Pennsylvania Stormwater Best Management Practices Manual

Chapter 2

Making the Case for Stormwater Management

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Chapter 2 Making the Case for Stormwater Management

2.1 A Brief Review of Stormwater Problems in Pennsylvania

Pennsylvania is the most flood prone state in the country. It has experienced several serious and sometimes devastating floods during the past century, often as a result of tropical storms and hurricanes, and heavy rainfall on an existing snow pack. To a large extent, the flooding that results from such extreme storms and hurricanes occurs naturally and will continue to occur. Stormwater management cannot eliminate flooding during such severe rainfall events (Figure 2-1).

Figure 2-1. Flooding impacts are devastating communities, even with conventional stormwater management programs (F. Thorton).

In many watersheds throughout the state, flooding problems from rain events, including the smaller storms, have increased over time due to changes in land use and ineffective stormwater management. This additional flooding is a result of an increased volume of stormwater runoff being discharged throughout the watershed. This increase in stormwater volume is the direct result of more extensive impervious surface areas (Figure 2-2), combined with substantial tracts of natural landscape being converted to lawns on highly compacted soil or agricultural activities.

Figure 2-2. Parking lots are common impervious surfaces that affect stormwater runoff.

The problems are not limited to flooding. Stormwater runoff carries significant quantities of pollutants washed from the impervious and altered land surfaces (Figure 2-3). The mix of potential pollutants ranges from sediment to varying quantities of nutrients, organic chemicals, petroleum hydrocarbons, and other constituents that cause water quality degradation.

Figure 2-3. Pollutant laden runoff degrades water quality.

Increased stormwater runoff volume can turn small meandering streams into highly eroded and deeply incised stream channels (Figure 2-4). Stream meander and the resulting erosion and sedimentation is a natural process, and all channels are in a constant process of alteration. However, as the volume of runoff from each storm event is increased, natural stream channels experience more frequent bank full or near bankfull conditions. As a result, streams change their natural shape and form. Pools and riffles that support aquatic life are disrupted as channels erode to an unnatural level, and the eroded bank material contributes to sediment in the stream and degrades it's health by smothering stream bottom habitat. The majority of this stream channel devastation is intensified during the frequently occurring small-to-moderate precipitation events, not during major flooding events.

Figure 2-4.Stormwater influenced stream bank morphology in Valley Creek.

Rainfall is an important resource to replenish the groundwater and maintain stream flow (Figure 2-5). When the stormwater runoff during a storm event is allowed to drain away rather than recharge the groundwater, it alters the hydrologic balance of the watershed. As a consequence, stream base flow is deprived of the constant groundwater discharge and may diminish or even cease. During a drought, reduced stream base flow may also significantly affect the water quality in a stream.

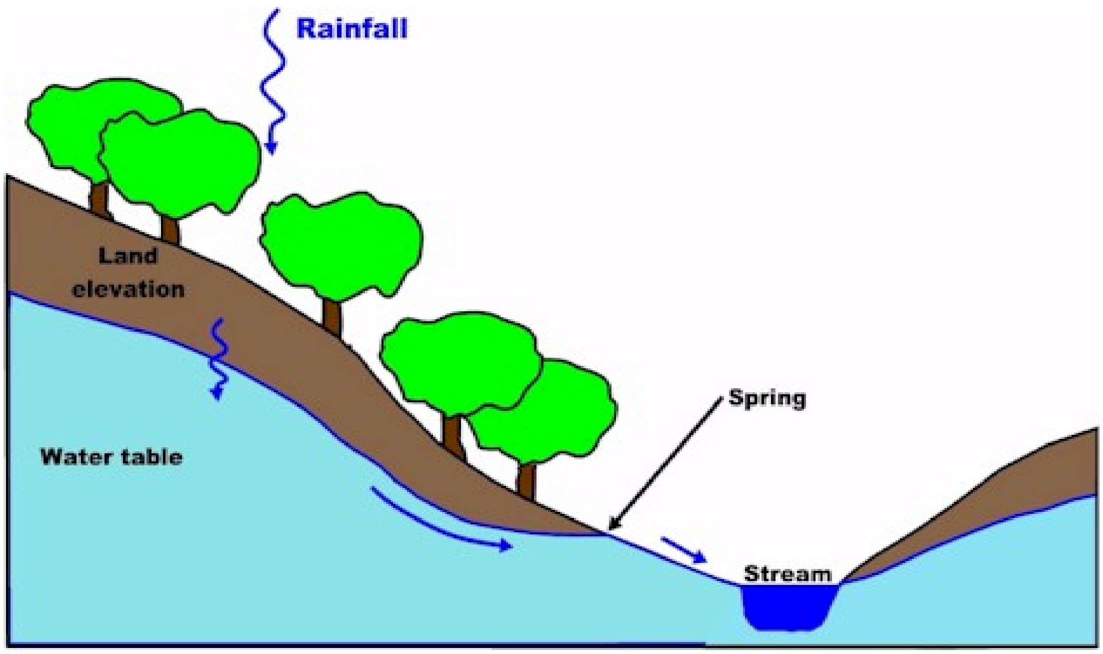

Figure 2-5. Rainfall replenishes the groundwater, which in turn provides stream base flow.

The groundwater discharge to a stream is at a relatively constant temperature, whereas stormwater runoff from impervious surfaces may be very hot in the summer months and extremely cold in the winter months. These temperature extremes can have a devastating effect on aquatic organisms, from bacteria and fungi to larger species. Many fish, especially native trout, can be harmed by acute temperature changes of only a few degrees.

Improperly managed stormwater causes increased flooding, water quality degradation, stream channel erosion, reduced groundwater recharge, and loss of aquatic species. But these and other impacts can be effectively avoided or minimized through better site design. This chapter discusses the potential problems associated with stormwater and explains the need for better stormwater management. The problems caused by impervious and altered surfaces can be avoided or minimized, but only through stormwater management techniques that include runoff volume reduction, pollutant reduction, groundwater recharge and runoff rate control for all storms.

2.2 The Hydrologic Cycle and The Effects of Development

The movement of water from the atmosphere to the land surface and then back to the atmosphere is a continuous process, with water constantly in motion. This balanced water cycle of precipitation, runoff, evapotranspiration, infiltration, groundwater recharge, and stream base flow sustains Pennsylvania's water resources. This representation of the hydrologic cycle, while depicting the general concept, over-simplifies the complex interactions that define the surface and subsurface flow processes of humid regions in the United States.

Changes to the land surface, along with inappropriate stormwater management, can significantly alter the natural hydrologic cycle. In a natural Pennsylvania woodland or meadow, very little of the annual rainfall leaves the site as runoff. More than half of the annual amount of rainfall returns to the atmosphere through evapotranspiration. Surface vegetation, especially trees, transpires water to the atmosphere (with seasonal variations). Water is also stored in puddles, ponds and lakes on the earth's surface, where some of it will evaporate. Water that percolates through the soil either moves vertically and eventually reaches the zone of saturation or water table, moves laterally through the soil and often emerges as springs or seeps down gradient or is stored in the soil.

