Appendix A-1
Water Resources – Quantity

A. The Water Cycle

Understanding the water cycle and how human development actions have affected this cycle is especially important in order to understand the natural resources of Radnor Township. Figure 1 illustrates the essential dynamics of the water cycle (or hydrologic cycle, a term which can be used interchangeably). The water cycle arrows make the point of continuous movement of water. Of all the aspects of the water cycle which must be emphasized, its dynamic quality--the never-ending cycling from atmosphere to the land and then to surface and groundwater pathways and back to the atmosphere--is most critical to appreciate. The often-heard observation that we drink the same water today that Native Americans drank hundreds, thousands of years ago is a function of this continuous cycling and recycling.

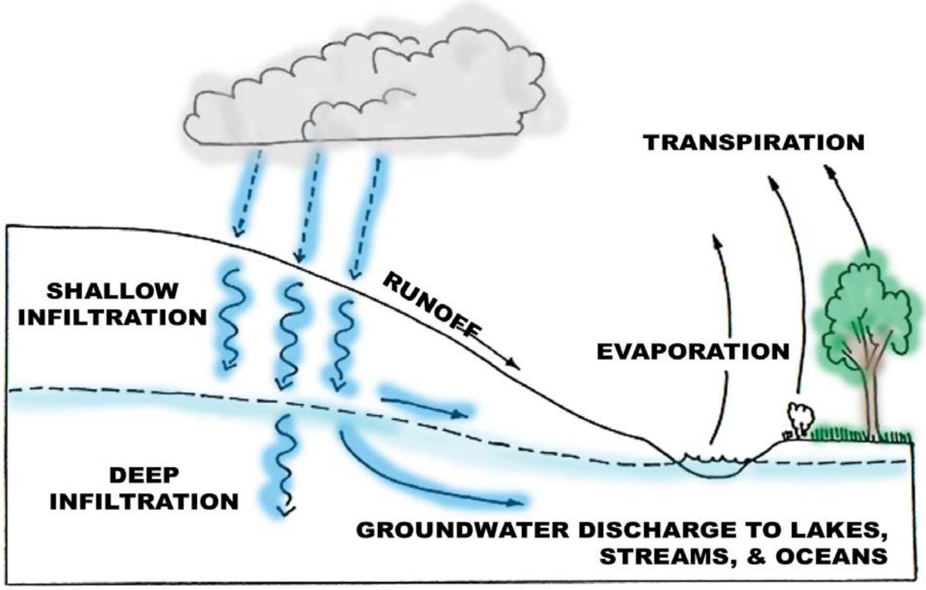


Figure 1 The Natural Hydrologic Cycle

The water cycle includes components, which can be displayed in the form of a system flow chart for an average year, shown in Figure 2. Precipitation data is based on precipitation gages both in Delaware County and in the region and includes data recorded over many years at many different stations (the closest official US National Oceanic Atmospheric Administration rain gage is located at the Philadelphia International Airport). Although rains may vary considerably from gage to gage for specific storms, there is an averaging of precipitation records over the longer run. Average precipitation really is quite comparable for Delaware County or Chester County or Montgomery County or Bucks County. Total stream flow data, similarly is based on stream gage data, which is typically recorded by the US Geological Survey, over as many years as possible. Special baseflow separation procedures are applied to separate out stormwater runoff from stream baseflow occurring during non-storm periods or dry weather. Different watersheds with different land covers and different geologies and aquifer characteristics, will demonstrate some variation in stormwater runoff and stream baseflow in average years, although the general relationships are remarkably consistent in this Piedmont region. It should be noted that data in Figure 2 assume a certain level of development and watershed alteration extant at that particular time. If we had data for watersheds in their purely natural state, as of 1600 AD for example, we would undoubtedly discover that Infiltration would be greater, Surface Runoff would be reduced, Evapotranspiration would be somewhat greater, and the Groundwater Reservoir component would be considerably larger. Real world experiences reinforced by partial data records have been documenting these water cycle changes over recent years in most watersheds.

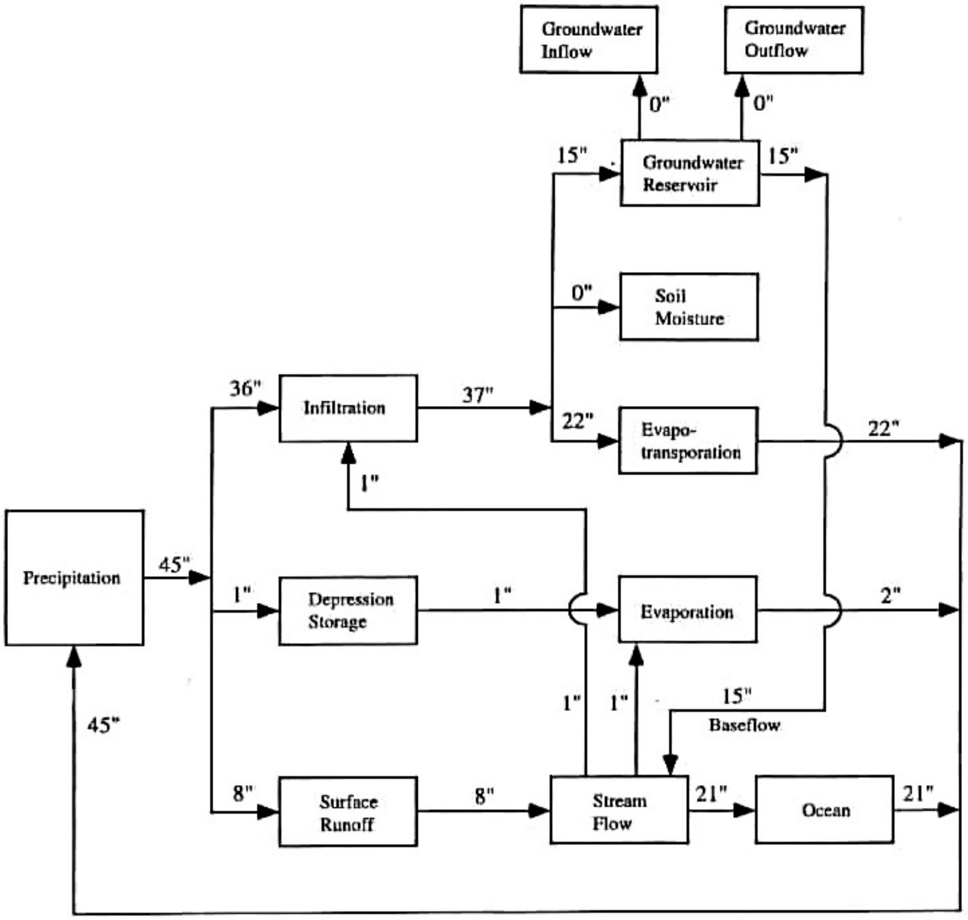


Figure 2 The Hydrologic Cycle Quantified for a Typical Piedmont Region (Cahill Associates 2001, based on various Southeastern Pennsylvania Watersheds)

It is important here to appreciate that the water cycle system itself is a closed loop. What goes in must come out. Impacts on one part of the cycle by definition create comparable impacts elsewhere in the cycle. If inputs to Infiltration are <u>reduced</u> by 10 inches somehow, then inputs to Surface Runoff (or Depression Storage which is highly unlikely) must be comparably <u>increased</u> by 10 inches. Furthermore, Infiltration <u>outputs</u> will have to be reduced by this same 10 inches as the water cycle system continues (i.e., the Groundwater Reservoir, Evapotranspiration and Soil

Moisture components together). Groundwater Reservoir reductions will further be reflected in Stream Baseflow reductions. Impacting one part of the system invariably results in impacts throughout the water cycle system. This action/reaction system sensitivity has important ramifications for any attempt to manipulate and manage components within the water cycle. Management programs which focus on one aspect of the water cycle – for example, managing only for peak rates of stormwater runoff as we have done so often in Radnor and other municipalities, without paying attention to all of the water cycle component impacts – produces all sorts of "surprises" and typically is doomed to failure.

Land development typically means a significant change in the natural landscape, including creation of impervious surfaces (roads, parking, roofs, other). When we pave over and make impervious surfaces, we increase surface runoff. Figure 3 demonstrates the impact. The arrows in the illustration are drawn to suggest size or extent of impact (in this case, total quantities of water involved year after year). Note that when we move from the pre-development to post-development site, the three medium-sized arrows become one increased surface runoff arrow with both evapotranspiration and infiltration substantially decreased in size. Figure 4 carries the comparison several steps further, contrasting a Natural Ground Cover scenario with 10-20 percent impervious, 35-50 percent impervious, and 75-100 percent impervious scenarios. Again, the point to be made is that increasing surface runoff <u>total volumes</u> translates into significantly reduced <u>total volumes</u> of infiltration, with significant consequences later in the water cycle. This issue is of paramount importance given the tremendous amount of development which already has occurred in Radnor Township.

