Part I

PHYSICAL COMPONENTS

A. Location and Size

The Lehigh River Watershed is located within the Delaware River Basin as shown in Map 1-1. The Lehigh River (Map 1-2) originates in a series of glacial bogs and marshes in the area of Pocono Peak Lake near Gouldsboro (about 15 miles southeast of Scranton). The elevation at the Lehigh River headwaters is approximately 2,200 feet above sea level and drops nearly 1,000 feet during its 103-mile journey to the Delaware River (see Map 1-3). The river flows through ten counties, shown in Table 1-1, and drains 108 municipalities; in many places the river forms the municipal (political, county) boundary.

TABLE 1-1. COUNTIES IN THE LEHIGH RIVER WATERSHED

County	Area, mi2
Berks	21.64
Bucks	0.93
Carbon	379.19
Lackawanna	40.10
Lehigh	275.94
Luzerne	126.38
Monroe	257.08
Northampton	174.98
Schuylkill	55.30
Wayne	12.49
Total	***1,345***

At White Haven, the Lehigh River and its banks become the Lehigh Gorge State Park. Over the next 30 miles, the river flows through a wilderness area that is a haven for whitewater boaters and mountain bikers. Within the boundaries of the park, access on paved roads is limited to White Haven on the north, the park headquarters at Rock Port, near the center, and the Glen Onoko take-out at the south. The Lehigh River exits the Lehigh Gorge State Park north of the town of Jim Thorpe. From Jim Thorpe to Bowmanstown, the Lehigh River contains less rapids and is enjoyed by summer boaters.

The Lehigh River then crosses Blue Mountain at the Lehigh Gap near Palmerton. Blue Mountain separates the Upper Lehigh region from the Lehigh Valley. The Lehigh River continues south through Walnutport and into Allentown. At Allentown, South Mountain impedes the Lehigh River's southward flow and turns it to the east and into Bethlehem.

At Bethlehem, the Lehigh River's speed continues to slow until it merges with the Delaware River at the dam in Easton. The Lehigh's watershed is approximately 1,345 square-miles in area and consists of approximately 2,006 miles of streams. The Delaware River, with a 13,539 square-mile watershed, flows south past Trenton, Philadelphia, and Wilmington-ultimately emptying into the Atlantic Ocean.

B. Physiography and Topography

As shown in Map 1-4, the majority of the Lehigh River basin lies mainly within two physiographic provinces. The Appalachian Plateaus Physiographic Province to the north is characterized by a high rolling plateau, dissected by many narrow and steep-walled stream valleys, as well as numerous lakes and wetlands at elevations ranging from 1,500 to 2,200 feet above sea level. The Glaciated Pocono Plateau section of the Appalachian Plateau province contains the headwaters of the Lehigh River. The Valley and Ridge province to the south, below White Haven, is recognized as consisting of two sections, the Appalachian Mountain Section and the Great Valley Section. The Appalachian Mountain Section, which adjoins the Plateaus province, is a broad band of long narrow ridges and intermediate valleys whose axes lie in the northeast-southwest direction, transverse to the general course of the river. The ridges and steep slopes are moderately wooded. Elevation of the terrain ranges from 400 to 1,400 feet above sea level. The southern-most ridge, Blue Mountain, is cut by the river at Lehigh Gap. The Great Valley Section, characterized by broad rolling terrain, extends northeast to the mouth of the Lehigh at

Easton. This section is bounded on the north and west by Blue Mountain and on the east and south sides by the South Mountain. The northern portion of the valley, is underlain by shale. These shale uplands are commonly 400 to 700 feet in elevation, and stream valleys cut 100 to 150 feet below that surface. In the eastern part of the valley, north of Allentown in Lehigh County, where there is slate rather than shale, the elevations and relief are 100 to 200 feet greater. These shale uplands commonly stand as much as 100 feet above the carbonate terrain to the south.

South of the Great Valley Section, minor portions of the Lehigh basin are within the New England and Piedmont provinces. The portion of the watershed within the New England province is entirely within the Reading Prong Section. It lies between the Great Valley and the Gettysburg-Newark Lowland. The Reading Prong consists of Precambrian granitic gneiss and Cambrian Hardyston quartzite. Elevations in the Reading Prong are as great as 1,000 to 1,300 feet. The portion of the watershed that extends into the Piedmont province is entirely within the Gettysburg-Newark Lowland Section. This section consists of red sedimentary rocks of the Mesozoic basins that include sandstones, siltstones, shales, and, locally, conglomerates. The Mesozoic rocks are intruded by numerous thick sills and thin dikes of diabase that almost invariably stand out in relief above the adjacent sedimentary rocks. Elevations can reach 1,000 to 1,300 feet and commonly are at least 900 feet.

C. Geology

The stratigraphy and structure of bedrock underlying the land surface plays an important role in the physical, chemical, and biological interactions of the watershed. The mineral composition of geologic formations determines, in large part, the quality, and chemical makeup of both surface and groundwaters throughout the watershed. The resulting chemical composition may be a determining factor in what species of flora and fauna live and thrive in the watershed. Factors of geologic structure such as degree of fracturing, folding, or dissolution of bedrock may all be relevant to the quantities of water available for withdrawal by public wells or for irrigation or recreational purposes.

1. Geologic History

The earth is about 4.5 billion years old and has a long geologic history. The major events that have shaped the Lehigh River watershed are described here and are shown in Figure 1-1.