Soils are influenced and formed by vegetation, climate, parent material, topography and time. All of these factors have some effect on how water will move through the soil. Restrictive soil horizons may impede the vertical movement of water and cause it to move laterally. It is important to understand these factors when designing an appropriate stormwater system at a particular location. Under natural woodland and meadow conditions, only a small portion of the annual rainfall becomes stormwater runoff. Although the total amount of rainfall varies in different regions of the state, the basic average hydrologic cycle shown below holds true (Figure 2-6).

Figure 2-6. Annual hydrologic cycle for an undisturbed acre in the Pennsylvania Piedmont region.

Changing the land surface causes varying changes to the hydrologic cycle (Figure 2-7). Altering one component of the water cycle invariably causes changes in other elements of the cycle. Roads, buildings, parking areas and other impervious surfaces prevent rainfall from soaking into the soil and significantly increase the amount of runoff. As natural vegetation is removed, the amount of evapotranspiration decreases.

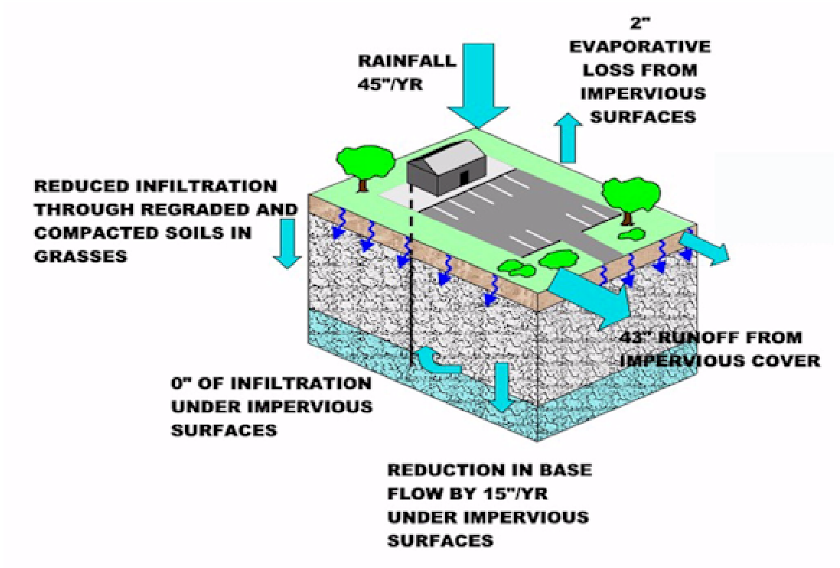

Figure 2-7. Representative altered hydrologic cycle for a developed acre in the Piedmont region.

These changes in the hydrologic cycle have a dramatic effect on streams and water resources. Annual stormwater runoff volumes increase from inches to feet per acre, groundwater recharge decreases, stream channels erode, and populations of fish and other aquatic species decline. Past practices focused on detaining the peak flows for larger storms. While detention is helpful in reducing peak flows for the immediate downstream neighbor, it does not address most of the other problems discussed earlier.

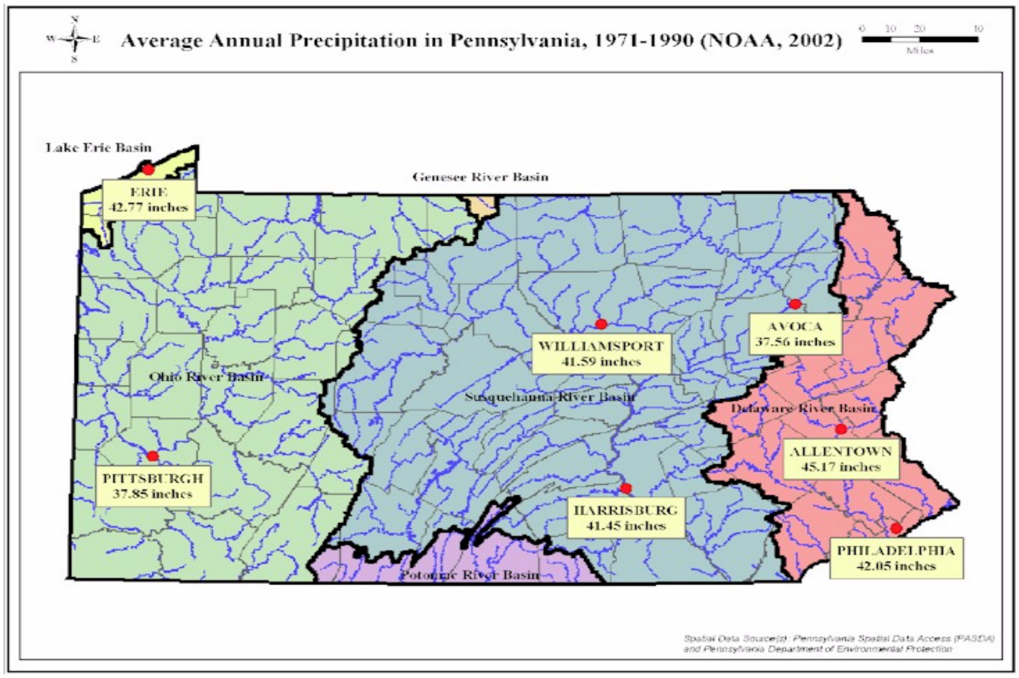

Figure 2-8. Average annual precipitation in Pennsylvania.

2.2.1 Rainfall, Runoff, and Flooding

In Pennsylvania, average annual precipitation ranges from 37 inches to more than 45 inches per year (Figure 2-8), and reflects a humid pattern. Nearly all of the annual rainfall occurs in small storm events (Figure 2-9**)**. Precipitation of an inch or less is frequent and well distributed throughout the year. However, large storms, hurricanes, and periods of intense rainfall can occur at any time.

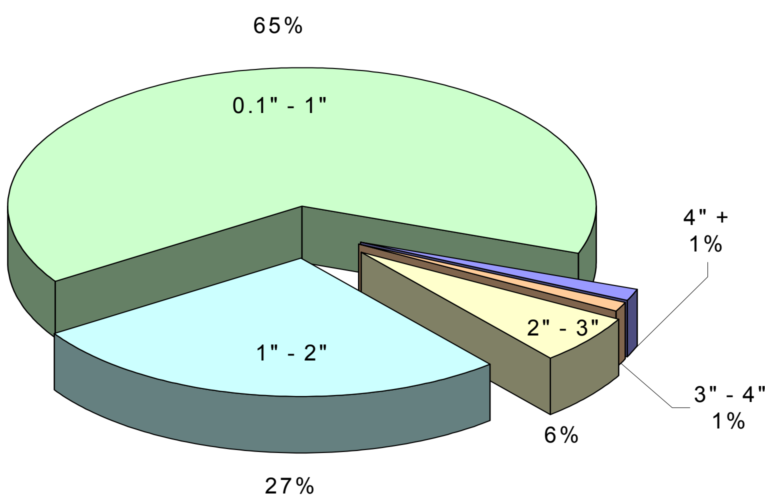

Figure 2-9. Distribution of precipitation by storm magnitude for Harrisburg, PA (Original Data from Penn State Climatological Office, 1926-2003)

Stormwater management has historically focused on managing flooding from the larger but less frequent extreme event storms (Table 2-1). Traditional site design has focused on the **peak rate** of runoff during such events; that is, how fast the stormwater runoff is leaving the site after development. Detention facilities are built to slow down the rate of runoff leaving a site during large storms so that the rate of runoff after development is not greater than the rate before development. Regulatory criteria is often based on controlling the "release" rate of runoff from the 2-year through 100-year storm events. Storm frequency is based on the statistical probability of a storm being exceeded in any year. That is, a 2-year storm has a 50% probability of being exceeded in any single year, and a 100-year storm, a 1% probability.

