ASSESSMENT

2.1 GEOLOGY, SOILS, AND SEDIMENTS

2.1.1 INTRODUCTION

The Chesapeake Basin, the largest of Delaware's five drainage basins, encompasses a 769-square-mile area of land along the western border of the state. The Basin extends northward from the state's southern boundary line encompassing nearly half of Sussex County, crosses through the western third of Kent County, and continues up along the Mason-Dixon Line into northern New Castle County, almost to Newark, where it occupies a relatively narrow and small portion of the county (*see Figure 1.2-1*). Watersheds within the Basin discharge to river and stream systems that flow through the State of Maryland and into the Chesapeake Bay.

Regionally, this Basin occurs within the heart of the Delmarva Peninsula, which lies within the Mid-Atlantic region of the eastern United States. This region is characterized by a temperate, mild, humid climate (Engleman, 1985). According to National Weather Service stations in Delaware, long-term, monthly mean air temperatures throughout the Basin range from 30.8˚F in January to 77˚F in July. Average annual rainfall is approximately 45 inches (Johnston, 1976).

The elevation of the land surface in the Basin ranges from approximately 20 feet to 50 feet above sea level (ASL) in the southernmost portion of the Basin, to 50 feet to 80 feet ASL in the northern portion. Flat expanses and shallowly incised stream valleys characterize the southern portion of the Basin. The topography becomes more hummocky north of Smyrna, and streams are more deeply incised.

Like much of the Eastern Seaboard and most of Delmarva, the Chesapeake Basin is within the Atlantic Coastal Plain physiographical province. Approximately 96 percent of Delaware's land area lies within the Atlantic Coastal Plan, and the Chesapeake Basin falls entirely within this province. The Atlantic Coastal Plain is characterized by a relatively low, broad, and flat-to-undulating terrain consisting of a thick wedge of primarily unconsolidated sand, silt, and clay.

2.1.2 GEOLOGY AND HYDROGEOLOGY

More geological formations exist in the Chesapeake Basin than in any of the other three Delaware basins. Twenty-one sedimentary units have been mapped within the Basin. Seven of these units are exposed, or outcrop, at the ground surface (*see Map 2.1-1 Surficial Geology*). Most of the remaining units lie immediately below the surficial

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units, or subcrop, at various locations within the Basin *(see Map 2.1-2 Subsurface Geology)*. These units consistently dip to the southeast at a slope ranging from 15 feet to 90 feet per mile *(see Map 2.1-3 Geologic Cross-Section)*. Older formations dip more steeply and subcrop beneath the younger formations (Talley, 1975).

To assist in the understanding and visualization of the Basin's geology and hydrogeology, the following maps and tables are included:

- *Map 2.1-1 Surficial Geology* shows the locations of the most recent geologic formations that are exposed at the ground surface.
- *Map 2.1-2 Subsurface Geology* shows the locations of the subcropping or underlying geologic formations. This map illustrates what the geology of the Basin would look like if the surficial sediments were removed.
- *Map 2.1-3 Geologic Cross-Section* shows a cross-section of the geology of the Basin. Refer to either of the geology maps (Map 2.1-1, Map 2.1-2) to see the location of the A – A' transect. The cross-section represents what the geology of the Basin would look like if it were cut and viewed along the cut face. The cross-section shows all of the 21 geological units that occur within 1,000 feet of the ground surface along an 82-mile path through the Basin. From this cross-section, aquifer thickness and depths to confining layers can be determined. Unconformities (periods of erosion or non-deposition) and faults are also indicated on the section. The locations of wells used to construct this cross-section are indicated using the Delaware Geological Survey well nomenclature.
- *Map 2.1-4 Hydrogeomorphic Regions* shows the geographic areas determined by certain physical features that greatly influence water-quality characteristics.
- *Map 2.1-5 Ground-Water Recharge Potential* separates the Basin into areas of differing infiltration rates. Categorized from excellent to poor, these regions show the relative ease with which rainwater, or any surface discharge, can enter the subsurface and thus the ground-water system.
- *Table 2.1-1 Geologic Properties* summarizes basic geologic information about formations depicted on Maps 2.1-1, 2.1-2, and 2.1-3. This table is organized according to the age of the unit and begins with the youngest sediments. The columns in the table are devoted to the following:
    - Age and name of the formation
    - Dominant lithology
    - Depositional environment
    - Resource value
    - Aquifer equivalent
    - Properties or facts
- *Table 2.1-2. Hydrogeologic Properties* summarizes basic hydrogeologic information about the 14 primary aquifers found within the Basin. The aquifers are arranged from youngest to oldest. The columns in the table are devoted to information regarding the following:
    - Aquifer formation
    - Aquifer type (confined or unconfined)
    - Area of resource value
    - Thickness
    - Transmissive properties
    - Quality
    - Ground water/surface water interactions
    - Properties or facts

These figures and tables will be referred to throughout the Geology and Hydrogeology Section. Location references for the occurrence of geological formations and areas with notable hydrogeological characteristics will be denoted by town locations that are shown on the maps. Unless otherwise noted, towns will be used to denote the approximate northern and southern extent of the physical feature or topic that is being described. For example, stating "The Calvert Formation subcrop area occurs in the area between Townsend and Viola" would specify the northern and southern extent, respectively, of the Chesapeake Basin's Calvert Formation subcrop area.

2.1.2.1 Geology

Physiographic Setting

The Atlantic Coastal Plain province lies between the Mid-Atlantic Continental Margin to the east and the Piedmont province to the west and north. The mid-Atlantic Continental Margin is the offshore extension of the coastal plain and begins at the coast and extends hundreds of miles offshore. Crystalline rocks of the Piedmont province bound the Atlantic Coastal Plain to the west and north. The northern portion of Delaware's Coastal Plain province begins at the Fall Line and extends southward where it reaches a thickness of approximately 8000 feet at Fenwick Island, Delaware. Coastal Plain geologic formations are composed of alternating layers of sands, silts, and clays that were deposited in various depositional environments over at least the past 120 million years. Many of these sand beds form thick ground-water aquifers that are utilized in Delaware.

Sedimentary deposits as thick as those of Delaware's Coastal Plain are possible only under unique geologic settings. Delaware's position along a once extremely active continental plate boundary has resulted in thick accumulations of sedimentary deposits. These sedimentary deposits occur in a deep depositional basin known as the Salisbury Embayment. The center, and thus the thickest portion of the embayment, is located near Ocean City, Maryland (Sheridan and Grow, 1988). The sedimentary deposits thin as one moves away from the center of the Salisbury Embayment and travels north in the Chesapeake Basin, which is toward the embayment's rim.

Progressively older subcropping and outcropping geological formations are encountered as one travels north in the Chesapeake Basin. Erosive forces remove younger material in areas of the Basin where the elevation is relatively high, such as around and along the Basin's rim. Removal of the younger surficial sediments leaves the underlying older formations exposed or less covered. In addition, relatively recent high-energy glacial streams, which flowed predominantly from north to south, eroded surficial sediments and have greatly contributed to the exposure of older formations in the northern portion of the Chesapeake Basin. Deposition in the low areas near the center of the Basin results in the formation of young sedimentary units, which cover older formations.

The stratigraphy, or series of geologic formations, changes relatively quickly when moving from north to south in the Basin *(see Map 2.1-3 Geologic Cross-Section)*. This direction is essentially perpendicular to the strike of Delaware's geological formations. In contrast, the geology remains more uniform when moving parallel to strike or in an east – west direction.

Hydrogeomorphic Regions

The U.S. Geological Survey (USGS) has characterized the Delmarva Peninsula into seven hydrogeomorphic regions (Hamilton et. al., 1993). These regions are defined by physical features including topography, surficial geology, hydrogeology, and soil conditions. Of the seven regions, the following four are found in the Chesapeake Basin: inner coastal plain, poorly drained upland, well-drained upland, and surficial confined *(see Map 2.1-4 Hydrogeomorphic Regions)*.

The inner coastal plain is located in the northern portion of the Chesapeake Basin between Townsend and Smyrna and comprises about 5 percent of the Basin's land area. The poorly drained upland comprises approximately 80 percent of the Basin's land area and lies south of the inner coastal plain. The well-drained uplands are found along the Nanticoke River and Broad Creek and occupy approximately 11 percent of the Basin's land area. The surficial confined region occurs within the Walston Silt and upper Omar Formation and is found along the southern Delaware/Maryland border in the southernmost part of the Basin. This region covers approximately 4 percent of the Basin.

Hydrogeomorphic classifications are useful for identifying water-quality properties and patterns within a region. Each hydrogeomorphic region is characterized by specific water-quality characteristics. Therefore, hydrogeomorphic regions can be used as a tool to help identify water quality patterns (Hamilton et al., 1993). The USGS has related ground-water quality types and patterns to hydrogeomorphic regions.

Stratigraphy

<u>Older Subsurface Sedimentary Units</u>

The Atlantic Coastal Plain sedimentary units found within Delaware's Chesapeake Basin rest upon pre-Mesozoic crystalline basement rocks that are older than 230 million years (m.y.) (Sheridan and Glow, 1988). The oldest sedimentary unit found within the Basin is the Lower Cretaceous-aged Potomac Formation. This formation comprises the bottom two-thirds of the Atlantic Coastal Plain sedimentary wedge or 4,750 feet (Sheridan and Glow, 1988). These sediments accumulated under fluvial or stream depositional conditions approximately 100 m.y. ago (Pickett, 1976). The dominant lithology types are silts and clays that were deposited within floodplains of ancient rivers. The sandy portions of this formation are river or stream channel deposits (Spoljaric, 1967a).

The Potomac formation was eroded during the early upper Cretaceous (approximately 90 to 100 m.y. ago) (Sheridan and Glow, 1988) as ocean water encroached upon the continent in response to a global sea-level rise. The sands of the Magothy Formation were deposited on top of the Potomac Formation and are the first marine sediments associated with this upper Cretaceous transgression, or sea-level rise (Pickett and Spoljaric, 1971). Full marine conditions persisted until about the middle Eocene (about 45 m.y. ago) and ended after the deposition of the Piney Point Formation (Pickett, 1976).