During PreCambrian times, (before about 550 million years ago (mya)), the granitic-gneisse rock which makes up South Mountain was formed. During the Cambrian period (550-500 mya) and Ordovician period (500-440 mya), many of the carbonate rocks in the watershed were created such as the Jacksonburg ("cement rock"), Beekmantown, and Allentown limestones. During the Ordovician period, the Martinsburg shale was formed. Blue Mountain was shaped during the Silurian and Devonian periods (440-360 mya) when the Taconic and Acadian mountain building events were taking place. The Shawangunk, Bloomsburg, Marcellus Shale, Trimmers Rock, and Catskill formations were also formed during this time. From about 360-290 mya (the Mississippian and Pennsylvania Periods), the Lehigh River watershed area looked like a large plain with swamps and peat bogs that formed the source of the present day anthracite coal seams in Pennsylvania. The Pocono, Mauch Chunk, Pottsville, and Llewellyn formations were formed during this time. In the late part of this period, a great mountain building event occurred called the Alleghenian orogeny resulting from the collision of the North American and

FIGURE 1-1 STRATIGRAPHIC COLUMN FOR BUCKS/MONTGOMERY/LEHIGH VALLEY/POCONO REGION
(Source: Frank Pazzaglia, Lehigh University, 2003)

Time: Ma	Era	Period	Formation	Description	Depositional Environment	Tectonic Events	Resource
206	Mesozoic	Triassic	Newark Supergroup*	shale, siltstone, fine to coarse-grained sandstone, conglomerate; greyish-red to reddish-brown; south of South Mountain (Bucks and Montgomery counties); JTrbl or Trb	rivers, lakes, alluvial fans	rifting, opening of Atlantic Ocean	brownstones building stone
			other	conglomerates, sandstones, dikes			
251							
286	Paleozoic	Pennsylvanian	Llewellyn Fm	gray to brown, green, or orange; coal-bearing sandstone, siltstone, shale, conglomerate; anthracite common; IPl	swamps	Alleghenian orogeny; formation of Pangaea	anthracite
			Pottsville Fm	yellow-brown, gray, olive; coal-bearing sandstone, siltstone, shale, conglomerate; ridges; IPp	rivers/ swamps		
325		Mississippian	Mauch Chunk Fm	grayish red shale, siltstone, sandstone, and some conglomerate; plateau and ridges; Mmc or IPMm			
			Pocono Fm	yellow-brown to light gray sandstone, some coal; plateau and ridges; Mp	delta		
360		Devonian	Catskill Fm	interbedded red, green, gray silts and sands, some conglomerates; Pocono plateau; Dck (undivided) or several members, e.g., Dcd, Dcpg.			flagstone
			Trimmers Rock Fm	siltstone, sandstone, black shale; turbidites; Dtr	prodelta	closure of proto-Atlantic (Iapetus)	flagstone
			Mahantango Fm	silty shale and siltstone, medium dark to dark gray; ridges; fossiliferous; Dmh	alternating shallow marine and nearshore	Acadian orogeny	
			Marcellus Shale	gray silty shale, fissile; Dm			
			Buttermilk Falls L.S.	gray limestone w/shale; Dbf			clay
			Palmerton S.S.	quartz pebble conglomerate and sandstone; Dp	shallow marine		refractory sand
			Schoharie and Esopus fms	dark silty and calcareous shale; Dseu			
			Oriskany S.S., Shriver Chert	quartz sandstone w/conglomerate, chert at base; Do			
			Helderberg Gp: New Scotland L.S., Coeymans Fm	limestone and shale; Valley and Ridge			
410		Silurian	Decker, Rondout, Bossardville L.S., Poxono Island fms	thin limestone and shales; north flanks of Blue Mountain into Valley and Ridge			
			Bloomsburg Fm*	red, green, gray shale, siltstone, sandstone; Blue Mountain; Sb	river/marsh / beach		
			Shawangunk cg	fine- to coarse-grained, light to dark gray, sandstone and conglomerate with shale; Blue Mountain; Ss	shallow marine sands	Taconic orogeny; contraction of proto-Atlantic	
440		Ordovician	Martinsburg Gp*	medium to dark gray slates and shales; Lehigh Valley, north; Om	continental rise/trench turbidites		slate
			Jacksonburg Fm	"cement rock", shaley limestone, fine-grained; very dark gray; Lehigh Valley, north; Ojn, Ojk, or Oj	continental slope	development of subduction zone off North America	natural Portland Cement
			Beekmantown Gp*	massive dolomite with some interbedded fine-grained limestone; light to mediumDdark gray; Lehigh Valley, north of Allentown fm; Oe (Epler member), Or (Rickenbach member) or Ob			
505		Cambrian	Allentown Fm*	fine- to coarse-grained, light to dark gray dolomite and limestone; sand, oolites, stromatolites common; Lehigh Valley; OCa or Cal	shallow marine carbonate banks, reefs		limestone/ aggregate
			Leithsville Fm*	fine- to coarse-grained, light to dark gray dolomite and shale; some interbeds of sand, oolites, phyllite; north and east of South Mountain; Cl or Clv		expansion of proto-Atlantic (Iapetus)	
			Hardyston Qtzite*	fine- to medium-grained, white to dark grey, commonly massive, lowest part sometimes pebbly and coarse; north flanks of South Mountain; Ch or Cha	river/marsh shallow marine		building stone
544	PreCambrian		basement rocks*	granite gneisses; South Mountain; Yba and Ybh or gn and hg	? (very ancient rocks)	rifting	building stone/ aggregate

cg = conglomerate, Fm = formation, Gp = group, Qtzite = quartzite   *common building stone

African continents. This mountain building event raised the Allegheny Mountain Range about 2 1/2 miles high. Following this period, the North American and African continents separated and a basin formed between the two continents that is the present day Atlantic Ocean; this basin continues to widen today.

