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City of Wilmington Source Water Protection Plan

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City of Wilmington
Source Water Protection Plan

Executive Summary

Foreword

Producing safe clean and affordable drinking water involves using a multiple barrier approach comprised of three main interrelated steps; (1) protecting source water supply areas, (2) treating drinking water to standards, and (3) monitoring and maintaining the integrity of the drinking water distribution system to ensure successful delivery to customers. However, the single most important barrier continues to be source water protection for the following reasons (Trust for Public Lands, 2004):

- The emergence of new contaminants that suppliers may not be prepared to test or treat
- More frequent spikes in contaminant loads due to storms and flooding that make treatment more challenging
- Constantly changing standards and regulations regarding new contaminants, which are present in the water long before they are identified as threats to public health
- Increases treatment and capital costs due to higher pollutant loads and changing water quality standards
- The loss of natural lands to development impacts not only the quality and quantity of drinking water, but also the cost of treating it.
- With the loss of natural barriers protecting the source water supply, man-made or engineered barriers must be introduced in treatment.

The constantly expanding diversity of contaminants, coupled with greater pollutant loads and fewer natural barriers, makes treatment more difficult over time and expensive and increase the chances that contaminants will reach the tap. Based on these factors, source water protection is the only approach that reduces the long term vulnerability of the water supplier to these concerns and ultimately is the most sustainable. With the promulgation of the Long Term 2 Enhanced Surface Water Treatment Rule by EPA in 2006, water suppliers are for the first time in history regulated based on the quality of their source water and required to upgrade treatment based on the water quality before it is even treated. This sets a regulatory precedent that can now be continued in the future for other contaminants.

Throughout the United States and the world, protecting watersheds for drinking water supplies has been shown to be a more cost effective and protective approach to water supplies than building or expanding treatment. In the Northeastern United States alone two of its biggest cities, New York and Boston both rely on heavily forested and protected water supplies to provide high quality drinking water to its citizens. Both cities have chosen to sustain land management of its water supplies in order to save costs. New York City has estimated that if water quality degraded and it was required to filter water that the additional treatment would cost nearly $ 7 billion, with over $300 million in annual operating costs (Trust for Public Lands, 2004). These benefits are not just available to large cities. The town of Auburn, Maine saved $30 million in capital costs, and an additional $750,000 in annual operating costs, by spending $570,000 to acquire land in their watershed. By protecting 434 acres of land around Lake Auburn, the water systems are able to maintain water quality standards and avoid building a new filtration plant (Trust for Public Lands, 2004).

A recent report from the World Bank concluded that source water protection is no longer a luxury but a necessity

Hundreds of communities have worked to preserve their upstream lands regardless of whether they had reservoirs or were along streams and rivers. This is shown in the desire of citizens to fund conservation of watershed lands to protect water supplies. Hundreds of local governments have passed ballot measures in recent years. During 2002 and 2003 local governments across the United States passed ballot measures that included funding for land conservation (Trust for Public Lands, 2004). Seventy-five percent (in 2002) and 83 percent (in 2003) of local ballot measures placed before the voters passed around the country. (Trust for Public Lands, 2004)

A recent report from the World Bank, titled Running Pure, continues to emphasize the critical need for source water protection. The report concluded that protecting forests around the catchment areas is no longer a luxury but a necessity (Dudley and Stolton, 2003, Barnes, 2009). The World Bank study also concluded when forests are removed, the costs of providing clean and safe drinking water to urban areas increase dramatically (Dudley and Stolton, 2003). Studies by the Trust for Public Lands and the American Water Works Research Foundation (Pyke, Becker, Head, and O'Melia, 2003, Trust for Public Lands, 2004) that compared forested land use to water supply water quality impacts indicated that watersheds with above 40% forested land cover were linked to a higher quality water supply. A higher quality water supply resulted in lower water treatment costs for the water utility. This 40% goal is also suggested by American Forests for urban tree canopies to support green infrastructure (mitigate stormwater impacts) and by studies of forest cover in many watersheds by the Stroud Water Research

Center indicate that watersheds with greater than 40% forest cover tend to support cold water fisheries and higher water quality, assuming other impacts are minimal (American Forests, 2009, Jackson, 2009).

Introduction

The City of Wilmington developed this Source Water Protection Plan (SWP Plan) in order to better protect its water supply for future generations, reduce long term operating costs and carbon footprint, avoid future treatment requirements, improve planning and response to future spills and water quality events, and leverage upstream investments to protect its water supply.

Recognizing the efforts and input of the many dedicated stakeholders in the Brandywine Creek Watershed who have been involved with this SWP Plan is very important. The SWP Plan integrates the significant amount of information from their previous studies and plans. Without the involvement of these stakeholders and the benefit of their previous efforts, this plan would have not been possible.

Key Water Quality Findings

- Chloride and conductivity appear to have the most pronounced and continuous increasing trends from the early 1970s to current periods in the Lower Brandywine. There is no indication that this trend is “leveling off” or diminishing.
- Alkalinity and hardness appear to have increasing trends that mirror that of chloride and conductivity, but appear to be related to groundwater and base flow changes.
- Total phosphorus appears to be decreasing while total orthophosphate concentrations remain relatively unchanged.
- Nitrate concentrations historically increased since the 1970s, but appear to be leveling off in recent years while ammonia concentrations have decreased historically.
- There were no discernible historical trends observed for total organic carbon (TOC), bacteria/pathogens, total iron and manganese, temperature, and pH. Trends may be occurring, but analytical method variability, analytical detection limits, analytical method changes, and frequency/seasonality of monitoring may not have been able to detect them.
- When turbidity (clarity of the water) in the Brandywine Creek exceeds 10 NTU it has the potential for negative impacts on water treatment and water quality.

Key Point Source Findings

- There are over 700 potential regulated facilities in the watershed. Approximately 35% of the sources are dischargers, 36% are storage tanks, 16% are septic systems, and the remaining sources include various types.
- Under dry weather conditions, spills from the farthest reaches of the watershed will make it to Wilmington's intakes in less than 6 days and potentially less than 2 days under normal conditions without delays from impoundments. Under dry weather conditions, spills from the Route 30 corridor such as Coatesville, Exton, and Downingtown can potentially reach Wilmington's intakes in roughly 1 to 3 days. Under dry weather conditions, spills into the main stem can reach the intake in less than a day in most cases. Under bank full flow (flooding related) conditions, all spills from all locations can potentially reach the Wilmington intake in 5 to 15 hours unless there is a delay caused by impoundments such as in one of the large reservoirs in the basin.

Key Non Point Source Findings

During the past decade the Brandywine Creek watershed lost 10% of its forest cover. How much will be left by 2100?

- Contaminant loading estimates suggest non point sources are the most significant sources of pollution in the watershed.
- The greatest non-point source contaminant loadings typically come from throughout the West Branch of the Brandywine Creek and its tributaries, mainly due to agricultural land use with some focus in the Coatesville area. The West Branch and its tributaries are high for all contaminant categories including nutrients, sediment, pathogens, and TOC. Only the sections of the East Branch including Downingtown, Exton, and West Chester appeared as areas with high potential loadings for TOC, fecal coliforms, and *Cryptosporidium*.
- The lowest non-point source contaminant loadings came from throughout the watershed usually focused in areas of low human population. However, these areas may coincide with areas of high loadings due to agricultural activity and suggest potential synergy areas for restoration and preservation work to be combined. In fact, three "synergy" areas were identified; these include Doe Run, Buck Run, and the West Branch of the Brandywine Creek in the Pocopson Township area.
- Livestock and dairy cattle in particular are potentially the most significant source of pathogens and certain emerging contaminants in the watershed.

Key Land Use Findings

- During the past decade the watershed lost 10% of its forest cover. The forest cover that is preserved in the watershed and development reduction of forest cover will reach a balance point between 2040 and 2100 and no additional forest cover will be gained in the watershed. Therefore, protection of existing forest cover is critical in this century for the future of the watershed.

Wilmington's Water Quality Priorities

Based on the potential source investigations and water quality information, the following are Wilmington's water quality priorities.

Contaminant Source	Priority issue	Contaminants Addressed
Agriculture	Dairy Farms, cows in stream, manure management	Cryptosporidium, pathogens, nutrients, turbidity, disinfection by products, trace organics (antibiotics)
Wastewater	Raw and untreated sewage discharges, outbreaks	Cryptosporidium, pathogens, trace organics, baseflow, nutrients
Urban/Suburban Runoff	Road Runoff, Streambank erosion	Turbidity, sodium & chloride, baseflow
Riparian buffer removal	Streambank erosion	Disinfection by products, turbidity

Summary of Recommended Implementation Activities

Based on the information compiled, a series of goals, objectives, indicators, and implementation tasks (short and long term) were developed for the City of Wilmington's water supply. Overall, 4 major goals, 29 major objectives, 78 implementation tasks covering various time periods, and 46 potential progress indicators were created as part of the implementation plan for Wilmington to initiate and sustain a Source Water Protection Program that can lead to successful achievement of its goals.

Implementation of the various objectives is further broken down into definable tasks at various time scales in order to be accomplished. The various tasks can be divided into the following types of major implementation activities:

- Agricultural Mitigation
- Agricultural Preservation
- Forest Preservation
- Riparian Buffer Restoration and Forest Reforestation
- Wastewater Discharge Enhancement and Emergency Response Preparation and Communication
- Stormwater Runoff Mitigation
- Stakeholder Partnerships and Outreach & Public Education
- Monitoring & Technical Studies
- Hoopes Reservoir Protection
- Financial Support and Analysis

These activities can have short term and long term elements as well as localized and watershed wide components. These elements can be implemented with partners and other sources of funding. In most cases, Wilmington's role will be technical support or helping stakeholder to access other funding sources. In some cases, Wilmington may need to take the lead to implement the activity. The most important source water protection activities for the previously mentioned categories are described below.

Agricultural Mitigation

Mitigating agricultural impacts provides benefits to the water supply. It prevents and reduces pathogens such as *Cryptosporidium*, sediment, livestock pharmaceuticals, ammonia, nitrate, and phosphorus. A study by AWWA and the Trust for Public Lands of water supplies suggested that for every 4 percent increase in raw water turbidity, treatment costs increase 1 percent. (Trust for Public Lands, 2004)

Agricultural Mitigation is a low cost / high return mitigation activity. Honey Brook is the top priority area for this work.

Agricultural mitigation efforts need to focus the primary efforts on the Honey Brook Township area of the West Branch of the Brandywine Creek. There are 1,700 acres of land and 25 miles of stream in need of protection in this priority area. In order to protect the Honey Brook clusters, roughly 10% or 170 acres or 2.5 miles of streambank would need mitigation annually. It will require about $217,000 per mile of streambank with fencing with a total cost of over 5 million dollars to ultimately address the Honey Brook township clusters.

In the New Castle County section of the main stem of the Brandywine Creek, activities need to focus on projects to get cows and livestock out of the tributaries to the main stem Brandywine Creek from the City's intake upstream to the Delaware border. There are roughly 3 miles of tributaries and stream along agricultural properties in Delaware upstream of Wilmington's intake that requires some level of mitigation or protection. There are also 92 acres of pasture areas that will need examination for potential mitigation. It should be an immediate priority to implement streambank fencing in areas where livestock are accessing the stream in Delaware and a long term effort to protect the remaining areas in Delaware.

Throughout the watershed the most important mitigation activities include streambank fencing and implementation of conservation and nutrient management plans at dairy and livestock farms. Approximately $450,000 per year of funding in the watershed from various non City sources should be dedicated to these efforts with a total of 8.9 million dollars to implement 20 miles of streambank fencing and mitigation work at 100 farms over the next 10 to 20 years. Some potential partners for this effort include the Pennsylvania Department of Environmental Protection, Chester County Conservation District, New Castle County Conservation District, Delaware Natural Resources Environmental Conservation, Chester County, United States Department of Agriculture, Natural Resources Conservation Service, Trout Unlimited, Duck Unlimited. Wilmington's role will be mostly related to technical support and assistance in accessing other funding sources with some potential for direct funding assistance if leveraging is available.

Agricultural Preservation

Agricultural preservation provides benefits to the water supply because properly managed and preserved farmland can support significant riparian buffers and prevents the addition of urban/suburban stormwater challenges due to development. A study by AWWA and the Trust for Public Lands of water supplies suggested that for every 4 percent increase in raw water turbidity, treatment costs increase 1 percent. (Trust for Public Lands, 2004)

Agricultural Preservation efforts should focus on preserving as much farmland as possible in riparian buffer areas along first and second order streams by 2100. This will cost about $5 million per year and attempt to preserve over 69 square miles of farmland (roughly 60% of existing farmland in the watershed). The 2,700 acres of farmland along first order streams in the Honey Brook area on the West Branch represents prime agricultural parcels should be the primary preservation target area of the initial 5 to 10 year period. In New Castle County there is approximately 1,778 acres of farmland that needs to be assessed for its preservation status.

Some potential partners for this effort include the Pennsylvania Department of Environmental Protection, Brandywine Conservancy, Chester County Conservation District, New Castle County Conservation District, Delaware Natural Resources Environmental Conservation, Delaware Nature Society, Chester County, United States Department of Agriculture, Natural Resources Conservation Service, Trout Unlimited, Duck Unlimited. Wilmington's role will be mostly related to technical support and assistance in accessing other funding sources with some potential for direct funding assistance if leveraging is available.

Forest Preservation

Forests prevent pathogens such as *Cryptosporidium*, road salts, and increased flows due to development. Forests also have significant buffer impacts that reduce/filter sediment, ammonia, nitrate, and phosphorus. Treatment costs increase as forested lands drop below 40% of the watershed. For every 10 percent increase in forest cover in the source area, treatment and chemical costs decreased approximately 20 percent, up to about 60 percent forest cover as reported in a study by AWWA and the Trust for Public Lands (Trust for Public Lands, 2004).

As noted in this plan, the forested land cover of the Brandywine Watershed is estimated at approximately 28% forested land cover in 2009 (data provided by GIS estimates by Brandywine Conservancy). Based on historical development rates and woodland loss information (Brandywine Conservancy report reference 2009), over the past 10 to 15 years there has been an average 1% per year loss in forested lands. This equals approximately 9.09 square miles of forested land lost per decade to development pre-recession.

Forest Preservation is a long term protection activity The Upper East Branch areas of Perkins and Indian Run is a top priority area

Forest Preservation efforts need to focus the short term efforts on the Perkins Run and Indian Run cluster areas along first order streams. Within the Delaware portion of the Brandywine Watershed there is approximately 1,000 acres of riparian forested lands that need to be examined for preservation.

Preservation of priority areas will require about $800,000 per year and protect 2 miles of stream bank and 1,000 acres per year. Watershed wide, approximately 75 square miles, need to be preserved at a cost of approximately 48 million dollars. Some potential partners for this effort include the Pennsylvania Department of Conservation of Natural Resources, Chester County Water Resources Authority, New Castle County, Delaware Natural Resources Environmental Conservation, Chester County, Brandywine Conservancy, Brandywine Valley Association, Natural Lands Trust, Trust for Public Lands, William Penn Foundation, Conservation Fund, Pennsylvania Environment Coalition, Delaware Horticultural Society, Delaware Nature Society. Wilmington's role will be mostly related to technical support and assistance in accessing other funding sources with some potential for direct funding assistance if leveraging is available.

Riparian Buffer Restoration & Forest Reforestation

Riparian Buffer Restoration efforts require a detailed watershed wide analysis and groundtruthing of riparian buffer gaps to be completed. The first step requires facilitating a watershed wide reforestation plan by stakeholders. In the meantime until complete watershed wide information is available, initial efforts by the City of Wilmington should be piloted within the tributaries to the main stem in New Castle County where detailed information is available and effectiveness can be monitored. Detailed information provided by the Brandywine Conservancy suggests the lands in the Wilson Run tributary and the agricultural lands near Smiths Bridge Road in Ramsey Run, Beaver Run, and an unnamed tributary are the greatest priority. This work involves a relatively limited number of stakeholders and property owners. The City of Wilmington should immediately meet with these stakeholders to discuss ways to improve riparian buffer protection in these areas.

In addition, a watershed wide initiative for reforestation should be developed that is linked to potential funding sources via carbon credits, carbon sequestration, or carbon cap and trade programs for energy suppliers and businesses. Many large industries reside in the watershed and region that may be interested in this approach. However a framework needs to be developed that regulators will accept and a champion to administer and implement the program will need to be identified.

Can watershed reforestation be funded by linking it to carbon credits and greenhouse gas emissions?

Some initial steps to starting this effort include the following:

- Develop programs to reforest key riparian parcels upstream of COW intake in New Castle County along the main stem and first order streams.
- Assist stakeholders to obtain funding to complete a reforestation plan for the watershed.

- Develop funding agreements with Brandywine Conservancy and Brandywine Valley Watershed association to leverage specific reforestation efforts in first order streams or headwaters areas.

- Develop regional initiative with BC, BVA, water suppliers, and Chester County to reforest remaining forested riparian buffer lands along first and second order streams by 2100.

- Support initiatives by partners to develop a "forest bank" related reforestation approach that is supported by carbon sequestration and greenhouse gas emission trades in the region.

Wastewater Discharge Enhancements and Emergency Response Preparation and Communication

These activities should result in improved response and awareness of upstream accidents and activities that could result in acute water quality events or long term water quality changes that will impact Wilmington's intakes. Point source management should focus on the following priority activities:

- Support upgrades to advanced tertiary and UV treatment to mitigate pathogens

- Enhance communications with Health Departments regarding upstream occurrence of waterborne or gastrointestinal disease events

- Increase communication for improved responses in case of accident

- Receive calls from Marsh Creek Lake during releases

- Develop internal protocols to respond to calls from upstream dischargers, water suppliers, etc.

- Visit high priority point sources to improve awareness for downstream notifications

- Develop appropriate phone and contact information list for high priority point sources immediately.

Emergency response efforts should focus on the following priority activities:

- Visit high ranked facilities upstream, update internal information, and exchange emergency contact information

- Visit all major upstream discharges upstream and exchange contact information

- Contact Chester County Health and get added to phone chain for spills

- Investigate enrolling in Delaware Valley Early Warning System
- Improve notification about reservoir releases upstream (CWRA)
- Enhance the turbidity early warning system to include conductivity warnings for road salt application
- Contact emergency responders in NCC upstream of COW intake and drinking water to communicate water supply sensitivity to wash down and accidents.
- Design and install water supply educational roadway signs at key locations in the watershed & Hoopes Reservoir.

Wilmington's role will be mostly related to technical support and direct outreach and communication with upstream facilities, health departments, and emergency responders.

Stormwater Runoff Mitigation

Stormwater management should focus on the following priority activities:

- Support riparian buffer ordinance protections upstream in DE and PA
- Identify opportunities to match SWP efforts with ACT 167 and Chester County Ordinance Initiatives (Landscapes, Watersheds, etc.)
- Monitor TMDL activities related to upstream MS4 permits
- Assist/facilitate creation of upstream stormwater utilities
- Set up a pilot project with DELDOT and COW for using brining to reduce road salt application near intake
- Examine the potential for ordinances to minimize salt use on private parking lots

Wilmington's role will be mostly related to technical support and sharing information on administering a stormwater utility.

Stakeholder Partnerships

Stakeholder partnership efforts should focus on the following priority activities:

- Implementation of the SWP Ordinance
- Obtain approval and endorsement of the Wilmington Source Water Protection Plan by key stakeholders, PADEP, DNREC, and EPA Region 3
- Integration of the SWP Plan into stakeholder activities through education
- Participate in the Phase 7 scope of work development for the EPA Watersheds Grant

- Working with stakeholders at Hoopes Reservoir for reforestation of the buffer area.
- Conduct workshops to enroll upstream golf courses in the Audubon Certification Program
- Design and install water supply educational roadway signs at key locations in the Brandywine Creek watershed (near the intakes) & Hoopes reservoir areas.
- Arrange SWP Program in order to submit application for AWWA Accreditation

Wilmington's role will be mostly related to direct outreach and communication with upstream stakeholders.

Monitoring

Awareness, understanding, and knowledge of water quality trends, phenomena, and events through monitoring can allow for predictive and preventative actions to protect the water supply or enhance its treatment.

Monitoring efforts should focus on the following priority activities:

- Microbial source tracking study completion and evaluation
- Add conductivity to early warning system upstream where needed
- Continue to track and evaluate watershed pharmaceutical monitoring efforts
- Updating long term monitoring trends

Wilmington's role will be mostly related to technical and financial support and direct participation of monitoring studies.

Hoopes Reservoir Protection

Hoopes Reservoir management should focus on the following priority activities:

- Conduct forest survey of Hoopes
- Improve markers of COW Property boundaries
- Create an enforcement process for deforestation
- Educate adjacent property owners
- Reforest the Hoopes Area in coordination with neighboring landowners
- Identify areas for critical land acquisition/easements around Hoopes if any remain
- Initiate communication and education of emergency responders near Hoopes

Wilmington's role will be mostly related to direct implementation and leadership of these activities by COW staff.

Financial Support and Analysis

Long term funding will lead to consistent implementation of water supply protection goals. Without funding programs in the watershed will not be able to mitigate current and future pollution sources and the water quality will degrade in the Brandywine Creek. Given the current global economic situation funding for these efforts is limited and highly competitive. Funding efforts should focus on two parallel tracks. The first effort will include efforts to support leveraging and obtaining funds through traditional grant opportunities with stakeholders for specific defined projects and efforts. The second effort will require working with stakeholders such as the University of Delaware Water Resource Agency to identify the value of the Brandywine and develop a sustainable source of funding in the watershed from non-grant sources.

Recommended Immediate Priority Activities

It may be difficult to determine where to start implementing the Source Water Protection Plan with the limited resources available since there are such a large number of activities recommended in the plan. The following activities are recommended for initial implementation.

- Implement the SWP Ordinance
- Facilitate and support streambank fencing directly upstream in New Castle County
- Continue to leverage preservation efforts with watershed partners
- Partner with Brandywine Conservancy on larger efforts for forest preservation and reforestation
- Implement several streambank fencing projects in the Honey Brook area with BC, CCCD, and BVA and evaluate the benefits to Wilmington
- Estimate the cost benefit and long term impacts of deforestation of the watershed on long term water quality and treatment costs
- Enhance current protocols for Hoopes Reservoir usage due to Brandywine Creek water quality
- Develop and establish protocols to respond to upstream notifications
- Familiarize staff with watershed and key upstream dischargers and information on watershed
- Continue to build partnerships with upstream stakeholders
- Present the SWP Plan to stakeholders and educate City officials
- Obtain endorsement of the SWP Plan by City Council
- Initiate monitoring for the Microbial Source Tracking Project
- Identify and leverage opportunities through the Christina Coalition
- Initiate road salt reduction discussions and develop a pilot project

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1. Section 1 - Overview of Source Water Program and Protection Plan

1.1. Introduction

Producing safe clean and affordable drinking water involves using a multiple barrier approach comprises three main interrelated steps; (1) protecting source water supply areas, (2) treating drinking water to standards, and (3) monitoring and maintaining the integrity of the drinking water distribution system to ensure successful delivery to customers. However, the single most important barrier continues to be source water protection for the following reasons (Trust for Public Lands, 2004):

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- Increased treatment and capital costs due to higher pollutant loads and changing water quality standards
- The loss of natural lands to development impacts not only the quality and quantity of drinking water, but also the cost of treating it.
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These constantly expanding diversity of contaminants, coupled with greater pollutant loads and fewer natural barriers, over time will make treatment more difficult and expensive and increase the chances that contaminants will reach the tap. Based on these factors, source water protection is the only approach that will reduce the long term vulnerability of the water supplier to these concerns and will ultimately be the most sustainable. With the promulgation of the Long Term 2 Enhanced Surface Water Treatment Rule by EPA in 2006, water suppliers are for the first time in history regulated based on the quality of their source water and required to upgrade treatment based on the water quality before it is even treated. This sets a regulatory precedent that can now be continued in the future for other contaminants.

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Source Water Protection is the first step of the multiple barrier approach that focuses on mitigating current and future water supply contamination. The basic principle of source water protection is simply that the cleaner the water at the source, the less it must be treated to provide safe drinking water. With rapidly increasing energy and chemical costs for water treatment in recent years, source water protection is more than a precautionary activity, but also a potential long term cost savings program. Also, as water utilities start adopting a triple bottom line approach which includes economic, environmental, and social costs the source water protection approach will become a more integral part of the business model for water utilities.

Source water protection, though already employed by many water utilities, was given a significant amount of national attention due to Federal legislation in 1996. The Safe Drinking Water Act Reauthorization of 1996 required states to develop a Source Water

Assessment and Protection (SWAP) Program. This program was designed to assess the drinking water sources that serve public water systems for their susceptibility to pollution and to use this information to eventually build voluntary, community-based barriers to drinking water contamination such as source water protection plans. These assessments were of the raw water quality, not of finished water quality or of water supplier compliance with standards.

The source water protection process can be summarized in three basic steps, 1) identify and prioritize the potential contaminants of drinking water, 2) determine the pathways by which these contaminants enter the source water, both surface water and groundwater, and 3) develop methods and programs which reduce or eliminate the contamination of water used for drinking water supply. The Source Water Assessment Program (SWAP) addressed number 1) above, the identification and prioritization of potential contaminants within the watershed of a source water. The Source Water Protection Plan efforts of Wilmington are focused on addressing numbers 2) and 3) above.

1.2. Background on Source Water Assessments

The USEPA established a new requirement under Section 1453 of the 1996 Safe Drinking Water Act. The Act requires each state to develop a Source Water Assessment and Protection Program (SWAP) to evaluate all drinking water sources that serve public drinking supplies and to provide a mechanism for development of local protection programs. As part of the requirement all surface water sources in the United States were investigated for potential sources of contamination and vulnerability to pollution.

In 1996 the U.S. Congress amended the Safe Drinking Water Act (SDWA) establishing a Source Water Assessment and Protection Program (SWAPP). The program, coordinated nationally by the U.S. Environmental Protection Agency (EPA), requires all states to develop a plan for evaluating the drinking water supply sources used by public water systems in their state and then follow the plan to conduct source water susceptibility assessments. Susceptibility assessments will include a determination of the area that has the greatest affect on the quality of each public drinking water source and an inventory of the potential contaminants within the designated area.

The ultimate goal of the SWAPP was to provide local government the information it needs to improve the protection of public drinking water sources through its land management authority. It should be recognized that for many years the primary mechanism for insuring the safety and quality of drinking water has been water treatment facilities. Public water suppliers have spent billions of dollars developing sophisticated water treatment techniques that remove materials that are harmful to our health. The SWAPP was designed to another protective mechanism to safeguard drinking water supplies by identifying the potential sources of contamination that may affect raw water quality and providing assistance in managing or eliminating these potential contaminant sources.

In October 1999 the U.S. EPA formally approved Delaware's Source Water Assessment Plan which outlined the methodology Delaware followed to determine the susceptibility of the 582 public water systems in the state. All assessments followed the same general approach, although the details may vary depending on the size of the water system. The Delaware Source Water Assessment conducted by the University of Delaware Water Resources Association used the following four step approach.

1. Delineate the source water areas for each intake (watershed) or well (wellhead).

Initially, the area most important to water quality for each public system was mapped. For surface water, the watershed area upstream of the intake was examined, with particular attention focused on areas adjacent to streams and tributaries.

2. Determine the vulnerability of each intake or well to contamination.

Second, the vulnerability of the surface water intake or well was determined using a decision making chart developed in Delaware's source water plan. Vulnerability was defined as the relative ease with which contaminants, if released within a source water area, could move and enter a public water supply well or intake at concentrations of concern.

3. ***Identify existing and potential sources of contamination in the source water area.***

Third, an inventory of all documented existing and potential sources of contamination from discrete sources within these delineated areas were developed. The land use within these areas was also assessed for potential non-point sources of pollution.

4. Determine the susceptibility of the source water area to contamination.

This last step examined water quality test data from the previous 10 years. This sampling data was supplemented by water quality tests that were conducted in August 2001 by the State as part of a special water quality investigation of drinking water supplies. All of this information was evaluated and distilled into a ranking of susceptibility based on the methodology and matrix developed by the SWAPP Citizen and Technical Advisory Committee.

Susceptibility was reported for eight categories of contaminants, as follows:

- Nutrients (nitrate, etc.)
- Pathogens (bacteria, cryptosporidium, giardia, etc.)
- Petroleum Hydrocarbons (benzene, toluene, etc.)
- Pesticides (endrin, lindane, etc.)
- Polychlorinated biphenyls (PCBs)
- Other Organics (chloroform, etc.)

- Metals (lead, copper, zinc, etc.)
- Other Inorganics (chloride, sodium, etc.)

The methods used for the assessment are outlined in the DNREC or Pennsylvania Department of Environmental Protection's (DEP) approved SWAP program, approved by USEPA in March 2000.

The original Source Water Assessment Report for the City of Wilmington, Delaware public water supply intake on the Brandywine Creek was prepared by the University of Delaware, Institute for Public Administration – Water Resources Agency (UDWRA) by contractual agreement with the Delaware Department of Natural Resources and Environmental Control (DNREC), Division of Water Resources. The UDWRA prepared the report utilizing best professional judgment in accordance with methodology established in the October 1999 State of Delaware Source Water Assessment Plan and supplemented by the policies prescribed by the DNREC with concurrence by the SWAPP Citizen and Technical Advisory Committee. The SWAPP assessment was prepared by Martin Wollaston and Jerry Kauffman, assisted by the following UDWRA staff and students: Nicole Minni, Vern Svatos, Justin Bower, Scott Smizik, Martha Corrozi, and Arthur Jenkins. Copies of this report are available from DNREC.

1.3. Key Findings of Source Water Assessments

The findings of the original source water assessment were the first step in understanding Wilmington's water supply and were considered appropriate and helpful within the boundaries of the intended purpose of the assessments. Given this preliminary nature, the application of the findings to Source Water Protection Planning efforts are limited. First, it provided high, very high, and exceeds standards susceptibility rankings for all the contaminant groups solely based on the presence and levels of various contaminants in the source water. The assessment did not take into account the ability of the removal of the treatment process, proximity of sources, or magnitude. Also, the assessment only accounted for 196 square miles of the 325 square mile watershed or roughly 60% of the watershed. The intent at the time of the assessment was that information from the upstream water intake source water assessments in West Chester and Coatesville in PA would be incorporated at a later period. However, this did not occur and major sources in Coatesville, Downingtown, West Chester and upstream of those areas were not included in the assessment. It was assumed that the intakes for those areas would take appropriate action to address local contaminant issues that would benefit Wilmington downstream. However, the actions resulting from the Source Water Assessments have been limited since there is no mandate or funding for water suppliers to address findings in the Source Water Assessments. Therefore, 90% of the drainage area for Wilmington's water supply depends upon the actions of upstream communities in another state and three upstream water suppliers. High ranking point sources from the SWAP are shown in Table 1-1 below.

Table 1-1 – High Ranking Point Sources Identified in 1999 SWAP

Source	Type	State	Contaminants	
Greenville Country Club	NPDES	DE	Pathogens	Other Organics
Winterthur	NPDES	DE	Pathogens	Other Organics
Hagley Museum	US Tank	DE	Petroleum	Other Organics
Texaco Service Sta.	US Tank	DE	Petroleum	Other Organics

The four sources above were the only high ranking sources of the 257 point sources identified upstream. The Christina Watershed Action Strategy identified 433 point sources upstream of the Wilmington intake. This means there were 176 additional point sources that were unaccounted for or ranked in the Source Water Assessment by DNREC. Also, these four top priority point sources were not field verified, nor were there performance, discharge violations, stream impacts, etc. A comparison of the top point sources to stream and intake water quality or other related studies and information to corroborate their current or potential impact was not conducted.

The top priority source types and issues from other SWAP reports upstream and other relevant watershed plans were compared with the Wilmington SWAP report (Table 1-2). The limits of the SWAP report are apparent when compared to the Wilmington WQ data and other studies (Table 1-3). As shown in Table 1-2, sources from wastewater, agriculture, transportation, and stormwater runoff are the greatest common concerns including riparian buffer loss. One study actually prioritized and ranked the importance of various subbasins within the Brandywine for action (Table 1-4). These priorities, priority areas and recommended actions and related ongoing initiatives in the Brandywine Watershed will need to be evaluated in the SWP Plan to determine if they will address the specific source related potential impacts at the Wilmington intake.

