

SECTION X

WATER BALANCE AND BUDGET

A. DEFINING WATER BALANCE AND WATER BUDGET

The term *water balance* is defined as “a quantitative statement of the amounts of water circulating through various paths of the hydrologic cycle.” Comparatively, the term *water budget* as used in this report may also be technically referred to as, and used interchangeably with, *hydrologic budget*, defined as “an accounting of the inflow to, outflow from, and storage in, a hydrologic unit such as a drainage basin or aquifer.” **Figure X-1—Generalized Water Balance for the Penridge Area** depicts a simplified version of the water balance for the Study Area. The diagram represents a water balance as opposed to a water budget because it does not account for impacts on the natural system from human factors such as those associated with land development.

From a cursory perspective, the water balance appears to be a simple process. Water enters the watershed as precipitation and leaves via evaporation and streamflow, i.e., the natural hydrologic cycle. However, **Figure X-1** does not account for the net human impacts (positive or negative) on the natural hydrologic cycle. Historically, the impact of excessive development has, in certain instances, been to diminish the benefits of a healthful, environmentally-balanced hydrologic system. Proper management of the water balance relative to land development will require achieving the following goal:

To prevent water from being removed from the system at a greater rate than required by people and stream-dependent life, ideally maintaining the water balance that existed prior to land development.

The complexity of understanding and managing the water balance and budget becomes more obvious as each component of the system is studied. There are many natural and man-made components of the budget with which we are familiar. In addition, new techniques are becoming available to better conserve water within the hydrologic unit, such as land application of treated sewage effluent, to return water back into the aquifer. In some cases, new techniques can complicate the situation because of the unfamiliarity of their influences on the water budget.

Water budget studies attempt to define natural and human behaviors in numeric terms for use in predictive regulatory and management models. In reality, quantitatively defining even one relatively simple factor such as “drought” can become a complex and controversial task.

Figure X-1
Generalized Water Balance for the Penridge Area

Flowchart

B. WATER BUDGET FUNDAMENTALS

Figure X-2—Stream Valley Cross-Section Schematic reveals the primary factors involved in a water budget. Arrows represent water movement into, out of, and through the system. The right side of the drawing shows natural conditions from which stream morphology and aquatic life had reached a relatively stable situation and represents the highest quality stream conditions. The left side of the drawing depicts a setting with relatively low-density land development and shows the majority of factors that influence water movement through an altered hydrogeologic system.

A simplistic evaluation of the water budget is described by the following equation:

$$P = R + G + ET + S$$

Where:

P	=	Precipitation
R	=	Runoff as Streamflow
G	=	Groundwater Discharge to Stream as Baseflow
ET	=	Evaporation and Plant Transpiration
S	=	Storage in Aquifers and Reservoirs [Filling (+) or Draining (-)]

In reality, each of these factors is significantly more complex, having many variables and additional influences. In a developed region the complexity increases further. Eight more hydrogeologic factors are present in **Figure X-2** for the developed region versus the natural setting. Provided below is a description of each of the primary factors governing water movement in the system and a statement regarding the best method to estimate each parameter. The reference abbreviations noted on **Figure X-2** are described here.

1. Water Movement Into the Hydrologic System

Precipitation (P) includes rain and melted snow. Earlier discussions within this chapter described the complexity of interpreting the effects of precipitation based upon timing and intensity. Thus, precipitation measurements should be recorded not only on a daily basis but ideally on an hourly basis to note how hard or fast of a rain occurred. Snowmelt should be noted, as well as frozen ground conditions, so that the lag time from the snowfall can be understood. Local stations should be used since rainfall data varies considerably during summer storms.

Infiltration–Precipitation (Ip) is water that soaks into the aquifer system by natural methods. The precipitation (rain or melted snow) must first pass over and be absorbed by plants, soil, and shallow bedrock before a surplus exists that can reach the water table. This infiltration does not include very shallow waters that

Figure X-2
Stream Valley Cross-Section Schematic

drain from the soil into ditches to feed streams immediately after a rain event. Infiltration from precipitation is very difficult to measure because it is affected by surface conditions, slope, soil, and bedrock, many of which can vary considerably. Therefore, the best method to measure infiltration from precipitation is to measure stream baseflow which is water leaving the aquifer. Stream baseflow approximates the water flowing into the aquifer. Other factors such as plant transpiration of groundwater, well consumption, and storage variances must be considered to accurately determine the true infiltration value. This value will vary significantly over time and location.