During the Mesozoic Era (250-65 million years ago), the region was transformed due to erosion that formed many of the land features we see today. Erosion from the Allegheny orogeny continued during much of the Cenozoic (the last 65 million years ago) and most of the area in the watershed was lowered by hundreds of feet, with the more resistant rocks becoming the higher ridge tops and the softer rocks becoming the valleys.

Two episodes of glaciation left marks on the Lehigh River watershed. The first glaciation, the Illinoian, receded about 150,000 years ago and the second, called the Wisconsian, receded about 13,000 years ago. The Illinoian glaciers spread more southward than the Wisconsian glaciers, which stopped just north of the Lehigh Valley. The Illinoian Glaciers flowed southward until encountering the ridge of the South and Blue Mountains, which caused the glacial flow to turn southeastward between the Blue and South Mountains. The Illinoian glaciers filled most of the Lehigh Valley and terminated at South Mountain. Glacial actions have produced marked effects mostly upon the northern segment of the watershed including the smoothing down of summits, the scouring of valley walls, and the deep accumulation of glacial till at irregular intervals.

2. Geologic Formations of the Lehigh River Watershed

The primary geologic formations of the Lehigh River watershed are sandstones, shales, and carbonates. These are shown in Map 1-5 and are described below.

a. North of Blue Mountain

This area is within the Appalachian Plateau Province and the Anthracite Upland or Appalachian Mountain Section of the Ridge and Valley Province. This area is mostly underlain by the Catskill, Pocono, and Mauch Chunk Formations, generally consisting of shale, sandstone, and conglomerate. Most of the consolidated rocks are covered by glacial deposits of non-uniform thickness. The Duncannon Member of the Catskill Formation comprises approximately three hundred square miles of the watershed north of the Blue Mountain. The Duncannon Member has a moderate infiltration capacity and a moderate aquifer potential. The Hickory Run Boulder field has resulted from weathering of the Duncannon Member conglomerate during glaciation.

The Polar Gap Member of the Catskill Formation has a similar consistency to that of the Duncannon Member. The watershed area covered by the Polar Gap Member is approximately eighty-five square miles. The Long Run Member of the Catskill Formation covers an area of approximately 55 square miles and consists primarily of sandstone and siltstone. The Pocono Formation covers about seventy-five square miles of the headwaters area. This formation also has a moderate aquifer potential. The Mauch Chunk Formation is approximately 110 square miles and is located in the Anthracite region. This formation has a low to moderate aquifer potential.

As shown in Map 1-6, the northern portion of the Lehigh River watershed contains two anthracite coal fields including the Eastern Middle field and the east end of the Southern field between Jim Thorpe and Tamaqua. Anthracite is a hard coal that is nearly pure carbon. The high carbon content makes anthracite difficult to ignite, but it burns longer and cleaner than bituminous coal, which is a softer type of coal with less carbon. When fully ignited it burns with a short, very hot,

The discovery of high-quality anthracite coal in the watershed fueled America's Industrial Revolution in the18th century.

almost colorless, smokeless flame and yields a small quantity of ash. Pennsylvania's anthracite deposits comprise four geographically distinct fields totaling about 480 square miles. The deposits generally run in a northeast-southwest direction along the line of the Appalachian Mountains.

The coal beds or veins were folded and faulted by the geological formation of the Appalachian Mountains. The intense pressures associated with this process produced the high carbon content that characterizes anthracite. Where the veins intersect the surface they can be mined using surface mining techniques without expensive equipment or any technical knowledge of mining principals. However, where the steeply pitched veins descend below the surface, frequently extending beneath the water table, underground mining is required.

1. EASTERN MIDDLE ANTHRACITE FIELD

The Eastern Middle Anthracite field, the smallest of the four major anthracite fields of northeastern Pennsylvania, is situated in Luzerne, Carbon, Schuylkill, and Columbia counties. Its maximum length is 26 miles, and its maximum width is 10 miles. Coal-bearing rocks underlie approximately 30 square miles. Most of the Eastern Middle field occupies a high plateau centered near the city of Hazleton. The highest elevations (1,600 to 1,800 feet) occur on the steep escarpments bordering the plateau and along several northeast-southwest trending ridges that have local relief of 200 to 300 feet (Hollowell, 1999).

Bedrock units exposed within and directly adjacent to the Eastern Middle field range from the Late Mississippian Mauch Chunk Formation to the Middle to Late Pennsylvanian Llewellyn Formation. The Pottsville Formation in the Eastern Middle field is composed of predominantly thick-bedded, light gray, oligomictic quartzose conglomerates that total 250 to 300 feet in thickness. Throughout the remainder of the Eastern Middle field, "white" quartz conglomerate, typical of the Schuylkill-Sharp Mountain Members, disconformably overlies the upper member of the Mauch Chunk. One or two coal beds (the Alpha and/or the Little Buck Mountain) occur in the finer-grained upper part of the Pottsville Formation. The Llewellyn Formation is about 1,500 feet thick and contains all of the major coal beds of the Eastern Middle field. Aside from its numerous anthracite seams, it consists predominantly of interbedded, dark-gray, carbonaceous sandstones (and some conglomerates), siltstones, claystones, and shales that are often arranged in fining-upward cycles, 50 to 60 feet thick (Inners, 1988). The Llewellyn contains an abundance of pyrite and siderite, attesting to a predominance of reducing and acidic conditions during deposition and diagenesis. Pyrite occurs interstitially in many of the coarser-grained sandstones adjacent to the anthracite seams, in stringers and blebs within the coal beds, and as large "sulfur balls" in claystone and siltstone seat rocks.