Table 1-2 – Comparison of Summary of Top Priority Point Sources & Issues from Previous SWAP and Watershed Studies

Priority Source Type / Issue	Wilmington SWAP - DNREC	Ingram Mills	Downing-town	Coatesville	303d list	Brandy-wine Action Plan	Christina Tributary Action Team	Chester County Compendium	Wilmington WQ Data	Total
transportation	1	1	1	1	1				1	6
wastewater		1	1	1		1	1	1	1	7
agriculture		1		1	1	1	1	1	1	7
auto & heavy equipment	1	1	1	1						4
recreational			1	1						2
reservoir releases		1	1							2
urban/suburban runoff		1	1		1	1	1	1	1	7
Superfund Sites				1						1
Riparian buffer loss/development		1			1	1	1	1	1	6
Taste & Odor compounds		1							1	2
Golf Courses			1	1			1			3

Table 1-3 – Summary of SWAP Report Characteristics

Utility	COW	Aqua PA		Downingtown MWA	PA American	
Intake	Wilmington SWAP	Ingram Mills	Fern Hill	E. Branch Brandywine	W. Branch	Rock Run
Regulator	DNREC	PADEP	PADEP	PADEP	PADEP	PADEP
Assessor	U of D WRA	SSM	SSM	SSM	SSM	SSM
Drainage Area	319	113	2.7	64	32	6
Branch	Main stem	E. Branch	E. Branch	E. Branch	W. Branch	Rock Run
Tributary	Main stem	E. Branch	E. Br. Chester Creek	E. Branch	W. Branch	Rock Run
# of contributing tributaries	all	12	1	7	Birch & 2 Log Run	2 UNT
# of municipalities	48			12	9	1
% Agriculture	37	50	18	62	68	64
% Forest	40	35	5	32	30	18
% Urban/Built	23	13	70	4	2	16
% Other	0	2	7	2	0	2
# of point sources inventoried	257/433	325	NA	70	40	NA

Table 3 – Summary of Priority Subbasins from Chester County Compendium

Water Quality General		Water Quality (303d)		Stormwater		Stream Preservation		Groundwater	
Subbasin	Priority	Subbasin	Priority	Subbasin	Priority	Subbasin	Priority	Subbasin	Priority
West Valley	1	Wilmington	1	Wilmington	1	West Valley	1	West Valley	1
Sucker Run/Rock Run	2	West Valley	2	West Valley	2	Beaver Creek	2	Beaver Creek	2
Wilmington	3	Doe Run	3	Above Chadds Ford	3	Pocopson Creek	3	Wilmington	3
Marsh Creek	4	Marsh Creek	4	Beaver Creek	4	Marsh Creek	4	Pocopson Creek	4
Beaver Creek	5	Above Chadds Ford	5	Pocopson Creek	5	Sucker Run/Rock Run	5	Marsh Creek	5
Shamona Creek	6	Buck Run	6	Broad Run	6	Shamona Creek	6	Above Chadds Ford	6
Upper West Branch	7	Sucker Run/Rock Run	7	Marsh Creek	7	Above Chadds Ford	7	Sucker Run/Rock Run	7
Above Chadds Ford	8	Upper West Branch	8	Taylor Run	8	Upper East Branch	8	Shamona Creek	8
Broad Run	9	Broad Run	9	Below Chadds Ford	9	Broad Run	9	Taylor Run	9
Upper East Branch	10	Beaver Creek	10	Sucker Run/Rock Run	10	Below Chadds Ford	10	Broad Run	10
Pocopson Creek	11	Taylor Run	11	Upper East Branch	11	Taylor Run	11	Upper West Branch	11
Below Chadds Ford	12	Shamona Creek	12	Buck Run	12	Doe Run	12	Upper East Branch	12
Taylor Run	13	Below Chadds Ford	13	Upper West Branch	13	Buck Run	13	Below Chadds Ford	13
Buck Run	14	Upper East Branch	14	Shamona Creek	14	Wilmington	14	Buck Run	14
Doe Run	15	Pocopson Creek	15	Doe Run	15	Upper West Branch	15	Doe Run	15

1.4. Relating the Source Water Assessments to the Protection Plan

This protection plan builds on the results of the source water assessments. It reassesses the inventory of sources and priorities based on their potential drinking water impact and refines previous contaminant based rankings based on pollutants of primary concern. This information is then utilized to develop a specific plan of actions to resolve current and future drinking water issues that can be used by water suppliers, regulators, or other watershed stakeholders.

1.5. Other Data Informing the Protection Plan

There are over 30 different water quality, water quantity, watershed characterization, watershed planning, and land use planning related studies and reports that have been conducted for the Brandywine Creek watershed or portions of it. Most of these studies have been influenced by the 303d impairment listings for the Clean Water Act. According to these studies agriculture and urban runoff/development are the biggest causes of impairment to the watershed.

The priorities and recommendations of the other studies will be examined and compared to the drinking water priorities in this plan in order to provide a comprehensive approach to improving the Brandywine Creek. By addressing priorities and sources that impact multiple watershed needs (water supply, aquatic life, recreation) the potential for successful efforts is greater than if they are pursued separately.

1.6. Implementing Projects Outlined in the Protection Plan

There are three levels of activity needed to successfully implement the protection plan. First, there are projects and initiatives that need to be undertaken by the City of Wilmington that are oriented towards protection of the water supply in the areas within the City of Wilmington along the Lower Brandywine Creek. These efforts include the adoption and enforcement of the Source Water Protection Ordinance. Second, the City of Wilmington will need to participate or lead specific initiatives that are being coordinated in the Christina River and Brandywine Creeks through the Christina Basin Water Quality Committee and Tributary Action Teams. These efforts will focus on helping to affect changes in regulatory policies and priorities as well as funding priorities from grants and government agencies (including USDA) that will also address Wilmington's drinking water issue. Third, specific partnerships will need to be developed to support and coordinate efforts with specific stakeholders to preserve critical lands, to influence positive land use management and growth in Chester County, and continue support and enforcement of ordinances and land controls in New Castle County.

2. Section 2 - Watershed Description, Characterization, & Analysis

2.1. Watershed & Surface Water intakes

2.1.1. General Overview

The Brandywine Creek watershed drains 325 square miles and includes two states, Delaware and Pennsylvania, and three counties (University of Delaware, 2002) (See Table 2-1). It consists of fifteen subbasins and flows into the Christina River at Wilmington, Delaware. All together, there are 48 municipalities in the two states that are either fully or partially within the Christina watershed. The Brandywine Creek is part of the Christina River Basin, which flows into the Delaware River at Wilmington, Delaware (Chester County Water Resources Authority, 2002).

Table 2-1 – State Land Area within the Brandywine Creek Watershed

Watershed	PA	DE	MD	Subtotal
Brandywine Creek	300.14	24.58	0	324.72
% of area	92	8	0	100

Source: PADEP, 2003

The headwaters of Brandywine Creek are in Chester County, PA, and the stream flows south into New Castle County, Delaware, where it is tributary to the Christina River (Figure 2-1, Table 2-3a). A small area in the easternmost part of the basin is in Delaware County, PA. The largest population centers in the watershed are the City of Wilmington, Delaware, and the boroughs of Downingtown, Coatesville, and West Chester, PA (Figure 2-2). According to PADEP (PADEP, 2003), a total of 372 streams flow for 536 miles in the Brandywine Creek Watershed of which over 50% are first order stream miles. Roughly 20% of the stream miles are impaired in the Brandywine Watershed and with future population growth these impairments may increase without additional management. Table 2-2 provides a summary of the general major watershed characteristics.

In 1995, 37% of the Brandywine Creek watershed, including the portion in the State of Delaware was in agricultural land use. In Chester County, the majority of the farms were dairy operations, with cash crops and livestock the 2nd and 3rd most common agricultural use. Sixty-five percent of the farms had conservation plans. The upper East Branch and West Branch, Doe Run, Buck Run, and the lower West Branch have the highest concentration of farms in the watershed.

Table 2-2 – Summary of Brandywine Creek Watershed Characteristics

Land Area	325	sq.miles
1995 Land Use as % of Total Land Area		
Agriculture	37	%
Developed	26	%
Other	37	%
Total Stream Miles	567	miles
1st Order Stream Miles	315	miles
% 1st Order Stream Miles	55	%
Impaired Stream Miles	140	miles
% Impaired Stream Miles	20	%
1998 Estimated Population	220,700	persons
2020 Projected Population	281,000	persons
% Population Increase by 2020	27	%
1998 Estimated Withdrawals (permitted)	19,463	MGY
1998 Estimated Withdrawals (permitted)	53.3	MGD
1998 Population on Public Water	62	%
Predominant Geology	Crystalline	

Source: Chester County Water Resources Authority, 2002

The Brandywine Creek is the source of drinking water for approximately 205,500 people used by five different water suppliers throughout the watershed (Table 2-3). The communities served by these suppliers depend on the quantity and quality of the Brandywine for current and future economic stability and growth.

Table 2-3 – Major Water Supplies and Population Served by the Brandywine Creek

Water System	Population Served
Wilmington	140,000
PAWC Coatesville	18,000
Downingtown Authority	10,000
Aqua PA Ingrams Mill	29,000
Honey Brook Borough	2,500
Total	**199,500**

Figure 2-1 – Streams and Drainage of the Brandywine Creek Watershed

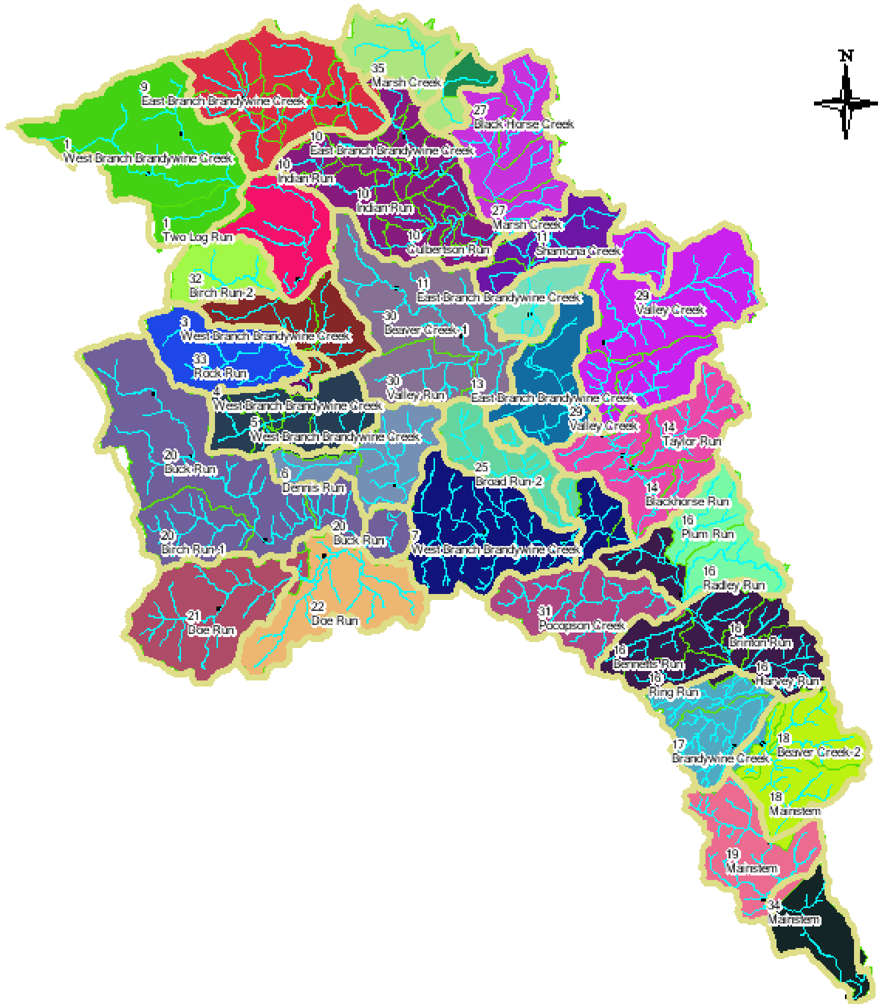


Table 2-3a – Streams and Drainage of the Brandywine Creek Watershed

		Related Subshed **				
EPA ID	EPA/USGS TMDL Subshed Description	CCWRAID	Christina ID	BVA SOW ID	CCWRA description (from compendium maps)	BVA SOW description (From State of Watershed Reports)
1	WBr Brandywine to gage nr Honey Brook	B12	B1	A1	Upper West Branch Brandywine Creek	Upper West Branch at Honey Brook
2	WBr Brandywine to Birch Run confluence	B12	B2	A1	Upper West Branch Brandywine Creek	Upper West Branch at Honey Brook
3	WBr Brandywine above Rock Run	B14	B2	A2/A3	West Branch Brandywine Creek/Rock Run/Sucker Run	Upper W. Branch at Coatesville/Hibernia
4	WBr Brandywine to gage at Coatesville	B14	B3	A2/A3	West Branch Brandywine Creek/Rock Run/Sucker Run	Upper W. Branch at Coatesville/Hibernia
5	WBr Brandywine to gage at Modena	B14	B3	A2/A3	West Branch Brandywine Creek/Rock Run/Sucker Run	Upper W. Branch at Coatesville/Hibernia
6	WBr Brandywine to Buck Run confluence	B14	B4	A2/A3	West Branch Brandywine Creek/Rock Run/Sucker Run	Upper W. Branch at Coatesville/Hibernia
7	WBr Brandywine to Broad Run confluence	B13	B4	A7/A4	West Branch Brandywine Creek/Broad Run	Broad Creek / Lower W. Branch at Embreeville
8	WBr Brandywine to Wawaset	B13	B4	A7/A4	West Branch Brandywine Creek/Broad Run	Broad Creek / Lower W. Branch at Embreeville
9	Upper EBr Brandywine Creek	B11	B8	B8	Upper East Branch Brandywine Creek	Upper East Branch at Struble Lake
10	EBr Brandywine to Marsh Creek	B7	B8	B8/B9	East Branch Brandywine Creek/Shamona Creek	Upper E. Branch at Shamona Creek
11	EBr Brandywine to gage nr Downingtown	B7	B9	B8/B9	East Branch Brandywine Creek/Shamona Creek	Upper E. Branch at Shamona Creek
12	EBr Brandywine to Beaver Creek	B9	B12	B12	East Branch Brandywine Creek/Beaver Creek	Beaver Creek
13	EBr Brandywine to gage below Dowingtown	B9	B10	B12	East Branch Brandywine Creek/Beaver Creek	Beaver Creek

		Related Subshed **				
EPA ID	**EPA/USGS TMDL Subshed Description**	**CCWRAID**	**Christina ID**	**BVA SOW ID**	**CCWRA description (from compendium maps)**	**BVA SOW description (From State of Watershed Reports)**
14	EBr Brandywine to Wawaset	B8	B10	B10	East Branch Brandywine Creek/Taylor Run	Lower East Branch
15	Main stem Brandywine to Pocopson confluence	B4	B14	C14/C15	Brandywine Creek/Pocopson Creek	Pocopson Creek / Main stem Above Chadds Ford
16	Main stem Brandywine to Chadds Ford gage	B1	B14	C14	Brandywine Creek above Chadds Ford	Main stem above Chadds Ford
17	Main stem Brandywine to Smiths Bridge	B3	B16	C16	Brandywine Creek below Chadds Ford	Main stem below Chadds Ford
18	Main stem Brandywine to Rockland Rd. Bridge	B3	B16	C16	Brandywine Creek below Chadds Ford	Main stem below Chadds Ford
19	Main stem Brandywine to gage at Wilmington	B3	B16	C16	Brandywine Creek below Chadds Ford	Main stem below Chadds Ford
20	Buck Run to Doe Run confluence	B5	B5	A5	Buck Run	Buck Run
21	Doe Run to gage near Springdell	B6	B6	A6	Doe Run	Doe Run
22	Doe Run to Buck Run confluence	B6	B6	A6	Doe Run	Doe Run
23	Buck Run tributary	B5	B5	A5	Buck Run	Buck Run
24	Little Broad Run to gage nr Marshallton	B13	B7	A7/A4	West Branch Brandywine Creek/Broad Run	Broad Creek / Lower W. Branch at Embreeville
25	Broad Run tributary	B13	B7	A7/A4	West Branch Brandywine Creek/Broad Run	Broad Creek / Lower W. Branch at Embreeville
26	Marsh Creek to gage nr Glenmoore	B10	B11	B11	Marsh Creek	Marsh Creek
27	Lower Marsh Creek	B10	B11	B11	Marsh Creek	Marsh Creek
28	Unnamed trib. to Valley Creek	B15	B13	B13	West Valley Creek	Valley Creek / W. Valley Creek
29	West Valley Creek tributary	B15	B13	B13	West Valley Creek	Valley Creek / W. Valley Creek
30	Beaver Creek tributary	B9	B12	B12	East Branch Brandywine Creek/Beaver Creek	Beaver Creek

		Related Subshed **				
EPA ID	**EPA/USGS TMDL Subshed Description**	**CCWRAID**	**Christina ID**	**BVA SOW ID**	**CCWRA description (from compendium maps)**	**BVA SOW description (From State of Watershed Reports)**
31	Pocopson Creek tributary	B4	B15	C14/C15	Brandywine Creek/Pocopson Creek	Pocopson Creek / Main stem Above Chadds Ford
32	Birch Run tributary (Chambers Lake)	B12	B1	A1	Upper West Branch Brandywine Creek	Upper West Branch at Honey Brook
33	Rock Run tributary	B14	B2	A2/A3	West Branch Brandywine Creek/Rock Run/Sucker Run	Upper W. Branch at Coatesville/Hibernia
34	Main stem Brandywine to Christina confluence	B2	B17	C17	Brandywine Creek at Wilmington	Main stem through Wilmington
35	Upper Marsh Creek	B10	B8	B11	Marsh Creek	Marsh Creek

** Note that the subsheds from EPA/USGS are smaller subshed areas than that used by CCWRA, University of Delaware, or BVA, thus the related subsheds are larger areas and not necessarily the same hydrologic boundaries and could incorporate multiple EPA subsheds. An EPA subshed may fall within two different CCWRA, BVA, or Christina subsheds depending on how they were created. A direct comparison or translation of information from non-EPA/USGS subsheds is not possible and any information from different subsheds must be evaluated within that system only.

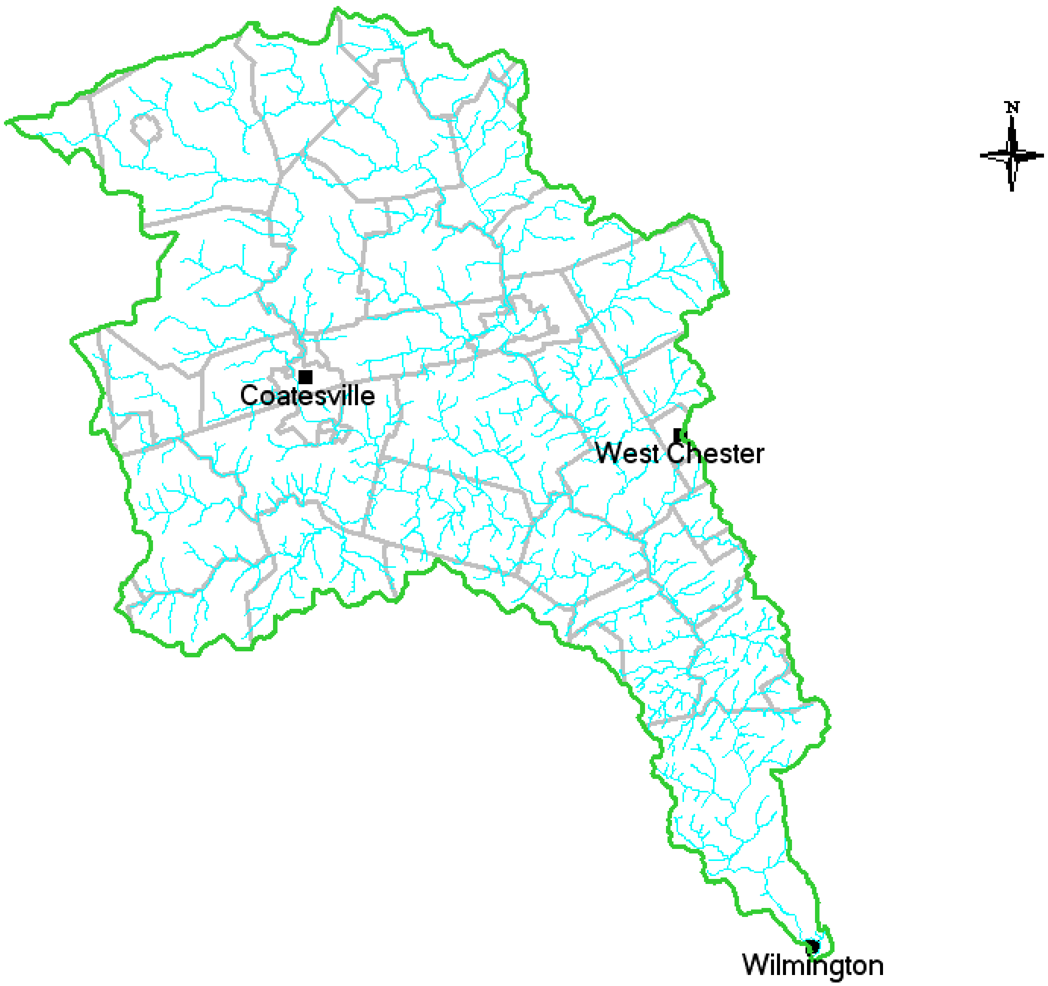


Figure 2-2 – Municipalities of the Brandywine Creek Watershed

2.1.2. Physiography and Geology

The geology of the Brandywine watershed is rooted in the central Appalachian Piedmont physiographic province of southeastern Pennsylvania and northern Delaware. The Piedmont, in its most basic definition, means foothills. These are the foothills to the Appalachian Mountains, a mountain range that originated in North America between 545 and 250 million years ago (M.A.). The Brandywine watershed lies primarily in the Piedmont Upland section of the province; however a thin band of piedmont lowland section, stretching from Parkesburg to West Whiteland Township nearly bisects it (Fig. 2-3).

Current studies indicate that the geology of the central Appalachian Piedmont preserves a record of plate tectonic convergence that includes subduction-related arc magmatism, arc-continent accretion, post-accretion magmatism and coincident low- to moderate-pressure high-temperature metamorphism, and regional metamorphism at moderate to deep levels resulting from crustal thickening during subsequent plate convergence (Bosbyshell, 2001). This means that there have been episodes where oceanic crust containing volcanic islands slid into what is now the present day North American continent (Plank et al, 1998). Over time the sediments from the island arc joined with those sediments from the colliding continent. During this process and later stages of continental collision magma was generated and moved upward through fissures creating some of the igneous bodies in the region. Later periods of continent-continent collision created additional folding and faulting of the many sedimentary layers in the region and contributed to the uplift of the Appalachian Mountains (Figure 2-4). These episodes of folding and faulting and the compression forces due to continental collisions have led to the many metamorphic rock types (quartzite, gneiss, marble, etc) observed in the region.

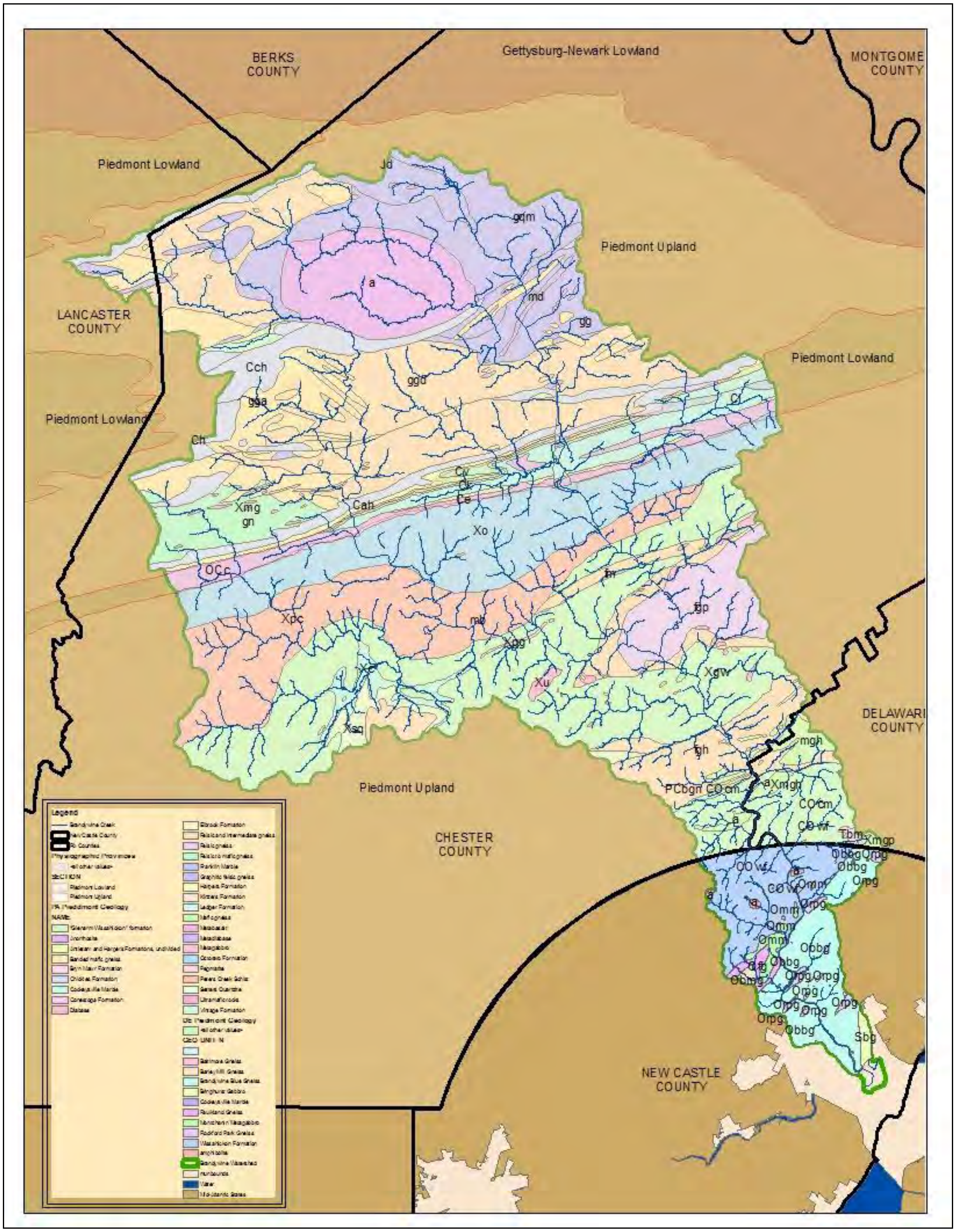


Figure 2-3: Physiography and Geology of the Brandywine Creek Watershed, Pennsylvania and Delaware

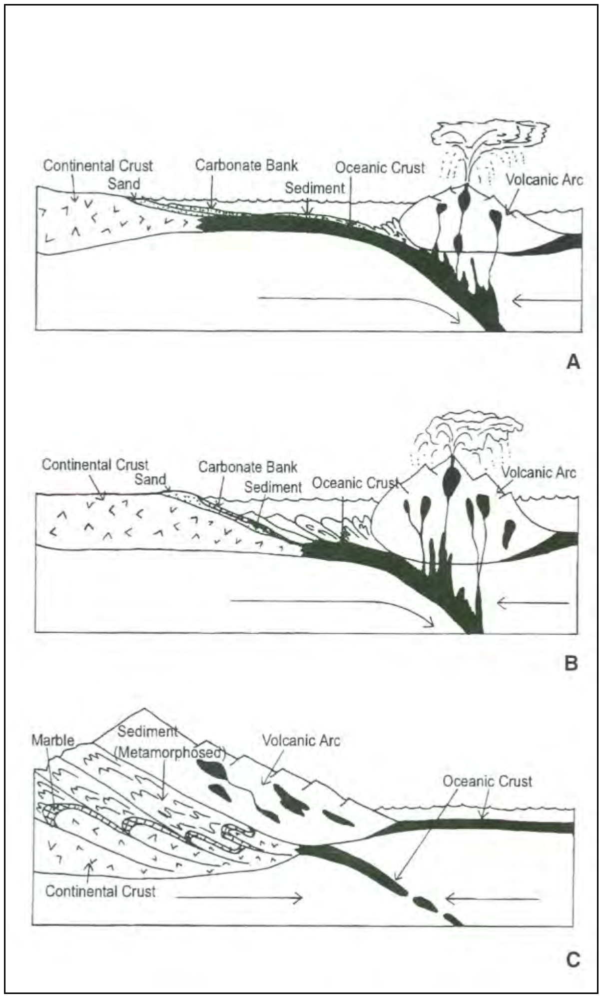
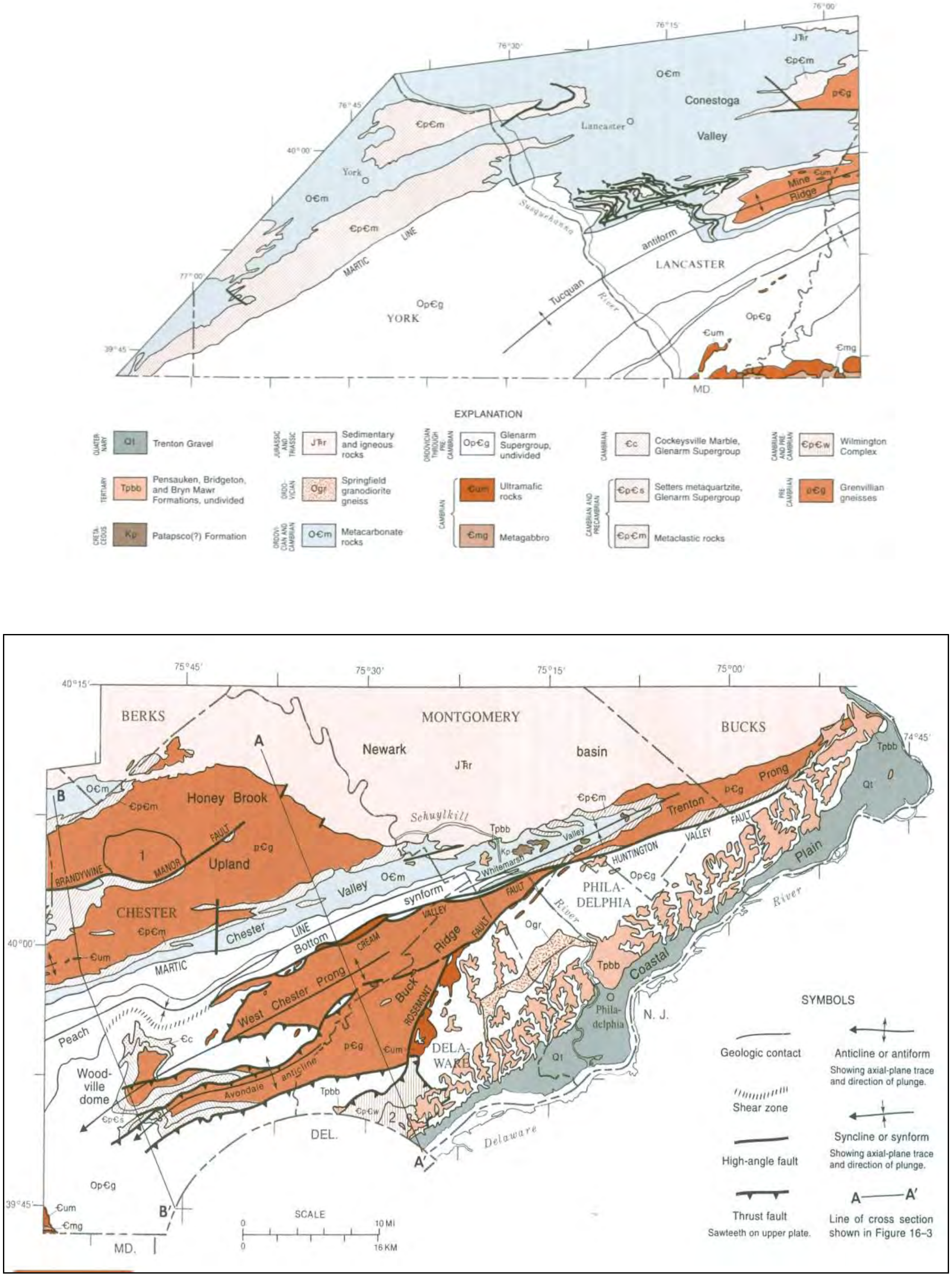


Figure 2-4: Cross section showing sequence of events related to the emplacement of rock types found in the mid-Atlantic Piedmont Province. (A) 543 million years ago, active volcano is offshore; (B) 500 million years ago, volcano and pile of sediments scraped off the subducting slab are larger than in (A); and (C) 440 million years ago, collision between the volcanic islands and the ancient continent has formed a tall mountain range. From Plank, M.O. and Schenck, W.S., 1998.

The headwaters of both the East and West Branches of the Brandywine Creek occur in the Piedmont Upland Province near Honey Brook in northwestern Chester County. As the branches flow east and south they flow across the crystalline rocks of the Honey Brook Massif, a large body of mostly metamorphosed granites and amphiboles overlain by a basalt-rhyolite sequence of volcanic rocks (Sloto, 1994). Adjacent to the Honey Brook Massif to the south is the Mine Ridge Massif. This is a body of amphibolites, felsic/mafic gneisses, metadiabases, and ultramafites closely mixed with each other throughout the formation.



Figures 2-5a&b: Geologic features of the Piedmont Upland province.. From Crawford et al, 1999.