Infiltration–On-Site Septic Systems (Ioss) is treated septic system effluent returned to the aquifer via seepage from an inground, sand mound, or spray irrigation system. Generally, the value provided for base (indoor) water use minus a 10 percent loss factor is used for inground and sand mound septic systems. Spray irrigation systems depend upon application timing and ground cover and can experience significant evaporative losses. Spray irrigation does benefit Infiltration–Precipitation by being lost to evapotranspiration instead of rainwater.

Infiltration–Retention Systems (Ir) is usually stormwater that is held back from flowing across the surface into streams so that it may soak into the ground and feed the aquifer system. Infiltration may occur through storage swales, basins, pervious pavement, or infiltration trenches. One complicating factor included in this value is the induced infiltration that occurs at the downslope edges of impervious surfaces where runoff from roof downspouts and sump pumps discharges onto grassed areas and soaks into the subsurface (e.g., uncurbed paved areas, grass strips along sidewalks, grassed swales).

Runoff–Sewage Treatment Plants (Rstp) is water discharged via a sewage treatment plant system into a watershed from an adjoining watershed. The waters may be discharged into a stream or a spray irrigation system. Larger sanitary sewer collection systems may alter the natural movement of water by draining or pumping sewage from one watershed to another. This data can be obtained from sewage treatment plant records. Careful analysis is needed regarding the source of the water relative to watershed boundaries to be certain the sewage originated out of the watershed. An additional factor contained within this value is infiltration water that has entered the piping from the shallow groundwater system. That value is the “infiltration” portion of what wastewater plant operators call “Inflow/Infiltration” or “I & I” and is often estimated by the treatment plant operators.

Storage–Loss (Sl): Water draining from saturated soils and bedrock, long after a rainfall, will feed the stream system as baseflow. This value is usually calculated by knowing the change in groundwater level and aquifer storage coefficient. Often the value cancels out with Storage–Gain when the aquifer and soil become resaturated during the following year of water infiltration. It is an important factor in an area experiencing a constant overall decline in groundwater levels or a significant drought.

2. **Water Movement Out Of The Hydrogeologic System**

Evapotranspiration–Trees (ETt) is water lost from the system by a combination of evaporation and transpiration from a wooded area. Evaporation is the direct movement of rainwater off of leaves and branches that evaporates into the air. Transpiration is the removal of water from the tree’s vascular system via water loss from leaves. Tree transpiration differs from grass transpiration in that during dry periods, the deeply rooted trees can withdraw water from the entire soil profile down to bedrock and even from the shallow water table, thus removing water from the system long after the surface soils become dry. This value can be calculated for the Study Area using an indirect method incorporating evaporative pan and soil moisture readings. Evaporative pan values are recorded at the Sellersville NOAA weather station. There are also standard empirically derived values that can be used to determine this factor; although they will vary significantly from reality as a result of the local effects of rainfall frequency, cloudiness, soil type, soil thickness and plant type.

Evapotranspiration–Grasses (ETg) A similar factor as “Evapotranspiration–Trees,” but the magnitude of water removed from the system may be less. This is because during an extended dry period, the only water the plants can remove is from the upper few feet of soil. Thus, the deeper soils and shallow bedrock zone remain significantly wetter than in a tree setting where deeper roots will continue to draw water from the ground and remove it from the system via transpiration. This value can be calculated for the Study Area using an indirect method incorporating evaporative pan and soil moisture readings. There are also standard empirically derived values that can be used to determine this factor although they will vary significantly from reality as a result of the local effects of rainfall frequency, cloudiness, soil type, and plant type.

Evapotranspiration–Irrigation (ETi) is water that originated from a potable water supply (e.g., lawn, golf course or agricultural watering of vegetation) that exits the system through plant transpiration. This value can be a significant consumptive value but is difficult to define. The value may vary depending upon age of home (e.g., more water consumption with new lawn watering), weather conditions, and accidentally leaving a hose running all night. Some homes have permanently installed lawn and shrub watering systems that may use over 3,000 gallons of water per day during dry summer periods. Public water systems may be able to discern this value through changes in base water use, combined with careful monitoring of weather conditions. On-site water supplies would require personal surveys or metering.

