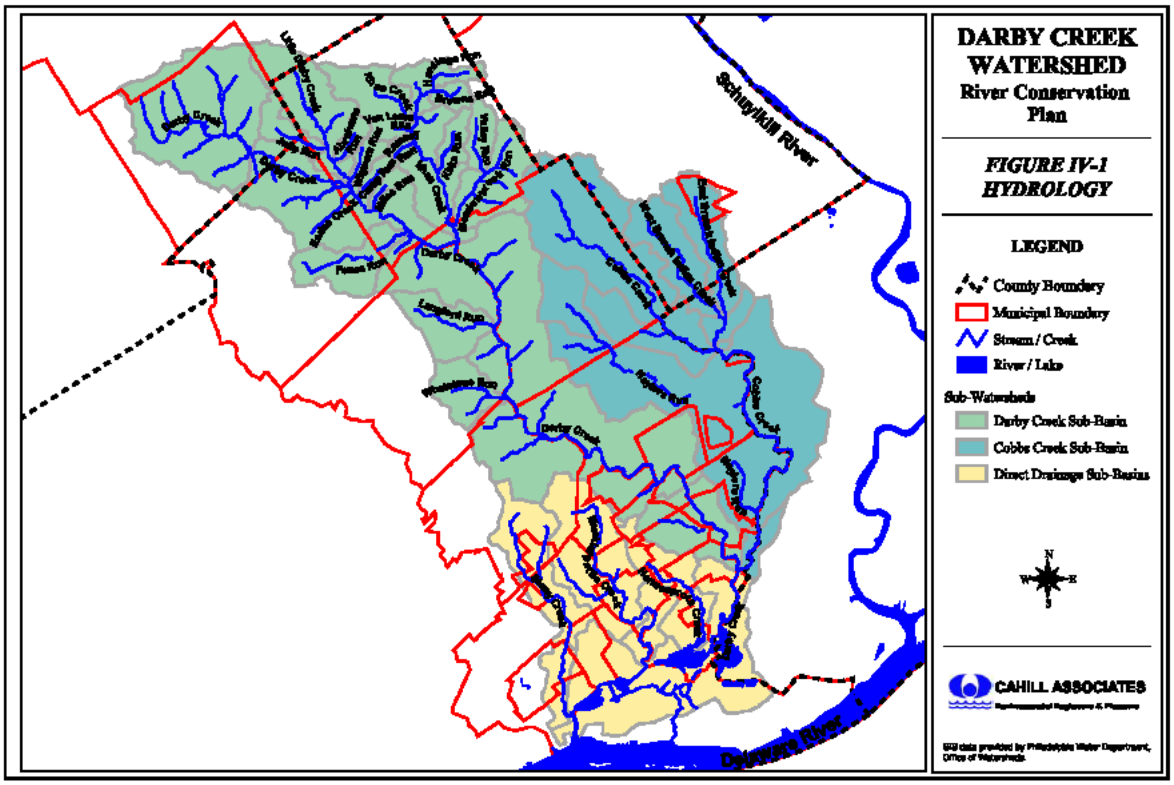
IV. Water Resources

IV. WATER RESOURCES

A. Surface Waters: Streams and Major Tributaries

The Darby Creek Watershed streams and stream sub-basins are shown in Figure IV-1. Sub-basin areas are listed in Table IV-1 for a total of 77 square miles; stream lengths by sub-basin and in total are listed in Table IV-1 as well for a total of 123 miles (data developed from GIS files). Cobbs Creek is the largest tributary of the Darby and has often been treated as a major stream itself, given its size and juncture with the Darby Creek so close to the Delaware River. The Cobbs Creek sub-basin includes about 18.7 square miles or 24.2 percent of the total Darby Creek Watershed.



There are no natural lakes in the Watershed. Several ponds exist in the upper northern portions of the Watershed, typically artificially created. These small bodies of water often have been created as part of landscape master planning for older estates, and have varying, though usually limited, functional benefit for the overall aquatic life and water resources of the Watershed. In fact, many of these small constructed impoundments suffer from water quality problems; for example, the ponds at the Willows recreational center in Radnor Township attract a vast goose population, and the water quality suffers as a result of nutrient loading due to excessive goose droppings.

Table IV-1 Watershed Sub-Basin Areas and Stream Length

SUB-BASIN	Basin Area, square miles	Stream Length, linear miles
COBBS CREEK SUB-BASIN	**18.68**	**24.80**
Cobbs Creek A	0.50	1.15
Cobbs Creek B	10.01	10.26
Cobbs Creek C	1.91	2.15
Cobbs Creek D	1.10	0.86
Cobbs Creek E	0.26	4.29
East Branch Indian Creek	1.74	2.57
Indian Creek Main Stem	1.41	0.72
West Branch Indian Creek	1.75	2.80
DARBY CREEK SUB-BASIN	**43.40**	**65.39**
Abrahams Run	0.32	0.65
Browns Run	0.34	0.75
Camp Run	4.79	0.72
Darby Creek B	2.29	3.30
Darby Creek C	16.89	25.11
Darby Creek D	5.19	10.02
Foxes Run	1.50	2.37
Hardings Run	0.83	1.95
Ithan Creek A	1.70	3.44
Ithan Creek B	1.49	1.49
Julip Run	0.65	1.09
Kirks Run	0.49	0.93
Langford Run	0.46	1.77
Little Darby Creek	2.30	3.45
Meadowbrook Run	1.76	3.68
Miles Run	0.23	0.54
Ramsey Run	0.15	0.49
Valley Run	0.60	1.14
Whetstone Run	1.10	1.81
Wigwam Run	0.33	0.70
DIRECT DRAINAGE SUB-BASINS	**15.32**	**32.88**
Darby Creek A	6.24	15.92
Hermesprota Creek	1.82	3.54
Muckinipattis Creek A	0.79	1.73
Muckinipattis Creek B	3.51	5.67
Stony Creek	2.96	6.02

Historic Streams

Figure IV-2 shows the location of historic perennial streams, based on a stream inventory from the mid-19th century (1870 Delaware County Historic Streams Map from the Delaware County Historical Society). A quick review of this inventory reveals a substantial reduction in the total stream system. Many first order tributaries (see discussion below) no longer appear on current maps. Although there may be a variety of explanations for the disparity between this historic stream network and the currently existing streams, certainly one plausible explanation for the loss of headwater streams is that substantial development has interfered with the natural water cycle. This has reduced infiltration of precipitation into the groundwater aquifers, thereby lowering the water table and reducing stream baseflow. Reduction in baseflow, in turn, means that streams cease flowing, and the extent of perennial streams is reduced over time.

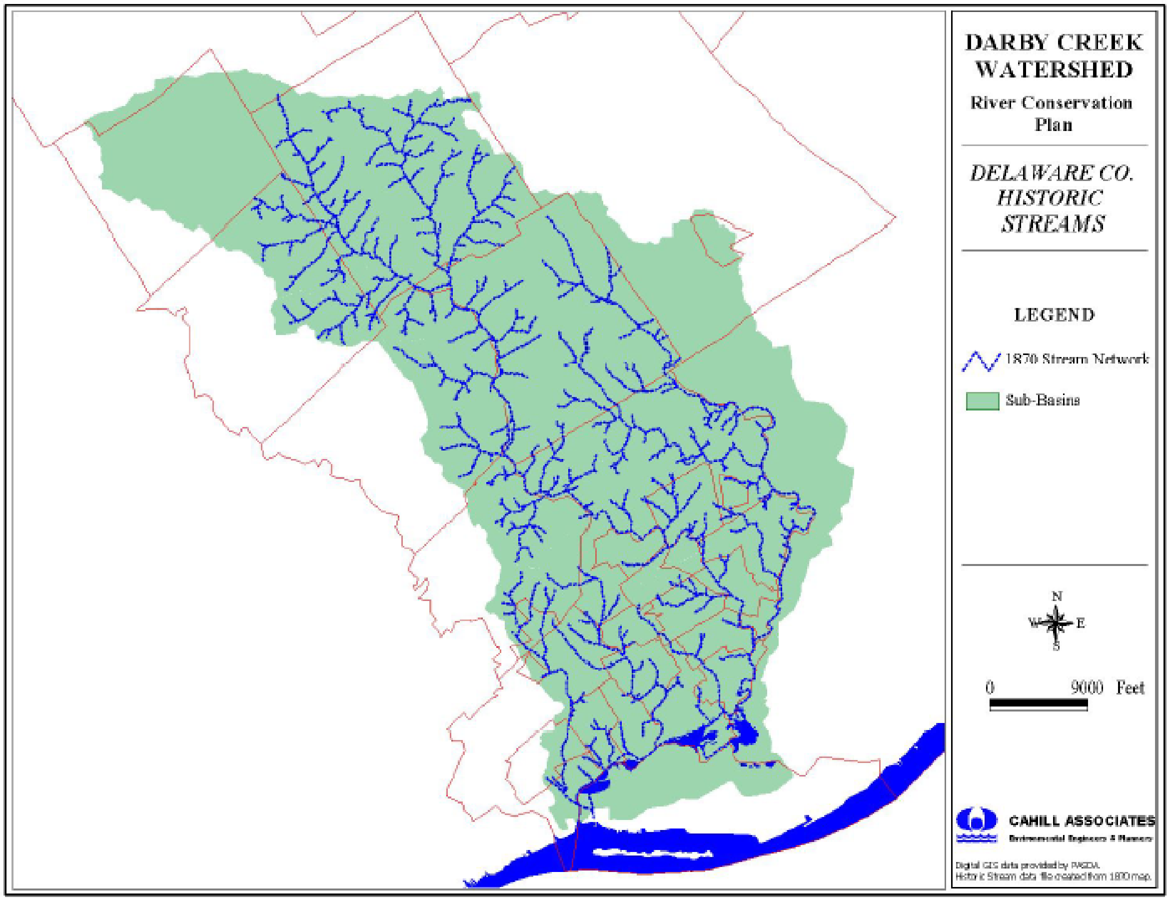


Figure IV-2 Delaware County 1870 Historic Streams

Buried Streams

Another important reality of the stream system in the Darby Creek Watershed is "buried" streams. Burial of the stream, though considered to be a viable development practice years ago, is now recognized as largely ineffective and environmentally destructive. Burial deprives stream water of essential sunlight, exposure to the atmosphere, and vegetation, all of which transform, bind up, and neutralize pollutants. Aquatic habitat, including feeding and spawning areas, is virtually eliminated. Furthermore, in most cases, increased runoff velocities and quantities have overtaxed "buried" streams. The Naylors Run flooding situation in Upper Darby Township and other problem areas vividly illustrate the results of burying streams. In a surprising number of locations in the Darby Creek Watershed, development has translated into the total enclosure and literal burying of the stream system in pipes, sometimes for considerable distances. Probably the longest section of such piping is in the Naylors Run in Upper Darby Township, a section of stream which has experienced considerable flooding problems, and where the stream is buried for several thousand feet. This piping and culverting exists in Stony Run tributary in Springfield Township (Figure IV-3 below), at Radnor Township (Figure IV-4, on the following page), and many other locations to varying degrees and distances. We should note here that Richard Pinkham's *Daylighting: New Life for Buried Streams* (Rocky Mountain Institute, 2000) provides a useful discussion of the problems relating to burial and channelizing of streams, and the benefits resulting from their "liberation" through various daylighting techniques. Where feasible, daylighting strategies should be explored in all those areas in the Darby Creek Watershed where streams have been buried (see discussions below).

Figure IV-3 Stony Run Tributary totally buried under Springfield Township Strip Center

Figure IV-4 The Little Darby Creek off Sugartown Road in Radnor Township

Stream Order

Another important characteristic of the Watershed relates to the ordering of the stream system. First order streams are especially important to watershed life because they 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. Because flows in these small headwaters are especially small, these first order streams are extremely sensitive and are the first streams to dry up when water levels decline. Figure IV-5 is a map of first order streams in the Darby Creek Watershed. One can imagine that a mapping of historical first order streams would show considerably more first order streams. Figure IV-5 is consistent with the scenario of an overall decline in water quantity and aquatic biota habitat in the Watershed as the result of increased development.

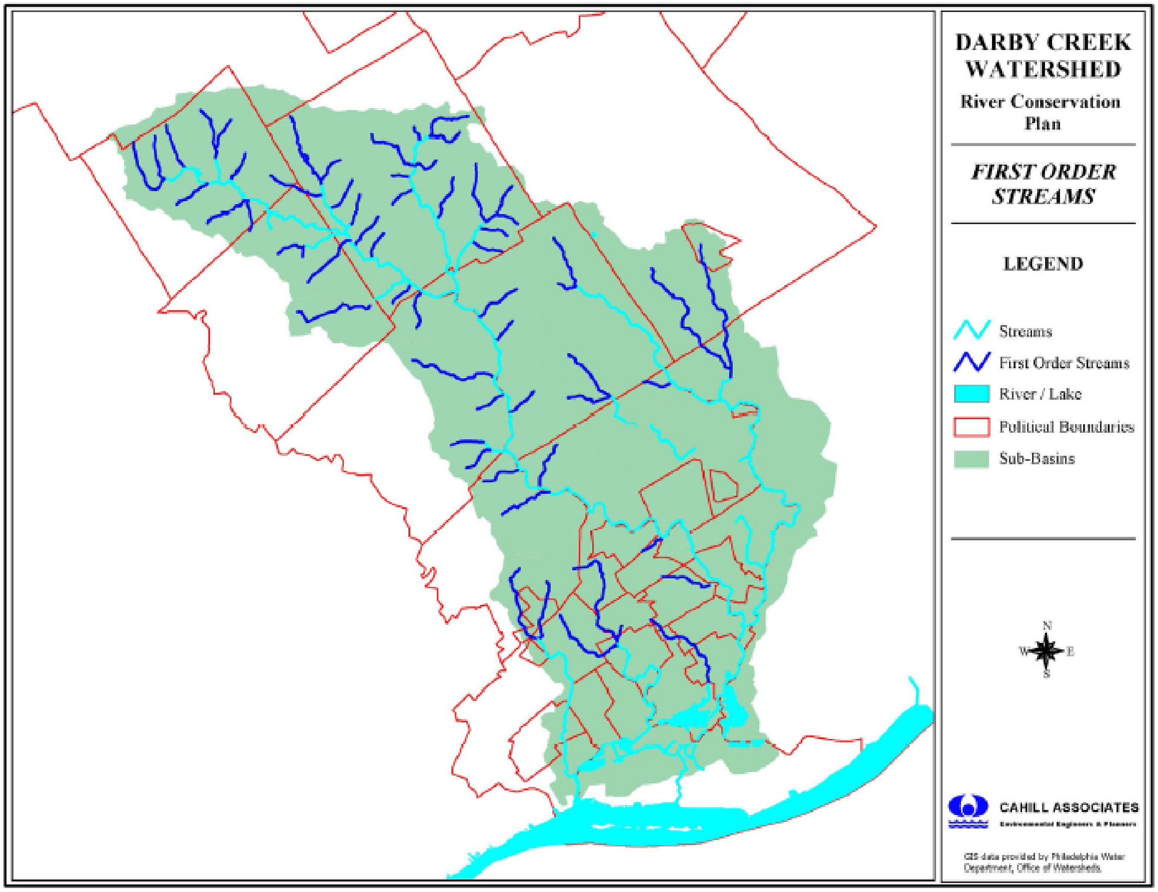


Figure IV-5 First Order Streams in the Darby Creek Watershed

B. Floodplains, Riparian Zones, Riparian Buffers

Floodplains and the riparian areas buffering streams, rivers, lakes, and other water bodies are especially sensitive watershed zones. In their naturally vegetated and undisturbed state, floodplains and riparian areas provide critical stormwater management and flood control functions, both in terms of water quantity and water quality. For example, floodplains intercept and reduce unmanaged sheet flow runoff and absorb/contain out-of-bank flows as storms increase in intensity. Flood flows are slowed, infiltrated into the vegetated floodplain zone, and actually "stored" when the entire watershed system is taken into account. Substantial physical filtering of nonpoint pollutants, especially particulates, occurs as stormwater and flood flows move across and through the vegetated floodplain, and a host of chemical and biological actions are at work both on the surface and in the sub-surface to reduce and convert nonpoint source pollutant loadings. The naturally vegetated floodplain and riparian zone typically provides substantial stream shading through the tree and shrub canopy, which reduces overheating of waters in the summer; aquatic species are often sensitive to water temperature. The vegetation also provides a balanced level of detrital matter, such as leaves and twigs, which serves as an important food source for aquatic biota. Floodplain vegetation anchors the stream bank and prevents scouring, undercutting, and overall erosion. This helps maintain the stream's morphology, its system of meanders and riffles, and the aquatic habitats they support. When floodplains are conserved as an area is developed, they provide a system of greenways linking larger open space areas that provide habitat for wildlife. In short, undisturbed floodplains and riparian areas are essential watershed elements.