As the waters continue to flow south and east they enter the Chester Valley and, in doing so, the Piedmont Lowland Province (Figures 2-5a&b). This is a narrow terrain that cuts across the center of the watershed from southwest to northeast in a band that trends through Parkesburg, Coatesville and Downingtown. This area is underlain by Cambrian and Ordovician (542-444 M.A.) limestones and dolomites as well as a bottom layer of quartzite that also appear north of the Chester Valley and west of the Honey Brook Massif (Sloto, 1994). These rocks were deposited in a marine environment associated with continental margin sedimentation during a time when this region was the eastern boundary of the North American continent. The quartzites of this region are very durable and form the distinct hills that are encountered. The limestones and dolomites are more susceptible to erosion from weather and flowing surface/ground waters. The Elbrook Limestone, for example, forms the low hills in the Chester Valley section of the Piedmont Lowlands (Sloto, 1994).

Flowing out of the Chester Valley, the waters once again enter the Piedmont Upland province on their way to their confluence southwest of West Chester. This section contains the Baltimore Gneiss and the Glenarm Group, a series of geologic units comprised of the Setters Quartzite, Cockeysville Marble, and the Glenarm Wissahickon formations. The Baltimore Gneiss is most likely the oldest rock in the mid-Atlantic Piedmont. These billion year old rocks support the hills of southeastern Chester County and northern New Castle County. They form the core of the Woodville Nappe, the Mill Creek Nappe, and the Avondale anticline. These are just a few of the dome-like structures that crop out in a belt stretching between Baltimore, Maryland and Philadelphia, Pennsylvania (Plank and Schenck, 1998).

After the east and west branches combine they flow south across the rocks of the Glenarm Group, across the Avondale Anticline section of the Baltimore Gneiss, and into the Mt. Cuba Wissahickon Formation. Sediments that became the Glenarm Group (Setters Quartzite, Cockeysville Marble, Glenarm Wissahickon Formations), and the Mt. Cuba Wissahickon Formation were deposited in marine rift basins floored by continental crust which is represented by the Baltimore Gneiss (Blackmer, 2005). The Mt. Cuba Wissahickon Formation forms the dominant rock type in the far southeastern Pennsylvania and Delaware Piedmont and may be as much as 8,000 feet thick due to numerous episodes of folding and faulting according to Thompson (1976). This formation is less resistant to chemical and physical weathering than the adjacent Wilmington Complex to the south and east. Thus, deeply incised stream valleys and steep slopes characterize this portion of the watershed. Amphibolites and gneisses of the Wissahickon support ridges while mica schists erode to form deep-sided valleys (Plank and Schenck, 1998).

The creek then crosses the formations of the Wilmington Complex prior to being withdrawn by the City of Wilmington. These Formations are comprised of mostly hard mafic and felsic gneisses and amphibolites that are primarily visible at the surface in the form of rounded boulders. The rocks of the Wilmington Complex form the gentle rolling hills of north Wilmington and its suburbs (Plank and Schenck, 1998).

2.1.3. Soils

The Brandywine Watershed has different soils types that have varying ranges of permeability and drainage which affect groundwater recharge, erodability, and stormwater runoff. The permeability of soils are dependent on the type (sand, silt or clay) and hydrologic soil group A,B,C,D. Soils are used to delineate floodplains, identify fragile erosion prone slopes and define septic system limitations. Generally silts and clays are less permeable, generate greater stormwater runoff, and sustain greater sediment loads. In contrast, sands and gravels provide greater groundwater recharge and less runoff and sediment loads (Bowers, 1998).

As shown in Figure 2-6, the majority of the soil associations in watershed of the Glenelg–Manor–Chester groups. The middle band of soils in the watershed is limestone. Small localized areas along the edges of the upper West Branch and the lower East Branch in PA are Neshaminy-Glenelg. There are some minor amounts of Edgemont in the upper watershed. There is one small patch of Neshaminy-Chrome-Conowingo near West Chester on the edge of the watershed boundary. There is Neshaminy-Talleyville-Urban land association and Elsinboro-Delanco-Urban land in the Delaware part of the watershed about halfway between Chadds Ford and the Wilmington intake. The characteristics of these soils are provided in Table 2-4.

Most of the development in the middle band of the watershed (Coatesville, Downingtown, and the Route 30 corridor) also coincides with the Hagerstown Conestoga Guthrie soils with low permeability. Thus development of this corridor in a limestone area with low permeability makes the traditional infiltration techniques for stormwater management difficult or not applicable. This clearly shows the conflict between the focused past and future growth of the watershed and its natural characteristics.

The Soil Conservation Service also classified soils into hydrologic groups to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The groups, which are A, B, C, and D, are also used in determining runoff curve numbers. The soil types in the Brandywine Creek watershed are classified as B, C, and D soils, but the majority of the soils are type B soils.

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

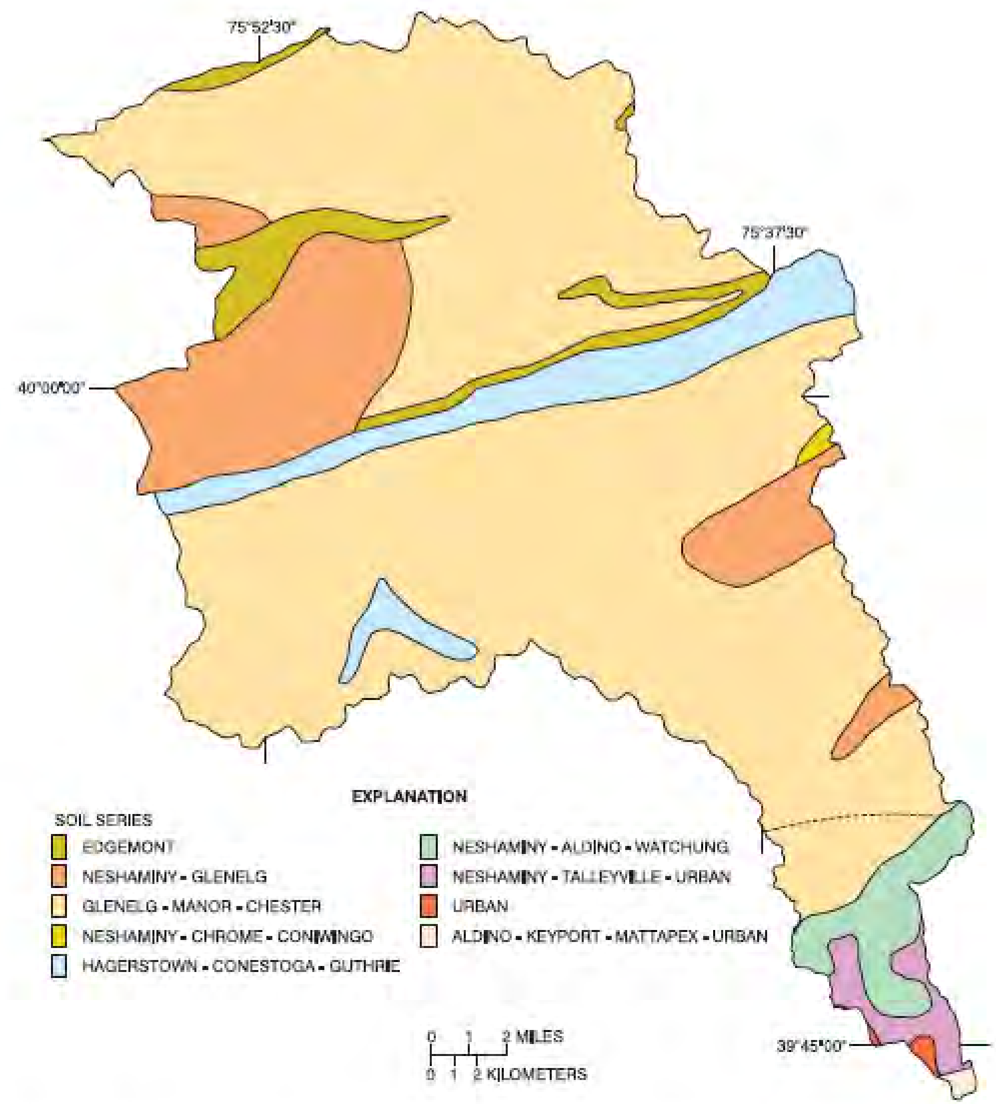


Figure 2-6 – Brandywine Creek Watershed Soils (source: Keorkle and Senior, 2002)

Table 2-4 – Soils of the Brandywine Creek Watershed

MAP ID	Desig-nation	Soil Association	Description	Depth to Bed-rock	Depth to Groundwater Table (ft)	SCS Hydrologic Soil Group (A, B, C, or D)	Permeability (in/hr)	Soil Type (sand, loam, clay)
1	GMC	Glenelg - Manor - Chester	Nearly level to steep, well-drained, medium-textured soils formed over micaceous crystalline rocks; on uplands	2-7	5+	B	0.63 - 2.0	loam, silt loam
2	E	Edgemont	Moderately deep, channery soils on grayish quartzite and phyllite	2-6	5+	B	0.63 - 2.0	channery loam
3	HCG	Hagerstown - Conestoga - Guthrie	Deep, silty soils on limestone	3-6	B/C/D	C,B,D	< 0.2	silt loam
4	NG	Neshaminy - Glenelg	Moderately deep and deep, well drained, silty, channery, and gravelly soils on gabbro and granodiorite	3-6	5+	B	0.63 - 2.0	gravelly silt loam
5	NCC	Neshaminy - Chrome - Conowingo	Moderately deep and deep, silty soils on serpentine	1-6	2-5	B/C	0.63 - 2.0	gravelly silt loam gravelly silty clay loam
6	NAW	Neshaminy - Aldino - Watchung	Level to steep, well drained, moderately well drained, and poorly drained, medium-textured soils formed over dark colored gabboric rocks on uplands	4-10	0-4	B/C/D	< 0.2	silt loam
7	NTU	Neshaminy - Talleyville - Urban	Level to moderately sloping, well-drained, medium-texture soils, relatively undisturbed to severely disturbed; fored over dark colored gabbroic rocks; on uplands	6-10	4-6	B	0.63 - 2.0	silt loam
8	EDU	Elsinboro - Delance - Urban	Level to gently sloping, well drained and moderately well drained, medium-textured soils, relatively undisturbed to severely disturbed; formed on old alluvium on stream terraces	6 -20	2-5	B/C	0.63 - 2.0	silt loam

Source: Appendix D, Phase III Report, - Bowers, 1999

2.1.4. Hydrology

The Brandywine Creek Watershed currently has a humid continental climate. Average yearly precipitation is about 43 in. with summer and winter mean temperatures of about 24 and 0 °C, respectively. Prevailing winds are westerly during the winter and southerly during the summer. Weather systems that affect the area generally originate in the central United States and move eastward over the Appalachians. Periodically, moist northward moving weather systems bring moderate and heavy precipitation to the area. It is important to note however that based on low and high emission models for climate change the climate is expected to change to be more similar to either Southern Virginia or Georgia by 2100 (Union of Concerned Scientists, 2008). Therefore, current climatological, meteorological, and hydrological analyses of past and current data may not be the appropriate predictors of future systems by 2100.

The water budget for the Brandywine Creek Watershed is dependent upon the geology, rainfall patterns during the period of record, topographic features such as slope, soils, and degree of development and impervious cover. The USGS prepared the water budgets for Brandywine Creek watershed in the Chester County Compendium (Chester County Water Resources Authority, 2001). Because average water budgets are calculated by averaging each component over the period of record, the results are often not additive to the total average annual precipitation. The average water budget components calculated by USGS for Brandywine Creek watershed by USGS shows that approximately 16% of the annual precipitation is lost to runoff in the watershed (Table 2-5).

Table 2-5 – Water Budget for the Brandywine Creek Watershed

Water Budget Element	inches/yr
Runoff	7.2
Evapotranspiration	25.9
Baseflow	12.8
Recharge	14.8
Precipitation	45.9

Source: Chester County Water Resources Authority, 2001

Though the water budget provides an overall idea of the hydrologic cycle, the daily observation of this is through flow in the Brandywine Creek. Analysis of the flow in the watershed provides a more specific description of its behavior during runoff and baseflow periods. Long-term historical data were examined in order to gauge the natural variation in climate and geology. Data was collected from the USGS gauge station network and Delaware rain gauge network. In the Brandywine Creek above Wilmington watershed in Delaware and Pennsylvania, the record low daily mean streamflow during drought dropped 35 percent, from 102 million liters per day in 1966 to 76 million liters per day in 2002 (Kauffman, 2006).

Figure 2-7 shows the average annual flow from 1972 to 2006 at Chadds Ford and Wilmington. The Wilmington gauge has an additional 27 square miles of drainage as compared to Chadds Ford and should have a greater annual flow. However, during extremely wet years (1996 and 2003) and the drought of record (2002) the Chadds Ford gauge registered a greater average annual flow than the Wilmington gauge station demonstrating the dominance of the flow contribution in the Pennsylvania part of the watershed (See Figure 2-8).

Precipitation can vary from 33.9 to 66.9 inches per year with an average of 46.5 inches per year based on rain gauge data from the Porter Reservoir from 1946 to 2006 (Figure 2-9). Monthly rainfall can range from 4.8 to 14.9 inches per month with an average of 7.9 inches per month (Table 2-6). Monthly maximum rainfall in Figure 2-9 shows that between 6 and 14 inches of rain can fall monthly. Annual rainfall can deviate by -13 to +22 inches per year from the annual average (Figure 2-11). As shown, there appears to be an increase in the extremes in annual precipitation and a potential upward trend in annual precipitation since 1970. Further analysis would need to be conducted to determine if this trend is real. As shown in Figure 2-11 there is a wide variation in annual flow from year to year (a factor of 2.5) depending upon the precipitation patterns. The comparison of annual flow to deviation in annual precipitation seems to provide a better indication of the severity of annual flow changes than total annual precipitation (Figure 2-12). Looking at the annual deviations in flow and precipitation combined suggests that an extremely dry year can lead to lower than normal flows the following year. However, the data also suggests that wetter than normal years do not lead to higher than normal flows in any following years. This suggests that wetter years do not seem to provide insurance against lower flows in subsequent years especially if there is a significant lack of rainfall.

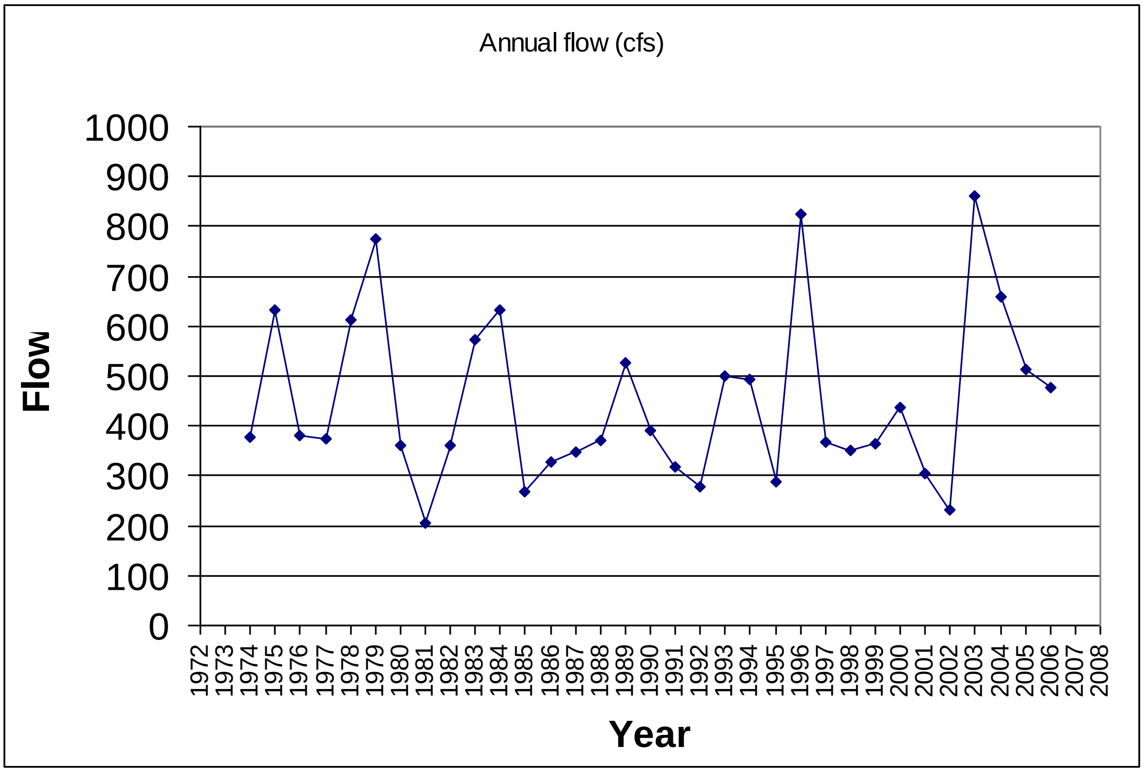


Figure 2-7 – Average Annual Flow at Chadds Ford 1974 to 2007

Table 2-6 – Summary of Rainfall for the Brandywine Creek Watershed at Porter WTP (1948 – 2004)

Parameter	Annual rainfall (in)	Monthly rainfall (in)
avg	46.2	7.9
max	68.9	14.9
min	33.6	4.8
stdev	8.4	2.2
90%tile	57.4	10.7
#	55	56

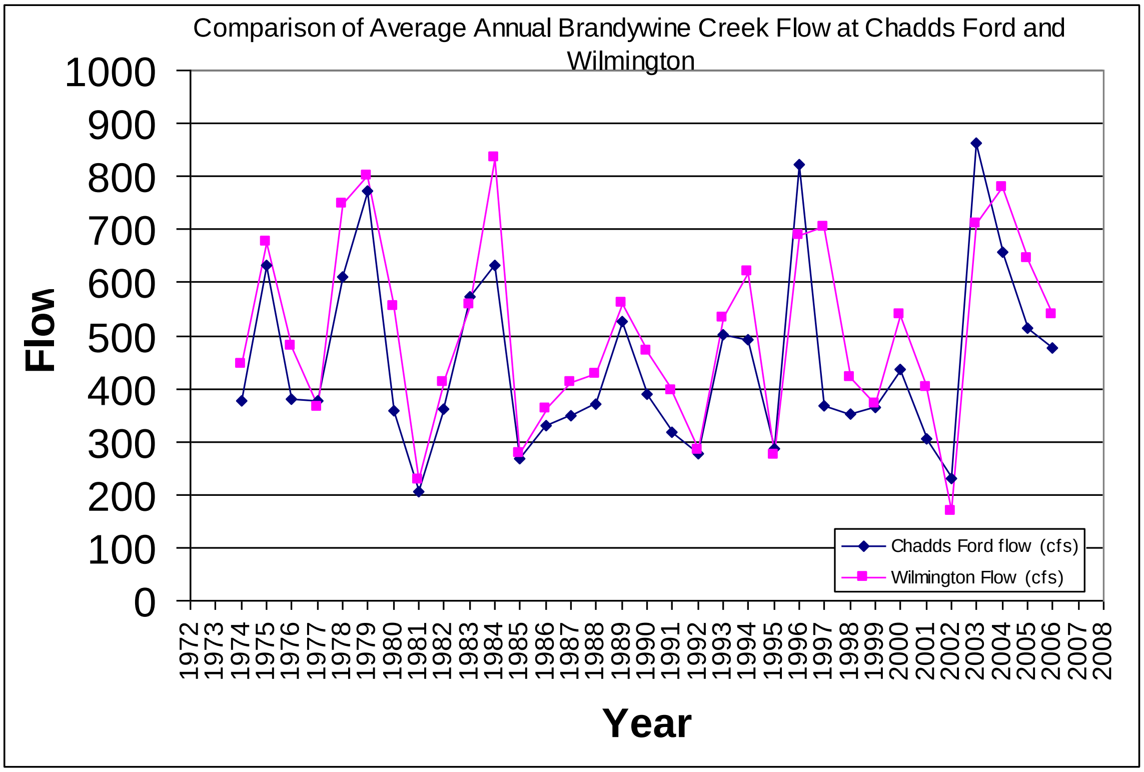


Figure 2-8 – Comparison of Avg. Annual Brandywine Creek Flow between Wilmington and Chadd Ford

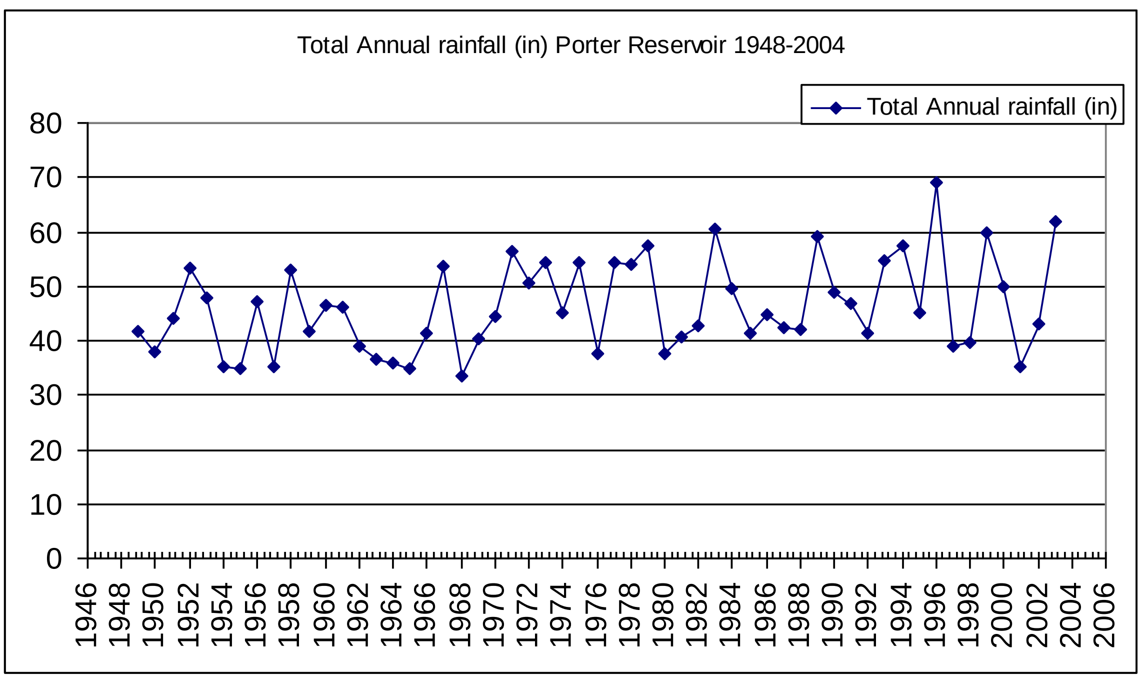


Figure 2-9 – Average Annual Rainfall at Porter WTP 1948 to 2004

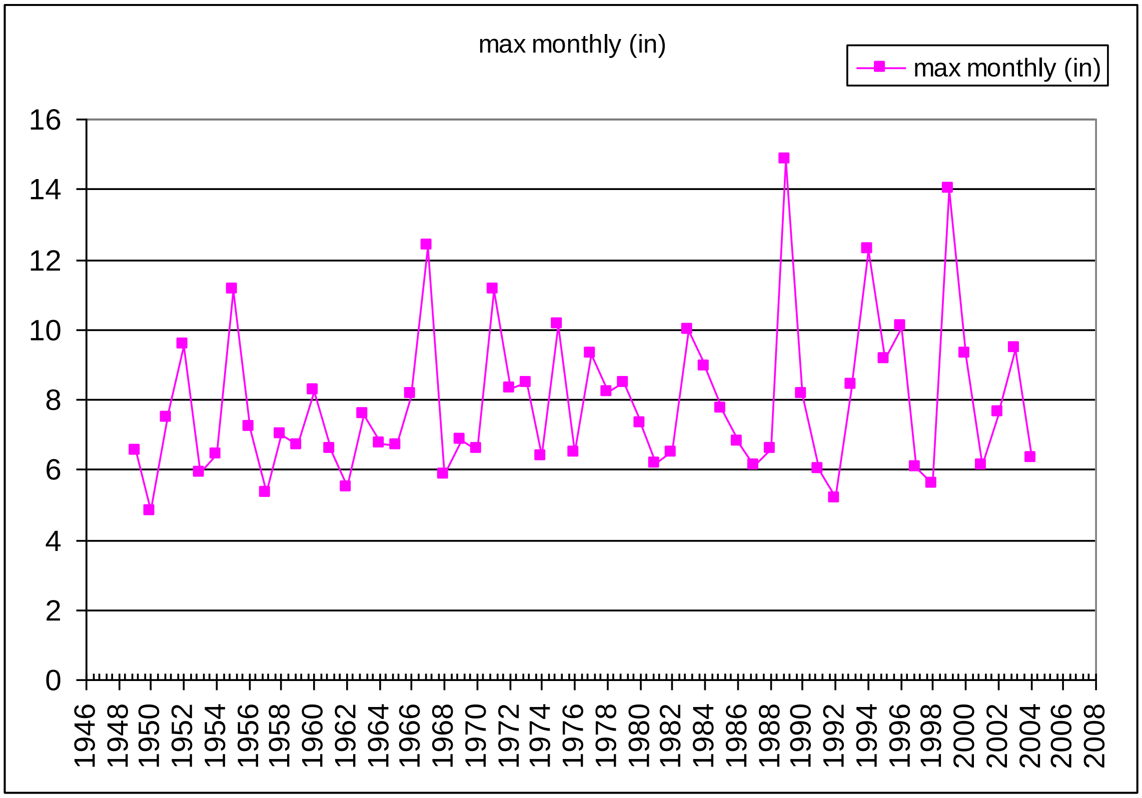


Figure 2-10 – Maximum Monthly Rainfall at Porter 1948 - 2004

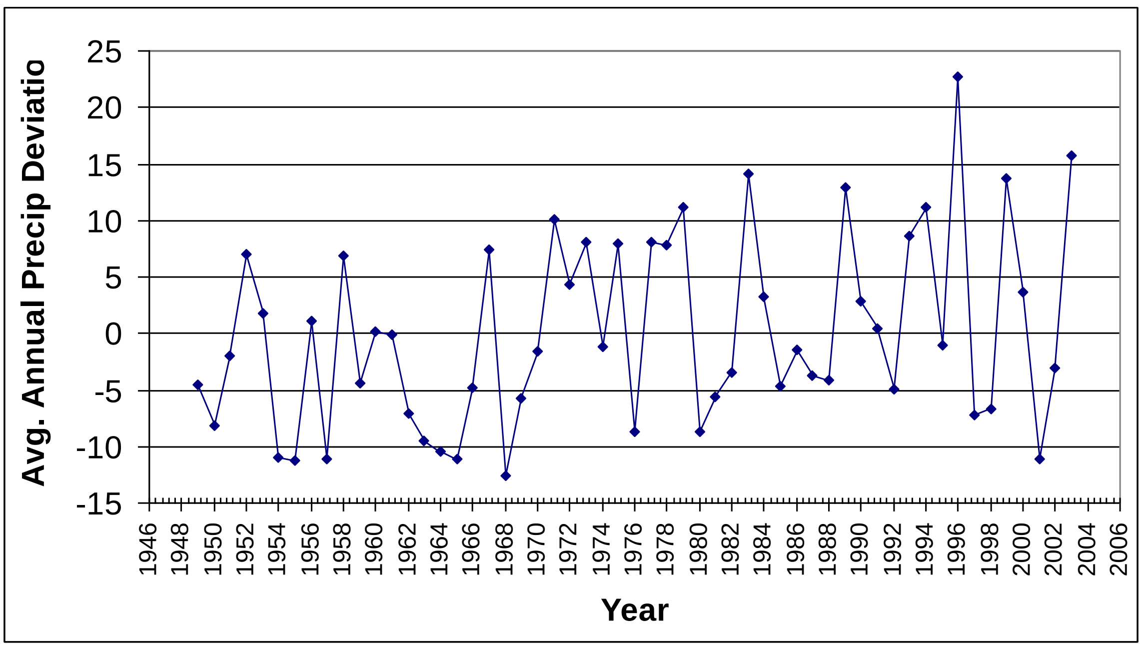


Figure 2-11 – Average Annual Rainfall Differences from Long Term Average Annual Rainfall 1948 to 2004

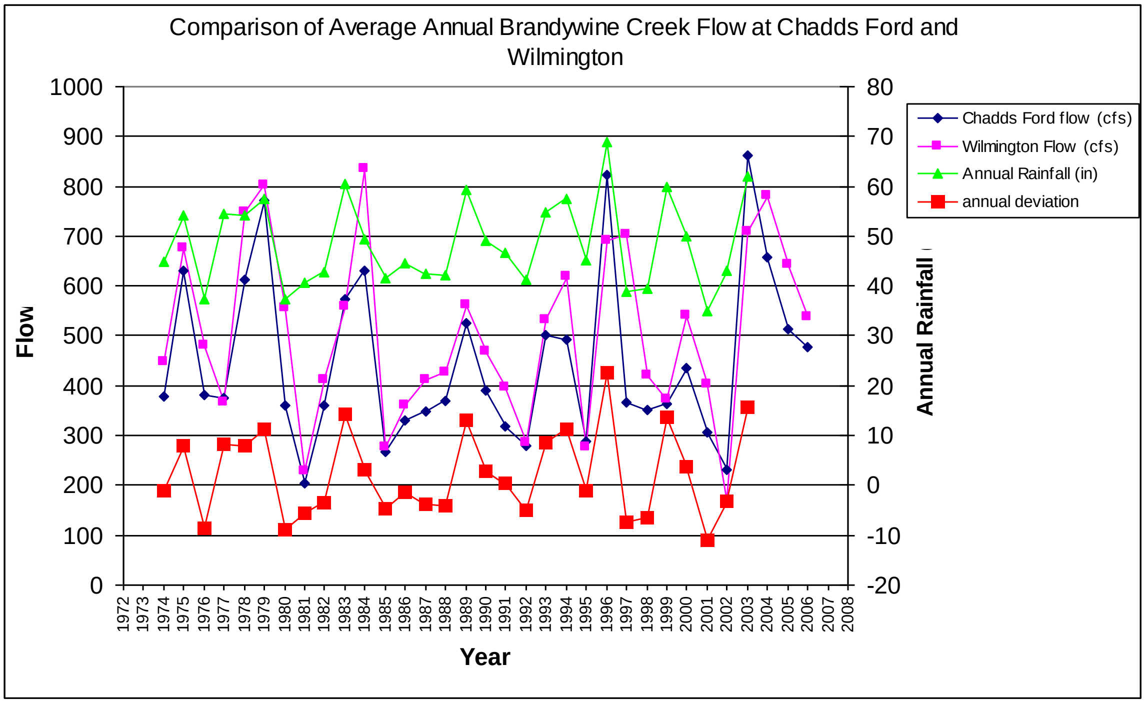


Figure 2-12 – Comparison of Average Annual Brandywine Creek Flow and Average Annual Rainfall Deficit/Surplus

Extreme flow conditions can represent periods of greatest concern for water suppliers where water quality can be extremely affected. For example, since 1911 there have been 11 events where the flow exceeded 8,000 cfs at Chadds Ford (Table 2-7). Those events most likely lead to intake closures or water quality that was challenging to treat at the water facility.

Table 2-7 – Detailed Summary of Extreme High Flow Events > 8,000 cfs

Years with flow > 8,000 cfs	Hurricane Name	Years with flow > 8,000 cfs	Hurricane Name	Years with flow > 8,000 cfs	Flow (cfs)	Hurricane Name
1920	NA	1972	Agnes	1999		Floyd
1933	NA	1978	10K	2000	>10,000	
		1979		2003	>10,000	
				2004	>10,000	Ivan/Jeanne
				2006		
Notes:		1971-1979 wet period		1993-2006 wet period		

As shown by the previous figures, the cycles of lowest daily flows and highest flows appear to follow a 30 to 35 year cycle as seen in other regional climate analysis (Interlandi and Crockett, 2000). The lowest flows occurred during the 1930s and 1940s, 1960s, and late 1990's into early 2000 (See Table 2-8 and Figure 2-13). 1971 to 1979 appears to be one of the periods with the greatest average daily flows. From 1959 to 1966 was the greatest period of consecutive years when the annual precipitation was below the average annual precipitation for Wilmington. This also coincided with one of the worst basinwide drought periods of record (> 200 year drought). Approximately 33 (60%) of the past 55 years between 1949 and 2003 were dryer than average and 22 (40% of the past 55 years were wetter than average. In the case of most of the wetter years of record, they can be associated with single significant named storm events. In 1999, Hurricane Floyd deposited record rainfall amounts in the region. In 1996, significant snowstorms dropped over 3 feet of snow in places in the Delaware Valley leading to snowmelt and baseflow elevation issues. In 1972 Hurricane Agnes came up the Susquehanna River Basin resulting in the flood of record which had residual effects on the adjacent Delaware River Basin.

