygen in the water column and is vital for the biological community. Dissolved oxygen concentrations are influenced by stream temperature, the time of day, point and non-point discharges, and the biological community. Dissolved oxygen exhibits diurnal patterns with elevated concentrations in the day from algae photosynthesizing and reduced concentrations at night when algae are respiring. These diurnal variations are expected in all freshwater systems, but are more pronounced in developed systems. Pennsylvania has a minimum WQS of 5.5 mg/L dissolved oxygen for a 7-day average, and 5.0 mg/L as a minimum throughout the year. Additionally, TSF must maintain a minimum 7-day average requirement of 6.0 mg/L from Feb 15 to July 31 (PA, 2001).

Stream MAP results indicate that during sampling most sites had 100% saturation, however these samples were all taken during the daytime when concentrations are expected to be highest due to peak photosynthesis. There were no samples taken during the nighttime, when dissolved oxygen concentrations are expected to be at their lowest. Again, due to the diurnal nature of dissolved oxygen and because Stream MAP samples sites are sampled one at a time it is impossible to use this data to examine watershed wide patterns.

Phosphorus

Nutrients are the limiting factors for the growth of primary production (e.g. algae) in system and phosphorus is typically the limiting factor in freshwater systems. Phosphorus is naturally occurring at very low concentrations from the breakdown of plant matter, and the weathering of rocks and sediments. However, in developed systems most phosphorus comes from human influences including point source discharges, wastewater treatment plants, stormwater runoff, fertilizers, agriculture, increased erosion from stormwater and many more. Excessive phosphorus in the Wissahickon Watershed is a known issue that is contributing to excessive algae growth (USEPA, 2015a; USEPA, 2015b).

Phosphorus was collected from 2004 to 2016 for Stream MAP in two forms, total phosphorus and orthophosphate. Total phosphorus is a measure of all forms of phosphorus including, organic, orthophosphate, and inorganic forms. Orthophosphate is the dissolved form of phosphorus and is available for organisms to use for primary production. Organic and inorganic forms of phosphorus are not bioavailable and are typically bound to particulate matter or soils.

Orthophosphate

QA/QC duplicates for orthophosphate were within acceptable ranges 20/24 times and blanks were in acceptable ranges 17/17 times. The Stream MAP data was separated for analysis from before 2011, when samples were collected three times a year, and after 2011 when samples were collected four times a year. The watershed wide trends were investigated by looked at the trends starting at the Upper Watershed and moving downstream to the mouth of the Wissahickon.

From 2004 to 2010 the upstream/downstream trend for orthophosphate was higher concentrations at WISS750, a slight reduction at WISS600, then an increase in concentrations at WISS550, and reduced concentrations heading downstream to the mouth of the Wissahickon (Figure 6-2). The Sandy Run sites had an increased concentration at SR200 and lower concentrations at the upstream (SR300) and downstream (SR100) sites. The one wet weather sampling event in Nov 2008 had decreased orthophosphate concentrations, indicating dilution during storm events. From 2011 to 2016 the same upstream/downstream trends were observed with increased concentrations at WISS750, WISS550, and SR200. WISS850 and WISS800 had the lowest orthophosphate concentrations in the Wissahickon Creek and the tributaries including, T100 (Trewellyn), T400 (Prophecy), and PR100 (Pine Run) had the lowest concentrations throughout the Wissahickon Watershed (Figure 6-3). Overall, 2011 to 2016 data had lower variability and lower concentrations than the data from 2004 to 2010.

Seasonal orthophosphate trends indicated more seasonal variability in sites below WISS600 compared to upstream of WISS600 (Figure 6-4). Typically, the spring had the lowest orthophosphate concentrations and the fall had the highest concentrations. This follows the pattern of vegetative growth during the spring and die off in the fall.

Changes in the annual orthophosphate concentrations were investigated at each site from 2008 to 2016 (Figure 6-5). This indicated that all sites that were above wastewater treatment plants and in small drainage areas had the lowest orthophosphate concentrations, including WISS850, WISS800, SR300, PR100, T400, and T100. The trends over time also found a significant trend of decreasing orthophosphate concentrations at WISS750 (p-value = 0.00827), WISS600 (p-value = 0.00536), WISS550 (p-value = 0.0092), and WISS150 (p-value = 0.0212). Trends over time also found a significant trend of increasing orthophosphate concentration at SR100 (p-value = 0.0123). Flow data would be needed to determine if the orthophosphate loading also changed between 2008-2016 at these sites.

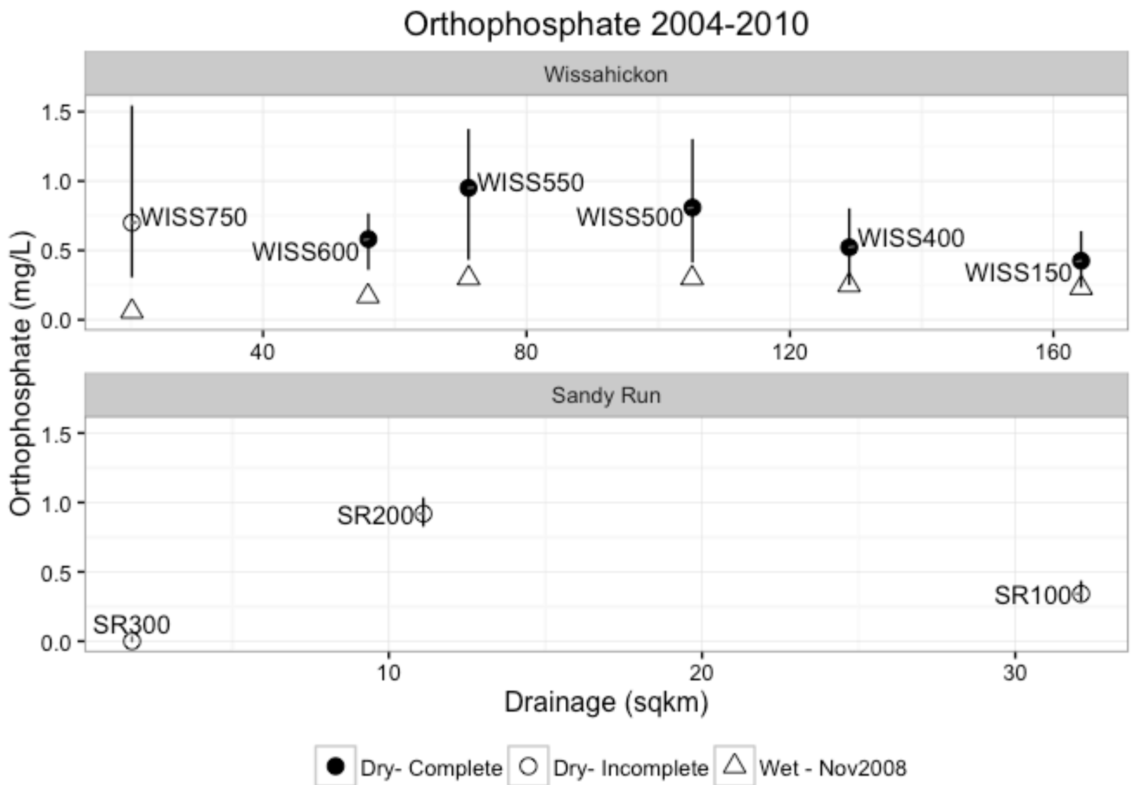

Figure 6- 2. Orthophosphate was sampled from 2004 to 2010 during dry weather and included one wet weather sampling event. The filled in circles represent the median orthophosphate concentrations of the sites that were sampled during all dry weather events. The hollow circles are the orthophosphate concentration of the sites that were not sampled for all sampling events and have missing data. The triangles are the orthophosphate concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

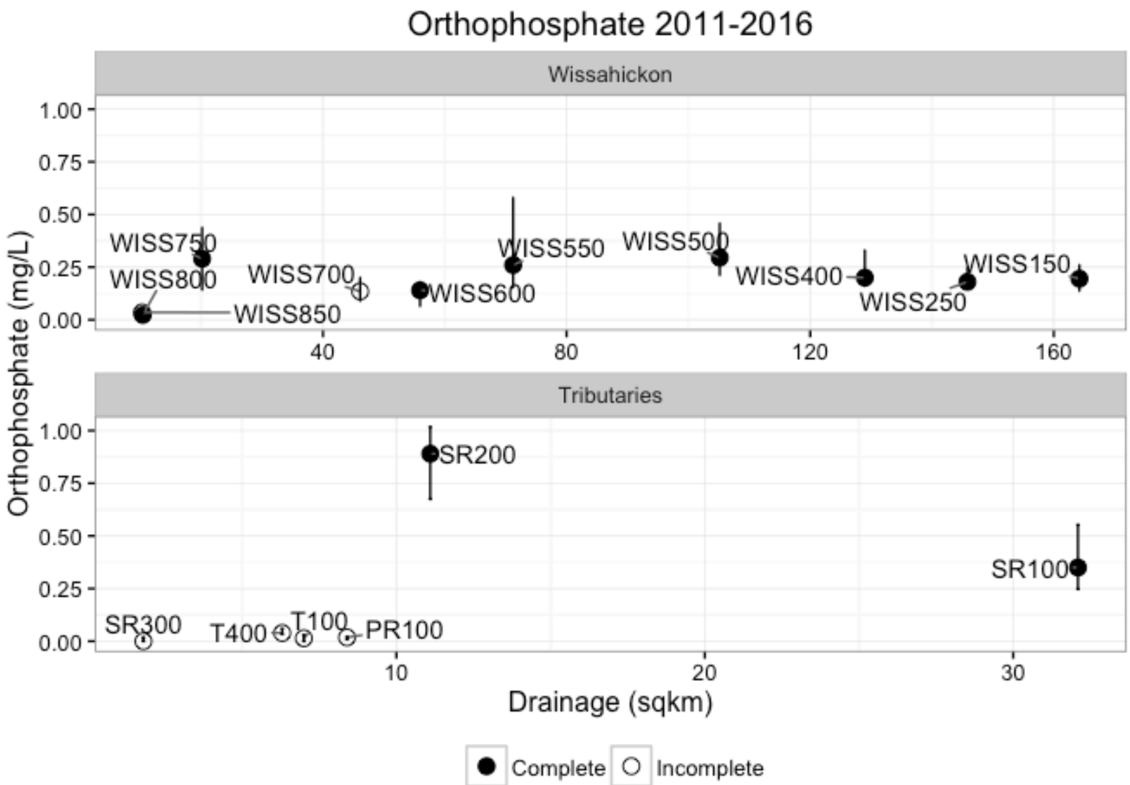

Figure 6- 3. Orthophosphate was sampled for all four seasons from 2011 to 2016 during dry weather. The filled in circles represent the median orthophosphate concentrations of the sites that were sampled during all dry weather events. The hollow circles are the orthophosphate concentration of the sites that were not sampled for all sampling events and have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

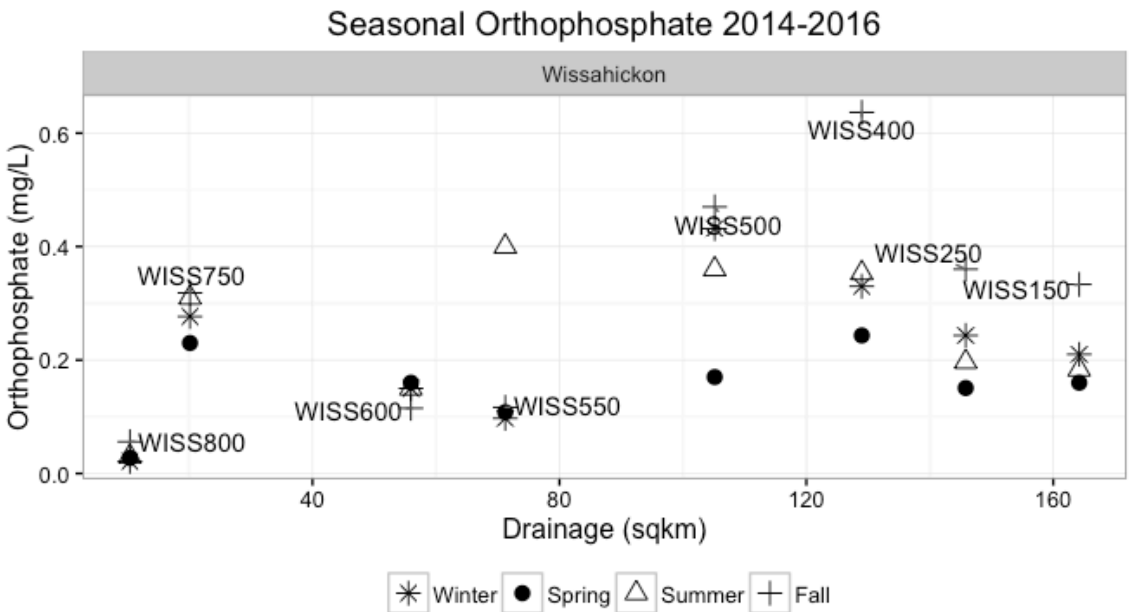

Figure 6- 4. Orthophosphate concentration data from 2014 to 2016 was used to investigate any seasonal trends in the Wissahickon Creek only. The symbols are as follows (1) star indicates average orthophosphate in the winter, (2) circle indicates average orthophosphate in the spring, (3) triangle indicates average orthophosphate in the summer, and (4) cross indicates average orthophosphate in the fall.

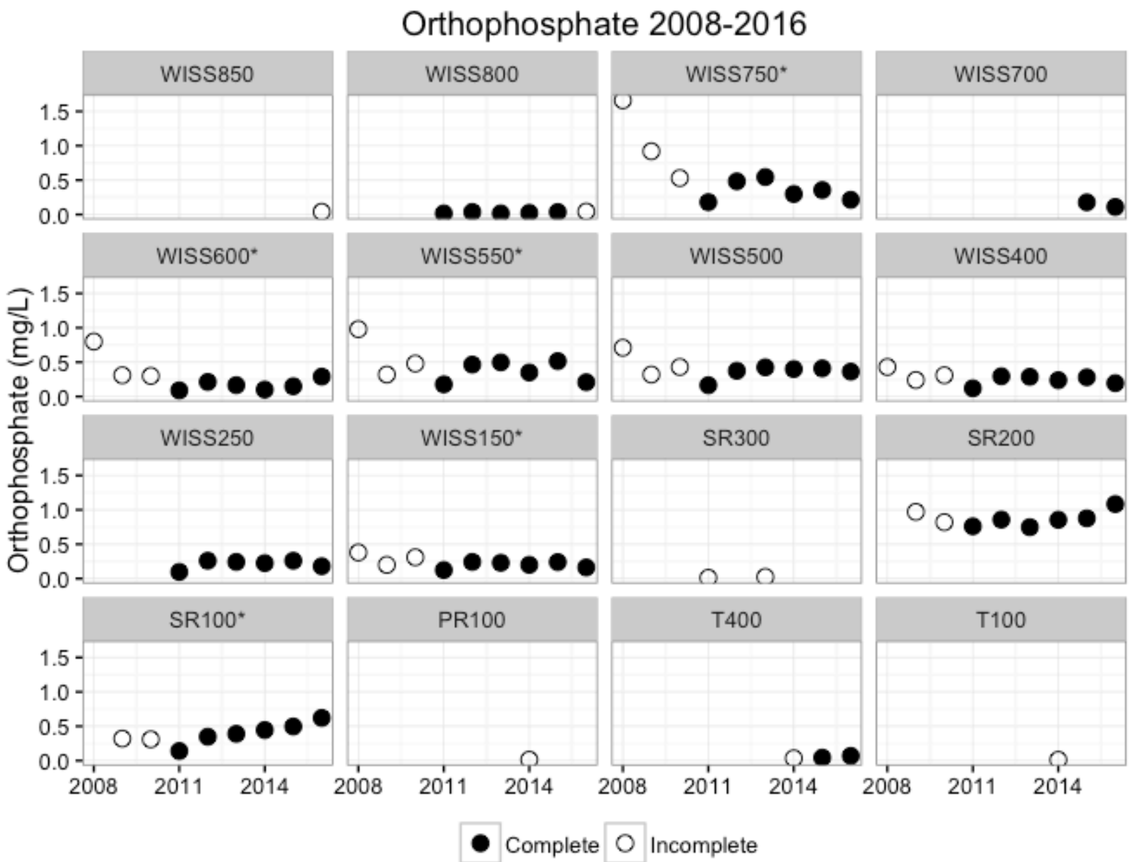

Figure 6- 5. Changes in orthophosphate trends over time at all sites in the Wissahickon Watershed were looked at using data from 2008 to 2016. The filled in circles are average orthophosphate concentration at the site if all four sampling seasons were collected. The hollow circles are the average orthophosphate concentration if three sampling seasons were collected. Sites and years with less than three sampling seasons were not included. Sites with an asterisk (*) indicate the change in concentration was significant (p-value <0.05).

Total phosphorus

Total phosphorus (TP) QA/QC duplicates were within acceptable ranges 20/24 times and blanks were in acceptable ranges 17/17 times. The Stream MAP data was separated for analysis between before 2011, where samples were collected three times a year, and after 2011 where samples were collected four times a year. Currently there is no PA WQS for TP, but the EPA has proposed a draft TMDL in 2015 that would limit the concentration of TP in the Wissahickon Watershed to 0.04 mg/L (USEPA, 2015a).

As expected, TP had similar watershed wide trends and patterns as orthophosphate. These trends included increased TP concentrations at WISS750, WISS550, WISS500, and SR200 compared to the rest of the watershed from 2004 – 2010 (Figure 6-6) and 2011 to 2016 (Figure 6-7). Seasonally, the fall had the highest TP concentrations while the spring typically had the lowest concentrations (Figure 6-8). Additionally the sites that were downstream of small drainage areas and upstream of wastewater treatment plant discharges all had the lowest TP concentrations, including WISS850, WISS800, T400, T100, PR100, and SR300. Lastly the same sites had significant trends of decreasing TP, including WISS750 (*p*-value = 0.008269), WISS600 (*p*-value = 0.005326), WISS550 (*p*-value = 0.009197), WISS150 (*p*-

value = 0.02123), and SR100 had a significant trend of increasing TP (*p*-value = 0.01231) (Figure 6-9). Flow data would need to be evaluated if the change is concentration is also a change in nutrient loading.

The Wissahickon CCR found similar phosphorus trends as Stream MAP, including (1) phosphorus concentrations were reduced during wet weather, and (2) Montgomery County sites had higher orthophosphate concentrations than Philadelphia sites in the Wissahickon Creek (PWD, 2007). The CCR mentions a long term decrease in orthophosphate from historical data and Stream MAP data also found this trend.

Though phosphorus has been found to be decreasing at several sites in the Wissahickon watershed, 374 of the 418 Stream MAP samples were above the proposed 0.04 mg/L TP standard. Of the 44 samples below 0.04 mg/L, 37 of these were from sites above wastewater treatment plants, including WISS850, WISS800, T100, T400, PR100 or SR300. Overall, even though TP and orthophosphate have reduced in concentrations since 2008 at several sites, the concentrations of phosphorus are still excessive in the Wissahickon Watershed.

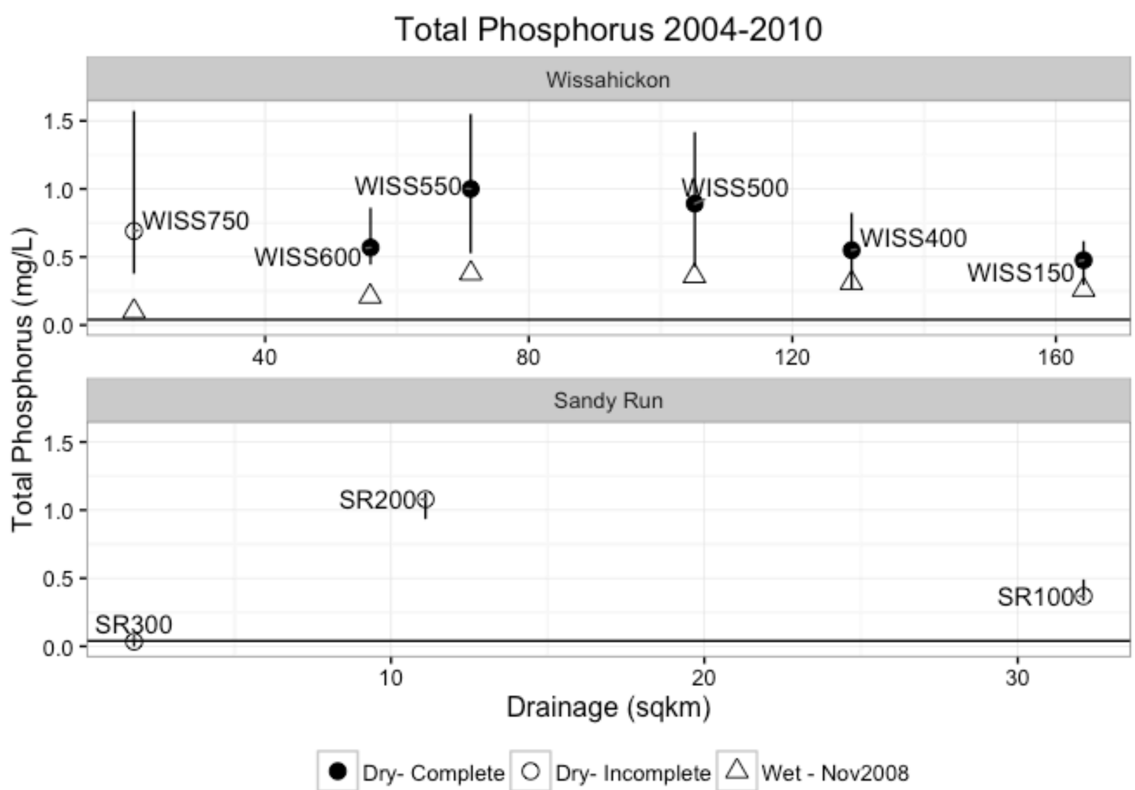

Figure 6- 6. Total phosphorus (TP) was sampled from 2004 to 2010 during dry weather and included one wet weather sampling event. The filled in circles represent the median TP concentrations of the sites that were sampled during all dry weather events. The hollow circles are the TP concentrations of the sites that were not sampled for all sampling events and have missing data. The triangles are the TP concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line is the EPA proposed TMDL TP limit of 0.04 mg/L.