Evaporation–Water (Ew) is water that evaporates directly into the air from exposed surfaces, puddles and reservoirs. Generally, this value is insignificant unless ponds and reservoirs exist. Evaporative pan values from nearby agriculture stations can be applied to calculate these losses.

Runoff–Surface (Rs) is water that flows over the surface during and shortly after a rain to directly enter a stream. The best measurements are made from direct stream flow data taken from a continuous recording station. Indirect, site-specific estimates can be made using empirically derived formulas such as the Soil Conservation Service TR-55 Method or the Rational Method. The variety in surface materials, slopes, soil types, and rainfall intensities affect the total volume and rate of runoff. Developed areas are influenced by the lack of trees that intercept the initial rain but are especially affected by impervious surfaces such as pavement (Rp) and rooftops (Rr). Impervious surface runoff should consider whether the waters enter a stormwater piping system or discharge onto an unpaved surface where some water can infiltrate.

Runoff–Sewage Treatment Plants (Rstp) is water discharged via a sewage treatment plant system that originated in the same watershed. The waters may be discharged into a stream or a spray irrigation system. This data can be obtained from treatment plant records but careful review of the distribution system is necessary to be certain the sewage was collected from within the watershed. An additional factor contained within this value is infiltration water that has entered the piping from the shallow groundwater system. The sewage treatment plant often calculates this value.

Groundwater–Baseflow (Gbf) is water that exists in the system via seepage of groundwater into streams. This is a combination of water draining the aquifer and infiltration waters passing through the system. Stream baseflow measurements are required to determine this value that fluctuates over the seasons and is dependent upon precipitation variations.

Groundwater–Wells (Gw) is water removed from the system by wells that pull water from aquifers to the surface. It includes wells used for groundwater heat pumps (if they do not recirculate the water) and industrial, commercial, and irrigation purposes. Public well data are reported on a monthly basis with daily measurements also usually available. The DRBC also collects noncommunity water consumptive values for well systems using more than an average of 10,000 gallons per day. Individual small wells would require a survey or metering to determine their usage. Basement sump pumps (Gsp), if discharging to a storm sewer or roadside, can remove a significant amount of water from the shallow groundwater source.

Any value that cannot be directly measured can be estimated by determining all of the other values and presuming the balance is the missing value. The likely limitation with this approach is the probability that more than one factor will be unknown.

C. FACTORS THAT DEFINE INPUT INTO THE WATER SYSTEM

1. Stormwater Runoff

Stormwater runoff is that portion of precipitation that runs off the surface of a drainage area and reaches a stream or other body of water or a drain or sewer. In the general sense, runoff is the portion of precipitation that is not absorbed by the soil or deep strata, but finds its way into water bodies after meeting the persistent demands of evapotranspiration, including interception. Such runoff typically drains from a watershed within three to five days after a precipitation event. The term “Total Runoff” is sometimes used to denote the total amount of water flowing in a stream. It generally refers to natural stream flow, unaffected by artificial diversion, stream channelization, storage, or other human modifications. It includes both surface water runoff (overland flow) and groundwater runoff (baseflow and interflow).

Continuous stream flow monitoring stations are the best method to measure runoff flows. The only valid monitoring station within the Pennridge Area is the USGS East Branch Perkiomen Creek station near Dublin. That station began operation in 1983 and is still recording readings. Unfortunately, since 1989, waters pumped from the Delaware River to the East Branch Perkiomen Creek by PECO Energy have significantly affected the station. The pumped water complicates the natural background water conditions, which makes determining the natural stream flow values difficult to discern.

2. Stream Baseflow

Looking at Figure X-1, it can be seen that the most important factor to define for understanding groundwater movement is stream baseflow. Stream baseflow is water that flows from the aquifer without being directly affected by runoff from precipitation. Baseflow is the water that allows a stream to flow during dry periods long after a rain has ended and is thus critical to the health of a stream. The amount of baseflow entering the stream is an indication of the amount of precipitation that has entered the aquifer. If aquifer withdrawal by wells consistently exceeds baseflow, the aquifer will experience deficit conditions resulting in declining groundwater levels. A local example is Warwick Township, Bucks County, where long-term well monitoring showed a net deficit in production well operation. This resulted in decreasing water levels through the years until the production well and neighboring wells reached a critical point where it was necessary to obtain water from a stream supply outside the area.