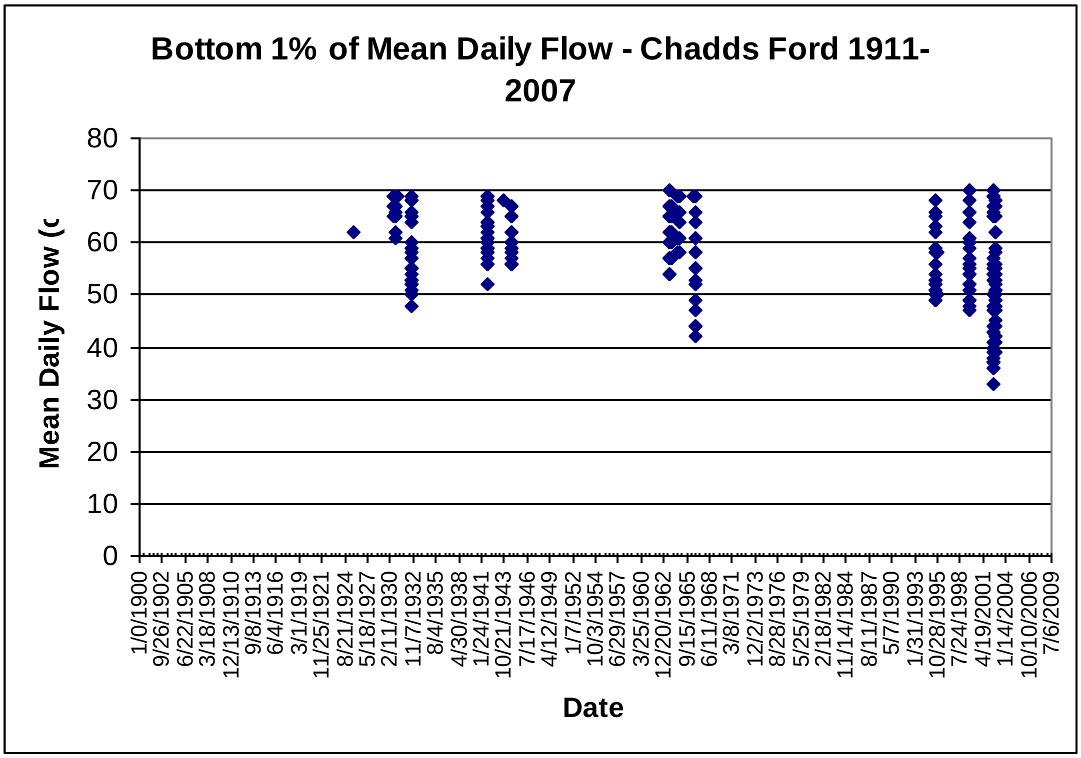


Figure 2-13 – Lowest Mean Daily Flows at Chadds Ford 1911 - 2007

Table 2-8 – Detailed Summary of Extreme Low Flow Events (< 70 cfs)

years with Flow < 70 cfs	years with Flow < 70 cfs	years with Flow < 70 cfs
1921	1963	1995
1930	1964	1999
1932	1966	2002
1941		
1944		

The flow response at various locations in the watershed is significant to examine potential runoff pollutant loadings. A detailed analysis of the average daily flow at a location can provide information on the frequency that a given average daily flow can occur. For example, as shown in Figure 2-14, the average daily flow at Chadds Ford from 1911 to 2007 is estimated to be 290 cfs, but ranges from 33 to 10,100 cfs. Eighty percent of the average daily flows occur between 121 and 765 cfs. Only 10% of the flows occur above and below those limits respectively.

A summary of the flow related statistics at various locations in the watershed is provided in Table 2-9. The data shows some level of relationship with drainage area which has been defined in USGS studies, but does not show any apparent differences in flow due to impervious cover between various parts of the watershed produce apparently different annual flow statistics on a per area basis. However, the impact of different cover types may be more evident when examined on a daily basis.

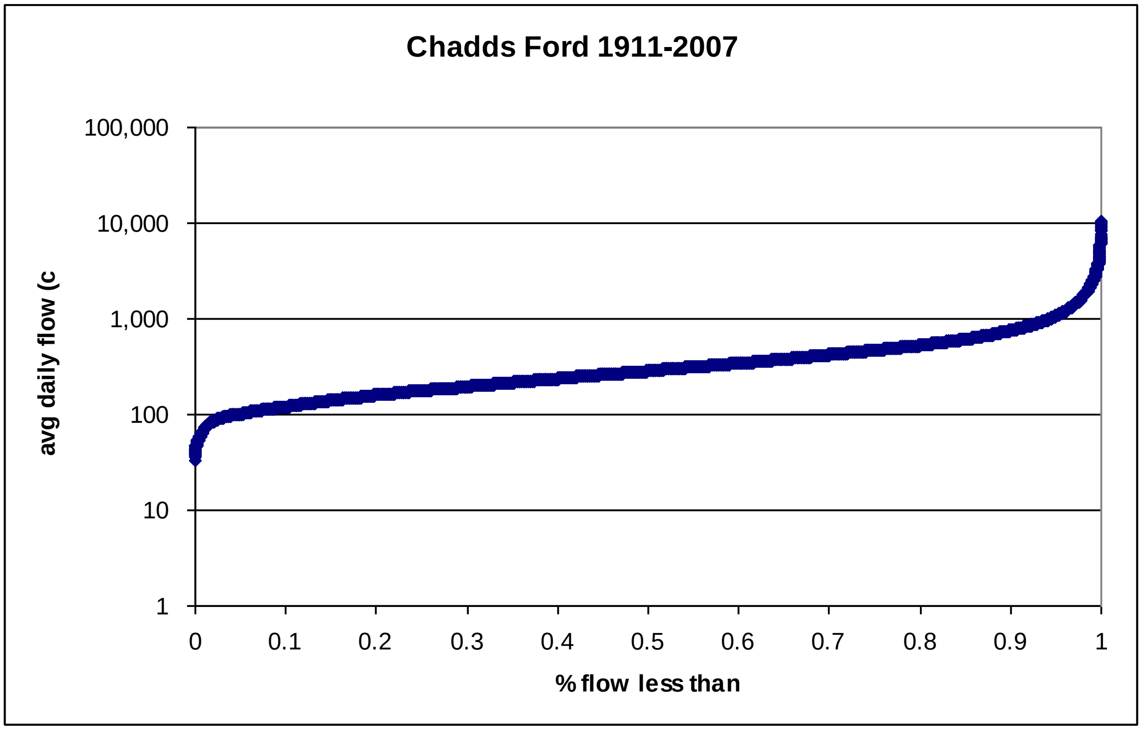


Figure 2-14 – Cumulative Frequency of Flows at Chadds Ford

Table 2-9 - Summary of Daily Flow Statistics at Various Locations in the Brandywine Creek Watershed

USGS Station #	Location/Description	Drainage Area (mi^2)	10%	50% (mean)	90%	min	max
1480300	West Branch Brandywine Creek near Honey Brook, PA	18.7	6.8	15	44	1	1620
1480400	Birch Run near Wagontown, PA	4.55	1.5	3.9	13	0.1	250
1480500	West Branch Brandywine Creek at Coatesville, PA	45.8	15	42	114	3	3400
1480617	West Branch Brandywine Creek at Modena, PA	55	26	57	150	7.4	4010
1480638	Broad Run at Northbrook, PA	6.39	3.7	9.6	23	1.7	277
1480675	Marsh Creek near Glenmoore, PA	8.57	2.1	7.8	26	0.21	444
1480685	Marsh Creek near Downingtown, PA	20.3	7	16	66	0.18	462
1480700	East Branch Brandywine Creek near Downingtown, PA	60.6	25	60	177	7.2	3220
1480870	East Branch Brandywine Creek below Downingtown, PA	89.9	42	101	306	19	3040
1481000	Brandywine Creek at Chadds Ford, PA	287	122	284	758	33	10600
1481500	Brandywine Creek at Wilmington, DE	314	134	340	890	35	14300

2.1.5. Reservoirs & Impoundments In The Watershed

Approximately nine major reservoirs are located within the watershed (Table 2-10). Some are owned and operated by individual water utilities and others are owned and operated by regional organizations such as the Chester County Water Resources Agency for both water supply and recreation. These reservoirs are used in two different ways. The reservoirs of Marsh Creek and Chambers Lake are multiple purpose reservoirs providing flood control, recreation, and water supply releases during extreme low flow periods. The Rock Run Reservoir and other utility owned reservoirs are designed for continuous direct withdrawal to meet daily demand from nearby water treatment facilities.

Releases from these reservoirs have been observed to have impacts on downstream water quality such as turbidity. Therefore, it is important to document the owners, operators, and operating principles behind these reservoirs.

Chambers Lake Reservoir / Hibernia Dam - Built by and is owned and operated by the Chester County Water Resources Authority (CCWRA) in partnership with the City of Coatesville Authority, the NRCS and other state and local sponsors. Its role in water supply was intended to solely serve as a supplemental source of replacement water to support water supply withdrawals when taken by CCA from the West Branch Brandywine Creek. The Chambers Lake Reservoir is used in “tandem” with the CCA owned Rock Run Reservoir during periods of extended dry weather and low stream flow. CCA withdraws water from both Rock Run and West Branch Brandywine Creek at pre-determined balances. A complicated series of “triggers” have been established to guide which source is to provide the majority of withdrawal. At certain points, the shift is switched between the Rock Run and West Branch Brandywine sources to insure that neither supporting reservoir is completely depleted and that both reservoirs are drawn down in a generally synchronized manner. Chambers Lake Reservoir was completed in 1994 and filled in 1995. It has been used to support CCA withdrawals during the droughts of 1997, 1998 and 1999. Chambers Lake is a 400 million gallon water supply reservoir that is used to provide water for the Coatesville regional water supply system during droughts. Hibernia Dam is of earthen construction. Its height is 64.5 feet with a length of 700 feet. Its capacity is 2016 acre feet. Normal storage is 1225 acre feet. It drains an area of 4.5 square miles. It has a normal surface area of 84.9 acres.

Struble Lake – Located on East Branch Brandywine Creek in Chester County, Pennsylvania, Struble Lake is used for flood control and recreation purposes. Construction was completed in 1971. It has a normal surface area of 146 acres. It is owned by Chester County Water Resources Authority. The dam is of earthen construction. Its height is 31 feet with a length of 1500 feet. Its capacity is 2880 acre feet. Normal storage is 1025 acre feet. It drains an area of 2.8 square miles.

Table 2-10 – Summary of Reservoir Characteristics in the Brandywine Creek Watershed

Reservoir	Purpose	Owner	Storage (MG)	Drainage Area (mi^2)	Surface Area (acres)	capacity (acre feet)	normal capacity (acre feet)	withdrawal draft
Chambers Lake/ Hibernia Dam	water supply	CCWRA, CCA, NRCS	400	4.5	84.9	2016	1225	NA
Marsh Creek	flood control, water supply and recreation	DCNR	2 billion	20	525	24,000	6380	NA
Struble Lake	flood control and recreation	CCWRA, CCA, NRCS	334	2.8	146	2880	1025	NA
Barneston Dam	flood control	CCWRA, CCA, NRCS	NA	11.9	NA	3700	NA	NA
Beaver Creek Dam	flood control	CCWRA, CCA, NRCS	14	3.1	11	1464	43	NA
Rock Run / Coatesville Reservoir	water supply	CCA	329	5.3	61	1250	1010	964 mg/yr withdrawal draft
Hoopes Reservoir	water supply	COW	2 billion	NA	NA	NA	NA	NA

Marsh Creek Reservoir - (similar to Chambers Lake Reservoir) was designed to operate only during periods when stream flows in Brandywine Creek are at extreme lows. Both Marsh Creek and Chambers Lake reservoirs are required to begin releases to support downstream withdrawals when the stream gage at Chadds Ford reads at or below 140 cfs. This flow trigger was agreed to several years ago by water supply planners and agencies in Pennsylvania and Delaware to assure that the natural stream flow is maintained under dry weather conditions to support the surface water withdrawals taken by the City of Wilmington from the lower Brandywine Creek. The Marsh Creek reservoir is 525-acres, and provides flood control, water supply and recreation. It has a normal surface area of 535 acres. It is owned by DCNR - Bureau of State Parks. Construction of the dam was completed in 1973. The dam at Marsh Creek is of earthen construction, rock fill. Its height is 90 feet with a length of 990 feet. Its capacity is 24,000 acre feet (over 7 billon gallons). Normal storage is 6,380 acre feet. It drains an area of 20 square miles.

Barneston Dam - is located on East Branch Brandywine Creek in Chester County, Pennsylvania and is used for flood control purposes. Construction was completed in 1983. It is owned by Chester County Water Resources Authority. Barneston Dam is of earthen construction. Its height is 43 feet with a length of 1305 feet. Its capacity is 3700 acre feet. It drains an area of 11.9 square miles.

Beaver Creek Dam - located on Beaver Creek in Chester County, Pennsylvania and is used for flood control purposes. Construction was completed in 1975. It has a normal surface area of 11 acres. It is owned by Chester County Water Resources Authority. The dam is of earthen construction. Its height is 36 feet with a length of 1370 feet. Its capacity is 1464 acre feet. Normal storage is 43 acre feet. It drains an area of 3.1 square miles.

Rock Run / Coatesville Reservoir - Coatesville Reservoir is the result of Rock Run Dam on the Rock Run River in Chester County, Pennsylvania and is used for drinking water and recreation purposes. Construction was completed in 1917. It has a normal surface area of 61 acres. It is owned by Pennsylvania - American Water Company. Rock Run, dam is concrete, buttress supported. Its height is 42 feet with a length of 583 feet. Its capacity is 1250 acre feet. Normal storage is 1010 acre feet. It drains an area of 5.3 square miles. The current average daily withdrawal volume is approximately 964 mg/year.

Hoopes Reservoir - Owned by the City of Wilmington and was originally Delaware's only reserve storage reservoir. The total capacity is 2.0 billion gallons and the useable capacity is 1.8 billion gallons. The reservoir was built in 1932 and it is an off-stream pump storage impoundment. Raw water is pumped from the Brandywine Creek through a 4-mile pipeline to replenish the reservoir. The City releases water from the reservoir back to Wilmington or to the United Water Delaware water company usually only during drought or low flow periods in the summer when stream flows are low in the Brandywine, Red Clay, and White Clay Creeks. However, water can be released from Hoopes Reservoir during other times, for instance while the City intake canal is closed for cleaning or due to hazardous waste spills on the above creeks. The City’s water treatment plants are located in Wilmington, not at the reservoir, at the Brandywine and Porter Filter Plants (University of Delaware, 2002). The releases vary depending on the stream flows and emergencies that occur. During the drought of 1999, the City released 95 mg from Hoopes Reservoir, 10 mg to Wilmington and 85 mg to United Water Delaware (University of Delaware, 2002). During the drought of

1995, Wilmington released 460 mg to the City and to United Water Delaware (University of Delaware, 2002).

2.1.6. First Order Streams

A first order stream, sometimes called a headwaters stream, is a stream that has no permanent tributaries. Therefore, this waterbody is the first section of the Brandywine Creek that will receive the impacts of land based activities and pollution. First order streams can provide important functions in maintaining baseflow, absorbing pollutants, and providing nursery areas and habitat for aquatic life. Given the important function and vulnerability of these streams to activities such as agriculture and development/urban runoff they must be given priority for protection.

A detailed analysis of first order streams is provided in the Chester County Watershed Compendium (Chester County Water Resources Authority, 2001). This information was examined to determine which areas have the most first order streams and related land area and then compared to land use to determine which areas may be more eligible for preservation, agricultural restoration, or urban restoration. Of the 567 stream miles in the watershed, 58% or 328 miles are first order streams. Over 55% of the land area within the Brandywine Creek watershed drains to first order streams.

The average miles of first order streams per drainage area for the entire Brandywine Creek is 1.01 miles of first order stream per square mile of drainage area (see Table 2-11). Approximately 8 of the 15 subbasins are above the watershed average. The remaining 7 are below the average. The range is from 0.35 miles/sq. mi. along the main stem Brandywine Creek at Wilmington to over 1.46 miles/sq. mi. along the Brandywine Creek at Chadds Ford. Though the highest ratio of 1st order stream miles to drainage area appears to be in the Lower Basin between Chadds Ford and Doe Run, this does not indicate the true impact of 1st order drainage areas from a contaminant perspective. The East and West Branch Brandywine Creek subbasins have the greatest total area of 1st order drainage area acreage as compared to the lower basin and main stem areas. This suggests preservation and protection efforts for first order streams will have the most impact on the E. and W. Branches and that pollution and land activities in these areas will have the greatest negative impact on the watershed. A more detailed analysis of land use within the first order stream and other stream corridors is discussed later in this section and section 3.

Table 2-11 – Brandywine Creek Watershed First Order Stream Characteristics

Subbasin Name	Total Stream Miles	1st Order Stream Miles	% of Total Stream Miles	Drainage Area (sq.mi)	1st order miles/DA	Total Acres	Acres in 1st Order Drainage Areas	% acres first order
Brandywine Creek at Wilmington	6.8	2.1	30.9%	6.06	0.35	3877	399	10.3%
Upper W. Branch Brandywine Creek	36.6	18.9	51.6%	30.24	0.63	19353	9751	50.4%
Upper E. Branch Brandywine Creek	34.4	17.5	50.9%	25.66	0.68	16425	8570	52.2%
W. Branch Brandywine Creek/Rock Run/Sucker Run	38.1	21	55.1%	27.08	0.78	17331	9760	56.3%
Buck Run	43.7	22.1	50.6%	26.89	0.82	17208	8631	50.2%
E. Branch Brandywine/Beaver Creek	47.4	24.6	51.9%	26.06	0.94	16677	8106	48.6%
E. Branch Brandywine Creek/Shamona Creek	28.2	17.4	61.7%	17.76	0.98	11368	7177	63.1%
Marsh Creek	34.6	20.1	58.1%	20.31	0.99	13000	7304	56.2%
Doe Run	39.4	23.7	60.2%	21.68	1.09	13872	8751	63.1%
West Valley Creek	37.2	24.4	65.6%	20.67	1.18	13227	8658	65.5%
Brandywine Creek/Pocopson Creek	40.3	23.9	59.3%	19.74	1.21	12633	7457	59.0%
Brandywine Creek below Chadds Ford	64.2	40.5	63.1%	30.36	1.33	19432	10891	56.0%
W. Branch Brandywine Creek/Broad Run	66.4	39.3	59.2%	29.09	1.35	18620	10653	57.2%
E. Branch Brandywine Creek/Taylor Run	27.4	17.5	63.9%	12.89	1.36	8247	5080	61.6%
Brandywine Creek above Chadds Ford	22.3	14.7	65.9%	10.06	1.46	6437	3954	61.4%
Total	567	327.7	57.8%	324.55	1.01	207707	115142	55.4%

Source: Chester County Water Resource Authority, 2002

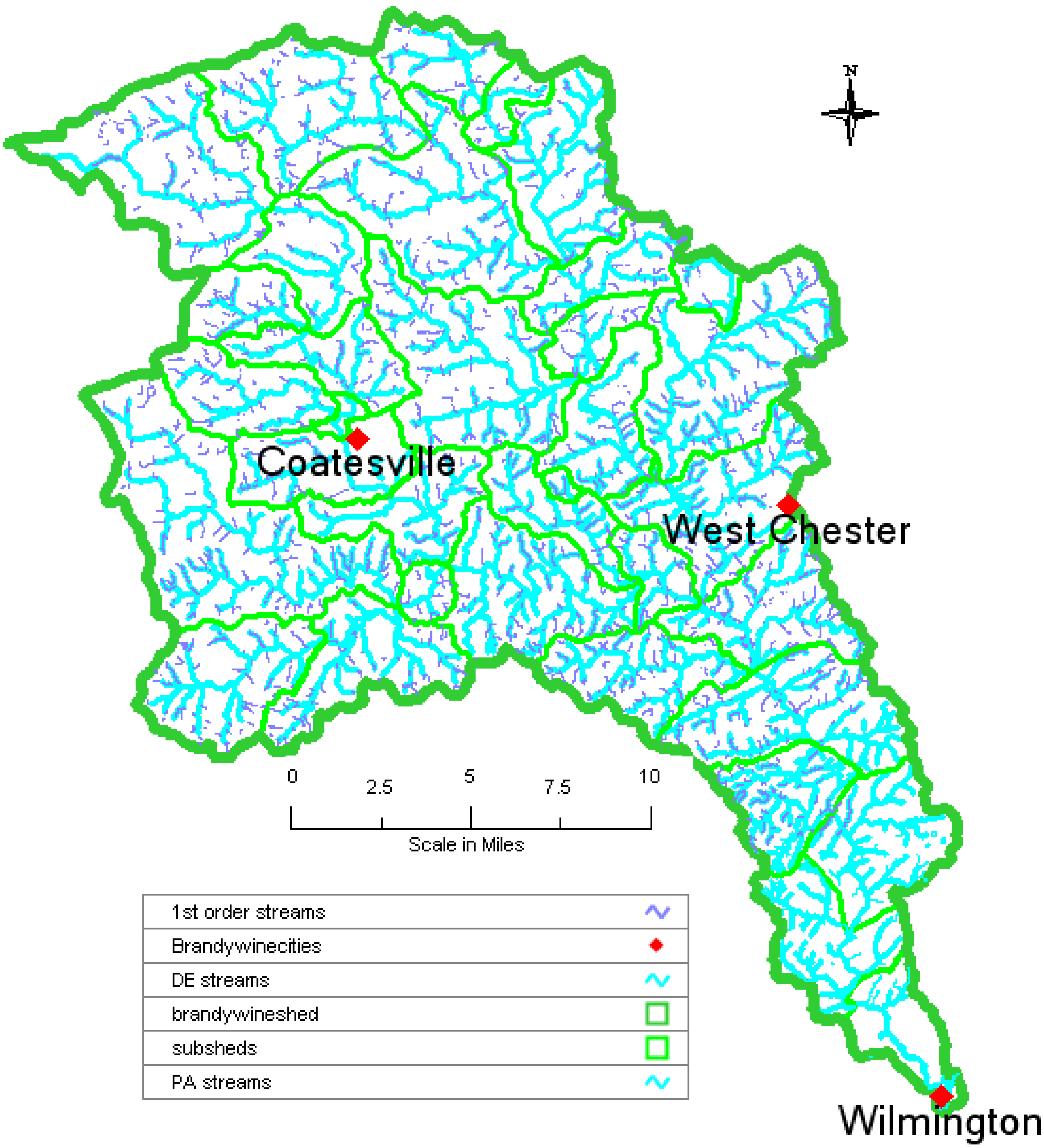


Figure 2-14 – First Order Streams

2.1.7. Watershed Growth, Population, and Land Use Impacts

The past, present, and future trends in population growth and land use in the watershed can be used to identify concerns and strategies related to current and future water quality issues. For example, less forests and more impervious cover can have water quality and quantity impacts. Though any general strategy is aimed at preventing both, the critical unknowns to most managers are how fast the land use will change and at what point a tipping point of irreversible negative impacts will be reached that could be avoided with long term planning and action.

There are very few estimates of long term population for the Brandywine Creek Watershed. However, there are recent estimates of the population in the watershed and predictions of future population growth. Table 2-12 provides these estimates and their relative population density in the watershed.

Table 2-12 – Past and Future Population Estimates For the Brandywine Creek Watershed

Source	Year	estimated average population density/sq. mile	estimated population in watershed
BVA SOW Report 1998	1980	400	130,000
BVA SOW, 1997	1995	681	221,325
Brandywine Watershed Action Plan	1998	679	220,700
BVA SOW Report 1998	2020	824	267,960
Brandywine Watershed Action Plan	2020	865	280,993

Previous studies have suggested population growth estimates of approximately 1,766 persons per year in the watershed (Brandywine Valley Association, 1998). These population growth estimates were used in past studies to predict future potential impervious cover in the watershed. It was estimated in 1998 that impervious cover would increase from 10.9% to 13.3% in 2020. This comes to an estimated 226 acres of impervious cover per year would be added to the watershed on average over that time.

Looking at these population and land use trends, it raises the question regarding how much forested land will be preserved or available to protect water quality over the coming 20 to 100 years. To answer this question, we need to understand a number of factors including the historical and current preservation rates of forests and the rate of forest cover loss. Historical rates of forest land cover suggest approximately 0.9 square miles of forest is lost per year in the watershed. For the purpose of this analysis a range from 0.5 to 1.875 square miles of forest lost per year was used. Historical rates of forest preservation are roughly 1.562 square miles per year. For the purpose of this analysis a range of 0.5 to 1.562 square miles per year was used.

If a range of forest preservation or forest losses and the starting point of 1998 are used for forested lands and preserved forested lands, a simplistic linear analysis estimates a range of future woodlands and impervious area scenarios that are possible in the next 10 to 60 years. Overall, this analysis suggests that the amount of forested land available and preserved forested land will roughly balance out between 2020 and 2070, depending upon the rates of forest land loss to development and rates of preservation. Depending on how preservation and development happens the forested land cover in the watershed could reach a balance point anywhere from 15% to 27% forested land cover (Table 2-13). As the forested land use drops towards the 15 to 20% range this will start to have negative impacts on aquatic life, water quality, flooding, base flow, and other hydrologic dependent aspects of the watershed. This also allows Wilmington to plan and estimate future water quality impacts and costs due to future land uses.

Table 2-13 – Past and Future Population Estimates For the Brandywine Creek Watershed

Scenario	best case	moderate case	worst case
% forests/woodlands remaining in watershed	21 to 27%	17-23 %	15 to 20%
years	2033 - 2070	2026 - 2046	2019 - 2028

According to equations for estimating treatment costs in the study by the Trust for Public Lands (Protecting the Source, 2004), the worst case reduction in forested land (15%) could have the potential for long term increased water treatment costs of over 30% for the City of Wilmington during the next 20 to 60 years. It is important to qualify that this is a preliminary estimate using national values and will need to be calibrated and validated with Wilmington specific costs at a later date. Regardless it does suggest some level of long term impact on treatment costs for Wilmington and a period (between 2030 and 2070) as to which actions to protect forested lands for the water supply will be ineffective. Overall, these findings also suggest that land preservation and loss of forested land will be a critical activity that will need to be conducted as soon as possible in order to protect Wilmington's water supply.

2.1.8. The Value of Watershed Preservation and Reforestation

A recent study by the United States Forest Service in the Northeast and Midwest found that the forests in 20 states help to protect more than 1,600 drinking water supplies that are the source of water for more than 52 million Americans (Barnes, 2009). The quality of the water depends, in part on the forest lands and their watersheds. The study mentions that the value of forests specifically to water quality and water supply is often overlooked by both the public and policymakers.

Potential for Significant Forest Losses

In the recent U.S. Forest Service study described above, the loss of forested lands is staggering in the Northeast and Midwest. Estimates suggest that forests in drinking water supply watersheds are being converted to other uses at an estimated rate of 350 acres per day with projected increases in the rate of loss to as much as 900 acres per day in 2030 with an overall loss of over 12 million acres of private forest land in these states by 2030. The common element to these losses is that over 82% of forested lands in the study were in private ownership which accelerates that loss of forested lands. Privately owned lands is a surrogate for the underlying factors related to zoning and other regulations of those private lands further accelerated by the residential real estate boom. Only 16% of the forested lands in the study were in State or Federal ownership. Specifically from the study, the State of Delaware and Pennsylvania were ranked using a number of factors. The study concluded that the State of Delaware was ranked above average in the Northeastern Area for having high-quality watersheds under development pressure. In addition, it identified that approximately 16.7 percent of private forestlands on high-quality watershed areas are subject to development pressure by 2030. In general, Delaware ranked in the top 11 percent of all the region's watersheds because the watershed is at high risk for development and also provides high-quality drinking water to a large population. Over 85% of the forested lands in Delaware watersheds were identified as owned by private owners.

As mentioned previously in this plan, the forested land cover of the Brandywine Watershed is estimated at approximately 28% forested land cover in 2009 (data provided by GIS estimates by Brandywine Conservancy). Based on historical development rates and woodland loss information (Brandywine Conservancy report reference 2009), over the past 10 to 15 years there has been an average 1% per year loss in forested lands. This equals approximately 9.09 square miles of forested land lost per decade to development. Thus, 0.909 square miles per year of land (582 acres) should be reforested per year to address these losses in order to maintain the current estimated forest cover of roughly 28% (91.57 square miles) of forested land in the Brandywine Watershed.

Setting Priorities for Reforestation

According to a riparian zone analysis by the Brandywine Conservancy that looked at forest cover within 100' of all mapped streams within the Brandywine watershed, there are roughly 13,000 acres of land potentially available for reforestation in riparian buffer areas in the Brandywine Creek Watershed (Brandywine Conservancy, unpublished data, 2009). Assuming 80% of these can actually be reforested, reforestation of all riparian buffer areas would only cover a portion of the total reforested lands needed for an ideal amount of forested lands like New York City or Boston uses for its water supply. Other high priority lands beyond riparian buffers such as headwaters drainage areas, steep slopes, significant connection to habitats and natural lands, etc. will need to be considered for reforestation as well as riparian areas. Other opportunities for reforestation include reforestation of a reasonable portion of currently protected open space of all kinds, including, for example state, county and municipal parks as well as private open space such as homeowner association lands and the eased properties of Brandywine Conservancy.

Though the costs to reforest the watershed may appear to be significant, increasing forest cover will help reduce many of the impairment issues with stormwater and other compliance needs would decrease. In terms of overall long term costs for the watershed this may be a viable strategy as an element of regulatory compliance. For example, stream restoration can cost upwards of $1 million per mile of streambank restored and with over 100 miles of impaired streams in the Brandywine Creek Watershed this could exceed $100 million to repair the stream without addressing the long term cause of the impairment. Managing an urban storm water utility for the entire watershed could have operating costs of up to $1 million per square mile per year depending upon the regulatory compliance needs and levels and extent of service. Thus, in terms of long term costs and returns, reforestation provides the best potential for long term return on investment, lowering stormwater compliance and water treatment costs compared to other approaches.

Perhaps the best way for stakeholders to achieve a significant increase in forested cover would be to merge efforts for carbon caps and carbon sequestration that need to be achieved by power companies and other industries with tree planting and reforestation and leverage regional, state, and national incentives and programs that will be developed around carbon reductions. For example, the costs of the trees and tree plantings could be subsidized by a company that needs the carbon credits. The cost of an easement for the reforested area could also be potentially added to those costs. Creating easements or land restrictions attached to property deeds for reforested areas would be a key to ensuring this approach. Another version of this program would be to create a “forest bank” similar to the approach used in wetland banking. An example of how this could occur is the following. A landowner that is interested in reforestation would contact a lead organization in the watershed. The organization would match the landowner looking for reforestation with funding from businesses in need of carbon credits. The organization in the middle of this transaction could serve as the banker or lender of the land for reforestation or for managing the reforestation funding depending on the most effective approach. The organization could also sell the carbon credits from other reforestation projects to interested businesses to recoup the costs of the reforestation and potentially cover funding for the next reforestation project.

Initial Steps to Address Future Deforestation and Reforestation

Because of its high value in protecting watershed health, preservation of existing forested lands is a primary priority. A secondary priority, however, is to establish more forested land cover than currently exists in the watershed through reforestation, particularly of high priority areas. It is recommended that the City of Wilmington reach out to other local governments in both states, key land management stakeholders, water suppliers, and environmental organizations in the watershed to discuss the concerning loss of forested lands and how to set in place a watershed wide initiative to stem the loss of forested lands and develop a sustainable framework for reforesting the watershed that could be linked to future carbon caps and credits. The management of the forested land in the watershed is the most critical long term activity that the region's water suppliers will need to invest resources and efforts in order to protect the high quality water and reliable quantity of water that they currently enjoy from the Brandywine Creek or Hoopes Reservoir.

2.1.9. Analysis of Stream Impairments & Sources

A stream is considered impaired if it cannot meet the water quality and narrative standards that are used to define the fishable and swimmable goals of the Clean Water Act. In practice, the impairments to a stream are mostly based on macroinvertebrate or living organism assessments and water quality measurements. If the water quality fails to meet the water quality standards and criteria established by the designated use of the stream, it is considered impaired. In general, the Brandywine Creek main stem is listed by section 303d as impaired by nutrients, pathogens, and chlordane. The West Branch Brandywine Creek (including Sucker Run and other small tributaries) is listed as impaired by nutrients and siltation from agriculture as well as chlordane. The East Branch Brandywine Creek (including West Valley Creek, Taylor Run and some small tributaries) is listed for flow alteration and siltation. Roughly 20% of the stream miles in the Brandywine Creek are impaired as shown in Table 2-14. Table 2-15 and Figure 2-15 provides the breakdown of the impairment sources. Figure 2-16 provides a map of the impaired stream areas by source.

As shown, agriculture is the single largest source of impairment followed by urban/stormwater runoff, habitat and hydromodification (riparian buffer losses), unknown sources. These impairments are described in more detail in following sections.