Even though full marine environments persisted from the upper Cretaceous until the middle Eocene, ocean levels rose and fell during the period which modified the types of sediments that were deposited (Johnston, 1973). These transgressive/regressive sea-level changes led to the deposition of the Merchantville, Englishtown, Marshalltown, Mt. Laurel, Hornerstown, Vincentown, and Nanjemoy Formations (Pickett and Benson, 1977). Most of these formations represent shallow to deeper shelf deposits. Some of these formations, especially the Hornerstown and Vincentown formations, are highly glauconitic (contains silicate minerals which are green and comprised of potassium, magnesium, and iron) and were primarily formed as a result of benthic organisms activity (Pickett and Benson, 1983). Midway between Smyrna and Dover, the Hornerstown, Vincentown, and Najemoy formations become undistinguishable from one another, are grouped together, and are called the Pamunkey Formation (Pickett and Benson, 1983).

The Magothy Formation, a clean quartz sand, is found in the upper portion of the Chesapeake Basin. The Englishtown, Vincentown, and Piney Point formations are dominantly sandy while the Mt. Laurel Formation is dominantly a silty-sand. The Hornerstown Formation is variable in texture ranging from silt to clay with intervening silty-sand layers. The Nanjemoy Formation is primarily silt *(see Table 2.1-1 Geologic Properties)*. The Pamunkey Formation is primarily fine grained, composed chiefly of silt and clay (Pickett and Benson, 1977).

The seas retreated during the middle Eocene. From the middle Eocene to about the Oligocene Epoch (22 m.y. ago), there is no stratigraphic record of sedimentary deposits within the Basin. Likely, erosional processes dominated during this period (Pickett, 1976).

During Miocene time (beginning approximately 22 m.y. ago), the ocean levels rose and again transgressed across the Basin. The sea extended at least as far north as the Townsend area and was responsible for the marine deposits of the Chesapeake Group (Pickett and Benson, 1983). These sediments include (from oldest to youngest) the Calvert, Choptank, St. Marys, Manokin, and Bethany formations. Basal sandy silts of the Calvert Formation formed on the outer continental shelf while near-shore marine conditions formed the dominant setting for the upper sandy members of the formation (Pickett and Benson, 1983). Deposition of the Choptank, St. Marys, and Manokin formation occurred in a delta front to shallow marine setting while the Bethany Formation represents primarily deltaic deposits.

The Calvert Formation is dominantly a sandy-silt with sand and shell beds. The Choptank is dominantly sandy with shell beds and thick fine-grained muddy beds. The St. Marys is dominantly clay but contains thin sandy beds. The Manokin is dominantly a sandy unit that coarsens upward from a silty-clayey sand to a fine to coarse sand. The Bethany Formation is dominantly a sandy-silt to silty-sand with intervening layers of fine to coarse sand *(see Table 2.1-1 Geologic Properties)*.

Younger Surficial Sedimentary Units

Younger and primarily sandy surficial formations blanket the underlying Chesapeake Group sediments and the older marine deposits. These units were deposited primarily under fluvial deltaic and estuarine environments south of Bridgeville. North of Bridgeville fluvial deposition dominated. With the exception of the southernmost portion of the Basin, the younger surficial units sit unconformably over the older formations. (An unconformity is the geological term applied to a break in the depositional history in a stratigraphic column due to either erosion or non-deposition). These surficial deposits become thicker in the southern portion of the Basin where they attain a maximum thickness of approximately 200 feet. In the northern portion of the Basin, these sediments are much thinner — less than 10 feet thick in many areas — or even entirely absent.

During the Pliocene Epoch (between 1.8 to 5 m.y. before present), deposition of sediments in the Basin began in the southern portion of the Basin with the fluvial to deltaic deposits of the Beaverdam Formation (Andres and Ramsey, 1995). These sediments cover most of the Sussex County portion of the Basin and occur from Delmar to just north of Bridgeville. Deposition of the lower portion of the Beaverdam Formation occurred under fluvial conditions while deposition of the upper portion occurred under deltaic conditions (Andres and Ramsey, 1995). In some areas, the lower unit of the Beaverdam Formation contains very coarse sediments (medium to coarse sand, gravelly sand, and sandy gravel with some cobbles and boulders reported up to 2 feet in diameter) that were deposited in high-energy rivers (Owens and Denny, 1979a). These fluvial systems likely eroded deeply into underlying sediments of the Chesapeake Group. The fluvial sediments of the bottom portion of the Beaverdam Formation are deeply weathered. This indicates that after deposition, the lower unit was exposed to the atmosphere for a relatively long period (Andres and Ramsey, 1995). Sea levels rose during the Pliocene Epoch resulting in the deposition of the upper unit of the Beaverdam Formation. This portion of the formation was deposited in a deltaic environment and is finer-grained than the lower unit. Sediment textures range from a fine-to-medium sand to a clayey-silt (Andres and Ramsey, 1995). The entire Beaverdam Formation (upper and lower units) is generally between 50 feet to 100 feet thick but may approach 200 feet thick in paleochannels located along the southern Delaware/Maryland border (Johnston, 1973).

In the southernmost portion of the Basin, estuarine conditions prevailed during the upper Pliocene Epoch when the Walston Silt was deposited. The dominant texture of the unit is silt and resulted from the erosion and weathering of older, exposed formations. The thickness of this formation ranges from approximately 10 feet to 30 feet (Owens and Denny, 1979b). The Walston Silt occurs just east of Delmar along the Delaware-Maryland Line *(see Map 2.1-1 Surficial Geology)*.

During the Pleistocene Epoch (10,000 to 1.8 m.y. before present) meltwater from glaciers located as close as 120 miles to the north in Pennsylvania formed massive rivers that flowed generally south into the region (Spoljaric, 1967a). These rivers eroded older marine and deltaic sediments, which at the time were exposed at the land surface. Erosion of these older surficial units occurred as far south as Bridgeville where the Beaverdam Formation becomes the surficial unit. Meltwater from glacial streams not only caused extensive erosion, it also brought massive amounts of sediments which covered the northern two-thirds of the Chesapeake Basin with medium to coarse sands of the Columbia Formation. The Columbia Formation contains gravel and silt beds and is the dominant surficial unit in Kent and New Castle counties. This formation is generally 20 to 30 feet thick in the northern portion of the Basin, and can reach a maximum thickness of 90 to 100 feet near its southern limit near Bridgeville. Columbia Formation sediments of 70 to 90 feet thick also occur in deeply cut channels paleochannels located southeast of Dover *(see Map 2.1-1 Surficial Geology)*.

The Staytonville unit (a Pleistocene-aged deposit composed of clay and silty-sand and sandy-silt) was deposited on top of the Columbia Formation in the area between Greenwood and Harrington. The relationship of this unit to the underlying Columbia Formation is unclear. The unit may be an estuarine deposit. The thickness of this unit ranges from 20 to 40 feet *(see Map 2.1-1 Surficial Geology)*.

Climatic changes during the Pleistocene Epoch resulted in at least four glacial/interglacial periods. Sea levels during the Pleistocene Epoch (also called the Ice Age) fluctuated in response to the advance and retreat of glaciers in the northern latitudes. Tremendous volumes of meltwater from glaciers caused sea levels to rise. As a result, major river valleys such as the Delaware and Susquehanna River were flooded (Owens and Denny, 1979a). Sea-level rise also drowned local river valleys within the Chesapeake Basin (such as the Choptank and the Nanticoke River). Sea levels during the last interglacial period (the Sangomonian between 300,000 to 360,000 years before present) were approximately 25 feet higher than today. This transgression, during the Pleistocene Epoch, likely resulted in the deposition of other surficial estuarine units within the Basin. These include the upper portion of the Omar Formation and the Nanticoke deposits *(see Map 2.1-1 Surficial Geology)*.

The upper Omar Formation is dominantly fine sand with interbedded silt, clay, and shell beds (Ramsey and Schneck, 1990). Lithological changes within this formation occur rapidly both vertically and horizontally. Some of the silt beds may be highly organic (Ramsey and Schneck, 1990). The total thickness of the Omar Formation is generally less than 25 feet in the Basin. This formation occurs in an extremely small area in the extreme southeastern part of the Basin.

Fine-to-medium sands of the Nanticoke Deposits occur along the Nanticoke River within the river valley and the river valley margins. This unit overlies the Beaverdam Formation and was likely deposited under fluvial conditions in the upper reaches of the Nanticoke River valley. Downriver, these sediments were likely deposited under estuarine conditions. The Nanticoke deposits are capped by sand dunes along the southeast side of the river. The deposit has a maximum thickness of approximately 25 feet (Andres and Ramsey, 1995).

The youngest sediments in the Basin are Holocene-aged and are primarily fluvial, swamp, marsh, and bog deposits. Deposition of these units began approximately 10,000 years ago and continues today (Andres and Ramsey, 1995). These sediments comprise a small percentage of the total sediment volume of the Basin and are scattered throughout the Basin along stream corridors and in wetland and bog environments. Tidal marsh deposits of the Basin are found only along the Nanticoke River and its major tributaries *(see Map 2.1-1 Surficial Geology)*.

The lithology of the Holocene sediments is highly variable and ranges from organic, silty clays, to medium gravels. The marsh, swamp, and bog deposits are finer grained and more organic than the fluvial sediments. Swamp and marsh sediments range from 10 feet to 20feet thick in the southern portion of the Basin. Bog deposits are generally less than 5 feet thick. These units overlie the Beaverdam Formation (Andres and Ramsey, 1995).

2.1.2.2 Hydrogeology

Ground water is to the sole source of drinking water throughout the Chesapeake Basin. Millions of gallons of ground water are withdrawn from the Basin's aquifers on a daily basis. Within the Chesapeake Basin 15 of the 21 sedimentary formations are important as water supply sources and serve as aquifers. An aquifer is a transmissive body of water-bearing sediments or rock formation which are capable of yielding significant quantities of water. Both unconfined and confined aquifers are utilized as drinking water supplies in the Basin.

Unconfined Aquifer

The Basin's unconfined aquifer system, also known as the surficial or water-table aquifer, occurs within the Columbia Formation and the Beaverdam Formation. The Columbia Formation covers the upper two-thirds of the Basin while the Beaverdam Formation covers the lower one-third of the Basin. Where the Columbia and Beaverdam Formations are hydraulically connected with older underlying sands, the unconfined aquifer becomes thick and includes other formations. In the southern portion of the Basin, sands of the Beaverdam Formation and underlying sands of the Manokin Formation are hydraulically connected and form extremely productive aquifers capable of yielding large quantities of water. The unconfined aquifer reaches a maximum thickness of approximately 200 feet near Delmar, Delaware, where Pliocene-aged rivers cut deep paleochannels which resulted in thick accumulations of Beaverdam sands (Johnston, 1973).