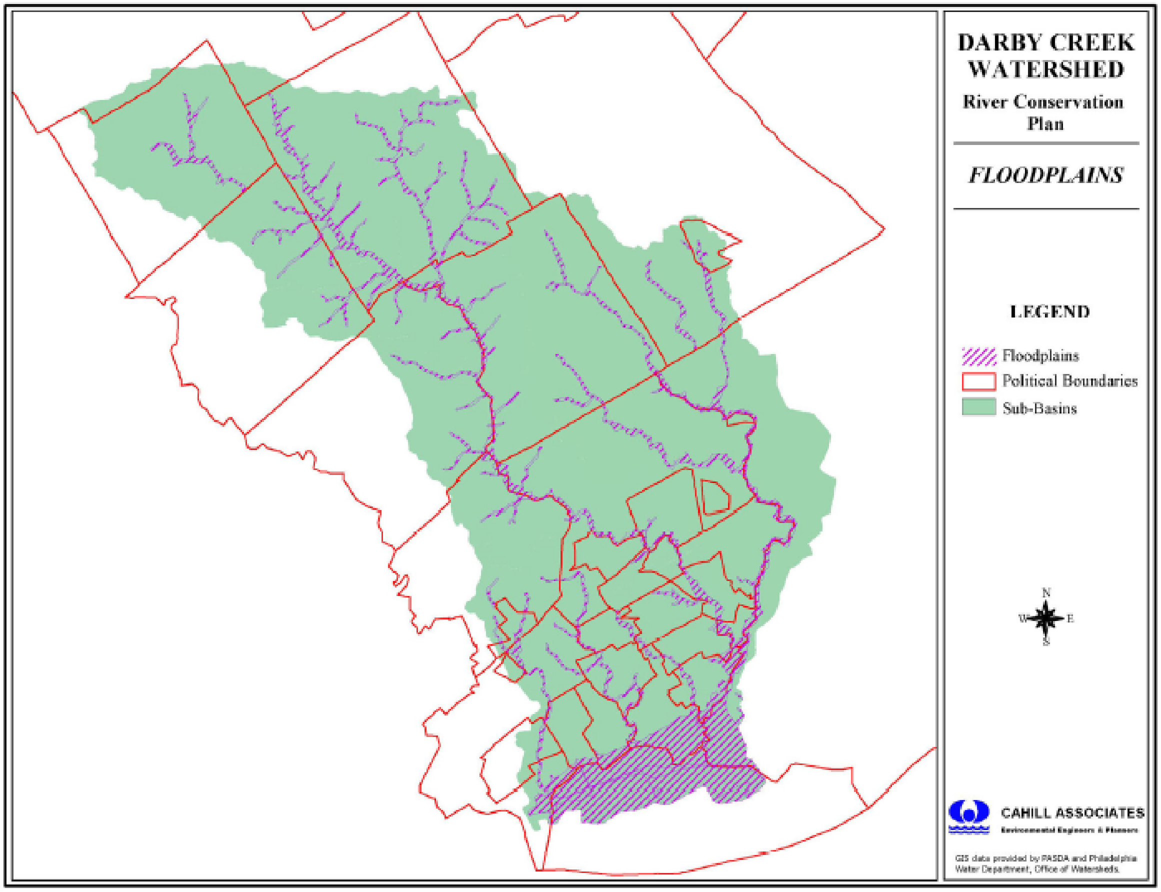


Figure IV-6 Floodplain Areas in the Darby Creek Watershed

It should be noted that these positive floodplain functions are closely interrelated to the positive functions of the riparian buffer. In many cases, assuming a riparian buffer width of 65 to 100 feet, the floodplain and recommended riparian buffer may be virtually one and the same, although certainly the floodplain may extend beyond the riparian buffer limit and vice versa, depending upon the upstream-to-downstream watershed location. In this discussion, floodplain and riparian buffer functions and benefits are treated as one. Floodplains are shown in Figure IV-6 (on the preceding page). If we hypothesize an average floodplain/riparian zone width of 100 feet (extending on both sides of the stream) and apply this buffer to the entire stream system of the Darby Creek Watershed, floodplains/riparian zones potentially comprise 2,984 acres (about 6 percent of the total Watershed area).

Over the years, development has encroached substantially into floodplains of the Darby Creek Watershed. In many places, this development has resulted in total stream enclosure/burial with virtual elimination of any semblance of the floodplain. Elsewhere, streams have been substantially channelized with structures that are built into and on the floodplain. Fill has been placed within floodplain areas to accommodate parking, roads, and other development elements, resulting in a broad array of impacts on natural floodplain functions. Even the relatively inoffensive clearing of floodplain areas with replacement as lawn and other landscaped areas takes its toll on the important water quality and water quantity functions of the natural floodplain. Figure IV-7 illustrates recent floodplain encroachment in the Drexelbrook area.

Conversely, an excellent example of floodplain and riparian zone conservation and protection is the Cobbs Creek Park itself, with the adjacent Morris Creek Park facility. Philadelphia had the foresight years ago to establish greenways along the Cobbs and its tributaries, both for conservation and recreational purposes. With the exception of the Heinz National Wildlife Refuge, the Cobbs Creek Park and related facilities constitutes the most significant conservation and recreation zone in the Watershed.

Figure IV-7 Floodplain Encroachment near Drexelbrook, main stem Darby Creek

Philadelphia Water Department ("*PWD*"): Cobbs Creek Restoration Project - A Sustainable Approach to Restoring an Impaired Urban Stream

This special effort by PWD focuses on the critical natural functions of the stream system, its floodplains and riparian buffer zones. This project will implement a sustainable approach to stream habitat restoration that will mitigate the impacts of urban development and related hydrologic and hydraulic modifications. By enlisting the members of the Darby-Cobbs Watershed Partnership and national experts, this local Watershed restoration effort will restore 1,000 linear feet of the Cobbs Creek stream corridor between Pine Street and Cedar Avenue using natural restoration techniques. The primary goal of this project is to identify and document existing stream conditions, develop conceptual alternatives, prepare final design and construction drawings, and stabilize a reach of Cobbs Creek using fluvial geomorphologic principals and natural channel design techniques. The most appropriate restoration techniques will be selected based upon a comprehensive, Cobbs Creek-wide, fluvial geomorphologic characterization completed by the PWD project team using Rosgen methodologies.

PWD is applying an holistic approach in this work, recognizing that a stable stream channel is a function of the balance of in-stream morphological features as well as the many interconnections with the surrounding riparian ecosystem. Restoration encompasses the replication of natural hydrologic and ecological cycles, sustainability, enhancement to riparian and in-stream aquatic habitat, improved aesthetics, all with significant cost savings over structural solutions. The results of this approach include not just a stable stream bank geometry, but also long term ecological stability. This approach to stream bank stabilization combines the disciplines of fluvial geomorphology, hydraulics, hydrology, and applied ecology and requires an accurate identification of stream classification type, an understanding of hydrologic actions within the watershed and their effects on a stream channel, and clearly defined restoration goals. Sound fluvial geomorphologic principles and an understanding of the natural stream system are integral to creating a stable stream channel that facilitates the restoration of the riparian ecosystem. The objective is to create a stream system that is stable, requires little maintenance, and is self-sustaining.

Floodplain/Riparian Zone Encroached Area Analysis

Although detailed inventory and analysis of the existing floodplain and riparian zone has not been undertaken for the preparation of this Plan , an approximate evaluation of the floodplain and riparian zone condition has been developed by combining the land use data file with the mapping of the Watershed stream system (Figure IV-8, on the following page). Land use/land cover categories including Vacant, Wooded, Recreation, Agriculture, and Water, which bounded the stream were assumed to be natural or relatively natural (a very forgiving and generous assumption; in truth, significant portions of these land use categories also could have been altered from their natural riparian condition). They were assumed to have some existing riparian buffer and/or undeveloped floodplain condition. All other land use categories were assumed to constitute some floodplain/riparian zone encroachment condition. Based on this combination of data layers, the resultant statistics indicate that 1,168 acres of the Darby's total 2,984 floodplain/riparian zone acres (approximately forty percent) have experienced encroachment by development, and are likely to have substantially reduced floodplain and riparian zone functions. This could well be a substantial underestimate, given the amount of clearing and disturbance which could occur in both the Recreation and Vacant categories; the situation could be worse than suggested by these numbers and may well approach 50 percent encroachment. In summary, substantial portions of the most sensitive and critical riparian zones in the Watershed have been adversely impacted by development. Clearly, restoration of these areas already impacted is important, and better management of the floodplain and riparian zones should be an important goal for the Darby Creek Watershed in the future.

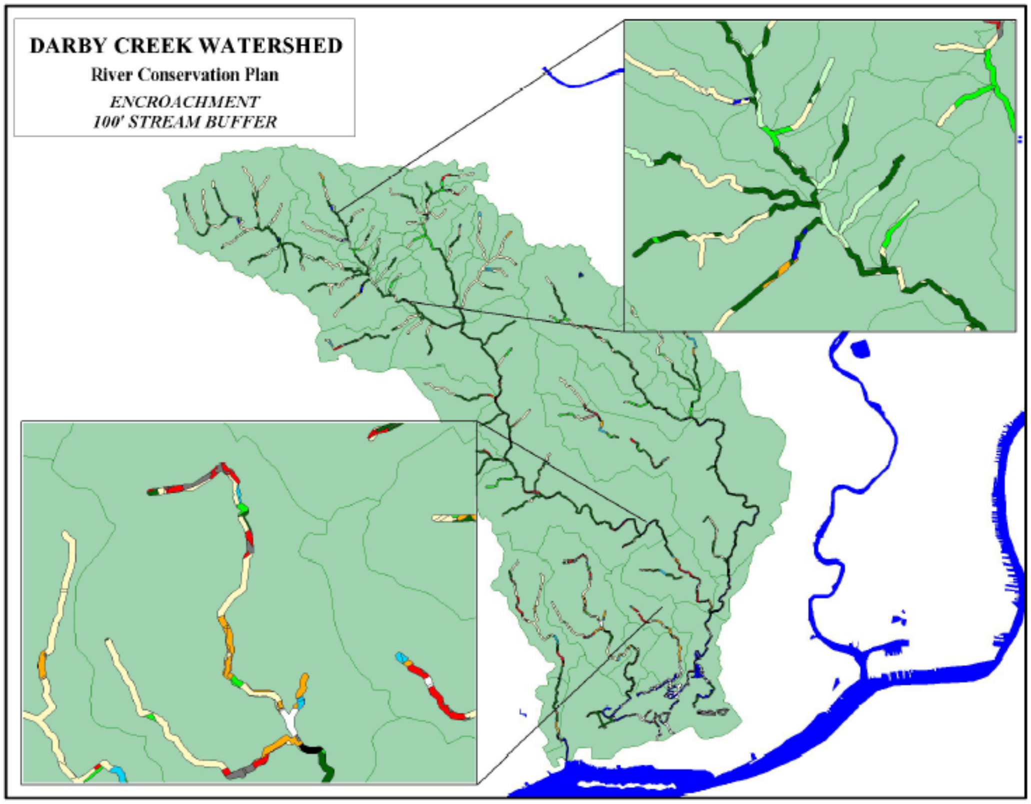


Figure IV-8 Stream Encroachment Analysis using 1995 DVRPC Land Use
(Colors relate to Figure II-3)

The method of riparian zone encroachment applied above is an estimate and may include a margin of error. The intent of this analysis in this Plan has been to provide an overall assessment of the state of riparian buffers throughout the Darby Creek Watershed, based on the existing GIS database, in order to highlight the major issues and problems to be confronted in future conservation planning. During the course of preparing this Plan, each of the Heritage Conservancy (Doylestown PA), supported by Pennsylvania Stream ReLEAF, the Pennsylvania Coastal Zone Management Program, and Pennsylvania Department of Environmental Protection has mounted a more intensive riparian zone inventory and assessment in southeastern Pennsylvania watersheds and has developed data for Darby Creek Watershed riparian zones. This data has been developed based on Year 2000 air photos supplemented with special helicopter flyovers. In future planning for the Darby Creek Watershed, this data may be very useful to assist in evaluating the condition of its riparian zone.

Federal Emergency Management Agency (FEMA)

Floodplain management in an undeveloped watershed is important, but effective management is especially important in a highly developed watershed where the benefits of the floodplain and riparian zone conservation take on heightened importance. A major problem, as the data indicate, is that so much of the Darby Creek Watershed has been developed before the emergence of any floodplain regulations, the most notable of which are the Federal Emergency Management Agency ("***FEMA***") set of minimum floodplain standards. At this time, virtually all of the 31 municipalities of the Darby Creek Watershed participate in the FEMA floodplain program; East Lansdowne is the one municipality in Delaware County which is not required to participate in the FEMA program. Most municipalities have incorporated minimum FEMA standards into their respective codes and ordinances, although some municipalities in Delaware County may not be in strict compliance with the FEMA program, (especially given the FEMA program changes which occurred in the mid 1990's). If a municipality is in violation of FEMA program requirements -- specifically elements of the National Flood Insurance Program ("***NFIP***") -- it could be suspended from the FEMA program and held responsible if flooding damages were to occur. In such cases, homeowners would be deprived of flood protection as part of the NFIP). A cursory review of the municipal ordinances throughout the Watershed indicate that most municipalities have not exceeded FEMA minimum requirements, although they are constitutionally enabled to enact more rigorous floodplain and riparian zone controls.

Important points need to be made here regarding floodplain management and the FEMA program in the Darby Creek Watershed. Of course, all new development projects and redevelopment projects must comply with these minimum floodplain standards, as part of municipal regulation. However, the number of new development projects and redevelopment projects is not great, especially in the middle and lower portions of the Watershed where the problems and Watershed impacts tend to be most serious. It is true that as available land has dwindled and availability of developable sites has declined, pressure to develop less desirable sites such as floodplain sites has intensified. A scarcity of land has led to more development in the floodplain and to filling, legally and illegally, of floodplain and even floodway areas for building foundations, parking lots, and other ancillary facilities. Nevertheless, new development and redevelopment are relatively limited, especially in the lower portions of the Watershed. Consequently, regulations for new land development projects in the respective subdivision and land development regulations of the 31 municipalities, though important, have limited effectiveness, whatever these regulations might require. In fact, a substantial amount of land on the floodplain was developed prior to the existence of any floodplain management program, whether it was the FEMA program or any other more local initiative. As is discussed elsewhere in this Plan, the very history of the Watershed itself is steeped in mills and waterpower, the construction of which meant direct encroachment into the floodplain.

Secondly and perhaps most importantly, the minimum FEMA standards themselves are inadequate and allow for substantial floodplain and riparian zone impacts to continue to occur, <u>even when fully and completely implemented and enforced</u>. FEMA standards focus primarily on the protection of life, limb, and property. Although standards have improved in the mid-1990's, FEMA standards are not intended statutorily to be a program of floodplain protection and watershed management. Filling and even structural construction may occur even within the highest risk floodway zone, provided that hydraulic and floodway impacts are not substantial and first floor areas are properly flood-proofed. Even more extensive clearing, filling and paving are possible in the "flood fringe" portion of the floodplain. These very generous allowances in the existing local and Federal regulations explain why development projects continue to be approved within the floodplain and riparian zone in the Darby Creek Watershed, and why Watershed impacts especially in terms of flooding may grow even more serious in the years ahead, unless something is done to curb this type of development. As this Watershed has developed and the overall hydrology has been altered so dramatically (see discussion below), flood events impinge upon it with greater and greater frequency and with more intensity. To add insult to injury, at the same time, the floodplain of the Watershed itself is paved, filled, and otherwise impacted by innumerable land development projects, even further reducing and compromising its critical natural functions—a devastating "double whammy".