Table 2-14 – Summary of Impaired Stream Miles in the Brandywine Creek Watershed

Watershed	Miles of Stream Impaired	Miles of Stream Attaining	Miles of Unassessed Steams	Total Miles
Brandywine Creek	102.94	427.5	5.41	535.85

Source PADEP, 2003

Table 2-15 – Sources of Impairment in the Brandywine Creek Watershed

Protected Water Use (Chapter 93)	Source of Impairment	Miles Impaired	Priority
Aquatic Life	Agricultural	46.38	High
Fishing	Fish Consumption Advisory*	5.85	High
Fishing	Industrial Point Source ***	0	High
Aquatic Life	Urban Runoff/Storm Sewers	30.82	High
Aquatic Life & Fishing	Unknown Sources ****	35.79	High
Aquatic Life	Habitat Modification	12.31	Low
Aquatic Life	Hydromodification	6.66	Low
Aquatic Life	Municipal Point Source	0	High
Aquatic Life	Construction	0	Low
Aquatic Life	Other	2.31	Low
Aquatic Life	Natural Sources	0.68	Low

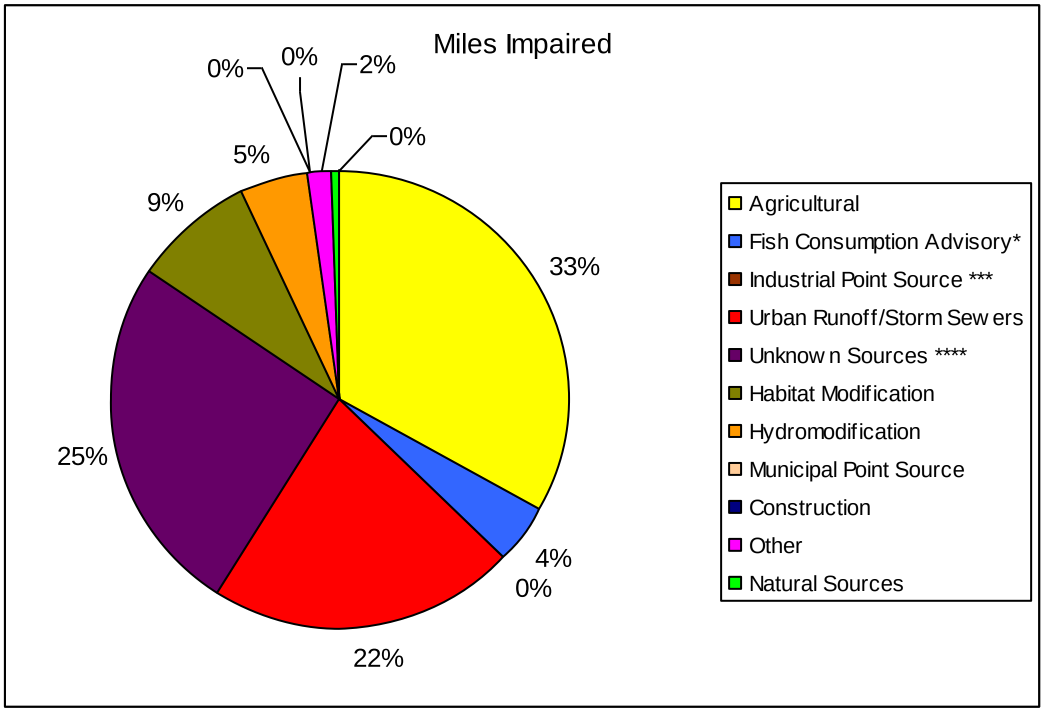


Figure 2-15 – Breakdown of Miles of Stream Impairments by Percentage of Total Amount in the Brandywine Creek Watershed

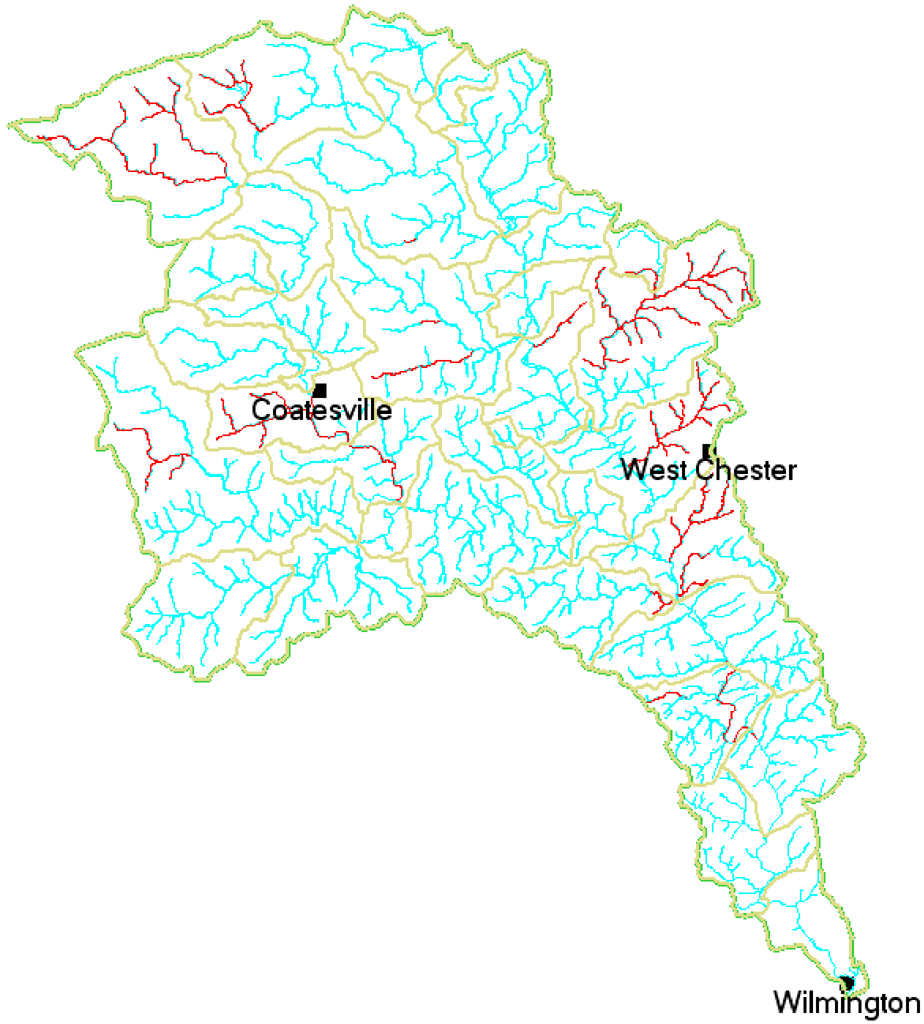


Figure 2-16 – Impaired Streams in the Brandywine Creek Watershed

2.1.9.1. Urban Runoff Impairments

The industrial and urban development in the cities and boroughs of West Chester, Coatesville, Downingtown and Parkesburg have resulted in degradation of portions the Brandywine Creek watershed from municipal and industrial discharges and urban runoff and storm sewers. Streams through the urbanized areas also suffer from habitat alterations, flow variability, and siltation. The streams in the Brandywine Creek with the most impairment are those in the industrial/urban areas of Dowingtown (East Branch Brandywine Creek and Beaver Creek), Coatesville (Valley Creek, Sucker Run, and West Branch Brandywine Creek), Parkesburg (Buck Run), and West Chester (Taylor Run). These impaired areas also have some of the highest percentage of impervious surface in the watershed. The highest percentages of impervious surface are in West Valley Creek watershed (20%), which flows into Downingtown and the lower East Branch Brandywine Creek near West Chester (15%).

2.1.9.2. Agricultural Impairments

Streams in the Honey Brook area (upper East Branch, West Branch and Honey Brook Creek) are impaired due to agricultural runoff. Agriculture impairments impact the East and West Branches of Brandywine Creek, Plum Run, Radley Run, Sucker Run, Buck Run, Broad Run, and Indian Run. Crop and animal production can adversely impact aquatic life. Erosion of topsoil and runoff of applied manure or chemical fertilizers contribute to stream sedimentation and nutrient loading. Barnyard runoff of manure and proximity of livestock to the stream can also contribute to nutrient loading and sedimentation (bank destabilization) respectively. Agricultural best management practices are voluntary and little regulation exists for reducing pollutant loads from agricultural areas.

2.1.9.3. Municipal Point Source Impairments

Municipal point source discharges also cause organic enrichment and low dissolved oxygen in Beaver Creek, Buck Run, and Broad Run.

2.1.9.4. Linking Impairment Reduction with Water Supply Protection

An impaired stream can be subject regulation in order to return it to an unimpaired status. Sometimes, but not always, the sources of impairment to aquatic life may also have impacts on water treatment. Since the regulatory authority to address water quality impacts for water supply is not organized in a way that makes it effective, the most powerful and effective regulatory approach is to coordinate regulation of water supply issues with impairment regulation. This can result in promulgation of total maximum daily loads to reduce permitted discharges from point sources such as wastewater plants and stormwater outfalls. TMDLs have been promulgated for nutrients, TSS, and bacteria for the Brandywine Creek. Thus, it is critical for Wilmington to monitor the TMDL implementation process to ensure it addresses their upstream sources of concern appropriately.

2.2. Surface Water Intakes

2.2.1. Surface Water Withdrawals and Community Water Systems

The Brandywine Creek watershed has numerous surface water withdrawals for public water supply, commercial and industrial uses. A total of 37 surface water withdrawals are inventoried in the watershed, and in 1998, it was estimated that there were over 15 billion gallons withdrawn from the watershed. A total of 31 million gallons of water per day are withdrawn by surface water supplies for drinking water, irrigation, and commercial/industrial needs in the watershed. This is roughly 17% of the average daily flow in the Brandywine Creek.

As described earlier, certain withdrawals are either partially or fully offset by waters stored in Marsh Creek Reservoir or Chambers Lake. Table 2-17 and Figures 2-17 & 2-18 provide a summary of the major withdrawals from the Brandywine Creek and their types.

Table 2-16 – Surface Water Withdrawals by Type in the Brandywine Watershed

Withdrawal Type	Maximum Permitted Withdrawal (MGD)	Total Average Withdrawal (MGD)
Public Water Supply	57.7	27.2
Commercial / Industrial	8	3.5
Irrigation	3.8	0.3
TOTAL	**69.5**	**31**

Several existing community water supply systems in the watershed rely on ground water sources. In addition, several surface water intakes and treatment plant facilities for public supplies exist in the Brandywine Creek watershed. Such sources may offer opportunities for future supplies both within and adjacent to their corresponding subbasins. Table 2-16 provides a specific breakdown of the detailed withdrawal information for major suppliers. Table 2-18 provides a list of the remaining 63 small community systems in the Brandywine Creek Watershed.

Specific information for the major water supply intakes are as follows:

Pennsylvania American Water Company Rock Run Reservoir – The current allocation is 3 MGD. The current average daily withdrawal volume is approximately 2.5 MGD.

Pennsylvania American Water Company West Branch Brandywine - The current allocation is 4 MGD. The current use of this intake is only on an as needed basis, generally during prolonged drought events, to supplement the Rock Run Reservoir. During recent drought events, maximum daily withdrawal volume was approximately 2 MGD.

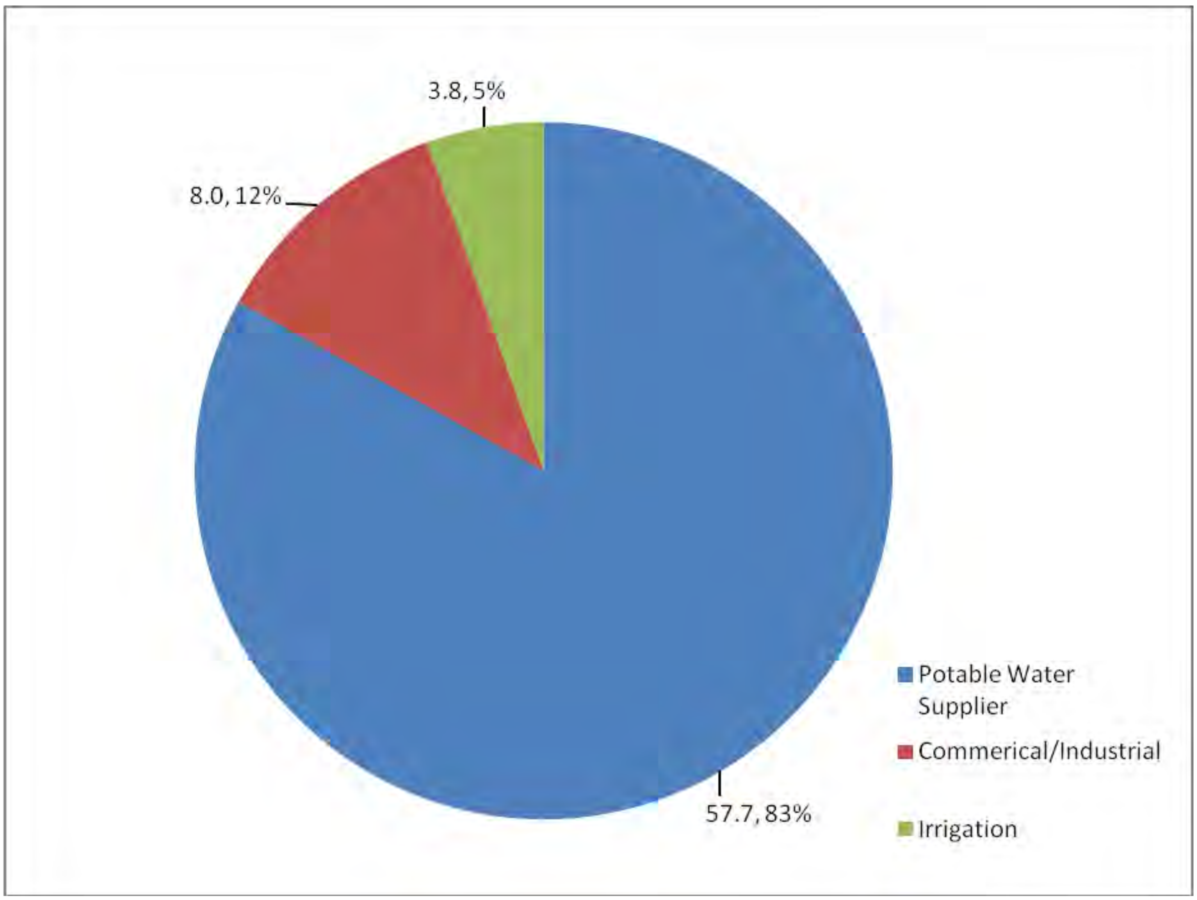


Figure 2-17 – Comparison of Maximum Major Surface Water Withdrawal from the Brandywine Creek

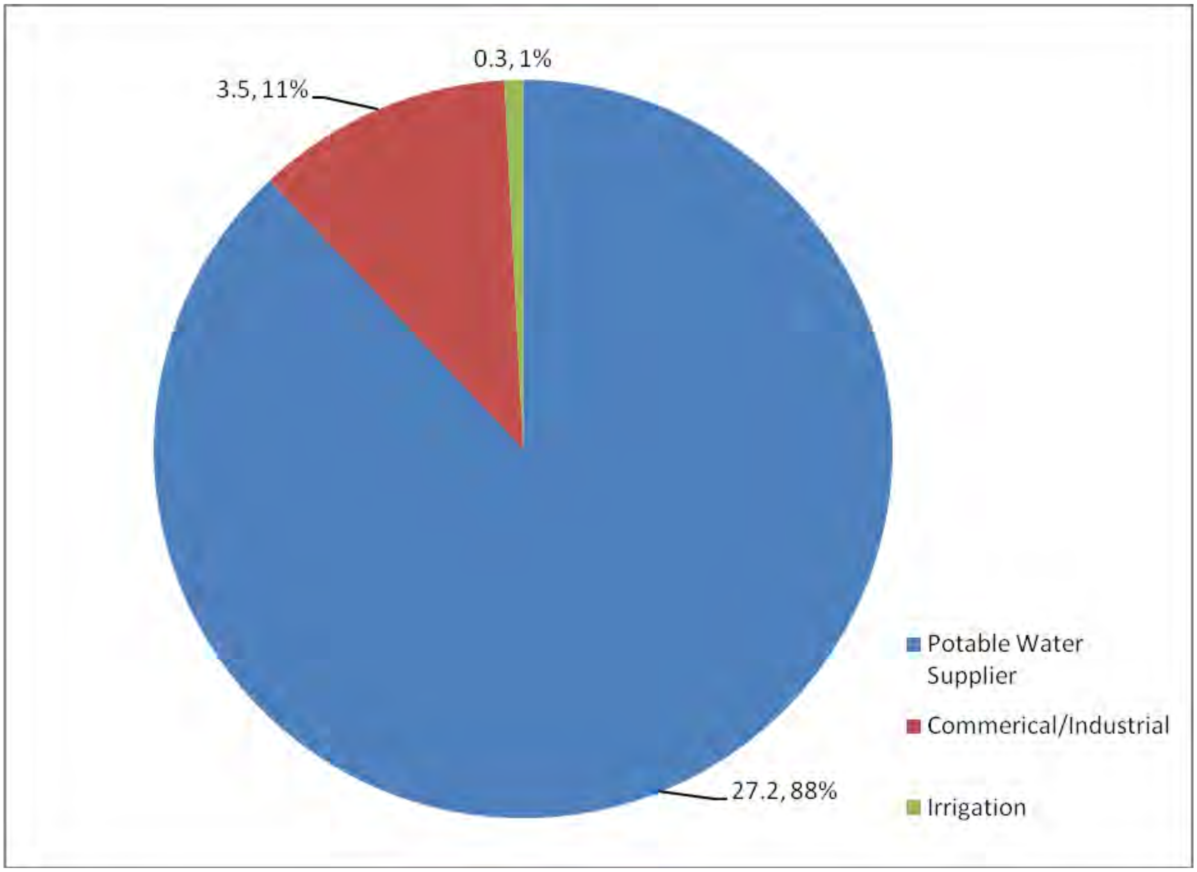


Figure 2-18 – Comparison of Average Major Surface Water Withdrawal from the Brandywine Creek

Downingtown Municipal Water Authority (DMWA) East Branch Brandywine Creek/Downingtown – The current maximum allocation is 2.5 MGD. The DMWA has additional water supply storage allocation available in Marsh Creek Reservoir to support a total allocation of 3.8 MGD. The DMWA's current average daily withdrawal volume is approximately 1.1 MGD.

Aqua Pennsylvania Water Company East Branch Brandywine Creek/Ingram's Mill - The current allocation is 6.0 MGD, with a 1-day maximum of 8.5 MGD. The current average daily withdrawal volume at this intake is approximately 2.8 MGD.

These existing surface water intakes potentially represent sources of additional water for other subbasins depending on the proximity of connecting infrastructure to the area of need and impact to subbasin water balances. Several inter-basin and inter-watershed transfers of water already exist in Chester County's watersheds. Examples of the distribution of water from surface water sources include:

The Pennsylvania American Water Company's Coatesville regional distribution system serves water from 3 sources of surface waters including the Rock Run and West Branch

Brandywine intakes listed above, and an intake on upper West Branch Octoraro Creek.

The Downingtown Municipal Water Authority's intake on East Branch Brandywine provides water for the immediate Downingtown region.

The Ingram's Mill intake (Aqua-PA) on East Branch Brandywine Creek serves water to much of the greater West Chester region.

The City of Wilmington's source of water for its water distribution system is in the lower Brandywine Creek watershed. The City also operates Hoopes Reservoir for use when extended dry weather events necessitate additional water to meet demands.

Table 2-17 – Detailed Listing of Major Surface Water Withdrawals From the Brandywine Creek Watershed for 1998

			Flow (Mgal/d)	
Subbasin withdrawals	**Name**	**Type**	**capacity or flow limit**	**1994-1998 average**
West Branch	City of Coatesville Authority - W. Branch Brandywine Creek	DW	1	0.354
West Branch	City of Coatesville Authority - Rock Run	DW	3	2.68
West Branch	Lukens Steel	IND	4.76	1.35
West Branch	Sealed Air Corporation	IND	0.278	0.034
West Branch	Embreeville Center	DW	0.2	0.149
East Branch	Downingtown Municipal Authority	DW	2.5	1.02
East Branch	Sonoco Products	IND	1.32	1.6
East Branch	Milestone Materials	IND	0.62	0.42
East Branch	Whitford Country Club	IRR	0.643	0.026
East Branch	Philadelphia Suburban Water-Ingrams Mill	DW	6	2.8
East Branch	Brandywine Paperboard	IND	0.024	0.019
Main stem	Radley Run Country Club	IRR	0.1	0.02
Main stem	Brandywine Country Club	IRR	0.51	0.022
Main stem	Wilmington Country Club	IRR	1.8	0.165
Main stem	Dupont Country Club	IRR	0.72	0.019
Main stem	Wilmington Finishing	IND	1	0.046
Main stem	City of Wilmington	DW	48	25

Source: Keorkle and Senior, 2002

Table 2-18 – List of Small Community Water Systems in the Brandywine Creek Watershed

Number	System Name	Number	System Name
1	Appleville Mobile Home Park	33	Londonderry Court
2	Avonwhell Estate Mobile Home Park	34	Longwoods Gardens
3	Brandywine Terrace Mobile Home Park	35	Malvern Courts Inc.
4	Caln Mobile Home Park	36	Maplewood Mobile Home Park
5	Camp Hill Special School	37	Martin's Mobile Home Village
6	Camphill Village USA Inc.	38	Movern Mushroom Farms
7	CFS - School at Church Farm	39	Mount Idy Mobile Home Park
8	Chatham Acres Nursing Home	40	Nottingham Manor Mobile Home Court
9	Chatwood Water Company	41	Oxford Village Mobile Home Park
10	Coatesville Veterans Administration Hospital	42	Perry Phillips Mobile Homes
11	Cochranville Mobile Home Park	43	Phoenix Mobile Homes
12	Coventry Garden Apartments	44	Phoenixville Mobile Homes Inc.
13	Coventry Manor Nursing Home	45	Philadelphia Suburban Water Co. - Culbertson Run
14	Coventry Terrace	46	Philadelphia Suburban Water Co. - Brandywine Hospital

15	Devereux Foundation	47	Ridgeview Mobile Homes
16	East Fallowfield Utilities, Inc.	48	Riveredge
17	Echo Valley	49	S.E. PA Veterans Center
18	Gregory Courts Inc.	50	Shady Grove Mobile Home Park
19	Heatherwood Retirement	51	Shady Side Mobile Home Park
20	Hideaway Mobile Home Park	52	Springton Court Mobile Homes
21	Highland Court	53	St. Mary's of Providence
22	Icedale Mobile Home Courts	54	St. Stephens Green
23	Imperial Mobile Home Park	55	Stone Barn
24	Independence Park	56	Stoney Run Mobile Home Park
25	Indian Run Village	57	Taylor's Mobile Home Park
26	Kendal Crosslands/Consiston	58	Tel Hai Rest Home
27	Keystone Court	59	Valley Springs Water Co.
28	Lake Road Mobile Home Park	60	Valley View Mobile Home Park
29	Lazy Acres Mobile Home Park	61	Warwick Mobile Home Park
30	Lincoln Crest Mobile Home Park	62	Wetherhill Estates
31	Loags Corner Mobile Home Park	63	Willowdale Water Company
32	London Grove Mobile Home Park		

Source: Chester County Water Resources Authority, 2001

2.2.2. Groundwater Withdrawals

Groundwater withdrawals are important sources of drinking water for small communities and can have localized or global impacts on the baseflow of a watershed depending on a number of factors. Table 2-19 provides a summary of the results from a groundwater withdrawal capacity and sustainability analysis in the Chester County Compendium (Chester County Water Resources Authority, 2001) to determine which subbasins in the watershed may see negative impacts. When the percent of net withdrawals is less than 50% of the subbasin's target, the ground water resources are considered non-stressed. Net withdrawals greater than 50% are considered potentially stressed. Net withdrawals near or exceeding 100% are considered stressed. Using these criteria, the only area determined to have potential negative impacts or unsustainable groundwater capacity was the West Valley Creek subbasin. All other subbasins in the watershed were determined to have appropriate capacity for growth up to and possibly beyond 2020.

In Table 2-20 the relative total annual withdrawals of groundwater and surface water are summarized along with future needs for water and wastewater by subbasin. The table shows that for the watershed, an estimated 4.05 billion gallons per year or 21% of the water withdrawn is from the ground water supplies. There is an estimated 1.6 billion gallons per year recharged back to the aquifers, for a net ground water withdrawal of 2.5 billion gallons per year for the Brandywine Creek watershed in 1998. The methodology and data used to develop these estimates were presented in the Chester County Compendium (Chester County Water Resources Authority, 2001).

Table 2-19 – Summary of 1998 Net Ground Water Withdrawals by Subbasin (in MGY)

Subbasin Name	1 in 25 year Average Annual Base Flow	Groundwater Withdrawal Target as % of 1 in 25 Yr Baseflow	Volume Withdrawn	Volume Recharged	Net Withdrawal	Net Withdrawal as % of Withdrawal Target
Brandywine Creek Above Chadds Ford	1098	50%	65	133	-68	-12%
Brandywine Creek at Wilmington	661	100%	17	14	3	0%
Brandywine Creek below Chadds Ford	3313	100%	112	31	81	2%
Brandywine Creek/Pocopson Creek	2154	100%	283	173	110	5%
Buck Run	2925	100%	121	82	39	1%
Doe Run	2358	100%	46	39	7	0%
East Branch Brandywine Creek/Shamona Creek	1938	50%	216	104	112	12%
East Branch Brandywine Creek/Taylor Run	1407	50%	174	67	107	15%
East Branch Brandywine / Beaver Creek	2825	50%	627	172	455	32%
Marsh Creek	2217	50%	274	149	125	11%
Upper East Branch Brandywine Creek	2800	50%	166	104	62	4%

Upper West Branch Brandywine Creek	3300	50%	302	120	182	11%
West Branch Brandywine Creek/Broad Run	3175	50%	310	230	80	5%
West Branch Brandywine Creek/Sucker Run	2945	50%	290	106	184	12%
West Valley Creek	2233	50%	1046	45	1001	90%
Total			4049	1568	2481	

Source: Chester County Water Resource Authority, 2001

Table 2-20 – Estimated Average Annual Water Withdrawals and Future Needs by Subbasin (in MGY)

	1998 Withdrawals				2020 Projected Needs	
Subbasin Name	**Groundwater Withdrawals**	**Surface Water Withdrawals**	**Total Water Withdrawals**	**Total Water Used**	**Additional Water Demand**	**Additional Wastewater Capacity Needs**
Brandywine Creek Above Chadds Ford	65	0	65	159	74	67
Brandywine Creek at Wilmington	17	9905	9922	1726	185	167
Brandywine Creek below Chadds Ford	112	74	186	613	119	107
Brandywine Creek/Pocopson Creek	283	22	305	601	166	149
Buck Run	121	0	121	266	43	39
Doe Run	46	0	46	46	11	10
East Branch Brandywine Creek/Shamona Creek	216	379	595	439	157	142
East Branch Brandywine Creek/Taylor Run	174	1480	1654	628	96	87
East Branch Brandywine / Beaver Creek	627	648	1275	929	237	213
Marsh Creek	274	0	274	188	145	131
Upper East Branch Brandywine Creek	166	2	168	143	54	48

Upper West Branch Brandywine Creek	302	0	302	212	71	64
West Branch Brandywine Creek/Broad Run	310	0	310	255	100	90
West Branch Brandywine Creek/Sucker Run	290	1777	2067	988	261	235
West Valley Creek	1046	1128	2174	966	303	273
Total	4049	15415	19464	8159	2023	1820

Source: Chester County Water Resource Authority, 2001

2.2.3. Time of Travel Delineations

The location of a potential source or existing source of contamination in relation to the downstream water intake is critical to determining its planning priority and emergency response preparation. For example, during a low probability accident, a large storage tank or bridge crossing located just upstream of an intake would potentially represent an opportunity for a significant negative immediate impact on the water supply intake downstream. Another situation might represent an upstream discharger that is always in compliance, but may have an unforeseen operational problem beyond their control. In these situations, the water utility will need to know how long a potential discharge from these facilities could reach the intake at the earliest, the most likely time to reach the intake, and how long it will take for the pollutant plume to pass. This information is critical for the water supplier to determine how long to pull from the creek, when to shut down the intake, and how long it will need to use an alternative source. Other information such as the type of contaminant will also determine what water monitoring methods and potential treatment changes are employed during the event. Other than accidents, routine events such as localized thunderstorms and discharges from facilities that are out of compliance or discharging different contaminants sporadically (taste and odor compounds) also represent periods when this information is useful.

The City of Wilmington has the capability to switch from the Brandywine Creek as its main water source to the Hoopes Reservoir during periods of undesirable water quality. In order to maximize this capability, the City of Wilmington contracted the USGS to develop a turbidity early warning system that would provide advance warning of approaching turbidity spikes to the City's intakes so it could switch to the Hoopes supply prior to the arrive of the turbidity spike. Typically during dry weather periods the turbidity is only 1-2 NTU, but during wet weather events it can exceed 200 NTU. These higher turbidities have been associated with elevated levels of other contaminants that are described in depth in section 2.3.

The first step in this process was developing potential relationships between the flow at Chadds Ford and the peak turbidity at Wilmington's intake. It was determined from analysis of existing data that at 2,000 cfs the turbidity at the Wilmington intake exceeded 20 NTU which was greater than desired for use by Wilmington. Another analysis of the timing of the turbidity peaks was conducted by USGS. It determined that when the flow at Chadds Ford reached 2,000 cfs that the turbidity spike would reach Wilmington's intakes in less than 8 hours. This was tested in the summer of 2006 and validated against existing data by USGS. Attempts were made later in 2006 by USGS to extend the warning system to upstream stations at the bottom of the East and West Branches of the Brandywine Creek, but similar relationships like the one with Chadds Ford could not be developed.

An analysis was conducted to estimate the ranges of time for something released into the Brandywine Creek or its tributaries to reach the City of Wilmington Intake. In Figure 2-19, a graph of the range of potential travel times is provided to estimate the earliest arrival of a contaminant in a given situation. The left side of the graph represents the distance of the release from the intake and increases as it progresses to the right. The right axis on the graph represents the estimated time in hours for the release to reach the intake. It is important to note that these estimates represent a conservative estimate of the leading edge of a plume to reach the intake under various conditions. A range of average flows are shown on the graph ranging from 0.5 ft/s to 5 ft/s. Flow velocities vary significantly across the stream cross section and along the length of a stream. Therefore, these are meant to represent average cross sectional velocities over the length of the release distance. It is important to note that this graph does not estimate the time for maximum concentration to arrive or for the tail of the plume to pass the intake. Also, the type of contaminant released can have a significant effect on transport. For example, some oils may tend to stay near the surface and be affected by wind dispersion or trapped behind rock weirs and dams while other contaminants may dissolve completely and not be affected by these phenomenons. Site specific bends and impoundment areas along a stream, especially mill dams may significantly delay a contaminant plumes arrival and can prolong its presence in the stream.

The effect of stream velocity on distance traveled is shown in Figure 2-20. As shown, the farthest stream distance to travel in the Brandywine Creek is roughly 50 miles. Depending upon the velocity of the stream it can take anywhere from 15 hours to 6 days to go that distance. A stream velocity of 0.5 ft/s represents an average slow flow in the creek. This flow typically is near settling velocity for larger particles. A stream velocity of 2 ft/s represents the speed at which particles reach a "scouring" velocity where particles on the stream bottom may become suspended. This speed represents a speed of particle transport with little settling attenuation. A velocity of 5 ft/s is the peak bank full velocity estimated by the USGS for various locations in the Brandywine Creek watershed and represents the fastest flow velocity that can be observed. This represents the fastest a contaminant could reach the Wilmington intake.

As shown in Figure 2-19, under dry weather conditions, spills from the farthest reaches of the watershed will make it to the intake in less than 6 days and probably less than 2 days under normal conditions without impoundments. Under dry weather conditions, spills from the Route 30 corridor such as Coatesville, Malvern, and Downingtown will reach the intake in roughly 1 to 3 days. Under dry weather conditions, spills on the main stem can reach the intake in less than a day in most cases. Under bank full flow conditions, all spills from all locations will reach the Wilmington intake in 5 to 15 hours unless there is an impoundment such as in one of the large reservoirs in the basin.