The geologic structure of the coal field is typical of the geology in the anthracite region. The Eastern Middle field lies in the east-central part of the great structural depression in the

Appalachian fold belt that forms the Pennsylvania Anthracite region. The coal-bearing areas of the Eastern Middle field consist of numerous relatively shallow, elongate, 2nd-order synclines that lie mainly on the crestal area of the Selinsgrove-Shade Mountain anticlinorium (Inners, 1988). These synclines are commonly chevron-shaped and complexly faulted, and the interven-ing anticlines are more open. The major structural fold in the field is the Hazleton basin, whose axis parallels the major regional folds trending northeast to southwest. The basin becomes broader and shallower in the eastern and western margins.

Faults are minor structural features in this area; most are small wedge faults that transect one or more beds and have displacements of three feet or less. Joints are developed in all lithologies but are particularly well expressed in sandstones and siltstones. Dominant joint sets strike either northwest southeast or northeast southwest (Nasilowski and Owen, 1998).

The Eastern Middle Anthracite field consists mainly of comparatively small, discontinuous coal basins, most of which lie above the natural drainage system of nearby watersheds. According to Ash and others (1949), the area covered by anthracite measures in this field is approximately 33 square miles. The synclinal coal basins are relatively long and narrow and separated by broad areas immediately underlain by members of the Pottsville conglomerate, which contains no anthracite. The anthracite measures are discontinuous because the crests of the anticlines have been eroded away.

The Mammoth and Buck Mountain beds were the most productive, respectively. Production from the other seams has been relatively less, both because of their usual lesser thickness and somewhat poorer quality and because of the limited extent of outcrop of the beds above the Mammoth. The Mammoth bed in the Eastern Middle field generally consists of a single bed that averages about 30 feet in thickness but has up to three splits in some basins. The Buck Mountain (#5) is mined in all the basins and averages about five feet of good coal; however, in many places the "Buck" consists of two splits 10 to 20 feet apart (Inners, 1988).

2. *SOUTHERN ANTHRACITE FIELD*

The Southern Anthracite Coalfield, the largest coalfield in northeastern Pennsylvania, is situated in Dauphin, Schuylkill, Northumberland, Columbia, and Carbon counties. It extends 56 miles from Jim Thorpe to Lykens. The larger part of the coalfield drains about 77 square miles toward the Delaware River while the remaining 64 square miles flows toward the Susquehanna River. The coal bearing rock of the Southern Coal basin covers approximately 141 square miles. The field drains approximately 270 square miles (Edmunds et al., 1998).

Much of the Southern field has been geologically mapped by Wood and associates, and the geologic structure and stratigraphy of the Southern field are described in *Geology of the Southern Part of the Pennsylvania Anthracite Region*, (Wood et al. 1969). The basin is made up of three distinct rock formations: the Mauch Chunk Formation, the Pottsville Formation, and the Llewellyn Formation.

Mauch Chunk Formation includes all of the strata between the Pocono and Pottsville Formations, and its rocks are poorly exposed and structurally complicated by faulting and folding. Lacking stratigraphic markers, they have been subdivided into three informal members: lower, middle, and upper. The lower and upper members contain more sandstone and siltstone and underlie moder-ate to steep slopes adjacent to the underlying Pocono and the overlying Pottsville Formations; the middle member, which contains mostly fine-grained sandstone, siltstone, and shale, underlies valleys where the relief is generally less than 300 feet (Wood et al., 1969).

The Pottsville Formation has a maximum thickness of approximately 1,600 feet in the Southern field. The Pottsville Formation consists of the Tumbling Run Member, the Schuylkill Member, and the Sharp Mountain Member. The Tumbling Run Member is composed of approximately 55% conglomerate and conglomeratic sandstone, about 30% fine- to coarse-grained sandstone, and about 15% shale and sandstone (Wood et al., 1969). The Schuylkill Member is comprised of about 50% conglomerate and conglomeratic sandstone, and the sandstone in the member ranges from very fine to very coarse, constituting about 30% of the member (Wood et al., 1969). The Sharp Mountain Member in most of the Southern Anthracite field is composed of about 45% conglomerate, 25% conglomeratic sandstone, 15% sandstone, 5% siltstone, 9.5 % shale, and 0.5% anthracite (Wood et al. 1969).

The Llewellyn Formation is as much as 3,500 feet thick, with a maximum thickness of 4,400 feet in Schuylkill County. The Llewellyn Formation contains up to 40 mineable coals (Edmunds et al., 1998). The dominant lithology of this formation is sandstone, including conglomerate units, as in the Pottsville Formation.

The Southern Coal field of the Anthracite Region is a complexly folded and faulted synclinorium. Deformation is most complex toward the southeast, where it is characterized by hundreds of thrust, reverse, tear and bedding-plane faults, and tightly compressed, commonly overturned folds (Wood and Arndt, 1960).