Table 2-1. Statistical Storm Frequency Events for locations in PA (24 hour duration) (Source: NOAA National Weather Service Precipitation Frequency Data Server, 2004).

Location	Frequency of Occurrence (Years)				
	2-year	5-year	10-year	50-year	100-year
Philadelphia	3.3	4.1	4.8	6.7	7.6
Pittsburgh	2.4	2.9	3.3	4.4	4.9
Scranton	2.6	3.2	3.7	5.4	6.4
State College	2.7	3.3	3.8	5.2	5.9
Williamsport	2.8	3.5	4.1	6.0	7.0
Erie	2.6	3.2	3.7	5.1	5.8

Preventing increased runoff rates from large storm events is extremely important but it does not do enough to protect streams and water quality. With a change in land surface, not only does the peak **rate** of runoff increase, the **volume of** runoff also increases. While a stormwater detention facility may slow the rate of runoff leaving a site, there may still be an increased volume of runoff. This is shown graphically in Figure 2-10. Detention controls the peak runoff rate by extending the hydrograph. So while the rate of runoff may not increase, the duration of runoff will be longer than before development because of the increased volume.

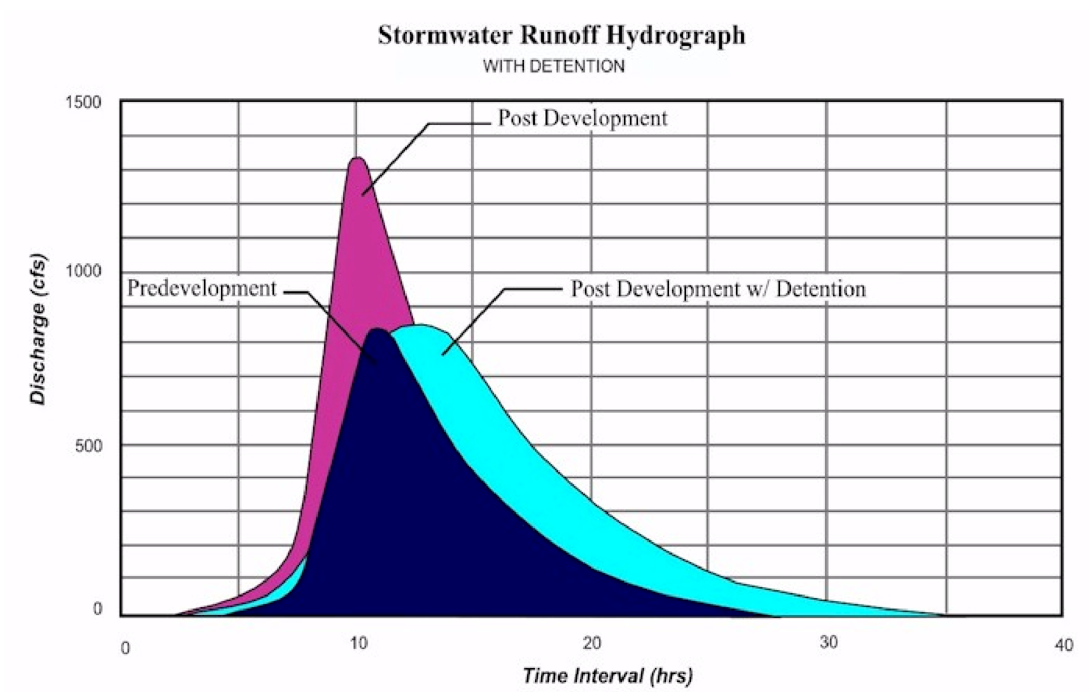

Figure 2-10. The hydrograph is an important tool used for understanding the hydrologic response of a given rainfall event. The area beneath the hydrograph curve represents the total volume of runoff being discharged.

On a watershed basis, detention becomes ineffective downstream as the sole management strategy for stormwater control due to the extended hydrograph and increased volume. There is even a possibility that the peak flows may **increase** downstream flooding. The combination of more runoff volume over a longer time period will result in downstream flow rates that are higher than before development, as indicated in Figure 2-11.