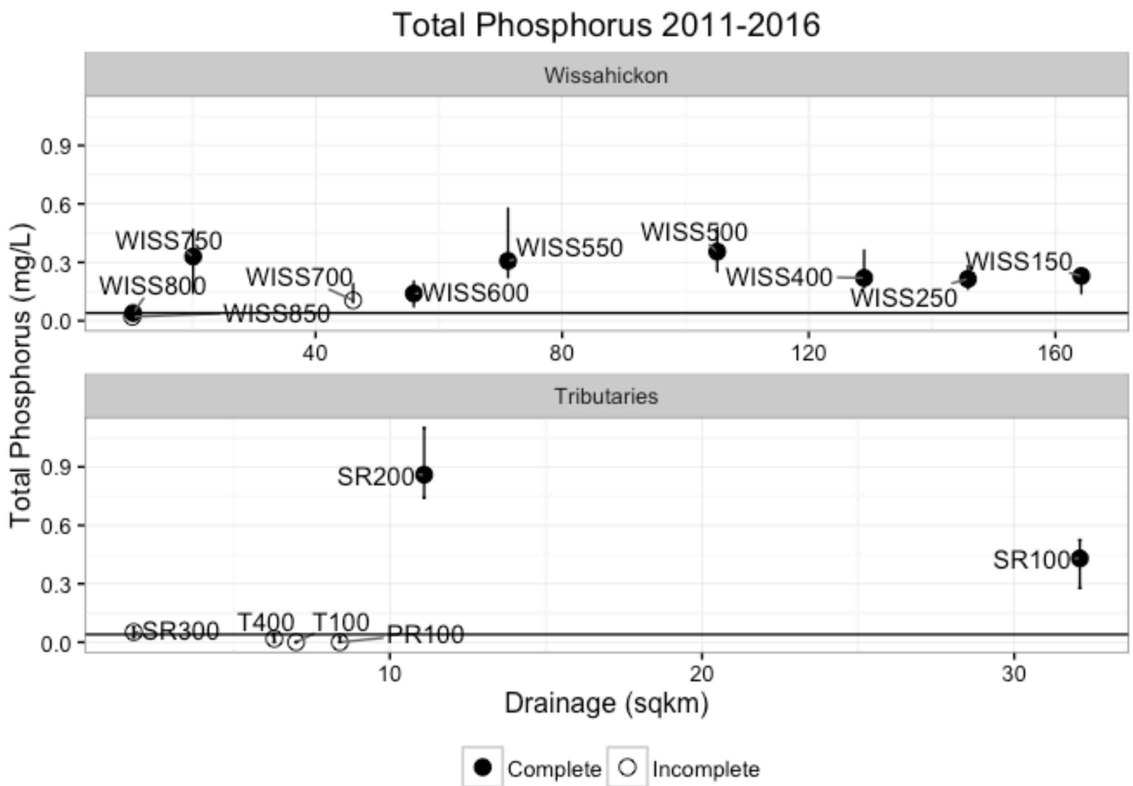

Figure 6- 7. Total phosphorus (TP) was sampled for all four seasons from 2011 to 2016 during dry weather. The filled in circles represent the median TP concentrations of the sites that were sampled during all dry weather events. The hollow circles are the TP concentration of the sites that were not sampled for all sampling events and have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line is the EPA proposed TMDL TP limit of 0.04 mg/L.

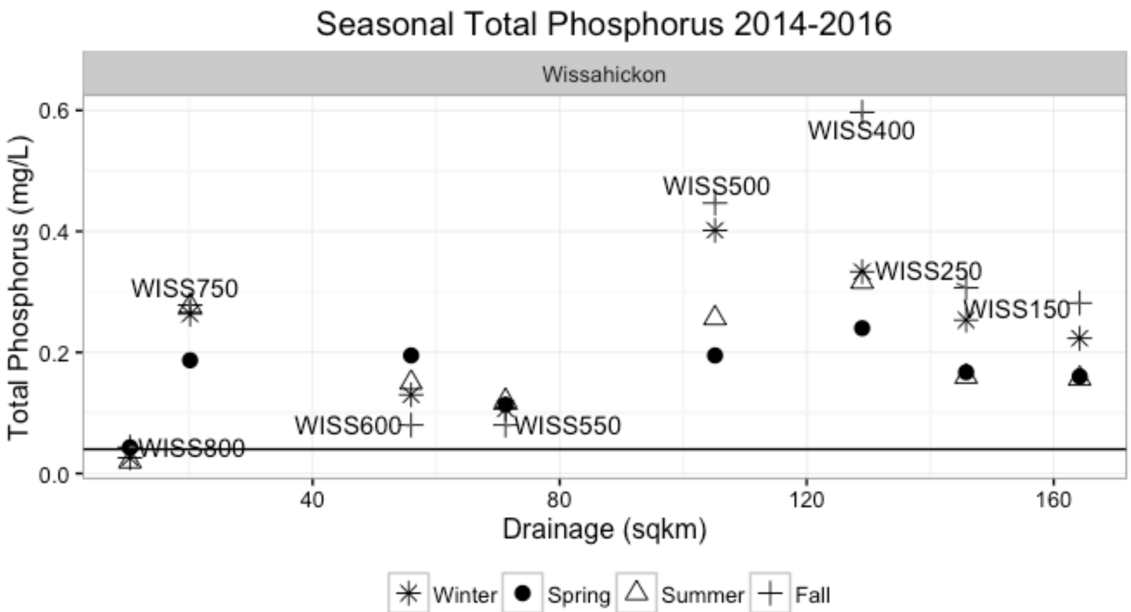

Figure 6- 8. Total phosphorus (TP) concentration data from 2014 to 2016 was used to investigate any seasonal trends in the Wissahickon Creek only. The symbols are as follows (1) star indicates average TP in the winter, (2) circle indicates average TP in the spring, (3) triangle indicates average TP in the summer, and (4) cross indicates average specific TP in the fall. The solid line is the EPA proposed TMDL TP limit of 0.04 mg/L.

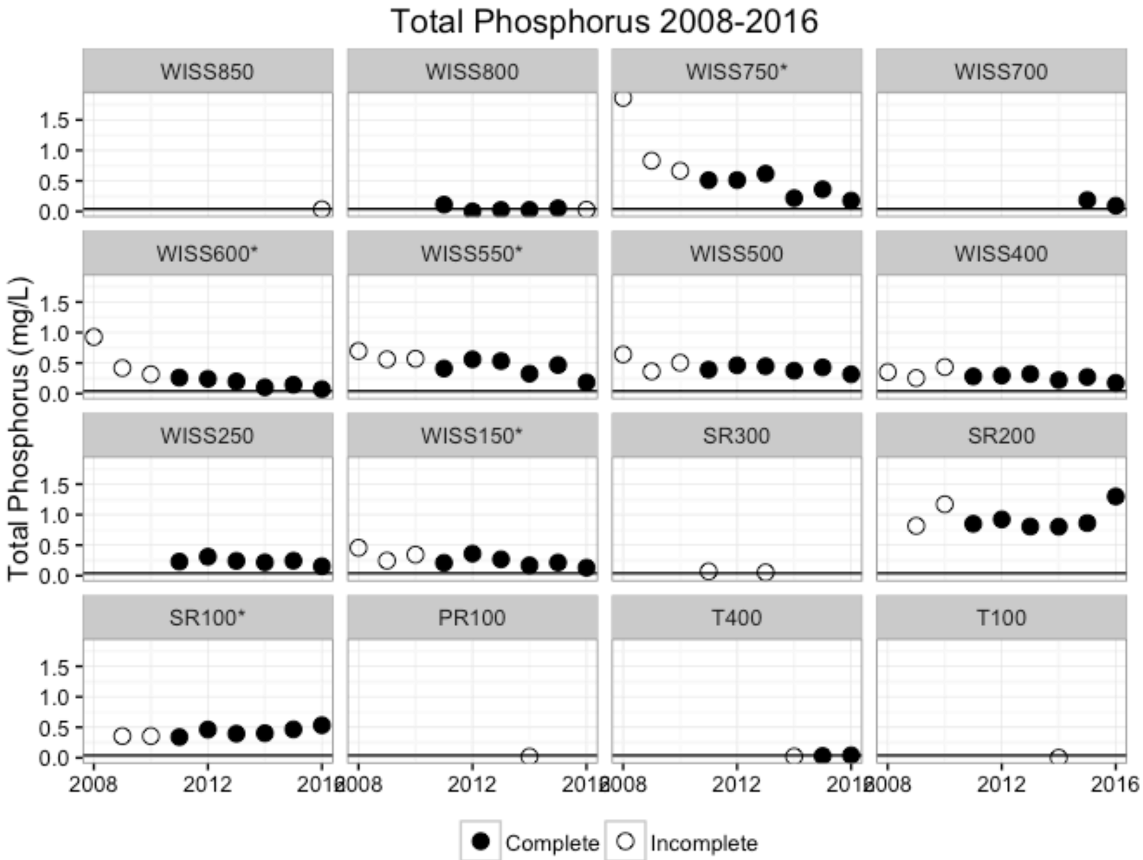

Figure 6- 9. Changes in total phosphorus (TP) over time at all sites in the Wissahickon Watershed were looked at using data from 2008 to 2016. The filled in circles are the average TP concentration at the site if all four sampling seasons were collected. The hollow circles are the average TP concentration if three sampling seasons were collected. Sites and years with less than three sampling seasons were not included. Sites with an asterisk (*) indicate the change in concentration was significant (p-value <0.05). The solid line is the EPA proposed TMDL TP limit of 0.04 mg/L.

Nitrogen

Nitrogen is typically not the nutrient limiting photosynthetic growth in freshwater systems. Nitrogen is naturally available through microbes fixing atmospheric nitrogen and the break down of plant matter. Similar to phosphorus, in urban systems the anthropogenic inputs of nitrogen tends to outweigh the natural inputs. Anthropogenic inputs include agricultural runoff, wastewater treatment plant effluent, fertilizers, and animal waste.

Nitrogen comes in many forms, including dissolved inorganic forms (nitrate, nitrite, and ammonium), organic forms, and ammonia. Pennsylvania has a WQS of <10 mg/L of nitrate + nitrite in public drinking water sources, but has no WQS for TSF like the Wissahickon. Nitrogen was collected as nitrate (2004 - 2016), nitrite (2004 - 2006, 2011 - 2016), ammonia nitrogen (2004 - 2006, 2011 - 2016), and Total Kjeldahl Nitrogen (2015 - 2016) for Stream MAP.

Nitrate

Nitrate was collected from 2004 to 2016 and the QA/QC blanks were always in acceptable ranges while duplicates were within acceptable ranges for 22/24 duplicates. Nitrate results were separated between 2004 to 2010 and 2011 to 2016, after winter sampling was added for analysis. From 2004 to 2010 nitrate was collected 16 times during dry weather and once during wet weather (Figure 6-10). The one wet weather sampling event had decreased nitrate concentrations, indicating dilution during storm events, a similar pattern to what was found in the Wissahickon CCR (PWD, 2007). From 2004 to 2010 the upstream/downstream trend indicated elevated concentrations at WISS750 that decreased at WISS600, and then increased again at WISS550 and decreased to the mouth of the Wissahickon Creek. This was the same trend as phosphorus. In the Sandy Run, SR200 had elevated nitrate concentrations while SR100 and SR300 were lower, but there was limited data for the Sandy Run sites from 2004 to 2010.

From 2011 to 2016 there were more sites sampled and winter was included as a sampling season. The same upstream/downstream trend continued with low concentrations at WISS850 and WISS800, increased concentrations at WISS750 that decreased to WISS600 and then increased to WISS550 and decreased to the mouth of the Wissahickon Creek (Figure 6-11). The tributaries PR100, T100, and T400 all had low nitrate concentrations while SR200 was elevated and SR100 was similar to the Wissahickon mainstem. From 2004 to 2016 the initial sites downstream of wastewater treatment plants (SR200, WISS750, and WISS550) had elevated nitrate concentrations compared to the rest of the sites. Additionally the sites that were downstream of a small drainage area and upstream of wastewater treatment plants (WISS850, SR300, T400, T100, and PR100) all had the lowest nitrate concentrations in the Wissahickon Watershed. These are all the same patterns seen from phosphorus sampling.

Seasonal variations of nitrate concentrations from 2013 to 2016 indicated that nitrate concentrations were highest in the fall and lowest concentrations in the winter (Figure 6-12). Changes in the annual nitrate concentrations from 2008 to 2016 was investigated at each site and found that WISS800 had a significant trend of decreasing nitrate (p-value = 0.03582), particularly after 2013 (Figure 6-13). The North Wales Wastewater Treatment Plant, upstream of WISS800, closed in 2013 and likely explains the reduced nitrate concentrations at this site. From 2004 to 2016 nitrate samples exceeded the 10 mg/L limit for public drinking water sources 50 out of 389 times.

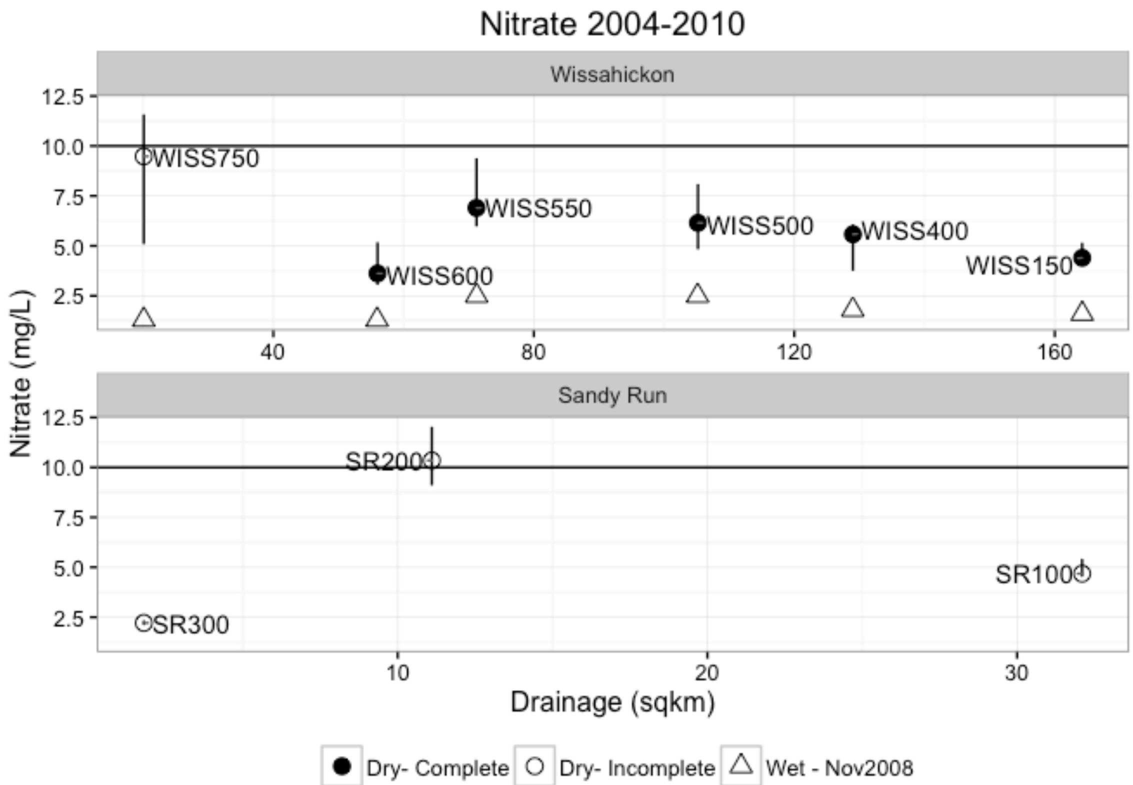

Figure 6- 10. Nitrate was sampled from 2004 to 2010 during dry weather and included one wet weather sampling event. The filled in circles represent the median nitrate concentrations of the sites that were sampled during all dry weather events. The hollow circles are the nitrate concentration of the sites that were not sampled for all sampling events and have missing data. The triangles are the nitrate concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

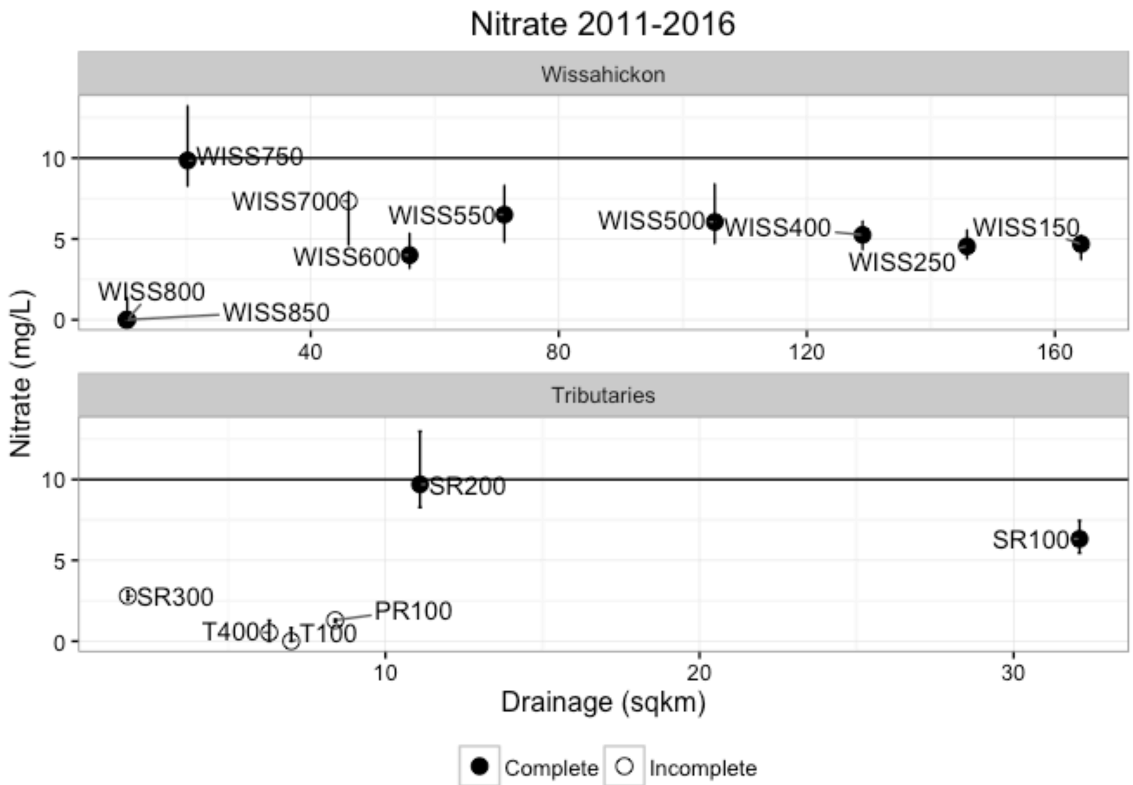

Figure 6- 11. Nitrate was sampled for all four seasons from 2011 to 2016 during dry weather. The filled in circles represent the median nitrate concentrations of the sites that were sampled during all dry weather events. The hollow circles are the nitrate concentration of the sites that were not sampled for all sampling events and have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site

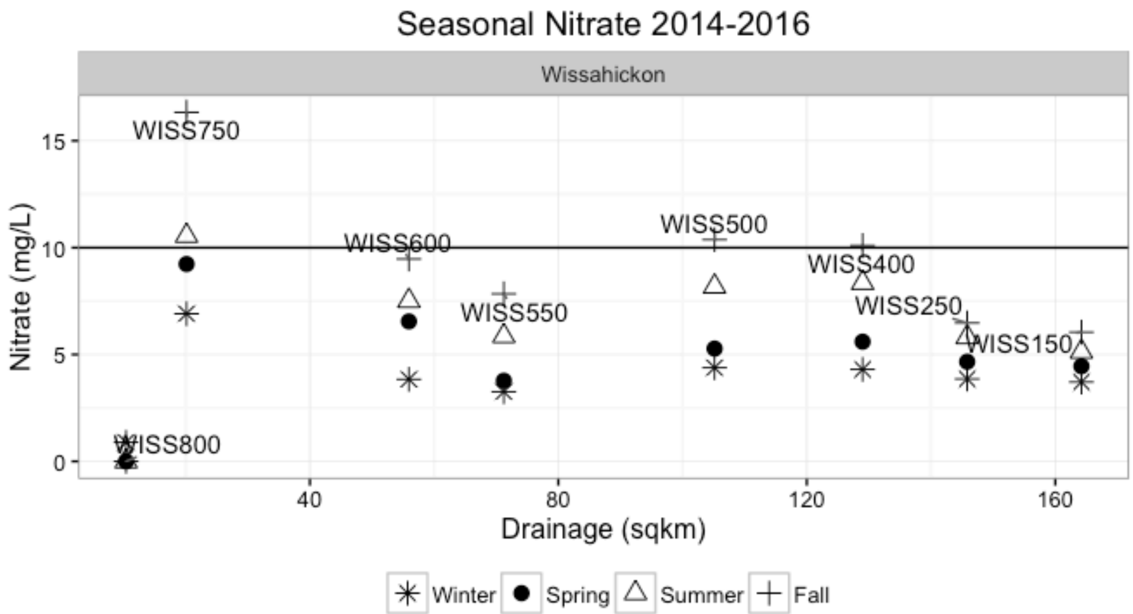

Figure 6- 12. Nitrate concentration data from 2014 to 2016 was used to investigate any seasonal trends in the Wissahickon Creek only. The symbols are as follows (1) star indicates average nitrate concentration in the winter, (2) circle indicates average nitrate concentration in the spring, (3) triangle indicates average nitrate concentration in the summer, and (4) cross indicates average nitrate concentration in the fall.