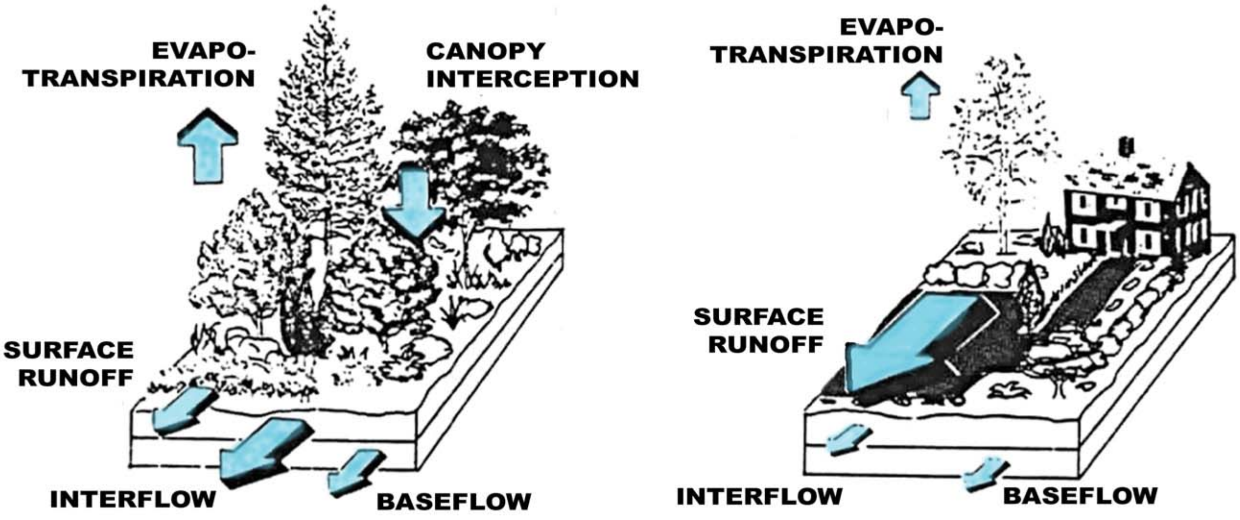


Figure 3 The Effects of Development on the Hydrologic Cycle

In the recent past most municipal stormwater management programs, including Radnor's, have focused on peak rate management. In fact, in many areas of Radnor, much of the existing development occurred prior to <u>any</u> stormwater management regulations. In these areas, like much of Wayne, the only stormwater management in place is a stormwater collection system, which directs stormwater runoff into the nearest stream without <u>any</u> type of peak rate control, volume control, or water quality control. More recently, detention basins have been engineered for land development projects to satisfy Radnor's regulations which have focused on the specific stormwater management need for peak rate control in order to prevent flooding on adjacent parcels downstream. To satisfy these regulations, peak rates of runoff at a site, pre- to post-development, must be held constant usually through use of a detention basin, although large increases in total runoff volumes are still allowed to be generated. As these increased volumes combine downstream, downstream flooding typically gets worse, detention basins notwithstanding. Because such peak rate control management efforts are so partial in concept, and because this approach to stormwater management fails to acknowledge and plan for critical system-wide water cycle impacts (and the critical issue of lost recharge and runoff as an essential watershed resource has not even been mentioned as yet!), the existing stormwater management system itself has become a problem, rather than a solution.

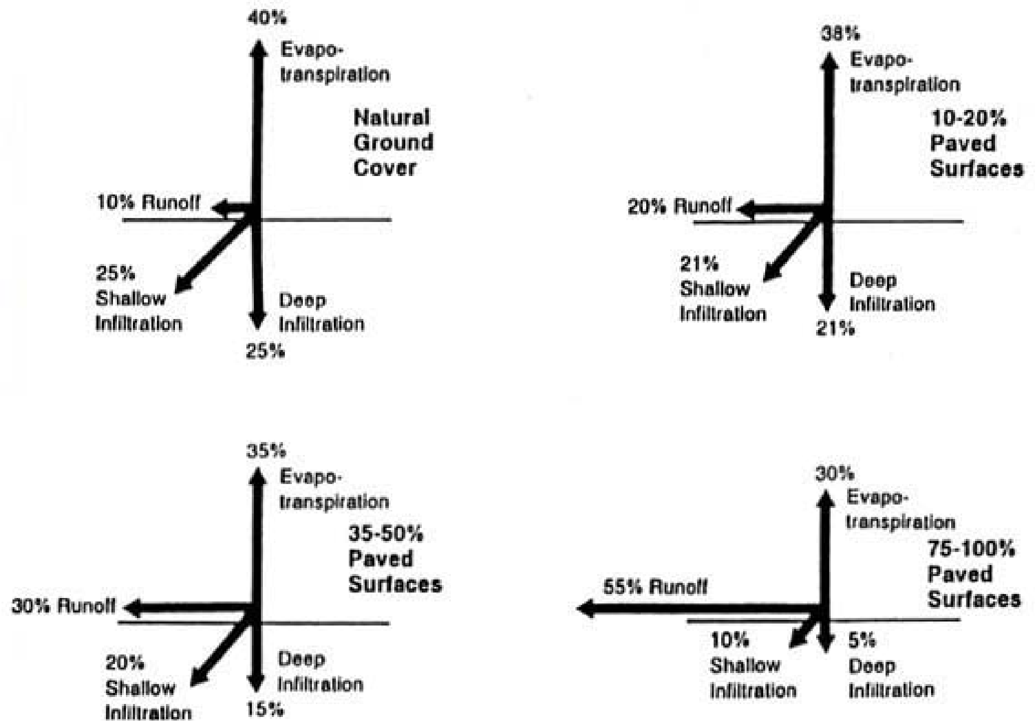


Figure 4 Typical changes in runoff resulting from impervious surfaces

Precipitation: Precipitation is fundamental to the water cycle. In southeastern Pennsylvania, average annual precipitation does vary to some extent from location to location, but long-term rain gage data generally indicate average annual precipitation to be about 45 inches--in other words, a relatively humid climate pattern, recent droughts notwithstanding. Overall, this water cycle is distinguished by substantial precipitation, which tends to be distributed throughout the year in frequent events of modest size. The long-term charting of precipitation month-by-month confirms this relatively even distribution of rainfall/precipitation events. No one specific month or season tends to be excessively wet or dry, though certainly times of precipitation extremes have occurred (especially hurricanes).

Also important is the distribution of rainfall by size of event. Data records indicate that precipitation occurs mostly during relatively small storms. Based on previous analyses of southeastern Pennsylvania data for various rain gages, over 95 percent of the total number of precipitation events occurring during the last several decades was classified in the "less than 2 inches in 24-hours" (approximately the 1-year storm) category. Even more important from a water cycle perspective, over 95 percent of the average annual rainfall **total volume** occurred in storms or "events" of less than 3 inches (less than the 2-year storm); 85 percent of the average annual rainfall **volume** occurred in storms or "events" of less than 2 inches. Over half of the total volume of the average annual precipitation occurs in "less than 1-inch" precipitation events. In short, the vast bulk of precipitation occurs in the smaller and more frequent storm events. Water management, especially stormwater and flooding management programs, have historically dwelled on only the largest catastrophic events, such as the 100-year storm, but these smaller storms are actually more critical when most water cycle questions are being asked (and answered). If the concern is keeping the water cycle in balance, storm size distribution data suggests that using the 1- or 2-year storm as the basis of design for stormwater management Best Management Practices, rather than the larger 100-year storm, will serve to capture the vast bulk of stormwater runoff and provide adequate water cycle balance.

Precipitation events have been classified in storm events as below:

1-year storm	2.4 inches in 24 hours
2-year storm	3.2 inches
10-year storm	5.6 inches
100-year storm	7.2 inches

Note that these events are to be understood as statistical probabilities. The 1-year storm has a 100 percent chance of occurring during any one year. A 2-year storm has a 50 percent chance of occurring in any one year, and so forth. The largest storms, certainly the 100-year storm (1 percent chance per year), tend to be hurricane-related events. Also, it should be noted that our very recent experience of frequent and extremely large storms seems to be calling some of these statistical calculations into question.

Stormwater and the Groundwater Reservoir/Stream Baseflow: Precipitation can take several routes after reaching the land surface. One possibility, Depression Storage, consists of small quantities of precipitation, which are intercepted and temporarily ponded or pooled on the land surface, later to be evaporated. Depression Storage tends to be relatively insignificant and not subject to significant change, pre-to post-development.