In some areas, younger surficial sediments that function as confining or semi-confining units cap the Columbia and Beaverdam Formations. These units, the Staytonville Unit, the Walston Silt, and the upper Omar Formation, are generally less than 40 feet thick and locally confine the Beaverdam and Columbia Formations *(see Map 2.1-1 Surficial Geology)*.

The unconfined aquifer is heavily utilized for supplying water to domestic, public, agricultural, and irrigation wells in lower Kent County and in Sussex County where surficial sediments are thicker.

The Columbia and Beaverdam formations not only function as productive aquifers, but also supply base flow to streams (Andres, 1994). Ground water from the surficial aquifer comprises a significant volume (on average as much as 75 percent of the total freshwater flow) of stream flow, particularly during dry periods. Thus, water quality in these aquifers can impact surface water quality.

Water Source (Recharge)

Recharging rainfall is the sole source replenishment for ground water in the unconfined aquifer system. On average Delaware receives 45 inches of rainfall per year. According to Johnston (1976), approximately 10 percent is discharged directly to surface water bodies through overland flow; 50 percent is evaporated or transpired by plants before reaching the water table. The remaining 40 percent infiltrate through soils and reach the water table. Evaporation and transpiration directly off of the water table accounts for an approximate 7 percent water loss. This means that only 33 percent (or 14 inches) of the total rainfall reaches the unconfined aquifer.

Rainwater moves into the ground-water system in recharge areas where permeable sediments enable the water to readily infiltrate. Most of the land area within the Basin is sufficiently permeable to be considered a recharge area. The Delaware Geological Survey (DGS) has been conducting ground-water recharge-potential mapping statewide. Mapping has been completed for much of the state including most of the Chesapeake Basin *(see Map 2.1-5 Ground-Water Recharge Potential)*.

The main purpose for the ground-water recharge potential mapping study is to categorize the ground-water recharge-potential of surficial sediments throughout Delaware. Categories include excellent, good, fair, and poor recharge potential. Based on the mapping completed thus far, excellent ground-water recharge areas are scattered throughout the Chesapeake Basin and occupy roughly 10 to 20 percent of the Basin area. Good recharge areas occupy 20 to 30 percent; fair recharge areas 50 percent; and poor recharge areas occupy less than 10 percent.

Most ground-water recharge occurs during the winter and early spring when evapotranspiration rates are low. Water tables of the unconfined aquifer systems respond to recharge and rise to their highest levels in late winter and early spring. Water tables are generally at their lowest levels during the period from late summer to late fall. Over the course of a year, the elevation between the seasonal-high water table and the seasonal-low water table ranges from 5 feet to 10 feet.

The seasonal-high water table of the poorly drained upland region is generally less than 5 feet below the ground surface (BGS) (Hamilton et al., 1993). Higher elevations and hummocky topography in the inner coastal plain region likely result in a lower seasonal-high water table. In addition, land along major stream corridors is often better drained and tends to have lower water tables. One of the lowest coastal plain water-table readings on record occurred just east of Middletown. At this location, the water table measured 35 feet BGS (Spoljaric and Woodruff, 1970).

Ground-Water Flow

Ground water moves much slower than surface water and follows specific flow paths as it moves through an aquifer. These flow paths vary in length depending on the thickness of the aquifer and the proximity of ground-water discharge areas (streams, rivers, ponds, bays, and oceans) where ground water enters surface water bodies. Ground-water flow paths within the unconfined aquifer of the Basin are relatively short, from hundreds of feet to less than 1 mile (Hamilton, et. al., 1993). The velocity of ground water along a flow path is slow, generally less than 1 foot per day. Age dating of ground water in areas located just outside the Basin indicates that most unconfined ground water is less than 50 years old (Hamilton, et. al., 1993).

Specific capacity (SC), transmissivity (T), and aquifer thickness indicate how readily water can move through an aquifer. The higher these values, the more productive the aquifer. These parameters vary widely from one locality to another, and such a range of values is reflective of the complexity and variable nature of the aquifer materials. The average SC and T values recorded for large-capacity unconfined wells are 27 gallons per minute per foot and

7,050 feet squared per day, respectively. These values range from 5 to 107 gallons per minute and 780 to 22,000 feet squared per day for SC and T respectively. The highest unconfined transmissivity value (22,000 feet squared per day) recorded in Delaware occurred in an area just east of the Basin between Harrington and Greenwood.

The highest well yield recorded in the Basin (1,400 gallons per minute) occurred in an irrigation well located west of Laurel. Based on information provided by Johnston (1973), yields from unconfined large-capacity wells located throughout and just outside the Basin averaged 668 gallons per minute. The lowest recorded unconfined aquifer well yield is 100 gallons per minute, which occurred in a well located just north of Middletown.

Water Quality

Ground-water quality within the Chesapeake Basin is highly variable. Much of the water in unconfined aquifers has been impacted by human activity at the surface. The confined aquifer contains natural contaminants and water quality that differs greatly from that of the unconfined aquifer. Ground-water quality variations within the unconfined aquifer are found in different geographical locations within a particular aquifer system. Water quality not only varies horizontally but also vertically with depth, especially within the unconfined aquifer. The ground-water quality of an aquifer is controlled by a number of factors. The dominant controlling factors include the composition of the sediments, the proximity of saltwater bodies, the aquifer oxygen content, rainfall composition, microbial activity, and the type, quantity, and concentration of introduced contaminants. The Basin's unconfined ground water can be broken down into two main water-quality groups: natural or non-impacted ground water and anthropogenically influenced or impacted ground water.

Natural Quality Issues. "Natural" ground water is often characterized by nitrate concentrations of less than 0.4 mg/l. These waters have not been impacted by land-use practices such as fertilizer application or wastewater disposal. This primarily occurs in areas where rainfall recharges through forested lands, or in the surficially confined hydrogeomorphic regions that occur in the lower portion of the Basin *(see Map 2.1-4 Hydrogeomorphic Regions)*. Recharge through the surficial Staytonville Unit often results in a natural type ground water as well.

In general, natural unconfined ground water is often oxygen-rich, acidic, and soft (containing relatively little calcium and magnesium). The presence of oxygen leads to iron concentrations below the 0.3 milligrams per liter (mg/l) secondary drinking-water standard and to the absence of hydrogen sulfide. However, there are certain areas where oxygen is scarce (oxygen levels are less than 0.4 milligrams per liter) in the ground water, and dissolved-iron compounds and hydrogen sulfide are present and can cause significant natural ground-water contamination (Denver, 1986). In addition, other naturally occurring compounds such as manganese, sodium, chloride, calcium, magnesium, and total dissolved solids (TDS), can be found in the unconfined aquifer and often become problematic in the surficially confined hydrogeomorphic regions referred to earlier and near saltwater bodies.

Human Impacts. Agricultural activities (primarily the wide spread application of nitrogen fertilizers) and the on-site wastewater discharge associated with residential and commercial development have significantly impacted ground-water quality over much of the Basin. In fact, because of its common occurrence, nitrate is often used as an indicator of impacted ground water. Nitrate concentrations in excess of 0.4 milligrams per liter indicate that ground water has been impacted by anthropogenic activities (Hamilton et al., 1993).

In addition to widespread issues like nitrate contamination, other site-specific contaminant problems exist in numerous locations throughout the Basin. Hazardous chemicals such as gasoline compounds from leaky tanks are being or have been released. In other areas, hazardous percolate from abandoned landfills continues to seep into the surficial aquifer. However, ground-water contamination associated with these sites is often localized impacting relatively small areas of the Basin.

Although both these widespread and local impacts exist, most ground water within the unconfined aquifer is still safe for drinking-water supply purposes. In many areas, nutrient concentrations are, however, above surface-water quality standards. Since ground-water supplies up to 75 percent of the total water volume in streams and rivers, nutrients found in discharging ground water are likely to contribute significantly to the eutrophication problems in some surface-water bodies.

Nitrate. A variety of sources (e.g. fertilizers, septic systems, atmospheric gases) can introduce nitrate, an oxidized form of nitrogen, into soils at the land surface. If this nitrate is not utilized by plants, it can enter the ground- water system. Where oxygen is also present, the nitrate can persist for long durations. Where oxygen is scarce, chemical reactions and natural microorganisms can convert the nitrate back into harmless nitrogen gas. Nitrate has a primary maximum contaminant level (MCL) drinking-water standard of 10 mg/l. Concentrations in excess of this are potentially harmful to humans. According to Hamilton and others (1993), approximately 20 percent of the ground-water samples taken from the Basin's poorly drained upland hydrogeomorphic region exceed this standard. The Basin's poorly-drained upland hydrogeomorphic region comprises approximately 80 percent of the Basin's land area *(see Map 2.1-4 Hydrogeomorphic Regions)*. Ground-water sampling in this region also reveals that the unconfined aquifer has a median nitrate concentration of 4.4 mg/l (Hamilton and others, 1993). The well-drained upland region of the Basin likely has higher median nitrate concentrations due to the increased depth to the water table in these regions.

Phosphorus. Phosphorus concentrations in the unconfined aquifer are relatively low, averaging less than 0.08 mg/l (Denver, 1986). According to Denver (1986), phosphorus concentrations as high as 1.1 mg/l can be expected in areas with elevated pH. In areas where soils are oxidized and acidic, and contain high amounts of iron and aluminum, most phosphorus applied at the land surface becomes bound to the soil particles. In some areas, however, the ability of the soil to adsorb phosphorus has been greatly reduced due to over-application of fertilizer and/or wastewater. When this occurs, phosphorus is much more mobile and readily moves into and through the ground-water system. Unlike nitrate, phosphorus does not have a primary MCL and does not occur in high enough concentrations in ground water to cause a substantial health risk.

Herbicides. Like fertilizers, pesticide use is widespread throughout the Chesapeake Basin. Herbicides (e.g. atrazine, cyanazine, metolachlor, and simazine) are readily detected in shallow unconfined ground water beneath sandy soils with low organic matter. Atrazine is the most frequently detected herbicide and occurs at the highest concentrations (Denver, 1993). However, more than 95 percent of the herbicides detected are found at concentrations generally at or near the 0.1 microgram per liter laboratory-detection limit. In most cases, this limit is substantially below the drinking water standards set by the EPA.

Confined Aquifers

A confined aquifer is an isolated water-producing formation that is located between two distinctly less permeable formations. Numerous confined aquifers can be found throughout the Basin. In certain areas, overlying formations do not completely protect these confined aquifers. In these subcrop areas, a portion of the confined aquifer becomes part of the water-table aquifer and is vulnerable to contamination from surface sources.