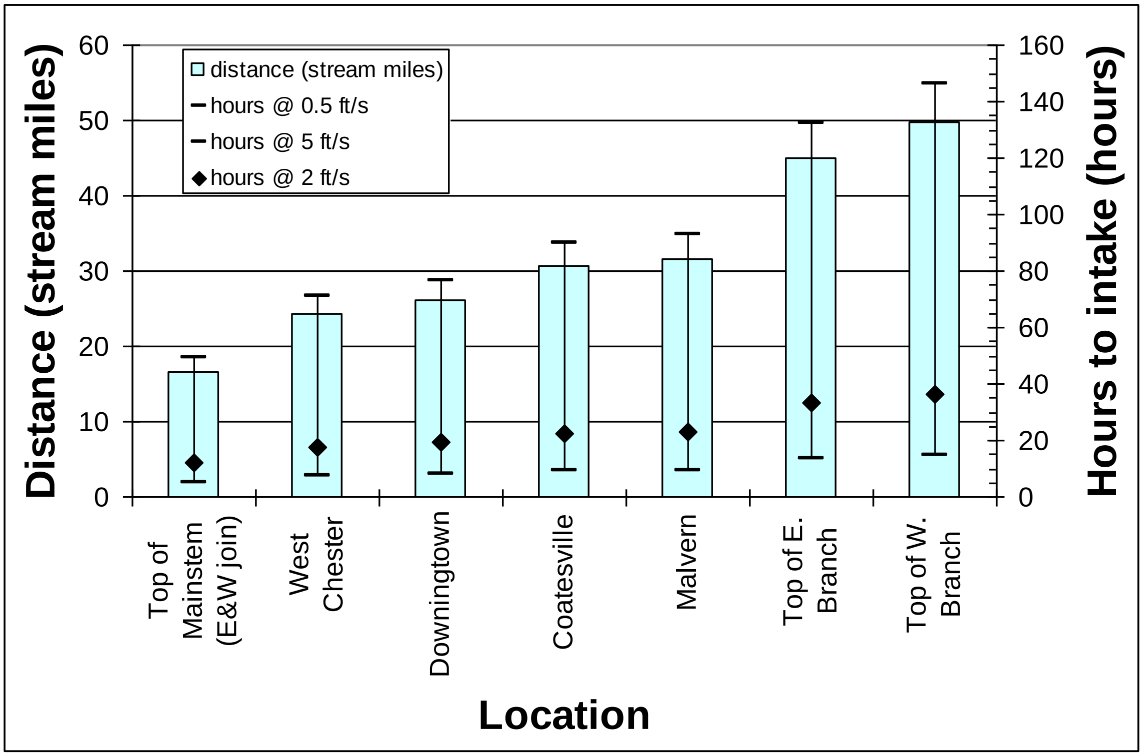


Figure 2-19 – Estimated Time of Travel and Distance from Various Locations in the Brandywine Creek Watershed to Wilmington's BFP Intake

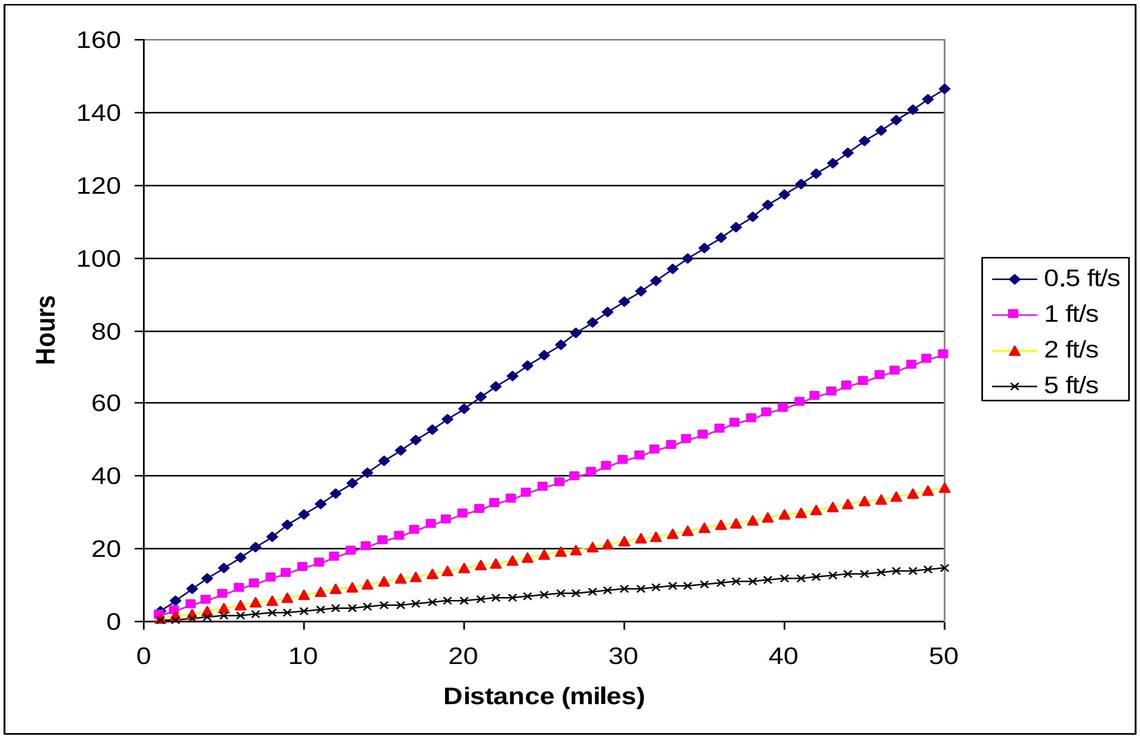


Figure 2-20 – Distance Traveled (miles) As a Function of Stream Velocity

2.3. Identification of Universal Water Quality Issues

Summary of Water Quality Data Findings

- When raw water turbidity exceeds 10 NTU the raw water quality has higher levels of disinfection by product precursors, pathogens, and ammonia.
- The greatest chloride, sodium, and conductivity concentrations are associated with periods of road salt application. Long term increasing trends of these parameters were observed. When the conductivity at Wilmington is approximately 500 to 600 (units), chloride levels may reach 100 to 150 mg/L.
- Preliminary data suggests that a UV254 reading of between 0.15 and 0.2 is a threshold where increased TOC and precursors are present and additional treatment or alternative sources such as Hoopes may be desired.
- The detection rates of *Cryptosporidium* and *Giardia* suggest there is greater than normal presence of protozoa at the Brandywine and Porter intakes.
- Pharmaceuticals have been detected in the Brandywine Creek including pharmaceuticals from both human and livestock sources.
- Nutrient spikes during spring wet weather events suggest agriculture and suburban runoff are considered the greatest sources of nutrients with agriculture considered the greatest priority
- Approximately one third to one half of the algae observed was filter clogging or nuisance algae. This suggests a potential for future taste & odor issues.
- Chloride and conductivity appear to have the most pronounced and continuous increasing trends from the early 1970s to current periods in the Lower Brandywine. There is no indication that this trend is "leveling off" or diminishing.
- Alkalinity and hardness appear to have increasing trends that mirror that of chloride and conductivity, but appear to be related to groundwater and base flow changes. If baseflow is reduced in the watershed and surface runoff is increased over time, the proportion of observations in the higher TOC removal categories will increase.
- Total phosphorus appears to be decreasing while total orthophosphate concentrations remain relatively unchanged.
- Nitrate concentrations historically increased since the 1970s, but appear to be leveling off in recent years while ammonia concentrations have decreased historically.
- Dissolved oxygen concentrations appear to have some limited decreasing trend since the mid 1980s.

Raw water quality can have significant impacts on water treatment and finished water quality. Some contaminants are easily removed by the water treatment process. Other contaminants can actually have a negative impact on the water treatment process performance, require additional treatment, or affect distribution system chemistry such as corrosion control. Table 2-21 summarizes the general contaminant groups and their importance to water treatment.

Table 2-21 – Summary of Generalized Water Treatment & Distribution Impacts from Raw Water Quality

Contaminant Group	Water Treatment Removal	Water Treatment Impact	Distribution System Impact	Finished Water Impact
Disinfection by Product Pre-cursors	Medium	Higher Chlorine demand & more chemicals added	biofilm	Higher Disinfection by-products
Pathogens (Cryptosporidium)	Low	N/A	N/A	Increased Risk of Gastrointestinal illness
Turbidity	High	More treatment chemicals added	N/A	Increased Risk of Gastrointestinal illness
Nutrients (ammonia, nitrate, etc.)	Low	Higher Chlorine demand	biofilm & corrosion control	Plumbing corrosion impacts
Algae	Medium	Filtration clogging, more frequent backwashing	N/A	taste & odor complaints
Metals	High	Higher chlorine demand	Corrosion control	Plumbing corrosion impacts
Trace Organics	Low	N/A	biofilm	N/A
Chloride & Sodium	Low	Limits chemical salt addition for coagulation	N/A	taste & plumbing corrosion
Hardness & Alkalinity	Medium	Affects coagulation chemistry & TOC control	Corrosion control	taste, scaling, plumbing

2.3.1. Summary of Wilmington Intake Water Quality Data (1996-2007)

Intake data for the City of Wilmington raw water intake was analyzed for the period from 1996 to 2007. Analysis included basic statistics, seasonal variation, and potential correlation with other parameters. The maximum, minimum, and average concentrations are shown in Table 2-22 and Figure 2-21. As shown the most variable data is pathogens which by the very nature of the analytical method can create a 100 fold variation. Then metals and nutrients are the next in terms of overall variability. Inorganics exhibit natural variability given it's a surface water body with a large drainage area. Finally, disinfection by product pre-cursors exhibit the least variability of all the contaminants, but are important because though low variability is observed, even small variability in pre-cursors can have a great impact on DBP formation during drinking water treatment.

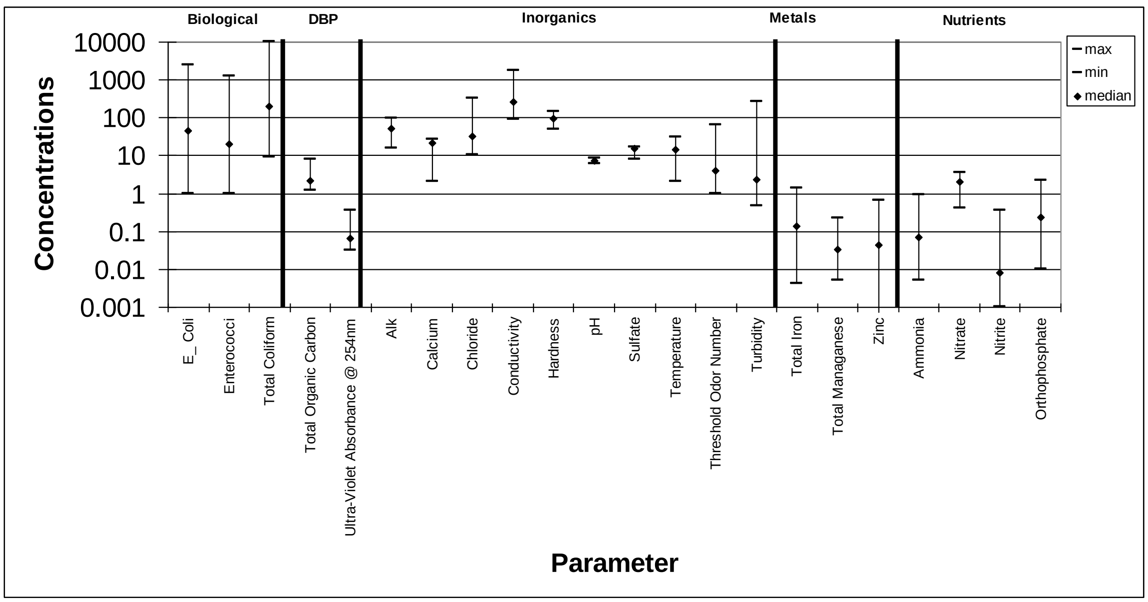


Figure 2-21 – Concentration Ranges for Various Parameters in Wilmington's Raw Water

Table 2-22 - Summary of Wilmington Raw Water (Brandywine Creek) Water Quality 1996 - 2007

Group	Parameter	max	min	average	95% confidence limit (upper)	95% confidence limit (lower)	median	standard deviation	90th percentile	count (N)
Biological	E. Coli	2419.2	1	182.1	224.3	140.0	45.3	432.7	291.9	405
	Enterococci	1226.2	1	96.9	173.4	20.5	19.7	230.8	256.2	35
	Total Coliform	9805	9	778.8	861.8	695.7	200.5	953.1	2419.2	506
DBP	Total Organic Carbon	7.69	1.2	2.5	2.6	2.3	2.1	1.0	3.8	336
	UV 254 Absorbance	0.36	0.031	0.079	0.083	0.076	0.065	0.0455	0.135	592
Inorganic	Alkalinity	94	15	52.6	53.0	52.2	52.0	9.2	64.0	2447
	Calcium	26	2	20.5	21.7	19.3	22.0	6.1	25.0	95
	Chloride	313	10	35.1	35.6	34.6	33.0	12.7	44.0	2449
	Conductivity	1720	90	269.3	271.7	267.0	270.0	59.6	320.0	2500
	Hardness	141	50	93.1	94.2	92.0	94.0	13.9	110.0	652
	pH	8.6	6.2	7.4	7.4	7.3	7.4	0.2	7.7	2582
	Sulfate	16.87	8.04	13.9	15.7	12.1	15.2	3.0	16.3	11
	Temperature	30	2	15.1	15.4	14.8	14.0	6.9	25.0	2080
	Threshold Odor Number	4	1	3.97	4	3.91	4	0.29	4	106

Group	Parameter	max	min	average	95% confidence limit (upper)	95% confidence limit (lower)	median	standard deviation	90th percentile	count (N)
	Turbidity	260	0.46	6.4	7.0	5.8	2.4	15.7	11.1	2587
Metals	Total Iron	1.401	0.004	0.2	0.2	0.2	0.1	0.2	0.3	396
	Total Manganese	0.221	0.005	0.0	0.1	0.0	0.0	0.0	0.1	119
	Zinc	0.662	0.0003	0.1	0.1	0.0	0.0	0.1	0.1	438
Nutrients	Ammonia	0.9	0.005	0.1	0.1	0.1	0.1	0.1	0.3	129
	Nitrate	3.6	0.4	2.1	2.2	2.0	2.1	0.6	2.9	143
	Nitrite	0.36	0.001	0.0	0.0	0.0	0.0	0.0	0.0	127
	Orthophosphate	2.2	0.01	0.3	0.3	0.3	0.2	0.1	0.4	623

Note: yellow highlights represent concentrations that have potential to create operational challenges:

Red represents concentrations that would exceed an MCL for finished water and therefore require removal by water treatment

2.3.2. General Potential Seasonal and Source Impacts

Based on the analysis of the seasonal impacts of the water quality data provided in later sections, the most important findings are provided in Table 2-23. Table 2-24 provides the detailed findings for all the contaminants analyzed. As shown in Table 2-23, wastewater, urban and suburban runoff, and agriculture are the three potentially greatest significant and driving sources that impact water quality at the Wilmington intake. In addition, the impacts of these activities on the hydrologic cycle and baseflow as well as peak storm flows are reflected in the observed intake data. Overall, the data suggests that wastewater discharges have the greatest dry weather impact on overall priority contaminants for water treatment in the Brandywine Creek. Urban/Suburban Stormwater Runoff and Agricultural Runoff (seasonal) tend to have the greatest impact on wet weather water quality. Some studies have suggested that runoff related contaminants such as bacteria can also have dry weather affects as they are released from sediment (Cinotto, 2006). Overall, wet weather sources are considered the most significant source of all contaminants except for pathogens and emerging contaminants such as personal care products and pharmaceutical compounds which require more study.

Table 2-23 - Summary of Priority Contaminants by Potential Impact

	Potential General Priority Contaminant Sources	
Priority Contaminant or Contaminant Group	**Dry Weather**	**Wet Weather**
Flow*	Wastewater discharges & groundwater withdrawals	Urban/Suburban Stormwater Runoff
Pathogens	Wastewater & sediment regrowth/release	Agriculture, wildlife, sediment resuspension, suburban runoff
Disinfection By Products	Wastewater	Trees, agriculture, urban/suburban stormwater runoff
Algae	Wastewater	Agriculture
Chlorides	Wastewater	Road Salt Runoff
Turbidity	Construction & accidents	Urban/Suburban Stormwater Runoff & Agriculture
Alkalinity	Groundwater	Urban/Suburban Stormwater Runoff
Nutrients	Wastewater	Agriculture & Urban/Suburban Stormwater Runoff
Metals	Groundwater	Urban/Suburban Stormwater & Road Runoff
Trace Organics (includes pharmaceuticals)	Wastewater	Agriculture & Urban/Suburban Stormwater Runoff

* flow is not a regulated contaminant, but has a major impact on the concentrations and loads of all contaminants and therefore hydrologic impacts must be considered in a source prioritization.

Table 2-24 – Summary of Seasonal Impacts and Potential Source Information

Group	Parameter	Dry Weather Potential Sources	Wet Weather Potential Sources	Peak value of record	Season(s) Peak Values Occur	Lowest value of record	Season(s) Lowest Values Occur	Preliminary Potential Dominant Source - dry weather	Preliminary Potential Dominant Source - wet weather
	E. Coli	wastewater, septic systems, defective laterals, animal sources	wildlife, livestock, urban/suburban stormwater	N/A	Winter/Spring	N/A	Summer	wastewater	agriculture & urban/ suburban stormwater
	Enterococci	wastewater, septic systems, defective laterals, animal sources	wildlife, livestock, urban/suburban stormwater	N/A	Winter/Spring	N/A	Summer	wastewater	agriculture & urban/ suburban stormwater
Biological	Total Coliform	wastewater, septic systems, defective laterals, animal sources	soils, wildlife, livestock, urban/suburban stormwater	N/A	Summer	N/A	Spring	unknown	soil related sources
	Total Organic Carbon	wastewater	spring due to near bank sources of plant organics, fall due to canopy material		May/June and Sept to Dec		late winter to early spring	unknown	unknown
DBP	UV 254 Absorbance	wastewater	spring due to near bank sources of plant organics, fall due to canopy material		May/June and Sept to Dec		late winter to early spring	unknown	unknown
	Alkalinity	groundwater	urban/suburban stormwater	2/00, 9/02, 10/99	Fall	1/99, 4/00	winter	groundwater	urban/suburban stormwater
	Calcium	groundwater	urban/suburban stormwater	August 2003	April, July, August			groundwater	urban/suburban stormwater
	Chloride	wastewater & industrial discharges	road salting	January 1999	early winter to early spring		late spring (May)	unknown	road salting
	Conductivity	wastewater & industrial discharges	urban/suburban stormwater	January 1999	early winter to early spring		late spring (May)	unknown	road salting
	Hardness	groundwater	urban/suburban stormwater	August 2003	April, July, August			groundwater	urban/suburban stormwater
	pH	algae	urban/suburban stormwater	N/A	April, July, August			wastewater	agriculture
	Sulfate	groundwater	urban/suburban stormwater					groundwater	urban/suburban stormwater
	Temperature	wastewater & industrial discharges	urban/suburban stormwater	8/06, 7/99	Summer	3/07, 12/00, 1/96	winter	wastewater	urban/suburban stormwater
	Threshold Odor Number	algae							
Inorganic	Turbidity	construction sites & accidents	Stream erosion from urban/suburban stormwater, agriculture					unknown	agriculture & urban/ suburban stormwater
	Total Iron	groundwater	urban/suburban stormwater	1999 drought	spring, summer, fall		winter	groundwater	urban/suburban stormwater
	Total Managanese	groundwater	urban/suburban stormwater	1999 drought	late spring/early summer		winter	groundwater	urban/suburban stormwater
Metals	Zinc	groundwater	urban/suburban stormwater	1999 drought	winter & spring		fall	groundwater	urban/suburban stormwater
	Ammonia	agriculture, wastewater, septic systems	agriculture, urban/suburban stormwater		winter/spring	summer 2002 drought	summer	wastewater	agriculture
	Nitrate	agriculture, wastewater, septic systems	agriculture, urban/suburban stormwater		winter	summer 2002 drought	summer	wastewater	agriculture
	Nitrite	agriculture, wastewater, septic systems	agriculture, urban/suburban stormwater		winter	summer 2002 drought	summer	wastewater	agriculture
Nutrients	Orthophosphate	agriculture, wastewater, septic systems	agriculture, urban/suburban stormwater		spring	summer 2002 drought	summer	wastewater	agriculture
	Algae	agriculture, wastewater, septic systems	urban/suburban stormwater	N/A	N/A	N/A	N/A	wastewater	agriculture
	Cryptosporidium	agriculture, wastewater, septic systems, animals	wildlife, livestock, urban/suburban stormwater	N/A	N/A	N/A	N/A	wastewater & sewage	agriculture & wildlife
	Giardia	agriculture, wastewater, septic systems, animals	wildlife, livestock, urban/suburban stormwater	N/A	N/A	N/A	N/A	wastewater & sewage	agriculture & wildlife
	EDCs	wastewater & industrial discharges	agriculture, urban/suburban stormwater	N/A	N/A	N/A	N/A	wastewater	agriculture & wildlife

2.3.3. Inorganics

Table 2-25 and Figure 2-22 provide a summary of the ranges of inorganics concentrations in the raw water at the Wilmington intake from 1996 to 2007. Conductivity was the most variable parameter followed by chloride, turbidity, and hardness. pH stayed within a limited range of 6.2 to 8.4 with an average of 7.4.

Table 2-25 - Inorganics Concentrations at the Wilmington Intake: 1996 To 2007

Parameter	Alkalinity	Calcium	Chloride	Conductivity	Hardness	pH	Temperature	Turbidity
max	94	26	313	1720	141	8.6	30	260
min	15	2	10	90	50	6.2	2	0.46
average	52.6	20.5	35.1	269.3	93.1	7.4	15.1	6.4
median	52	22	33	270	94	7.36	14	2.4
std. dev.	9.21	6.15	12.66	59.56	13.87	0.24	6.94	15.73
90%tile	64	25	44	320	110	7.7	25	11.1
N	2447	95	2449	2500	652	2582	2080	2587

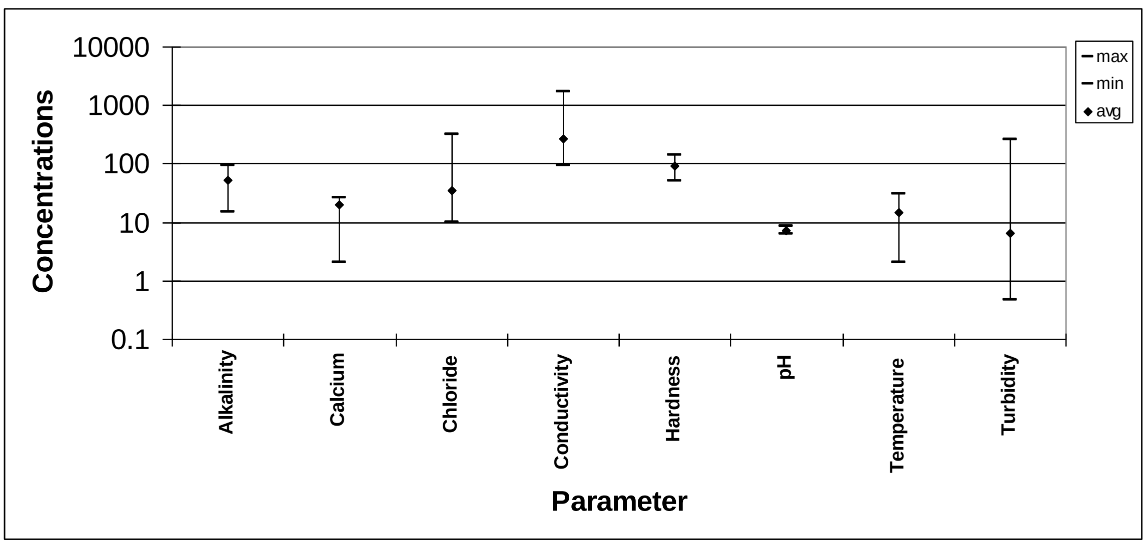


Figure 2-24 - Summary of Inorganics Concentrations at the Wilmington Intake from 1996 To 2007

As shown in Figure 2-25, the greatest conductivity occurred during January 1999 and

January 2002. The greatest chloride occurred during January 1999. The greatest turbidities were observed during November 2002, April 2004, and June 2006 (after a tropical depression). The lowest chloride and conductivity values were observed on 9/17/99 after Hurricane Floyd. The warmest water temperatures occurred during August 2006 and July 1999. The coldest water temperatures occurred during March 2007, December 2000, and January 1996. The greatest hardness was observed on August 2003. The greatest alkalinity was in February 2000, September 2002, and October 1999. The lowest alkalinity concentrations were observed from January 1999 to April 2000.

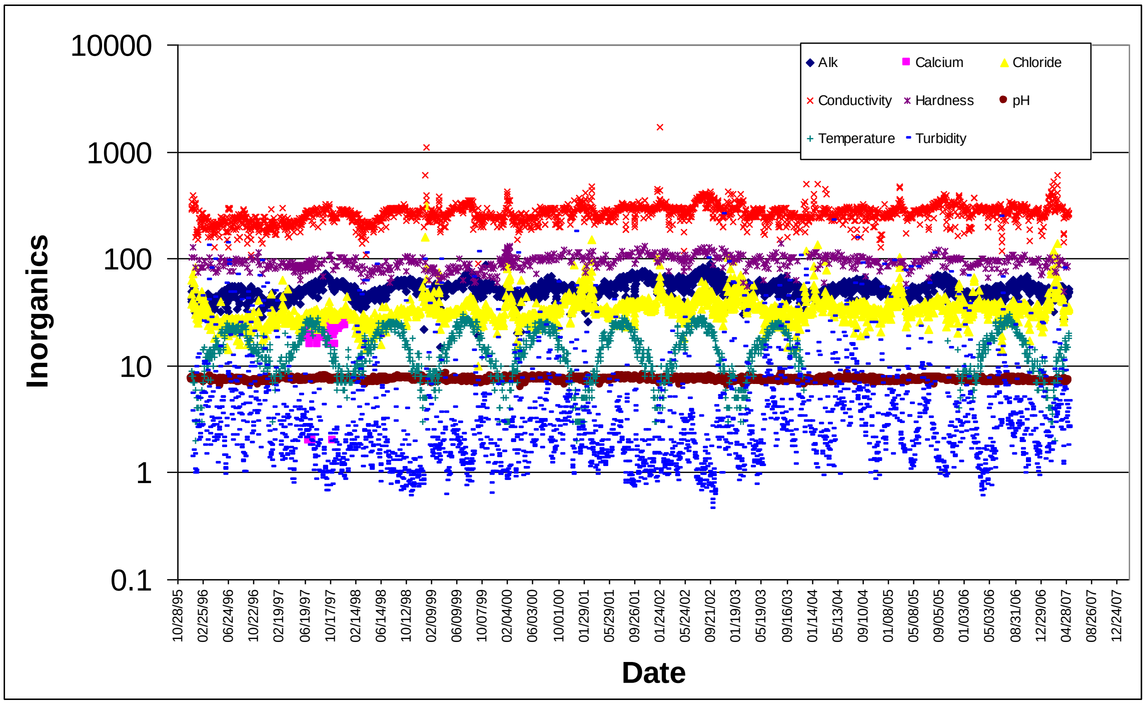


Figure 2-25 - Comparison of Daily Measurements of Inorganics at the Wilmington Intake 1996 - 2007

2.3.4. Chloride & Conductivity Trends From Road Salts

Based upon preliminary review of Wilmington's intake data from 1996 to 2007, it is apparent that the highest conductivity and chloride concentrations appear during the months of December, January, February, and March (see Figures 2-26 to 2-28). Smaller increases in chloride and conductivity are observed in the summer months as well. Chloride and conductivity may appear to correlate well, but by basic linear regressions fail to achieve a significant R squared value of 0.9 or greater (see Figure 2-29). However, chloride and conductivity extreme concentrations do appear to have some limited correlation (Figure 2-30). The greatest chloride and conductivity concentrations do not trend with alkalinity seasonally (alkalinity is at a maximum during fall months) suggesting that groundwater influence or baseflow discharge sources are not dominant. The conductivity and chloride impact appears to not be linked to upstream point source discharge increasing with decreasing baseflow (i.e. higher alkalinity). When loadings from 2006 to 2007 were evaluated, loads were greater during the periods of snowfall and freezing conditions (see Figure 2-31). Based upon these findings, the greatest chloride and conductivity concentrations appear to be linked with road and sidewalk salt application and runoff into the Brandywine Creek.

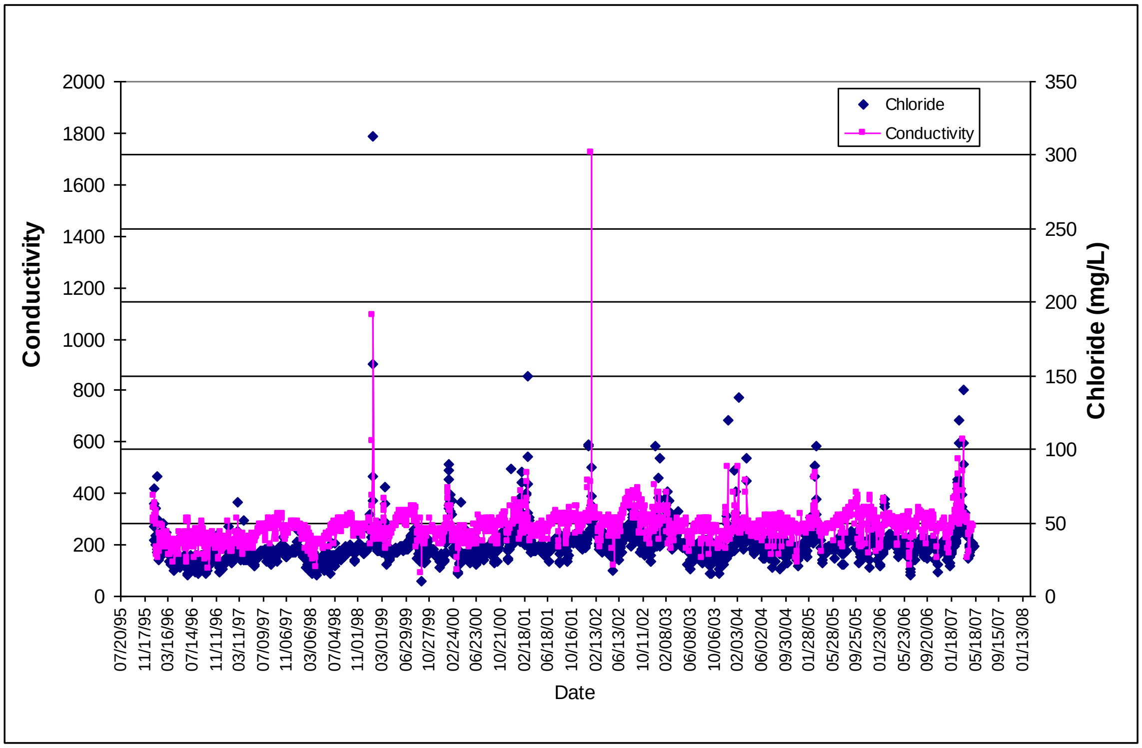


FIGURE 2-26 - Concentrations of Chloride and Conductivity at Wilmington's Intake (1996-2007)

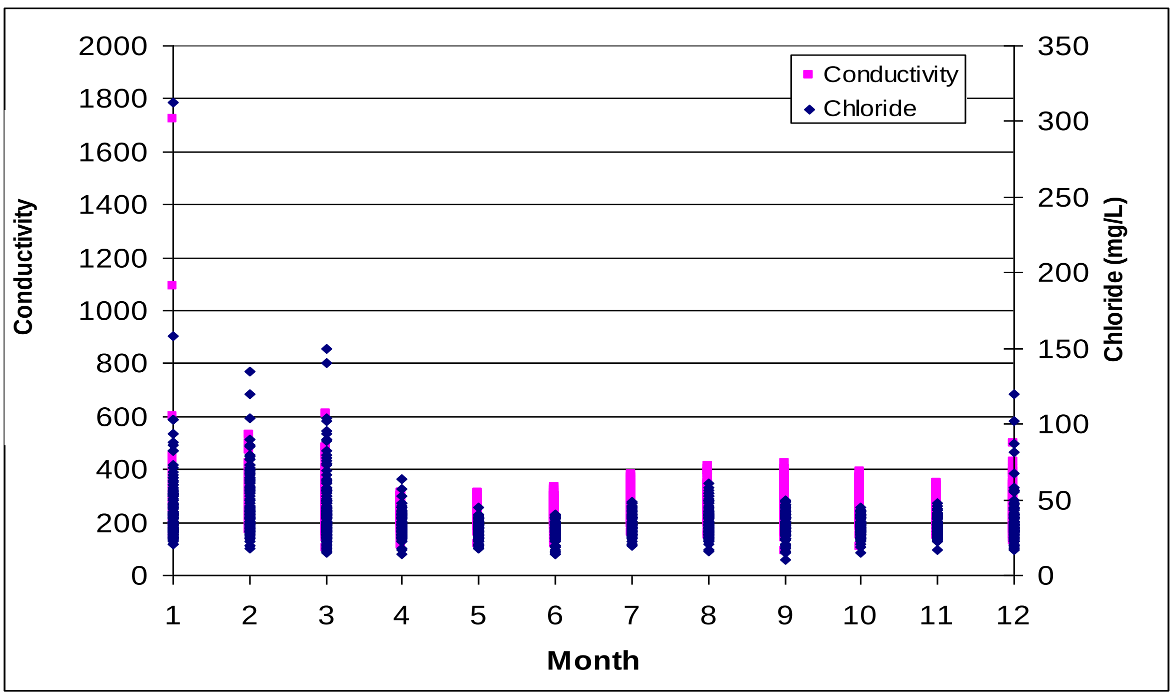


Figure 2-27 - Comparison of Chloride and Conductivity at Wilmington's Intake by Julian Month (1996-2007)