Really, the focus of interest for stormwater and overall water resources management is both Infiltration and Surface Runoff. As discussed above, increased Surface Runoff by definition means decreased Infiltration. Land development creates both impervious surfaces and pervious surfaces such as lawns, often further compacted during the construction process, both of which result in reduced quantities of infiltration when compared with the pre-development natural condition. Important here is the pre-development vegetative cover condition of the site; existing stands of forest or meadow or even scrub vegetation allow for considerably more Infiltration than will occur with a post-development lawn on a disturbed and at least partially compacted soil base.

A critical water cycle impact here focuses on the Groundwater Reservoir component, also commonly referred to as groundwater or aquifer recharge. Decreases in Infiltration mean decreases in the Groundwater Reservoir. As these reductions continue acre-by-acre, development-by-development, their cumulative effect grows larger. As the effects accumulate, Groundwater Reservoir depletion grows more serious, and the water table, the uppermost surface of this groundwater reservoir, declines as well. Figure 5 illustrates a simplified pre-development situation in cross-section, where normal Precipitation patterns combine with natural vegetation to produce a particular Groundwater Reservoir or aquifer condition.

In post-development conditions shown in Figure 6, well development and impervious surfaces have been added, resulting in reduced inputs to the Groundwater Reservoir. The water table declines. If we add in the effect of drought further reducing Groundwater Reservoir inputs and further lowering the water table, the cumulative effects of development and drought become quite significant. Springs and streams--especially first order headwater streams--are jeopardized and may even cease flowing. Wells, especially older shallow wells, may fail, and wetlands, typically fed by groundwater discharge, will be adversely impacted.

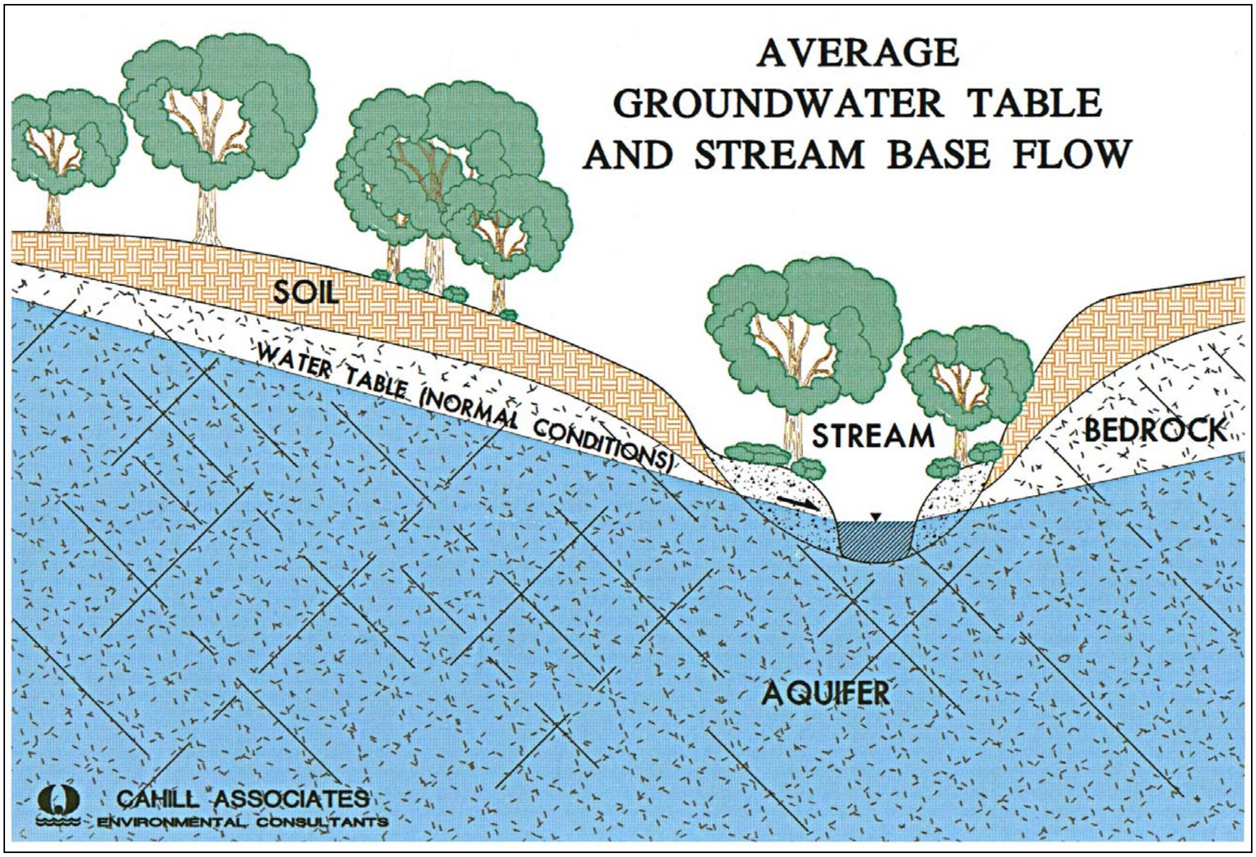


Figure 5 Groundwater and stream base flow (pre-development)

Most wells can be re-drilled at greater depths, though at considerable expense. Not so, for headwater streams and springs--the lifeblood of the stream system. The illustrations in Figures 5 and 6, though simplified, clearly establish the dynamic and critical relationship between the Groundwater Reservoir and Stream Baseflow. If the water table declines, Stream Baseflow declines by definition. The Groundwater Reservoir might be thought of as a saturated sponge where Precipitation inputs are added from time to time on the surface. In the consolidated aquifers of the Piedmont, groundwater then moves gradually through a myriad of pathways down and through the nooks and crannies of the sponge, ultimately flowing gradually out at the bottom in the form of Stream Baseflow. However slow the movement and indirect the pathways might be for this continuous flow, however distant the point of stream discharge might be, the point here is that **when subtractions are made from this Groundwater Reservoir flow, at some point the impact will be seen in the form of a lowered water table and reduced Stream Baseflow discharge.**

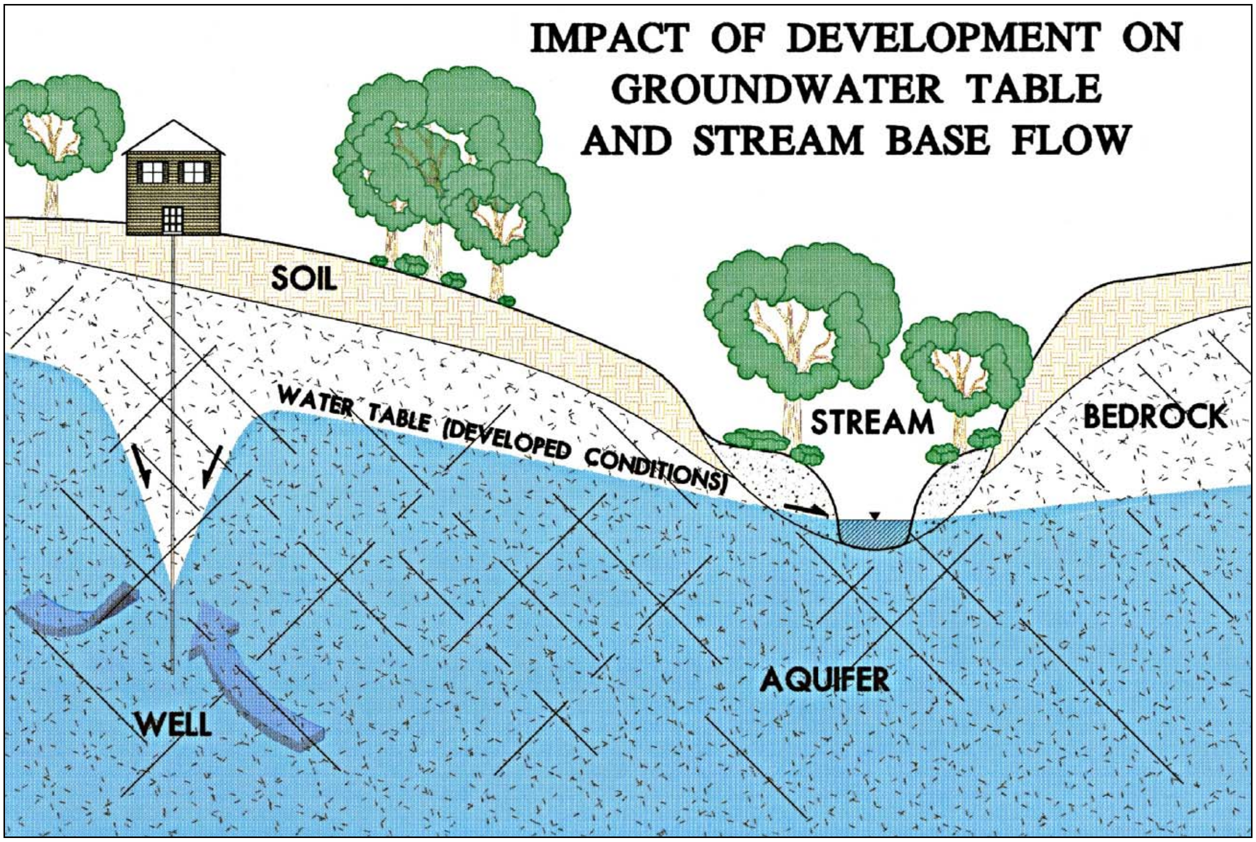


Figure 6 Impact of development on groundwater table and stream base flow

In Piedmont physiography like Radnor, **Surface Runoff** comprises Stream Flow a relatively small fraction of the time, perhaps less than 20 percent of the time in first order headwaters streams. The vast bulk of the time, Stream Flow in Radnor consists of Stream Baseflow discharged from the

Groundwater Reservoir. This Stream Baseflow discharge occurs continuously, a reflection of the continuous movement occurring within the groundwater, which is such a distinguishing characteristic of the water cycle.

