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4.0 Characterization of Regional and Local Geology, Hydrogeology, and Hydrology

4.1 Physiography

The study area is situated within the Appalachian Plateaus Physiographic Province, a region that extends from Alabama into New York. The Appalachian Plateaus Physiographic Province in Pennsylvania is currently divided into seven sections based on characteristic geomorphic features unique to each. One of these divisions includes the Pittsburgh Low Plateau Section – the location of the study area. The current land surface within the Pittsburgh Low Plateau Section resulted from the stream erosion of a prehistoric plain. The highest elevations within Washington County (1,200 to 1,500 feet above sea level) mark the remnants of this plain. Due to differences in prevailing elevations, varying depths of dissection, and amount of structural involvement, the Pittsburgh Low Plateau Section is subdivided into two areas – the Prototypical and Intermontane areas. The study area is located in the Prototypical Area of the Pittsburgh Low Plateau Section.

The Prototypical Area is the largest unit of the Appalachian Plateaus Physiographic Province in Pennsylvania, occupying approximately 6,500 square miles. The Prototypical Area is characterized by broad rolling interfluves separated by relatively narrow, steep-walled moderately incised valleys. The crests of the interfluves are at essentially equal elevations forming a true plateau. The base level for the Prototypical Area is developed in mostly homogeneous bedrock consisting of shale and locally dominant sandstone and limestone. The majority of the bedrock units are gently folded, with amplitudes decreasing northwestward and dips rarely exceeding 5 degrees. Low-amplitude anticlines and synclines are present, often reflected by subdued linear topographic highs. Many stream segments with the Prototypical Area are straight implying effects from jointing. Dendritic patterns are prevalent in headwater streams of upland surfaces. Terraces and benches are common along sides of deeper valleys.

4.2 Regional Geology

Pennsylvanian and Permian sedimentary rocks comprise the uppermost stratigraphic units of Washington County and include bedrock of the middle Conemaugh, Monongahela, and upper Dunkard groups. The rocks of the Pennsylvanian and Permian systems in Pennsylvania are predominantly clastic and contain subordinate amounts of coal and limestone. The stratigraphic relationship between these groups is presented in Sheet 5.

4.2.1 Pennsylvanian System

4.2.1.1 Conemaugh Group

The Conemaugh Group is stratigraphically defined as the rock units positioned above the Freeport Coal and below the Pittsburgh Coal. In Washington County, the Conemaugh Group constitutes approximately 520 feet of the stratigraphic column and gradually thickens to the east, approaching 890 feet in adjoining Somerset County. The Conemaugh Group is subdivided into a lower formation, the Glenshaw, and an upper formation, the Casselman. The division of the two formations is based on the lack (Casselman) or abundance (Glenshaw) of marine units. The regionally persistent Ames Limestone is the generally accepted boundary between the two formations. The lithologic character of the Conemaugh Group is clastic sequence dominated by claystone, siltstone, sandstone, and shale. Bedrock of the Conemaugh Group is not exposed within the study area with exposures limited to the northwestern corner of the county.

4.2.1.2 Monongahela Group

The Monongahela Group overlies the Conemaugh Group and stratigraphically extends from the base of the Pittsburgh Coal to the base of the Waynesburg Coal. The Monongahela Group is a sedimentary sequence and, unlike the rocks of the underlying Conemaugh Group, composed of nonmarine rocks. In Washington County, the Monongahela Group reaches a thickness of 270 feet and follows the regional trend of thickening to the east. Rock types include limestone, dolomitic limestone, calcareous mudstone, shale, and thin-bedded siltstone. The group is separated into the Pittsburgh and Uniontown formations using the base of the Uniontown Coal as the division.