As challenging and difficult as this might be, municipalities in the Watershed must realize that rigorous floodplain and riparian zone protection is cost effective and ultimately the wisest course of action. Development and redevelopment projects must avoid floodplains and riparian zones in order to prevent disastrous future flooding. To protect intensive development in adjacent areas, the floodplain itself must be kept as fully and densely vegetated as possible, so that it can provide maximum flow reduction and retention. Strict ordinances must be enacted so that natural floodplain/riparian zone functions are preserved and restored. Though this restoration will take many years and comes at a cost, given the current level of impact, benefits will begin to accrue to Watershed residents, who will also benefit in so many other ways from this floodplain and riparian zone restoration.

C. Wetlands

Wetlands are transitional lands between terrestrial and aquatic environments, and include lands commonly known as swamps, marshes, bogs, springs, and seeps. Wetlands can also include areas which may not always have standing water. Wetlands are unique environments that provide critical ecological and overall environmental functions, which ultimately have natural, economic, and even social benefits. These wetland functions include water storage, flood water abatement, water quality improvement, provision of vital plant and wildlife habitat (including an inordinate proportion of Pennsylvania's rare, threatened, and endangered species), groundwater discharge that maintains stream base flow, and groundwater recharge in some cases. In terms of the Darby Creek Watershed, all of these benefits are important, though given the Darby's problems of both water quality and stormwater flooding, these wetland benefits undoubtedly top the list. Because an unknown quantity of wetlands have been lost to development (i.e., filled) over the years in the Watershed (it can be surmised that a considerable quantity of wetlands located adjacent to the Watershed's major streams and tributaries have been filled as development has encroached across the floodplain and overall riparian zone), those wetlands which remain are of particular importance and are deserving of special protection.

National Wetlands Inventory Program
Wetlands within the Darby Creek Watershed have been identified and mapped (Figure IV-9) based on National Wetland Inventory ("***NWI***") data. The NWI wetland classification system is hierarchical, with habitats divided among five major systems at the broadest level. Three major systems are represented in the Watershed; the other two classes, Marine and Estuarine, are not. Lacustrine (lakes and ponds), Palustrine (marshes and swamps), and Riverine (rivers, creeks, and streams) systems only comprise 3% of the total Watershed area (2.1 square miles) with the remaining 97% of the Watershed classified as Upland. While few Palustrine fragments dot the northern Watershed landscape, the majority of the wetlands in the Watershed which remain are located at or near the John Heinz Wildlife Refuge at Tinicum, the largest remaining freshwater tidal wetland in Pennsylvania. The NWI data source provides an approximate mapping of wetlands and is appropriate for use in this Plan. NWI wetlands delineation is based on interpretation of high altitude aerial photography and should not be used for regulatory purposes. Many small wetlands typically are omitted from NWI mapping.

Wetland Construction
Wetlands can be recreated. Special wetland studies by the City of Philadelphia with USEPA support have indicated the potential for creating wetlands between the Darby and Cobbs, immediately above their confluence. Approximately two acres of wetlands were recently

reconstructed adjacent to Naylor's Run in Delaware County, through the Natural Lands Restoration and Environmental Education Program. Though opportunities are limited, additional wetlands creation potential exists throughout the Watershed and would be beneficial from a water quality, flood reduction, and habitat perspective.

Special PWD/USEPA Wetlands Program

The Philadelphia Water Department ("***PWD***") Office of Watersheds ("***OOW***"), in conjunction with other Watershed stakeholders, has undertaken a comprehensive watershed-based planning initiative to characterize and develop solutions to regional urban water pollution problems. An important component of this initiative is to define appropriate water quality improvement approaches for abatement of point and nonpoint source pollution impacts pursuant to achieving the goals of USEPA's Total Maximum Daily Load Program ("***TMDL***"). This PWD/USEPA wetlands project is intended to help illuminate the vital role that wetlands play in contributing to Watershed health and to further support the protection and enhancement of their inherent water quality improvement function. The goal of this project is to *expand* PWD's existing wetland inventory and assessment program to define opportunities for wetland protection and enhancement for four watersheds in the Southeast Region of the Commonwealth of Pennsylvania.

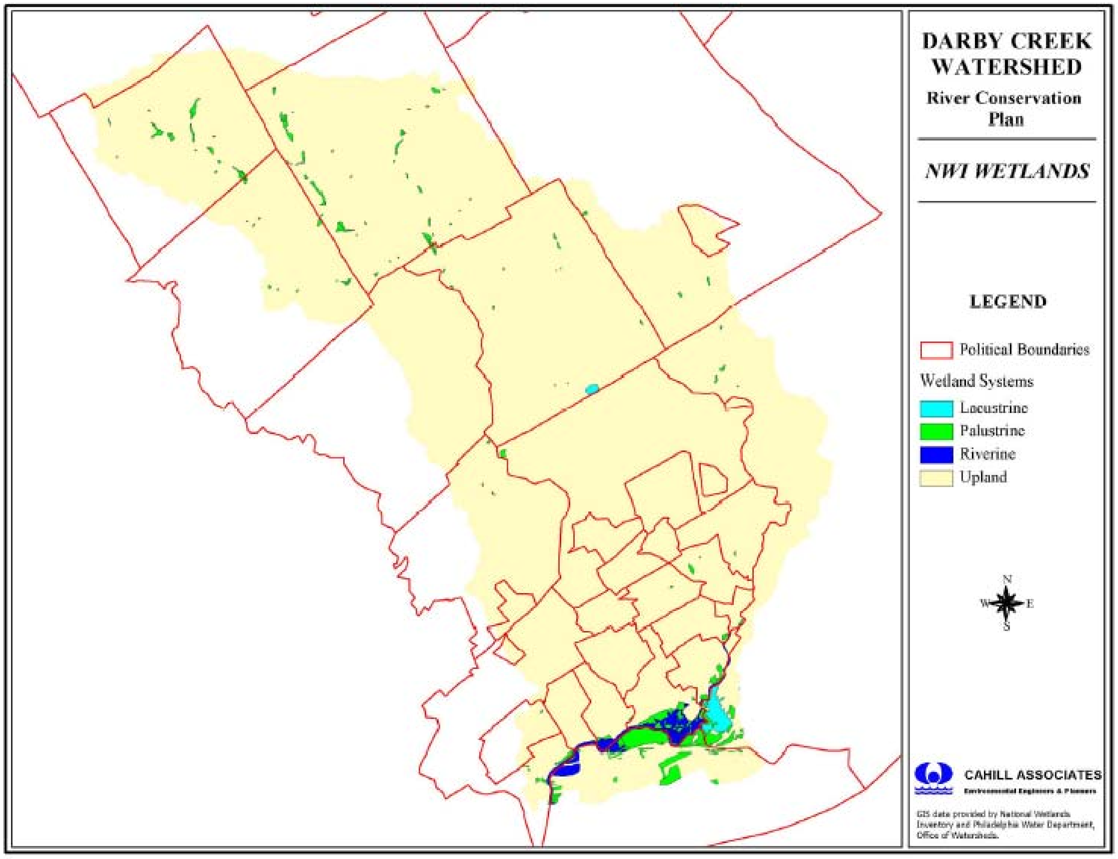


Figure IV-9 Wetland Systems in the Darby Creek Watershed

This project will both provide and receive information from other ongoing projects in the Watershed, including a fluvial geomorphologic master plan under development for the Cobbs Creek portion of the Watershed. In an effort to identify and reduce major wetland stressors, assessment efforts will be focused around existing stormwater discharge infrastructure - especially those areas that are presently targeted for renewal. The data collected from this project will provide a foundation for continued wetland protection efforts and support future wetland preservation, enhancement, and creation activities. This project will also promote the integration of floodplain management, runoff pollution source management, and water quality management in priority Watershed areas through the identification and assessment of wetland habitats. Finally, the project will identify the best approaches to implement water quality improvements through construction of stormwater treatment wetlands that appropriately integrate with existing wetland systems, and that do not intrude on existing wetlands, consistent with the guidance provided in EPA 843-B-00-003 *Guiding Principles for Constructed Treatment Wetlands.*

D. The Water Cycle

Understanding the water cycle and how human development actions have affected this cycle is especially important in understanding the Darby Creek Watershed. Figure IV-10 illustrates the essential dynamics of the water cycle (or hydrologic cycle, a term which can be used interchangeably). The water cycle arrows illustrate continuous movement. 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 of years ago is a function of this continuous cycling and recycling.

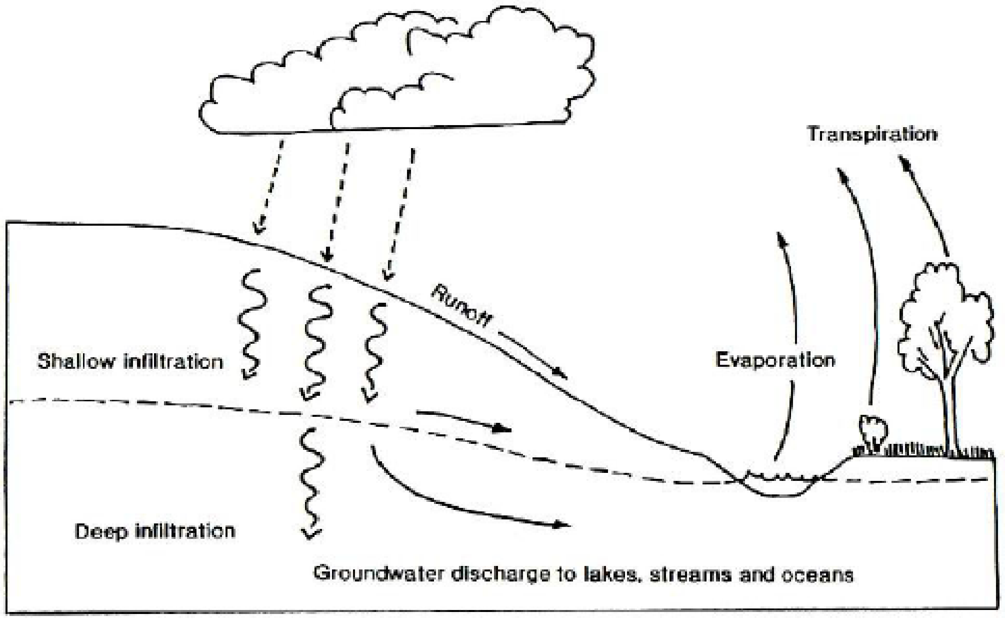


Figure IV-10 The Hydrologic Cycle

The water cycle for an average year in our general climate zone includes a variety of components which can be displayed in the form of a relatively simple system flow chart (Figure IV-11, on the following page). Precipitation data is based on rain gauges and includes data recorded over many years at many different stations (the closest official National Oceanic Atmospheric Administration rain gauge is located at the Philadelphia International Airport, relatively close to the Darby Creek Watershed). The PWD has instituted a system of rain gauges, several of which are located in the Cobbs Creek Watershed. Total stream flow data, where available, similarly is obtained from stream gage data, typically recorded by the US Geological Survey, over as many years as possible, with special procedures applied to distinguish stormwater runoff from stream baseflow occurring during non-storm periods or dry weather (i.e., baseflow separation). USGS stream gauge locations within the Watershed are shown in Figure IV-12 (on the following page). Different watersheds with different land covers and different geology and aquifer characteristics will demonstrate some variation in stormwater runoff and stream baseflow volumes in average precipitation years, although the general relationships between the two are remarkably consistent in this Piedmont and Coastal region.

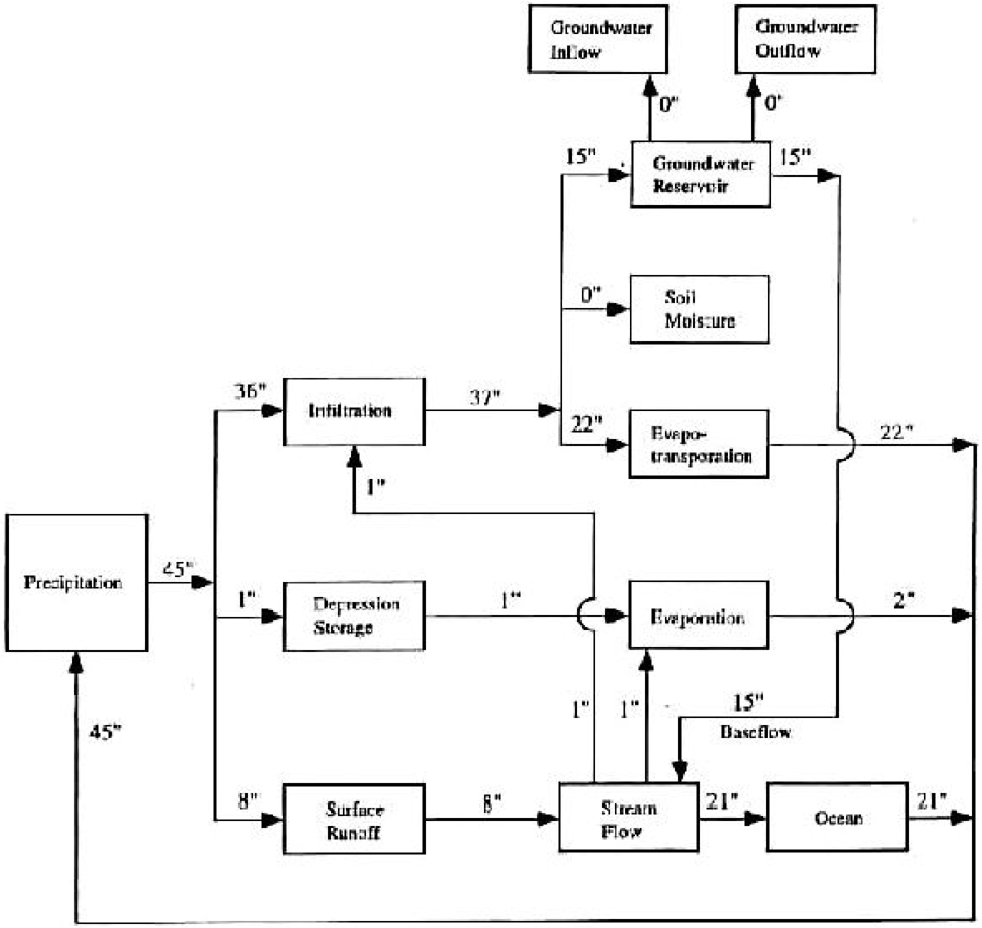


Figure IV-11 The Hydrologic Cycle Quantified for the Piedmont Region

Before delving into any one of the water cycle elements in greater detail, it is important to stand back and appreciate that the system 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>decreased</u> by 10 inches, then inputs to surface runoff and/or depression storage must be <u>increased</u> by the same amount to balance the cycle. Further along in the cycle, infiltration <u>outputs</u> will have to be reduced by the same 10 inches. Following along on the flow diagram, the groundwater reservoir, evapotranspiration and soil moisture elements together would be reduced by 10 inches, which would be reflected in stream baseflow reductions.