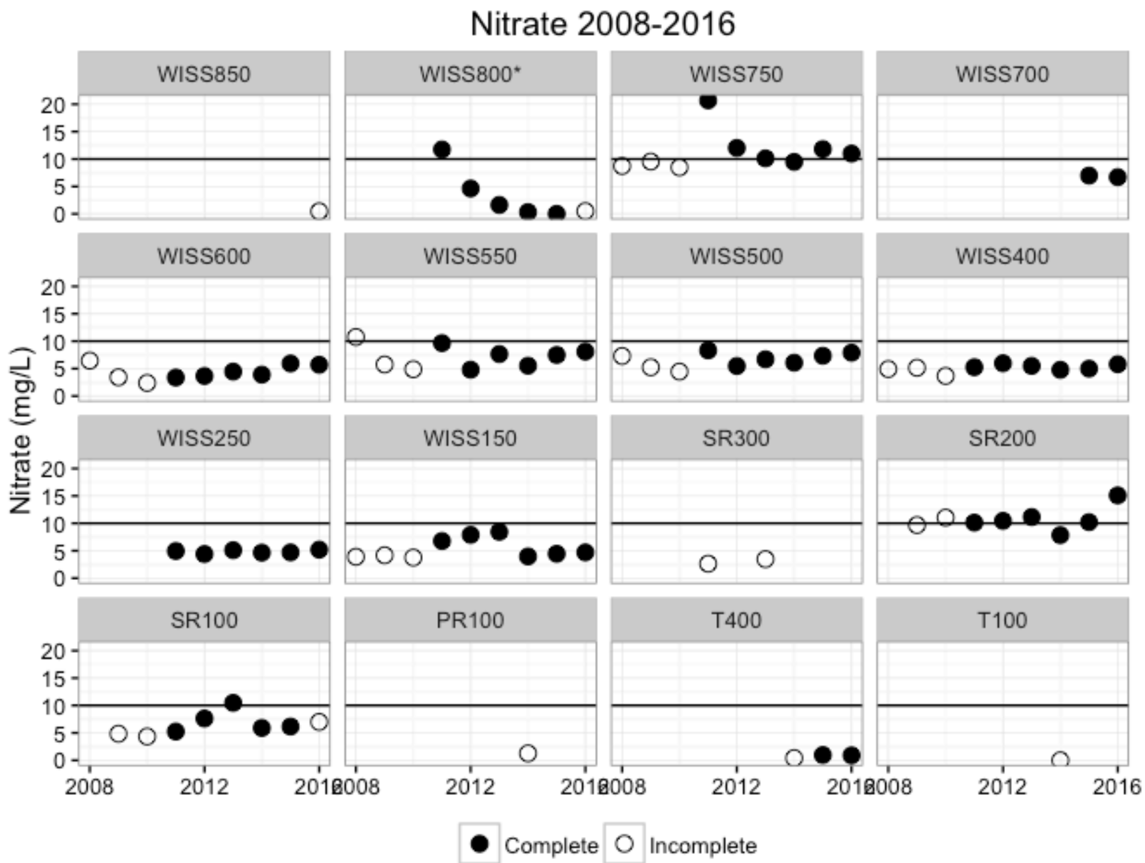

Figure 6- 13. Changes in nitrate trends over time at all sites in the Wissahickon Watershed were looked at using data from 2008 to 2016. The filled in circles are average nitrate concentration at the site if all four sampling seasons were collected. The hollow circles are the average nitrate concentration if three sampling seasons were collected. Sites and years with less than three sampling seasons were not included. Sites with an asterisk (*) indicate the change in concentration was significant (p-value <0.05).

Other forms of nitrogen

The other forms of nitrogen (nitrite, ammonia, and Total Kjeldahl Nitrogen) were all typically below detection limits during Stream MAP sampling. Nitrite was collected from 2004 – 2006, and again from 2011 to 2016 and had consistently acceptable QA/QC results. Nitrite results from 2004 - 2016 indicated nitrite was typically below detections limits and always below 0.5 mg/L of nitrite. Low nitrite concentrations are typical in freshwater systems as nitrite is quickly converted to nitrate. This was also found in the Wissahickon CCR where nitrite was typically below detection limits (PWD, 2007).

Ammonia was also typically below detection limits throughout Stream MAP. Ammonia was collected from 2004 – 2006 and again from 2011 – 2016. QA/QC duplicate samples were above detection limits 9 out of 24 times and only 4 of the 9 samples were within an acceptable range. Ammonia was collected 317 times for Stream MAP and only 111 samples were above detection limits (typically 0.1 mg/L). Overall, ammonia was not a large component of nitrogen in the Wissahickon Watershed. Stream MAP had similar patterns to the Wissahickon CCR that found only 18% of samples with ammonia above detection limits (PWD, 2007).

Total Kjeldahl Nitrogen (TKN) was collected from 2015 to 2016 and had consistently acceptable QA/QC samples. TKN was collected for 99 samples and only 31 had TKN above detection limits (0.5 mg/L). This is similar to the Wissahickon CCR that found low TKN concentrations during dry weather sampling (PWD, 2007).

Total suspended solids

Total suspended solids (TSS) includes visible particulates in the stream water including, sediment, algae, and decaying matter. Typically, samples that are below 20 mg/L are clear while samples above 40 mg/L are cloudy (MDEQ). Negative impacts of TSS on aquatic organisms include (1) blocking sunlight from penetrating into the water column (2) smothering organisms and clogging their gills, and (3) covering habitats with silt and sediment rendering the habitat unusable.

All QA/QC blanks were within acceptable ranges while duplicate samples were inconsistent with 11/19 in an acceptable range. This is likely due to TSS being very low in the Wissahickon Watershed during dry weather events and variability between the samples being high because TSS being a measure of coarse particulate matter that is not always homogenous. TSS samples were collected in the Wissahickon Creek from 2004 to 2006 and again from Spring 2014 to the present. Overall TSS has very low values during dry weather sampling, as expected because the Wissahickon Creek typically runs clear. Throughout TSS collections there were different collection methods and detection limits. To analyze the data, these time periods were kept separate, including (1) 2004- 2006 with a detection limit of 1.0 mg/L, and (2) sampling between Spring 2015 to Fall 2016 that had a detection limit of 1.0 mg/L. All 2014 sampling and the summer of 2015 sampling events were excluded because the detection limits were 4 or 5 mg/L and most readings were below detection limits.

TSS sampling from 2004 to 2006 had a slight pattern of lower readings in the upper Wissahickon, increasing concentrations to WISS400 and decreased concentrations at WISS150 (Figure 6-14). TSS is known to increase if there is erosion during wet whether events, but there was not a substantial increase in TSS in the Wissahickon Creek during the one wet weather event sampled in 2006. TSS was low across the watershed in 2015 and 2016, but there was variability in TSS across the watershed and between sampling events (Figure 6-15). In the tributaries the Sandy Run sites had similar patterns as the Wissahickon Creek and T400 had lowest TSS concentrations. One data point had readings an order of magnitude above the rest of the TSS samples collected on the same day and was removed as an outlier (Spring 2016, WISS700).

Overall TSS concentrations were low and variable for both sampling periods. However, the sampling was done primarily during dry weather events, and sampling at the Wissahickon CCR and USGS gages both indicate large increases in turbidity, a proxy for TSS, during storm events. The Wissahickon Watershed has a sediment TMDL due excessive sediment in the Wissahickon Watershed.

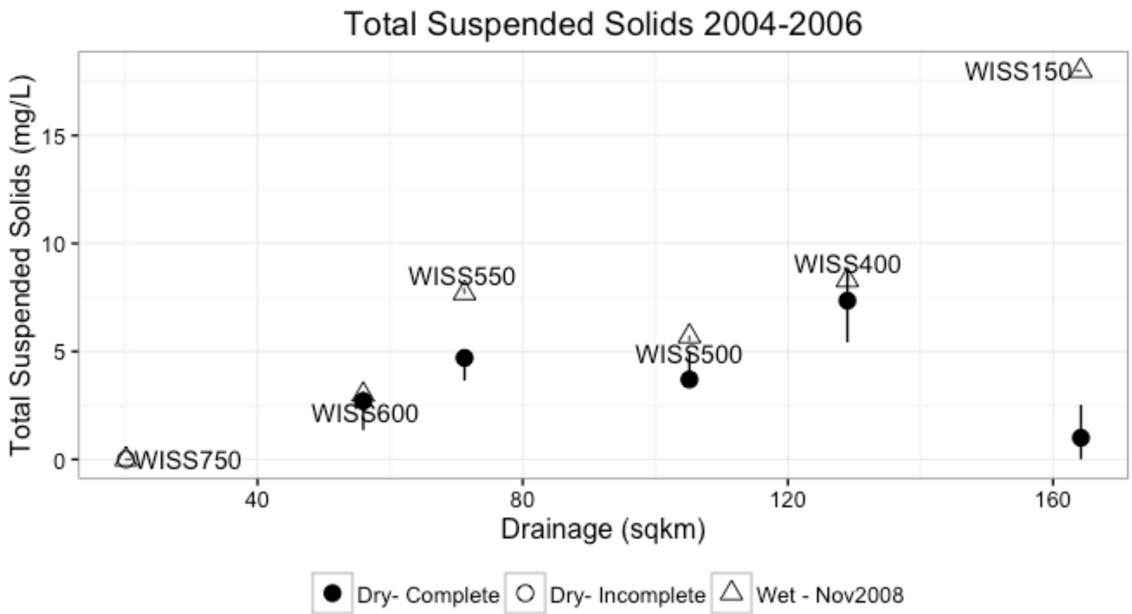

Figure 6- 14. Total suspended solids (TSS) were sampled from 2004 to 2006 during dry weather and included one wet weather sampling event. The filled in circles represent the median TSS concentrations of the sites that were sampled during all dry weather events. The hollow circles are the TSS concentrations of the sites that were not sampled for all sampling events and have missing data. The triangles are the TSS concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

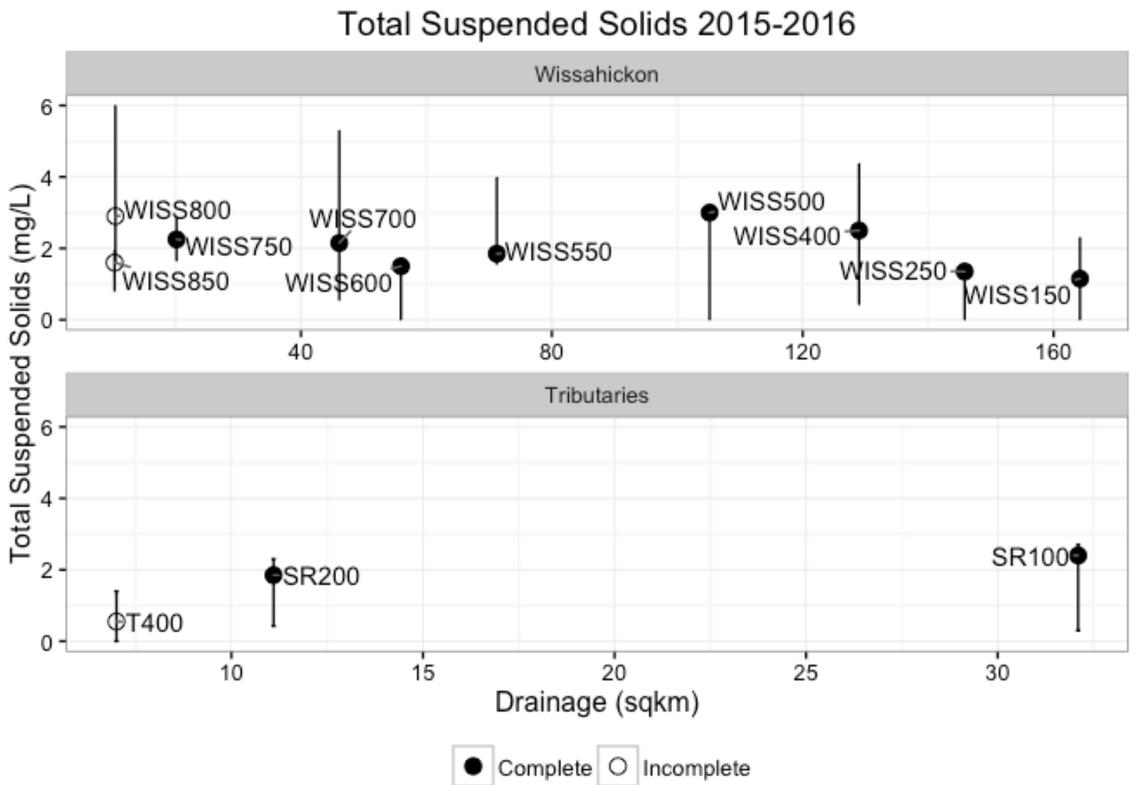

Figure 6- 15. Total suspended solids (TSS) were sampled for all four seasons from 2015 to 2016 during dry weather. The filled in circles represent the median TSS concentrations of the sites that were sampled during all dry weather events. The hollow circles are the TSS concentration of the sites that were not sampled for all sampling events and have data have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

Total dissolved solids

Total dissolved solids (TDS) are a combination of major ions, including sodium, potassium, calcium, magnesium, chloride, sulfate, carbonate, and bicarbonate. Total dissolved solids are determined by filtering a sample, drying the sample, and weighing the material that was able to pass through the filter. Weathering of the rocks, point source discharges (e.g. wastewater treatment plants), road salt, stormwater, and other factors all add to the concentration of TDS in a stream. The PA WQS for public drinking water sources for TDS is a maximum of 500 mg/L as a monthly average, and 750 mg/L as an acute maximum (PA, 2001). There is no WQS for the Wissahickon Creek as a TSF.

TDS was sampled from 2004 to 2016 and all QA/QC blanks were in acceptable ranges. QA/QC duplicates were in acceptable ranges 25/26 times. TDS data was separated between before and after winter sampling was started in 2011. From 2004 to 2010, WISS750 had the highest TDS concentrations that then reduced moving downstream to the mouth of the Wissahickon Creek (Figure 6-16). In the Sandy Run sites the upstream site (SR300) had the lowest TDS, while the downstream site was similar to the site downstream of where the Sandy Run enters the Wissahickon Creek (WISS500). Data from 2011 to 2016 has a similar pattern with high TDS at WISS750 and then decreasing with moving downstream to the mouth of the Wissahickon Creek (Figure 6-17). SR300 continued to have lower TDS than the rest of the Sandy Run. T100 (Trewellyn) had similar TDS to the Wissahickon mainstem, while T400 (Prophecy Creek) had the lowest TDS of all sites.

Average seasonal TDS concentrations were determined from 2014 to 2016 and found that the winter sampling season had higher TDS concentrations while the other three sampling seasons had similar concentrations (Figure 6-18). Separating the sampling seasons also indicated that WISS800 had the highest TDS concentrations in the winter, while WISS750 had the highest concentrations for the rest of the seasons. The elevated TDS concentrations in the winter are likely due to road salt that is running into the stream. This is particularly apparent at WISS800, which is likely the most run-off dominated site on the Wissahickon mainstem as it is above wastewater treatment plants and is in an area with little ground water input.

Lastly, 2011 to 2016 data was used to examine changes over time at sites using the annual average TDS concentration at each site (Figure 6-19). Only sites with sampling over all four seasons were used for this due to the increase of TDS during the winter season. Several sites were found to have a significant trend of increasing TDS, including WISS600 (p-value = 0.02416), WISS550 (p-value = 0.02547), WISS500 (p-value = 0.02229), WISS400 (p-value = 0.04441), SR100 (p-value = 0.01532), and SR200 (p-value = 0.003013). Flow data is needed to evaluate if the TDS loading also changed over this time period.

Overall, TDS is high in the Wissahickon Watershed and indicates human influence and development. A concentration of >250 mg/L TDS is considered a sign of high salinity (Allan and Castillo, 2009), and 364/385 collected samples for Stream MAP were above 250 mg/L.

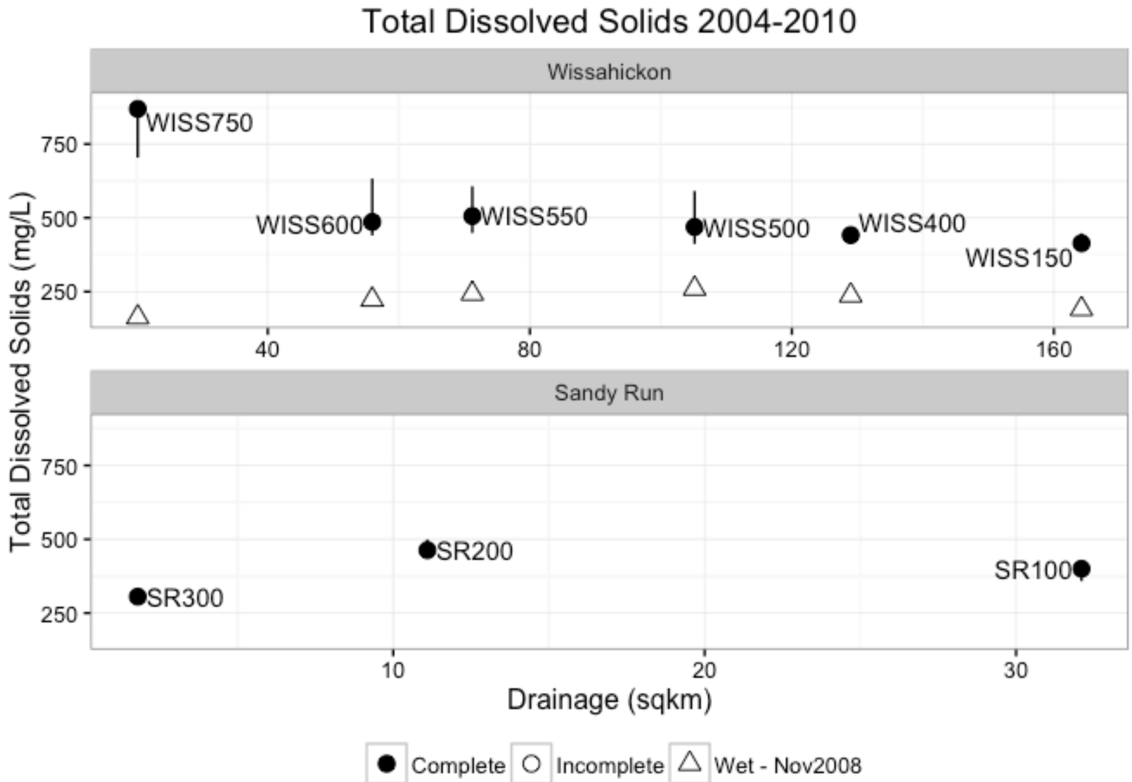

Figure 6- 16. Total dissolved solid (TDS) was sampled from 2004 to 2010 during dry weather and included one wet weather sampling event. The filled in circles represent the median TDS concentrations of the sites that were sampled during all dry weather events. The hollow circles are the TDS concentration of the sites that were not sampled for all sampling events and have missing data. The triangles are the TDS concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