Wood and Bergin (1970) noted that not only does the structural complexity vary geographically, but it also varies stratigraphically. They defined five lithotechtonic units in the region, each of which occupies a particular stratigraphic zone. These units each control the vectoral resolution of stresses, resulting in assemblages of structural features in each unit. The relatively competent rocks of the upper member of the Mauch Chunk Formation are commonly deformed into long, concentric, symmetric, open folds broken by low-angle thrust and bedding faults and fewer reverse faults. In contrast, rocks of the Llewellyn Formation range from competent to incompetent, are folded more tightly into numerous shorter, narrower, lower amplitude, commonly disharmonic anticlines, and synclines broken by reverse faults and low-angle thrust and bedding faults.

Coal in the Southern field has been thickened by flowage associated with folding and faulting. Commonly, the coal thickens in the axis of synclines and is increased as much as three- to four-fold, but this thickening is not predictable. Thrust faults often create local thickening of the coal by dragging of the less competent coal and of the enclosing strata. Structural thickening can be seen in stripmine highwalls and has also been reported in underground mining and in drill hole data (Wood and Bergin, 1970).

Several mine discharges in the Southern Anthracite field have significant alkalinity concentrations, including Wadesville, Eagle Hill, and Kaska discharges. It is almost certain that a detailed study of stratigraphy in this area would reveal calcareous strata or calcareous secondary mineralization. Several Southern field discharges have significant acidity concentrations (Brady et. al., 1999).

b. Blue Mountain Region

The Blue Mountain area is within the Blue Mountain Section of the Ridge and Valley Physiographic Province. The Blue Mountain area consists of a large number of formations. The mountain region contains streams, seeps, springs, vernal pools, and wetland areas that are important habitat for a wide diversity of plant and animal species. The Mahantango and

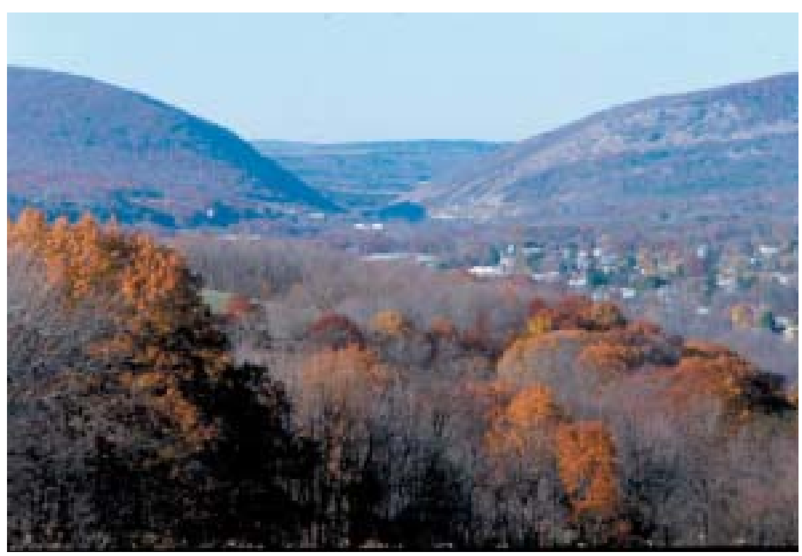
Marcellus Formations cover a large area of this region. The areas are, respectively, 37 and 22 square miles. The Mahantango Formation consists primarily of shale and siltstone and contains fossils. Shale makes up the Marcellus Formation. The Walcksville Member of the Catskill Formation covers the second largest area in this region covering approximately 35 square miles. It consists primarily of sandstone and siltstone with smaller areas of claystone. The Beaverdam Member of the Catskill Formation covers an area in this region of approximately 21 square miles. It consists of sandstone and siltstone as well as containing some marine fossils. The Bloomsburg Formation covers about 21 square miles of this area and consists of shale, siltstone, and sandstone. The Lehigh River crosses this formation at Palmerton. The southern most part of the Blue Mountain region is bordered by the Shawangunk Formation consisting of sandstone, conglomerate, and shale. This formation covers approximately 20 square miles in this area. The Long Run Member of the Catskill Formation is present in both the headwaters region and the Blue Mountain region. This particular section is located approximately in the center of the Blue Mountain area. It consists of sandstone, siltstone, and claystone.

c. South of Blue Mountain

The lower half of the watershed is located primarily in the Great Valley section of the Ridge and Valley Physiographic Province and is bounded to the south by South Mountain, which is part of the New England Physiographic Province. This area is underlain from north to south by a shale and slate region (Martinsburg Formation), a valley composed of carbonate rocks (Jacksonburg, Beekmantown, Allentown limestones), and South Mountain, which is composed of metamorphic crystalline rock. The carbonate areas in the watershed are shown in Map 1-7.

The groundwater that seeps into streams from the carbonate rocks is alkaline and capable of buffering some of the acid coal mine drainage that enters the Lehigh River above Lehighton. In Lehigh and Northampton counties, the subterranean structure can contain cavities and caverns where soluble limestone deposits were dissolved by groundwater flow. Cavities may form sinkholes when the roof of the cavity collapses.

The southern-most region of the Lehigh River watershed is composed primarily of the Allentown Formation. This region has a significant impact on the water quality of the Lehigh River due to its high content of limestone (calcium carbonate). The Allentown Formation itself covers an area of eighty-three square miles and consists of broad-banded magnesium limestone. The Jacksonburg Formation creates a northern border to this region, covers approximately twenty-two square miles, and is composed of dark-colored limestone. The Jacksonburg limestone formation is used for the manufacturing of cement. The Epler Formation covers sixty square miles with limestone and dolomite. South Mountain at the southern border of the Lehigh River watershed is generally made up of granitic gneiss and is part of the Reading Prong Physiographic Section.