Confined aquifers are utilized more often in the upper two-thirds of Kent County and in New Castle County where the unconfined aquifer is thin and where confined aquifers are closer to the ground surface.

Sandy units within the Potomac Formation (the deepest and oldest sedimentary unit in the Basin) act as a major confined water supply for many wells in New Castle County *(see Map 2.1-3 Geologic Cross Section)*. Clays and silts of the Potomac confine this aquifer and separate it from the overlying sands of the Magothy, Englishtown, and Mt. Laurel Formations. The Magothy, Englishtown, and Mt. Laurel Formations provide water to many small domestic wells from the Chesapeake and Delaware Canal area to Middletown. South of the canal, larger production wells rely on the marine deposits of the Rancocas Group as an important water supply.

Although the confined Piney Point Formation is an important source of water elsewhere in the state, it is not used within the Chesapeake Basin. Silty clays of the Calvert Formation separate the Piney Point from the overlying Chesapeake Group aquifers. These clays are up to 100 feet thick in some areas and comprise an important regional confining layer. The Chesapeake Group contains extensive sand layers that are useful for water-supply purposes throughout most of the Basin south of Smyrna. Two of the lower sandy units, the Cheswold and Frederica aquifers, subcrop in the Smyrna to Dover area where they form the lower portion of the unconfined aquifer. The Federalsburg Aquifer, a third sandy unit, exists in the Dover area. This aquifer lies between the Cheswold and Frederica aquifers but does not subcrop beneath the overlying Columbia Formation.

Farther to the south, the Choptank Formation subcrops in the area between Viola to approximately 2 miles south of Greenwood. Sands of the Choptank Formation become thick enough to yield significant quantities of water south of the Harrington area where the aquifer is confined. This aquifer remains useful for water-supply purposes at least as far south as Laurel.

The St. Mary's Formation confines and separates the underlying Choptank Formation from the Manokin and Bethany formations. These two formations subcrop in the lower-most portion of the Chesapeake Basin. The northern limit of the Manokin aquifer subcrop area occurs along a northeast trending line passing through Seaford and Bridgeville and extends south to the town of Laurel. The Bethany Formation is the southernmost subcropping unit. The lithology of this formation has not been adequately characterized in the Basin. In many locations, this formation is fine-grained and acts as a semi-confining layer for any underlying sands. In some areas, however, the Bethany Formation may be hydraulically connected to the overlying Beaverdam Formation and function as the lower portion of the water-table aquifer.

Water Source (Recharge)

Water in the unconfined aquifer recharges deeper confined aquifer systems. In subcrop areas, this recharge can be relatively rapid. However, in areas where extensive confining layers exist, recharge to deeper confined aquifers can be extremely slow. These confining layers greatly reduce the ground-water flow velocity; subsequently, confined-aquifer water is often much older than that in the unconfined aquifer. In fact, water from the deepest confined aquifers can be thousands of years old and may have traveled several miles.

Water-Bearing Characteristics

Confined aquifers are generally less transmissive than unconfined aquifers. A comparison of confined and unconfined aquifer parameters in the Chesapeake Basin indicates that the average transmissivity for the confined aquifers is approximately four times less than that of the unconfined aquifer. However, the data supporting this conclusion are scarce and in some instances data from only one well were used to characterize an entire confined aquifer.

Information provided by Woodruff (1972, 1990), Andres (1994), and Sundstrom et al. (1975) indicates that the transmissivity of the various confined aquifers range from 187 to 5,481 feet squared per day. The highest values recorded occurred in the Piney Point Aquifer in the Dover area. The lowest values occurred in the Englishtown/ Mt. Laurel Aquifer system near Middletown. Based on these data, the most transmissive aquifers (from highest to lowest) are the Piney Point, Choptank, Cheswold, Rancocas, Frederica and Potomac aquifers. Transmissivity values recorded for the various confined aquifers averaged approximately 1,675 feet squared per day.

Water Quality

Overlying fine-ground sediments protect confined aquifers from anthropogenic contaminants. However, confined aquifers may contain naturally occurring contaminants such as iron and hydrogen sulfide that are undesirable. A major reason for this is that confined aquifers have a relatively low oxygen content, which influences the geochemistry. Analyses of water-quality data compiled from USGS and DGS Reports indicate that confined aquifers, on average, contain roughly three times less oxygen than unconfined aquifers. Ground-water analytical data from Andres (1994), Woodruff (1970, 1972), Bachman and Ferrari 1995), Sundstrom et al. (1975), and Denver (1986) were combined and analyzed to determine minimum, maximum, and average concentration values for various parameters for each aquifer. The following statements regarding water-quality similarities and differences between the various aquifers are based on a comparison of this information. The number of available water-quality analyses varied greatly. For some confined aquifers, only very limited water-quality information exists.

Iron and Hydrogen Sulfide. Low oxygen levels result in geochemical reactions that favor the production of soluble iron compounds and hydrogen sulfide gas. Confined aquifer iron concentrations generally exceed the secondary drinking-water standard of 0.3 milligrams per liter (Bachman and Ferrari, 1995). Even though a drinking-water standard has not been established for hydrogen sulfide, this compound often becomes objectionable because of the rotten-egg smell it produces. Hydrogen sulfide commonly occurs in confined aquifers rich in sulfur-bearing organic material.

The Rancocas, Potomac, and Magothy aquifers contain the highest iron concentrations while the Chesapeake Group and Piney Point aquifers contain the lowest. In some localities, the Rancocas Aquifer has extremely high iron concentrations. Concentrations as high as 21 mg/l (the highest iron level found in any of the confined aquifers of the Basin) have been documented. Elevated iron levels within the Rancocas are probably related to the high percentage of iron-bearing glauconite. The Potomac Aquifer, with an average iron concentration of 3 mg/l, contains the highest average iron concentration found in the Basin. The Chesapeake Group aquifers contain the lowest average (0.02 milligram per liter) and the lowest maximum (0.75 milligrams per liter) iron concentration.

Nitrate. Nitrate, which is problematic and common in the unconfined aquifer, is not stable in aquifers with low oxygen levels and thus is usually not a problem in confined aquifers. In such settings, nitrate readily undergoes denitrification and changes into harmless compounds. Confined-aquifer nitrate levels are generally less than the detection limit of 0.02 milligrams per liter (Bachman and Ferrari, 1995).

Radon. Radon gas can be a problem in some confined aquifers. In adjacent states, this constituent has been identified in concentrations exceeding the primary maximum contaminant level of 300 picocuries per liter in the Englishtown/Mt. Laurel aquifers and in the Rancocas group aquifers. Radon is thought to be associated with glauconitic minerals found in these aquifers (Bachman and Ferrari, 1995). To date, radon has not been adequately characterized within the Basin.

Hardness/TDS. Hardness is a measure of the concentration of calcium, magnesium, and other dissolved solids contained in water. In Delaware, aquifers containing shelly, marine deposits can often have water-quality problems associated with hardness and TDS. Concentrations of these minerals are usually higher in confined aquifers than in unconfined aquifers. The highest levels in the Basin occur in the Chesapeake Group and Piney Point aquifers. Shell material and siliceous tests from saltwater diatoms comprise a relatively high percentage of the sediments forming the Chesapeake Group aquifers and contribute silica to the ground water resulting in elevated TDS (Woodruff, 1970).

pH. The pH (hydrogen ion content) of confined aquifers is also generally higher than that of unconfined aquifers. The Piney Point and Chesapeake Group aquifers contain the highest pH levels, which average 8. Shell deposits, which buffer acidity, and the lack of acidifying reactions are largely responsible for the elevated pH values.

Sodium and Chloride. Sodium and chloride are the dominant constituents that limit the use of confined aquifers to certain areas of the Basin. Sodium and chloride become elevated with increasing depth. Many confined aquifers, such as the Potomac Aquifer, that have low salinity in the upper portion of the Basin lie too deep and become too salty to drink in the southern portion. In most areas, aquifers lying deeper than 800 feet below the ground surface become salty and non-potable. Around the Nanticoke River, however, the depth at which sodium and chloride becomes excessive is much shallower. A well (DNREC ID 91390) installed along the Nanticoke River at Woodland Ferry in 1992 yielded water with a salinity content of 0.4 parts per thousand and a specific conductance of 800 micromhos per centimeter. This well draws water from a depth of 360 to 380 feet below the ground.

2.1.3 SOILS

Soils are defined as a "collection of natural bodies in the Earth's surface, in places modified or even made by man of earthy materials, containing living matter or capable of supporting rooted plants in the natural environment." Its upper limit is air or shallow water. At its margin, it grades to deep water or to barren areas of rock or ice. Its lower limit, to the material beneath which is not soil, is perhaps the most difficult to define. Soil includes the horizons near the soil surface that differ from the underlying rock material as the result of interactions, through time, of climate, living organisms, parent materials, and relief. In the few places where it contains thin, cemented horizons that are impermeable to roots, soil is as deep as in the deepest horizon. More commonly, soil grades at its lower margin to hard rock or to earthy materials virtually devoid of roots or marks of other biological activity. The lower limit of soil, therefore, is normally the lower limit of bio-logical activity, which generally coincides with common rooting depth of native perennial plants (Soil Survey Staff, 1975).

Advances in soil science have broadened the definition of soils to include soils that have formed in saturated conditions associated with open water. This broader definition will now allow soils that are under rivers, streams, estuaries, and other water bodies to be mapped and characterized. This characterization may be vital in the re-establishment of submerged aquatic vegetation and increased information about shellfish beds in many of the rivers within the Basin. In the Chesapeake Basin portion of Delaware, soil depth approaches its lower limits of the definition into the earthy materials devoid of biological activity.