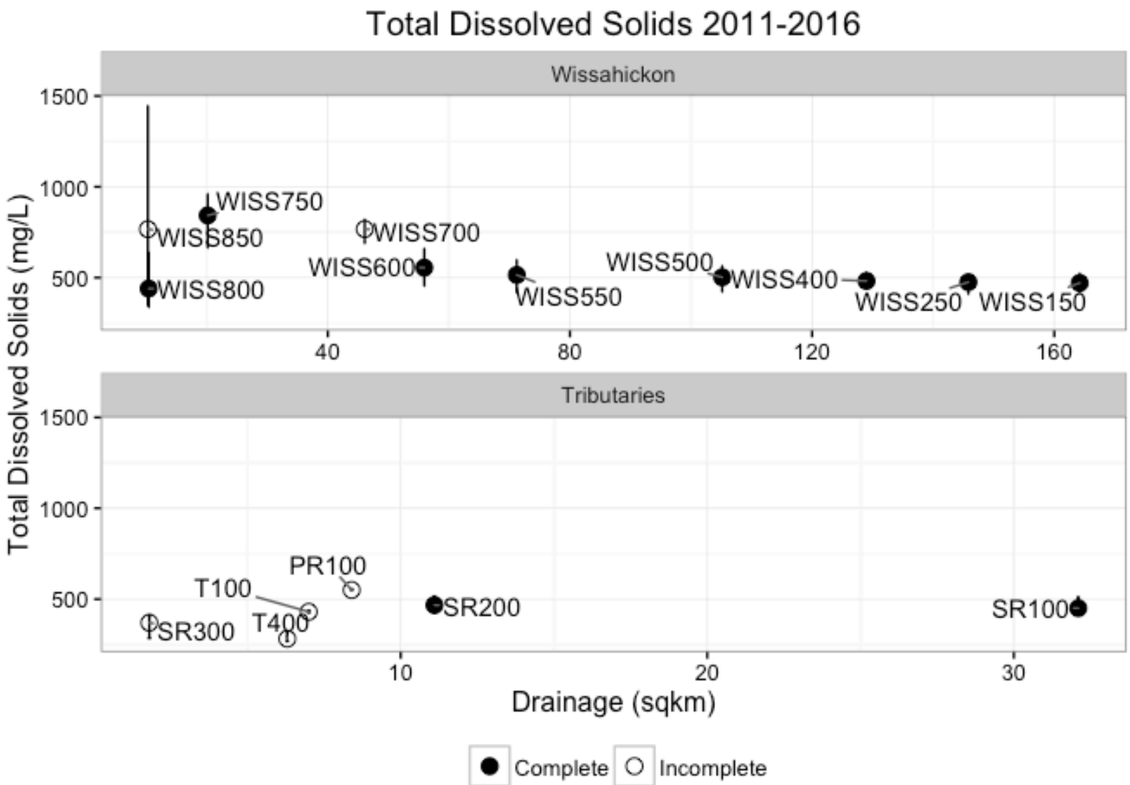

Figure 6- 17. Total dissolved solids (TDS) was sampled for all four seasons from 2011 to 2016 during dry weather. The filled in circles represent the median TDS concentrations of the sites that were sampled during all dry weather events. The hollow circles are the TDS concentration of the sites that were not sampled for all sampling events and have missing data .The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

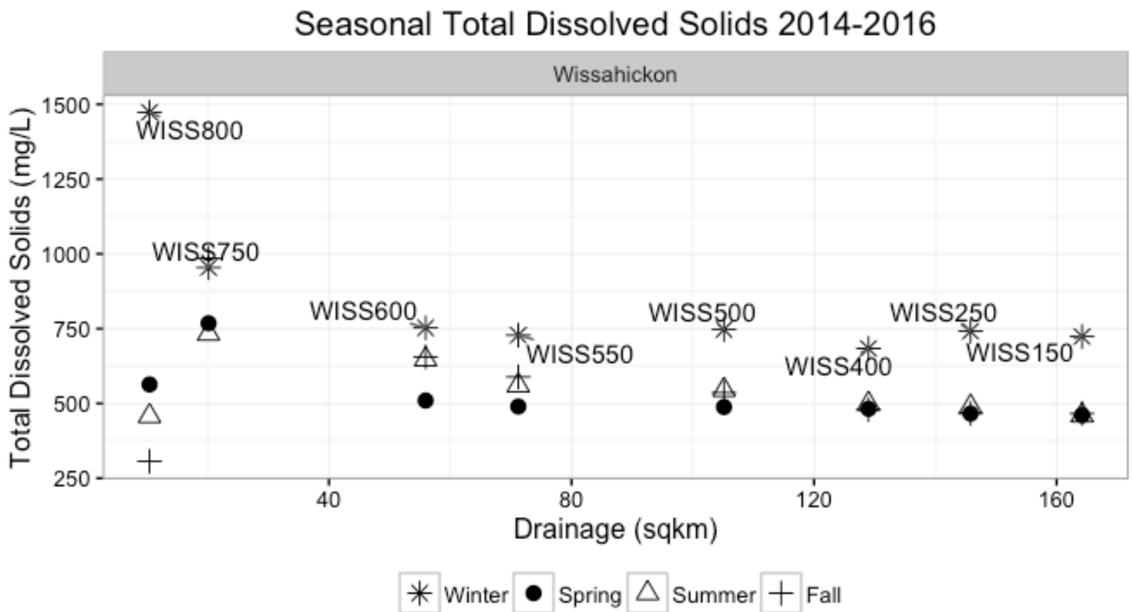

Figure 6- 18. Total dissolved solids (TDS) concentration data from 2014 to 2016 was used to investigate any seasonal trends in the Wissahickon mainstem only. The symbols are as follows (1) star indicates average TDS in the winter, (2) circle indicates average TDS in the spring, (3) triangle indicates average TDS in the summer, and (4) cross indicates average TDS in the fall.

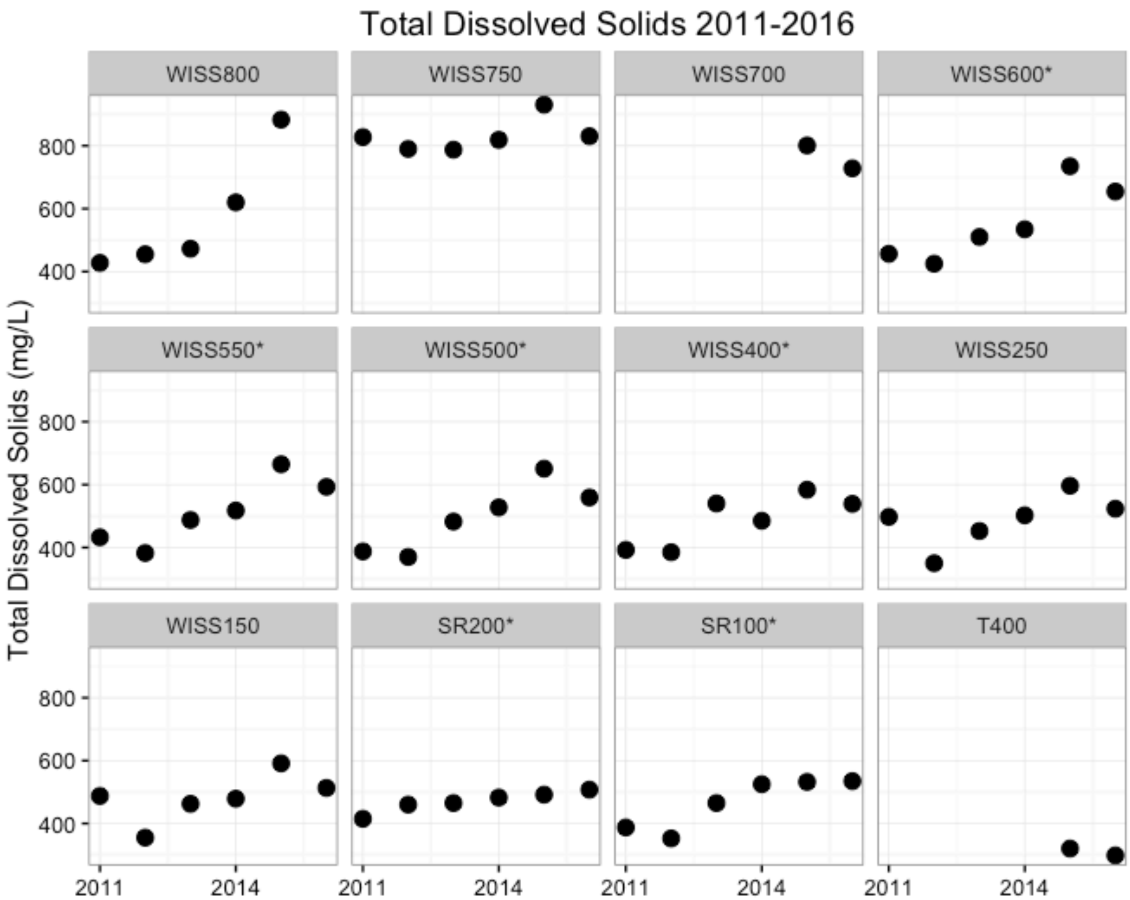

Figure 6- 19. Changes in total dissolved solids trends over time at all sites in the Wissahickon Watershed were looked at using data from 2011 to 2016. The filled in circles are average TDS concentration at the site if all four sampling seasons were collected. The hollow circles are the average TDS concentration if three sampling seasons were collected. Sites and years with less than three sampling seasons were not included. Sites with asterisks (*) indicate that the change in concentration was significant (p-value <0.05).

Chloride

Chloride is a common water quality parameter that indicates the 'saltiness' of water. Chloride is influenced by geology and weathering of rocks, inputs from marine systems, and road salt in winter months in developed watersheds. Chloride is biologically inactive in aquatic systems and has a long residency time once it is in a waterbody. The PA WQS for public drinking water sources is 250 mg/L and the EPA recommended aquatic life criteria is less than 230 mg/L as a continuous concentration and less than 860 mg/L as an acute maximum.

Chloride was collected for Stream MAP from 2004 to 2016. All collected QA/QC duplicates and blanks were in acceptable ranges. Chloride data was separated between before and after 2011 because winter sampling started in 2011. From 2004 to 2010, one wet weather and 16 dry weather samples were collected (Figure 6-20). During wet weather sampling the chloride concentrations were reduced compared to dry weather sampling, indicating dilution during storm events. WISS750 had the highest chloride concentrations and then concentrations decreased moving downstream to the mouth of the Wissahickon Creek. Chloride concentrations at Sandy Run sites were slightly lower than WISS500, just downstream of where the Sandy Run enters the Wissahickon Creek. From 2011 to 2016 winter sampling was conducted and additional sites were added to the sample regime. The median chloride concentrations from 2011 to 2016 were all higher than 2004 to 2010, potentially from the additional winter weather sampling (Figure 6-21). Again WISS750 had the highest chloride concentrations and chloride decreased in concentration moving downstream to the mouth of the Wissahickon. SR100, close to the Wissahickon, had similar chloride concentrations as the Wissahickon mainstem. PR100 had the highest chloride concentration for all of the tributaries and T400 had the lowest concentration throughout the watershed.

Since 2011, sampling was conducted in all four seasons. Data from 2013 to 2016 was used to look at the average seasonal chloride concentrations (Figure 6-22). Winter had the highest chloride concentrations and all sites were above the recommended aquatic life criteria. All other seasons had lower concentrations and were below the aquatic life criteria. The change in annual chloride concentrations at each site was investigated using only data since 2011 at sites with data from all four seasons (Figure 6-23). Significant trends of increasing chloride concentrations were found at WISS600 (p- value = 0.0497), WISS500 (p- value = 0.04164), and WISS400 (p- value = 0.03884). Flow data would need to be evaluated to determine if the chloride loading has also changed during the same time period.

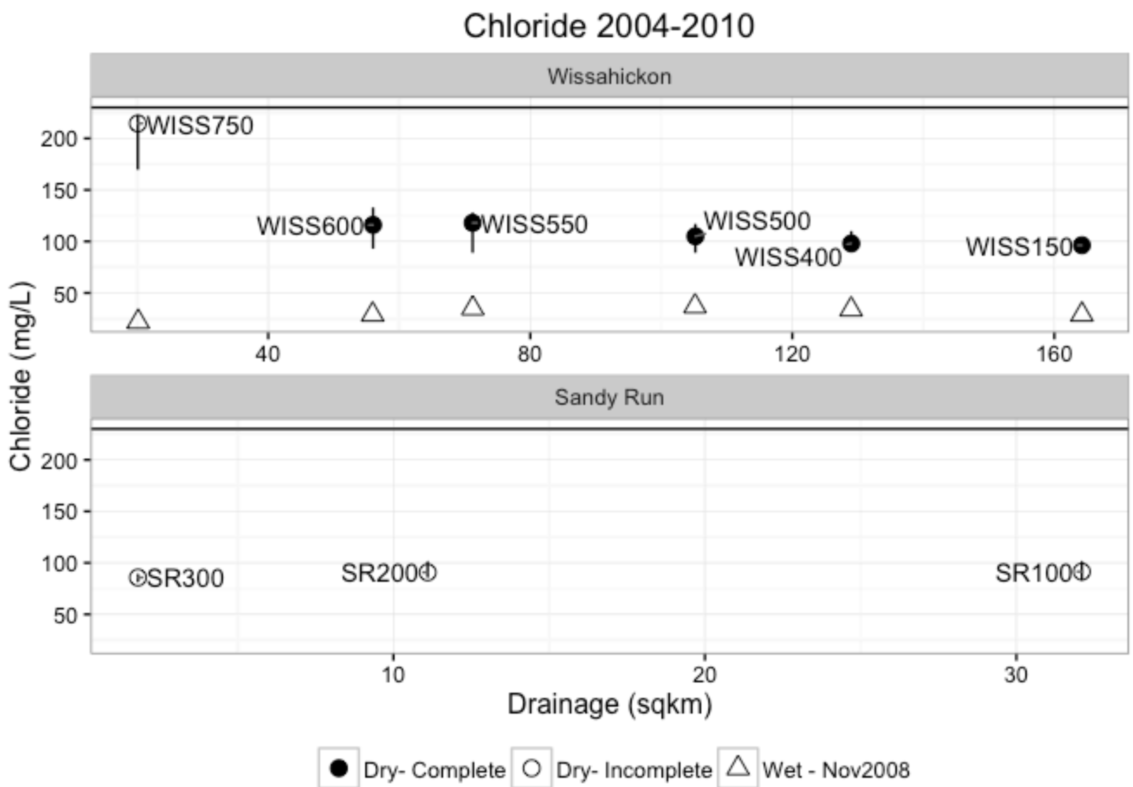

Figure 6- 20. Chloride was sampled from 2004 to 2010 during dry weather and included one wet weather sampling event. The filled in circles represent the median chloride concentrations of the sites that were sampled during all dry weather events. The hollow circles are the chloride concentration of the sites that were not sampled for all sampling events and have missing data. The triangles are the chloride concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line is the EPA maximum recommended aquatic life criteria.

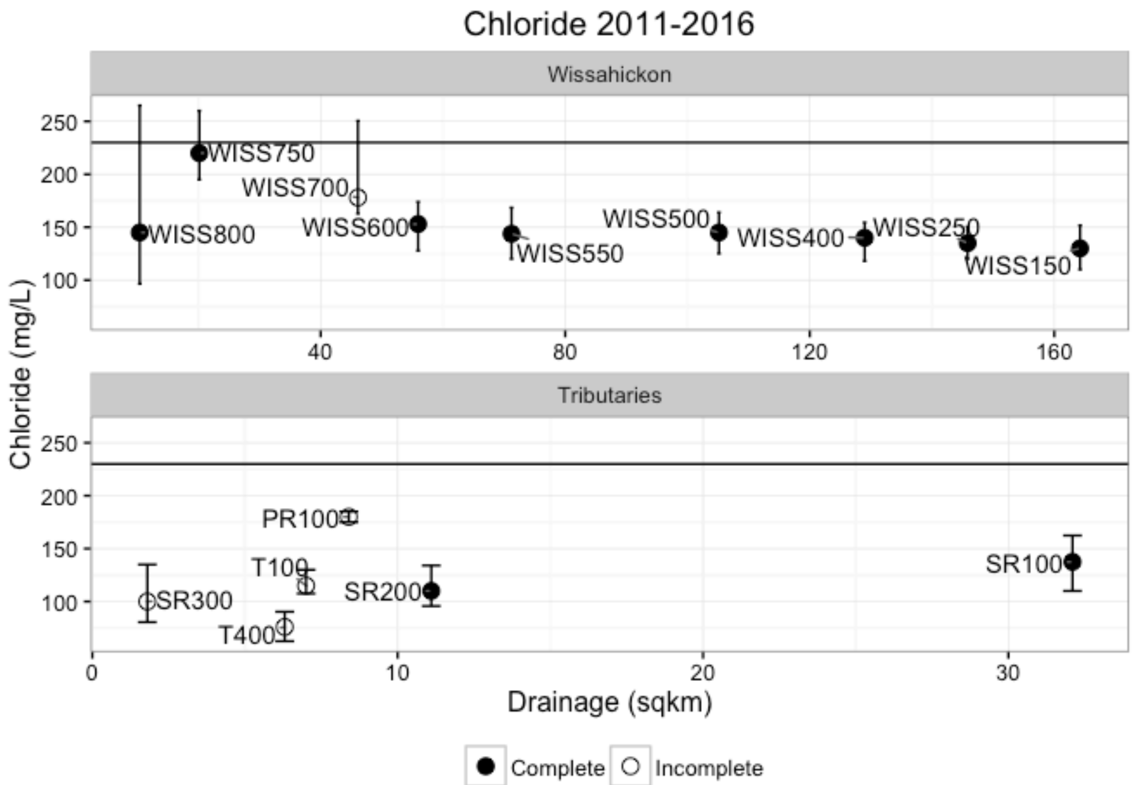

Figure 6- 21. Chloride was sampled for all four seasons from 2011 to 2016 during dry weather. The filled in circles represent the median chloride concentrations of the sites that were sampled during all dry weather events. The hollow circles are the chloride concentration of the sites that were not sampled for all sampling events and have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line is the EPA maximum recommended aquatic life criteria.

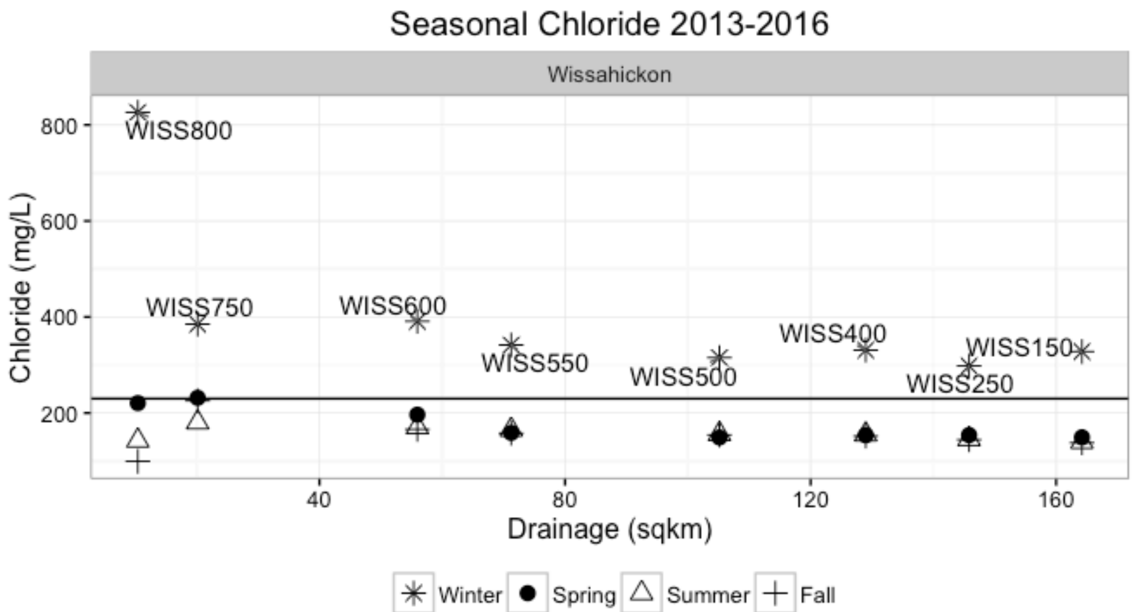

Figure 6- 22. Chloride concentration data from 2014 to 2016 was used to investigate any seasonal trends in the Wissahickon mainstem only. The symbols are as follows (1) star indicates average chloride in the winter, (2) circle indicates average chloride in the spring, (3) triangle indicates average chloride in the summer, and (4) cross indicates average chloride in the fall. The solid line is the EPA maximum recommended aquatic life criteria.