Stream baseflow is affected by precipitation, evapotranspiration, well withdrawal, infiltration systems (sewage systems), aquifer storage, geology, and topographic considerations. The rate of stream baseflow varies geographically. Therefore, it is desirable to determine the stream baseflow for a specific region.

Refer to **Appendix G —Technical Discussion Narratives** for further discussion on stream baseflow.

3. Periods of Diminished Precipitation

Another important value considered by some for water budget management is the one-in-ten-year frequency lowest stream flow during a consecutive seven-day period, referred to as Q_{7-10} . This represents a low flow that is considered a reasonable flow rate that can be sacrificed.

Due to the lack of valid long-term continuous monitoring streamflow measurements within the Pennridge Area, a direct Q_{7-10} value could not be obtained. An indirect method to determine the value is to identify the date when a Q_{7-10} value was directly measured at a nearby comparable stream station. For comparison, a USGS study of Q_{7-10} values for the North and East Coventry Township area of Chester County, which has similar shale geology as the central Pennridge Area, had a measured Q_{7-10} value of 143 gallons per day per acre or 91,520 gallons per day per square mile. This is approximately half the rate measured for the 1-in-25-year annual low baseflow rate.

D. FACTORS THAT ALTER THE NATURAL WATER SYSTEM

1. Stormwater Runoff from Modified Landscape

Under natural, forested conditions, stormwater would fall on tree leaves and branches before flowing over the forest floor to enter small streams. Modifications through changes in vegetative cover, plowing, paving, and building rooftops usually result in an increased total volume and peak rate of stormwater flow (i.e., runoff). The peak rate of stormwater discharges from land developments during and after storm events is in some cases controlled by stormwater detention basins. Over the past 15 to 20 years or so, the stormwater detention basins that can be seen as one passes by residential and commercial developments have become commonplace. Unfortunately, that method of controlling stormwater runoff only reduces the peak rate of stormwater entering a stream, but does not reduce the volume. Because the creation of any new impervious surface reduces natural infiltration and increases the volume of stormwater runoff, there will be a net increase in the amount of stormwater leaving a land development site unless certain Best Management Practices (BMPs) are installed to improve infiltration and reduce runoff volume.

Although land developers are required to install stormwater control structures for all new construction, there is no formal mechanism in place at present to catalog or monitor the various stormwater controls as built. Such a lack of information makes it difficult to determine stormwater runoff rates and volumes for the wide range of storm events and landscape conditions that occur in the Study Area.

2. The Effects of Quarries on the Water Balance

Figure III-10 shows the locations of the four active stone quarries within the study area: Blooming Glen, M&M Telford, Naceville and Skunk Hollow. All four quarries extract a relatively similar crushed shale product. The Blooming Glen and M&M quarries are extracting red shales of the Brunswick Formation. The Naceville quarry removes a red shale hornfels rock

of the Brunswick Formation that was baked by the adjoining diabase rock into a black shale material. The Skunk Hollow quarry is removing black argillite shale of the Lockatong Formation. Generally, quarries and wells in the Lockatong Formation yield the least amount of ground water. None of the quarries penetrate carbonate rocks that can produce very large groundwater flows in the millions of gallons per day.

The M & M Quarry in Hilltown Township is used here as an example of the approximate means by which water passes through a quarry. The M&M quarry is reported to extract an average of 400,000 gallons of water per day from its 40-acre pit, which amounts to 146 million gallons of water per year. Of this amount, 49 million gallons per year on average, or 33 percent, is estimated to be from precipitation that falls directly into the pit. The remaining 97 million gallons per year is presumed to be groundwater that has flowed into the pit. All rainfall and groundwater are discharged to the adjoining stream via pumps, with discharge water quality monitored by the DEP under a NPDES permit.