Topography (relief) controls or modifies soil formation. Relief affects landscape distribution of soils, landscape distribution of moisture, erosion and alleviation patterns, temperature difference caused by aspect (the compass direction the slope faces), and combined temperature and rainfall effects as a result of elevation (Fanning and Fanning, 1989). Topography in the Chesapeake Basin is gently sloping in the northern part to nearly level going southward in the drainage Basin. Subtle differences in the landscape of 0.5 to 1.0 foot greatly affect the drainage of the soil. Surface-water runoff either collects in depressions or flows towards watercourses. The infiltrated water can discharge into depressions or flow down-gradient to upland head waters and streams areas. These depression and upland headwaters contain many of the wetlands in the Chesapeake Drainage Basin. The Delaware portion of the Chesapeake Basin occurs at the drainage divide between the Delaware River Basin and the Chesapeake Bay. Hamilton et al. (1993), also defined this area as the Poorly Drained Uplands. Tidal wetlands are found in the floodplains of the Nanticoke River and along the lower portions of Broad Creek. Most of these creeks and stream areas have been ditched for agricultural production and have lost many of their associated wetlands. Landscape changes caused by ditching within portions of the watershed, and channelization of the stream, can significantly alter flow volumes. Both of these practices will affect wetland hydrology, either by reducing the water supply available to the wetland or by increasing the speed in which the water flows through the wetland. In addition, these practices tend to increase sediment loads in the stream due to bank scouring and/or increased water velocities, which allows the stream to transport sediments longer and farther. About 65 percent of the land area in the Atlantic Coastal Plain have soils that are suitable for cultivation. The other 35 percent of the land area consists of soils that are not well suited to cultivation because of very poor drainage.

2.1.3.1 Hydric Soils

Soils are placed in natural drainage classes based on the correlation of mottles used to identify saturated zones within a soil associated with the seasonal water table. These mottles are indicators of seasonal high water tables and are found in soils where they are encountered. Mottles are actually the gray and red blotches that have formed in the soil from the interaction of soil bacteria, organic matter, and ground-water table. The ground water in saturated soils will quickly become oxygen deficient (anoxic); consequently, microorganisms will transfer the energy primarily to iron in saturated soils, which solubilizes the iron. The classes are based on the depth to mottling or gray colors, which indicate the maximum of the stable height of the water table. Significant portions of the soils that are found in the Basin are poorly to very poorly drained. Some of these soils would be considered hydric. Hydric soils are defined by the USDA Soil Conservation Service (1982) as "a soil that is either (1) saturated at or near the soil surface with water that is lacking free oxygen for significant periods during the growing season, or (2) flooded frequently for long periods during the growing season." The following soils have a potential to be considered hydric: Berryland, Elkton, Fallsington, Hurlock, Longmarsh, Mullica, Othello, Pone, Portsmouth variant, Puckum, Tidal Marsh, Trussum, and Zekiah. Areas are considered to be wetlands when comprised of hydrophytic plants, hydric soils, and hydrology indicative of periods of continuous soil saturation during the growing season. A majority of these soils *(see Map 2.1-6 Hydric Soils)* are located within the headwater areas of the creeks and rivers. The headwaters and floodplain comprises 48 percent of the Basin.

2.1.3.2 Drainage

Improved drainage is one of the principal soil management needs of the Chesapeake Basin. Improved soil drainage has an increased benefit on agricultural production activities. Currently, there are approximately 1,500 miles of private ditching and 1,500 miles of publicly maintained tax ditches draining over 292,000 acres, which is 64 percent of the Basin. Only a few farms are located entirely on well-drained soils. These soils are chiefly in the upper part of the Basin and occur in areas that are higher in elevation adjacent to the Nanticoke River and its tributaries. Considerable acreage in the upper part of the Basin is being converted to residential development, which modifies soil drainage needs to storm-water management options.

Artificial drainage is needed in some degree in about 60 percent of the total acreage based on the soil types found in the Chesapeake Basin, or about 70 percent of the acreage suitable for crop production. Crop yields are often poor or crops fail completely unless a drainage system is well established, maintained, and controlled. This is especially true in the middle (Kent County) and lower part (Sussex County) of the Basin. Of the total acreage needing drainage, more than 70 percent is occupied by moderately well to very poorly drained soils. Very poorly drained soils occupy 43 percent *(see Map 2.1-6 Hydric Soils)* of the Chesapeake Basin acreage that needs intensive drainage to lower the ground-water levels. Soils that require intensive artificial drainage are Berryland, Elkton, Fallingston, Hurlock, Long Marsh, Mullica, Othello, Pone, Pocomoke, Portsmouth-variant, Puckum, Trussum, and Zekiah. Moderately well-drained soils make up 13 percent of the remaining acreage needing less intensive drainage. Draining these soils may consist of only removing excess surface water. Soils that may require removing excess surface water are Hammonton, Ingleside, Keyport, Mattapex, and Woodstown.

2.1.3.3 Erosion

Most of the soils (95 percent) within the Chesapeake Basin *(see Map 2.1-7 Soil Erodibility)* are not highly erodible. Infiltration capacity and structural stability influence the inherent erodibility of a soil (K factor). The K factor varies from near 0.1 to about 0.6. Soils with low erodibility tend to be sandy and have K factors below 0.2. Soils with intermediate infiltration capacities and moderate soil stability have K factors of 0.2 to 0.3. Soils that are easily eroded have a K factor greater than 0.3. Less than 5 percent of the soil in the upper part of the Basin (New Castle County) tend to have low infiltration capacities and easily eroded surfaces. The Lenni, Keyport, Matapeake, and Matapex are highly erodible (K factor > 0.4) because of the silty to fine sandy loam texture of the soil surface. With the high inherent erodibility of the soils in this watershed coupled with gently sloping terrain associated with Lenni-Matapeake-Matapex soils, erosion can be a significant factor affecting surface-water quality. As stated previously, when new development projects (residential and commercial) are initiated, most of the soils are cut and graded, which makes them highly susceptible to erosion. Delaware's erosion control regulations require areas that will not be worked (site disturbance) for at least two weeks to be stabilized. With Delaware's rainfall pattern, a considerable amount of erosion can occur even with control measures.

The middle (Kent County) and lower (Sussex County) portion of the Basin have some of the least erodible soils found within the Chesapeake Basin *(see Map 2.1-7 Soil Erodibility)*. Soil infiltration capacities tend to be higher due to the sandy texture of the soils found in both the moderately well and poorly drained soils. Moderately erodible soils make up 16 percent of the soil in the Basin with a K factor greater than 0.3, these soils tend be located on dunal landscape positions and along stream terraces of the Nanticoke River and Broad Creek.

2.1.3.4 Characteristics of the Basin

Soils in the Chesapeake Basin are designated chiefly by two criteria: soil drainage class (excessively well to very poorly drained) and soil texture (sandy to clayey). *Map 2.1-8 Soil Types* shows 35 dominant soil types in the Chesapeake Basin. The soils map provides a general idea of the soils in the Basin, while providing the location of soils suitable or unsuitable with certain land-use activities (farming, septic suitability, wetlands, etc.).

Soils have been placed in natural drainage classes. As discussed previously, the classes defined from the correlation of mottles have been used to identify saturated zones with anoxic conditions and, thus, the seasonal water table. The classes are based on the depth to mottling or gray colors, which indicate the maximum of the stable height of the water table.

Excessively well-drained soils encompass broad areas of nearly level moderately sloping, dune-like ridges, some depressions, and steeper slopes bordering major streams (Nanticoke River) that are generally the sandiest in the Basin. This grouping of soils consists mainly of Fort Mott/Pepperbox (15.2 percent), Downer (5.7 percent) and Evesboro (0.6 percent). These soils have rapidly permeable subsoil of sand to sandy loam. Most of the soil areas have been cleared for crop production and residential home sites, but small areas remain in forest in steeper slopes along drainage ways.

In areas where high-value crops (processing vegetables) are grown, irrigation is commonly used as a supplemental water source. Most of the soils in this grouping are suited for residential (high septic suitability) and other non-farm uses, but their loose sandy nature are major limitations.

Well-drained soils occupy a large area that extends from the Chesapeake and Delaware Canal southward through New Castle County to the Kent County line. Small areas are scattered southward through Kent County and northern Sussex County on upland landscape positions. The soils in this grouping include Greenwich (3.2 percent), Hambrook (0.4 percent), Matapeake (3.3 percent), Rosedale (1.9 percent), Reybold-Hambrook (0.3 percent), Reybold-Sassafras (3.7 percent), and Sassafras (3.0 percent). These deep soils occur in upland areas that are nearly level to steep. The Matapeake, Reybold-Hambrook, and Reybold-Sassafras soils have a silt loam surface layer and silty clay loam subsoil. The Sassafras, Rosedale, Hambrook, and Greenwich soils have a sandy loam surface layer and a sandy loam and sandy clay loam subsoil.

Farming is the dominant land use on these soils; it is both intensive and extensive. The potential for farming the soils in this well-drained grouping is better than any other part of the Chesapeake Basin. Except for slope and the erosion hazard of the silty Matapeake and Reybold soils, these soils have few limitations for other land-use options (residential development, etc.). In New Castle County (upper Basin), the well drained soils are dominant soils used for residential development and have been experiencing the greatest loss of farmland in the southern part of the county.

This grouping of moderately well-drained soils consists of nearly level rolling uplands with some depressional landscape features separated by gently sloping ridges. These soils are scattered throughout the Chesapeake Basin, mostly in southern Kent County and northwestern Sussex County. This grouping of soils consists mainly of Hammonton (7.6 percent), Woodstown (4.3 percent), Ingleside (0.1 percent), Mattapex (0.1 percent), and Trussum (0.1 percent). These soils have a friable sandy loam to sandy clay loam subsoil. Many of these soil areas are associated with drainage ways and headwater areas. They are wet and slow to warm up in the spring, and in some places they are unsuitable for early crop planting. Ditches are needed in most nearly level areas for disposing of excess surface waters at planting time and during the growth periods of the crop. Except for slope and susceptibility to erosion in small areas, most of these soils have moderate limitations for most land uses. This grouping has a moderate suitability for septic systems because of a seasonal high water table during wet periods. The pressure-dosed septic disposal systems are the dominant system type used because this system maximizes the distance to a seasonal high water table. Residential development continues to occur in these areas even though septic systems fail at a 5 percent rate.

The poorly drained soil grouping occupies the greatest area (44 percent) of the Chesapeake Basin. These soils occur on mainly level or nearly level (less than 2 percent slope) upland flats and slightly depressional areas. Some of these soil areas have been cleared and are used for farming, but most of the areas remain as wet woodlands. The soils that occupy most of the area in this grouping are Fallingston (17.5 percent), Pone (9.0 percent), and Hurlock (10.9 percent), while Berryland (0.6 percent), Lenni (1.0 percent), Mullica (0.7 percent), Othello (0.9 percent), Portsmouth (2.3 percent), and Zekiah (0.1 percent) make up the rest of the soils in the grouping. In all the soils other than Othello and Lenni, the surface layer is loam to sandy loam and the subsoil is strongly mottled, friable to firm sandy clay loam that is underlain by sands. Lenni and Othello soils have a silty surface layer and a silty clay loam subsoil through which water moves very slowly. For all uses, the chief limitation of these soils is the impeded drainage caused by clay in the subsoil.