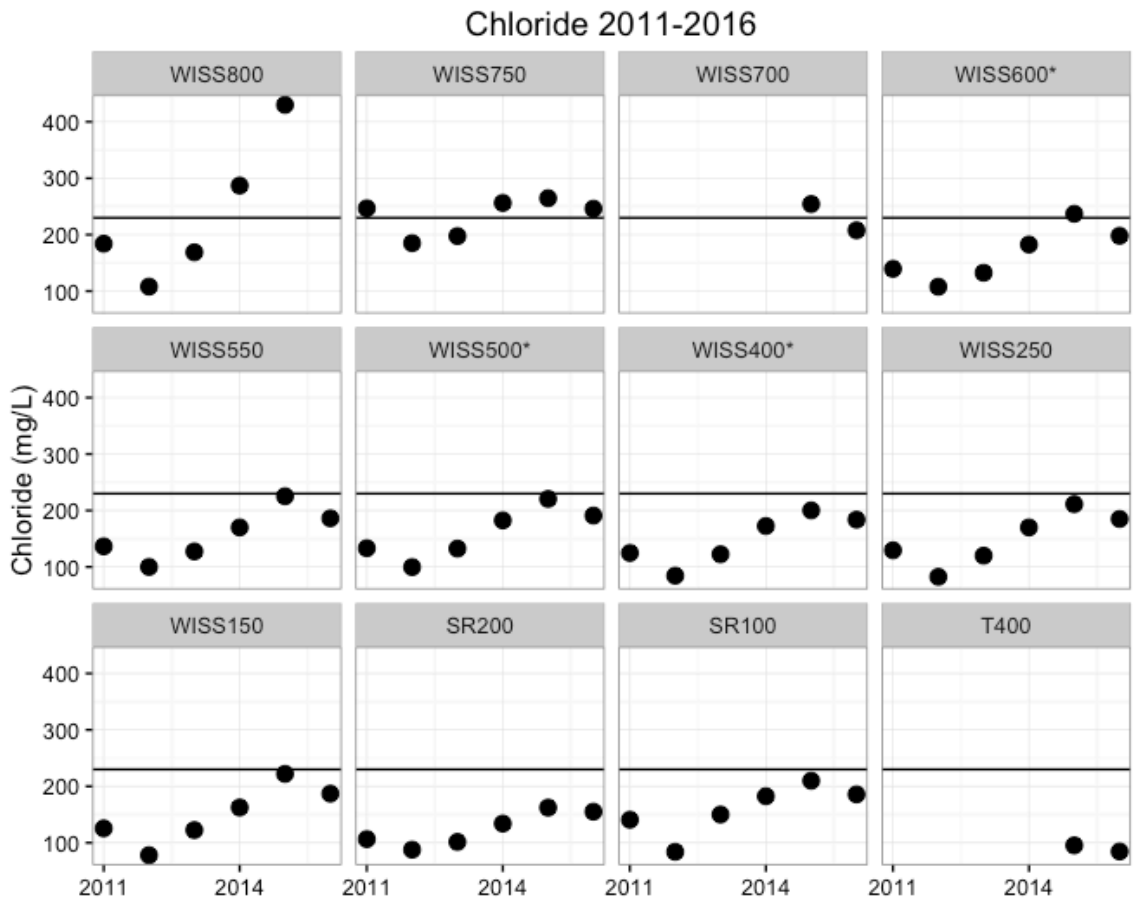

Figure 6- 23. Changes in chloride trends over time at all sites in the Wissahickon Watershed were looked at using data from 2011 to 2016. Only sites and years with all four seasons sampled were included. Sites with an asterisk (*) indicate the change in concentration was significant (*p*-value <0.05). The solid line is the EPA maximum recommended aquatic life criteria.

Sulfate

Sulfate concentrations are influenced by natural inputs, including weathering rocks, and anthropogenic inputs including mining, fertilizers, non-point discharges, and burning of fossil fuels. The PA WQS for sulfate is 250 mg/L for public drinking water sources. There is no WQS for the Wissahickon Creek as a TSF.

Sulfate was measured from 2004 to 2016 for Stream MAP. QA/QC duplicates were in acceptable ranges 23/24 times and blank samples were always in acceptable ranges. Sulfate data was split between before 2011 and after 2011, when all four sampling seasons were collected. From 2004 to 2010, one wet weather and 15 dry weather sampling events were conducted. Sulfate concentrations were consistently below 250 mg/L and the one wet weather sampling event had a reduced sulfate concentration indicating dilution from storm events (Figure 6-24). In the Wissahickon Creek sulfate was high at WISS750 and then decreased moving toward the mouth of the Wissahickon Creek. Sandy Run sites had lower sulfate concentrations than the Wissahickon Creek sites.

From 2011 to 2016 samples were collected for all four seasons. The data from 2011 to 2016 had similar patterns as 2004 to 2010 with WISS750 as the site with the highest concentrations throughout the Wissahickon Watershed and then decreasing concentrations moving toward the mouth of the Wissahickon Creek (Figure 6-25). Tributaries had lower sulfate concentrations than the Wissahickon mainstem and Prophecy Creek (T400) had the lowest sulfate concentrations. Sulfate concentrations differed seasonally with the fall and summer having higher concentrations compared to the spring and winter (Figure 6-26). This is possibly due to changes in stream flow, but cannot be determined with the Stream MAP data because flow was not recorded at each site during sampling.

Annual changes in sulfate concentrations at each site were looked at with data from 2008 to 2016 (Figure 6-27). WISS800 had a significant trend of decreasing sulfate from 2011 to 2016 (p-value = 0.0406), with a sharp decrease between 2012 and 2013. Additionally, WISS600 had a significant trend of increasing sulfate (p-value = 0.01283). The decreasing trend at WISS800 may be from the closing of the upstream North Wales Wastewater Treatment Plant in July 2013. The 2011-2016 annual data also highlights the low sulfate concentrations at WISS850, PR100, T400 and T100, and high concentrations at WISS750.

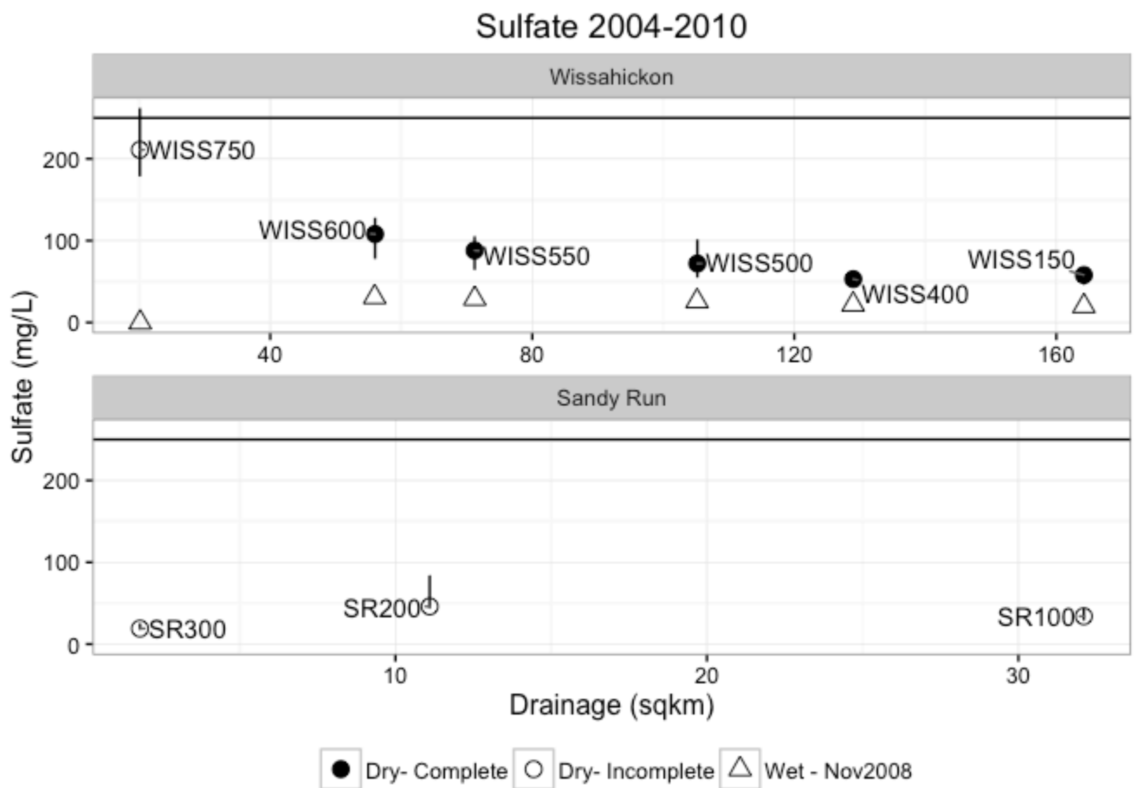

Figure 6- 24. Sulfate was sampled from 2004 to 2010 during dry weather and included one wet weather sampling event. The filled in circles represent the median sulfate concentrations of the sites that were sampled during all dry weather events. The hollow circles are the sulfate concentration of the sites that were not sampled for all sampling events and have missing data. The triangles are the sulfate concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line is the maximum PA WQS for drinking water sources.

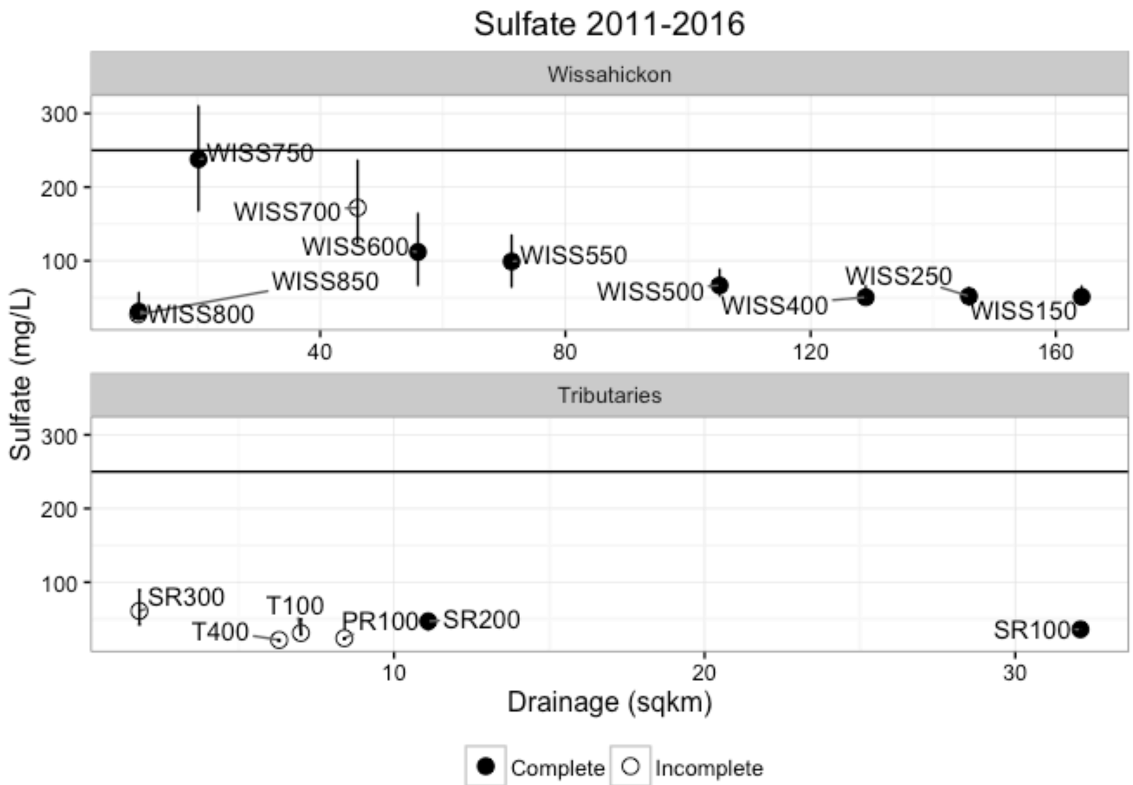

Figure 6- 25. Sulfate was sampled for all four seasons from 2011 to 2016 during dry weather. The filled in circles represent the median sulfate concentrations of the sites that were sampled during all dry weather events. The hollow circles are the sulfate concentration of the sites that were not sampled for all sampling events and have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line is the maximum PA WQS for drinking water sources.

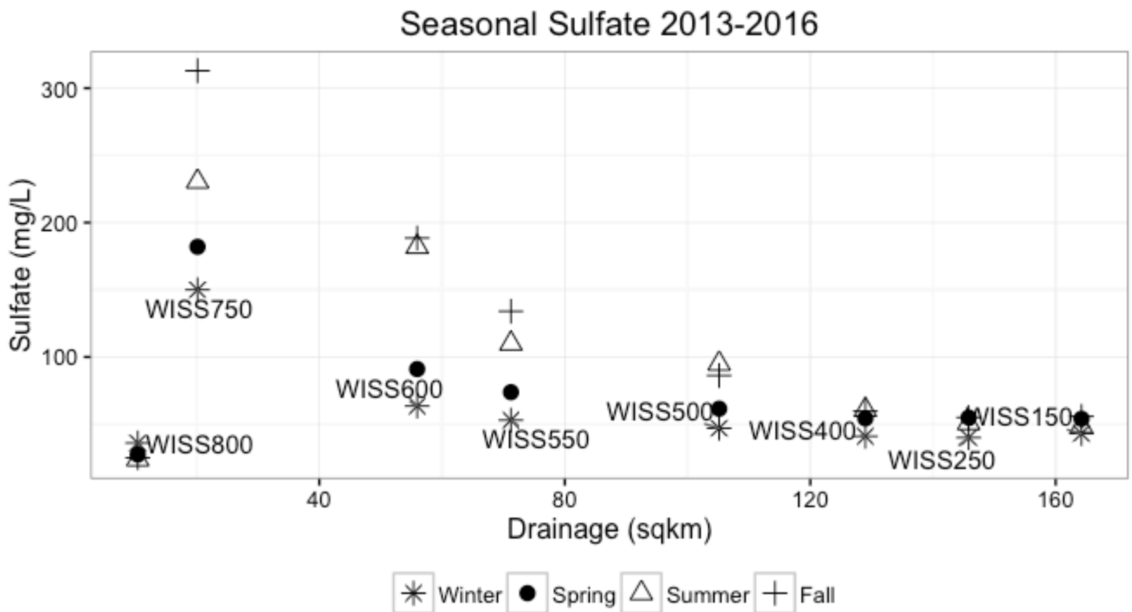

Figure 6- 26. Sulfate concentration data from 2014 to 2016 was used to investigate any seasonal trends in the Wissahickon mainstem only. The symbols are as follows (1) star indicates average sulfate concentrations in the winter, (2) circle indicates average sulfate concentrations in the spring, (3) triangle indicates average sulfate concentrations in the summer, and (4) cross indicates average sulfate concentrations in the fall. The solid line is the maximum PA WQS for drinking water sources.

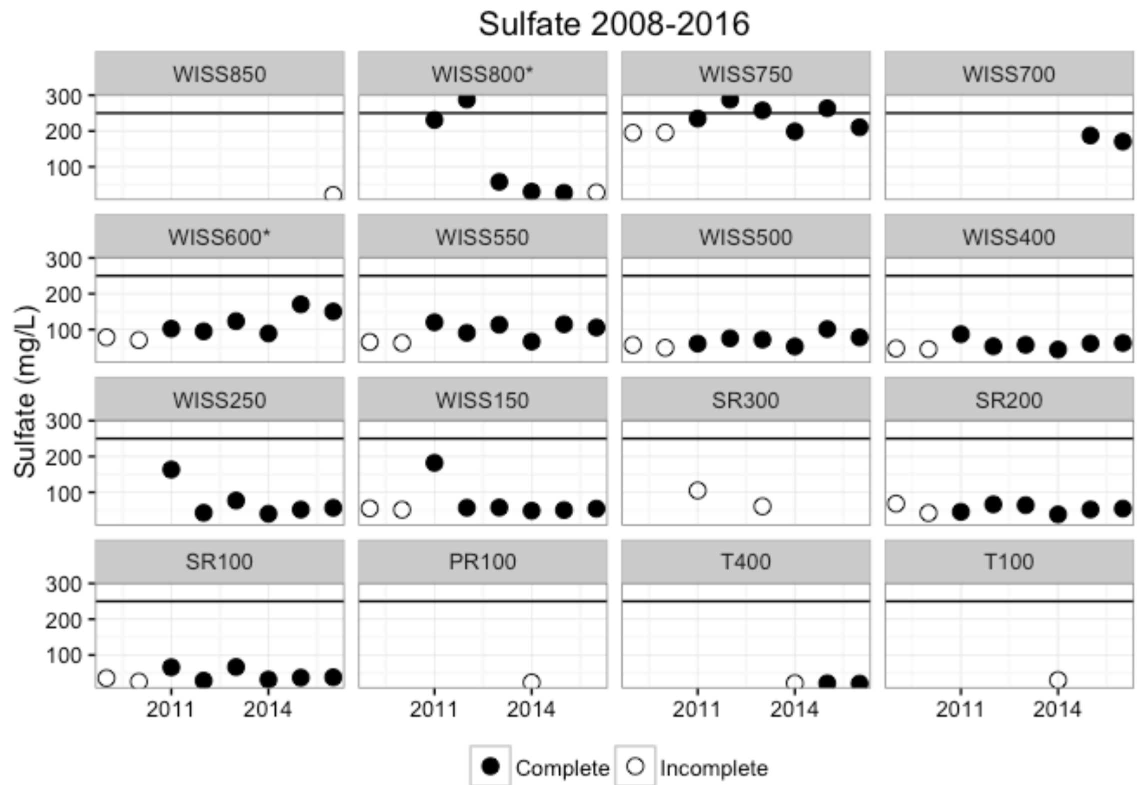

Figure 6- 27. Changes in sulfate trends over time at all sites in the Wissahickon Watershed were looked at using data from 2008 to 2016. The filled in circles are average sulfate concentration at the site if all four sampling seasons were collected. The hollow circles are the average sulfate concentration if three sampling seasons were collected. Sites and years with less than three sampling seasons were not included. Sites with an asterisk (*) indicate the changes in concentrations are significant (*p*-value <0.05). The solid line is the maximum PA WQS for drinking water sources.

Alkalinity

Alkalinity is the acid neutralizing capacity of a system and was collected from 2004 to 2006 and 2011 to 2016. Alkalinity is determined by measuring the amount of acid need to change the pH of a sample to 4.5. Alkalinity is particularly important in areas with acid rain, where additional acid rain can change the pH of a waterbody if the alkalinity is low (e.g. Adirondacks), but will remain unchanged in an area with high alkalinity (e.g. NY Finger Lakes). Alkalinity is determined by the geology of an area. Pennsylvania has minimum WQS for alkalinity of 20 mg/L in trout stocked fisheries (PA, 2001).

QC/QA duplicate and blank samples were always within acceptable limits for alkalinity. Alkalinity was collected from 2004 to 2006, and again from 2011 to 2016. From 2004 to 2006, seven dry weather samples and one wet weather sample was collected in Nov 2008. The wet weather sample had lower alkalinity than the dry weather samples, indicating dilution during wet weather events (Figure 6-28). The upstream/downstream trends indicated an increase in alkalinity downstream of WISS550, where ground water becomes a larger component of stream flow. Lastly, all alkalinity concentrations were above the minimum WQS of 20 mg/L.

Data from 2011 to 2016 had similar patterns as the 2004 to 2006 data, with alkalinity consistently above the minimum WQS of 20 mg/L throughout the Wissahickon Watershed (Figure 6-29). Again in 2011 to 2016 alkalinity increased at WISS400 and then decreased toward the mouth of the Wissahickon Creek. Data from 2011 to 2016 also included Sandy Run and tributary data. This showed that SR300 had the lowest alkalinity in all of the Wissahickon Watershed sites while T100 had the highest levels of alkalinity.

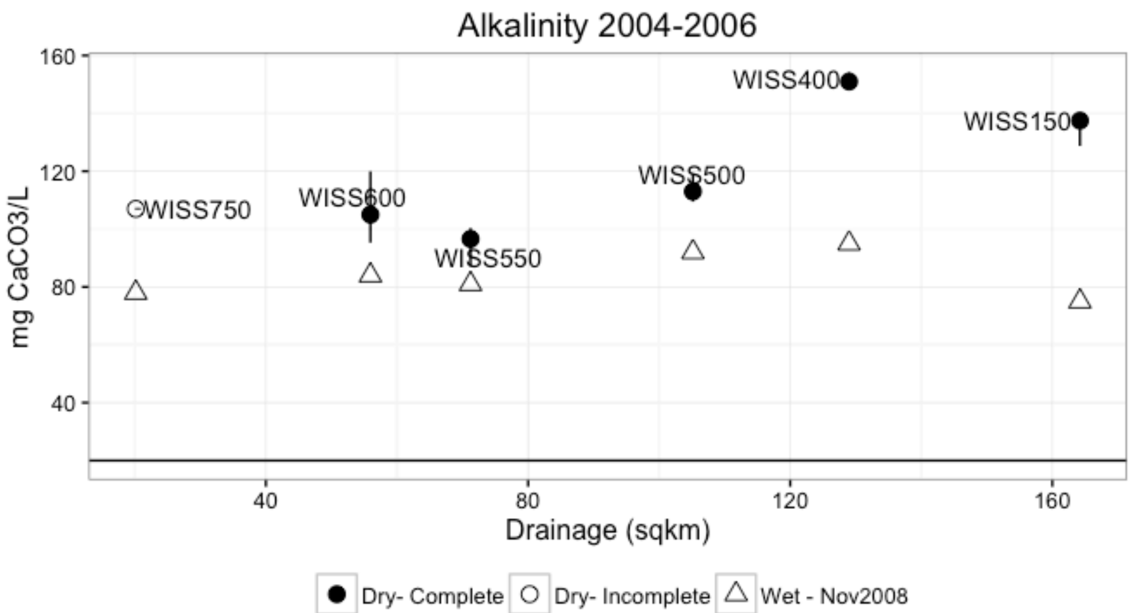

Figure 6- 28. Alkalinity was sampled from 2004 to 2006, including seven dry weather sampling events and one wet weather sampling event. The filled in circles represent the median alkalinity concentrations during dry weather at the sites that were sampled for all seven events. The hollow circle is the alkalinity concentration of WISS750 from one sampling event in the Fall of 2004. The triangles are the alkalinity concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line is the PA WQS minimum for alkalinity in TSF.