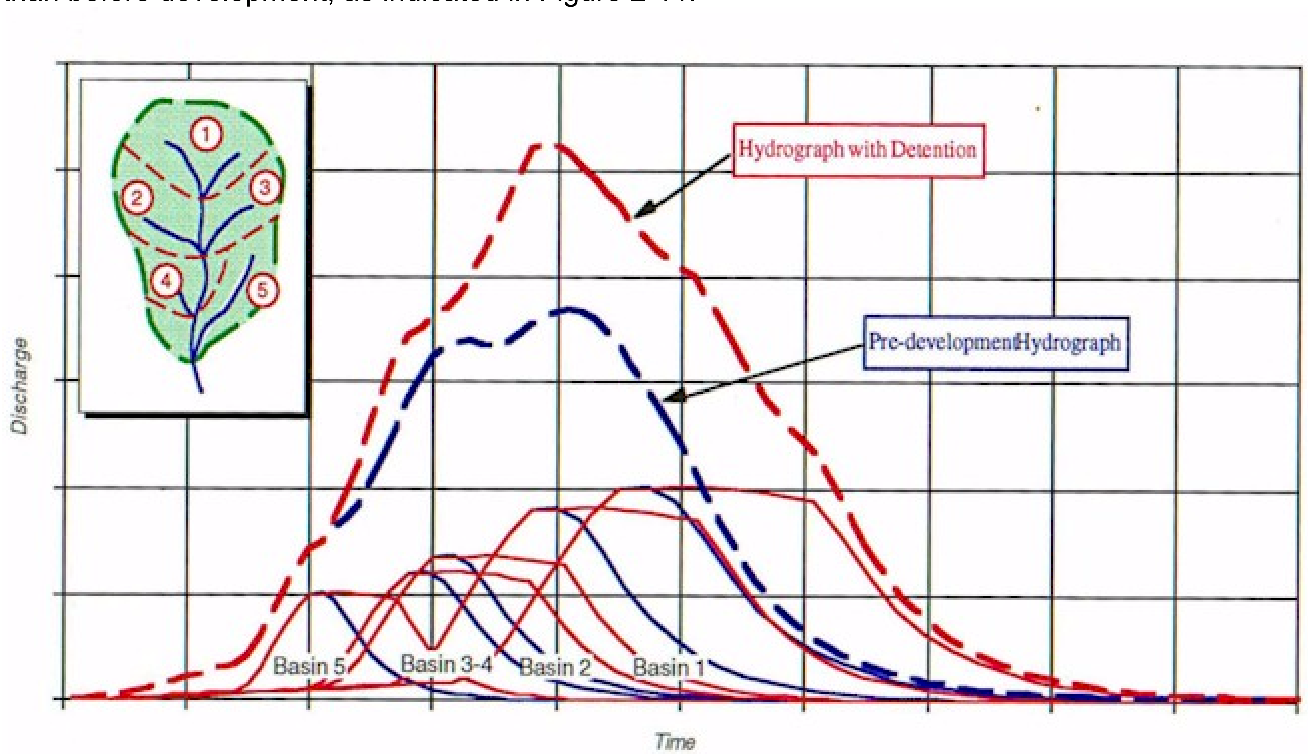

Figure 2-11. This figure illustrates a small watershed comprised of five hypothetical Subbasin development sites, 1 through 5, each of which undergoes development and relies on a separate peak rate control detention basin. As the storm occurs, five different hydrographs result for each sub-area and combine to create a resultant pre-development hydrograph for the overall watershed. The net result of the combined hydrographs is that the watershed peak rate increases considerably, because of the way in which these increased volumes are routed through the watershed system and combine downstream. Flooding increases considerably in peak and duration, even though these detention facilities have been installed at each individual development.

The second reason that detention alone is not sufficient for stormwater management is that it does not address the frequent small storm events in Pennsylvania. Most of the rainfall in Pennsylvania occurs in relatively small storm events, as indicated for the Harrisburg area (Figure 2-9). In Harrisburg, over half of the average annual rainfall occurs in storms of less than 1 inch (in 24 hours). Over 90 percent of the average annual rainfall occurs in storms of 2 inches or less, and over 95 percent of average annual rainfall occurs in storms of 3 inches or less. This pattern is typical of the entire state.

Detention facilities that are designed to control the peak flow rate for large storm events often allow frequent small storm events to “pass through” the detention facility. These small frequent rainfall events discharge from the site at a higher rate and a greater volume of runoff than before development. There is also an increase in the **frequency** of runoff events because of the change in land surface. For example, little runoff will occur from most wooded sites until over an inch of rainfall has fallen. In contrast, a paved site will generate runoff almost immediately (Figure 2-12). After development, runoff will occur with greater frequency than before development, and runoff may be observed with every rainfall. The design of stormwater systems that collect, convey and concentrate runoff may further degrade conditions.

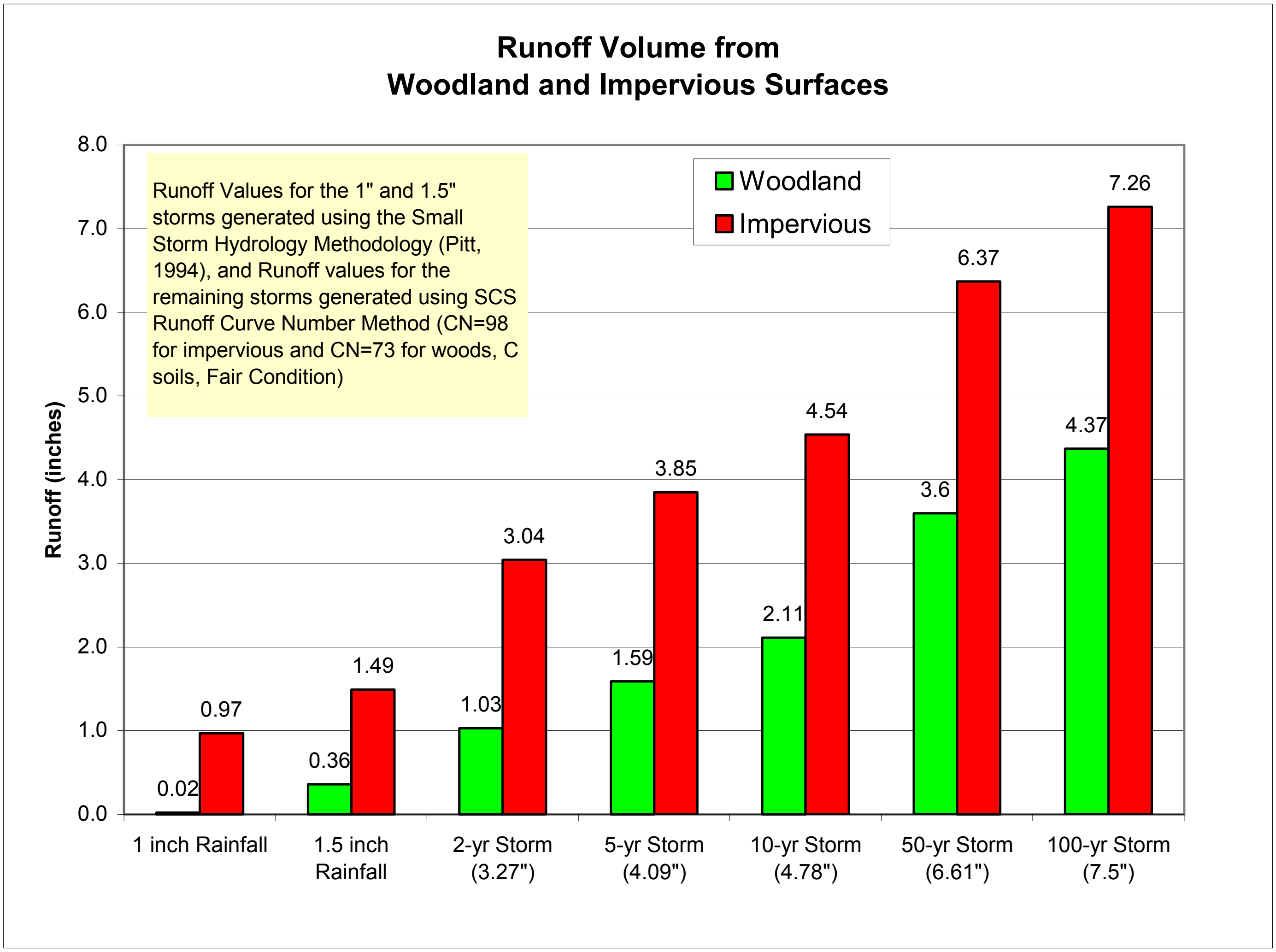

Figure 2-12. This graph generally compares the volume of runoff generated from a woodland site with the volume of runoff generated by impervious area for different rainfall amounts. Note that the volume increase for small storms is significant.

The combination of more runoff, more often and at higher rates will create localized flooding and damage even in small storm events. Throughout the state, over 95 percent of the annual rainfall volume occurs in storm events that are less than the 2-year storm event. The net effect is that during most rainfall events, stormwater discharges are not managed or controlled, even with numerous detention basins in place.