Intensive drainage practices are needed on all of these soils because of the shallowness of the ground water.

After drainage is improved, the soils are well suited for crop production. Even if the soils are drained, the soils in this grouping generally have severe limitations that restrict their use for residential development and septic suitability.

2.1.3.5 Quality of Mapping

Soil survey data included in this assessment include a compilation of soils mapping from the 1960s to the present. The soils mapping for most of New Castle County except for a small portion of the Basin above the Chesapeake and Delaware Canal recently has been updated and incorporates most of the mapping conventions now employed by Natural Resources Conservation Service (NRCS). This mapping program is divided into soil mapping, description of those mapping concepts, and prediction of the behavior of these mapping concepts for various uses. Soil behavior relies on the evaluated and named soil properties (USDA, 1993). The current mapping techniques use planimetrically correct photography, which allows the data to be easily automated for natural resources geographic information activities. A digitized soil survey facilitates better land-use decisions concerning growth management and increased or sustained conservation of natural resources. It also provides users with soils maps made to a national standard that are easily registered with other digital maps. Soil databases link soil interpretations to digitized soil maps.

The current NRCS soil mapping program requires that most of these soil map units be field-verified using transects to quantify soil composition of individual map units. Most of the soils that are found within these individual map units have had representative samples characterized by laboratory analysis. The older soil surveys primarily focused on agricultural uses of the soil, and the soil mapping units were neither as controlled nor as defined. In the older surveys, the agricultural lands were mapped more accurately than urban or forestlands. This difference in mapping detail can easily be determined by comparing soil maps in agricultural lands to soil maps for forest or urban lands. Soil interpretations for forests and urban purposes are poor and are, at times, inconsistent with the intended use. Most of the soil laboratory data included in the old survey reports were from tests conducted on soils from adjoining states and not on soils within Delaware. Consequently, the quality and merit of the data may not be appropriate for some areas of Delaware.

Most of the soils in the Chesapeake Basin of Sussex County have been re-mapped under new NRCS standards, but the maps have not been digitized. The old Evesboro loamy sand and loamy substratum map unit originally occupied 127,580 acres in Sussex County. The updated survey separates this unit into 14 separate soil map units. The cost of digitizing the updated soil maps in Sussex County would be approximately 13.5 cents per acre or $84,500. One county in the state has estimated saving over $200,000 annually on one soil interpretation. The saving was generated in water and sewer pipe maintenance versus pipe repair. The maintenance is done based on pipe-corrosivity-soil-interpretation ratings.

Unfortunately, the only data that we have for Kent County is the old published soil survey. At the present time, it is unlikely that the Kent County Soil Survey will be updated very soon. The actual digitized soil maps for the Kent County data were obtained from a private consultant on a fee basis. Even though these maps are outdated and are not up to current standards, without them, the Basin assessment report would lack necessary information about hydric soils, septic system suitability, and general soil information within the Kent County portion of the Basin. Therefore, this soil information was assembled from all available sources in order to tie various sections of the report together in a relevant discussion of soils suitability and land use.

The GIS soil maps in the assessment are of various ages and quality. Using the new soil legends in Sussex and New Castle counties as the basis for an updated legend, the older soil mapping units from Kent and Sussex counties and the small area above the Chesapeake and Delaware Canal in New Castle County were re-coded as to the new, updated legend. This was done by using NRCS field review reports which discuss map unit composition, soil variability, and the best professional judgment and personal conversation of soil scientists with NRCS members who conducted the updates. Notwithstanding, the quality of the GIS maps presented can be debated and questioned, but at the scale presented, the errors correlating the old map units to the new updated units would be minimal, especially when these maps contain data from the updated New Castle County survey.

2.1.3.6 Suitability for Development

The Chesapeake Basin has one of the highest percentages (95 percent) of land area served by septic systems *(see Map 2.1-9 Septic System Suitability)*. Thousands more lots exist that are currently undeveloped but are recorded and could be developed. Most of these undeveloped lots are stripped from farm-field frontages along county roadways and waterways. Overall, the Basin has moderate to severe limitations for on-site septic disposal due to the moderate (31 percent) to poorly drained soil conditions (48 percent) *(see Map 2.1-9 Septic System Suitability)*. Systems that are suitable for the area range from gravity disposal systems (21 percent) to engineered pressure disposal systems (31 percent).

Siting a septic system is a three-step process. The first step requires a site evaluation. The site evaluation consists of investigating, evaluating, and reporting the basic soil and site conditions that are used to design on-site systems. Each report describes specific site conditions or limitations including, but not limited to isolation and separation distances, slopes, existing wells, cut and fills, and unstable landforms. Each report contains the type of on-site disposal system that must be constructed and assigned permeability. This siting procedure ensures that septic systems are located on the following soil properties: permeability, texture, structure, consistence, redoximorphic features, slope, and depth to rock, all of which may limit or hinder septic system performance.

The second step requires a licensed system designer to design the septic system required by the approved site evaluation and to obtain the approval of the Department. After the permit is approved, the final step is initiated. A licensed system contractor is hired to construct the system under the supervision of the Department.

Development will only continue within the Chesapeake Basin. It is expected that the number of septic systems will steadily increase because residential development is occurring throughout the whole Basin. It will not be possible to provide central sewer to all unsewered communities and locations. The Department developed evaluation criteria at the request of the Wastewater Facilities Advisory Council to determine the relative need and feasibility for central disposal either through sewer to treatment facility or through an on-site community disposal system. The evaluation criteria considers water-quality issues, other environmental issues, soils suitability for septic systems, septic system siting limitations, distance to existing sewers, cost-effectiveness of providing central sewer, and community well-being. These criteria were used to identify the unsewered communities with the highest needs. The Hartly area was the only community evaluated within the Basin. Based on the evaluation criteria, Hartly had only a moderate need when compared to 59 other communities statewide included in the feasibility assessment.

2.1.3.7 Suitability for Farming

The Chesapeake Basin is particularly favorable for agricultural production because the soils respond well to management, the temperate climate provides a fairly long growing season, and rainfall is well distributed. Currently, agriculture makes up 50 percent of the land use, forestry makes up 39 percent, and other land uses/urban development makes up the other 11 percent. General soil management practices are applicable to all or nearly all of the soils used for crop production in the Basin. These practices include draining the soils that are too wet part of the year or most of the year, applying the proper soil amendments (manure, commercial fertilizer, and lime), choosing suitable crop rotations, managing crop residue (cover crops), and irrigation.

2.1.3.8 Interrelationships

Current septic regulations deny the placement of standard (gravity and elevated sand mounds) and/or alternatively designed low-pressure pipe septic systems on soils where the seasonal high water table is within 20 inches of the soil surface. As an option for those property owners, the septic regulations allow for alternatively designed septic systems (Section 6.12010) on a case-by-case basis to be placed on some of these parcels. These alternative septic systems utilize technologies that pre-treat the effluent to a specific level, usually to levels below 10 PPM of nitrate-nitrogen. Total and fecal coliform levels are also significantly reduced within these pretreatment units. The soil must still dispose of the effluent generated. The cost of these pretreatment units has dropped significantly (from $12,000 – $15,000, to $10,000 – $12,000) so that more people can afford them. Consequently, a number of these units are being permitted (17 in 1994).

A problem arises on many of the parcels where alternative technologies would be utilized. These parcels are inherently wet and many are freshwater wetlands. In the past, several engineers have stated that when the water table is within 10 inches of the soil surface, it is difficult to get an elevated sand mound to work hydraulically. Thus, on parcels where the seasonal high water table is perceived to be within 10 inches of the soil surface, the Soil Assessment Branch has required that observation wells be installed to verify the depth to the seasonal high water table. If the water table is within 10 inches of the soil surface during the monitoring period, the parcel is considered unacceptable as a site for an alternative septic system. However, ground-water mounding calculations done by the Department system can be designed to hydraulically eliminate the effluent generated by these alternative systems when the water table is higher than 10 inches without significant mounding.

Most of these sites are located in wooded areas with hydrophytic vegetation indicative of wetlands. Most soils are hydric, and in many cases the wetland hydrology has been observed. These sites are jurisdictional wetlands as defined by the Clean Water Act and as delineated with the *1987 Army Corps of Engineers' Wetlands Delineation Manual*. The Department allows these systems to be sited on these areas in accordance with Section 6.12010. In the past, on parcels considered to be freshwater wetlands, the property owner(s) was informed of the possibility that his parcel may contain jurisdictional wetlands and depending on the location of the wetland (i.e., isolated, adjacent or headwater), a permit from the appropriate federal agency may be needed. In most cases, the property owner does not notify the appropriate federal agency. Consequently, freshwater wetlands are slowly being lost to residential development one acre at a time.

Should the Department allow the development of the state's wetlands regardless of the function of those wetlands? We have been allowing development because technology has overcome the limitations of the site hydrology as it relates to septic systems. Should we continue to allow this to occur simply because the technology exists? Conversely, by not allowing any development on lots deemed to contain freshwater wetlands, are we not "backdooring" a freshwater wetlands program through the septic system site evaluation program?

2.1.4 SEDIMENTS

The processes of erosion and deposition, whether resulting from geologic activities or from acceleration by human activities, occur when particles of soil, surficial material, and rock become detached as a result of the hydrologic (*fluvial*) processes of sheet erosion, riling, and gully erosion. Mass wasting and the action of the wind (*eolian processes*) also contributes to sediment erosion and deposition. The characterization of sediment is, of course, closely linked to the geology, climate, and soils of a particular watershed. Relative differences in the ratio of silt, sand, and clay in the individual soil series determine their cohesiveness and, thus, their ability to resist erosive forces. Soils composed mostly of silt and sand will erode more easily, with heavier sands tending to settle out in the stream system and lighter sands and silts being deposited in ponds, lakes, and tidal outfalls. The eroded clays often stay in suspension, causing turbidity problems in the Basin's water bodies.

2.1.4.1 Erosion

Soil erosion from upland areas is an ongoing natural process, and a certain amount of sediment bed-load transport is necessary to maintain stream stability. However, through man's influence on the landscape, this process can be accelerated by orders of magnitude. As a result, the natural balance is upset, often leading to serious environmental degradation. According to information contained in EPA's *National Water Quality Inventory Report* (1992), siltation is the most prevalent cause of impairment in assessed rivers and streams and is one of the five leading causes of lake impairment.