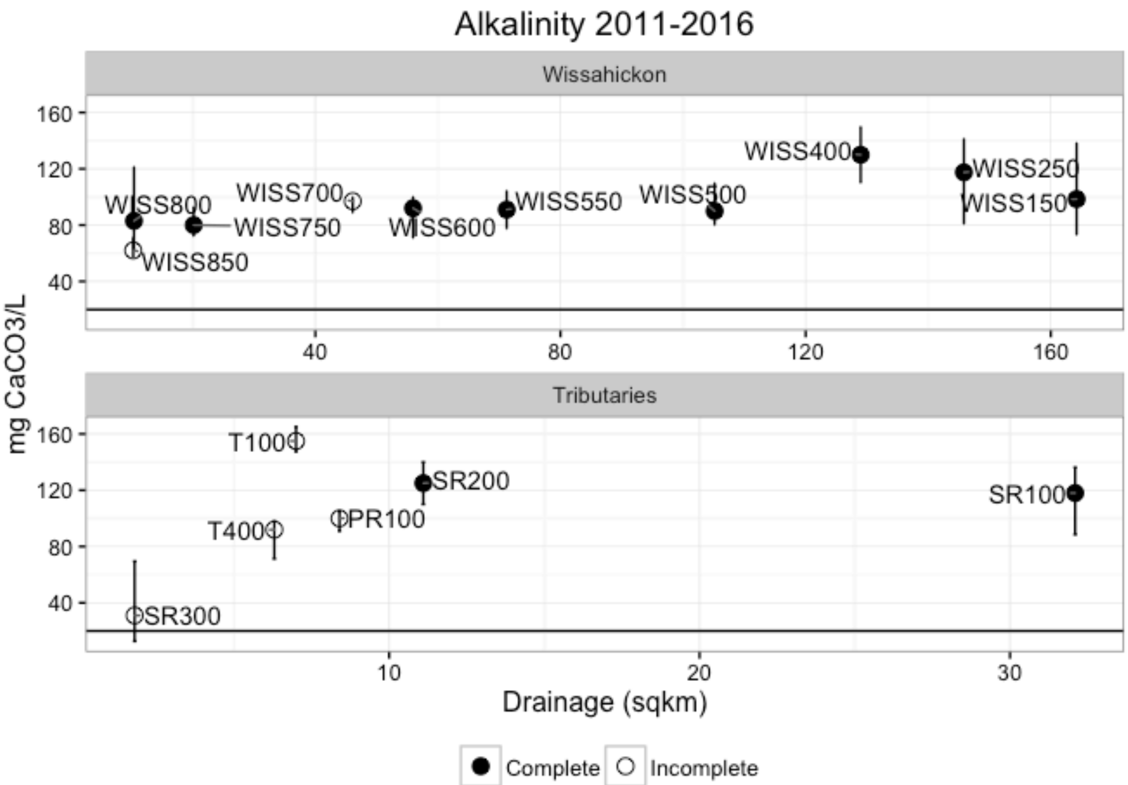

Figure 6- 29. Alkalinity was sampled for all four seasons from 2011 to 2016 during dry weather. The filled in circles represent the median alkalinity concentrations of the sites that were sampled during all dry weather events. The hollow circles are the alkalinity concentration of the sites that were not sampled for all sampling events and have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line is the PA WQS minimum for alkalinity in TSF.

Hardness

Hardness is the concentration of calcium and magnesium cations and is influenced by the geology of an area. High ion concentrations produce insoluble compounds when mixed with soaps and detergents, commonly known as the difference between having 'hard' or 'soft' water. Waters with less than 60 mg/L as calcium carbonate are considered soft, 61 to 120 mg/L are moderately hard, 121 to 180 mg/L as hard, and more than 180 as very hard (USGS). Hardness can be important in natural systems as the toxicity of many dissolved metals is inversely related to hardness concentrations. Alkalinity and hardness are commonly confused with each other as both are expressed as the mg of calcium carbonate (CaCO3) per liter (Allan & Castillo, 2009). In many systems these two parameters are highly correlated, but it is possible for systems to be high in one parameter and not the other one.

Hardness was sampled for Stream MAP from 2011 to 2016. All QA/QC blanks and duplicates were in acceptable ranges. Stream MAP data indicated that the headwater sites (WISS850 and WISS800) were more variable than the rest of the watershed (Figure 6-30). Hardness was lower at the headwater sites, increased at site WISS700, decreased to WISS550, and increased to WISS400 and then decreased to the mouth of the Wissahickon Creek. Most sites throughout the Wissahickon Watershed were above 180 mg/L and were considered 'very hard,' except for SR300 and T400 that were above 120 mg/L and considered 'hard.' The Wissahickon CCR found a similar trend and had no sample sites that were below 103 mg/L (PWD, 2007). Overall the Wissahickon Creek is very hard and it is unlikely to have increased toxicity of dissolved metals due to lack of hardness.

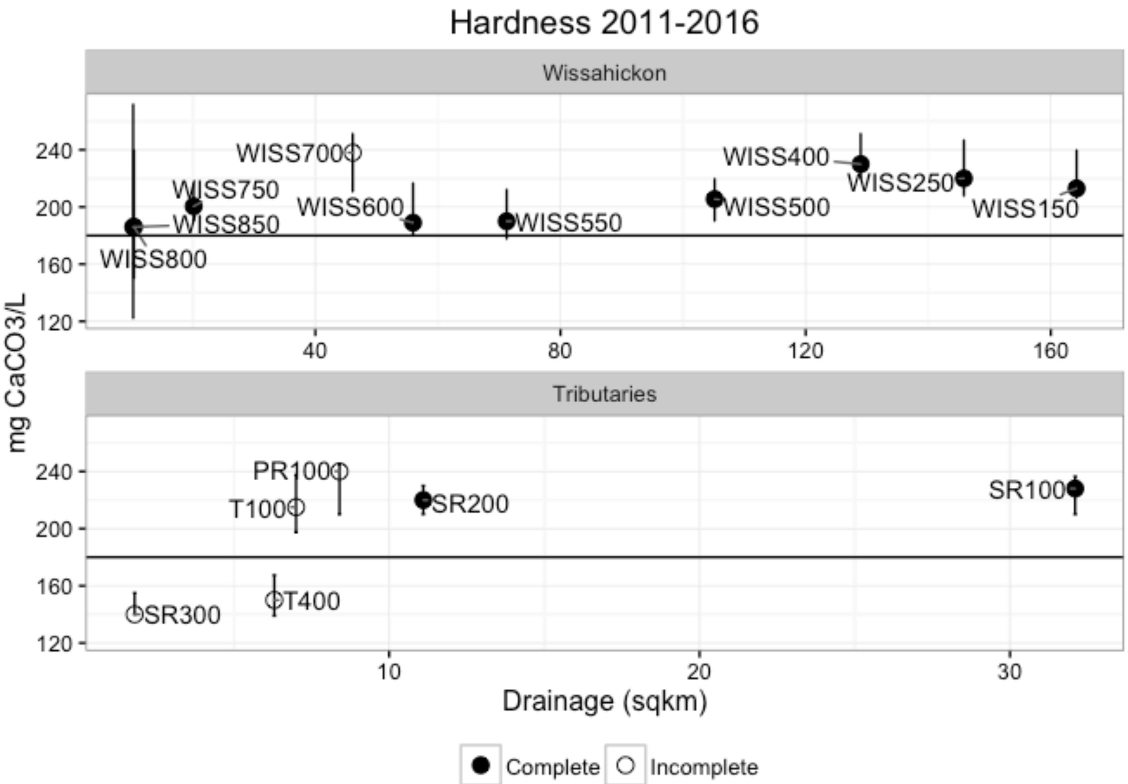

Figure 6- 30. Hardness was sampled for all four seasons from 2011 to 2016 during dry weather. The filled in circles represent the median hardness concentrations of the sites that were sampled during all dry weather events. The hollow circles are the hardness concentration of the sites that were not sampled for all sampling events and have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. The solid line at 180 mg/L is the cut off between 'hard' and 'very hard' water.

Bacteria

Bacteria were measured in three different forms for Stream MAP, including *E. coli*, fecal coliform, and total coliform. *E. coli* was collected from 2004 to 2006, total coliform from 2008 to 2010, and fecal coliform from 2004 to 2016 with some breaks between 2008 and 2010 where total coliform was used instead. *E. coli* is the major species of fecal coliform that is only found in digestive tracts of animals and rarely occurs naturally in the environment. Total coliform is a measure of all of the coliform bacteria that is found in a sample. Coliform bacteria are found in the digestive tract of animals, including humans, and in soils and plants. Fecal coliforms are coliforms that are specifically found in the digestive tracts of warm-blooded animals (mammals and birds) and their wastes. These are more specific to bacteria contamination from wastes than total coliform.

PA WQS for waterbodies classified for water contact sports is less than 200 colony forming units (CFU)/100ml of fecal coliform based on five samples taken within a 30 day period between May 1 and Sept 30 and less than 2000 CFU/100ml based on five consecutive samples taken within a 30 day period for the rest of the year. The Wissahickon Creek is a TSF and does not have any WQS for coliforms.

E. coli

E. coli samples were collected from 2004 to 2006 including six dry weather and one wet weather sampling event. All samples were collected before QA/QC protocols. Results from 2004 to 2006 indicated an *E. coli* was elevated during wet weather sampling compared to dry weather sampling (Figure 6-31). During dry weather sampling *E. coli* was variable and did not exhibit a strong upstream/downstream trend.

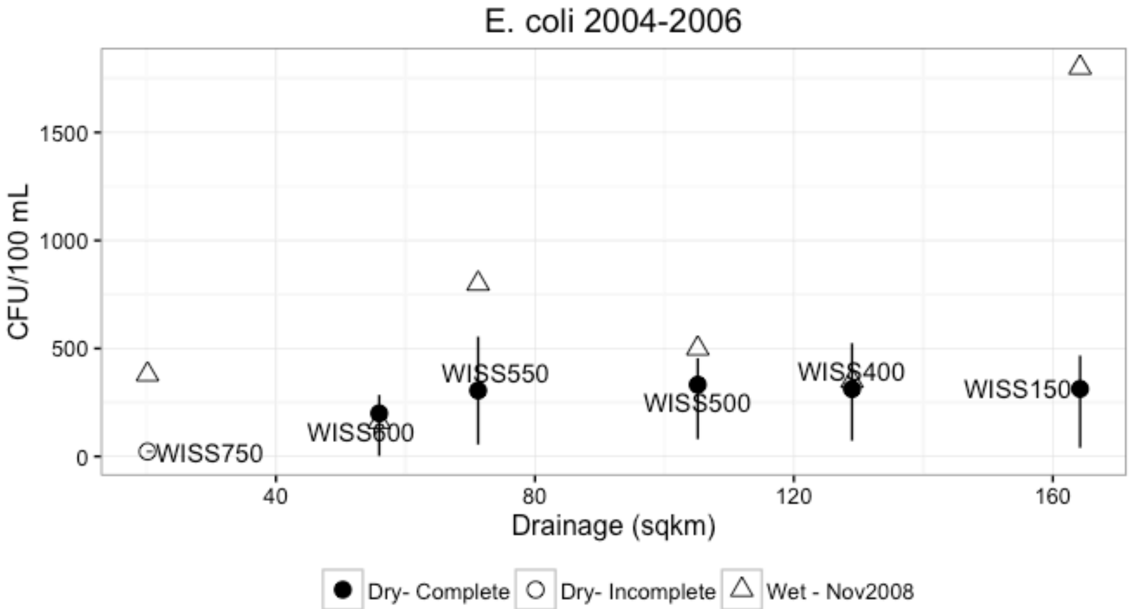

Figure 6- 31. *E. coli* was sampled from 2004 to 2006, including seven dry weather sampling events and one wet weather sampling event. The filled in circles represent the median total *E. coli* during dry weather at the sites that were sampled for all seven events. The hollow circle is the *E. coli* of WISS750 from one sampling event in the Fall of 2004. The triangles are the *E. coli* during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

Total coliform

Total coliform was collected for three seasons in 2008, two seasons in 2009, the fall of 2010, and winter of 2011. Of the seven sampling events, four of them also had fecal coliform collected and the remaining three sampling events all had total coliform concentrations that exceeded the method detection limits. QA/QC duplicates were collected twice for total coliform and one was in an acceptable range while the other was not. Given these factors, total coliform results will not be reported and fecal coliform will be used instead.

Fecal coliform

Fecal coliform was collected semi-continuously from 2004 to 2016. In 2015 and 2016 the number of sites with fecal coliform collections were reduced in order to meet sample-handling times. All QA/QC sample blanks were within acceptable ranges, while only 5 of the 15 sample duplicates were in acceptable ranges. The results of fecal coliform sampling will still be reported here, but the data should not be used to make conclusions about fecal coliform in the Wissahickon Watershed.

From 2004 to 2011, one wet weather and 16 dry weather sampling events took place. The wet weather sampling event had more CFU than the dry weather sampling events (Figure 6-32). There was no strong upstream/downstream trend. Data from 2012 was not used because the average fecal coliform in the spring and summer of 2012 was over 8000 CFU/100ml. From 2013 to 2016 the results were variable at each site, but the median was less than 200 CFU/100ml at all Wissahickon mainstem sites (Figure 6-33). In the tributaries, T100 had the lowest concentration. Lastly, the seasonal differences were looked at with the five sites that were sampled for all of 2013 and 2016 and found that the summer was highest and winter was lowest in fecal coliform. Though the Stream MAP data should be evaluated with caution, many of the patterns seen in Stream MAP were also found in the Wissahickon CCR, including elevated fecal coliform during wet weather events and dry weather events typically below 200 CFU/ 100 ml (PWD, 2007).

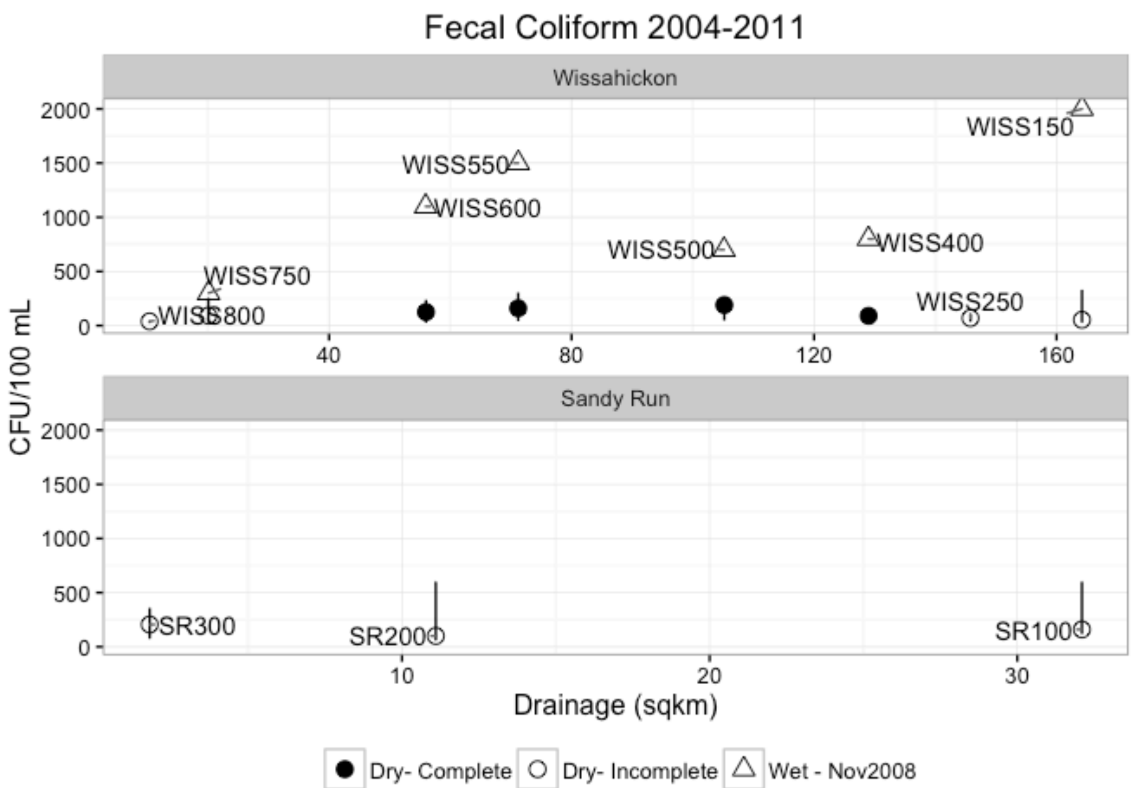

Figure 6- 32. Fecal coliform was sampled from 2004 to 2011 during dry weather and one wet weather sampling event. The filled in circles represent the median fecal coliform of sites that were sampled during all dry weather events. The hollow circles are fecal coliform of the sites that were not sampled for all sampling events and have missing data. The triangles are the fecal coliform during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. Results should be looked at with caution as QA/QC results were beyond acceptable limits.

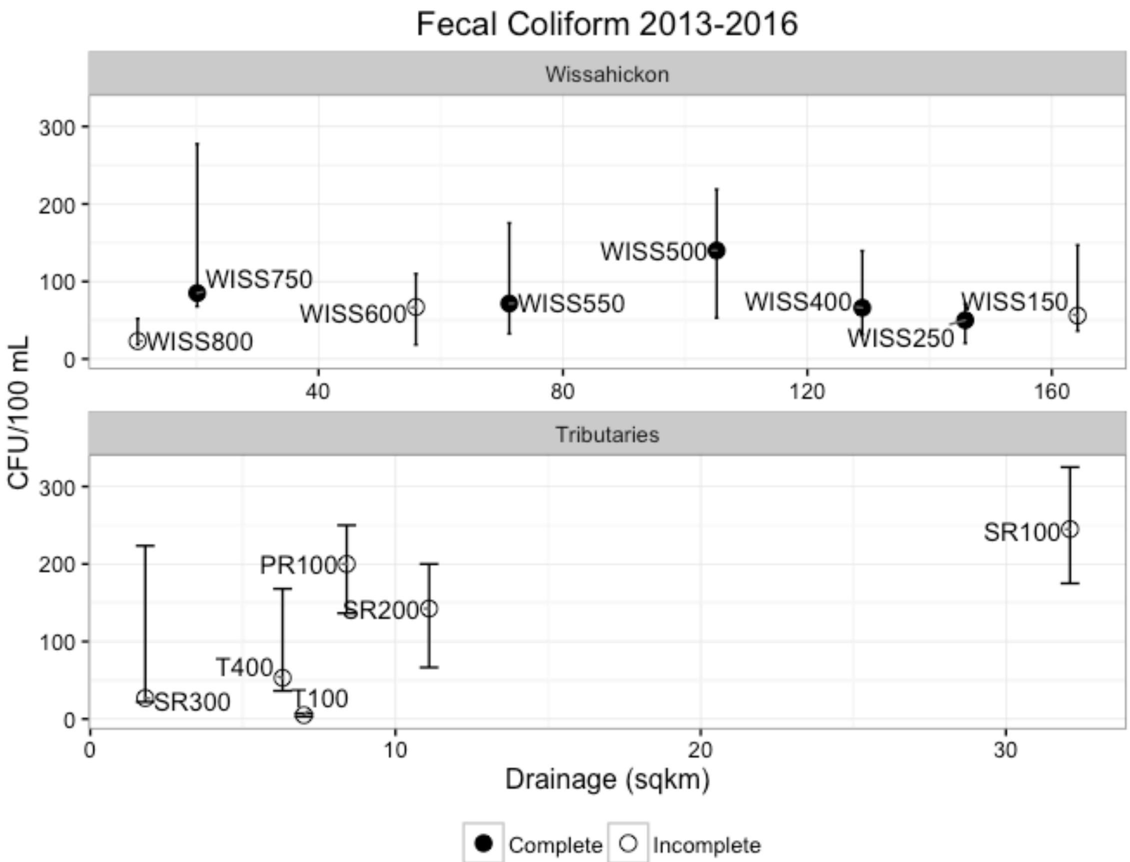

Figure 6- 33. Fecal coliform was sampled for all four seasons from 2013 to 2016 during dry weather. The filled in circles represent the median fecal coliform concentrations of the sites that were sampled during all dry weather events. The hollow circles are the fecal coliform concentration of the sites that were not sampled for all sampling events and have missing data. The error bars indicate the 25th and 75th percentiles of all sampling events at each site. Results should be looked at with caution as QA/QC results were beyond acceptable limits.