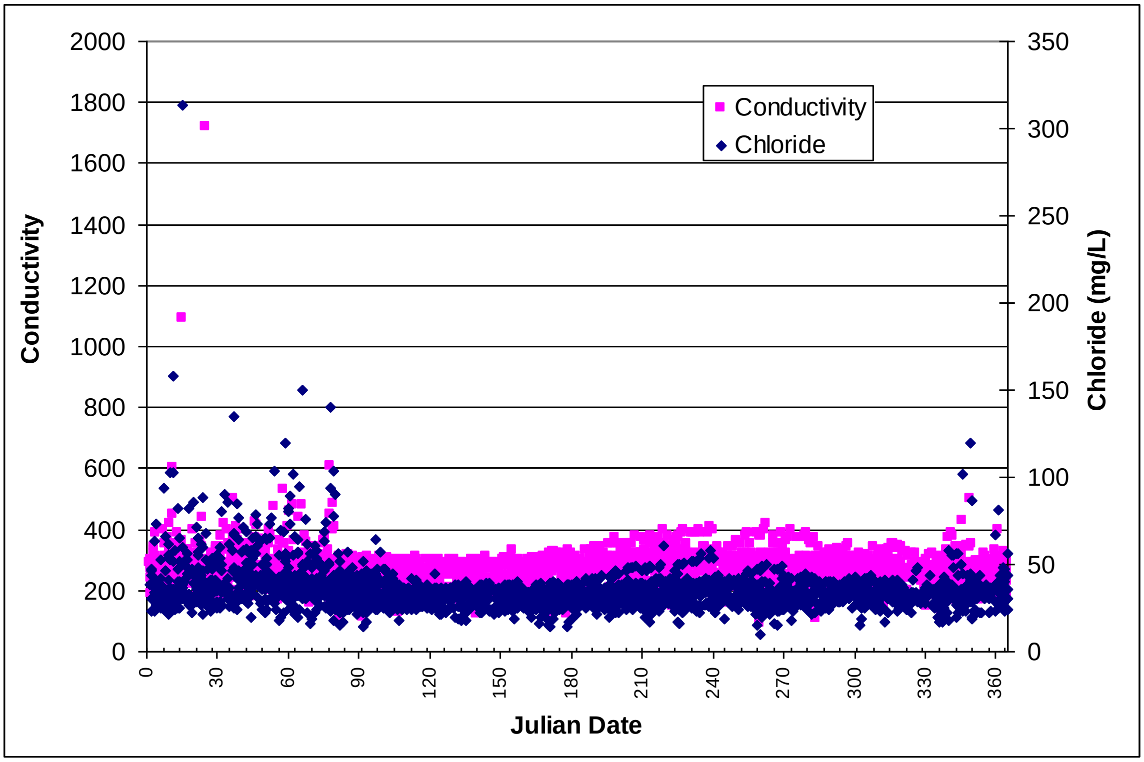


Figure 2-28 - Comparison of Chloride and Conductivity Concentrations at Wilmington's Intake by Julian Date (1996-2007)

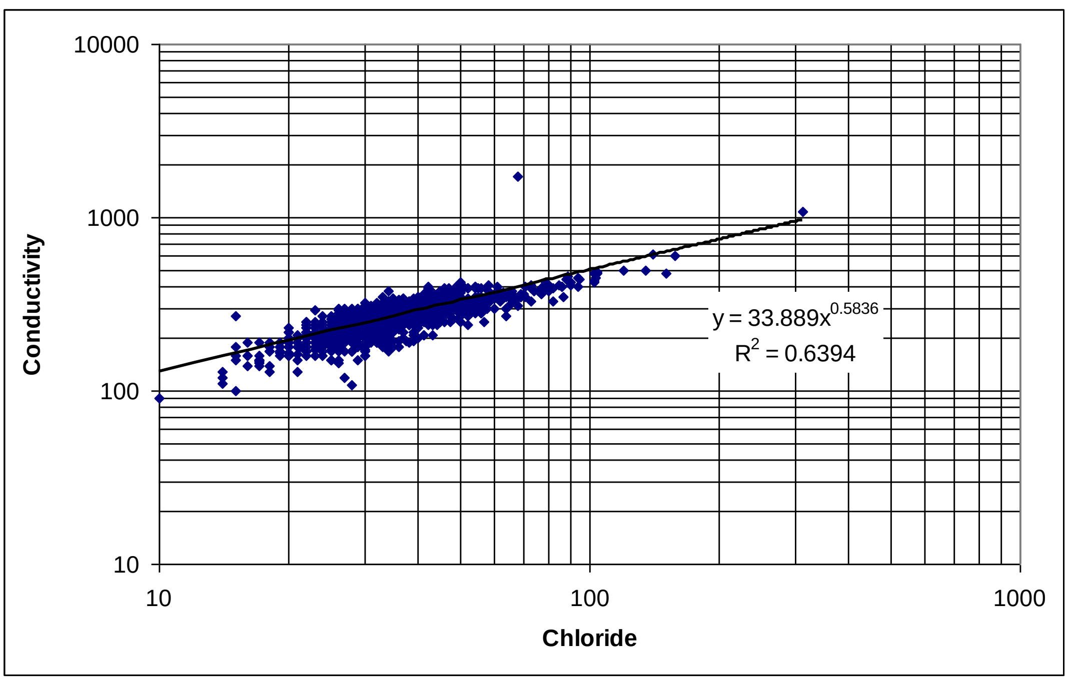


Figure 2-29- Comparison of Regression between Chloride and Conductivity Concentrations at Wilmington's Intake by Month (1996-2007)

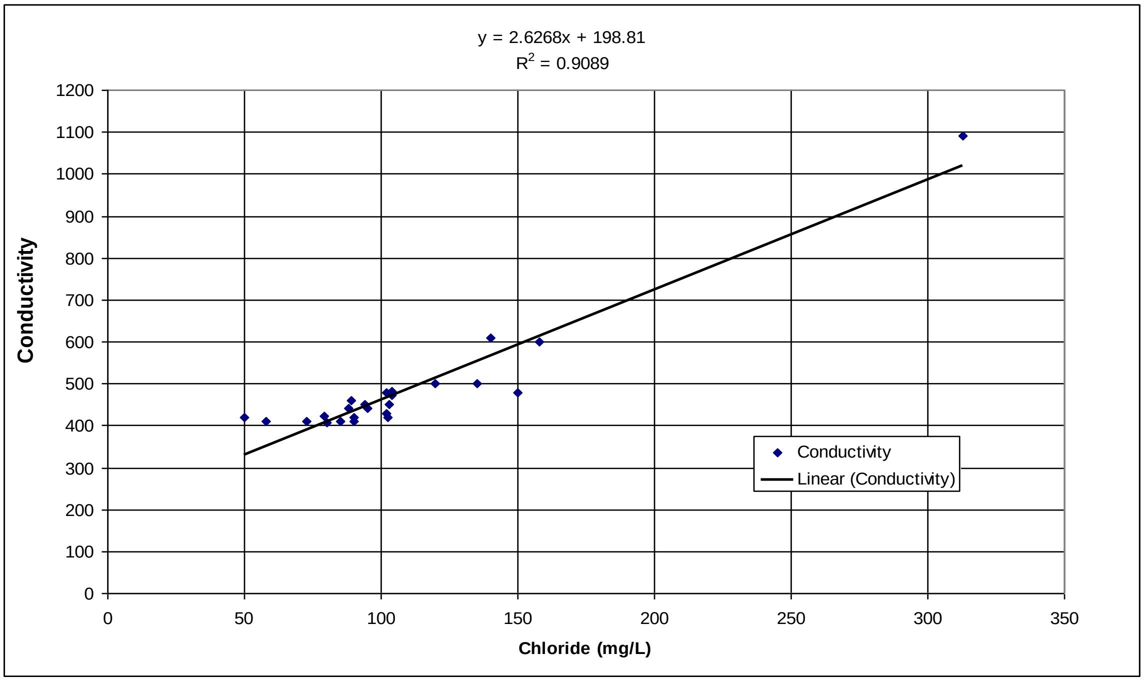


Figure 2-29 - Comparison of Regression between Chloride and Conductivity Concentrations at Wilmington's Intake for Extreme Concentrations

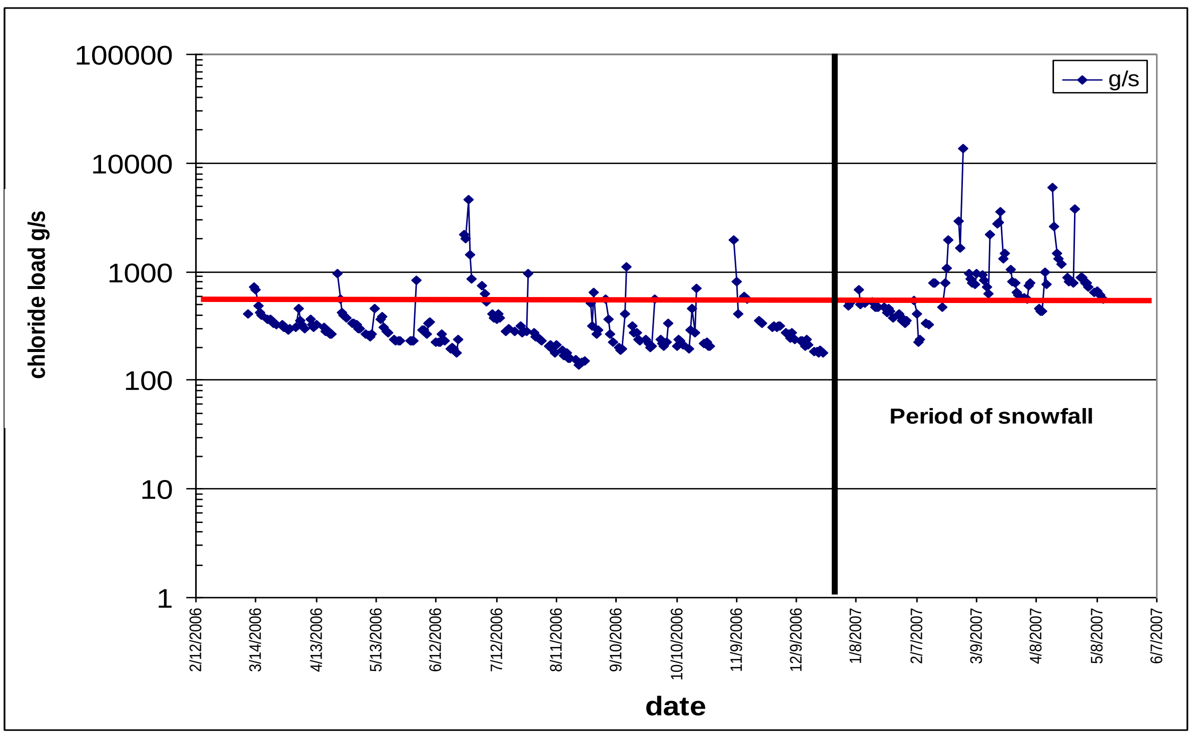


Figure 2-31- Chloride Loads (Flow*Concentration) For the Brandywine Creek at the Wilmington Intake For 2006 To 2007

Table 2-26 provides a summary of the concentrations of chloride, conductivity, and alkalinity for Wilmington's intake between 1996 and 2007. Chlorides ranged from 10 to 313 mg/L with a median concentration of 33 mg/L (std. dev. 20 – 46 mg/L). Wilmington's raw water chloride concentration is therefore not considered unpolluted using the 10 mg/L threshold established by the World Health Organization.

Table 2-26- Summary of Wilmington Intake Concentrations 1996-2007

Parameter	Chloride	Conductivity	Alkalinity
max	313	1720	94
min	10	90	15
avg	35	269	53
median	33	270	52
stdev	13	60	9
90%tile	44	320	64
N	2449	2500	2447

It is important to note that the chlorination process and the coagulation process (using ferric or aluminum salts) will inherently increase the finished water chloride concentration. Therefore, using estimates of chloride impacts from chlorination plus a safety factor for impacts from coagulation salts, intake concentrations beyond 150 mg/L to 200 mg/L could represent periods when the finished water could approach the SMCL of 250 mg/L depending upon the impact of the chemical water treatment process. This would indicate periods of potential customer complaints or noticeable taste.

2.3.5. Alkalinity Impacts on TOC Removal and Corrosion Control

A comparison of the TOC and alkalinity data from 2004 to 2007 (199 observations) was conducted to estimate the required TOC removal for Wilmington (Figures 2-32 to 2-34). Based on these observations it is estimated that 35% of the TOC in the raw water would need to be removed over 75% of the time. 25% and 45% of the TOC would need to be removed during 11% and 14% of the time, respectively. Currently, the average alkalinity is 52 mg/L at Wilmington's intake with a standard deviation of 9 mg/L. This means that 67% of the observations were between 61 mg/L and 43 mg/L, just under or near the 60 mg/L alkalinity threshold for TOC removal changes from 35% to 45%. If baseflow is reduced in the watershed and surface runoff is increased over time, the proportion of observations in the higher TOC removal categories will increase. If baseflow is protected and enhanced then lower TOC removal categories will increase. Though higher alkalinity will mean lower TOC reduction requirements it also means that TOC reduction will be more difficult to achieve. TOC reduction requirements appear to be the greatest during periods of greater surface runoff such as winter and spring when alkalinity tends to be lower and TOC can achieve higher concentrations.

Alkalinity and hardness are directly affected by baseflow from groundwater sources. Any changes in baseflow from lack of groundwater recharge of rainfall or increases in surface runoff could have significant impacts on alkalinity and hardness driving it downward. This may have a mixed impact on water treatment since lower alkalinity will make corrosion control more difficult and expensive for lead and copper control (via addition of more lime and zinc orthophosphate) while TOC removal may be easier to achieve despite higher required TOC removals. Also, the water could reduce in hardness and result in improved usage by various specialized industrial user sectors.

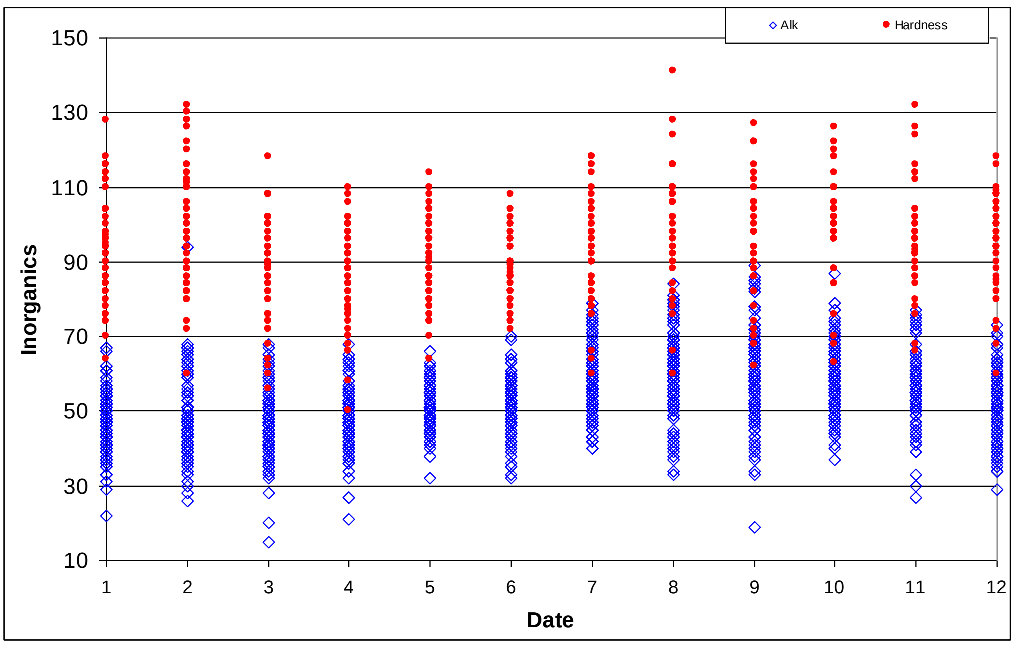


Figure 2-32 - Comparison of Alkalinity and Hardness Seasonal Trends at the Wilmington Intake 1996-2007

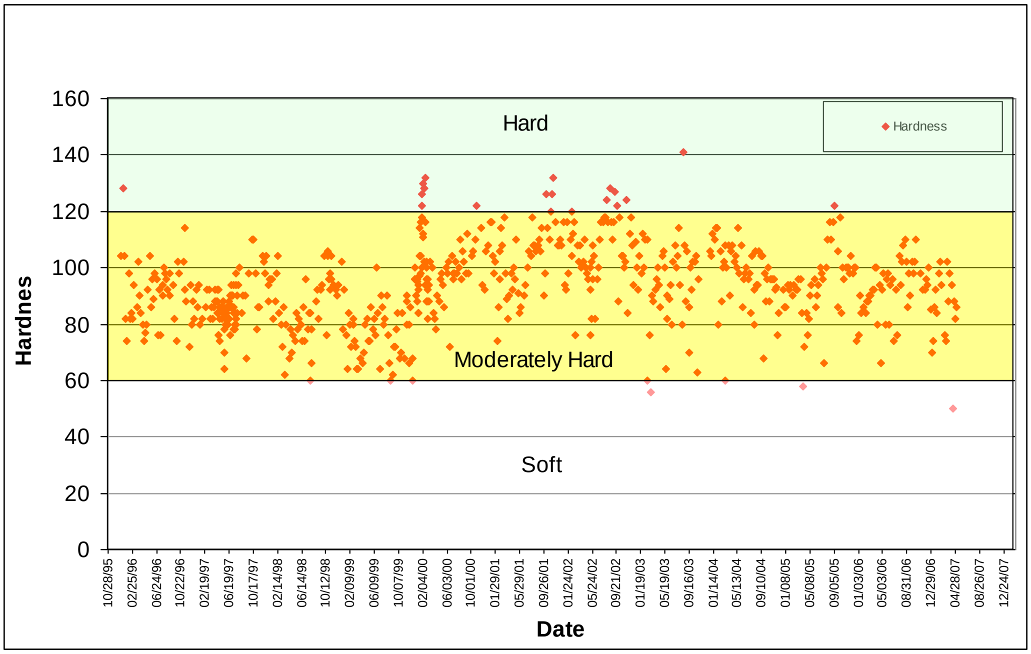


Figure 2-33 - Hardness Trends at the Wilmington Intake 1996-2007

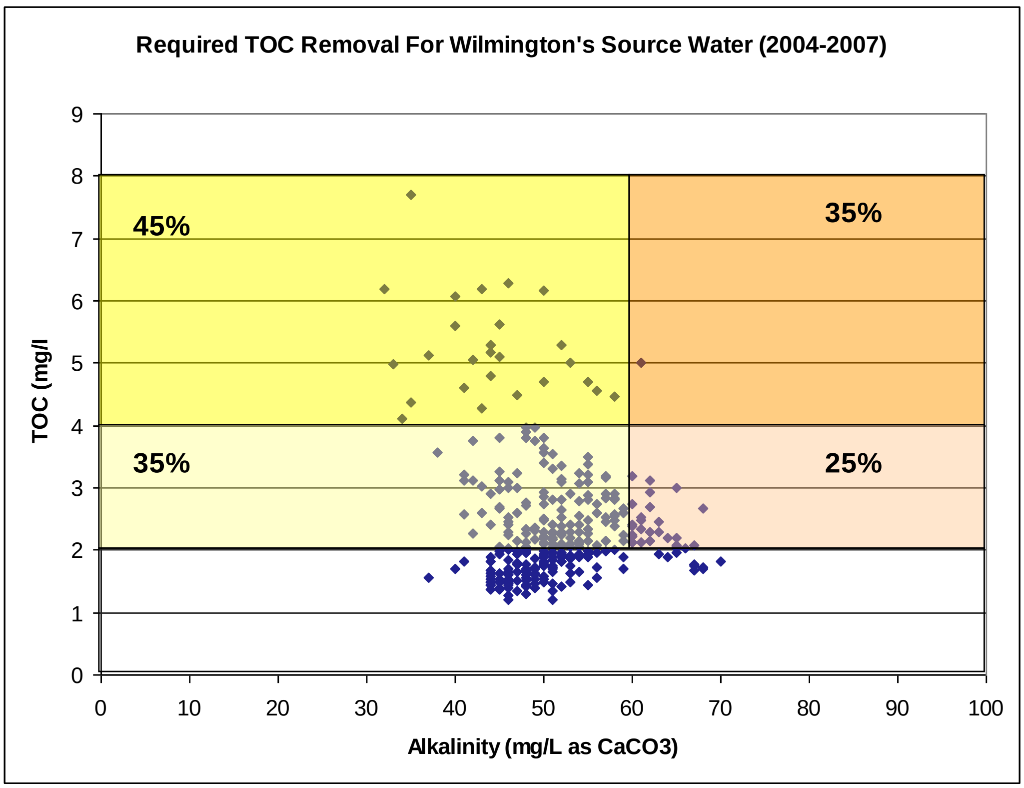


Figure 2-34 - Alkalinity and TOC Removal at the Wilmington Intake 1996-2007

2.3.6. High Turbidity Impacts on Wilmington Intake Water Quality and Treatment

An analysis of water quality at the Wilmington intake from 1996 to 2007 identified the following conditions related to intake turbidities of greater than 10 NTU:

- *E. coli* bacteria levels in the raw water increase to undesired levels (see Figure 2-35) and research studies of *Cryptosporidium* in the region suggest that turbidities over 10 NTU usually have elevated levels and more frequent presence of *Cryptosporidium* oocysts. The LT2ESWTR monitoring to date for Wilmington is not complete enough or designed collect data to determine if the same relationships are appropriate for the Brandywine. Therefore, until enough data is available a conservative assumption that higher turbidity raw water will have greater pathogen potential should be considered.

- UV absorbance and Total Organic Carbon (TOC) have the potential to (but will not always) increase to levels that represent potential challenges for Disinfection by product (DBP) precursors (see figures 2-36 & 2-37)

- A strong correlation between raw water UV254 and TOC exists suggesting UV254 can be a good operational predictor of TOC levels in the raw water (see Figure 2-38).

- A UV254 absorbance of greater than 0.2 would potentially result in approximately 5.5 mg/L of TOC in the raw water.

- A UV254 reading of between 0.15 and 0.2 is a threshold where increased TOC and precursors have the potential to be present and additional treatment or switching to Hoopes Reservoir may be desired.

- A UV254 reading of over 0.2 was almost always associated with turbidities of 10 NTU or greater suggesting this is a potential period to avoid.

- Ammonia levels over 0.35 mg/L have occurred at turbidities greater than 10 NTU. Higher ammonia levels represent periods of greater chlorine demand to maintain appropriate chlorine residuals.

- Switching to Hoopes for better water quality during periods greater than 10 NTU is recommended for better LT2ESWTR and Stage 2 DBPR compliance

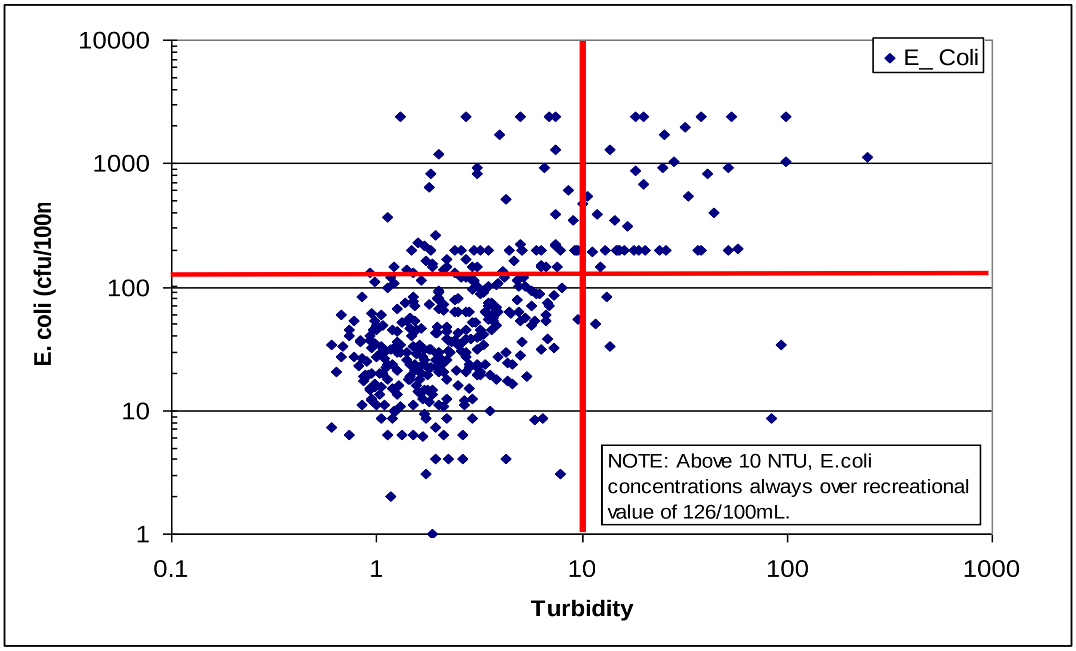


Figure 2-35 - Comparison of E. Coli and Turbidity Concentrations at the Wilmington Intake from 1996 To 2007

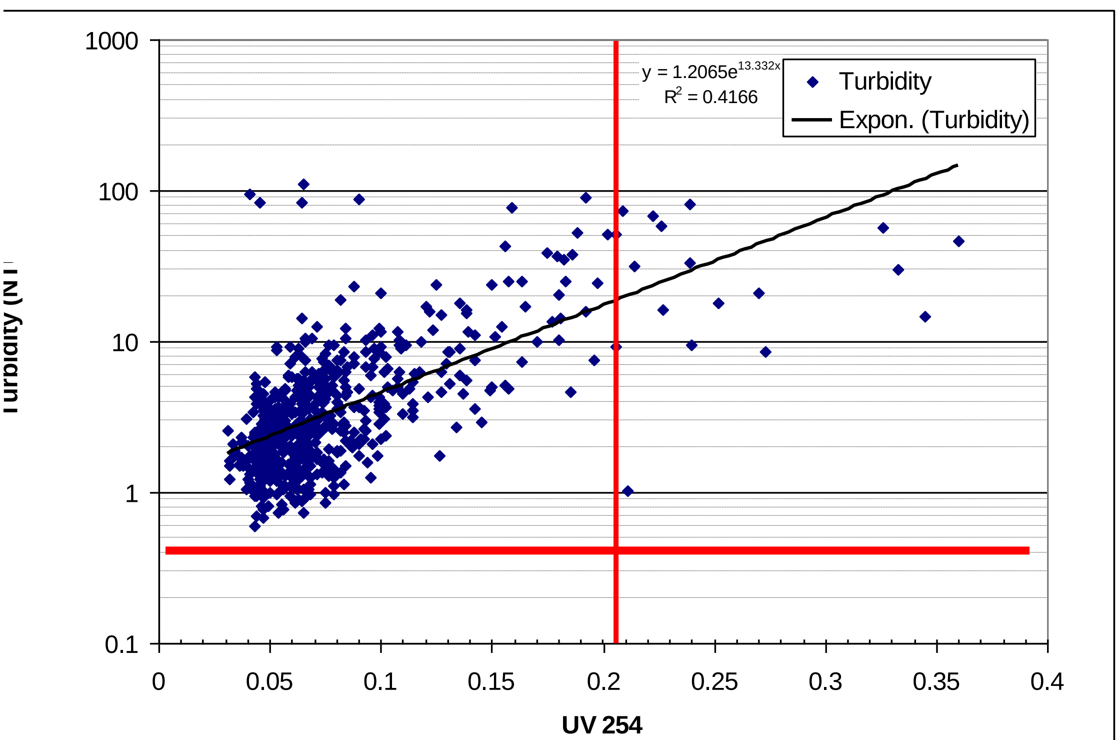


Figure 2-36 - Comparison of UV 254 Absorbance And Turbidity Concentrations at the Wilmington Intake from 1996 To 2007

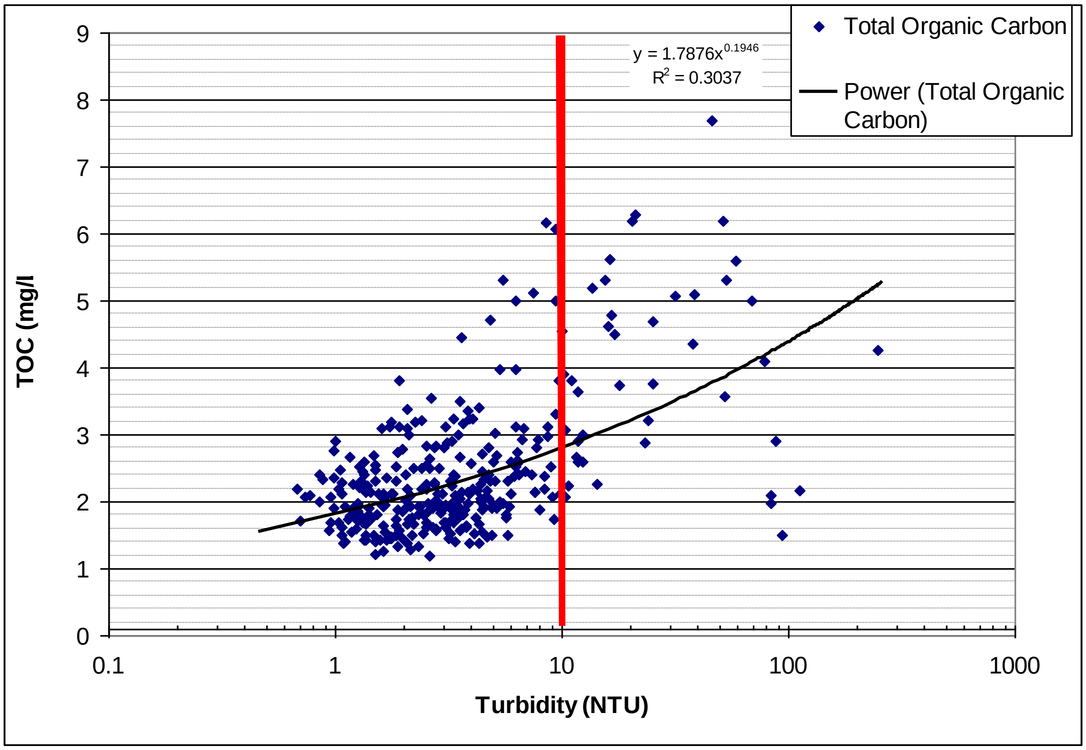


Figure 2-37 - Comparison of Total Organic Carbon and Turbidity Concentrations at the Wilmington Intake from 1996 To 2007

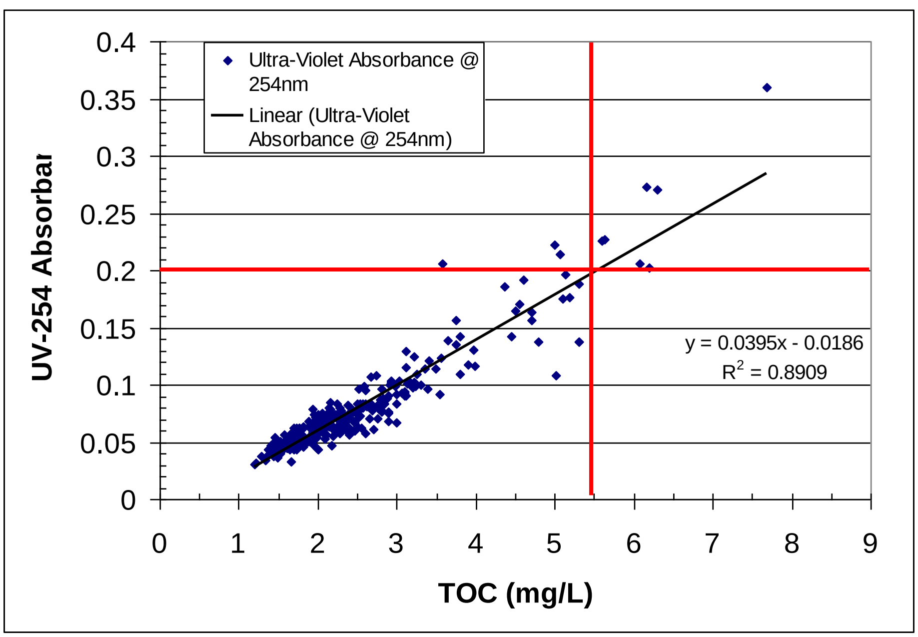


Figure 2-38- Comparison of Total Organic Carbon and UV254 Absorbance Concentrations at the Wilmington Intake from 1996 To 2007

2.3.7. Pathogens

Based on the analysis of intake data, it is not uncommon for concentrations of *E. coli* to exceed 1,000 cfu/100mL in the raw water. However, there is no direct correlation between turbidity and E. coli suggesting that not all significant pathogen levels are associated with wet weather events. A comparison of *E. coli* and turbidity does reveal that when raw water turbidity exceeds 10 NTU that *E. coli* concentrations are always above the EPA recreational limit suggesting a challenge period for pathogens (Figure 2-40).

The lowest concentrations of *E. coli* appear to occur during the summer months while the highest concentrations of *E. coli* appear to occur during the winter and spring months (See figure 2-39). Comparisons of the ratio of the *E. coli* to Total Coliform were conducted to determine periods and events when bacteria were predominately that from human sewage or animal runoff. The greatest *E. coli* and total coliform concentrations of identical values (EC/TC ratio =1) were all observed during winter during high turbidity events. These events produced concentrations of 2,420 cfu/100mL of total coliforms and *E. coli*. Only 53% of the EC/TC ratios of 1 were observed during high turbidity events (turbidity > 9 NTU). The remaining events were during turbidities that were not considered influenced by wet weather events and sources. The concentrations of *E. coli* and Total Coliform were 200 cfu/100mL during this period and suggest that pathogen sources such as sediment regrowth/release, leaking septic systems, defective laterals, direct livestock stream access, or wastewater discharges were likely sources of pathogens.