2.2.2 The Impacts of Vegetation Loss and Soil Changes

On woodland and meadow areas, over half of the average annual rainfall returns to the atmosphere through evaporation and transpiration (Figure 2-6). The vegetation itself also intercepts and slows the rainfall, reducing its erosive energy, reducing overland flow of runoff, and allowing infiltration to occur. The root systems of plants also provide pathways for downward water movement into the soil mantle.

Evapotranspiration (ET) varies tremendously with season and with type of vegetative cover. Trees can effectively evapotranspire most, if not all, of the precipitation, that falls in summer rain showers. Evapotranspiration dramatically declines during the winter season. During these periods, more precipitation infiltrates and moves through the root zone, and the groundwater level rises. Removing vegetation or changing the land type from woods and meadow to residential lawnscapes reduces evapotranspiration and increases the amount of stormwater runoff.

Soil disturbance and compaction also increases stormwater runoff. Soils contain many small openings called "macropores" that provide a mechanism for water to move through the soil, especially under saturated conditions. When soil is disturbed (grading, stockpiling, heavy equipment traffic, etc.) the soil is compacted, macropores are smashed and the natural soil structure is altered. Soil permeability characteristics are substantially reduced.

Compaction can be measured by determining the bulk density of the soil. The more compacted the soil is, the heavier it is by volume. Heavy construction equipment can compact soil so significantly that the soil bulk density of lawn soil approaches the bulk density of concrete (Table 2-2 Ocean County, New Jersey Soil Conservation District, 2001; Hanks and Lewandowski, 2003). The result is a surface that is functionally impervious because the water absorbing capacity of the soil is so altered and reduced.

Table 2-2. Common Bulk Density Measurements

Undisturbed Lands Forest & Woodlands 1.03 g/cc	**Residential Neighborhoods 1.69 to 1.97 g/cc**
Golf Courses - Parks Athletic Fields 1.69 to 1.97 g/cc	**CONCRETE 2.2 g/cc**

As discussed in Chapters 5 and 6, comprehensive stormwater management focuses on preventing an increase in stormwater runoff volume by protecting vegetation and soils, or minimizing stormwater impacts by restoring vegetation and soils to reduce runoff volumes and the velocity of runoff. Vegetation and soils are a critical component of the "water balance" and are an essential part of better stormwater management.

2.2.3 Groundwater Recharge, Stream Base Flow, and First-Order Streams

Water moves through the soil until it is evapotranspired or reaches the groundwater table and replenishes the aquifer. The actual movement of water through the sub-surface pathways is complex, and less permeable soils, clay layers, and rock strata are often encountered. The water moving through the soil is generally referred to as gravitational water or drainage water. Other types of water in soil include capillary water and hygroscopic water. Capillary water is that water held in soil pores by surface attraction (sometimes referred to as capillary action); this is the water that is typically available to plants for uptake. Hygroscopic water is water that is tightly held by the soil particles and can only be removed by physical drying. Although capillary water does play an important role in evaporation processes, gravitational water is of primary concern from a stormwater management prospective.

The movement of gravitational water through the soil is influenced by a soils texture, structure, layering and the presence of preferential flow pathways (macropores). Soil textures are defined by the percentage of sand, silt and clay present in the soil. In general, the permeability and hydraulic conductivity of a soil will decrease with decreasing textural grain size (i.e., gravitational water moves more easily through sands than silts and clays). Soil texture also influences the shape of the wetting front as water moves through a soil.

It has also been observed that there is a discontinuity of soil-water movement at the interface between soils of different textures. This layering causes percolating water to concentrate at certain points along the layer interface and then break into the layer interface in finger-like protrusions. The significance is that even a change in soil texture within a vertical profile will cause a disruption in the soil-water movement. This disruption often causes water to “back up” at the interface, which can cause water to move laterally.

Soil structure also influences the movement of water through a soil. A disruption in the movement of soil water will occur at the interface between soil layers of differing structures. While texture and structure are certainly important to how water moves through soils, soil layering and the presence of dominant flow paths (macropores) play the most significant role in defining how water moves through the subsurface.

Soils form over time in response to their landscape position, climate, presence of organisms and parent material. Soils that have formed in place from the weathering of their parent material, usually form a typical profile with A, B and C horizons above bedrock. However, many soils form from a combination of the weathering of parent materials and the deposition of transported soils creating a more complex layering effect. In general, any interface between soil layers can slow the downward movements of water through a soil profile and promote lateral flow. This is especially true in sloping landscapes typical of most of Pennsylvania.

Restrictive soil layers within a soil profile also disrupt the vertical movement of soil-water and promote the lateral movement of water through the soil. Restrictive soil layers include clay lenses, fragipans or plow pans, for example. Fragipans are layers within a soil profile that have been compressed as a result of some external influence (glaciation for example). This compressed layer often causes water to perch above the fragipan and promotes lateral flow. Fragipans are commonly found in colluvial and glacial soils. In addition, many soils in agricultural regions of Pennsylvania contain “plow-pans” which are compressed layers of soil formed by the repeated traversing by moldboard plows.

Soil water also follows preferential flow paths through the soil. Preferential flow paths include pathways created by plant roots, worm or rodent burrows, cracks or voids in the soil resulting from piping action caused by the lateral movement of soil-water. Preferential flow paths also form at the soil rock interface and within rock structures.

The groundwater level rises and falls depending on the amount of rainfall/snowmelt and the time of year. The water cycle illustration of Figure 2-6 estimates that approximately 12 inches of the 45 inches of average annual precipitation in this natural watershed system finds its way into the groundwater table.

A variety of processes can occur when precipitation falls on a natural soil surface. Hillslope hydrology processes have been identified by Chorley (1978) and are systematically illustrated in Figure 2-12. The flow processes illustrated here are only representative examples of the complex interactions that occur in nature. Simplified descriptions of these processes follow:

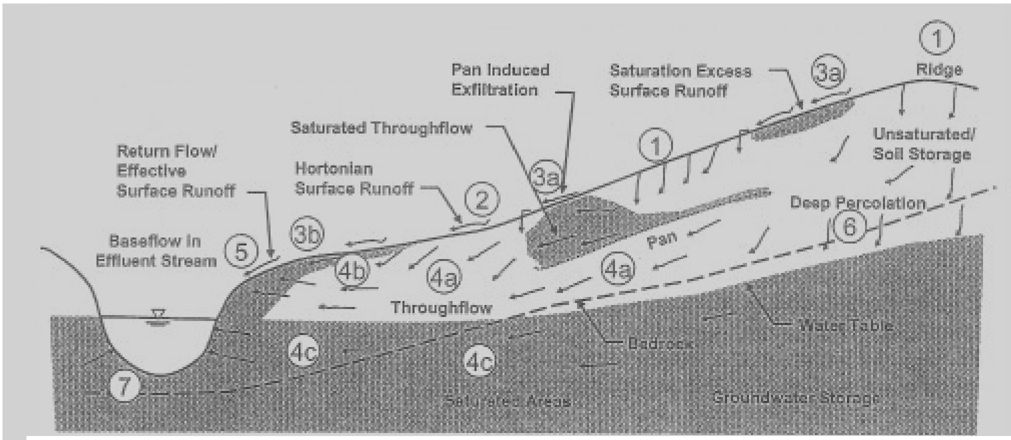

Figure 2-12 Components of hillslope hydrology (Adapted from Chorley [1978])