In the watersheds of the Chesapeake Basin, as in most watersheds, the more erosion-prone steeper slopes tend to be adjacent to the streams and their tributaries. This also occurs along the Nanticoke River and the Broad Creek, especially with the old sand dunes found along the Nanticoke River. In general, as the distance to a stream channel increases, the soil slope tends to flatten.

Where appropriate, soils were also mapped as being "moderately eroded" and "severely eroded" in their natural state during the course of the soil survey. Not surprisingly, the "severely eroded" soils were generally located on the steeper slopes adjacent to the tributaries. This can be seen graphically in the *Map 2.1-7 Soil Erodibility*. This map indicates that many of the soils within the Basin were mapped as being "moderately eroded." The implication is, of course, that the eroded material ended up as sediment in the receiving waters.

Since the Dust Bowl, soil conservation has been a priority in the agricultural community. Though the intent has been to maintain productive land rather than to improve water quality, federal and state erosion control programs (voluntary) through the local conservation districts have been in place for many years. The federal Food Securities Act required all highly erodible lands to have a soil conservation plan developed and implemented by the end of 1994 if those farmers wished to maintain eligibility for future federal incentive programs. This only applies to lands classified as highly erodible. In Delaware, most lands classified as highly erodible are in New Castle County because of the slope and the silty soil surface in this area. Soil conservation management is otherwise voluntary. Based on NRCS data, there are over 7,000 acres of highly erodible land (HEL) in the Chesapeake Basin based on soil mapping units and an erosion index greater than 8. These highly erodible lands correspond to those shown on *Map 2.1-7 Soil Erodibility* with a K factor of 0.4 or greater. Based on the total acreage in the Basin (453,760 acres): 43.8 percent of the acreage has a soil K factor of 00 – 0.19 (lowest potential for erodibility; 35.1 percent is rated as 0.2 – 0.29; 15.8 percent is rated at 0.3 – 0.39; and only 5.3 percent of the acreage in the Basin is rated as 0.4 – 0.49 (highest potential for erodibility).

2.1.4.2 Sediment and Nutrient Transport

While conservation tillage is very effective in reducing sediment loading to surface waters, it may not be as effective for improving overall water quality; it may actually increase loading of other pollutants. No-till requires increased use of pesticides and fertilizers. Those chemicals are not mixed into the soil. While the soil may stay in place, storm-water runoff may transport chemicals that are water soluble or attached to plant debris. Nitrogen and pesticide leaching also may increase. Using conservation tillage to control sediments may increase dissolved nutrient and pesticide transport. The role of tax ditches in delivering sediments warrants further exploration.

Maximizing the use of farm acreage is an incentive for farmers to forgo buffer strips along ditches and streams. Sediment loads from fields without buffer strips or grassed waterways can be dramatic.

As a physical pollutant, excessive accumulation of sedimentary material can fill streams and lakes to the point where they are no longer navigable. The acceleration of the erosion process started with the colonization of North America, as the native forest cover was removed and converted to agricultural areas or farmland. According to the DNREC Drainage Section, tax ditch systems typically undergo the removal of accumulated sediment in the channel bottom approximately every 15– 20 years. The importance of agricultural drainage to nutrient transport from cropland to surface waters has not been investigated fully in Delaware or in most other states. This is partially because soil erosion and surface runoff have historically been viewed as the major mechanisms for nutrient losses to surface waters. The rather flat topography of southern Delaware suggests that erosion and runoff will be less of a factor in nutrient transport than in other Mid-Atlantic states. However, many fields in southern Delaware are farmed only because of the extensive ditch drainage system that exists in this area. The water table in these fields can be at or near the soil surface during the spring or following heavy rainfall events in summer. These ditches are extensions of the natural drainage system in the watershed and serve to drain the fields by capturing surface runoff and by lowering the water table. Little is known about the possible transport of phosphorus and nitrogen from agricultural fields to downstream surface waters via these drainage systems (Sims et al., 1996).

Moreover, since 1987, Water Control Structures (WCS) have often been installed in these ditches to artificially slow drainage, raising the water table beneath fields during the growing season in an effort to “sub-irrigate” crops. Research in other states has shown that WCS enhance water quality by reducing water flow and thus delivery of nitrogen and phosphorus to surface waters. Anoxic conditions created by these WCS may promote denitrification in soils, thus removing nitrate from shallow ground waters. However, previous studies in Delaware and in other regions have shown that phosphorus released from soils and sediments can be greater under anoxic conditions, resulting in increased concentrations of soluble phosphorus in drainage waters. Hence, a management practice installed to mitigate one environmental problem (nitrate contamination) may be creating or intensifying another (solubilization and transport of phosphorus). Analysis of agricultural drainage ditch waters conducted as part of a recent nonpoint source study in Delaware provided some support for this possibility. Total phosphorus concentrations in water samples from 17 ditches consistently exceeded values normally associated with eutrophication of fresh waters. Total phosphorus ranged from 0.01 to 0.03 milligrams per liter. In the spring, total phosphorus ranged from 0.21 to 6.14 milligrams per liter, from 0.04 to 1.14 milligrams per liter the summer, and from 0.04 to 0.85 milligrams per liter in the winter (Sims et al., 1996).

Given all the above factors, it seems apparent that more detailed information on the role of agricultural drainage, controlled or otherwise, is needed. Data on nonpoint source pollution of ground and surface waters by nitrogen and phosphorus are badly needed to aid in the development of management practices that improve ground and surface water quality in Delaware (Sims et al., 1996).

2.1.4.3 Dredging

Sedimentation has been an ongoing process within the Basin as evidenced by the fact that many colonial ship landings such as the town of Bethel are no longer accessible by larger watercraft. A more contemporary impact is the loss of water-carrying capacity in the streams of the Basin and their associated bridges, culverts, etc. This can lead to flooding problems and disrupt the transportation infrastructure. Keeping these streams and structures sediment-free requires constant maintenance in many instances, and this, of course, translates into public expenditures. Sediments that aren’t deposited in the streams themselves will tend to settle out in the ponds and lakes fed by those streams. For recreational ponds and lakes, surface area is often lost as the upper reaches silt in. In some cases, it may be necessary to remove accumulated sediments by dredging in order to restore recreational capabilities.

Historically, dredging operations within the Nanticoke River Basin have been conducted by the U.S. Army Corps of Engineers, Baltimore District. Most operations have been confined to the main stem of the Nanticoke River between its mouth at Tangier Sound/Chesapeake Bay, Maryland, and the bascule bridge (Route 13-A) at Seaford and Blades, Delaware. Also, two of the river’s tributaries, Marshyhope Creek (a.k.a. Northwest Fork, Maryland) and Broad Creek have been dredged. With the exception of Broad Creek, the Corps has continued to maintain navigable depths in these waterways because of the vital role they play in economic development and growth throughout the entire Basin (Williams et al., 1997).

During the 1980s, two maintenance-dredging projects were implemented by the Corps to alleviate shoaling conditions hindering commercial shipping activities in the Nanticoke River. In 1983, a project was undertaken to remove approximately 30,000 cubic yards of material from the Hawks Nest Shoal area of the main channel and from the section between Turtle Creek and the Seaford Harbor. A similar project was initiated in 1989–90 involving the dredging of over 50,000 cubic yards of material between Turtle Creek and the Harbor (Williams et al., 1997).

For both of the maintenance dredging projects identified above, Sussex County was responsible for providing the necessary confined disposal facilities (CDFs) to retain the material being dredged. In 1983, the county secured a 6-acre tract of upland near the Delaware-Maryland state line (area known as the Gum property), and in 1989, they secured a 25-acre tract of upland on property owned by the DuPont Company. Records of areas used for disposal before 1980 are not readily available, but there is speculation that Prickly Pear Island was created as a result of dredging activities in the downstream portion of the Nanticoke (Williams et al., 1997). See *Map 2.3-2 Known and Potential Chemical Sources* for the location of confined disposal facilities (CDFs) for dredge spoils.

2.1.4.4 Contaminated Source

Sediment has been identified as one of the major non-point source (NPS) pollutants due to its diffuse nature. Even though urban construction is the most intense source of erosion, agricultural activity has been identified as the leading source of sediment to receiving waters nationwide. This is probably also true for the State of Delaware as a whole. The Chesapeake Basin encompasses most of the agricultural areas in the state. Based on 1992 land-use data, all of the sub-watersheds of the middle and lower Chesapeake Basin exceeded (50 percent) in agricultural land uses.

Besides human impacts, sediment has serious physical impacts on aquatic ecosystems as well. It can cover the stream bottom, smothering fish eggs and bottom-dwelling organisms, which rely on the “nooks and crannies” provided by the natural bottom substrate. Sediment particles can abrade and accumulate on the gills of fish and other aquatic creatures, causing stress and death in some cases. Similar impacts can be observed in lakes and their associate ecosystems as well. It is generally accepted that deposition of sedimentary material and its attached nutrients is the major mechanism leading to the accelerated eutrophication of ponds and lakes. Submerged aquatic vegetation (SAV) is particularly susceptible to problems associated with excessive sedimentation. The act of removing accumulated sediments can itself have negative impacts, as wetlands and other aquatic ecosystems are disturbed in the process.

Some of the more serious environmental impacts associated with sediment come from chemicals that may hold onto the sediments. Individual sediment particles have a large surface area, and many molecules easily adsorb, or attach, to them. As a result, sediments can act as chemical sinks by adsorbing metals, nutrients, hydrocarbons, pesticides, and other potentially toxic materials. Indicator bacteria are also associated with runoff-borne soil and organic matter. Thus, areas of high sediment deposition sometimes have high concentrations of nutrients, persistent (i.e., long-lived) chemicals, and contaminants, which can be later released. Sediments that contain concentrations of constituents greater than those found in nature are classified as “enriched,” while those with concentrations of constituents which are not normally found in natural sediments are classified as “contaminated.”

According to the *1994 Delaware Watershed Assessment Report* (also known as the *305(b) Report*), bacteria is the most widespread contaminant in Delaware’s surface waters, but nutrients and toxics pose the most serious threats to aquatic life and human health. Many bottom-dwelling benthic organisms are filter feeders. As contaminated sediments pass through their bodies, some of the contaminants themselves can be absorbed into their body tissues. Since these organisms are often on the bottom tier of the “food web,” the contaminants can be passed on through the entire web, eventually reaching vertebrates such as fish. If higher vertebrates, such as birds and mammals (including humans), consume these fish in large enough quantities, there can be serious health consequences.