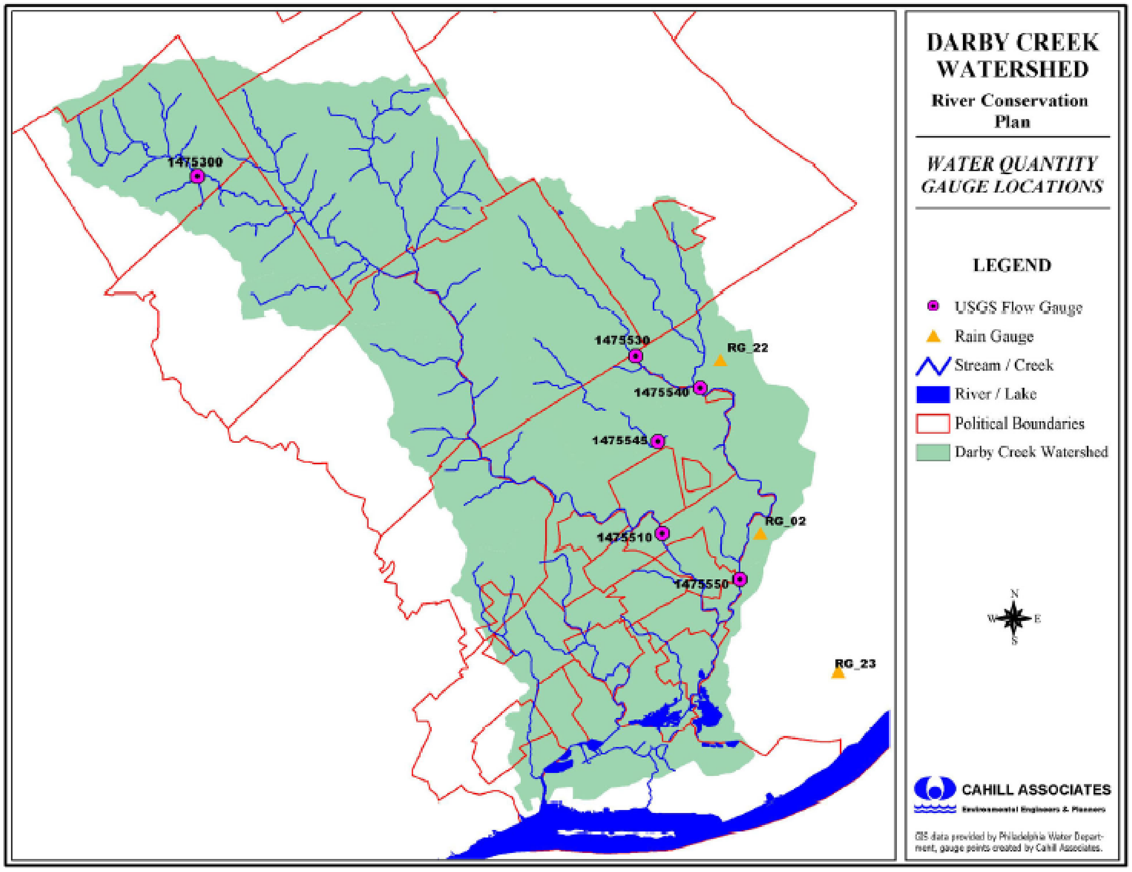


Figure IV-12 USGS Water Flow Gauges in the Darby Creek Watershed

To repeat, the point here is that impacting one part of the water cycle invariably affects the entire system. This action/reaction system sensitivity has important ramifications for any attempt to manipulate and manage individual elements within the water cycle. Management programs which purport to focus exclusively on one aspect of the water cycle--for example, controlling only for peak rates of stormwater runoff as we have done so often, without paying attention to the total water cycle volume impacts--produce all sorts of “surprises” elsewhere in the cycle and typically are doomed to failure.

Land development has come to mean a significant change in the natural landscape, including creation of vast areas of impervious surfaces. When we pave over and create impervious surfaces, we increase surface runoff. Figure IV-13 (on the following page) illustrates the effects if increased impervious surfaces. 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 3 medium-sized arrows become one large surface runoff arrow with both evapotranspiration and infiltration substantially decreased in size. Figure IV-14 (on the following page) 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 water runoff <u>total volumes</u> translates into significantly reduced <u>total volumes</u> of infiltration, with significant consequences elsewhere in the water cycle. This issue is of paramount importance given the tremendous amount of development which has already occurred in this Watershed.

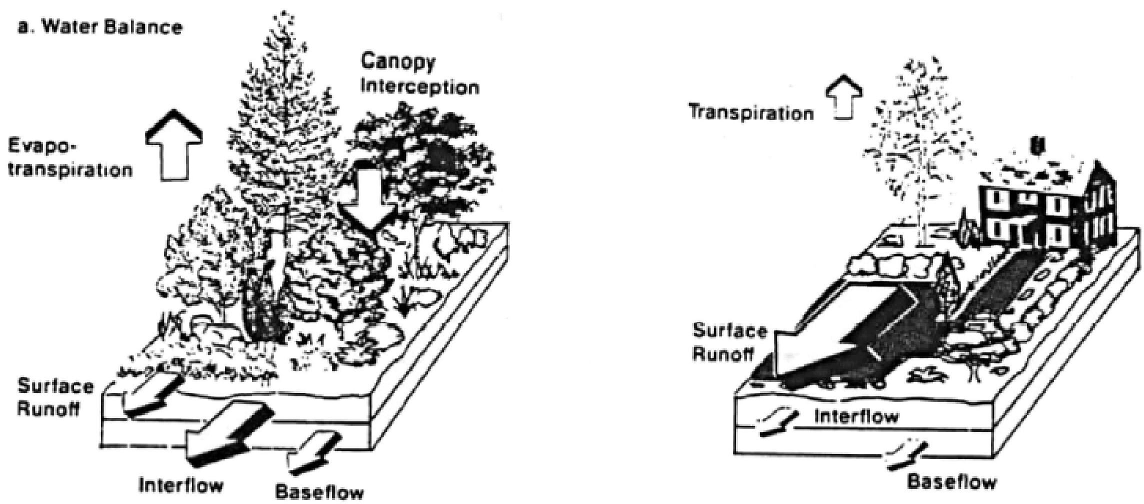


Figure IV-13 The Effects of Development on the Hydrologic Cycle

In the recent past, most municipal stormwater management regulations have focused on peak rate stormwater management. In fact, in many areas of the Darby Creek Watershed (especially the lower and middle portions), much of the existing development occurred prior to <u>any</u> stormwater management regulations. The only stormwater provisions put in place often are stormwater collection systems which directly discharge any and all 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 plans to satisfy adopted municipal regulations which have focused on the single stormwater management need of peak rate control in order to prevent flooding on adjacent parcels downstream. According to these municipal regulations, peak rates of runoff at a site, pre- to post-development, are to be held constant, although large increases in <u>total runoff volumes</u> are allowed. As these increased volumes combine 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, the existing stormwater management system itself has become a problem, rather than a solution.

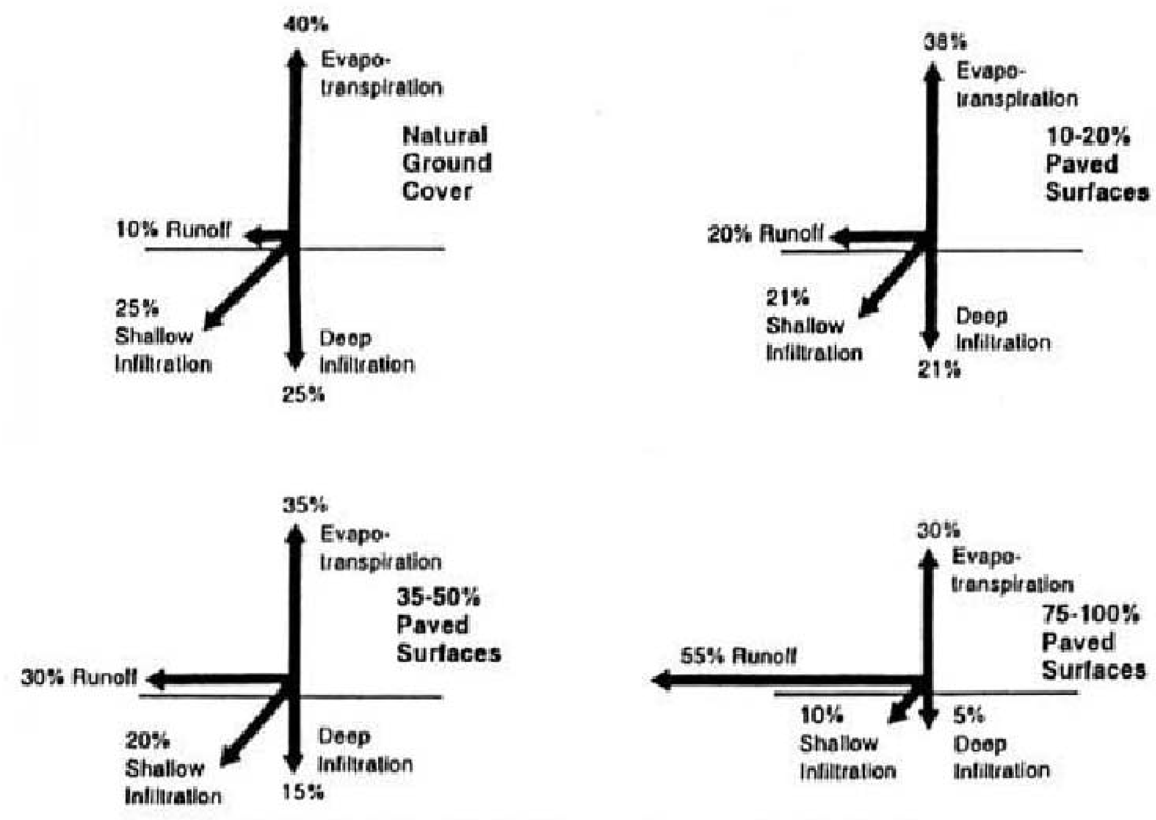


Figure IV-14 Typical changes in runoff resulting from paved surfaces

Precipitation

Obviously precipitation is fundamental to the concept of the water cycle. In southeastern Pennsylvania, average annual precipitation does vary to some extent from location to location, but long-term rain gauge data generally indicates average annual precipitation to be about 45 inches (the PWD lists the Philadelphia International Airport gauge as 41.5 inches per year)--in other words, a relatively humid climate pattern, the relatively 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. 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 small events. Based on previous analyses of southeastern Pennsylvania data for various rain gauges, over 95 percent of the total number of precipitation events occurring during the last several decades were classified in the “less than 2 inches in 24-hours” (approximately the 1-year storm) categories. 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. Surface water management strategies, 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 our 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 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 for our region have been classified in storm events as below:

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

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, tend to be hurricane-related events, although not all storms fit the hurricane pattern.

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.

The focus of interest for stormwater management lies with both infiltration and surface runoff. As discussed above, increased surface runoff by definition means decreased infiltration. Land development creates both impervious surfaces and altered pervious surfaces such as lawns, 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 volume. Subtract from infiltration and you subtract from the groundwater reservoir. As these subtractions 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 IV-15 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 the post-development condition (Figure IV-16), water well development and withdrawal 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 dry up. Wells, especially older shallow wells, may fail, and Piedmont wetlands, typically fed by groundwater discharge, will be adversely impacted. Depending upon location, salinity levels in both ground and surface water systems may actually increase.

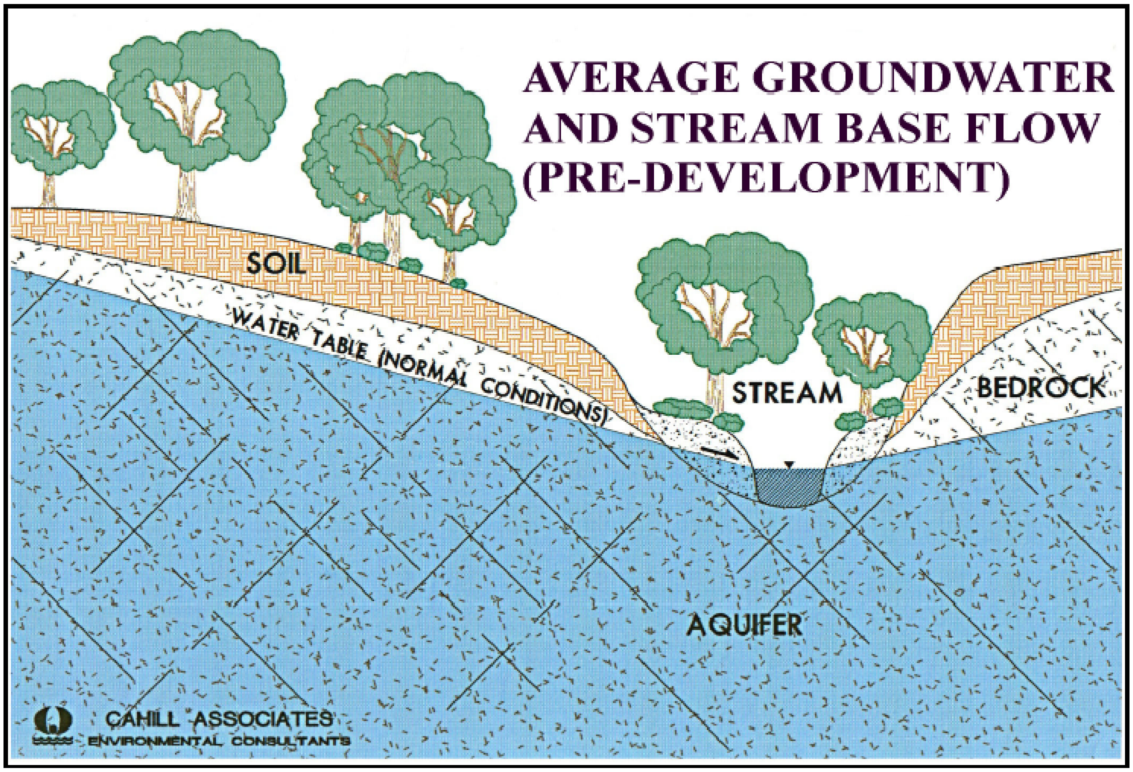


Figure IV-15 Groundwater and stream flow with pre-development activities

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 IV-15 and IV-16, 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 of the groundwater reservoir 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.

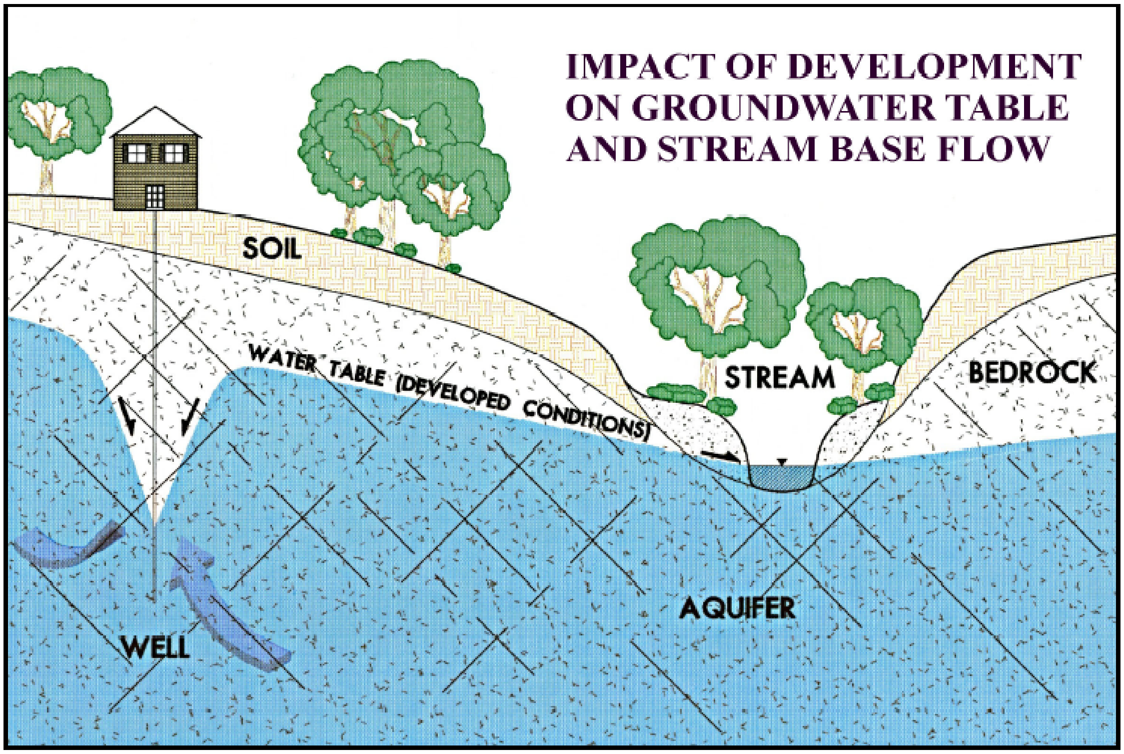


Figure IV-16 Groundwater and stream flow affected by development activities

In Piedmont physiographic contexts, stormwater runoff comprises stream flow for a small fraction of the time, perhaps less than 20 percent of the time in first order headwater streams. The vast bulk of the time, stream flow 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 hydrogeologic 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 hydrogeologic model described above remain valid.