1. Areas marked with a “1” are areas where the infiltration capacity of the soils exceeds the rainfall rate. All rain falling on these areas infiltrates into the ground.
2. Areas labeled with a “2” identifies an area where the rainfall rate exceeds the surface infiltration rate, and the excess rainfall becomes surface runoff (Hortonian surface runoff).
3. Areas marked with a “3” represents areas where the soil has become saturated and cannot hold additional moisture; all rain falling on these areas immediately becomes surface runoff. Saturation can occur as a result of various subsurface conditions. Areas marked “3a” illustrates where a restricting layer (fragipans, clay lenses, etc.) limits the downward movement of soil water creating a perched water table that reaches the ground surface. Area “3b” identifies an area where water moving through the soil (through-flow) reaches the surface as a spring or seep (return-flow); in these cases the surface in the vicinity of the seep or spring becomes saturated.
4. The areas marked with a “4” represent areas of through-flow. Through-flow is the lateral movement of water through the soil. Area “4a” illustrates through-flow along preferential flow paths in unsaturated soils; area “4b” shows shallow surface flow (a common occurrence in PA); and area “4c” illustrates through-flow in saturated areas.
5. Areas marked with a “5” represents an area of return-flow. Return-flow is water that has moved through unsaturated or saturated subsurface areas and re-appears as surface flow through springs or seeps.
6. The area labeled as “6” represents an area of deep percolation or groundwater recharge.
7. Area “7” points to a location where groundwater discharges to the stream (influent streams). For effluent streams, water moves from the stream into the ground water table in these areas. In some streams, both processes may occur during different times of the year. (Brown/Fennessey/Petersen)

Most of these flow processes occur within natural watersheds in Pennsylvania. The extent to which one or more of these processes are active within a particular area is influenced by soil characteristics, geology and topography or landscape position.

Figure 2-13 Leaves and organic matter are initially broken down by bacteria and processed into food for higher organisms downstream.

Eventually the groundwater table intersects the land surface and forms springs, first order streams and wetlands (Figure 2-5). This groundwater discharge becomes stream base flow and occurs continuously, during both wet and dry periods. Much of the time, all of the natural flow in a stream is from groundwater discharge. In this sense, groundwater discharge can be seen as the “life” of streams, supporting all water-dependent uses and aquatic habitat. First-order streams are defined as “that stream where the smallest continuous surface flow occurs” (Horton, 1945), and are the beginning of the aquatic food chain that evolves and progresses downstream (Figure 2-13). As the link between groundwater and surface water, headwaters represent the critical intersection between terrestrial and aquatic ecosystems. During periods of wet weather, the water table may rise to near the ground surface in the vicinity of the stream. This higher ground water table coupled with through-flow, return-flow and shallow subsurface flow result in an area of saturation in the vicinity of the stream channel. As a result, this area saturates quickly during rain events; and the larger the rain event, the more extensive the area of saturation may be. It is understood by researchers that a significant amount of the surface runoff observed in streams during precipitation events is generated from the saturated areas surrounding streams (Chorley, 1978; Hewlett and Hibbert, 1967). The runoff generated from rainfall on saturated land areas is referred to as saturation overland flow. Hydrologists understand that the watershed runoff process is a complex integration of saturation overland flow and infiltration excess (Hortonian) overland flow (Troendle, 1985). Areas that generate surface runoff pulsate, shrink and expand in response to rainfall. This concept on a watershed scale is consistent with the hillslope hydrologic processes.

Changes in land use cause runoff volumes to increase and groundwater recharge to decrease. Wetlands and first order streams reflect changes in groundwater levels most profoundly, and this reduced flow can stress or even eliminate the aquatic community. As the most hydrologically and biologically sensitive elements of the drainage network, headwaters and first order streams warrant special consideration and protection in stormwater management.

2.2.4 Stream Channel Changes

The shape of a stream channel, its width, depth, slope, and how it moves through the landscape, is influenced by the amount of flow the stream channel is expected to carry. The stream channel morphology is determined by the energy of stream flows that range from “low flow” to “bank full”. The flow depths determine the energy in the stream channel, and this energy shapes the channel itself. In an undeveloped watershed, bank full flow occurs with a frequency of approximately once every 18 months. During larger flood events, the flow overtops the stream banks and flows into the floodplain with much less impact on the shape of the stream channel itself.

In a developing watershed, the volume and rate of stormwater runoff increase during small storm events and the stream channel changes to accommodate the greater flows. Because the stream is conveying greater flows more often and for longer periods of time, the stream will try to accommodate these larger flows by eroding stream banks or cutting down the channel bottom. Since traditional detention basins do not manage small storms, these impacts are often most pronounced downstream of detention basins.

Numerous studies have documented the link between altered stream channels and land development. The Center for Watershed Protection (Article 19, Technical Note 115, Watershed Protection Techniques 3(3): 729-734) states that land development influences both the geometry (morphology) and stability of stream channels, causing downstream channels to enlarge through widening and stream bank erosion. These physical changes, in turn, degrade stream habitat and produce substantial increases in sediment loads resulting from accelerated channel erosion.

As the shape of the stream channel changes to accommodate more runoff, aquatic habitat is often lost or altered, and aquatic species decline. Studies, such as US EPA's *Urbanization and Streams: Studies of Hydrologic Impacts* (1997), conclude that land development is likely to be responsible for dramatic declines in aquatic life observed in developing watersheds. These stream channel impacts have been observed even where conventional stormwater management is applied.

The effects occur at many levels in the aquatic community. As the gravel stream bottom is covered in sediment, the amount and types of microorganisms that live along the stream bottom decline. The stream receives sediment from runoff, but additional sediment is generated as the stream banks are eroded and this material is deposited along the stream bottom. Pools and riffles important to fish and other aquatic life are lost, and the number and types of fish and aquatic insects diminishes. Trees and shrubs along the banks are undercut and lost, removing important habitat and decreasing natural shading and cooling for the stream.

The runoff from impervious surfaces is usually warmer than the stream flow, and can harm the aquatic community. When the stream flow is comprised primarily of groundwater discharge, the constant, cool temperature of the groundwater buffers the stream temperature. As the flow of groundwater decreases and the amount of surface runoff increases, the temperature regime of the stream changes. Runoff from impervious surfaces in the summer months can be much hotter than the stream temperature, and in the winter months this same runoff can be colder. These changes in temperature dramatically affect the aquatic habitat in the stream, ranging from the fish community that the stream can support to the microorganisms that form the foundation of the food chain. Important fungal communities can be lost altogether. It is apparent that increasing impervious areas can lead to significant degradation of surface water by altering the entire aquatic ecosystem.