The most significant landform in the lower watershed – the Blue (or North) Mountain.

These rocks are some of the oldest found in Pennsylvania and date back to about a billion years ago. The Granitic Gneiss covers thirty-six square miles of divided smaller areas and is composed primarily of quartz and feldspar.

D. Soil Characteristics

Soil characteristics directly influence many natural functions and interactions of a watershed, as well as many activities occurring within and values placed on a watershed. For instance, different types of soils allow different rates of precipitation infiltration, thus affecting soil moisture content, groundwater recharge, and base flows in creeks. People may also value one soil type over another because it has more nutrients, making it more favorable for agricultural use, or because the depth of one is more conducive to development than another. The parent materials of a soil type may also lead to significant impacts on water quality.

Soil surveys are available for each county and should be consulted for detailed soil information. Maps 1-8 through 1-16 show soil maps for each county in the watershed, with the exception of Bucks County, since Bucks County represents a very small area in the watershed. Soil names, soil texture or classification information, hydric soils, and drainage characteristics are shown on the maps. In general, South and Blue Mountains have thin, rocky, somewhat infertile soil, with mesic to xeric moisture regimes (middle moisture to dry conditions). The valley areas tend to have thick soil that can be very fertile with good infiltration rates and mesic to hydric moisture regimes (middle to wet moisture conditions). The northern portions of the study area that lie in the Appalachian Plateau province contain soils formed in glacial till, which generally have very slow infiltration rates and hydric moisture regimes. Most of the watershed is classified as having moderately-well to well-drained soils; however, the area north of Blue Mountain has a more mixed distribution of drainage characteristics ranging from poorly to excessively drained.

E. Climatology

The climatology of the watershed is largely characteristic of continental areas despite its proximity to the Atlantic Coast. Generally, west to southwest airflows are responsible for the hot, dry weather that causes occasional summer droughts.

Mean annual precipitation in the Lehigh River basin ranges from 42 inches at Bethlehem to 48 inches at Jim Thorpe and averages about 45 inches for the basin. The lowest monthly average, 2.6 inches, normally occurs in February, and the highest monthly average, 4.9 inches, normally occurs in July. Mean annual air temperature is 8° C near Allentown and ranges from an average low of -2° C in winter to an average high of 22° C in the summer (U.S. Weather Bureau).

1. Air Quality

Over the past 30 years, scientists have collected a large amount of convincing information demonstrating that air pollutants can be deposited on land and water, sometimes at great distances from their original sources, and can be an important contributor to declining water quality. These air pollutants can have undesirable health and environmental impacts, such as contaminated fish, harmful algal blooms, and unsafe drinking water.

According to the Department of Environmental Protection, air pollution is the largest environmental health risk in the nation. In order to combat air quality problems, Congress passed a Clean Air Act in 1963; our air pollution standards are based on the 1970 version of the law. In 1990, the Clean Air Act was amended to strengthen many of the provisions. In accordance with the law, the Environmental Protection Agency established standards for six major air pollutants: ozone, nitrogen oxides, carbon monoxide, sulfur dioxide, particulates, and lead. The Clean Air Act requires each state to reduce air pollution through a state implementation plan (SIP), which must be approved by the EPA.

In Pennsylvania, air pollution results from industry, power plants, cars, and numerous consumer products. Emissions from automobiles contribute to approximately one-third of Pennsylvania's air pollution. Although the emissions given off by one car are low, the combined emissions from millions of automobiles make the personal vehicle the single greatest air polluter in many of Pennsylvania's cities and towns. Carbon monoxide and ozone-forming compounds such as hydrocarbons and nitrogen oxides are the components of car emissions that are especially environmentally harmful. In Pennsylvania, highway vehicles create two-thirds of carbon monoxide pollution, and wood stoves and industry are accountable for the other one-third. If inhaled, carbon monoxide takes the place of oxygen in the blood and results in impairment of many mental and physical processes

Ozone, which consists of three oxygen atoms bound together, exists naturally in the stratosphere and helps block ultraviolet radiation. However, in the lower atmosphere, the existence of ozone is not natural and contributes to poor air quality. Ozone at ground level forms from a series of reactions involving sunlight, hydrocarbons, and nitrogen oxides. The hydrocarbons and nitrogen oxides are the result of various industrial and combustion processes, one-half of which comes from automobiles, trucks, buses, and airplanes. Ozone can cause significant damage to crops and forests since high levels in the lower atmosphere hinder the growth of plants. In addition, inhaled ozone affects breathing due to its reaction with tissue in our lungs

Various other air pollutants contribute to poor air quality in Pennsylvania. Nitrogen oxides and sulfur dioxide, a gas produced by power plants and furnaces, are the two main components of acid rain. Sulfuric acid forms when sulfur dioxide and water vapor react, resulting in formation of extremely corrosive acid rain, snow, or fog. Both nitrogen oxides and sulfur dioxide can cause restriction of air passages and difficulty breathing.

Carbon dioxide and methane are other prevalent air pollutants and are considered heat-trapping gases. Scientists believe that excess amounts of either compound in the atmosphere may cause trapping of the sun's heat, which can contribute to global warming. Carbon dioxide forms from the burning of fossil fuel, while methane enters the air from swamps, landfills, oil and gas exploration, and coal mines.