- *Pittsburgh Formation:* The Pittsburgh Formation is composed almost entirely of flat-lying layered limestone and calcareous mudstone. The Pittsburgh Formation is divided into five members: the lower member; Redstone; Fishpot; Sewickley; and the upper member. The lower member includes the thick and persistent Pittsburgh Coal bed overlaid by only clastic rock within the Pittsburgh Formation, the Pittsburgh Sandstone. The Pittsburgh Sandstone is a fluvial unit deposited within the confines of a paleo-river system that extended northwest through the middle of Washington County. The sandstone unit often replaces the Pittsburgh Coal bed in places within the county. The Redstone Member is stratigraphically above the lower member and is characterized by siltstone and mudstone and includes a persistent limestone unit. The division between the lower member and the Redstone Member is typically marked by the Redstone Coal; however, the coal is laterally discontinuous making the contact indistinct, particularly within the study area. The Fishpot Member, the next highest stratigraphic unit within the Pittsburgh Formation, is also the thinnest unit. The Fishpot includes mainly siltstone and mudstone with several thin sandstone bodies. The Sewickley Member represents the thickest limestone sequences, the Benwood Limestone, within the study area. The Benwood Limestone transitions from a thick massively bedded unit in the northern part of the county to a clayey limestone and calcareous mudstone in the south half. The upper member of the Pittsburgh Formation contains four limestone units designated in ascending order as "A", "B", "C", and "D." These four limestone units are not to be confused with the four limestone units given the same designation within the Greene Formation (see description below).

- *Uniontown Formation:* The Uniontown Formation, unlike the underlying Pittsburgh Formation, consists mostly of thin-bedded sandstone with interspersed channel sandstone. The unit also contains finer-grained clastic units (shale and siltstone) that grade into bedded and cherty limestone. The Pittsburgh Formation also contains several coal seams, including the laterally extensive Pittsburgh Coal. The Pittsburgh Coal bed is the basal member of the Pittsburgh Formation. The other coals seams may be locally thick, but in general lack the aerial persistence of the Pittsburgh Coal.

Bedrock of the Monongahela Group are not exposed within the study area. Exposures of the group are limited to the northern and eastern portions of the county.

4.2.2 Permian System – Dunkard Group

The boundary between the Pennsylvanian and Permian systems is indistinct but is generally defined by the sequence of rocks extending from the base of the Waynesburg Coal bed to the present topographic surface. This sequence is referred to as the Dunkard Group in southwestern Pennsylvania. The Dunkard Group is divided into the Waynesburg, Washington, and Greene Formations. The lower section of the Dunkard Group resembles that of the Monongahela Group in that it contains laterally persistent coal beds. The coal beds become increasingly thinner higher in the stratigraphic column.

4.2.2.1 Waynesburg Formation

Depending on the amount of erosion by Robinson Fork, rocks of the Waynesburg Formation comprise the lowermost stratigraphic unit that outcrops in the study area. The exposures of the Waynesburg Formation are limited to the extreme southern reaches of Robinson Fork, along the base of the valley. The Waynesburg Formation, the lowest stratigraphic unit in the Dunkard Group, represents a transition between the underlying Pennsylvanian System and the overlying Permian System. The uncertainty in fossil evidence prohibits the precise placement of the boundary between the two systems, hence the referral to the Waynesburg Formation as a transition sequence. Earlier descriptions of the Dunkard Group included the Waynesburg Formation as part of the overlying Washington Formation.

The Waynesburg Formation extends from the base of the Waynesburg Coal to the base of the Washington Coal with the predominant lithologies being sandstone and siltstone. The formation ranges in thickness from 80 to 180 feet within the county, increasing from the northwest to south at a rate of approximately

3.5 feet per mile. The maximum thickness of the formation, 210 feet, occurs further to the south in Greene County. The formation is divided into three members – lower, middle, and upper.

- *Lower Member:* The basal Waynesburg Coal and massive sandstone distinguish the lower member of the formation. The Waynesburg Coal is present throughout the county and can attain thickness approaching 100 inches. The coal generally occurs in two benches separated by either a clay or sandstone parting. The parting as well as the overall coal bed thins to the west forming a single bench. The Waynesburg Coal is mineable throughout most of the eastern portion of the county. The Waynesburg Sandstone overlies the Waynesburg Coal and throughout the eastern part of the county and is described as a massive sheet-like unit attaining a thickness of 65 feet. Progressing westward, the sandstone locally grades (laterally and vertically) into siltstone and shale. Two limestone units occur at the top of the lower member.