It should be noted that this presentation of the water cycle and the groundwater phase of this cycle has been highly simplified for this discussion. In fact, the hydrogeological context can be quite complex. Rock types may vary from high capacity carbonate formations to tighter and less water-yielding rock. These variations and complexities notwithstanding, the basic dynamics of the simplified hydrogeological model used here remain valid.

Of course, during dry periods, both the water table and Stream Baseflow also decline, even under natural conditions. When the effects of drought and development are combined, the Groundwater Reservoir and water table may be so reduced that Baseflow ultimately is virtually eliminated from the stream, and the stream dries up with catastrophic ecological consequences. Even if Stream Baseflow is not entirely eliminated, significant reductions in flow occur which also adversely stress the aquatic community in a variety of ways, well before total dry up results.

Adding to the seriousness of the problem is the fact that these stormwater-related impacts are magnified in the smallest streams--the headwaters zones--of the total stream system. Headwaters are defined here as 1st-order perennial streams, where the stream system with its aquatic community literally begins. In headwaters, Stream Baseflow by definition is modest even in pre-development and non-drought conditions. Therefore, any subtraction from flows in these small streams proportionally has greatest adverse impact. The potential for actual dry up is greatest in this most vulnerable, most sensitive headwaters zone. Furthermore, headwaters zones comprise the largest percentage of the total stream system on a lineal percentage basis. Headwaters are the locations of critical ecological functioning where exchange of energy from land to water occurs most directly and is most ecologically vital. Headwaters zones therefore are both most sensitive and of special value.

In some cases, the Groundwater Reservoir does not discharge to a stream, but rather to a wetland. Frequently, wetlands are zones of groundwater discharge and are in fact "fed" and kept alive by the Groundwater Reservoir. In these instances, reduced Infiltration and a lowered water table ultimately translate into loss of wetlands themselves, reduced wetland extent, reduced wetland vibrancy and richness, and other wetland functional losses. In sum, the impacts resulting from stormwater-related reduced inputs to the Groundwater Reservoir and Stream Baseflow can have serious and far-reaching consequences. Because the balance has already been so impacted and so tipped by so much existing development done the wrong way, it is especially critical that new development projects not make the problems even worse.

Stormwater and Surface Runoff: Because land development alters the water cycle by increasing Stormwater Runoff, the management concern historically has focused on how to handle excess water, how to prevent flooding. In fact, flood prevention continues to be the focus of most conventional stormwater management programs; flood prevention, of course, is a critical issue.

Understanding stormwater runoff means understanding the concept of a hydrograph, a graphical comparison of runoff being discharged from any particular site (measured in cubic feet per second) on the vertical axis, versus time (measured as time into the storm event such as Hour 1, 2, 3, and so forth) on the horizontal axis. Hydrographs can be developed for sites of any size--one acre or 100 acres or 1,000 acres--and for all different size storm events. Hydrographs can actually be measured in the field (no simple matter) or can be estimated through a variety of mathematical modeling methodologies (the most typical approach). Figure 7 presents a hydrograph for a typical site in Radnor before development has occurred (not many of these left; note that the actual discharge values, site sizes, etc. are largely irrelevant for sake of the comparison developed here). A storm – hypothetically, the 100-year storm – begins. As can be seen from the Pre-Development hydrograph, surface runoff from the site does not begin for a while, until hour 2 or so, at which point the site soil becomes saturated (when the rate of Precipitation exceeds the rate of permeability of the soils). At this time, the rate of precipitation is assumed to increase, similar to hurricane-type events, such that the rate of runoff increases rapidly as well. In time, precipitation rates decline, and surface runoff rates decline as well.

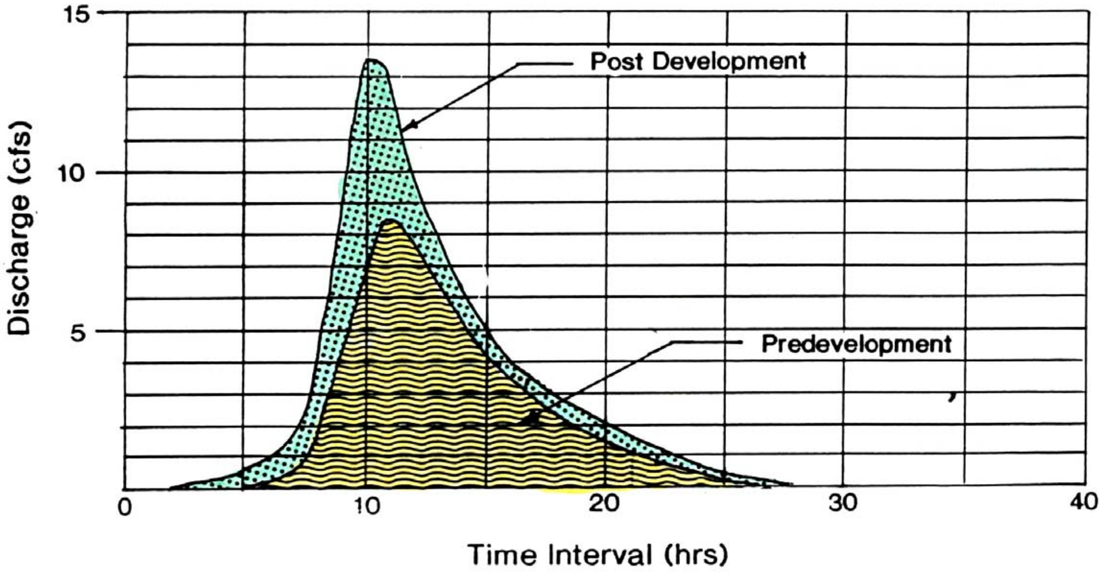


Figure 7 Stormwater hydrographs for Pre-development conditions and Post Development Uncontrolled conditions

Note that the hydrograph is a graph of the rate of stormwater runoff. Rate must be carefully distinguished from volume of runoff. The area beneath the hydrograph curve constitutes the total volume of runoff discharged from the site. A second point to be stressed is that the pattern of runoff even in the pre-development or natural site condition is very much dictated by the assumed precipitation rates defining the storm event. If these assumed rates of precipitation were to be modified, then runoff rates would be modified as well. Lastly, note that there is runoff occurring even in pre-development conditions for the largest storm events. Because the rate of precipitation increases so dramatically in the 100-year storm event assumed here, maximum Infiltration rates are exceeded even without development. Even in forests, runoff results during the 100-year storm, given the assumed storm distribution.

Figure 7 also includes a hypothetical development at the hypothetical site and presents a post-development hydrograph without any stormwater management controls in place (Post-Development Uncontrolled). Several observations relating to the two hydrographs can be made. First, the Post-Development Uncontrolled hydrograph rises or increases earlier in time when compared with Pre-Development. Runoff starts occurring earlier after development because portions of the site have been made impervious and immediately start to discharge as rain begins to occur. More importantly, Post-Development Uncontrolled runoff rapidly increases and peaks out at a runoff rate level which is considerably higher than the peak rate of runoff for Pre-Development. The extent of this peak rate increase is very much linked to the amount of impervious surface and other land cover changes involved in the development process. If only 10 percent or so of the site were to be made impervious, then increase in peak rate would not be so great. If 50 percent of the site were made impervious, extent of increase in peak rate would be dramatic.

Introducing stormwater management, Figure 8 adds a Post-Development Controlled hydrograph to the comparison, where "Controlled" is here defined as a detention basin which functions to hold constant the pre-development rate of Surface Runoff by engineering design via a notched weir or perforated riser or some other technique to regulate the site discharge rate (this would be a detention basin sized without regard to a release rate percentage factor). However, the detention basin simply collects and detains the added runoff, discharging this increased runoff volume at the maximum pre-development rate over an extended period of time. Total volume of stormwater being discharged with Post-Development Controlled in Figure 2-8 is significantly increased. By design, detention facilities control runoff **rates**, but do not reduce increased post-development runoff **volumes**.