2.2.5 Water Quality

Impervious surfaces and maintained landscapes generate pollutants that are conveyed in runoff and discharged to surface waters. Many studies of pollutant transport in stormwater have documented that pollutant concentrations show a distinct increase at the beginning of a flow hydrograph referred to as the "first flush". In fact, the particulate associated pollutants that are initially scoured from the land surface and suspended in the runoff are observed in a stream or river before the runoff peak occurs. These pollutants include sediment, phosphorus that is moving with colloids (clay particles), metals, and organic particles and litter. Dissolved pollutants, however, may actually decrease in concentration during heavy runoff. These include nitrate, salts and some synthetic organic compounds applied to the land for a variety of purposes.

Managing stormwater to minimize pollutant loading includes reducing the sources of these pollutants as well as restoring and protecting the natural systems that are able to remove pollutants. These include stream buffers, vegetated systems, and the natural soil mantle, all of which can be put to use to remove pollutants from stormwater runoff.

Stormwater quantity and quality are inextricably linked and need to be managed together. Although the most obvious impact of land development is the increased rate and volume of surface runoff, the pollutants transported with this runoff comprise an equally significant impact. Management strategies that address quantity will in most cases address quality.

Stormwater runoff pollutants include sediment, organic detritus, phosphorus and nitrogen forms, metals, hydrocarbons, and synthetic organics. The increased stormwater runoff brought on by land development scours both impervious and pervious land surfaces. Stormwater runoff transports suspended and dissolved pollutants that were initially deposited on the land surface. Hot spot impervious areas such as fueling islands, trash dumpsters, industrial sites, fast food parking lots, and heavily traveled roadways contribute heavy pollutant loads to stormwater.

Many so-called pervious surfaces, such as the chemically maintained lawns and landscaped areas, also add significantly to the pollutant load, especially where these pervious areas drain to impervious surfaces, gutters and storm sewers. The soil compaction process applied to many land development sites results in a vegetated surface that is close to impervious in many instances, and produces far more runoff than the pre-development soil did. These new lawn surfaces are often loaded with fertilizers that result in polluted runoff that degrades all downstream ponds and lakes.

The two physical forms of stormwater pollutants are particulates and solutes. One very important distinction for stormwater pollutants is the extent to which pollutants are particulate in form, or dissolved in the runoff as solutes. The best example of this comparison is the two common fertilizers: Total phosphorus (TP) and nitrate (NO3-N). Phosphorus typically occurs in particulate form, usually bound to colloidal soil particles. Because of this physical form, stormwater management practices that rely on physical filtering and/or settling out of sediment particles can be quite successful for phosphorus removal. In stark contrast, nitrate tends to occur in highly soluble forms, and is unaffected by many of the structural BMPs designed to eliminate suspended pollutants. As a consequence, stormwater management BMPs for nitrate may be quite different than those used for phosphorous removal. Non-Structural BMPs (Chapter 5) may in fact be the best approach for nitrate reduction in runoff.

Particulates: Stormwater pollutants that move in association with or attached to particles include total suspended solids (TSS), total phosphorus (TP), most organic matter (as estimated by COD), metals, and some herbicides and pesticides. Kinetic energy keeps particulates in suspension and some do not settle out as easily. For example, an extended detention basin offers a good method to reduce total suspended solids, but is less successful with TP, because much of the TP load is attached to fine clay particles that may take longer to settle out.

If the concentration of particulate-associated pollutants in stormwater runoff, such as TSS and TP, is measured in the field during a storm event, a significant increase in pollutant concentration corresponding to but not synchronous with the surface runoff hydrograph is usually observed (Figure 2-14). This change in pollutant concentration is referred to as a “chemograph”, and has contributed to the concept of a “first flush” of stormwater pollutants. In fact, the actual transport process of stormwater pollutants is somewhat more complex than “first flush” would indicate, and has been the subject of numerous technical papers (Cahill et al, 1974: 1975; 1976; 1980; Pitt, 1985, 2002). To accurately measure the total mass of stormwater pollution transported during a given storm event, both volume and concentration must be measured simultaneously, and a double integration performed to estimate the mass conveyed in a given event. To fully develop a stormwater pollutant load for a watershed, a number of storm events must be measured over several years. The dry weather chemistry is seldom indicative of the expected wet weather concentrations, which can be two or three orders of magnitude greater.

Because a major fraction of particulate associated pollutants is transported with the smallest particles, or colloids, their removal by BMPs is especially difficult. These colloids are so small that they do not settle out in a quiescent pool or basin, and remain in suspension for days at a time, passing through a detention basin with the outlet discharge. It is possible to add chemicals to a detention basin to coagulate these colloids to promote settling, but this chemical use turns a natural stream channel or pond into a treatment unit, and subsequent removal of sludge is required. A variety of BMPs have been developed that serve as runoff filters, and are designed for installation in storm sewer elements, such as inlets, manholes or boxes. The potential problem with all measures that attempt to filter stormwater is that they quickly become clogged, especially during a major event. Of course, one could argue that if the filter systems become clogged, they are performing efficiently, and removing this particulate material from the runoff. The major problem then with all filtering (and to some extent settling) measures is that they require substantial maintenance. The more numerous and distributed within the built conveyance system that these BMPs are situated, the greater the removal efficiency, but also the greater the cost for operation and maintenance.