Of course during dry periods, both the water table and stream baseflow decline as well. When the effects of drought and development are combined, the groundwater reservoir and water table may be so reduced that flows ultimately are virtually eliminated from the stream, and the stream dries up with catastrophic ecological consequences. Even if stream baseflow is not entirely eliminated, reductions in flow occur which also adversely stress the aquatic community in a variety of ways, well before total dry up results. In addition to potential loss of base flow, adding to the gravity 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 translates into loss of wetlands themselves, reduced wetland extent, reduced wetland vibrancy and richness, and other wetland functional losses.

In sum, reduction of groundwater recharge and stream baseflow due to impervious cover has serious and far-reaching consequences. Comprehensive stormwater management must strive to recognize the full range of functional impacts occurring when new land development generates increased stormwater runoff. Comprehensive stormwater management strategies must maintain as many of these critical water cycle-linked functions as possible. Because the balance in the Darby Creek Watershed has already been so impacted by existing development, it is especially critical that new development projects do not make the problems even worse.

Stormwater and Surface Runoff

Because land development alters the water cycle by increasing stormwater runoff, stormwater management has historically focused on handling excess water to prevent flooding. In fact, flood prevention continues to be the focus of most conventional stormwater management programs, and generally focuses on moving a stormwater flood peak through the stream system and downstream as fast as possible. This practice is fraught with problems.

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, 100 acres, or 1,000 acres--and for all different sized 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 IV-17 presents a hydrograph for a typical site showing both pre- and post-development conditions (note that the actual discharge values, site sizes, etc. are largely irrelevant for the sake of the comparison developed here). A storm--hypothetically, the 100-year storm—commences. As can be seen from the pre-development hydrograph, runoff from the site does not begin for a while, until Hour 2 or so, at which point the site soils have become saturated (when rate of precipitation exceeds the rate of permeability of the soils). At this time, the rate of precipitation is assumed to increase such that the rate of runoff increases rapidly. As precipitation rates decline, runoff rates decline as well.

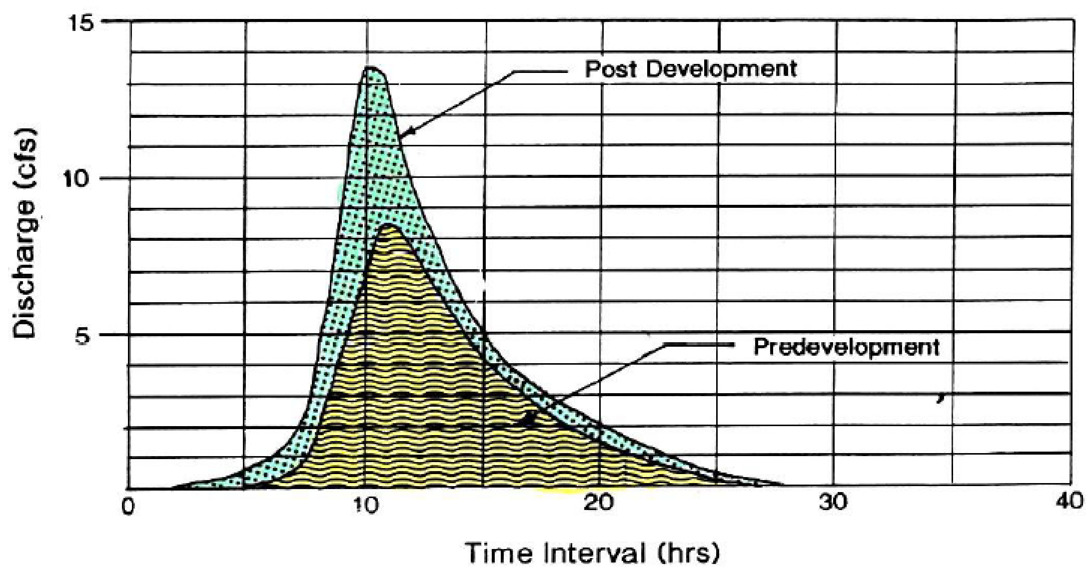


Figure IV-17 Pre-development and post-development stormwater hydrograph (no controls)

Note that the hydrograph is a graph of the <u>rate</u> of runoff. Rate must be carefully distinguished from <u>volume</u> of runoff. The area beneath the hydrograph curve in Figure IV-17 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 large storm events. Because the assumed rate of precipitation increases so dramatically in the 100-year storm event illustrated here, maximum infiltration rates are exceeded even without development. Even in forests, a considerable amount of runoff results during the 100-year storm, given the assumed storm distribution.

Figure IV-17 shows the changes that result from development at the hypothetical site and presents a Post-Development hydrograph without any stormwater management controls in place. Several observations relating to the two hydrographs can be made. First, the Post-Development hydrograph rises or increases earlier in time when compared with Pre-Development. Runoff starts occurring earlier in a Post-Development scenario because portions of the site have been made impervious and immediately start to discharge as rain begins to occur. More importantly, Post-Development runoff rapidly increases and peaks at a runoff rate 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.

The Post-Development hydrograph encompasses the entire Pre-Development hydrograph. The area under the Post-Development Uncontrolled curve is considerably larger than the area under the Pre-Development curve, meaning that the Post-Development volume discharge is larger as well.

Now let's introduce stormwater management to the picture. Figure IV-18 adds a Post-Development with Detention hydrograph to the comparison, where management is in the form of a detention basin which functions to keep the rate of runoff at pre-development levels by engineering design (via a notched weir, perforated riser, or some other technique to regulate discharge rate). However, because the detention basin simply collects and detains the added runoff, discharging this increased volume at the maximum pre-development rate over an extended period of time, the end result is that the total area under the Post-Development with Detention hydrograph is considerably larger than the Pre-Development hydrograph. Total volume of stormwater being discharged by Post-Development with Detention is significantly increased. By design, detention facilities control runoff rates, but do not reduce post-development runoff volumes.

Peak rate control is a stormwater management strategy in large part designed to protect the adjacent downstream property from flooding, ignoring properties farther downstream. That limited objective is usually achieved. If the studied area is extended to the broader sub-watershed or watershed area, the effect of this increased volume of runoff can be seen farther downstream. 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 of widespread development? Real-world examples of such development show that even if detention basins are employed to limit peak rate, flooding has worsened nonetheless.

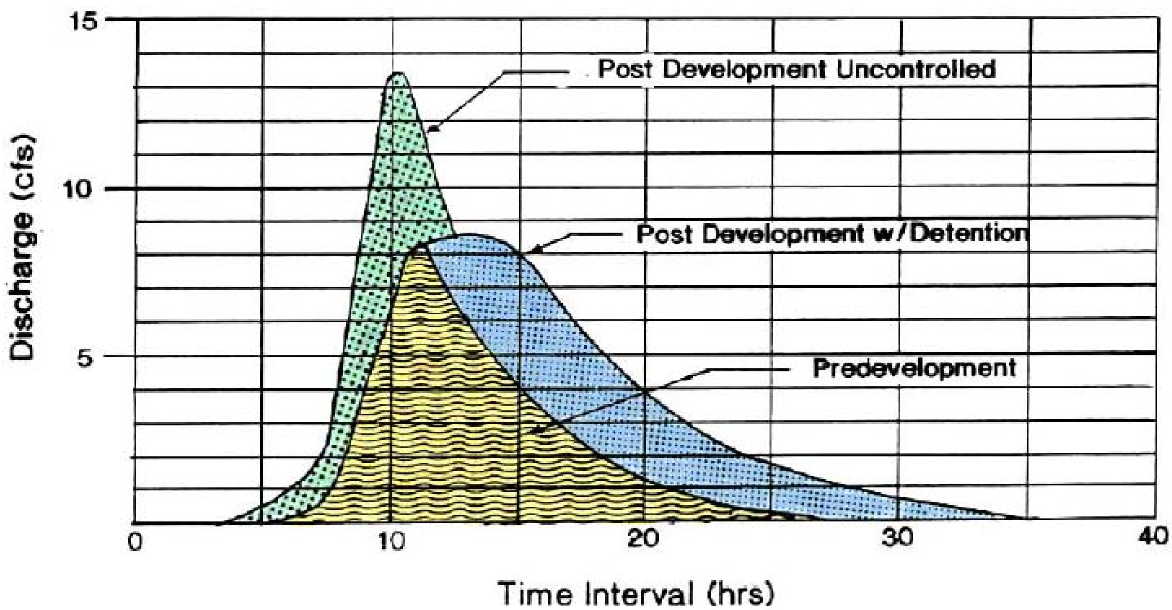


Figure IV-18 Comparison of pre- and post-development stormwater hydrographs

Figure IV-19 (on the following page) illustrates the possible flooding impacts (depending upon the location within the watershed) which can result when a peak rate control philosophy is used watershed-wide. The illustration shows a hypothetical watershed comprised of five sub-basin development sites, or Sub-Basins 1 through 5, each of which undergoes development and relies on a peak rate control/ detention basin approach to stormwater management. Pre-Development, when the hypothetical storm occurs, five different hydrographs result for each Sub-Basin, and combine to create a resultant Pre-Development hydrograph for the watershed, shown in blue (note that the vertical y-axis value for the total watershed hydrograph is simply the addition of the 5 y-values for the 5 sub-basins at any one time).

Figure IV-19 assumes that all five developments utilize detention basins. The five hydrographs are modified as shown, with Pre-Development peak rates not being exceeded, but being extended over time. What is the impact at the base of the watershed? As these extended peak rates are added up, the resultant watershed hydrograph grows taller. Not surprisingly, the resultant Post-Development with Detention hydrograph for the watershed not only exceeds the Pre-Development hydrograph in terms of total area under the respective curves (i.e., more volume clearly is discharged Post-Development, which would be anticipated), but peak rate of runoff for the watershed increases considerably, because these increased volumes compound as they are routed 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 limit by definition will be expanded. Property loss, possible loss of life and limb--all the costs associated with flooding--can be expected to worsen.

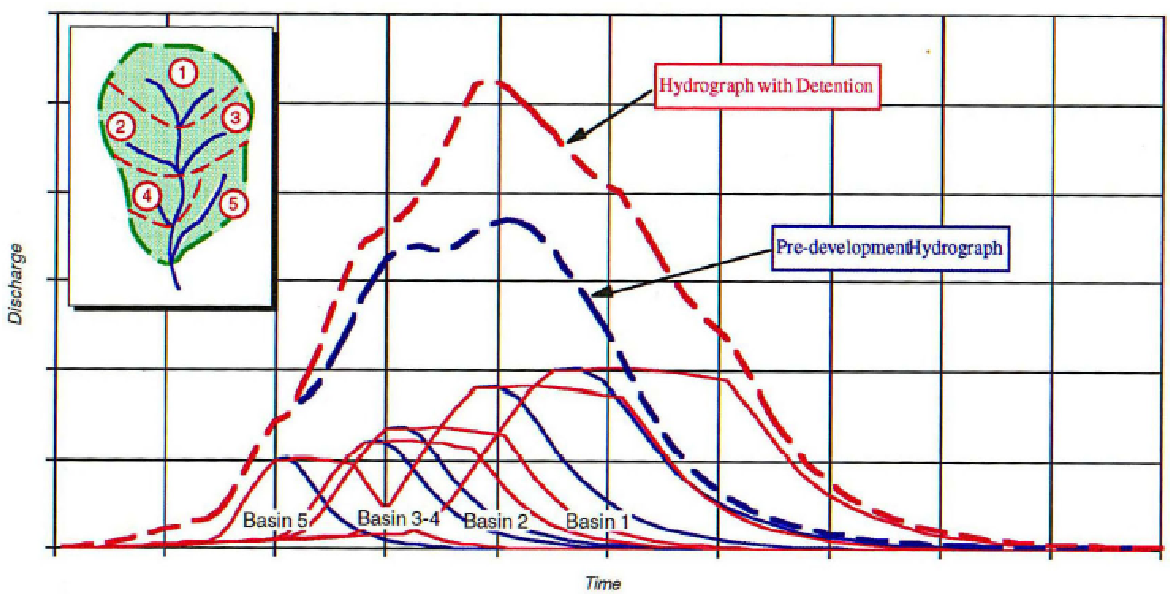


Figure IV-19 Effects of stormwater detention in a hypothetical watershed

Based on Figure IV-19, the peak rate increases significantly, as does the duration of flood flows. In the Pre-Development condition, the peak runoff rate may last for an hour or so. In the Post-Development with Detention condition, the peak rate or near peak rate may last for 11 or 12 hours. Although the hypothetical nature of all of these hydrographs must be kept in mind, the point here is that the time of peak flooding can be expected to increase, as well as the rate at which these flood waters move through the lower watershed. This increased flooding results in serious impacts to the stream system, including but not limited to:

- significant stream bank erosion
- bank undercutting
- elimination of meanders
- channel widening and straightening
- increased sedimentation and deposition
- elimination of pools and riffles
- reduced aquatic life

Over time, these impacts can transform a stream from a high quality waterway, with excellent species diversity and richness, literally to a functional storm sewer.

E. Impervious Cover Analysis and Water Cycle Impacts in the Darby Creek

Using the existing land use mapping as a base, the Philadelphia Water Department has applied appropriate impervious cover assumptions to these land use categories (see Section II and Table II-11). Figure IV-20 illustrates the mapping of this impervious cover in the Darby Creek Watershed.

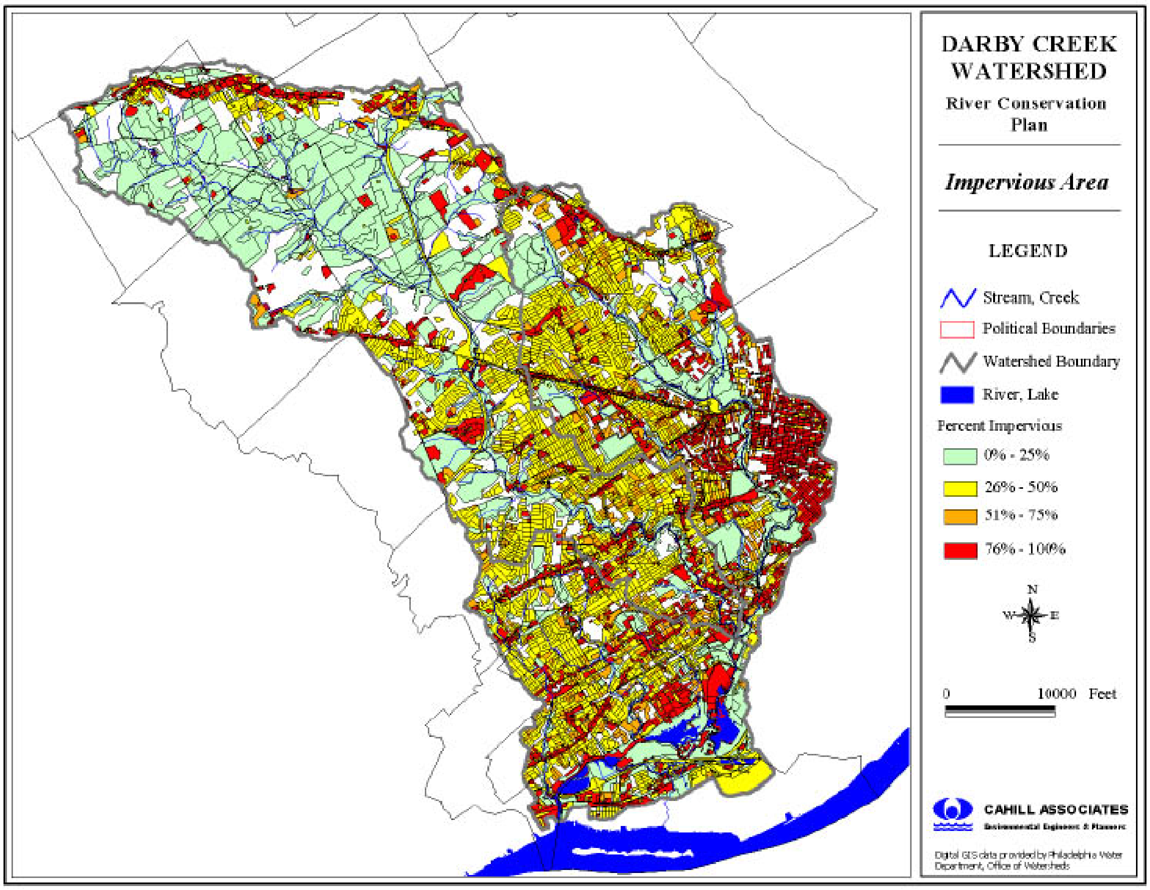


Figure IV-20 Impervious Area Percentages based on land uses (PWD)

Table IV-2 Impervious Area within the Darby Creek Watershed (PWD)

	Acres	% Impervious
Lower Watershed	6,613	51.4
Middle Watershed	4,644	44.6
Upper Watershed	7,513	28.8
Total Watershed	18,769	38.0

Table IV-2 (on the preceding page) provides a summary of PWD's statistics for impervious cover in the Lower, Middle, and Upper portions of the Watershed. The summary reveals that the total impervious area for the Watershed is a very high 38 percent; even the least developed Upper Watershed is 28.8 percent, and the Lower Watershed is an extremely high 51.4 percent. Table IV-3 and Figure IV-21 (both on following page) translate impervious cover into a water cycle reality. Figure IV-21 shows the increased runoff created by impervious surfaces on a hydrologic sub-basin basis. Table IV-3 conversely shows the loss or reduction in natural infiltration into the ground, caused by impervious surfaces in the three Watershed sub-areas. The loss in recharge is many billions of gallons each year. Any way you choose to look at it, development has had a tremendous detrimental impact on the natural water cycle in the Darby Creek Watershed.