Thus, the quarry acts like a combination stormwater detention basin and well. No water is lost from the watershed by the quarry through interbasin pumping or evapotranspiration. While the quarry does have an influence on the adjoining aquifer, which may affect wells and stream baseflow, ultimately the water enters the stream as it would from natural means, the difference being that water is pumped from the ground and discharged at one point, instead of flowing naturally from seeps in the ground into the stream. Ideally, the quarry should regulate large stormwater flows to some degree by collecting large rains and pumping them more slowly into the stream than would have occurred from direct surface runoff. Water that would have been transpired from the soil into the air during the summer months by plants will be captured and pumped into the stream. During periods of relatively low groundwater level, if the quarry is deeper than the stream channel, water may be pumped into the stream when it may not have flowed under natural conditions.

Each quarry is unique in its design, current depth, rock type and hydrogeologic setting. **Figure X-3** shows schematically that, in general, quarries depress the local groundwater table and may thus adversely affect wells. This may also affect stream baseflow upstream of the discharge point. Downstream of the discharge point, stream baseflow may be more regulated and higher than pre-quarry conditions. Sediments, increased temperature and vehicle fluids may degrade water quality. Theoretically, these water quality effects should be minimized through the DEP regulatory process.

A temporary, but possibly extended, period of significantly reduced stream baseflow and stormwater flow may occur when a quarry pit permanently closes. If the pit is below the level of the adjoining stream when the pumps are shut off, groundwater and stormwater will be retained until the water level reaches the quarry brim and begins to flow unimpeded into the surface water system. Filling of the quarry may take tens of years in some cases, depending upon hydrogeologic and quarry conditions. If an abandoned quarry is ultimately used as a reservoir,

Figure X-3
Potential Quarry Influences on Groundwater

the quarry pit may be of benefit to the hydrologic system by providing water for emergency use during extended droughts for either drinking water use or to retain stream baseflow.

3. Surface Wastewater Discharges

While stormwater discharges feed streams with water, the discharges are short-lived and thus not dependable to support aquatic life. Wastewater discharges, usually from municipal sewage treatment plants, large businesses, and quarries, may provide consistent flows that influence natural stream baseflow. There are many chemical and temperature factors, as well as consistency factors, that ultimately determine the viability of such flows benefiting aquatic life.

The most readily available source of information is from National Pollution Discharge Elimination System (NPDES) permits, granted by the Pennsylvania Department of Environmental Protection (PA DEP). NPDES permits regulate any process water discharged onto the land surface, including businesses that discharge cooling waters, large and small-scale sewage treatment systems, and quarries that pump water from the pit to keep it dry. **Figure III-10** shows the locations of those large-volume discharges.

4. Subsurface Wastewater Discharges

On-site sewage system permits, regulated by DEP through the Bucks County Health Department (BCHD) involve septic systems that collect sewage from one or more homes and businesses and discharge the treated wastewater into the ground through an on-site infiltration system. This would include sand mounds, standard inground infiltration beds and drip irrigation systems. Currently, the BCHD, which manages permitting of these systems, does not have a simple method to identify where and how much water is discharged. These sites could be defined as all homes and businesses not on either an NPDES-permitted public sewerage system or large-scale community system.

Groundwater recharge systems that return stormwater to the aquifer via pervious pavement, rooftop infiltration and retention basins are another form of subsurface discharge. Few of these systems are believed to exist in the Pennridge Area and there is no formal listing of their presence.

5. Subsurface Water Withdrawals

Water wells extract groundwater out of the aquifer and thus intercept its natural flow. The potential effect of disrupting the natural flow is that the groundwater would have eventually entered the stream system as baseflow. Thus, under extreme scenario conditions, virtually every gallon of water that is pumped from a well, unless recharged back into the ground, will rob water from the stream's baseflow.

For the purposes of this study, wells were categorized into four general categories, typically from smallest to largest: (1) private home wells; (2) wells used for commercial (small business) establishments; (3) community water supply wells; and (4) wells serving industrial activities.

Quarries, which pump surface water runoff from precipitation and groundwater from their quarry pit, fall into the industrial category.

Community water supply wells are wells regulated by the DEP through the BCHD, that supply water to more than 15 houses or more than 25 people. They may include housing developments, schools, restaurants and larger businesses. **Figure X-4 — Wells** shows the locations of those wells. Virtually no data were available regarding individual house and small business wells.

The Delaware River Basin Commission (DRBC) permits wells, or a system of wells, that withdraw more than 10,000 gallons per day averaged over any 30-day period. Their records contain permitted allocations but do not have current water use records. The DRBC listing of “Most Recent Groundwater Withdrawal Data” is used as a guide for controlling subbasin water withdrawal rates. The values are based partially upon water consumption data provided by the DEP for 1996. It also calculates net instead of gross water use and therefore does not represent total groundwater withdrawal.