Particulate pollution consists of dust, metal, liquid, or other materials that exist as small particles in the air. A variety of sources produce particulate pollution including volcanoes, forest fires, steel mills, municipal waste incinerators, coal mines, and power plants fueled by coal-burning. Breathing problems result when these particles enter the lungs, and severe health problems will result if toxic and cancerous chemicals attach themselves to the particulate matter (DEP 2002).

All of the aforementioned air pollutants have deleterious effects on Pennsylvania's stream and river system. Poor air quality causes degradation of the Lehigh River watershed through contribution of nutrients and other matter. Across every square inch of their surface, the Lehigh River and its tributaries are in constant contact with the atmosphere. Just as the health of its waters is dictated by the health of its watershed, so is the Lehigh River impacted by the health of its "airshed." The airshed has no precise borders; it changes with the direction of the wind. Since airflow occurs from west to east, the watershed receives fallout from air pollutants originating in urban areas to the west. The air moves eastward from those highly polluted areas and air pollutants are emptied into the water system when rainstorms wash them from the air – and as "dryfall," the steady, slow sifting down from above during the rest of the year. Additionally, at least part of the air pollutants that fall on the lands of the watershed also wash into the water during rainstorms.

The state and the nation have been working for decades with mixed success to control air pollution. The true amounts of nutrients and other pollutants deposited from the air onto the Lehigh and its tributaries are not well understood, but indications from studies done on the Chesapeake Bay watershed (more than one-third of which is in Pennsylvania) suggest they may be substantial. As early as 1982 scientists with the EPA Chesapeake Bay Program speculated that as much as 15 percent of the nitrogen reaching the main bay resulted from direct deposits on the water's surface from the air. More recently, studies by the Environmental Defense Fund and EPA have suggested that the air contribution may be up to 25 percent. Some rough calculations by the Washington Council of Governments estimated that nearly six million tons of nitrogen and a quarter million tons of phosphorous fall on the waters of the Potomac River basin each year from the air.

Excess nutrients emptied into the watershed can cause low-oxygen levels and decreased plant growth. Acid rain and toxic air pollutants can negatively impact fish populations in the watershed. Increasing acidity in the water may kill small fish and fish eggs along with other aquatic species that are sources of food for fish. In addition, acid rain releases aluminum from the earth's crust. When washed into streams and rivers, very small amounts of aluminum are lethal for various forms of aquatic life (Horton, 1990).

The outlook for reducing many airborne nutrients has improved in recent years with passage of the 1990 revisions to the federal Clean Air Act. Projections up until 1990 showed nothing but a steady increase in emissions of nitrogen oxides, a source of acid rain and nutrients. The new revisions have altered the scenario for the better, but the newest act still does not put an ultimate limit on nitrogen oxides, the bulk of which come from automobiles. "Unless we change our driving habits and patterns of sprawling land development, we are certain to repeat our previous history—offsetting any positive impacts of cleaner cars with increases in driving and auto ownership." (Horton, 1990). Pennsylvania has seen a 10 percent increase in the total number of vehicle miles traveled in the last decade. Continued increases like this—and all projections show the current trends continuing—will outstrip new air quality regulations in less than a few decades (Horton, 1990).

2. ACID RAIN

Acid deposition is primarily the result of human-made emissions from burning fossil fuel, automotive exhausts, and other industrial processes, which emit sulfur dioxide (SO2) and nitrogen oxide (NOx) gases. These pollutants are transported in the atmosphere, chemically transformed, and deposited either as wet deposition (such as rain, sleet or snow) or in the form of sulfuric and nitric acids, or as dry deposition in the form of sulfate and nitrate particles. These acids can be carried hundreds of miles by the wind before they eventually drop or wash down. The emissions that cause acid rain are not distributed evenly in the United States. SO2 and NOx emissions are concentrated in the coal-burning Ohio River Valley and its surrounding area. The wind carries the gases in a northeasterly direction toward the Mid-Atlantic States, New England, and Canada (DEP, 2002).

Scientists measure the amount of acidity in the water using the pH scale. Monitoring since 1982 has shown that the pH of some Pennsylvania rainfall averaged 4.1 to 4.3, which is around 25 times the acidity of "pure" rain (DEP, 2002). Different areas of the state may respond differently to acid deposition, depending on the region's natural ability to "buffer" or neutralize the incoming acidity. This ability of a body of water to neutralize acids is called its "acid neutralizing capacity," and depends on the dissolved mineral content in the water, which, in turn, depends on the composition of the soils and bedrock in the watershed. If the watershed is primarily underlain by sandstone or igneous rocks such as granite or basalt, then the streams and lakes in the region will have low acid-neutralizing capacity. Limestone rocks in the watershed will have more acid-neutralizing capacity. If soils and waters of an area continually receive acid deposition, their neutralizing capacity will decrease. With little or no neutralizing capacity, the water will gradually acidify and fish and other aquatic life forms will be adversely affected.