In December 1994, the Department conducted a study of sediment contamination in the Delaware portion of the Nanticoke River. The study featured a random stratified survey design and involved collection of five sediment samples from a 3.4-mile tidal reach of the Nanticoke above the City of Seaford and five sediment samples from a 3.2-mile tidal reach below Seaford. The study showed that the level of chemical contamination from sediments below Seaford is significantly greater than the level of contamination above Seaford. Metals proved to be the principal contaminants of concern based upon their detection at levels that may cause toxicity to benthic organisms. Bioaccumulative contaminants such as PCBs, dioxins/furans, and chlorinated pesticides were not detected at levels expected to pose a significant risk to aquatic life or human health (Greene, 1997).

Contaminants in the sediments below Seaford appear to be originating from land-based sources in Seaford as well as from sources above Seaford. Algae (fueled from excess nutrients) and other solids in the water column may serve to scavenge the contaminants from the water column and deliver these contaminants to the bottom through settling. More research is needed to characterize the complex relationship between pollutant sources, fate and transport, and ecological effects in the Nanticoke River watershed (Green, 1997).

The sediments above Seaford were classified as sand, ranging in diameter from approximately 0.1 mm up to 1 mm. Below Seaford, the sediments were composed of much finer (silt and clay) particles, generally ranging from 0.002 mm up to 0.075 mm. Specifically, smaller particles are more likely to be transported farther downstream than are larger particles. Smaller particles generally have a greater capacity to retain trace metals than do larger particles. In the case of the Nanticoke, we see that larger particles (with low pollutant-binding capacity) have settled out above Seaford, while finer particles (with greater pollutant-binding capacity) have settled out below Seaford (Greene, 1997). The finer particles absorb most of the contaminants and can carry them far from the original source.

The report, entitled *Chemical Contaminants in Sediments of the Nanticoke River,* states that riverbed sediments represent an important sink for many pollutants that enter the surface-water environment (Greene, 1997). Once incorporated into bottom sediments, these pollutants can pose a direct toxic threat to benthic-dwelling organisms and may also represent an indirect threat to human health through food chain transfer/bioaccumulation processes. In addition, re-suspension and diffusion of "in-place" contaminants can deliver significant quantities of toxics back to the water column, thereby representing an ongoing risk to the ecosystem and human health. The report also states that even sediment contaminants that are effectively sequestered due to deep burial or strong site-specific binding may become bioavailable when significantly disturbed by major storms or activities such as dredging and other channel modifications (Greene, 1997).

The Chesapeake Whole Basin Team should review and map out available pollutant source data for the area of the watershed above the Bridgeville gauge. The relative importance of these sources in comparison to sources in the Seaford area should be considered within an overall mass balance context.

Based on statistical testing and nonbiased sampling design, the authors of the report safely conclude that the sediments below Seaford are significantly more contaminated than the sediments above Seaford. Simply because contaminants were detected at elevated concentrations in bed sediments below Seaford does not mean that all of the contamination originated exclusively in the Seaford area. It is quite feasible that part of the sediment contamination below Seaford is due to complex fate and transport phenomena that act over the entire watershed, including the area above Seaford. It may be that we do not see elevated levels of contaminants in the sediments above Seaford simply because those contaminants are transported downstream in a dissolved state or as sorbed chemicals on colloidal particles. These contaminants may not settle out of the water column until they are scavenged by particles that are in the water near Seaford. These particles could include, for instance, solids released from the City of Seaford wastewater treatment plant, phytoplankton that have grown in response to excessive nutrient levels, or simply street dust that has entered the river as part of storm-water runoff. Contaminants delivered from the drainage area above Seaford may not settle out until the salinity is high enough to induce classical coagulation/flocculation (Greene, 1997). Salinity levels in the Nanticoke River fluctuate significantly from season to season and from year to year. During the dry months of September and October, the salinity levels upstream increase substantially.

Research recently published as part of the Chesapeake Bay Fall Line Toxics Monitoring Program does in fact suggest that the area above Seaford contributes to downstream transport of contaminants in the Nanticoke watershed (EPACBP, 1996). This work involved the collection of water samples from the Susquehanna River and eight major tributaries of the Chesapeake Bay, including the Nanticoke River. The Nanticoke was sampled at the USGS gauging station in Bridgeville, Delaware once in the spring of 1994 and again in the fall of 1994. The samples were analyzed for dissolved and particulate fractions of trace elements and organic constituents. Surprisingly, the Nanticoke had the highest Basin yield (i.e., mass per time per drainage area) for cadmium and zinc in both the spring and fall sampling efforts. In addition, during the spring survey, the Nanticoke also registered the highest Basin yields for nickel and pesticides such as simazine, gamma-BHC (benzene hexachloride), alpha-BHC, gamma-Chlordane, alpha-Chlordane, and p,p'DDE (dichlorodiphenyldichloro-eythylene — a breakdown product of DDT (Greene, 1997).

The USGS and the State of Maryland are interested in conducting more extensive follow-up studies at the USGS Bridgeville gauge beginning in fiscal year 1998. It is suggested that the Whole Basin Management initiative should follow this work closely and review its files to determine if there are any obvious contaminant sources above the Bridgeville USGS gauge that might help to explain the results discussed above, including, for instance, federal or state Superfund sites.

The sediment study conducted in the Nanticoke River concluded through several assessment techniques that metals below Seaford represent a potential risk to benthic organisms. In particular, arsenic, cadmium, mercury, nickel, and zinc were identified as potential contaminants of concern in these sediments. Furthermore, and surprisingly, silver emerged as a significant potential ecological stressor both above and below Seaford. Equally surprising from this study were the moderately high levels of polyaromatic hydrocarbons (PAHs) detected below Seaford and the extremely low frequency at which organochlorine pesticides were detected overall. As documented in the report by Greene (1997), it was concluded that despite the moderate levels of PAHs, no adverse ecological or human health effects are expected from these compounds.

It was also shown in this study that the highly bioaccumulative compounds PCBs and dioxins/furans are not at levels that are likely to accumulate in the food chain to the point where they pose a significant risk to people who consume fish from the Nanticoke. This is an extremely positive finding in light of the popularity of fishing in the Nanticoke. The other positive finding in this study was the significant decline in lead levels from the concentrations detected back in the 1980s. Although dioxins and furans below Seaford were not at levels expected to cause a bioaccumulation problem, they were, nevertheless, slightly elevated above background levels for clean U.S. waters (Greene, 1997).

Finally, this study provides strong circumstantial evidence that toxic substances have been and continue to be released from land-based sources in the Seaford area. However, the results of this study cannot be used to conclude that all of the sediment contamination below Seaford is due solely to sources in and around Seaford. The quality of surface waters and their underlying sediments are strongly influenced by the activities that occur on the lands that drain to the water body. If chemicals are stored used, or disposed of within the watershed, there is a greater likelihood that those chemicals will find their way to the lowest spot on the landscape, which is the receiving stream. In general, urban land uses are associated with a greater number and variety of sources of toxics than are non-urban areas (Greene, 1997).

2.1.4.5 Interrelationships

As soil particles erode from the land surface and stream channels during rainfall events, they become temporarily suspended in the water column. From a water-supply perspective, this causes turbidity problems, increasing the cost of treatment. Due to their relatively large surface areas, these particles also have a high affinity for other chemically active constituents, such as metals and nutrients. If potential contaminant sources exist in the watershed, eroded soil particles can act as vehicles for transporting toxics to receiving waters. In high enough concentrations, these adsorbed constituents may cause surface water-quality standards to be exceeded.

Although limited in terms of the number of samples, the results of the Chesapeake Bay Fall Line Toxics Monitoring Program for the Bridgeville USGS gauge location suggest there are sources of eroded sediments that both carry pollutants and are pollutants. Pathogens, nutrients, and toxic substances are transported on sediments. Sediment erosion is both an urban and an agricultural problem. Where land is disturbed, erosion occurs. Although urban construction is a temporary land use, active sites are the most intense source of erosion. Urban construction causes 10 times more erosion than the next competing source, farming.

Suspended soil particles also act as a source of stress on aquatic life, especially fish. Once the soil particles settle out of suspension and become sediment deposits, impacts to aquatic life are compounded. Bottom-dwelling organisms can pass contaminants in the sediments through the food web to higher organisms. In some cases this can preclude the consumption of fish from such waters. Thus a direct impact to living resources can lead to an indirect impact on recreational activities. Sediment can also have adverse impacts on habitat. The bottom substrate on which many organisms rely to live on and lay eggs on can be completely covered with sediment. Wetlands can lose their habitat value and function through the same process.

Perhaps the single most important sediment cross-media link is that of land use. In a watershed with a completely wooded land cover, surface erosion is minimal and sediment transport in the stream system is in equilibrium. Once that cover is removed for agricultural production or for construction purposes, the land is exposed to accelerated erosion. Cumulative increases in impervious cover such as roof tops, parking lots, and driveways change hydrologic conditions such that streams become unstable and contribute to the sediment loading. Anyone attempting to mitigate the many negative impacts associated with sediment must recognize this link with land use.

Since the passage of the Delaware Sediment and Stormwater Law in 1991, all new construction activities that disturb over 5,000 square feet are required to have an approved sediment and storm-water plan unless specifically exempted. The program is delegated to various local agencies with oversight by the Department's Sediment and Storm-water Program and uses a "best available technology" approach to control nonpoint source (NPS) pollution associated with construction activities.

As part of the overall conservation planning process in the state, the local conservation districts, and the NRCS work with agricultural landowners in the Basin to develop and implement plans that are intended to reduce NPS pollution associated with agricultural activities.

Several federal cost-share programs promote conservation tillage. No-till has been very effective in Delaware. These practices may not be the best solution everywhere, however. No-till fields with heavy soils will not dry out fast enough in the spring. Where it is successful, farmers may not want to do it every year; fields are sometimes plowed every few years to break pest and weed cycles.

2.1.5 DATA GAPS AND RECOMMENDATIONS

1. Complete recharge-potential mapping for the rest of the state. This mapping shows areas where water and/or contaminants can rapidly enter the ground water.
2. Develop depth to ground-water maps for the entire state that highlight areas with an extremely shallow water table.
3. Support additional funding for updating statewide soil survey maps.

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