F. General Water Quality Issues

The importance of water quantity issues notwithstanding, important changes in water quality result from development. We sometimes make this distinction between water quality and water quantity, as though the two issues were separate and unrelated. But the truth is that both aspects of water management are inextricably linked, and many management strategies that effectively address water quantity will in many cases address quality as well. Runoff from impervious surfaces both increases volume and rate of runoff. This means that pollutants are scoured and swept into the sensitive aquatic ecosystem. Strategies that reduce this impervious surface and/or redirect runoff into natural swales directly reduce the stormwater runoff source and indirectly reduce the transport of stormwater-linked pollutants. If we eliminate runoff quantitatively, erosion by definition will be eliminated. Once in the stream, increased volumes and rates of runoff mean streambank erosion, undercutting, flattening and straightening of the channel, re-suspension of sediment, all of which become serious quality problems. Even if flooding is not worst case, full or near full bank flooding has serious water quality ramifications. Therefore, although the focus of this chapter has been on water quantity and the water cycle, both quantity and quality are very much at issue.

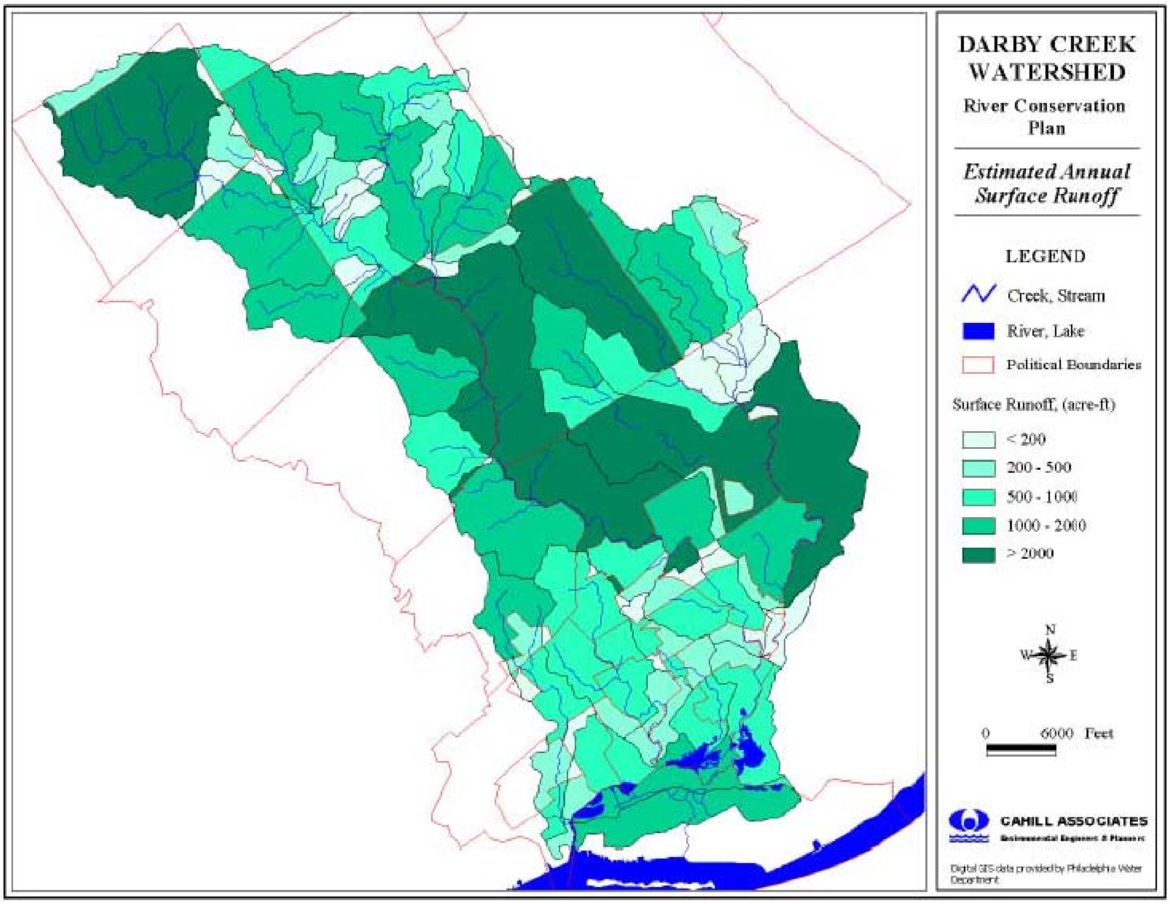


Figure IV-21 Estimated annual surface runoff in the Watershed sub-basins

Table IV-3. Average Annual "Lost" Recharge in the Darby Creek Watershed (CA 2001)

Watershed Area	Gallons
Lower Watershed	2,693,363,772
Middle Watershed	1,891,511,325
Upper Watershed	3,060,024,903
Total Watershed	7,644,900,000

Even so, not all quality pollutant loads can be eliminated through quantity reduction techniques. Roads and highways are necessary, and will generate vehicle use and pollution by definition (i.e., there is some proportion of these pollutant loads which are not variable and will be generated even if maximum reduction in quantity can be achieved). At the other end of the quantity spectrum--reductions in stream baseflow--water quality and water quantity issues emerge as well. To the extent that any fixed or constant source of pollution--for example, point source discharges or malfunctioning onsite septic systems--continues to generate pollution loads as infiltration and stream baseflow decline, this reduced stream baseflow translates into increased concentrations of instream pollutants, and pollution-related problems grow more severe.

Nonpoint Source Pollution

Water quality aspects of stormwater management have become a major concern nationwide. In fact, stormwater-linked nonpoint source pollution--the mix of pollutants that is washed off the earth's surface with each precipitation event--is often cited as the primary water quality problem in the nation today. As a result, numerous manuals such as the new *Pennsylvania Handbook of Best Management Practices for Developing Areas* have been produced setting forth management programs designed to minimize stormwater-linked water quality problems.

Stormwater-linked pollutants vary with type of land use and intensity of land use and have been shown to include bacteria, suspended solids, nutrients, hydrocarbons, metals, herbicides and pesticides, other toxics, organic matter, and others. Pollutant loads are generated both from impervious areas ("hot spots" such as gas stations, fast food parking lots, and heavily traveled roadways are primary culprits) as well as from pervious zones, such as the chemically-maintained lawns and landscaped areas where chemical maintenance can be considerable. Some nonpoint pollutants are even air-borne, deposited onto the land surface and then washed into receiving water bodies.

Sources of this pollution include:

- vehicles
- fertilizers
- pesticides/herbicides
- road surface litter (salt, sand, ashes, etc.)
- oils, pet wastes and pet litter, solvents, trash, etc.
- other nonpoint materials (even those of natural occurring organic, vegetative or soil sources) might well be considered pollutants when dumped in excessive quantities into waters or near drainage channels

Note: Normal deposition of leaves, grasses, twigs, bark and soils are valuable amendments to watershed biota. Such seasonal background depositions may be considered enrichment until any accumulated levels reach toxic proportions. Too much of any (good) thing can be troublesome in excess.

Point Source Pollution
Additionally, an important source of pollutant loading in selected portions of the Darby Creek Watershed (Cobbs Creek) is combined sewer overflow (Figure IV-22, on the following page), where due to the physical interconnection of sanitary and stormwater collection systems and the tendency of these interconnected systems to malfunction, there is released significant amounts of untreated sanitary wastes into the stream, in addition to the load of nonpoint source pollutants. Furthermore, there also appear to be serious problems of inflow and infiltration, or "I/I" as it is commonly called, throughout many portions of the Watershed which are sewered. As discussed in more detail below, elevated pollutant loadings in both wet weather and dry weather in those stream reaches where large sanitary collection and conveyance systems parallel the stream (sometimes on both sides of the stream) suggest that these sewers are leaking their sanitary wastes directly into the streams. In such a highly developed watershed, point source wastewater treatment plants would be expected to be a pollutant source, but are not significant pollutant sources in the Darby Creek Watershed, given the export of wastewater to Philadelphia's Southwest Treatment Plant.

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).

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 is available for use and should be exploited to the maximum extent possible. Because these processes tend to be associated with, or 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.

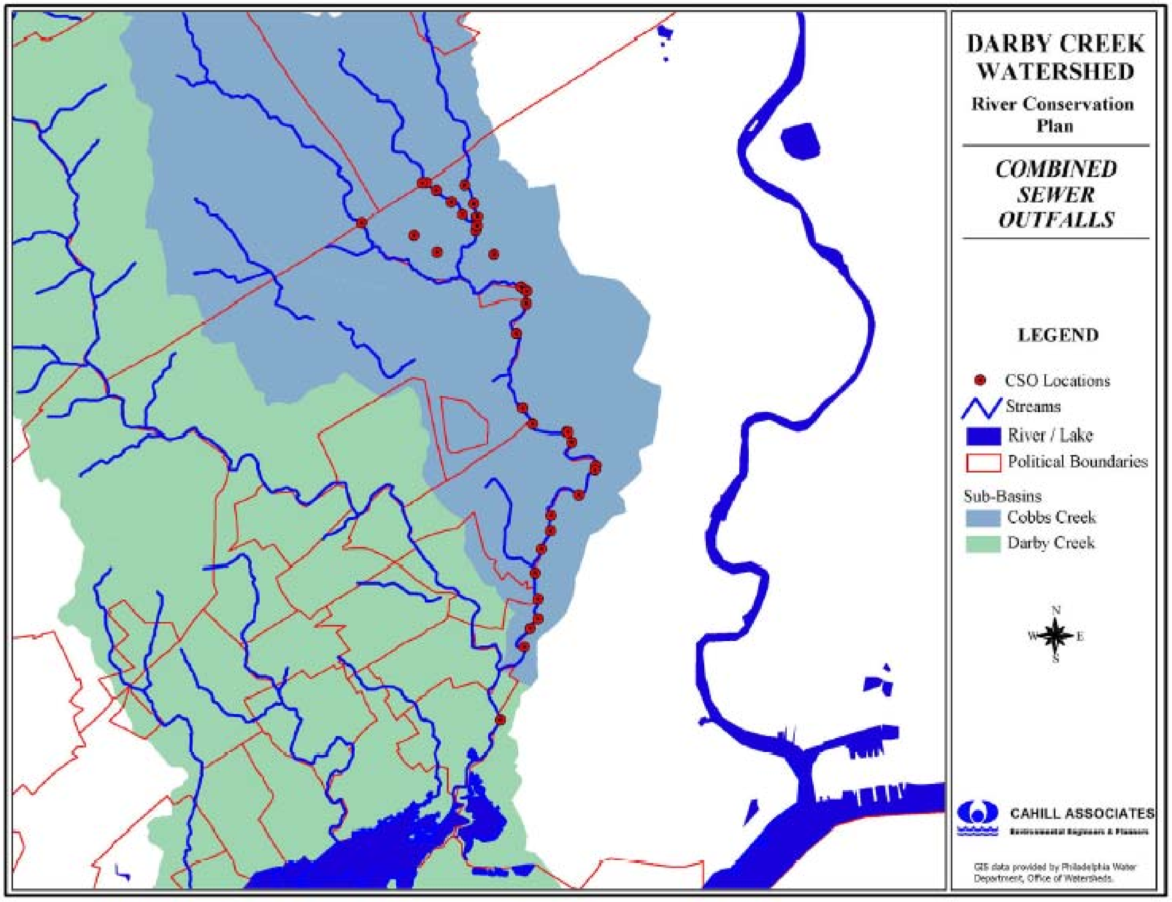


Figure IV-22 Combined sewer overflow locations in the Cobbs Creek Sub-watershed

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 <u>through</u> 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 moved 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 by most municipalities in the Watershed. 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.

G. Water Quality Issues: Interaction between Water Quantity and Quality

Water quantity and water quality typically are closely interrelated. As the natural flow patterns of a watershed undergo change, water quality and the aquatic biota present in the stream system typically change as well. Usually these changes are not for the best. This is certainly true of the Darby Creek Watershed.

The Philadelphia Water Department's Technical Memorandum No. 4 provides an excellent discussion of how impacts to water quantity have in turn caused significant impacts to water quality, especially the aquatic biota which comprise the Darby Creek Watershed. The considerable urbanization which has occurred in the Cobbs and Darby Creeks has translated into dramatic encroachment into the floodplain and directly into the stream channel itself (in the most extreme, completely burying the stream underground in some cases). Changes in the natural hydrology—in the patterns of infiltration and runoff--have resulted in extreme stream channelization, creating a system which is not in dynamic equilibrium. Time to peak has been decreased, sometimes dramatically; peak flow rates are increased equally dramatically. Smaller rainfall events produce more and more bankfull and out-of bank flooding, unable to be accommodated by the existing stream channels, floodplains, and wetlands. More erosion occurs; more sediment is deposited. Increased flood flows scour stream banks, fill pools and cover riffles with sediment. A more short-lived, homogeneous, and unstable species system is created with increased sediment deposition and decreased habitat diversity. The aquatic ecosystem has lost much of its critical energy linkage in first order streams and wetlands, as these valuable areas are disturbed and paved over and their ecological functions destroyed.

Benthic Macroinvertebrates

The bottom dwellers of the stream, benthic macroinvertebrates are critical links in the food chain and are crucial for the support of the high order icythyfaunal (fish) community. Animals in this group include a variety of aquatic insects and insect larvae, as well as worms and crustaceans. Unfortunately, the impacts of urbanization have hit the benthic macroinvertebrate community especially hard. Because these organisms rely heavily on the stream's system of natural riffles as primary habitat for most of their life cycle activities, the increased flows, plus sediment deposition and scouring that have resulted in the Darby Creek system, have adversely impacted the reproductive and feeding activities of many macroinvertebrates. Eggs are either scoured downstream or covered with sediment. Many species have been eliminated; others tremendously reduced in terms of richness and abundance. Organisms adapted to hydrologic extremes proliferate.

Fish
As with the benthic macroinvertebrates, habitat change means fish species change. Those species reliant on riffles, rocks and vegetation for egg depositing, or those where egg nests located in larger constant pools are guarded by parents, are seriously impacted. Sudden changes in flow regimes physically destroy eggs which have been deposited and kill the fry. At the other end of the spectrum, sudden stream flow reductions and reduced stream baseflows means that biotic life in pools can be killed off quickly as these pools literally dry up.

Further, stormwater outfalls and combined sewer overflows worsen the overall stream condition for the aquatic community by increasing flood flows, increasing sedimentation and erosion, and then reducing water quality (e.g., fecal coliform releases ultimately result in increased biological oxygen demand with reduced dissolved oxygen levels as flows decrease, ultimately depriving fish life of oxygen).