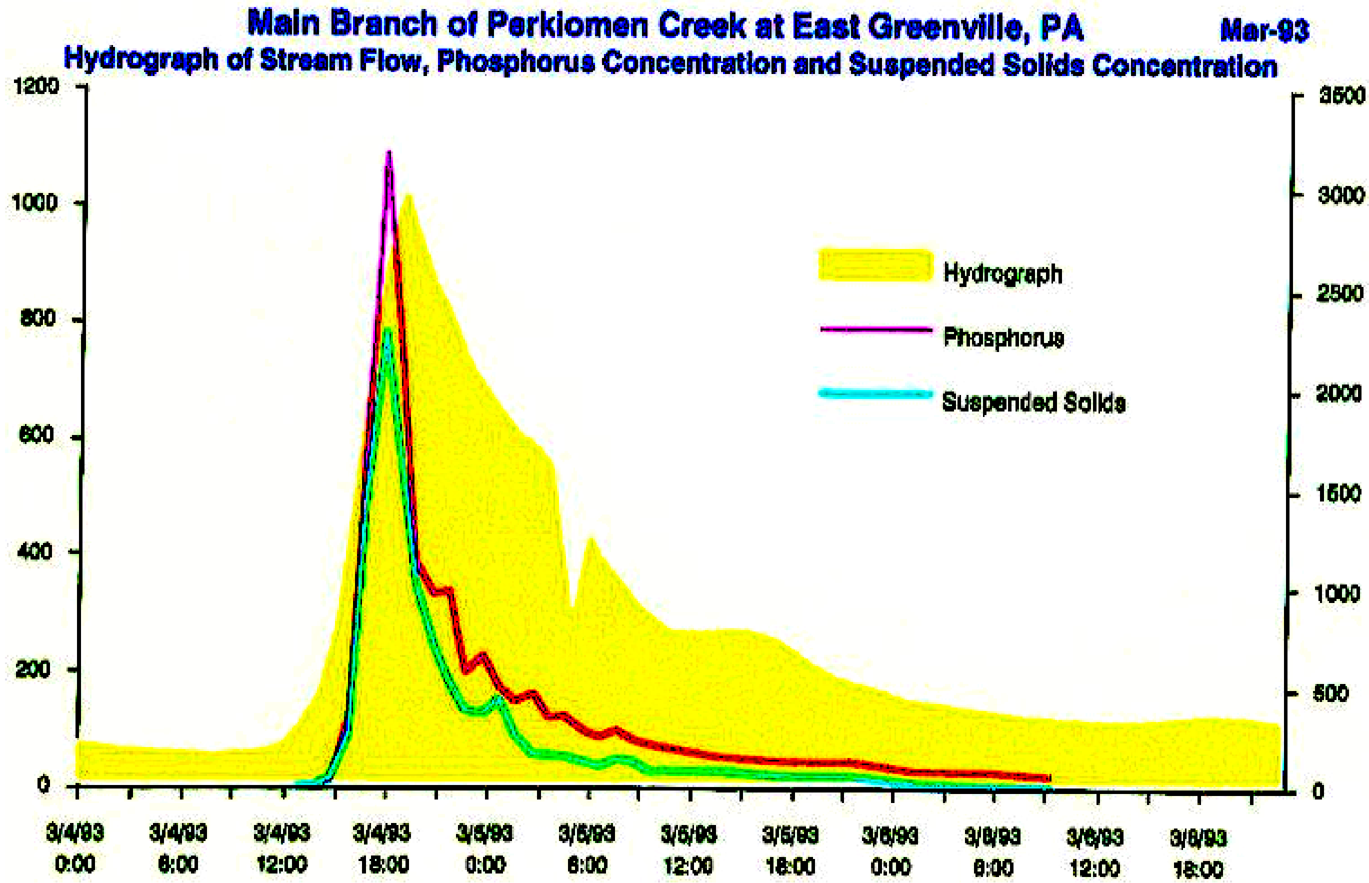

Figure 2-14. Chemograph of phosphorus and suspended solids in Perkiomen Creek (Cahill, 1993).

Solutes: Dissolved stormwater pollutants generally do not exhibit any increase during storm event runoff, and in fact may exhibit a slight dilution over a given storm hydrograph. Dissolved stormwater pollutants include nitrate, ammonia, salts, organic chemicals, many pesticides and herbicides, and petroleum hydrocarbons (although portions of the hydrocarbons may bind to particulates and be transported with TSS). Regardless, the total mass transport of soluble pollutants is dramatically greater during runoff because of the volume increase. In some watersheds, the stormwater transport of soluble pollutants can represent a major portion of the total annual discharge for a given pollutant, even though the absolute concentration remains relatively constant. For these soluble pollutants, dry weather sampling can be very useful, and often reflects a steady concentration of soluble pollutants that will be representative of high flow periods.

Some dissolved stormwater pollutants can be found in the initial rainfall, especially in regions with significant emissions from fossil fuel plants. Precipitation serves as a “scrubber” for the atmosphere, removing both fine particulates and gases (NOX and SOX). Chesapeake Bay scientists have measured rainfall with NO_3 concentrations of 1 to 2 mg/l, which could comprise a significant fraction of the total input to the Bay. Other rainfall studies by NOAA and USGS have resulted in similar conclusions. Impervious pavements can transport nitrate load, reflecting a mix of deposited sediment, vegetation, animal wastes, and human detritus of many different forms.

Pollution prevention through use of Non-Structural BMPs is very effective. A variety of Structural BMPs, including settling, filtration, biological transformation and uptake, and chemical processes can also be used. Stormwater related pollution can be reduced if not eliminated through preventive Non-Structural BMPs (Chapter 5), but not all stormwater pollution can be avoided. Many of the Structural BMPs (Chapter 6) employ natural pollutant removal processes as essential elements. These "natural" processes tend to be associated with and rely upon both the existing vegetation and soil mantle. Thus preventing and minimizing disturbance of site vegetation and soils is essential to successful stormwater management.

Settling: Particles remain suspended in stormwater as long as the energy of the moving water is greater than the pull of gravity. In a natural stream, the stormwater that overflows the banks slows and is temporarily stored in the floodplain, which allows for sediment settling, and the building of the alluvium soils that comprise this floodplain. As runoff passes through any type of man-made structure, such as a detention basin, the same process takes place, although not as efficiently as in a natural floodplain. Where it is possible to create micro versions of runoff ponds (rain gardens), distributed throughout a site, the same settling effect will result. The major issue with settling processes is that the dissolved pollutant load is not subject to gravitational settling.

Filtration: Another natural process is physical filtration. Filtration through vegetation and soil is by far the most efficient way to remove suspended stormwater pollutants. Suspended particles are physically filtered from stormwater as it flows through vegetation and percolates into the soil. Runoff that is concentrated in swales, however, can exceed the ability of the vegetation to remove particles. Therefore, it is important to avoid concentrated flows by slowing and distributing the runoff over a broad vegetated area.

Stormwater flow through a relatively narrow natural riparian buffer of trees and herbaceous understory growth has been demonstrated to physically filter surprisingly large proportions of larger particulate-form stormwater pollutants. Both filter strip and grassed swale BMPs rely very much on this surface filtration process as discussed in Chapter 6.

Biological Transformation and Uptake/Utilization: This category includes an array of different processes that reflect the remarkable complexity of different surface vegetative types, their varying root systems, and their different needs and rates of transformation and utilization of different "pollutants," especially nutrients. An equally vast and complex community of microorganisms exists below the surface within the soil mantle, and though more micro in scale, the myriad of natural processes occurring within this soil realm is just as remarkable.

Phosphorus and nitrate are essential to plant growth and therefore are taken up through the root systems of grasses, shrubs and trees. Nitrogen transformations are quite complex, but the muck bottom of wetlands allows the important process of denitrification to occur and convert nitrates for release in gaseous form. Nitrates in stormwater runoff passing through wetlands is removed and used by wetland plants to build biomass. The caution in terms of a wetland or similar surface BMP is that if the vegetation dies at the end of a growing season and the detritus is discharged from the wetland, the net removal of nitrate is maybe less than expected. The guidance for BMP applications is that if biological transformation processes are considered, care must be taken to remove and dispose of the biomass produced in the process.

Chemical Processes: Various chemical processes occur in the soil to remove pollutants from stormwater. These include adsorption through ion exchange and chemical precipitation. Cation Exchange Capacity (CEC) is a rating given to soil, that relates the soil organic content to its ability to remove pollutants as stormwater infiltrates through the soil. Adsorption will increase as the total surface area of soil particles and/or the amount of decomposed organic material increases. Clay soils have better pollutant reduction performance than sandy soils, and their slower permeability rate has a positive effect. CEC values typically range from 2 to 60 milli-equivalents (meq) per 100 grams of soil. Coarse sandy soils have low CEC values and therefore are not especially good stormwater pollutant removers. The addition of compost will greatly increase the CEC of sandy soils. A value of 10 meq. is often considered necessary to accomplish a reasonable degree of pollutant removal.

Section 2.3 References

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