- *Middle Member:* The middle member of the Waynesburg Formation includes two parts – a lower part that includes the Waynesburg "A" coal and an upper part that includes the Waynesburg "B" coal. Both of these coal seams are discontinuous and poorly developed and can be represented carbonaceous shale and mudstone. The "A" coal bed is the more persistent of the two and can attain a thickness of 24 inches. The "B" coal bed thickness is almost always less than 12 inches.

- *Upper Member:* Laminated sandstone and siltstone dominate the upper member, although thinly bedded sandstone is present at some localities. The Little Washington Coal marks the base of the upper member and, where present, is represented by a thin poorly developed coal or carbonaceous shale. In the vicinity of the study area, the upper member has a thickness of approximately 25 feet.

4.2.2.2 Washington Formation

The Washington Formation is the first lithologic unit within the county that can be defined as Permian. Within the study area, rocks of the Washington Formation outcrop along the base of the valley occupied by Robinson Fork. The Washington Formation includes rocks that extend from the base of the Washington Coal to the base of the Greene Formation and ranges in thickness from 140 to 235 feet. The formation is divided based on the occurrence of limestone units into an upper, middle, and lower member.

- *Lower Limestone Member:* The lower limestone member consists of limestone, claystone, siltstone, shale, sandstone, and coal. The Washington Coal marks the basal portion of the lower member and is typically 2- to 4-feet thick but locally has attained a thickness of 12 feet. The coal, where present, is impure and split by carbonaceous shale partings. In the absence of the coal, the stratigraphic column is occupied by carbonaceous shale. Locally, interbedded sandstone and siltstone represent the entire member. A limestone or mudstone overlies the Washington Coal.

- *Middle Member:* The basal portion of the middle member includes a basal coal unit (unnamed) followed by a sandstone and a limestone. The top of the limestone unit is typically represented by a breccia-conglomerate that weathers to distinctive yellowish-orange. The central portion of the middle member consists of clastic units ranging from sandstone to mudstone. A thin coal or carbonaceous shale occurs locally and is often referred to as the Washington "A." The upper part of the middle member includes a thick laminated shaly mudstone and the Jollytown Coal unit. The coal unit is persistent although ranges from a poorly developed coal to a fissile black mudstone.

- *Upper Limestone Member:* This member is widely exposed in the county and is quarried in locations. A distinctive feature of the upper limestone member is the high calcium carbonate content. The member can be split by a clastic sequence of mudstone, siltstone, and, at locations, sandstone.

4.2.2.3 Greene Formation

The Greene Formation comprises the uppermost stratigraphic bedrock unit within the study area. Except for the valley bottoms where the Washington Formation crops out, the Greene Formation overlies most of the southwestern part of the county. The Greene Formation includes all Permian bedrock units above the upper limestone member of the Washington Formation (see above). The Greene Formation, which attains thickness of 500 feet, is represented by a cyclic sequence. In ascending order, the cyclic sequence includes coal, carbonaceous shale, sandstone, siltstone, mudstone, and clay. The limestone and coal beds are thin, irregular, and impure.

The Greene Formation informally is divided into six sequences – a coal measure and four limestone units (denoted as "A", "B", "C", and "D"):

- *Sequence 1:* Sequence 1 extends from the base of the formation to the base of the Tenmile coal bed. A slabby carbonaceous shale or mudstone occurs at the base of the sequence and is overlaid by beds of mudstone, siltstone, and sandstone.

- *Sequence 2:* Sequence 2 extends from the base of the Tenmile coal bed to the base of limestone "A" and has an average thickness of 45 feet. A local coal bed (unnamed) occurs in the middle of the sequence.

- *Sequence 3:* Sequence 3 extends from the base of limestone "A" to the base of limestone "B" and ranges in thickness from 25 to 40 feet. The distinctive limestone unit occurs at the base of the sequence and is followed by thin-bedded and locally cross-bedded sandstone. Lenses of limestone and carbonaceous shale occur within the sandstone.

- *Sequence 4:* Sequence 4 extends from the base of limestone "B" to the base of limestone "C" and ranges in thickness from 35 to 60 feet. The lithology of Sequence 4 is mostly interbedded thin sandstone, siltstone, and mudstone. Lenses of limestone, coal, and carbonaceous shale occur within the sandstone.