H. Water Quality Sampling Data and Water Quality Problems in the Watershed

Although water quality in the Darby Creek Watershed is not as well-documented as we might like, our understanding has benefited tremendously by recent sampling and analysis work performed by the PWD and other agencies such as PADEP and the Fairmount Park Commission as part of their Natural Lands Restoration Master Plan. There have been a variety of special study efforts conducted during recent years, which have increased our understanding of water quality in the Watershed. PWD, jointly with the USGS, undertook special water quality work in the 1970's, which included two sampling stations in the Darby (both in the Cobbs Creek; Station 12 Cobbs at US 1 and Station 15 Cobbs just upstream of Darby Creek). Monthly sampling for a variety of parameters was performed for about 10 years, demonstrating significantly higher loadings of BOD, ammonia, phosphate and fecal coliform upstream and during wet weather storm events. PWD's consultant Camp Dresser & McKee reported that the quality problems "…were attributed to malfunctioning regulators and higher pollutant loading rates during storm events" (CDM Technical Memo 1, November 16, 1999). There are no portions of the Darby Creek Watershed which have been designated by PADEP as Special Protection Waters (High Quality or Exceptional Value).

Philadelphia Water Department

PWD has recently undertaken a watershed-based planning initiative, to a large degree triggered by the combined sewer overflow problems being experienced in the Cobbs Creek portion of the Darby Creek Watershed which is within the City's jurisdiction. In Technical Memorandum No. 1, PWD undertook special analysis and loading estimates of its 1970-1980- sampling data for two Cobbs Creek stations (12 and 15) and compared results with another study by Radziul et. al (American Water Resources Association, 1975) to establish baseline data for Cobbs Creek only. Based on this analysis, notable results included: "DO concentrations at the upstream range seasonally from about 8 mg/l to 14 mg/L. DO concentrations at the downstream location are almost always lower and drop as low as 0 mg/L during the summers… Suspended solids are greatest in the downstream location, ranging as high as 60 mg/L, except for two peaks in the upstream concentration… Fecal coliform counts appear to increase by a factor of approximately ten from the upstream to downstream locations."

The most interesting and reliable water quality data undoubtedly has been developed recently by the PWD. 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. In addition, it should be noted that PWD also added to this individual sampling program data from 2 shallow depth continuous samplers (Sondes) that were deployed three times at Station 6 and once at Stations 3, 7, 8, and 10. Due to the variability and limited nature of these sampling results, they are not reported here (see Technical Memorandum No. 2, November 30, 1999).

Results indicate a remarkable degree of PADEP standards violations for fecal coliform; exceedances were greatest in the Cobbs (160,000/100 mL at Station 6 on 6/15/99) but were also remarkably high on the Stony (73,000) and the Muckinipattis (31,000) and were quite high farther up the Darby mainstem (7,000 and 6,000 stations 4 and 5 respectively). Exceedances were much higher during the wet weather samples, yet were definitely present during dry weather flows, again both in the Cobbs and throughout the Darby Creek system stations. The second parameter of interest is dissolved oxygen where two stations on the Cobbs and three stations on both the Stony and Muckinipattis violated the State standard of 5.0 mg/L on several individual sampling occasions (averages for all sampling were not in violation). Iron also exceeded State standards (five times at four stations during three individual sampling events). Metals toxicity does not appear to be a significant problem, although metals and other toxics buried in sediments and re-suspended may be a problem. Ammonium-nitrogen may be a possible concern due to the violations of standards reported by the continuous sampling from the Sondes devices. In sum, the PWD concludes, "…the pollutants of concern for the Darby and Cobbs Creek Watershed are dissolved oxygen, fecal coliform, and dissolved iron."

Fairmount Park Commission

As part of the Fairmount Park Commission's work for the Cobbs Creek Park Master Plan, special water quality and habitat analysis have been undertaken:

> "In addition to the physical, water quantity-related problems, parts of Cobbs Creek and its tributaries have severely degraded water quality. Although water quality is not specifically addressed by this restoration plan, it did arise as an issue for this park. A known source of pollution comes from combined sewer overflows (CSOs), which contribute untreated wastewater to the creek during storm events (Marengo, 1992). Undoubtedly, other impairments to Cobbs Creek's water quality include typical urban pollutants such as vehicle fluids (oils, antifreeze), and household and lawn chemicals (detergents, fertilizers, pesticides). Still other impacts to some streams of Cobbs Creek Park come from Cobbs Creek and Karakung Golf courses. Those streams running through and adjacent to the golf course are at high risk of having water quality and water quantity related problems. Pesticides and fertilizers used on the courses may drain into the streams causing poor water quality. Furthermore, many of the streams within the golf course lack a forested riparian buffer, and in some cases the maintained grass is mowed to the edge of a stream bank. This practice does not allow beneficial stream-side vegetation to take root, and consequently stream banks can be very unstable."

"A stream quality index (SQI) was developed to rate habitat quality of tributaries in Cobbs Creek Park. The SQI combines information on channel morphology, aquatic habitat (as indicated by macroinvertebrates) and riparian condition. Based on the SQIs, the majority of Cobbs tributary reaches were impaired, with several severely impaired reaches and no slightly or nonimpaired reaches. In comparison, over the entire Fairmount Park system, the majority of reaches were classified as moderately impaired." (p. II-6)

Table IV-4 summarizes this Stream quality Index data for the stream system contained within the Cobbs Creek Park system and studied as part of the Master Plan process. The Cobbs Creek Master Plan also includes specific recommendations for mitigating existing water quality problems in these particular streams and waterways (see additional discussions in Sections II and VII).

Table IV-4 Steam Quality Index Categories and Results in the Stream System of theCobbs Creek Park (Cobbs Creek Master Plan, 1999)

Stream Quality	Stream Quality Index Range	Number and % of Reaches - Fairmount Park System	Number and % of Reaches - Cobbs Creek Park
Severely Impaired	0 to 75	11 (3%)	3 (7%)
Impaired	76 to 150	164 (38%)	27 (60%)
Moderately Impaired	150 to 225	248 (58%)	15 (33%)
Slightly or Non-impaired	226 to 300	3 (1%)	0 (0%)
Totals	0 to 300	426 (100%)	45 (100%)

Note: This index and the number of stream reaches does not include FDR Park.

I. Water Quality and Aquatic Biota (see Section V)

PA Department of Environmental Protection, 1995-1996

The abundance and diversity of the aquatic biota, of course, are excellent indicators of water quality. In 1995 and 1996, Pennsylvania Department of Environmental Protection performed special investigations of the Darby Creek Watershed, sampling for water quality, fish, and benthic invertebrates at a variety of stations. As reported in PWD's Technical Memorandum No. 1, the benthic was rated as "fair" at upper Watershed Stations 1 and 2 with both benthic and fish rated as "very good" and "good" respectively farther downstream at stations 3 and 4 (Radnor

Township). Ratings generally declined to "poor" and "fair" for benthic and fish immediately downstream, from Radnor down through Springfield Township (sampling for benthic and fish does not appear to have been performed below Station 9). In terms of water quality sampling results, PWD reports that this same PADEP sampling generally indicated levels above detection limits for iron, aluminum, total suspended solids, and fecal coliform, with low dissolved oxygen and elevated ammonia, phosphorus, iron, lead and manganese on the Cobbs Creek. Although PWD concludes that "…the overall water quality in the Darby Creek was good…", it would appear that pollution and pollution impacts on the aquatic biota are present in much of the Darby Creek system, especially as one moves downstream.

Normandeau Associates, 1997

In 1997, a special study by Normandeau Associates was conducted on the Cobbs Creek for PWD, triggered by a fish mortality incident resulting from a water main break. Stations were all within Cobbs Creek Park from just above Manoa Road down to below City Line Avenue. Although the habitat was rated as "good" to "excellent," the data itself indicated "…poor taxonomy, domination by pollution tolerant species, and low diversity. The fisheries data indicated that although numerically dense, the fish community was species poor, containing a preponderance of blacknose dace and white suckers."

PA Department of Environmental Protection, 1998

Finally, and perhaps most significantly, PADEP has performed biological assessment of the Darby Creek system in 1998, including 28 stations using EPA's Rapid Bio-Assessment Protocol and habitat assessment methods. The purpose of this special study was to determine stream impairment, based on quality and quantity of habitat and the macroinvertebrate community data. This work also was to be used as the basis for the 303(d) list that PADEP is required to develop under the Federal Clean Water Act. Figure IV-23 (on the following page) indicates the findings based on this sampling. Substantial portions of the Darby Creek system (52 percent of the stations) are classified as "impaired," with the bulk of the impairment being located below PA Route 3. Curiously, impairment also has been classified in the upper tributaries of the Cobbs Creek system in Lower Merion Township, Narberth Borough, and Haverford Township, as well as in the Little Darby in Radnor Township. The PWD, summarizing this work, reports that "…Stormwater, CSOs, and habitat modification were surmised as the primary and secondary causes of impairment. As a result, TMDLs will need to be developed for pollutants causing stream impairment, once those pollutants are determined." (Technical Memorandum No. 1, November 16, 1999)

Philadelphia Water Department Bioassessment, 1999

The PWD, with the Academy of Natural Sciences and PADEP, has performed additional evaluations of fish species, macroinvertebrates, and overall habitat in the Cobbs Creek specifically (see PWD's Technical Memorandum No. 4). In terms of fish sampling (undated), results indicate wide variation of fish in the Cobbs Creek, with the station at Woodland Avenue offering the highest species richness and species diversity (relatively diverse and relatively evenly distributed, although several of the species were pollution tolerant); other stations offered poorer richness and diversity. No "pollution intolerant" species were counted in any samples. In terms of macroinvertebrate sampling conducted in December 1999, results indicate moderate to severe impairment, reflective of episodes of poor water quality (organic enrichment) and habitat degradation (substantial sediment deposition, heavily imbedded substrate, lack of riparian vegetation, etc.).

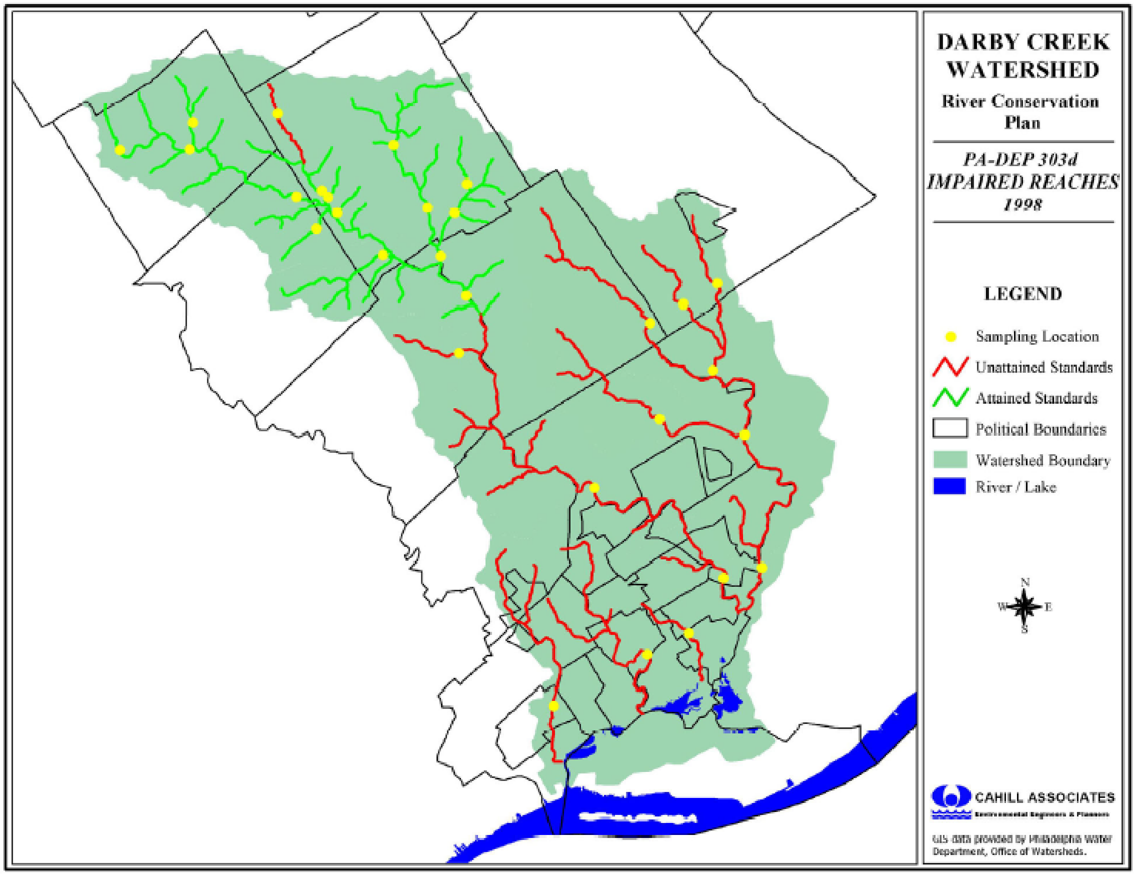


Figure IV-23 PADEP sampling locations and results from TMDL assessment

Natural Lands Restoration and Environmental Education Programs, 1999

Extensive discussion of aquatic biota and macroinvertebrates is included in the Cobbs Creek Master Plan (1999); much of this work was conducted by the Academy of Natural Sciences. Based on their analysis of existing data plus sampling and analysis conducted for the Plan itself, the biota in the stream system within the Cobbs Creek Park system generally appeared to be impaired, reflective of the water quality and overall habitat conditions (see pp. II-14 through II-19 for data by stream reach and tributary). Restoration recommendations in the Master Plan have been limited for biota due to the need for first remedying the causal water quality and habitat degradation factors which are so significant.

J. Point and Intermittent Point Sources of Pollution

Wastewater Treatment

In general, the Darby Creek Watershed is quite different from most highly developed watersheds. Although virtually the entire Watershed has public or centralized sewer systems, there are hardly any significant wastewater treatment plants, or point sources of pollution as they are called, discharging treated sewage effluent into the Darby or any of its tributaries—at least intentionally discharging. This atypical situation has resulted from the fact that over the years, a massive system of sewer mains was constructed in and along the Darby Creek valley in Delaware County, conveying sewage flows by gravity to large pumps (pump stations) located at the bottom of the Watershed. Sewage was/is then pumped over to the large wastewater treatment plants in Philadelphia (Southwest Treatment Plant). Figure IV-24 illustrates the array of wastewater treatment authorities which exist locally in the Darby Creek Watershed. These authorities typically own and manage the local collection systems in the Watershed. Additionally, DELCORA exists as the regional authority which provides the link, physically through pumping stations/force mains and administratively, to the treatment function in Philadelphia.