Aluminum

Aluminum is naturally occurring from weathering rocks and ground water inputs, but is also found in industrial discharges. Aluminum was a parameter for Stream MAP from 2004 to 2006 including seven dry weather and one wet weather sampling event. No samples were collected for QA/QC purposes. The EPA recommends aquatic life criteria for aluminum of 0.75 mg/L (USEPA, 2004).

Aluminum concentrations never exceeded the aquatic life criteria for any sampling events (Figure 6-34). Aluminum was below the method detection limit (0.1 mg/L) for 17 of the 34 dry weather samples. Aluminum concentrations were highest at the middle Wissahickon sites (WISS550, WISS500, and WISS400). Aluminum concentrations were elevated during the one wet weather sampling event compared to the dry weather sample, but was still below the aquatic life criteria. The Wissahickon CCR also observed increased aluminum concentrations during wet weather sampling events (PDW, 2007).

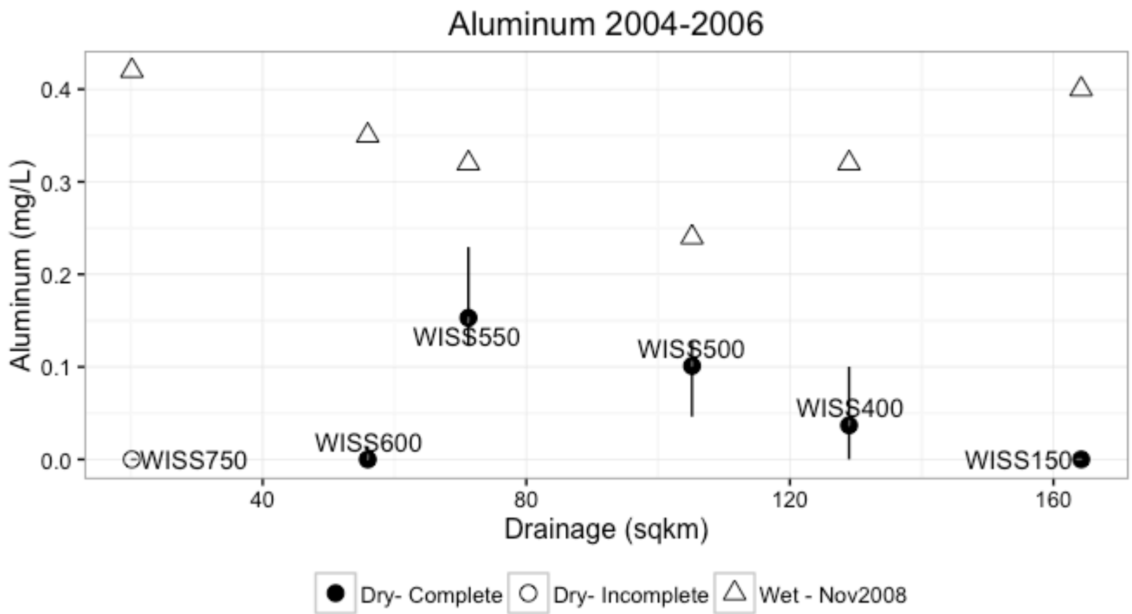

Figure 6- 34. Aluminum was sampled from 2004 to 2006, including seven dry weather sampling events and one wet weather sampling event. The filled in circles represent the median aluminum concentrations during dry weather at the sites that were sampled for all seven events. The hollow circle is the aluminum concentration of WISS750 from one sampling event in the Fall of 2004. The triangles are the aluminum concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25^{th} and 75^{th} percentiles of all sampling events at each site. The USEPA recommends an aquatic life criteria of less than 0.75 mg/L.

Iron

Iron is naturally occurring in the environment from weathering of rocks and ground water inputs. Typically, iron is low in freshwater environments and is not toxic to organisms. Iron can become toxic in systems with low pH, but Stream MAP sampling has indicated that the Wissahickon Watershed pH is typically from 7 to 9. The USEPA recommends an aquatic life criteria of less than 1.0 mg/L for iron (USEPA, 2004). The PA WQS for iron is less than 1.5 mg/L of total recoverable iron as a 30-day average for TSF (PA, 2001).

Iron was a parameter for Stream MAP from 2004 to 2006, including seven dry weather and one wet weather sampling event. No samples were collected for QA/QC purposes. Iron concentrations in the Wissahickon Creek were always below the aquatic life criteria all dry weather sampling events (Figure 6-35). The one wet weather sampling event had elevated iron concentrations, but concentrations were still below the aquatic life criteria and the PA WQS. From 2004 to 2006, iron concentrations slightly increased from upstream sites to WISS400 and then decreased at WISS150. WISS400 had the highest iron concentrations, possibly due do the increase in ground water in the Wissahickon Creek above WISS400. The Wissahickon CCR reported similar results to Stream MAP findings including that iron was present in most samples and iron concentrations were elevated during wet weather events, possibly due to stormwater runoff through iron piping and storm drains (PWD, 2007).

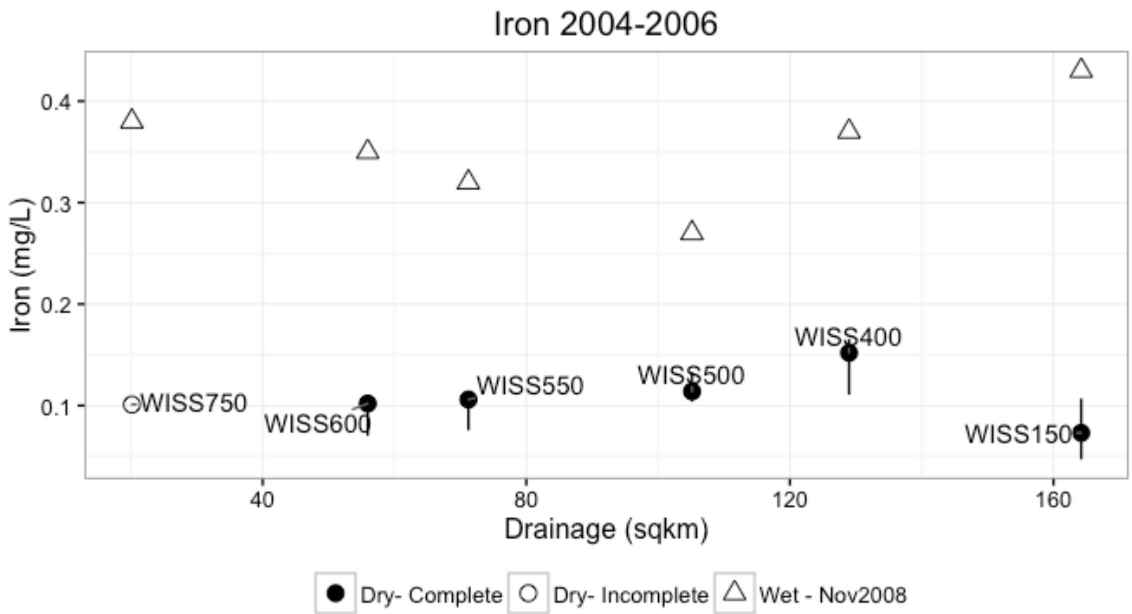

Figure 6- 35. Iron was sampled from 2004 to 2006, including seven dry weather sampling events and one wet weather sampling event. The filled in circles represent the median iron concentrations during dry weather at the sites that were sampled for all seven events. The hollow circle is the iron concentration of WISS750 from one sampling event in the Fall of 2004. The triangles are the iron concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

Total organic carbon

Total organic carbon (TOC) in freshwater systems is from soils, vegetation, algae, and other sources. TOC is particularly of interest to water treatment facilities, where increased TOC concentrations require additional treatment for drinking water. TOC was a parameter for Stream MAP at six sites from 2004 to 2006, including seven dry weather sampling and one wet weather sampling. No samples were collected for QA/QC purposes during these sampling events and TOC does not have a WQS.

TOC in the Wissahickon Creek had a consistent upstream/downstream pattern during the dry weather sampling events. TOC was low at WISS750 and WISS600, increased at WISS550 and then decreased moving downstream to the mouth of the Wissahickon (Figure 6-36). The one wet weather sampling event on Nov 2008 had elevated TOC concentrations at all sites, as rain events bring organic carbon into the stream through runoff.

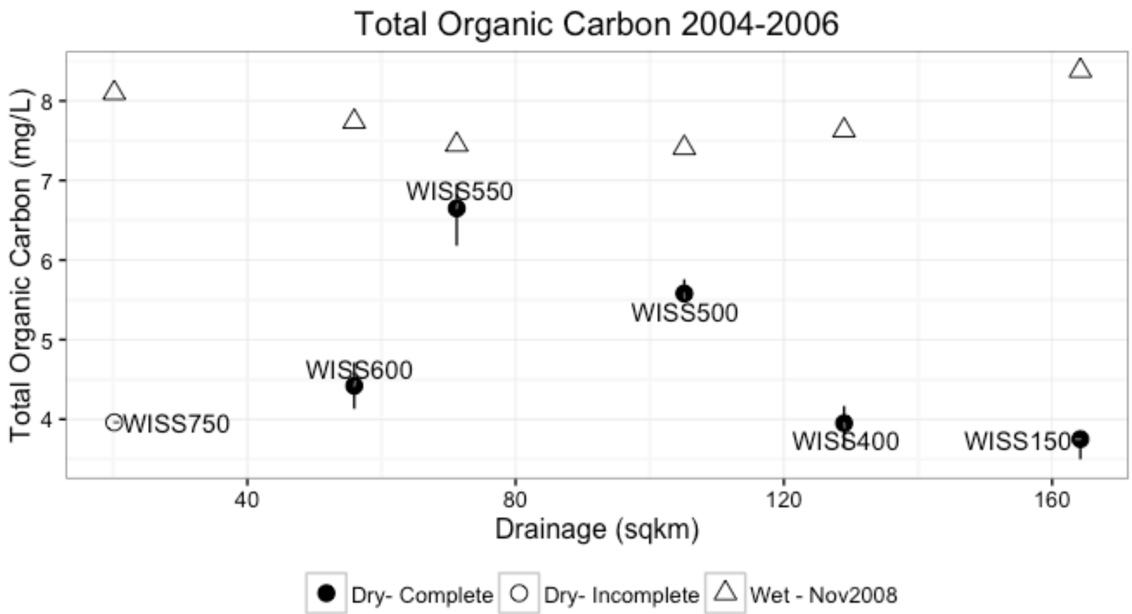

Figure 6- 36. Total organic carbon was sampled from 2004 to 2006, including seven dry weather sampling events and one wet weather sampling event. The filled in circles represent the median total organic carbon concentrations during dry weather at the sites that were sampled for all seven events. The hollow circle is the total organic carbon concentration of WISS750 from one sampling event in the Fall of 2004. The triangles are the total organic carbon concentrations during one wet weather sampling event in Nov 2006. The error bars indicate the 25th and 75th percentiles of all sampling events at each site.

Bromide

Bromide is common in marine systems, but is typically low in freshwater systems. Higher concentrations in freshwater systems are typically associated with mining operations for fossil fuels (McTigue et al., 2014). Bromide was a parameter for Stream MAP at six sites from 2004 to 2006, including seven dry weather sampling and one wet weather sampling. No samples were collected for QA/QC purposes during these sampling events and there are no water quality standards for bromide in Pennsylvania for a trout stocked fishery or recommended aquatic life criteria.

Stream MAP results indicated low bromide concentrations in the Wissahickon Creek. Of the 34 sampling events, only six had detectable concentrations of bromide (>0.1 mg/L). No bromide was detected during the wet weather sampling event in Nov 2008. Overall, bromide was rarely detected in the Wissahickon Watershed, as expected because there are no mining activities in the Wissahickon Creek.

Conclusions

WVWA Stream MAP was created to provide a better understanding of the water quality of the Wissahickon Watershed including upstream/downstream trends, changes over time, and to identify problem areas in the watershed. Stream MAP results indicated that the water quality of the Wissahickon Watershed shows signs of development, human interaction, and the urban stream syndrome.

Stream MAP data indicted that the Wissahickon Watershed had elevated nutrient concentrations from 2004 to 2016. All nutrient concentrations had a similar upstream/downstream pattern in the Wissahickon Watershed (Figure 6-37, 6-38). The sites upstream of wastewater treatment plants had the lowest nutrient concentration. The sites directly downstream of wastewater treatment plants (WISS750, WISS550, SR200) all had the highest nutrient concentrations. In addition, the sites with low concentrations were also downstream of a small drainage area and are potentially subject to less nutrient rich run off from fertilizer and land use, which also contribute to elevated nutrients in urban and suburban systems. Lastly, orthophosphate and total phosphorus concentrations had decreasing trends from 2008 to 2016 at three Wissahickon mainstem sites, but most sites still have concentrations that are above 0.04 mg/L, the draft TMDL limit.

Another indicator of development in the Wissahickon Watershed was elevated concentrations of total dissolved solids, chloride, and sulfate. These parameters all follow a similar upstream/downstream pattern with high concentrations at WISS750 and decreasing concentrations moving toward the mouth of the Wissahickon Creek (Figure 6-39, 6-40). Total dissolved solids and chloride had large seasonal variations, with the highest concentrations occurring in the winter. The elevated concentrations in the winter are likely from road salts washing into the Wissahickon Creek. Total dissolved solids and chloride concentrations were also found to be increasing at several sites between 2011 and 2016.

Parameters that were primarily influenced by geology, including alkalinity and hardness, had an upstream/downstream pattern of increased concentrations around the middle of the watershed (WISS550/WISS400), where ground water becomes a larger proportion of the stream flow in the Wissahickon Creek. Additionally, nearly all collected parameters decreased in concentration from WISS400 to the mouth of the Wissahickon. It is possible that this decrease in concentration is due to dilution from increased flow, but without flow data for all sampling events it is unclear.

There are several other watershed wide trends to note. First, there were low concentrations of trace metals (aluminum and iron) and bromide in the Wissahickon Watershed. This was expected, as there is no mining activity in the Wissahickon and limited industrial discharge throughout the watershed. Second, the tributary sites tended to have the lowest concentrations of all collected parameters. Prophecy Creek (T400), the most protected subwatershed in the Wissahickon Watershed, consistently had the best water quality. Fourth, there were some indications that WISS700, downstream of an area with no tree canopy, had higher productivity and temperatures. This highlights the importance of the tree canopy to protect streams. Finally, nitrate and sulfate both significantly decreased at WISS800 from 2011 – 2016, with a distinct reduction in concentrations after 2013 when the North Wales Wastewater Treatment Plant was closed.

Take-away points and summary maps

A few take away points from water quality monitoring in the Wissahickon Watershed from 2004 to 2016:

- Phosphorus concentrations decreased at four Wissahickon Creek sites between 2008 and 2016, and increased at one Sandy Run site. However, phosphorus concentrations in the Wissahickon Watershed are still elevated and flow data would be needed to determine if the phosphorus loading also decreased during this time period.

- The lowest nutrient concentrations are found upstream of wastewater treatment plants and in small drainage areas. The highest nutrient concentrations were found at downstream of wastewater treatment plants (Figure 6-37, 6-38).
- Prophecy Creek, the most protected subwatershed, has the best water quality of the Stream MAP sites.
- Chloride and total dissolved solid concentrations are higher in the winter sampling season, likely due to run off of road salts. Chloride concentrations were commonly above the recommended aquatic life criteria limit in the winter.
- At some sites, chloride and total dissolved solids concentrations had significant increasing trends from 2011 to 2016. Flow data is needed to determine if the loading also increased during this time period.
- Chloride and TDS concentrations were highest at site WISS750 and then decreased moving downstream to the mouth of the Wissahickon Creek (Figure 6-39, 6-40).

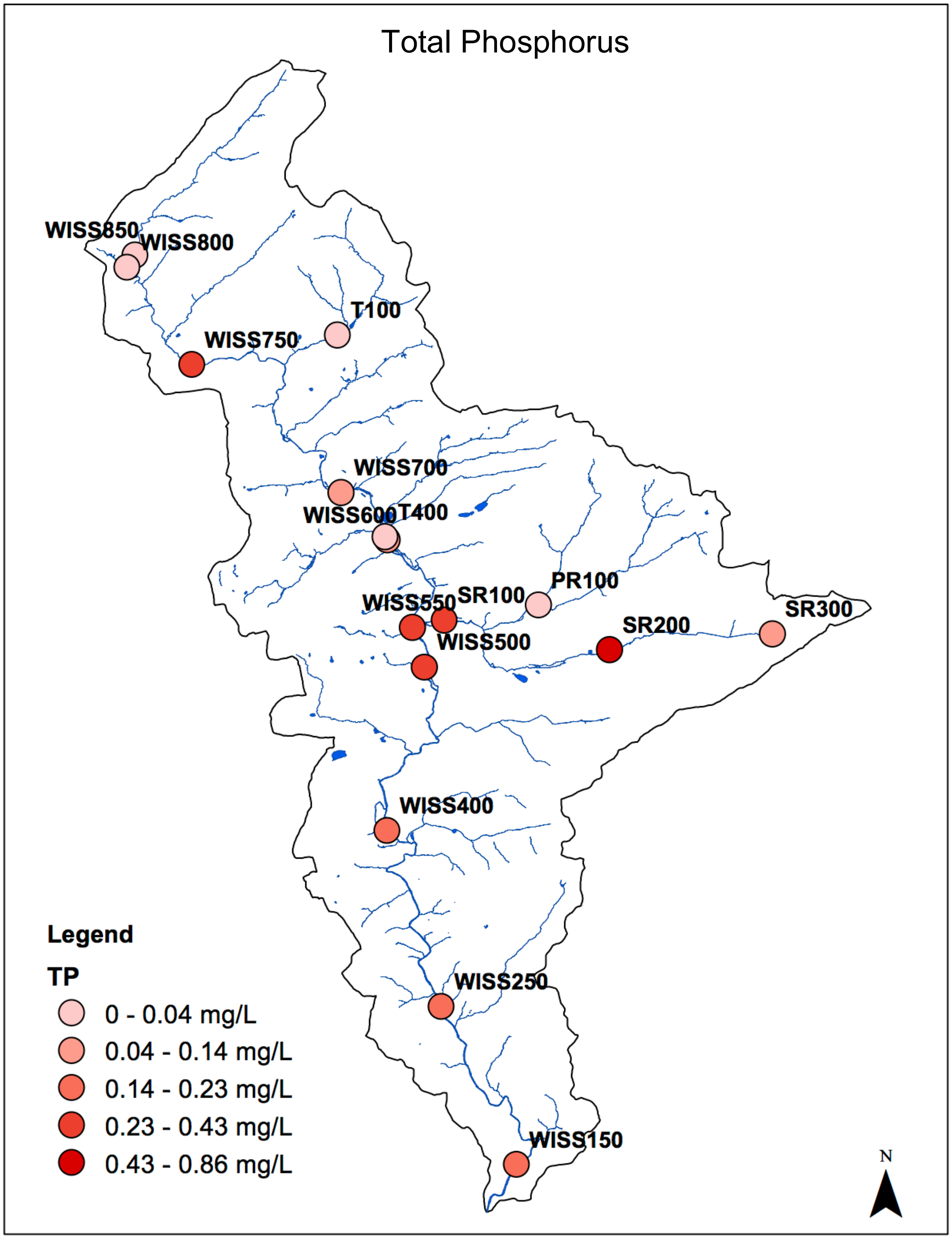

Figure 6- 37. Total phosphorus (TP) was sampled for all four seasons from 2011 to 2016 during dry weather. The map represents the median TP concentrations at each site from 2011 to 2016. Sites between 0 and 0.04 mg/L were below the EPA proposed TMDL TP limit of 0.04 mg/L. All sites were not sampled from 2011 to 2016.