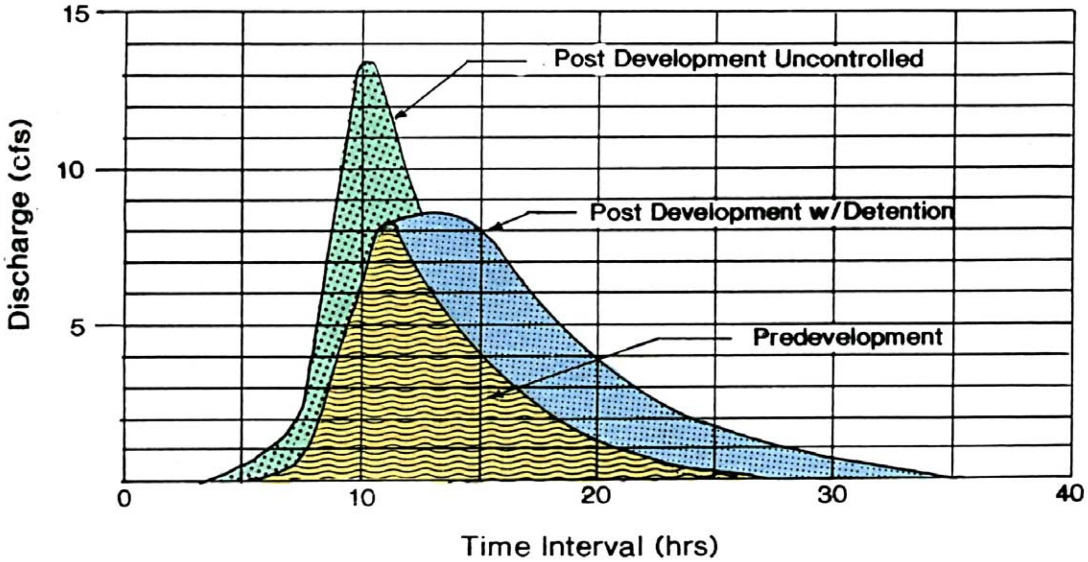


Figure 8 Comparison of pre- and post-development stormwater hydrographs

Peak rate control is a stormwater management strategy in large part designed to protect the adjacent downstream property from worsened flooding. That objective usually is achieved. However, if the perspective is extended to the broader sub-watershed or watershed zone, what is the effect of this increased volume of Runoff being discharged? What happens when many different sites throughout the watershed are developed with many different detention facilities discharging these increased volumes site-by-site? What is the cumulative watershed impact? These questions are reinforced by real world experiences where whole watersheds or sub-watersheds have been developed with reliance on a "no increase in peak rate/detention basin" philosophy and where flooding downstream has worsened nonetheless.

Figure 9 illustrates these cumulative downstream flooding impacts which can result when stormwater management is based upon <u>peak rate control</u> watershed-wide. Assumed here is a hypothetical Watershed "A" comprised of five hypothetical development sites (numbered 1 through 5 in the inset), each of which relies on a peak rate control/detention basin stormwater management approach.

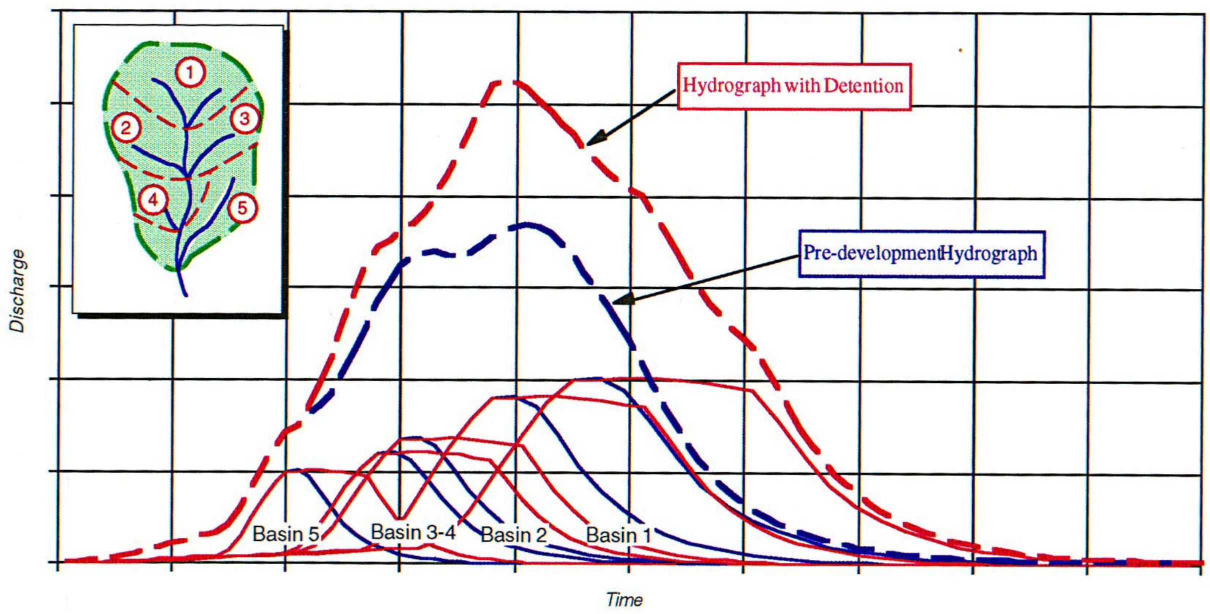


Figure 9 Effects of stormwater detention in a hypothetical watershed

The figure shows the Pre-Development hydrographs – colored blue –for each Basin site 1 through 5. These 5 separate hydrographs when combined, create a Resultant Pre-Development hydrograph for the entire Watershed (dashed blue line). The Post-Development hydrograph – shown in red – assumes that all five developments utilize detention basins for stormwater management. The five hydrographs are modified as showing the Pre-Development peak rates not being exceeded, <u>but being extended.</u> The impact at the base of the Watershed is detrimental. As these extended peak rates are summed, the resultant Hydrograph grows taller (dashed red line). Not surprisingly, this resultant Hydrograph with Detention for the entire watershed not only exceeds the Pre-Development Hydrograph in terms of total area under the respective curves. In addition, the combined peak rate of runoff for watershed A with Detention increases considerably because of the way in which these increased volumes are directed down the watershed system.

In short, flooding worsens considerably downstream, even though elaborate and costly detention facilities have been installed at each individual development. The floodplain by definition will be expanded. Property loss, possible loss of life and limb – all the costs associated with flooding – can be expected to worsen. The simple "peak rate control with detention basin" approach to stormwater management frequently does not even solve the problem of flooding.

Additionally, note that based on Figures 7, 8 and 9, the duration of flood flows – though not necessarily the absolute peak flooding rates – also increases and continues for longer durations, with potential adverse impacts:

- Significant stream bank erosion
- Bank undercutting
- Elimination of meanders
- Changes in the morphology of the stream, including channel widening and straightening
- Increased sedimentation and deposition
- Elimination of pools and riffles
- Reduced stream ecological value

Looking at the Pre-Development hydrograph, the peak runoff rate may occur for an hour or so. Moving to Post-Development with Detention and with release rate reduction factors applied, that peak rate or "release rate reduced" peak rate may extend for 11 or 12 hours. Over time, these impacts can transform the stream from a high quality if not pristine water, with excellent species diversity and richness, literally to functional storm sewers, devoid of biota.

Appendix A-2
Water Resources – Quality

A. General Water Quality Issues

1. Physical Types of Pollutants: Soluble vs. Particulate

The physical form of the pollutant has major bearing on all aspects of water quality management. One very important way of differentiating pollutants is the extent to which pollutants are particulate vs. soluble in nature. Good examples of this comparison are the nutrients phosphorus and nitrogen. Phosphorus typically occurs in particulate form, often bound to soil particles. Because of this physical form, stormwater management practices which rely on physical filtering and/or settling out can be largely successful for phosphorus removal. In stark contrast is nitrogen, which tends to exist in highly soluble forms where any sort of attempt at physical filtering has little if any effect. As a consequence, management approaches for nitrogen must be quite different in approach (wetlands/wet ponds and other approaches where anaerobic conditions are promoted and where denitrification can occur are preferable).