Subsurface water withdrawals include shallow groundwater that leaves the watershed via storm and sanitary sewers. This is referred to as infiltration water that travels within the relatively permeable backfill around a pipe and enters the pipe through cracks and loose connections. Studies have been performed on some sewage treatment systems in the area. The Pennridge Wastewater Treatment Authority’s facility averaged estimated annual infiltration rates from 1985 to 2000 that ranged from 28 to 48 percent of total sewage flow. This is water that is bypassing either the aquifer system or the stream system through travel within the sewage piping system. Attempts by sewerage authorities to reduce infiltration and thereby reduce treatment costs and exportation of groundwater out of the watershed typically meet with varying levels of success.

Basement sump pumps are another means by which shallow aquifer water levels can be diminished. If sump pumps are piped to discharge into a surface water conveyance system, the water that had been in the shallow aquifer is removed and rerouted for eventual discharge into streams and possibly exportation out of the watershed.

E. PENNRIDGE AREA WATER BUDGET

1. Climate of Study Area

Bucks County has a humid continental climate characterized by warm summers and moderately cold winters. Average yearly temperature is approximately 50 to 55°F. The normal mean temperature for January, the coldest month, is approximately 30°F, and the normal mean temperature for July, the warmest month, is approximately 74°F. (Sloto, 1994). The average annual precipitation is approximately 45 to 50 inches. (Sloto, 1994) Heavy rainfall associated with tropical storms and hurricanes moving up the coast occasionally reach Bucks County. Winter precipitation is often light but frequent. Most winter precipitation is in the form of rain.

There are usually several snowfalls each winter with more frequent snowfalls in recent years. Heavy snows (greater than 12 inches) occasionally blanket the study area. Spring and fall are characterized by rapidly changing weather patterns. Alternate periods of freezing and thawing are common during both seasons. The length of the growing season ranges from 120 to 200 days.

2. Generalized Water Balance for the Study Area

An understanding of the movement of water through the hydrologic system is important to develop an accurate water budget. Research into all available data for the neighboring and immediate study area resulted in creation of a representation of water movement through the hydrologic system. **Figure X-I** provides a generalized water balance flow diagram under average conditions. Water is shown to move to the right as precipitation flows through the system. Precipitation that falls on the ground has three general options for initial movement: (1) Infiltration into the soil; (2) Direct evaporation while being exposed on surfaces (depression storage); and (3) Flow across the surface to enter streams (surface runoff). The water then may diverge further as it is either absorbed or transpired by plants or infiltrated into the aquifer system to enter streams as baseflow.

Figure X-I reveals that approximately 19 inches (42 percent) of precipitation eventually leaves the watershed via flow out of the system down the stream. The remaining 26 inches (58 percent) is removed from the watershed via evaporation of water exposed on wet surfaces along with transpiration from plants. The ratio of streamflow to evapotranspiration loss changes significantly through the seasons in response to plant growth and temperature. Ratios may also vary considerably over time depending upon the intensity of rainfall, saturation of soil, and amount of water in aquifer storage.

Of the many values used to create **Figure X-I**, only three factors are reasonably measurable: precipitation, stream baseflow, and stream flow. The remaining factors are computed from residual values or ratios derived from other more detailed studies. The water balance diagram, as presented, is a modification of the water balance prepared for the *Neshaminy Creek Watershed Stormwater Management Plan* (BCPC, 1992). Modifications of the values were made using data more pertinent to the Pennridge Area. The primary difference between the two basins is the predominance of shale in the Pennridge Area instead of the mixture of sandstones and shales found in the Neshaminy Creek watershed.

The average annual precipitation value of 45 inches per year was derived using values for surrounding areas: Neshaminy Creek Watershed Plan (45"), Doylestown data 1968 to 2000 (46"), Allentown data 1912 to 1991 (45") and data from *Sustainable Watershed Management for Northern Chester County Watersheds* (45"). The NOAA precipitation station at Sellersville, while being the closest station to the Study Area, provides only eight years of data from 1948 to 1951 and 1996 to 2001 with a lack of data from 1951 to 1996.