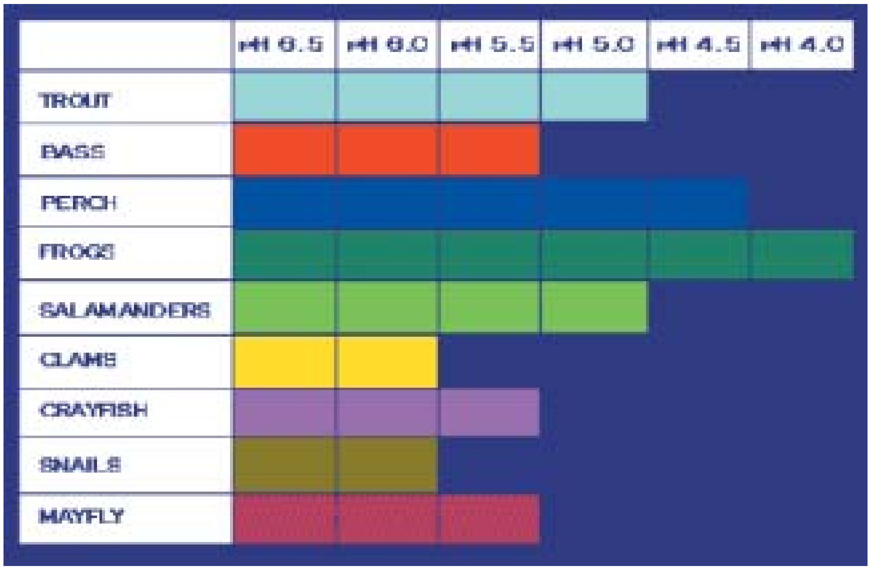
As a waterway becomes acidified, algae and rooted aquatic plants die off, reducing the available food supply for aquatic insects and fish. Healthy aquatic insect communities are replaced by acid-tolerant individuals, which are not as desirable or abundant a food supply for higher organisms such as certain species of fish. More tolerant fish species may begin to replace the original populations, or the fish may disappear entirely from a waterway.

Fish populations can also be directly affected in several ways. Acidity can stress a fish's basic body function, because it upsets the fish's ability to regulate its blood chemistry. Toxic metals, such as aluminum, can be leached from the soils and delivered to the lakes and streams by acidic rainfall. For example, small amounts of dissolved aluminum can cause mortality in fish by damaging their gills and decreasing sodium in their bloodstream. Finally, fish eggs and fry are very susceptible to high acidity and toxic metals. Partial or entire year classes can perish, leaving older, more resistant individuals to maintain a remnant population. At pH 5, most fish eggs cannot hatch (http://www.epa.gov/airmarkets/acidrain/effects/surfacewater.html). At lower pH levels, some adult fish die. Some acid lakes have no fish. Figure 1-2 below shows that not all fish, shellfish, or the insects that they eat can tolerate the same amount of acid; for example, frogs can tolerate water that is more acidic (has lower pH) than trout.

Experts also believe that acid rain contributes to the reduction of crop and forest yields. Instead of adding nourishment to fields and forests, acid rain leaches nutrients (as well as toxic aluminum) that causes sensitive trees and plants to grow slowly or even die. Scientific reports suggest widespread forest damage in the northeastern United State and Canada due to acid rain (DEP, 2002).

Numerous acid rain government and university studies have been conducted in Pennsylvania. Studies conducted by the U.S. Environmental Protection Agency indicate that the Pocono lakes region is the second most negatively affected lakes region in the country. A Lehigh University study determined that out of 160 lakes in the Pocono region for which there were data, 70 percent were sensitive to acid deposition, and 8 percent were already acidified. Scientists from the Pennsylvania State University and from California University of Pennsylvania conducted many watershed studies on the Laurel Hill area, which contains the majority of the natural trout streams

FIGURE 1-2: ACID TOLERANCE OF SOME FISH, SHELLFISH, AND INSECTS
(http://www.epa.gov/airmarkets/acidrain/effects/surfacewater.html)



in southwestern Pennsylvania. One of their studies revealed that 10 of the 61 watershed samples were fishless and concluded "26 percent of the headwater streams on the Laurel Hill are severely impacted by acidification episodes." The National Academy of Science has stated that protection or recovery would occur on 80 percent of the nation's affected waters if sulfate deposition were reduced to 17 kg/ha/year (15 pounds/acre/year). In Pennsylvania, sulfate deposition ranges from 25 to 45 kg/ha/year (23 to 41 pounds/acre/year), so a reduction of approximately 50 percent would be required.

Acid rain may have a serious toxic impact on the fish of the Lehigh River. During the last twenty years, rain falling across much of the northeast has become substantially more acidic. Pennsylvania has recorded acid rain with a pH as low as 3.69. Severe storms can cause pulses of highly acidic water to enter streams and rivers, stressing or killing small fish and fish eggs as well as aquatic species important as food for young fish. Pennsylvania has documented extreme vulnerability of freshwater trout streams to acid rain.

Acid rain is one of the many air pollution issues addresses by Title IV of the Clean Air Act Amendments of 1990. The amendments required a 10 million ton reduction of sulfur dioxide emissions by industry from 1980 baseline levels (nearly one-half). This reduction had two phases. The first phase, effective January 1, 1995, required the largest power plants in the United States to reduce sulfur dioxide emissions. The second phase, effective January 1, 2000, required additional smaller power plants to also reduce their emissions. Statistics show that as a result of both phase, sulfate concentrations in Pennsylvania's rain from 1995-2000 were 27.3 % lower than observed from 1982-1994. The NO_x control program under Title IV also had two phases – the first one was effective January 1, 1996 and the second on January 1, 2000. The overall goal was a national reduction of NO_x emissions from power plants of two million tons form 1980 baseline levels. As a result of both phases, the emissions from affected units in 2000 decreased 23 % from 1990 levels. However, the total NO_x emissions from all sources, including automobiles (the other major source), have increased. Therefore, overall NO_x emissions have not changed significantly from 1980 (DEP, 2002).

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