2. Natural Mechanisms for Stormwater Pollutant Reduction/Mitigation

Although stormwater-related pollution often can be reduced if not eliminated through preventive Best Management Practices (BMPs) driven by quantity reduction objectives, not all stormwater pollution can be avoided. In such cases, an array of natural pollutant removal processes are available for use and should be exploited to the maximum. Because these processes tend to be associated with, even reliant upon both the vegetation and soil realms, they can be readily incorporated into many BMPs. Such natural pollutant removal processes include:

> **Settling:** as discussed above, the kinetic energy of stormwater washes all types of matter; particulate form and other, from land cover surfaces. Particles remain suspended in stormwater flows as long as the energy level is maintained. Larger particles require more kinetic energy in order to remain in suspension. As the energy level declines--as the storm flow slows, these suspended particles begin to settle out by gravity, with larger, heavier particles settling out most quickly and the smallest colloidal particles requiring considerably more time for settling. To the extent that time can be maximized, more settling can be expected to occur, holding all other factors constant. Therefore, approaches which delay stormwater movement or approaches that reduce kinetic energy in some manner (e.g., energy dissipaters) serve to maximize settling and deposition.
>
> **Filtering:** another natural process is physical filtration. As pollutants pass through the surface vegetative layer and then down through the soil, larger particles are literally physically filtered from stormwater. Vegetation on the surface ranging from grass blades to underbrush removes larger pollutant particles. Stormwater sheet flow through a relatively narrow natural riparian buffer of trees and understory herbaceous growth has been demonstrated to physically filter surprisingly large proportions of larger particulate-form stormwater pollutants from stormwater flows. Both filter strip and grassed swale BMPs rely very much on this filtration process. Filtration may also occur in stormwater which is infiltrated and then gradually moves downward through the various soil layers, although once this

infiltration process begins, a variety of other pollutant removal processes (see below) are set into motion as well.

Biological Transformation and Uptake/Utilization: though grouped as one type, this category includes a complex array of different processes that reflect the remarkable complexity of different vegetative types, their varying root systems, and their different needs and rates of uptake of different "pollutants" (in this case, clearly "resources out of place"). An equally vast and complex community of microorganisms exists within the soil mantle, and though more micro in scale, the myriad of natural processes occurring within this realm is just as remarkable. Certainly both nutrients phosphorus and nitrogen are essential to plant growth and therefore are taken up typically through the root systems of the various vegetative types, from grass to trees. Nitrogen processing is quite complex, a function of nitrate/nitrite and ammonia/ammonium forms. The important process of denitrification occurs through the action of widely present facultative heterotrophs, which function to facilitate the exchange of ions in the absence of oxygen and ultimately convert nitrates for release in gaseous form. These processes ultimately become chemical in nature, as discussed in the next section). As wetland species are introduced, all of this processing becomes more chemically complex.

Chemical Processes: For that stormwater which has infiltrated into the soil mantle and then moves vertically toward groundwater aquifers, various chemical processes also occur within the soil. Important processes occurring include adsorption through ion exchange and chemical precipitation. Cation Exchange Capacity (CEC) is a rating given to soil which relates to a particular soils ability to remove pollutants as stormwater infiltrates through the soil mantle (i.e., through the process of adsorption). Adsorption will increase as the total surface area of soil particles increases; this surface area increases as soil particles become smaller, as soil becomes tighter and denser (in other words, large particle sandy soils end up having considerably lower total surface areas per unit volume measure than a heavy clayey soil. CEC values typically range from 2 to 60 milliequivalents (meq) per 100 grams of soil. Coarse sandy soils have low CEC values and therefore are not especially good stormwater pollutant removers (a value of 10 meq is often considered to be the minimum necessary to accomplish a reasonable degree of adsorption-related pollutant removal). Conversely, "tighter" soils such as clayey types have much higher CEC values.

Through reliance on these processes, management practices can be applied which substantially increase pollutant removal potential above and beyond any mitigation being provided by the detention basins currently utilized at most sites. Through a combination of vegetative-linked removal combined with a host of processes occurring within the soil mantle, pollutants entrained in stormwater runoff can be removed and even eliminated.

3. Water Quality Sampling

Water quality in the Township’s streams is not as well documented as we might like, especially in the northern Gulph Creek portion of the Township. There have been a variety of special studies conducted during recent years, which have increased our understanding of the water quality in the Darby Creek system.

The most interesting and reliable water quality data undoubtedly has been developed recently by the Philadelphia Water Department; this data fortunately extends to both the Cobbs Creek and non-Cobbs Creek portions of the Darby Creek system. In 1999, the PWD undertook special water quality sampling, which included both actual sampling and computer model simulations of water quality. Ten additional sampling stations were selected, five in the Cobbs Creek and five in the remainder of the Darby Creek system, based on varying rationales. Sampling generally was performed weekly during the late Spring and early Summer, 1999, with 4 of the 10 samples occurring during what considered to be "wet weather." Parameters include Statewide Specific Criteria as well as a variety of basic water quality parameters to be later used by the PWD in its analysis of water quality problems and their respective sources (see Technical Memorandum No. 2, November 30, 1999).

Results indicate a remarkable degree of PADEP standards violations for fecal coliform (standard at 200/100 ml); exceedances were greatest in the Cobbs but were also remarkably high on the Stony and the Muckinipattis and were quite high farther up the Darby mainstem (peaking at 6,000/100 ml at Station 5 with the wet weather average at 1,473 and the dry weather average at 771; Station 5 was located at Darby Creek at Marple Road next to Haverford State Hospital in Haverford Township; because of its downstream proximity to Radnor, Station 5 should give a reasonable reading of water quality flowing from Radnor; it should be noted that in other sampling such as the 1995 PADEP biological investigations at Station 3 in Radnor on the Darby above the confluence with Foxes Run the fecal coliform count in dry weather was 1200/100 ml, again comparably high). Exceedances of the fecal coliform standard were much higher during the wet weather samples, yet were definitely present during dry weather flows, suggesting that fecal coliform to some extent are being discharged on an ongoing basis, possibly from leaking sewer interceptors, from individual onsite septic systems, possibly from geese. Other parameters of interest such as dissolved oxygen and metals toxicity do not appear to be a significant problem, although again the sampling record is not extensive.

Appendix A-3
Air Quality

The air we breathe is a blend of various gases and substances. Like a giant stew, the ingredients are eaten, digested, altered, and replaced. Animals infuse oxygen into their blood and exhale carbon dioxide; plants take in the carbon dioxide and respire oxygen. Volcanoes erupt and emit sulfur into the mixture, lightening strikes fixing nitrogen into the ground, bacteria composts nutrients, releasing methane into the air. Coal fired power plants produce electricity, sulfur and nitrogen oxides. Cars, trucks, planes, trains and buses in their travels leave unburnt hydrocarbons and particulate matter in the air. In short, the air we breathe is a mix of nitrogen, oxygen and carbon dioxide, with a complex, of other ingredients; just as good food promotes good health, clean, or reasonably pure, air facilitates healthy life.

Polluted air causes cancer, birth defects, brain damage, respiratory complications, problems with eyes and noses, and can even be fatal. Damage extends to trees, lakes, streams and animals, all of which we depend on for our own survival. Air pollution affects buildings, homes and cars, as pollutants dissolve and corrode. Airborne pollutants which are ultimately deposited on the land surface are now recognized as major nonpoint source water quality factors as well.

1. Sources of Air Pollution

Several general categories exist for classifying air pollution: point sources, nonpoint mobile sources, biogenic sources, and area sources. Point sources are those inputs that are stationary and directly measurable, such as smoke stacks or vents. Nonpoint sources are mobile and not directly measurable, such as automobiles and airplanes. Biogenic sources include trees, bacteria, vegetation and other natural sources of gases and particles. Area sources are stationary sources such as chemical producers and dry cleaners, that are too small to monitor individually, but are often grouped together to determine emissions. Although the pollutants produced by each source may vary in composition and concentration, all sources are all combined on a regional scale to produce an areas ambient air quality. Weather and wind patterns obviously are important in understanding air quality at any one location.

Although Radnor is substantially developed, Radnor is substantially developed with low density residential uses which support considerable vegetation and "green areas." The vegetation is beneficial from an air quality perspective. Furthermore, Radnor has few if any point sources of air pollution. On the other hand, Radnor is bisected by massive regional highways, with comparably massive traffic flows occurring daily on the Blue Route and Lancaster Avenue. Significant daily problems of congestion translate into comparably significant mobile source emissions along these major regional corridors, as well as local roads such as Conestoga and which carry increasing traffic loads and experience back ups (queuing with the resultant acceleration is a notorious mobile source emission problem). As the entire road-system carries more traffic and experiences more congestion, mobile source emissions increase, unless it is assumed that each vehicle is polluting less. Air quality in Radnor therefore may be deteriorating, although the actual air quality sampling undertaken is extremely sparse (see discussion below).