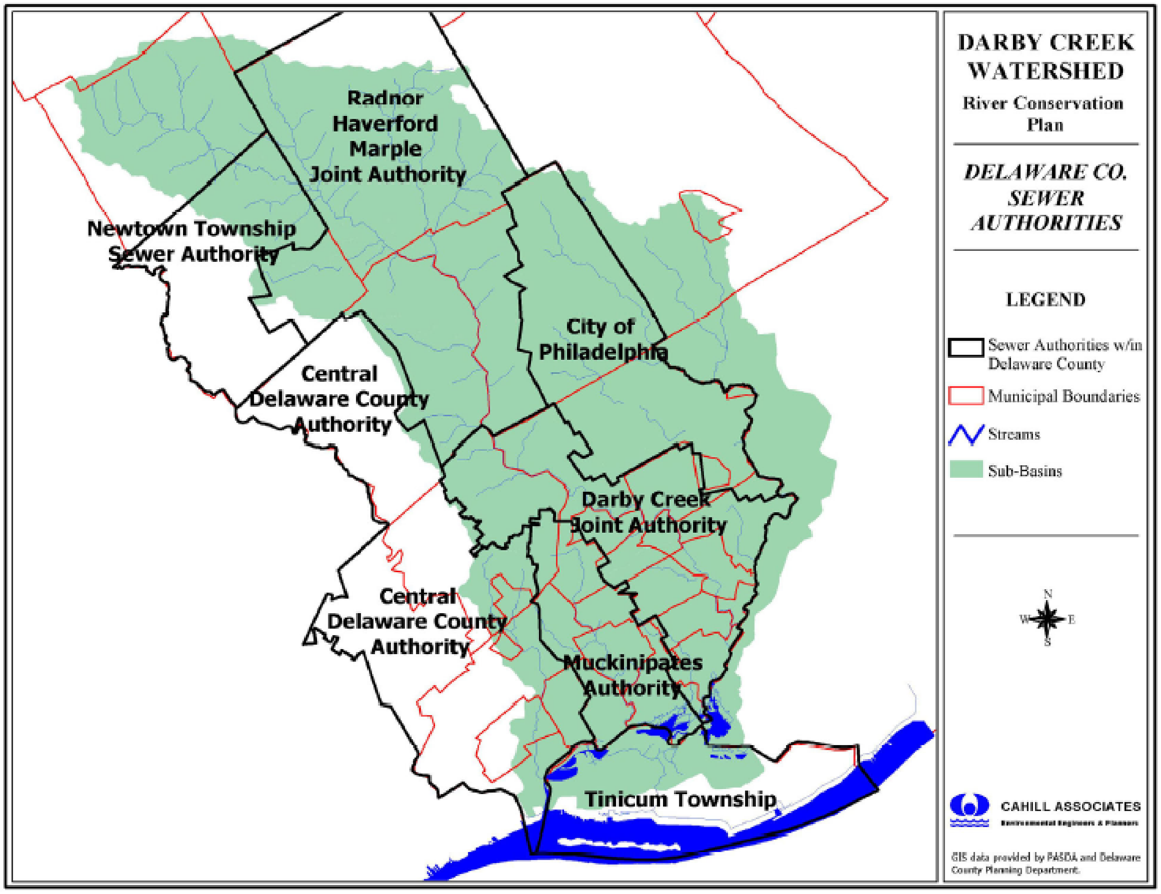


Figure IV-24 Wastewater Treatment Authorities in the Darby Creek Watershed (also DELCORA)

Point sources of pollution also may include private wastewater treatment plants, including industrial processing facilities. The Philadelphia Water Department reports that PADEP records indicate the existence of eight permitted point source dischargers in the Darby Creek Watershed (Figure IV-25), none of which is especially significant in terms of quantity of flow and severity of pollutant load (at least according to volunteer reporting provided by the point sources themselves). These plants, only one of which treats sanitary or non-industrial wastes (Tinicum Township), are listed in Table IV-5 (on following page). Obviously these treatment plant discharges themselves are not the cause of the water quality problems in the Darby and its tributaries discussed here, although to the extent that these treatment plant effluents are discharged into the stream, water quality is negatively affected to some extent. The relatively small (1.4 million gallons per day) Tinicum Township wastewater treatment plant, which discharges into the Darby relatively close to its mouth, is having difficulty complying with its NPDES permit limits and is exceeding its maximum allowable pollution discharge limits. The Pennsylvania Public Interest Research Group ("***PennPIRG***") and the Widener University Environmental Law Center have contacted the Tinicum Township Authority regarding this situation. The Authority has indicated that it is fast-tracking development of a solution which will solve this problem, subject to PADEP approval.

Table IV-5 Point Source Dischargers in the Darby Creek Watershed (Facilities Permitted under the National Pollution Discharge Elimination System, Data from PADEP; see Figure IV-25)

Permit No.	Name of Facility	Pollutant Discharged
PA0056839	Sun Oil Co	Benzene,BTEX, ethylbenzene, toluene, xylene, pH
PA0011541	Sun Oil Co	Oil, grease, TOC, pH
PA0056685	SEPTA Victory Terminal	None
PA0056642	Meenham Oil Co	None
PA0052752	Mobil Oil Co	Benzene, toluene, xylene, pH
PA0013323	Boeing Defense/Space Group	TDS, TSS, oil, grease, CN Asg, Cd, Cr, Cu, Ni, Pb, Zn
PA0028380	Tinicum Twp Sewerage Auth	Settled solids, TSS, BOD, chlorine, Fecal coliform, pH
PA0057002	Haverford Twp Public Works (Landfill)	TSS, TDS, Mn, Mg, Color, Fe, barium, specific conductance, pH

Wastewater from some source traditionally is a source of pollution in most watersheds, though given the relative lack of onsite septic systems and the relative lack of large wastewater treatment plants discharging into the streams, wastewater-linked pollution should be minimal. Given the water quality data as discussed above and the remarkably high evidence of fecal coliform reported in recent sampling, wastewater-related pollution is surprisingly great. Although there are undoubtedly scattered pockets of onsite septic systems some of which probably do malfunction, the vast majority of land uses in the Watershed are connected to centralized sewers; most wastewater generated in the Watershed is directed into a collection system and piped and exported to a centralized wastewater treatment plant beyond the Watershed. With virtually no wastewater treatment plants present, what is the source of the wastewater problem?

The apparent answer, being corroborated by other study efforts such as the Draft Eastern Delaware County Act 537 Sewage Facilities Plan Update (Eastern Plan of Study Draft 2001), indicates that the wastewater collection system is leaking. For much of its length, sewer interceptors run up and down the Darby Creek valley, sometimes on both sides of the Creek, in the floodplain and sometimes quite close to the stream itself. In some cases, this piping system is quite old, and over the years, erosion and settling and other forces have served to weaken the system, expose piping in some highly eroded places, and clearly jeopardize its integrity. During precipitation events, inflow occurs through defective manholes and other parts of the system, increasing sanitary flows and sometimes overtaxing the pump stations at the bottom of the system; overflows may be released. Analysis has indicated that the general problem is serious. In its discussion of the Darby Creek Joint Authority System, the 2001 Draft states, "The I&I Summary Report indicated that flow metering confirms the presence of severe I&I." (p. 3-22, 2001 Draft). The pollutant readings are also quite elevated during dry weather, the implication being that pollutants are being released (i.e., are leaking) even when it's not raining and quite possibly in numerous locations. Again, the data suggest that the problems exist along the Darby mainstem as well as many tributaries such as the Muckinipattis and Stony. Because remediation of these types of problems involves a complex array of different local and regional authorities and would be quite costly, remedies cannot be expected to be quickly forthcoming. Nevertheless, if significant money must be spent on these interceptor sewers along the stream, on these lineal features, the question emerges as to whether this might present an opportunity for conservation efforts, perhaps greenway efforts, perhaps passive recreational trails, as the remediation project unfolds.

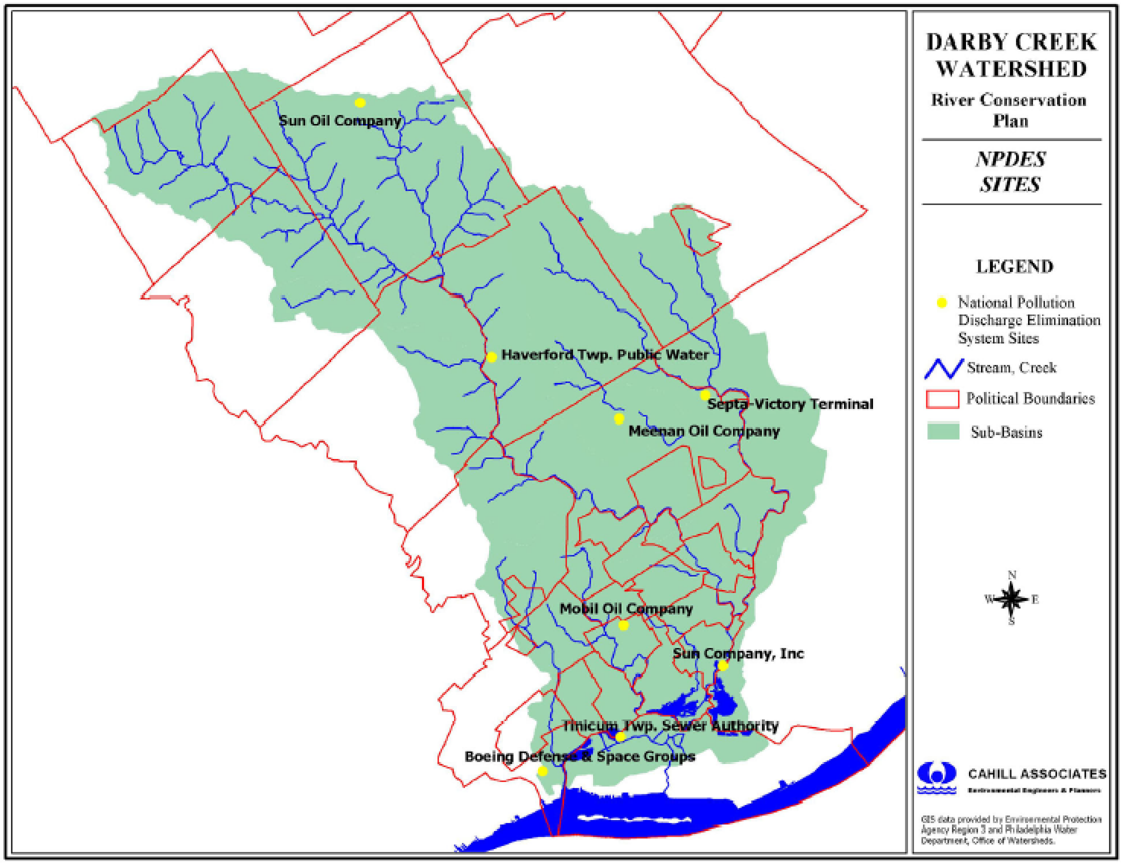


Figure IV-25 NPDES permitted dischargers in the Darby Creek Watershed

Combined Sewer Overflows

Although combined sewer overflows are not specifically a point source of pollution (they are really intermittent point sources), they are present in the Watershed in the Cobbs Creek portion and are a significant source of pollution. Combined sewers are both a water quality blessing and a curse, in that combined wastewater and stormwater runoff flows are directed into wastewater treatment facilities up to a point at which treatment capacity is exceeded. At this point in order to protect the treatment plant, the system is designed to deflect overflows directly into a receiving stream without treatment, meaning that raw sewage plus runoff is discharged into the stream. Conversely, the good news is that before this overflow occurs, both sanitary wastewater as well as some amount of stormwater runoff (and this typically is the initial flush most laden with nonpoint source pollutants) is being treated at the wastewater treatment plant, in contrast to other conventional stormwater systems which discharge directly into streams.

The PWD has undertaken a major pollution abatement program to reduce the impacts of combined sewer overflows (CSOs) on the Cobbs Creek. Combined sewers are often found in older cities where one pipe is used to convey sanitary sewage and storm water runoff. During wet weather, flows of stormwater and wastewater which exceed the wastewater treatment plant capacity are conveyed, untreated, to local water bodies. In response to national policy addressing this issue and as part of a PADEP-approved plan, PWD is implementing a series of capital programs to increase the amount of combined flow that receives treatment. In addition, and in recognition that total CSO removal will still not allow the stream to attain water quality standards, PWD is developing a watershed-based control plan that will recommend controls for CSO discharges along with other point and nonpoint source pollution reductions necessary for the stream to attain beneficial use standards. Benefits of this work are substantial and an ambitious water quality sampling program has being undertaken by the City, extending beyond the Cobbs Creek portion of the Watershed. This data will be used to further confirm the nature and extent of the water quality impacts in the Watershed and will be used to begin the development of water quality solutions for the Watershed.

Act 537 Sewage Facilities Plan Update: Eastern Plan of Study
This new wastewater facilities planning, being undertaken jointly by the Delaware County Planning Department and DELCORA, continues a long tradition of joint planning begun in 1971 with the Delaware County Sewerage Facilities Plan, adopted by all 49 Delaware County municipalities and used as their respective officially State-mandated 537 Sewage Facilities Plans. Wastewater and wastewater planning is complex in Delaware County, reflecting the complexities of the physical systems which are in place and are being planned, as well as the complex of institutions which have been created to accommodate these physical systems. DELCORA, the Delaware County Regional Authority has been created as a regional authority to manage certain functions, in addition to several sub-regional authorities and local authorities, all managing different aspects of collection of wastewater, conveyance, and then treatment of wastewater (it should be noted that the eastern portion of the County, which includes all of the Darby Creek Watershed lying in Delaware County, is considered to be virtually all sewered, though a small number of onsite systems are scattered about, and differs substantially from the western portion of the County; the eastern portion is the focus of this discussion).

There are a variety of issues facing the aging wastewater treatment system in eastern Delaware County. One extremely important issue, possibly the most important issue, involves the extensive amount of inflow and infiltration which has now been documented generally throughout this complex collection and conveyance system. Inflow and infiltration relates to all that extraneous water, especially runoff and precipitation during wet weather, which manages to make its way into the sanitary sewer system, possibly through leaking and defective manholes and other direct ports of entry, as well as the day-by-day infiltration of groundwater into the collection and conveyance system that is cracked and generally compromised. A series of studies undertaken by the different authorities as well as for this 537 Update has documented the substantial amount of I&I which exists (see *Act 537: Sewage Facilities Plan, Municipal and Authority Inflow and Infiltration Study, Summary Report Revised July 2000*). This *Summary Report* process included flow monitoring, field investigations (including visual inspection, smoke testing, televising of sewer lines in some cases), data analysis, and preparation of a corrective action plan. The *Summary Report* concludes that there is a tremendous amount of I&I occurring throughout the wastewater system; the *Plan Update* reports:

1. It is estimated that DELCORA's member municipalities and authorities are paying to treat over 14 MGD of I&I. Removal of this I&I could equate to significant conveyance and treatment capacity as well as significant cost savings to member municipalities.
2. Both CDCA (Central Delaware County Authority) and DCJA (Darby Creek Joint Authority) are currently under modified sewer bans ("restrictions") with respect to new connections. This is due to problems with wet weather capacity issues associated with the systems
3. The various authority-owned pump stations have received numerous Notices of Violation for wet weather overflows. Such incidences can lead to health problems." (*Plan Update*, p. 3-25)

Remediation of these serious I&I problems, the *Summary Report* further concludes, would increase sewer infrastructure capacity for other uses, reduce treatment and O&M costs related to wastewater disposal, and would reduce or eliminate public health hazards associated with sewage overflows such as at pump stations and other overtaxed facilities. Recommendations for remediation include regular sewer cleaning, implementation of an I&I monitoring program, better sewage facilities documentation, and implementation of a sewage facility management system. An array of specific corrective actions were identified and analyzed in terms of cost-effectiveness, as follows (*Plan Update*, p. 6-2):

1. Manhole inserts
2. Public education/information
3. Roof leader/sump pump disconnects
4. Manhole frame repairs

5. Slip lining of stream crossings
6. Chemical grouting
7. Manhole repairs
8. Slip lining of other segments
9. Disconnect inlets
10. Sewer replacement

The I&I problems as documented clearly are related to some level of water quality problem in the Watershed. Overflows at pump stations are essentially the same type of problem as combined sewer overflows, contributing some amount of raw sewage into receiving streams. To the extent that sewers are not "tight" and are receiving substantial infiltration during wet as well as dry weather, it is also possible that untreated raw sewage is also making its way out of the collection and conveyance system during both wet and dry periods (this would help explain the sampling results and fecal coliform exceedances during both wet and dry periods, as discussed above in this Section). Unfortunately, this 537 planning does not seem to address these water quality and overall environmental issues and the extent of pollution which these I&I-plagued sewers are having on the Darby Creek Watershed. The water quality issue is not identified as a major problem; the potential water quality benefit of removal of this pollution source is not addressed in this I&I discussion. Given water quality sampling results, the question must be raised whether the potential water quality impacts of the I&I-plagued sewer system are being adequately addressed in this 537 planning process.

If I&I recommendations are adopted and implemented as the result of this 537 Plan Update, clearly reduction of I&I problems will have a beneficial impact on water quality in the Darby Creek Watershed. If the water quality impacts of the sewer system are included in the analysis, remediating actions are even more critical—and will yield even greater benefit.

During the course of preparation of this Plan, the 537 Plan Update has been completed and adopted by resolution of all participating municipalities. By adopting this Plan, participating municipalities agree to further investigate identified problems and to implement a corrective action program as set forth in Chapter 9 of the 537 Plan.

In addition, under the Water Resources Planning Act of 2002, the Commonwealth will update the State Water Plan for the first time in 25 years. The legislation requires all water supply agencies, industries and individuals who withdraw or use more than 10,000 gallons of water per day on average to register their water use. Regional water resources planning boards for each of the 6 major river basins in Pennsylvania, including the Delaware, will develop water management planning recommendations for inclusion in the State Water Plan, based on existing and projected water use. The regional boards will recommend the identification in the State Water Plan of any critical planning areas where existing or potential water use conflicts may arise.