These findings suggest that runoff and wet weather sources (such as SSOs, stormwater, sediment resuspension, and animal runoff) are potentially significant sources of pathogens at the Wilmington intake responsible for the most extreme concentrations observed, but other sources during dry weather (sediment regrowth/release, leaking septic systems, cattle access to streams, defective laterals, and sewage discharges) may have greater periods of influence. Given the inaccuracy of bacteria indicator monitoring specific monitoring using bacteria source tracking and fingerprinting methods for various pathogen sources (*E. coli* and *Cryptosporidium*) should be conducted. Given the difficulty to monitor for viruses, it is not practical to conduct studies for these pathogens, but studies using indicators such as coliphages should be considered.

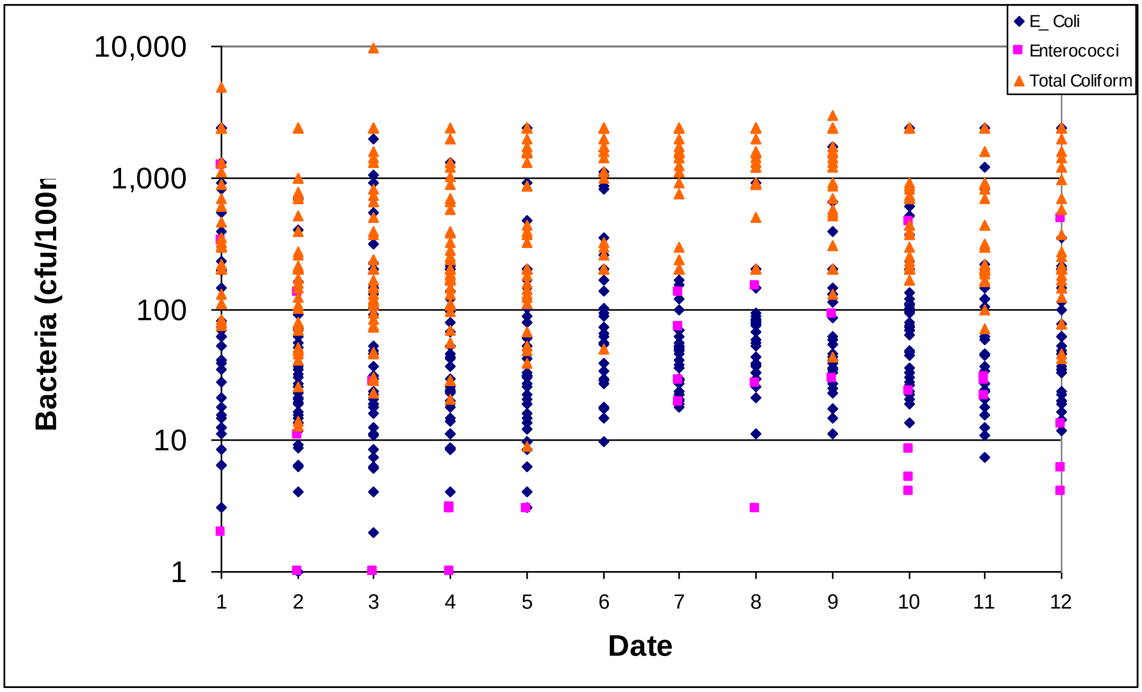


Figure 2-39 – Concentrations of Coliforms at the Wilmington Intake by Julian Month (1996-2007)

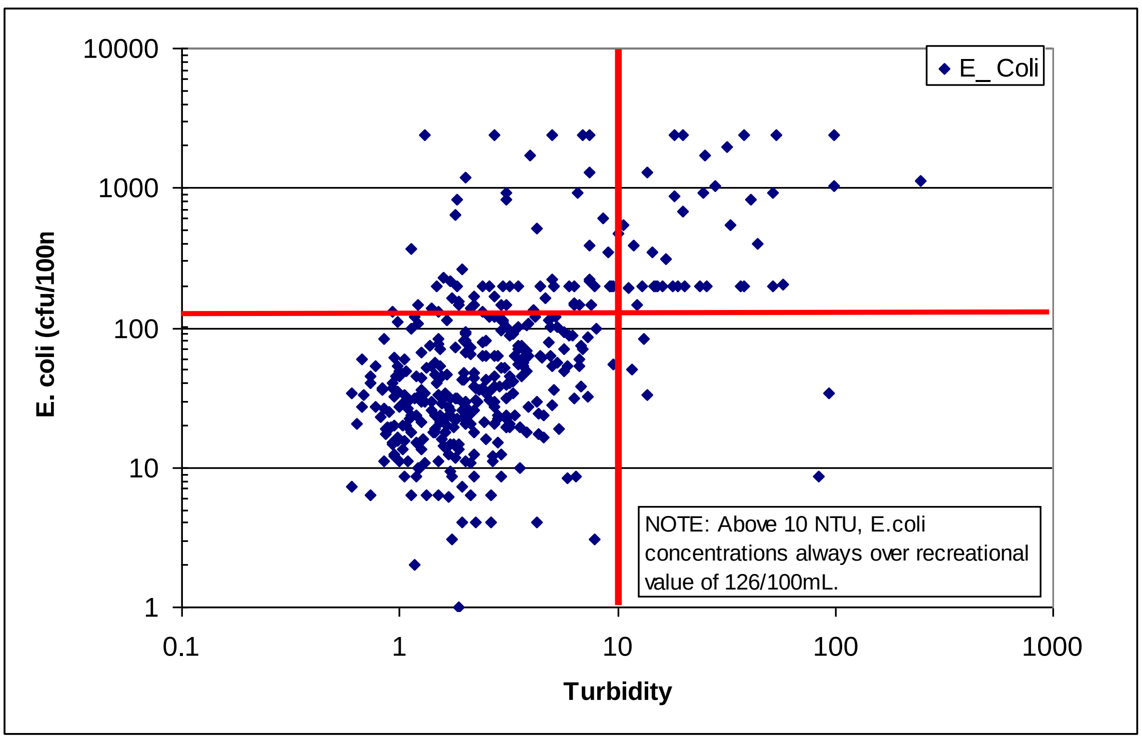


Figure 2-40 - Comparison of *E. Coli* and Turbidity at the Wilmington Intake (1996-2007)

2.3.8. Giardia and Cryptosporidium

Giardia and *Cryptosporidium* monitoring was conducted monthly at the intake to the three water treatment plants for the LT2ESWTR required bin classification monitoring. After a 24 month effort, the data does provide some information of value. As shown in Table 2-27, the average *Cryptosporidium* concentration at the Brandywine plant is three times higher than the Porter plant, while the Hoopes Reservoir has only had one *Cryptosporidium* detected despite having wildlife present. The Hoopes Reservoir had near pristine levels of *Cryptosporidium* and *Giardia*.

Though the variability of the *Cryptosporidium* testing method is significant it does suggest something is causing a potential difference (sampling method or location) between the Porter and Brandywine Intakes. It was determined that the Porter samples were collected after raw water basin settling and the Brandywine samples were collected directly at the creek. This suggests the raw water basin at Porter provides some pathogen reduction.

The mean concentration of *Cryptosporidium* at the Brandywine Plant was just less than the 0.075 oocysts/L cutoff for requiring additional treatment as stated in the LT2ESWTR. Therefore, if water quality continues to degrade, future resampling in 5 years during the "rebinning" process may push the Brandywine Plant over the regulatory threshold. This potential future degradation could require the Brandywine Plant to install additional treatment processes such as membrane filters or ultraviolet light disinfection to meet regulatory requirements by 2020.

Table 2-28 shows the concentrations of *Giardia* at the three sites. The data shows the greatest average *Giardia* concentration at the Porter plant almost two times greater than the Brandywine Plant despite the raw water basin settling effect. Comparison of frequency of detection can also be used as an indicator of contamination (see Figures 2-41 & 2-42). The Brandywine Plant had *Cryptosporidium* detected twice as often (40%) as the Porter WTP (20%). The Brandywine Plant also had *Giardia* detected more frequently than the Porter WTP despite Porter having a higher average *Giardia* concentration. Again the sampling at the Porter Plant after the settling basin compared to the sampling from the raceway at the Brandywine Plant can explain the reasons for these observations and suggests the Brandywine Plant observations of *Giardia* and *Cryptosporidium* are the most accurate reflection of intake pathogen concentrations for both plants.

It is important to note the detection rates of *Cryptosporidium* and *Giardia* suggest there is significantly frequent contamination of protozoa at the Brandywine and Porter intakes. The 20 to 42% detection rate of *Cryptosporidium* is similar to more contaminated streams and rivers nationwide, but may also be a result of higher filter volumes which provide lower overall concentrations. The *Giardia* detection rate of 85% to over 96% at the Porter and Brandywine intakes was also significantly higher than national detection rates and more similar to that of more contaminated water bodies with higher concentrations. These findings suggest some constant source of *Cryptosporidium* and *Giardia* in the watershed. Analysis of upstream disease rates is recommended and a loading analysis to predict upstream disease levels is recommended. This would include DNA fingerprinting of

Cryptosporidium in the creek and from different sources in the watershed.

TABLE 2-27 - Comparison of *Cryptosporidium* Concentrations in Wilmington's Raw Water From LT2ESWTR Monitoring (2006-2007)

Source	% positive	Average (oocysts/L)	Min (oocysts/L)	Max (oocysts/L)
Brandywine	42%	0.063	0	0.240
Porter	19%	0.029	0	0.500
Hoopes	4%	0.001	0	0.020

TABLE 2-28- Comparison of *Giardia* Concentrations in Wilmington's Raw Water From LT2ESWTR Monitoring (2006-2007)

Source	% positive	Average (cysts/L)	Min (cysts/L)	Max (cysts/L)
Brandywine	96%	0.310	0.020	1.70
Porter	85%	0.470	0	7.20
Hoopes	8%	0.002	0	0.02

TABLE 2-28 - Summary of Average *E. Coli* Concentrations in Wilmington's Raw Water From LT2ESWTR Monitoring (2006-2007)

E. coli in raw water	Brandywine Filter Plant	Porter Filter Plant	Hoopes Reservoir
Average (cfu/100mL)	139	48	2

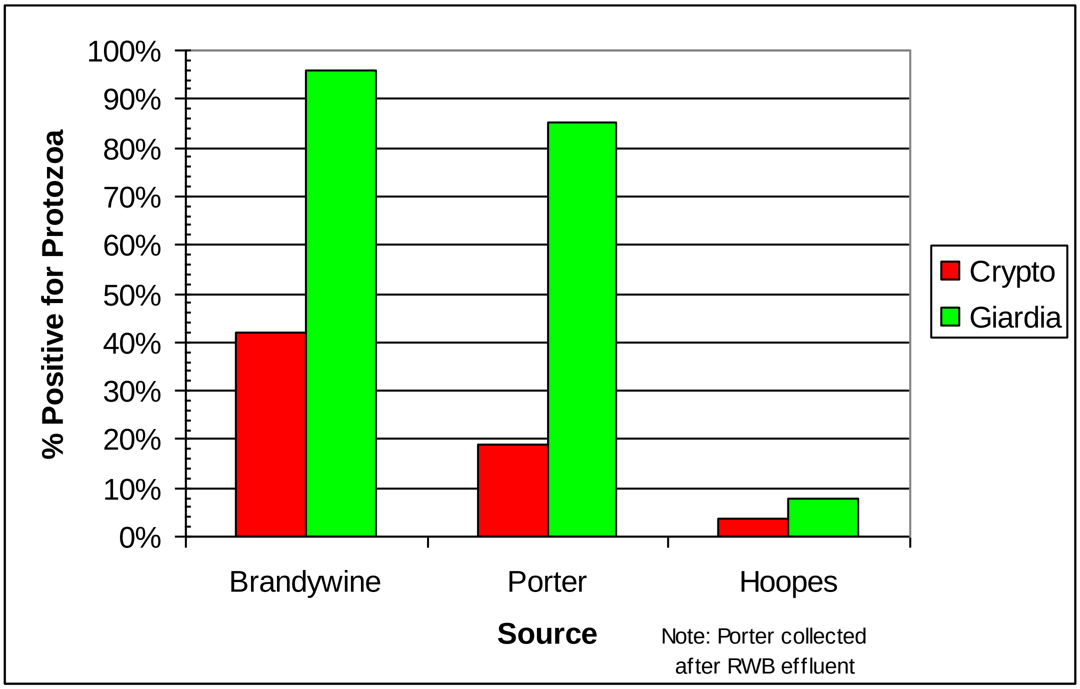


Figure 2-41 - Frequency of *Cryptosporidium and Giardia* Detection in Wilmington's Raw Water from LT2ESWTR Monitoring (2006-2007)

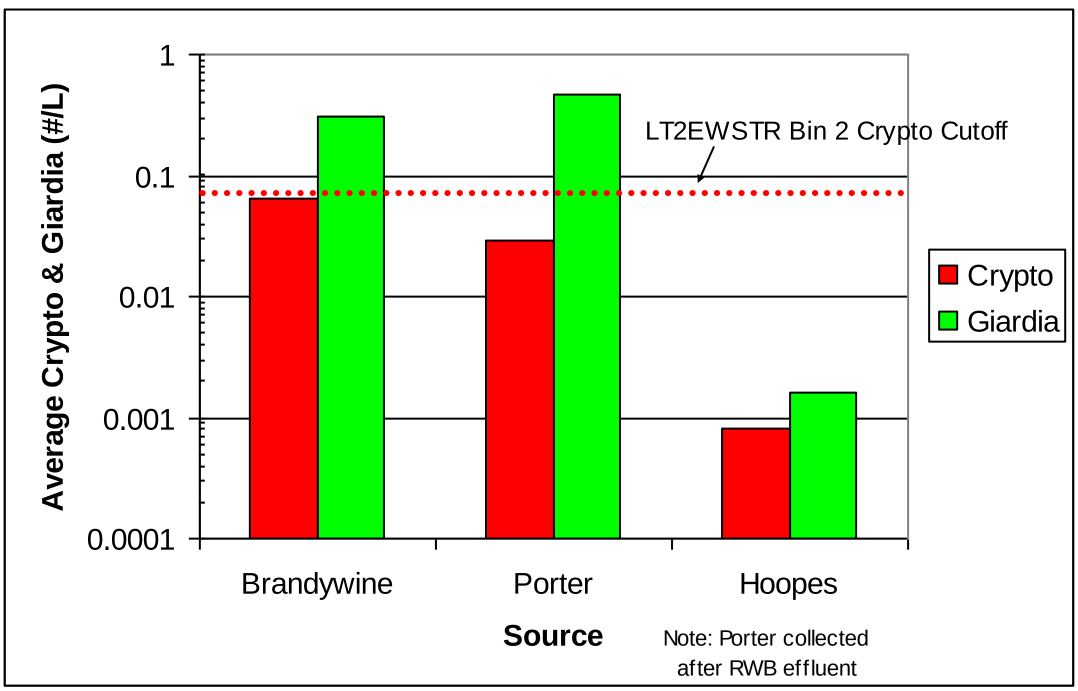


Figure 2-42 – Average Concentrations of *Cryptosporidium* & *Giardia* in Wilmington's Raw Water from LT2ESWTR Monitoring (2006-2007)

2.3.9. Disinfection by Product Pre-cursors

Analysis of the TOC data was presented in the alkalinity as it relates to TOC removal requirements for enhanced coagulation. It is generally preferred to have raw water TOC of less than 4 mg/L for lowest disinfection by products. However, TOC values are observed occasionally every year over 4 mg/L (see Figure 2-43). Seasonally two peaks appear in TOC. The first peak occurs during May and June and the second peak occurs during September through December (see Figure 2-43). Generally TOC is lower during the spring. UV254 follows a similar trend. These trends indicate that in the fall TOC is related to leaf and plant detritus since this is a period of warmer water and low rainfall and the May and June increases are related to the warming of the water and intense storms bringing organic material from along the near stream banks into the creek.

A correlation between raw water UV254 and TOC with an R value of 0.89 indicates a relatively strong correlation between the two parameters and that UV can be a good operational predictor of TOC levels in the raw water (see Figure 2-44). Thus a UV254 absorbance of 0.2 would potentially result in approximately 5.5 mg/L of TOC in the raw water. These findings suggest that a strategy of utilizing the Hoopes reservoir not only for turbidity, but to avoid periods of high precursors be developed or if switching to Hoopes is not an option that specific treatment techniques be developed and optimized for these periods. Preliminary data suggests that a UV254 reading of between 0.15 and 0.2 is a threshold where increased TOC and precursors are present and additional treatment or alternative sources such as Hoopes may be desired.

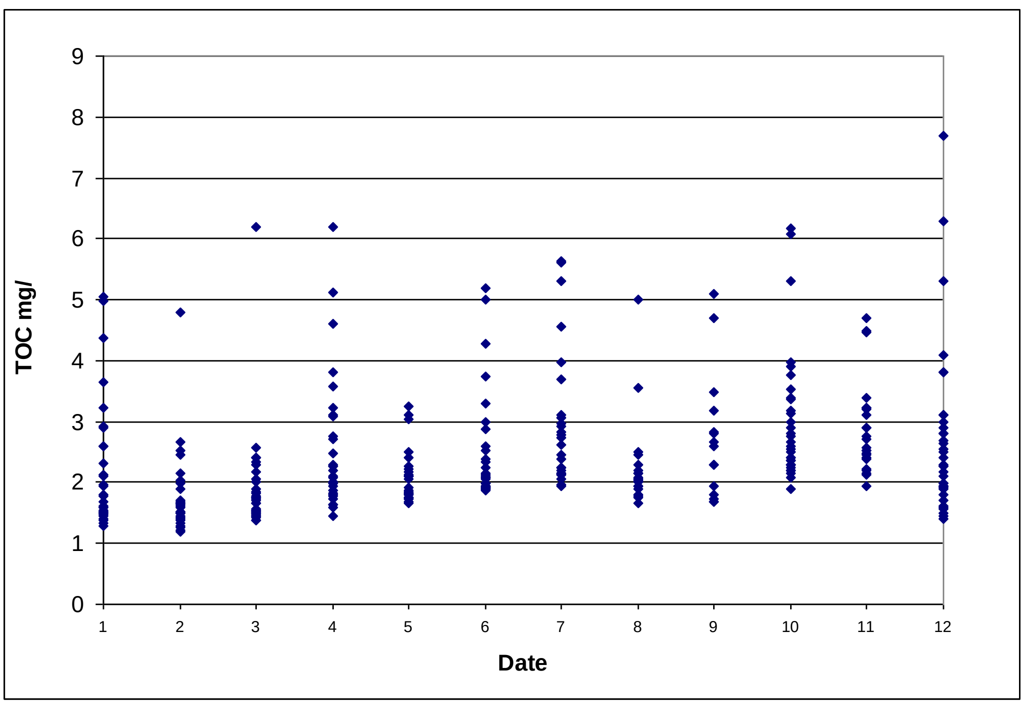


Figure 2-43- Total Organic Carbon Concentrations in Porter Raw Water by Julian Month (1996-2007)

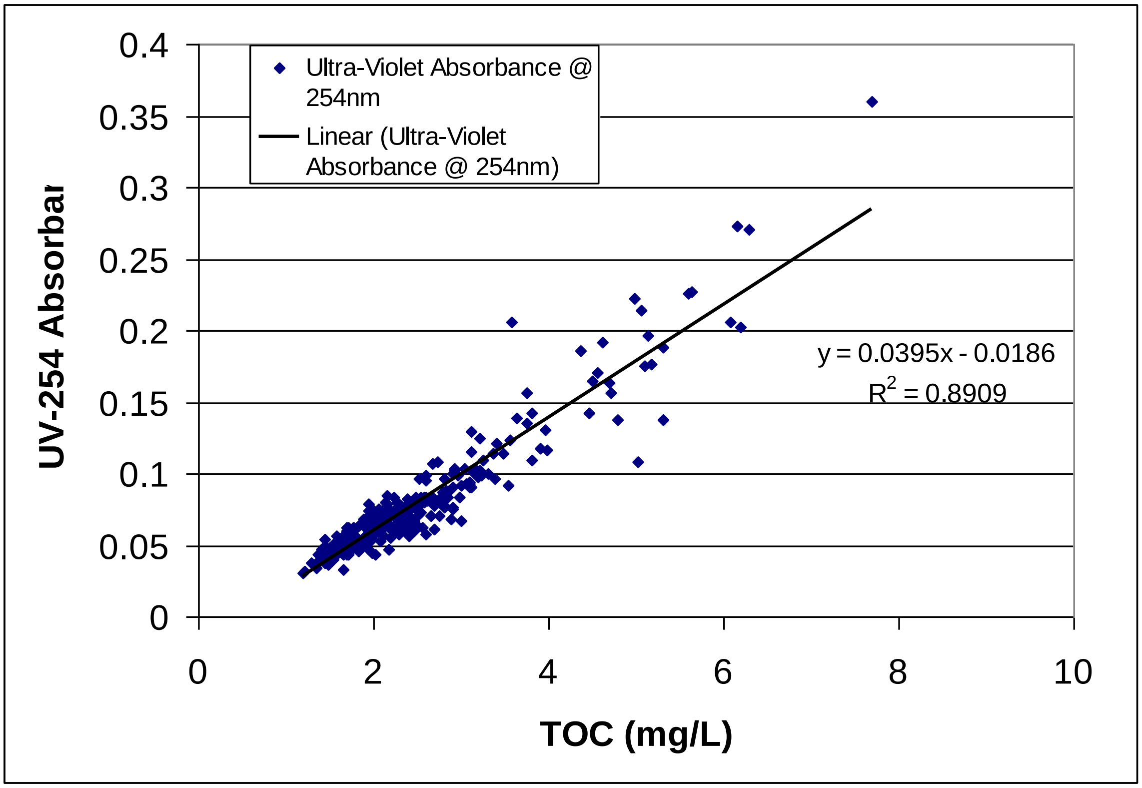


Figure 2-44 - Comparison of TOC and UV254 for the Porter Intake

2.3.10. Nutrients

Nutrients are important to drinking water for reasons ranging from public health to taste an odor. Nitrate is an example of a nutrient with public health concerns. Nitrate is essentially harmless to most people, but is considered an acute toxin to infants under six months of age. In infants, it causes a condition known as methemoglobinemia or "blue-baby syndrome," which can be fatal. Blue-baby syndrome is caused when bacteria in the digestive tract of infants change the nitrate into nitrite, a much more harmful substance. The nitrite then enters the bloodstream, where it can lower the blood's ability to carry oxygen to the body, causing a blueness to the skin. Infants under six months of age are at higher risk than others because their digestive tract is not fully developed. The most obvious symptom is a bluish skin coloring, especially around the eyes and mouth. Ruminant animals (cattle, sheep) are susceptible to nitrate poisoning because bacteria present in the rumen convert nitrate to nitrite. Nonruminant animals (swine, chickens) rapidly eliminate nitrate in their urine. Horses are monogastric, but their large cecum acts much like a rumen. This makes them more susceptible to nitrate poisoning than other monogastric animals (Seif, 1998). Nitrate levels at the Wilmington intake were the lowest during the drought in 2002. Nitrate levels were at their highest in 2003 and 2004 which had greater precipitation, but still well below the nitrate MCL. This suggests that nitrate is controlled by runoff from either agricultural or stormwater sources. Regardless of the observed impacts nitrate does not exceed 3.6 mg/L which is relatively good compared to other streams and rivers in the region. However, if the limit for nitrate is changed from 10 mg/L due to blue baby syndrome and a new limit of 2 – 3 mg/L is implemented due to proposed concerns over bladder cancer then nitrate removal may need to be revisited. Nitrate and nitrite levels exhibited expected behaviors. Nitrite concentrations were greatest in winter and early spring before waters are warm and biological activity increases. Nitrite levels reach their lowest concentrations during the fall when precipitation and runoff of ammonia is lowest and biological activity diminishes. The maximum observed nitrite level of 0.36 mg/L was well below the 1 mg/L MCL suggesting nitrite is not a concern at this time. However, any consideration of switching from free chlorine to chloramines should take ammonia and nitrate levels into account because it could cause disinfection impacts as well as distribution Heterotrophic Place Count Bacteria (HPC) and biofilm growth impacts.

Ammonia concentrations tended to be the greatest during winter and spring months when biological activity is low and conversion to nitrite or nitrate is inhibited. Ammonia concentrations exceeded 0.2 mg/L at times in every season with the most frequent in winter and spring and the lowest in fall. As discussed previously ammonia levels over 0.2 mg/L can cause challenges for disinfection efficiency and chlorination. The periods of ammonia concentrations beyond 0.2 mg/L suggest impacts from upstream sources of human sewage or agriculture.

Orthophosphate is a measurement of the dissolved form of phosphorus in water and only a fraction of the total phosphorus present in water. The amount of orthophosphate in the water is dependent upon the form from the source discharging phosphorus and oxygen conditions in the water. Most environmental phosphorus is in the precipitate form attached to iron and in particulates that settle out in sediments. However if the sediment is exposed to an anoxic condition, the phosphorus can then be reduced to the dissolved form and then leach back into the water column. Orthophosphate is the phosphorus form that is most readily taken up by plants and algae. Thus, high levels of orthophosphate can result in relatively sudden and intense algal blooms. Normally runoff from stormwater from residential and urban areas is not as high in orthophosphate as agricultural runoff from fertilizers. Orthophosphate dose have some positive impacts. Zinc orthophosphate is added by many water suppliers for corrosion control of distribution piping systems.

Analysis of the orthophosphate measurements at the Wilmington intake observed the trend of lowest concentrations during summer months due to uptake and biological activity and higher concentrations in winter when biological activity is its lowest. There were some relatively high levels of orthophosphate observed during the spring. These spikes suggest that they are related to runoff from agricultural activities such as runoff after early manure and fertilizer spreading or tilling activities.

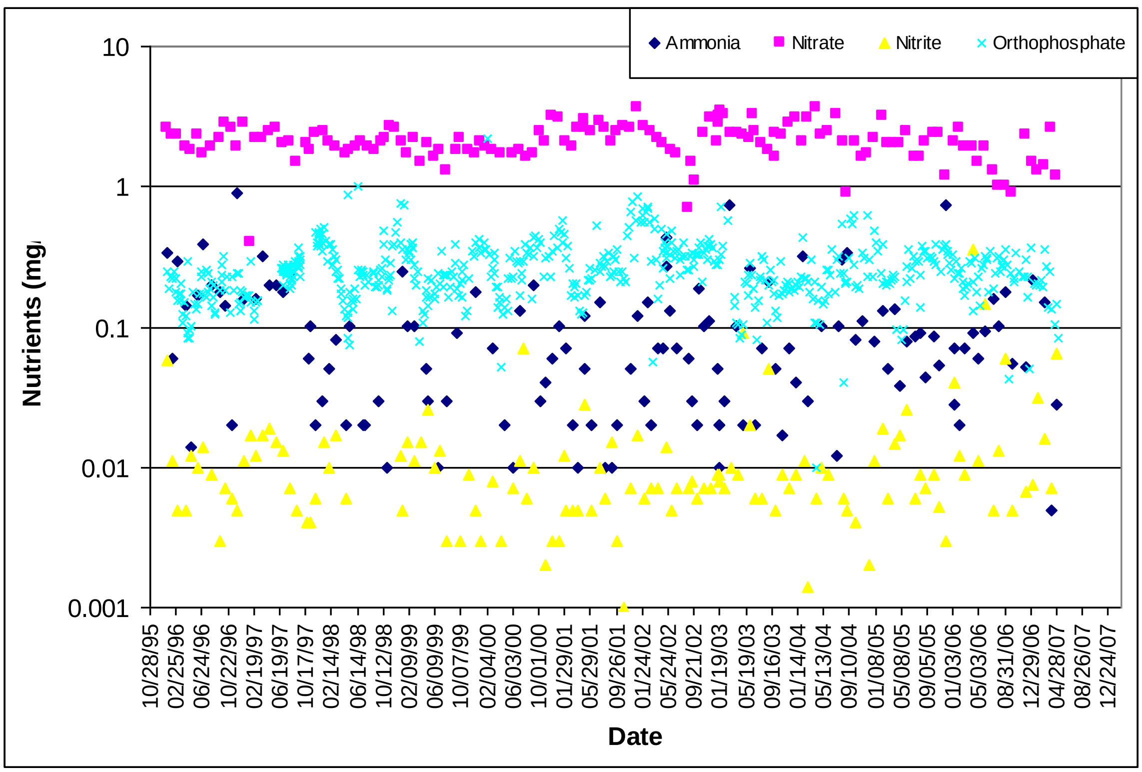


Figure 2-45 – Nutrient Concentrations in Porter Raw Water (1996-2007)

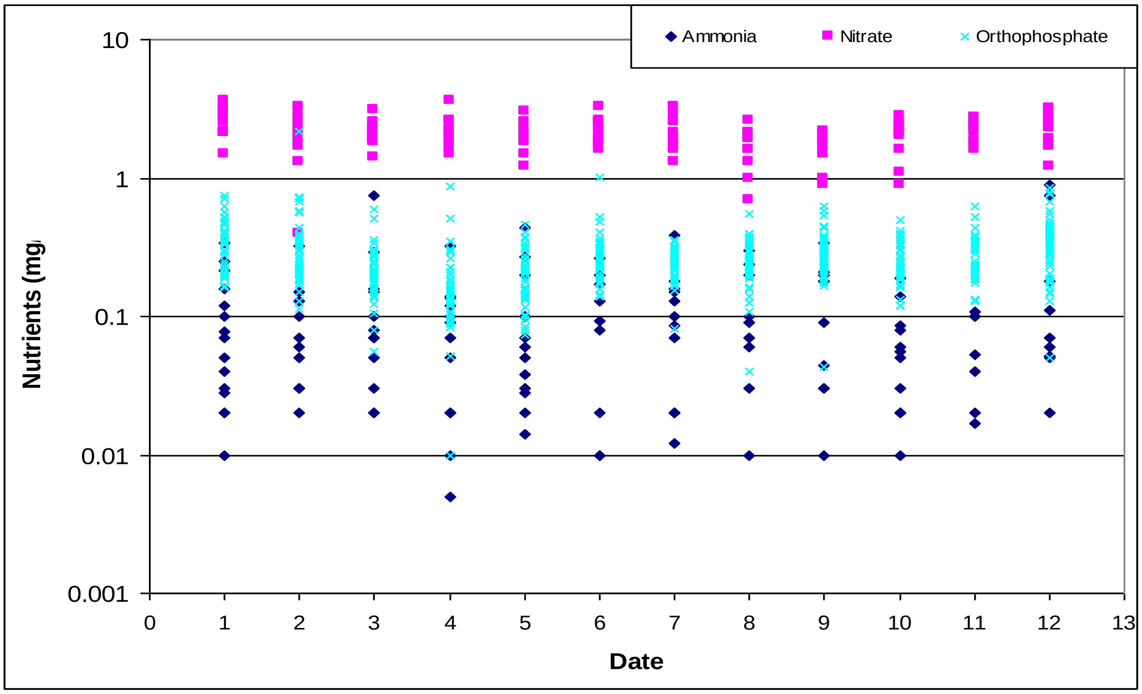


Figure 2-46 - Nutrient Concentrations in Porter Raw Water by Julian Month (1996-2007)

2.3.11. **Algae**

Algae are microscopic oxygen producing photosynthetic organisms. They use light energy to convert carbon dioxide and water to sugars and cell matter. When light is not present they use oxygen and respire releasing carbon dioxide. During respiration of algae if enough are present it can actually drive the pH in the water down. The pH goes down because the algae produce CO_2 and that combines with the water to form bicarbonates and carbonic acids. During photosynthesis the release of oxygen by algae (if enough are present) can raise the pH. This occurs when the oxygen reacts with the water to create hydroxyl ion (OH-) and raises the pH.

Algae can dramatically affect the pH in the water over the course of a day affecting coagulation chemistry. Certain algae called diatoms actually can cause head loss and filter clogging problems. Other algae such as blue green algae can release taste and odor causing chemicals at the part per trillion levels that produce taste and odor complaints by customers. There are a growing number of reports that algae such as dinoflagellates release toxic chemicals that have killed animals drinking from lakes and ponds. The red tide is an example of the impacts of the toxic effects of dinoflagellates. Therefore, algae can have routine nuisance impacts costing water suppliers time and money to treat the problem as well as more dramatic impacts under extreme conditions.

Two sampling events were conducted by COW in spring 2006 and 2007 and sent to a laboratory for algae identification and counting. The samples included Porter and Brandywine raw water. Based on analysis of these samples the following was determined:

- Filter clogging algae are present and there is evidence of algal blooms occurring based on online DO and pH data (Table 2-30)
- Over half of the algae detected in the detailed samples (by frequency, not count/concentration) were filter clogging or nuisance algae (Figure 2-47).
- Approximately one third to one half of the algae concentration observed from individual samples were filter clogging or nuisance algae.
- The Brandywine Membrane Filtration Pilot Plant must consider these impacts during studies
- Geosmin and MIB samples collected with the algae samples only detected geosmin once (7/21/06 at 3.5 ng/L). All other samples were non detect for MIB and Geosmin. Once concentrations cross the 10 ng/L threshold powdered activated carbon would need to be added at the WTP to avoid potential taste & odor complaints. (The normal human threshold is 10 ng/L).
- The presence of these algae suggest a potential for future taste & odor issues