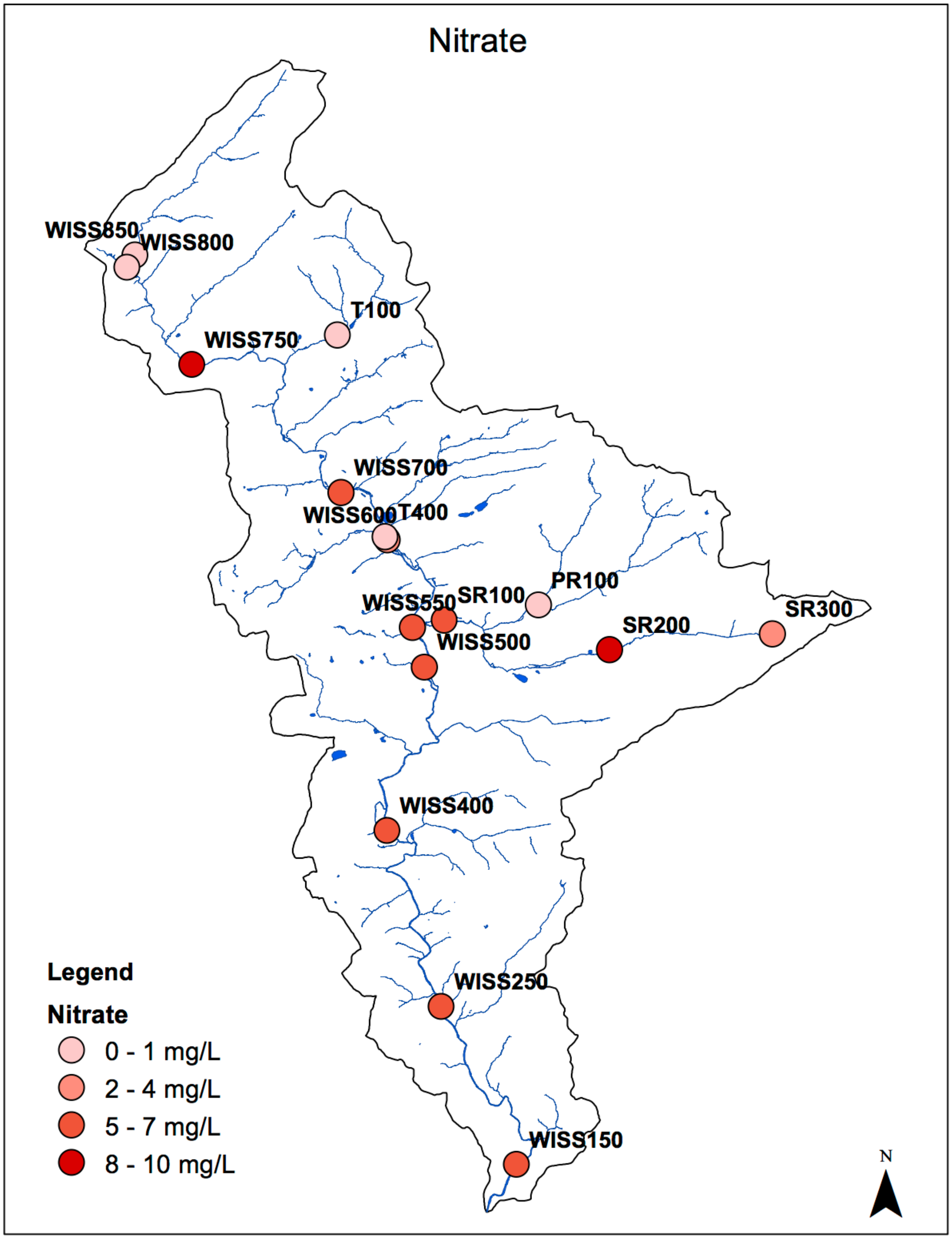

Figure 6- 38. Nitrate was sampled for all four seasons from 2011 to 2016 during dry weather. The map represents the median nitrate concentrations at each site from 2011 to 2016. All sites were not sampled from 2011 to 2016.

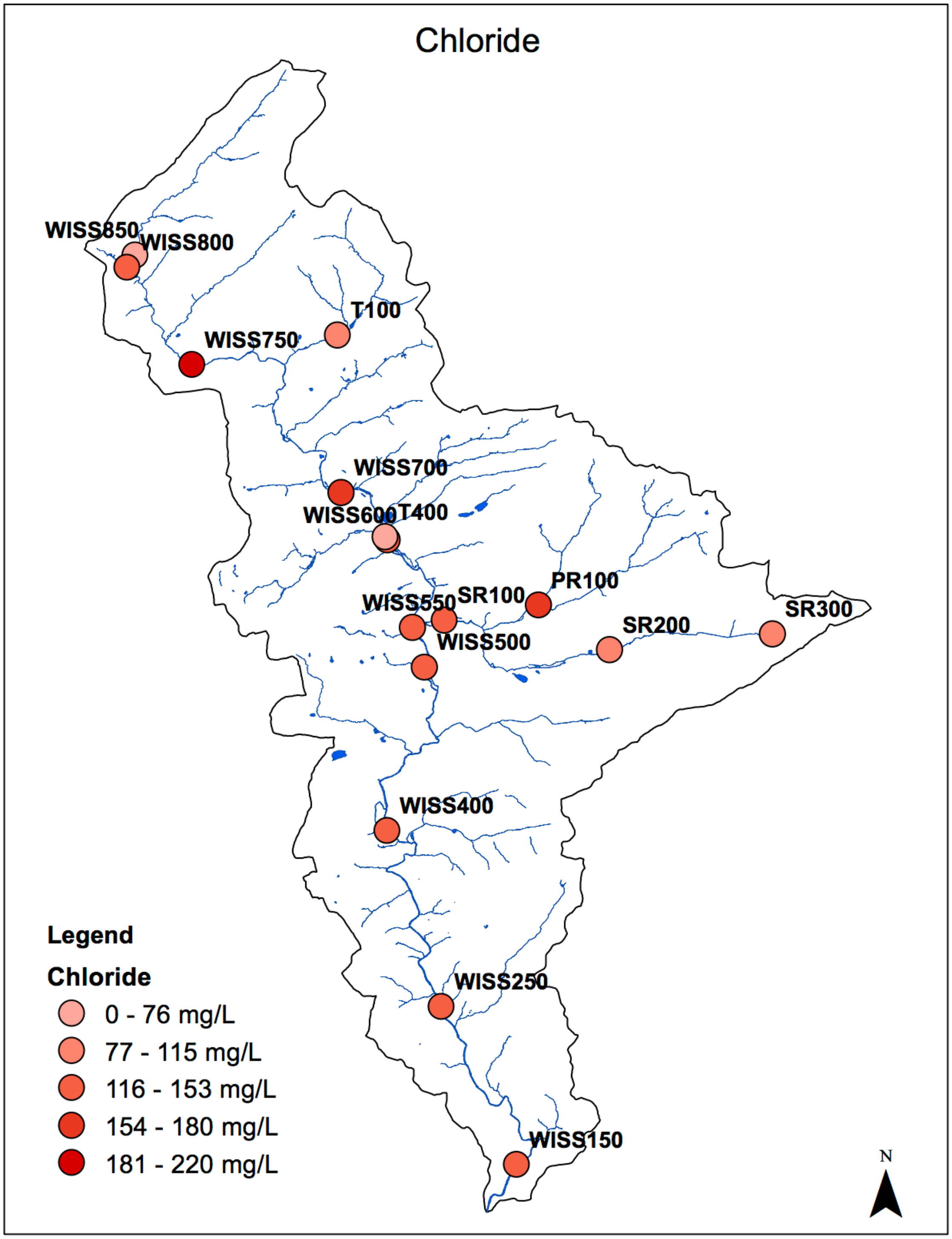

Figure 6- 39. Chloride was sampled for all four seasons from 2011 to 2016 during dry weather. The map represents the median chloride concentrations at each site from 2011 to 2016. All sites were not sampled from 2011 to 2016.

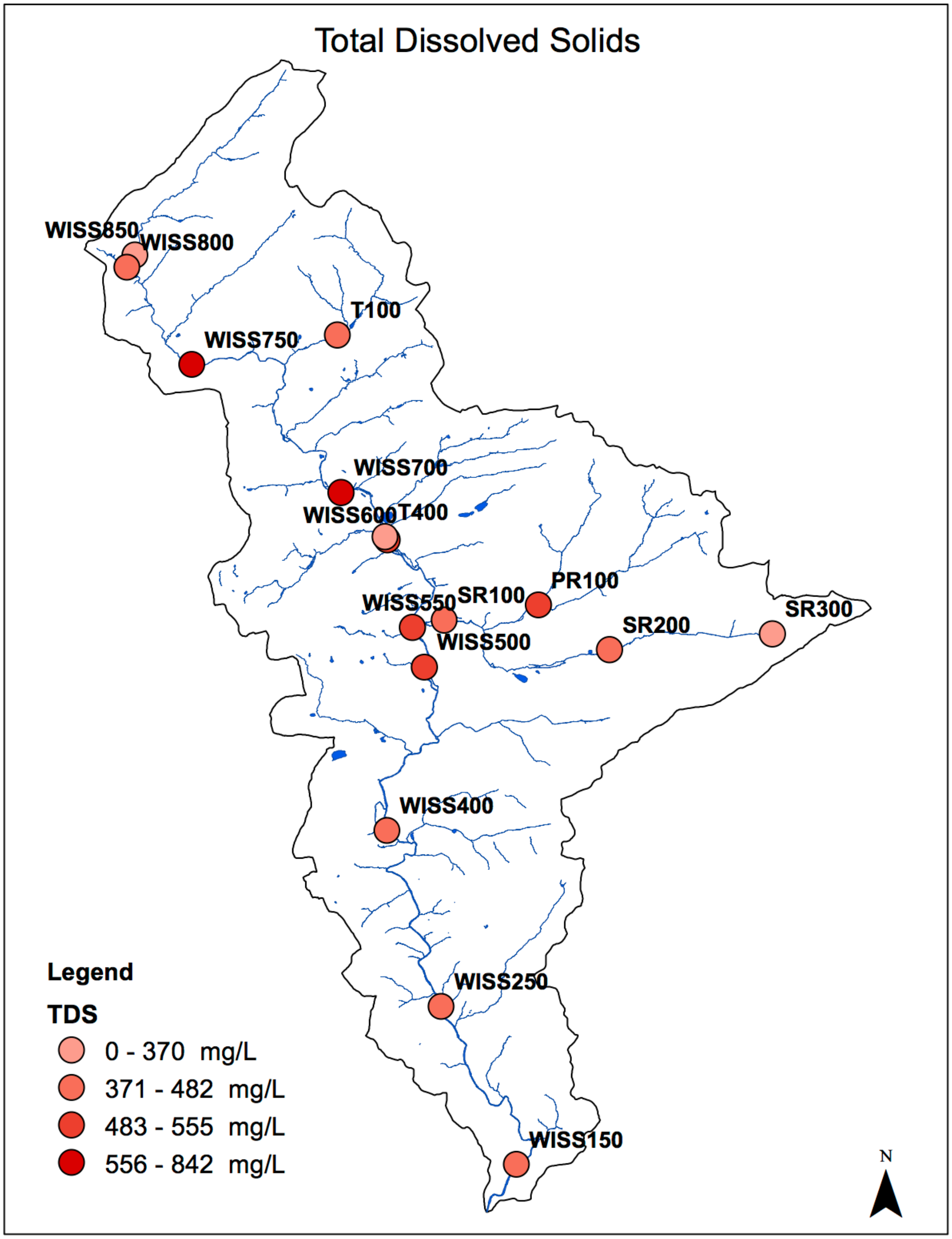

Figure 6- 40. Total dissolved solids (TDS) were sampled for all four seasons from 2011 to 2016 during dry weather. The map represents the median TDS concentrations at each site from 2011 to 2016. All sites were not sampled from 2011 to 2016.

SECTION SEVEN: CONCLUSIONS

The WVWA collected data for the Stream Monitoring and Assessment Program (Stream MAP) from 2004 to 2016, including macroinvertebrate surveys (2011 to 2015), habitat assessments (2011 – 2016), and water quality (2004 to 2016). Each component of Stream MAP provided evidence that the Wissahickon Watershed has impairments that are associated with urban/suburban development. These impairments, known as the urban stream syndrome, are common in watersheds with more than 10% impervious cover and the Wissahickon Watershed has 29% impervious cover.

The expected impacts of high impervious cover are detailed in Section Two. The same figure used in Section Two (page 12) to describe the urban stream syndrome will be used here to describe the evidence from Stream MAP of these impairments (Figure 7-1).

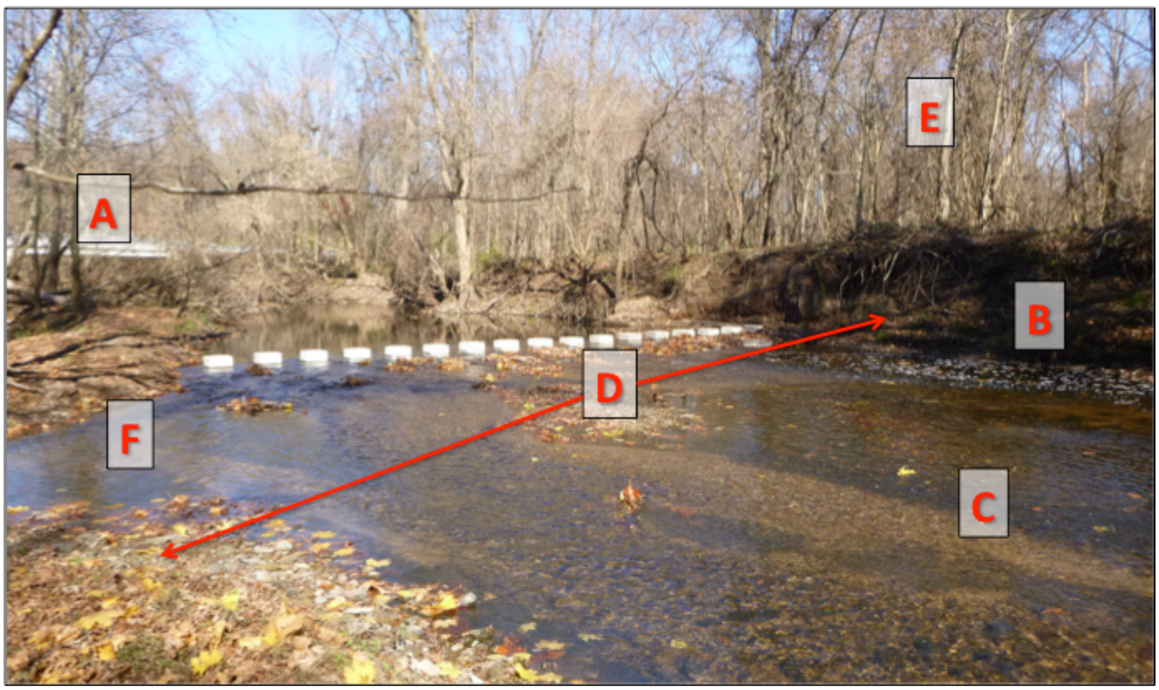

Figure 7- 1. Site WISS550 with letters highlighting signs of the urban stream syndrome.

In the above figure:

- (A) During a rain event, stormwater quickly runs off impervious cover, like the pictured bridge, directly into the creek or nearby storm drain and is then piped into the creek without treatment. Stormwater can be rich in trash, road salt, and nutrients from fertilizers.
    - Stream MAP water quality sampling data found elevated total dissolved solids, chloride, and nutrients in the Wissahickon Watershed (Section Six).

- (B) Due to increased impervious cover, stormwater enters the creek more quickly than in a natural system and at higher volumes, causing large erosion events.
    - Stream MAP habitat assessments found low bank stability scores at several sites, indicating erosion in the watershed (Section Four).

- (C) Erosion releases sediment from the banks that deposits on the streambed and reduces the quality of habitat for macroinvertebrates.
    - Stream MAP habitat assessments found that embeddedness was the lowest ranked parameter throughout the Wissahickon Watershed, signifying that sediment from erosion events is covering the stream bed and reducing the habitat for aquatic organisms (Section Four). The Stream MAP macroinvertebrate surveys indicated that the macroinvertebrate community was consistently impaired in the Wissahickon. The average Pennsylvania index of biotic integrity (IBI) in the Wissahickon Watershed was less than 20%, and any IBI below 50% is considered impaired (Section Five).

- (D) Over time, erosion causes the streambed to widen, the stream depth to reduce, and the stream flow to become homogenous.
    - Stream MAP habitat assessments found reduced flow diversity with an average score of 11 (scale 0-20) for the parameter velocity/flow regime (Section Five).

- (E) As the streambed widens, more sunlight is able to reach the streambed due to the trees being set back from the stream.

- (F) Additional sunlight, plus the additional nutrients from stormwater runoff and other inputs, allows for prolific algae growth that reduces the habitat quality for aquatic organisms.
    - Stream MAP did not directly survey algae productivity, but diurnal fluctuations associated with algae productivity were found in dissolved oxygen and pH even in sampling that was restricted to the daytime (Section Six). Diurnal fluctuations in pH and dissolved oxygen are clear at USGS continuous gages (Gage #01474000 and #01473900). Additionally, the macroinvertebrate community was impaired with little diversity throughout the watershed (Section Five).

Stream MAP data supports that the Wissahickon Watershed has impairments that are commonly found in streams in urban/suburban systems. The Wissahickon Watershed would benefit from actions that mitigate the impacts of development, including:

- Widespread implementation of green infrastructure to reduce the effective impervious cover. This includes breaking up large sections of existing impervious cover, like parking lots, and adding green infrastructure (e.g., rain gardens) throughout.
- Restoring the riparian buffer and tree canopy where needed.
- Upgrading wastewater treatment plants to reduce nutrient concentrations.
- Stormwater best management practices, including improving stormwater detention basins to include infiltration of stormwater.
- Implementing low impact development practices for any new developments.

Stream MAP also found positive signs in the Wissahickon Watershed. First, habitat assessments were typically marginal or suboptimal, higher than would be expected if the land directly surrounding the Wissahickon Creek were not preserved as part of the Green Ribbon Preserve. This was particularly evident in the higher habitat scores associated with channel alteration, bank vegetative protection, and riparian vegetative zone. Second, while nutrients remain high, since 2008 phosphorus concentrations have decreased at four sites on the Wissahickon Creek, but also increased at one site on the Sandy Run. Third, Prophecy Creek, the most protected subwatershed, was consistently the best-rated site, highlighting the importance of protecting open space and maintaining a tree canopy. Lastly, the closing of the North Wales Wastewater Treatment Plant in 2013 was correlated with reductions in nitrate and sulfate concentrations at WISS800, just downstream of the closed plant.

LITERATURE CITED

Academy of Natural Sciences of Drexel University (ANS). 2014. Quality Assurance Project Plan for Cluster Groups: Delaware River Watershed Initiative.

Allan, J. D. and Castillo, M. M. 2009. Stream Ecology: Structure and Function of Running Waters. Second Edition. Springer. Dordrecht, The Netherlands.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. United States Environmental Protection Agency. Office of Water. Washington, D.C. EPA 841-B-99-002.

Center for Watershed Protection. 2003. Impacts of impervious cover on aquatic ecosystems. Watershed Protection Research Monograph No. 1. Ellicott City, Maryland.

Commonwealth of Pennsylvania Department of Environmental Protection. (PA) 2001. Pennsylvania Code Title 25. Environmental Protection. Chapter 93. Water Quality Standards.

Gorman, O. T. and Karr, J. R. 1978. Habitat Structure and Stream Fish Communities. Ecology, 59: 507–515. doi:10.2307/1936581.

Maddock, I. 1999. The importance of physical habitat assessment for evaluating river health. Freshwater Biology. 41: 373 – 391.

Meyer, J. L., M. J. Paul, and W. K. Taulbee. 2005. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society. 24:602–612.

Michigan Department of Environmental Quality (MDEQ). Total Suspended Solids. Retrieved from http://www.michigan.gov/documents/deq/wb-npdes-TotalSuspendedSolids_247238_7.pdf).

Pennsylvania Department of Environmental Protection (PADEP). 2012. A Benthic Macroinvertebrate Index of Biotic Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania. Division of Water Quality Standards.

Philadelphia Water Department (PWD). 2002. Philadelphia Water Department – Belmont & Queen Lane Treatment Plants (PWSID #151001) Section 3: Queen Lane Intake Sources Water Assessment Report.

Philadelphia Water Department (PWD). 2007. Wissahickon Creek Watershed Comprehensive Characterization Report.

Roy, A. H., A. D. Rosemond, M. J. Paul, D. S. Leigh, and J. B. Wallace. 2003. Stream macroinvertebrate response to catchment urbanisation (Georgia, USA). Freshwater Biology. 48:329–346.

Temple University and Newell, Tereska and Mackay Engineering. 2014. Wissahickon Creek Watershed Act 167 Plan.

United States Environmental Protection Agency (USEPA). 2003a. Modeling Report for Wissahickon Creek, Pennsylvania Nutrient TMDL Development.

United States Environmental Protection Agency (USEPA). 2003b. Nutrient and Siltation TMDL Development of Wissahickon Creek, Pennsylvania.

United States Environmental Protection Agency (USEPA). 2004. National Recommended Water Quality Criteria. Office of Water.

United States Environmental Protection Agency (USEPA). 2015a. Total Phosphorus TMDL for the Wissahickon Creek Watershed, Pennsylvania.

United States Environmental Protection Agency (USEPA). 2015b. Evaluation of Nutrients as a Stressor of Aquatic Life in Wissahickon Creek, PA.

United States Geological Survey. Water Hardness and Alkalinity. Website: https://water.usgs.gov/owq/hardness-alkalinity.html. Visited on Feb 2017.

URS. 2011. WVWA Field Methodology. Internal Report.

United States Geological Survey (USGS). 2016. The StreamStats program, online at http://streamstats.usgs.gov. Accessed on Nov 2016.

Walsh, C. J., A. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman, and R. P. Morgan. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society. 24(3):706-723.

Walsh, C. J., T. D. Fletcher, and A. R. Ladson. 2005. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. Journal of the North American Benthological Society. 24:690–705.

Wissahickon Valley Watershed Association (WVWA). 2013. Stream Monitoring and Assessment Program: 2012 Report. Internal Document.