The stream baseflow value of 7 inches per year (15 percent total precipitation) was obtained using the Skippack Creek USGS stream flow data that has been employed by the DRBC for well

Figure X-4 — Wells

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water management in shale areas. The stream station is located 20 miles to the west of the Pennridge Area and is within a similar bedrock formation and geographic setting. The average (one-in-two) year stream baseflow for the stream station was determined to be 314,000 gallons per day per square mile, which equates to 6.6 inches of water per unit area per year.

The surface water stream flow rate, after losses from direct surface evaporation and streambed infiltration, was obtained from the same USGS Skippack Creek data. Surface runoff stream flow was found to represent 64.21 percent of total stream flow. This equates to 563,340 gallons per day per square mile or approximately 12 inches of water per unit area per year.

Because the neighboring Neshaminy Creek watershed has similar precipitation and topographic setting as the Pennridge Area, evaporation, transpiration, and infiltration factors remained the same between the two basins. There is no direct evaporation data known for the region. It is interesting to note that surface runoff for the Pennridge Area is estimated to be 5 inches per year (11 percent) greater than the Neshaminy Creek watershed. Inversely, the infiltration rate for the Pennridge Area is 11 percent lower than the Neshaminy Creek watershed. This variability is most likely the result of the Neshaminy Creek containing sandstone bedrock not found in the Pennridge Area. Sandstone produces sandier soils that are relatively more conducive to allowing precipitation to soak into the soil and aquifer system compared to shale bedrock that produces clay rich soils.

Human impacts on the water cycle can affect ratios of natural water flow within the water budget diagram. For example, paving of a property would increase surface runoff while reducing infiltration, evapotranspiration, and stream baseflow values. The effects of human impacts can be calculated and incorporated into water budgets for regulatory and environmental impact evaluation purposes.

3. Local Water Budgets by Watershed

Table X-1 presents a generalized water budget for the various DRBC-delineated watersheds within the Pennridge Area (shown in **Figure I-2**). The budget employs the rates presented in the water balance diagram (**Figure X-1**) relative to the sizes of each DRBC-delineated watershed. The four primary water flow factors are presented in a gallon-per-year format and represent average conditions. The factors are precipitation, runoff that has entered stream flow, groundwater that has entered stream baseflow, and evapotranspiration. The calculations are based on natural conditions and do not account for human impacts on groundwater or surface water. These water budgets are general and are based on the presumption that conditions are similar in each of the DRBC-delineated watersheds across the Study Area.

A more detailed look needs to be taken in order to account for all of the components that factor into a watershed water budget. Human factors, such as impervious surfaces, stream discharges of treated wastewater, and withdrawals of surface water and groundwater, need to be incorporated into the equation. This approach tailors water movement in a manner more sensitive to the conditions within the DRBC-delineated watersheds under study.

Table X-1
Generalized Water Budgets for Pennridge Area

Factors that influence groundwater discharge into streams as baseflow also need to be considered. In addition to considering the natural infiltration from pervious surfaces, the effects of infiltration from sources such as on-lot septic systems, spray irrigation systems, and stormwater best management practices (e.g., infiltration basins), should be considered. Groundwater withdrawals from public wells that enter a public sewer system and is carried out of the DRBC-delineated watersheds as treated wastewater effluent represents a net loss of stream baseflow water from the system. The cumulative effect of individual, on-lot well pumping will be a negative factor in the equation since it is removing water that would have ultimately entered the stream as baseflow. Changes in aquifer storage from seasonal variations and wet versus dry precipitation years will ultimately balance out and may be considered as having no long-term effect on the equation.

4. Need for On-going Monitor Data

Table X-2—Regional Hydrologic Budget Data lists the various sources of information on water budget that was available at the time the plan was prepared. The problems of data gaps and lack of sufficient quantities of data point to a need for establishing a watershed monitoring network throughout the Study Area. Further refinement of water budget and water balance formulas should be done as more monitoring data are generated. Tabulation of data in an electronic format will allow for quick and accurate transfer of information into water budget equations. Accurate and timely tracking of water budgets can then be correlated with biological as well as stream flow and groundwater monitoring data to understand the impacts resulting from disturbance of the natural balance of the hydrologic system.

Table X-2
Regional Hydrologic Budget Data