2. The Air Quality Regulatory Framework

The Federal government, through the US Environmental Protection Agency (USEPA), controls air quality under the Clean Air Act, originally passed in 1970 and amended in 1990. Although the Clean Air Act includes the entire nation, it is largely administered and implemented by the individual states. The main responsibilities of USEPA are to set standards for pollutant levels and to ensure that these air quality standards are met.

USEPA has outlined six criteria pollutants, called National Ambient Air Quality Standards (NAAQS), to monitor and regulate: carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), particulate matter (PM_{10}), sulfur dioxide (SO_2) and lead (Pb). Table 1 lists the standards established for the NAAQS.

Table 1 National Ambient Air Quality Standards (NAAQS; http://www.dep.state.pa.us/dep/deputate/airwaste/aq/standards/standards.htm)

Pollutant	**Average**	**Concentration**
Carbon Monoxide	8-Hour 1-Hour	9 ppm 35 ppm
Lead	Max Quarterly	1.5 ug/m3
Nitrogen Dioxide	Annual	0.053 ppm
Ozone	Max Daily 1-Hour Max Daily 8-Hour	0.125 ppm 0.085 ppm
Particulate Matter ≤ 10 microns	Annual 24-Hour	50 ug/m3 150 ug/m3
Particulate Matter ≤ 2.5microns	Annual 24-Hour	15 ug/m3 65 ug/m3
Sulfur Dioxide	Annual 24_hour	0.03 ppm 0.14 ppm

At the state level, PADEP has a constitutional obligation to protect Pennsylvanian's right to clean air. Furthermore, PADEP has been delegated multiple authorities and responsibilities under the Federal Clean Air Act. PADEP's Bureau of Air Quality regulates emissions from thousands of point sources statewide and works with companies to ensure compliance, while enforcing penalties against those in violation. In addition, PADEP monitors ambient air quality to determine regional compliance, to gather data and trends and to provide information to the public. PADEP also works jointly with the Pennsylvania Department of Transportation in management of transportation-related mobile source emissions. PADEP publishes annual reports summarizing ambient air quality; the 2000 report is available on line at http://www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/aqreport.htm

3. NAAQS: Air Pollution Sources and Health Effects

Carbon Monoxide (CO): Carbon monoxide is a by-product of burning gasoline, natural gas, coal, oil and wood. Automobiles are a major source of CO. CO enters the bloodstream through the lungs and decreases the amount of oxygen delivered to the body. Low levels of CO are a threat to people with cardiovascular disease. In healthy people, higher levels of CO cause visual impairment, reduced work capacity, reduced dexterity, and reduced brain function

Ozone: Ozone is derived from chemical reactions of pollutants, volatile organic compounds (VOC), and oxides of nitrogen (NOx). Ozone is the principle component of smog. Exposures (1-3 hours) to ozone are linked to increased respiratory cases in hospitals. Repeated exposures increase the likelihood of respiratory infection, lung inflammation, decrease lung function and aggravate asthma.

Nitrogen Dioxide: Nitrogen dioxide is derived from burning gasoline, natural gas, coal, oil, and wood. Cars are a major source of NO_2. Exposure to NO_2 causes lung damage and respiratory infections. In addition, NO_2 leads to ozone and acid rain problems.

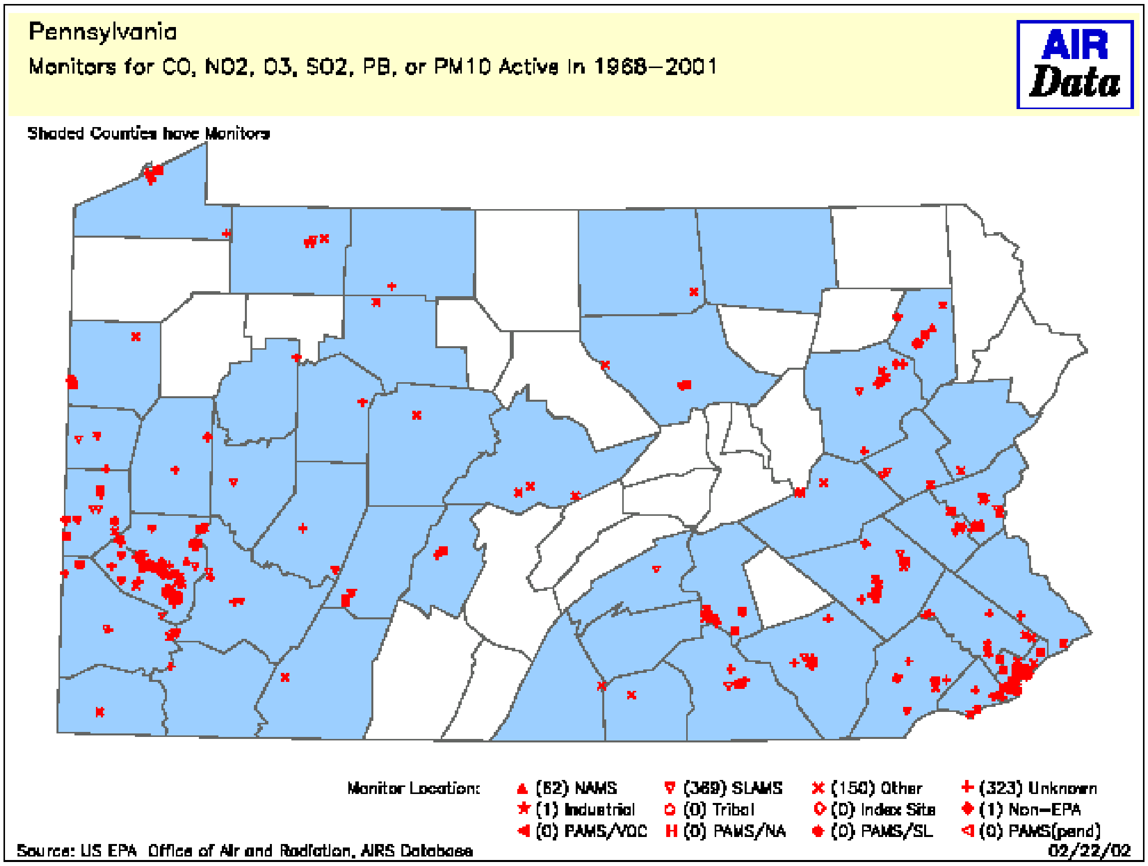
Particulate Matter: Particulate matter (PM) is derived from burning wood, diesel, gasoline, industrial plants, agriculture, construction and unpaved roads. PM can cause respiratory infections and diseases, decreased lung function and premature death. The elderly and those with cardiopulmonary disease are particularly susceptible. PM also causes reduced visibility and upon settling it damages materials. A controversy continues regarding the size of particles that should be regulated, with recent research suggesting that USEPA standards are not sufficiently “fine grained” (literally).

Sulfur Dioxide: Sulfur dioxide is derived from industrial processing of paper and metals, burning coal and oil, especially high-sulfur coal typically in the eastern United States. The health effects include respiratory problems and infections, cardiovascular problems; permanently damage to lungs may result.

Lead: Lead is derived from leaded gasoline, paints, smelters, and manufacturing of lead batteries. Lead enters the body through inhalation and ingestion of food, water, soil or dust particles. Once in the body, lead tends to be accumulated and not readily excreted. Health effects of lead exposure include problems with the kidneys, liver, nervous system, seizures, mental retardation, and/or behavioral disorders. Even at low doses, children and fetuses suffer central nervous system damage. Lead is also linked to high blood pressure and heart disease.

4. Air Quality in the Region

What can we say about air quality in and near Radnor Township? Unfortunately, air quality sampling is costly and complex, and therefore is undertaken in relatively few locations. The air quality for southeastern Pennsylvania is monitored from several locations in Montgomery, Bucks, Chester, Delaware and Philadelphia Counties. There are several point sources that are directly measured, and also several ambient monitoring stations. Station locations are presented in Figure 1. Southeast Pennsylvania is in attainment for all the air quality standards, except for the ozone standards (see Figures 2 and 3). Over the past 10 years, levels of CO, NO_2, Pb and PM have decreased on average, and SO_2 has remained roughly steady.



Source: US EPA Office of Air and Radiation, AIRS Database

Figure 1 Locations of Air Quality Monitoring Sites in Pennsylvania

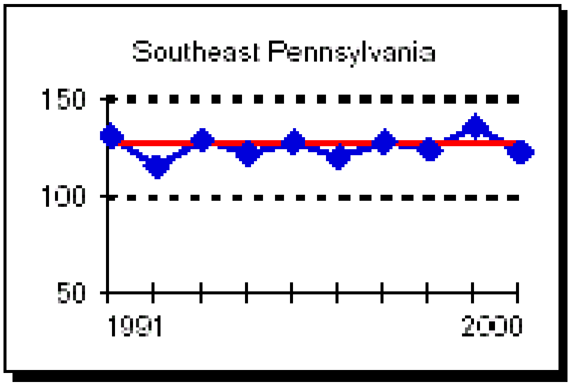
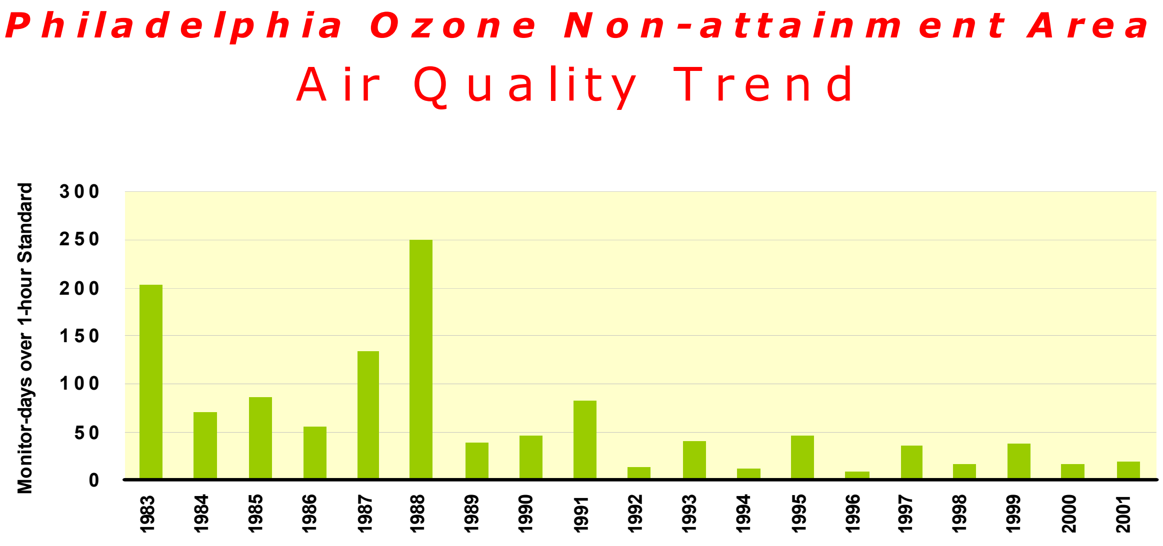


Figure 2 Ozone Trends 1991 to 2000 Second Daily Maximum 1-hour (parts per billion)
(taken from PA DEP 2000 Ambient Air Quality Monitoring Report)



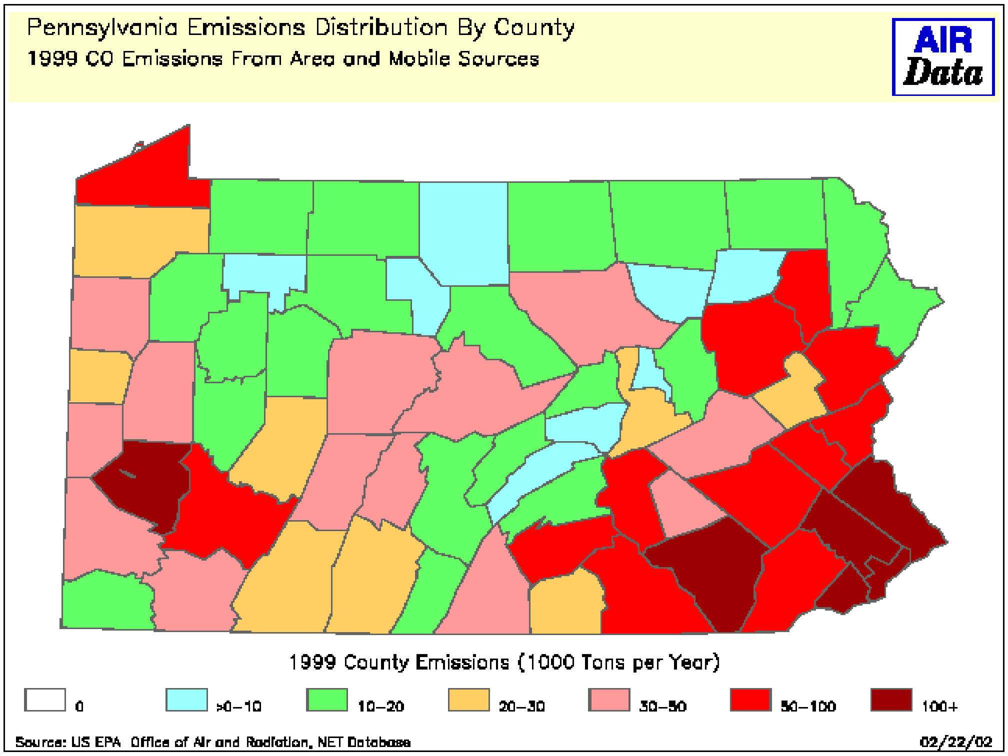
Philadelphia Ozone Non-attainment Area
Air Quality Trend

Figure 3 Ozone Trends in the Philadelphia Region

Figures 4 and 5 describe the air quality conditions throughout Pennsylvania. In addition, PADEP posts a daily air quality index, which describes the current air conditions for a given area and assigns a qualitative value, such as good, moderate, hazardous, and so forth (http://www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/aqi.htm).

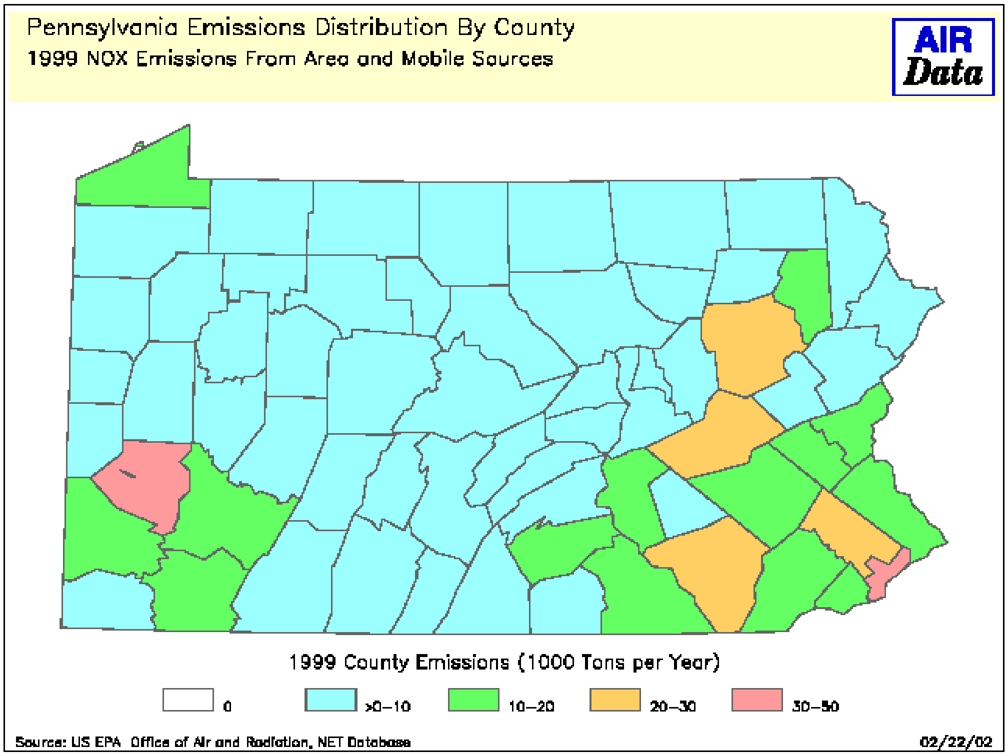
5. Additional Resources

The monitoring network for air quality is rather limited and highly generalized. Measurements from a small number of sites are used to judge the air quality of a large area. There is a need for more data (and for less pollution). Local municipalities have little authority over regional air quality, but there are still ways that municipalities can positively affect the air quality situation. USEPA has a variety of programs aimed at improving air quality. For instance USEPA offers grants for cleaner transportation and air quality programs (http://yosemite.epa.gov/aa/grants.nsf). They provide assistance for small businesses to lower emissions; they provide consumer information rating emission efficiency for automobiles. On a smaller scale, the Plants for Clean Air Council, provides information on maintaining and improving air quality with the aid of plants (http://www.plants4cleanair.org/).


Pennsylvania Emissions Distribution By County
1999 CO Emissions From Area and Mobile Sources

Source: US EPA Office of Air and Radiation, NET Database 02/22/02

Figure 4 Carbon Monoxide Emissions by County


Pennsylvania Emissions Distribution By County
1999 NOX Emissions From Area and Mobile Sources

Source: US EPA Office of Air and Radiation, NET Database 02/22/02

Figure 5 Nitrogen Oxide Emissions by County