- *Sequence 5:* Sequence 5 extends from the base of limestone “C” to the base of limestone “D” and ranges in thickness from 40 to 55 feet. Limestone “C” is the most prominent limestone in the sequence and may be equivalent to the “Prosperity Limestone.” Above the limestone are interbedded thin sandstone, siltstone, and mudstone.

- *Sequence 6:* Sequence 6 includes all the rocks occurring above limestone “D.” Interbedded thin sandstone, siltstone, and mudstone overly the limestone.

4.2.3 Quaternary System

The stream valleys located throughout the study area, including Robinson Fork, contain the youngest deposits within the county. These deposits include mostly sand and gravel with occasional boulders. Silt and clay do occur in these deposits, but are mobile in the alluvial environment. These deposits are mostly alluvial in origin, although alluvial-colluvial fans are present at the base of slopes and at the mouth of gullies. These deposits are considered to be “Recent” in age. Narrow terraces situated above and adjacent to some of the major stream may be Pleistocene.

The alluvium, consisting of lenticular deposits of clay, silt, sand and gravel, is most extensively developed along the major streams within the county (Chartiers, Little Chartiers, and Tenmile). Along these streams, the alluvium can attain a thickness of 15 to 20 feet. The colluvium, deposited with the alluvium at the foot of slopes, consists largely of angular fragments of rock carried downslope due to erosion.

4.2.4 Coal Resources

Seventeen coal beds are known to crop out within Washington County and of these coals beds, only the Pittsburgh and the Waynesburg Coal are economically viable on a regional scale. The other coals attain locally minable thickness, but only for stripping or country bank operations. The Waynesburg Coal does attain minable thickness; however, impurities and discontinuous nature of the seam prevent the deposit from being exploited on a large basis.

The depth to the Pittsburgh Coal varies through the study area, but typically is between 530 to 545 feet below the Robinson Fork channel bottom. The Pittsburgh Coal, within the county, occurs as two benches separated by a clay parting. The lower bench ranges in thickness from 4 feet to slightly more than 8 feet and forms the main part of the seam. The majority of the coal production is from the lower bench of the Pittsburgh Coal. The upper bench is generally not mined and ranges in thickness from 0 to 5 feet. The clay parting can be on the order of several inches up to several feet thick.

4.3 Structural Geology

4.3.1 Appalachian Plateaus Physiographic Province

Bedrock of the Appalachian Plateaus Physiographic Province, including those of the study area, contains folds that are parallel to those within the adjoining Ridge and Valley Province. The folds within the Appalachian Plateaus Physiographic Province are low-amplitude slightly arcuate features with broad wavelengths (on the order of 5 to 20 miles). These gentle warps are surface expressions of small displacements along deep-seated faults in many cases. Deformation of strata in the Appalachian Plateaus is extremely subtle compared to the folding in the Valley and Ridge Province. The amplitude of the folds decreases to the northwest and display asymmetry around the fold axis. Typically, the steep flank of the folds faces to the southeast, although the asymmetry only varies by a few degrees. Dips range from 3 to 5 degrees of the northwest flanks and 4 to 6 degrees on the southeast flanks. These ranges are averages and dips upwards of 60 degrees have been measured in areas.

4.3.2 Prototypical Area of the Pittsburgh Low Plateau Section

Structurally, rocks of the Prototypical Area mimic the regional trend for the Appalachian Plateaus Physiographic Province. Bedrock folds manifested as a series of “u-shaped” (synclines) and “inverted u-shaped” (anticlines) flexures with northeastward trending axes, extend across the county. The trends of the fold axes are sinuous and the northeast trend is a general one. In Washington County, the synclinal axes plunge to the northeast and, the anticlinal axes to the southwest. Folds identified in the county include the following (from west to east): Claysville Anticline, Finney Syncline, Washington Anticline, Nineveh Syncline, and Amity Anticline.

The study area is located approximately midway between the axes of the Claysville Anticline and the Finney Syncline. The distance between the two fold axes is approximately 2.5 miles. This intermediary location results in a general southward dip to the bedrock; however, due to the sinuosity of the fold axes, the dips can vary from the southeast to the southwest. Within the mined section of the study area, the bedrock dip is to the southeast, whereas in the unmined section the bedrock dip is to the south and southwest. The southern section of the Finney Syncline is broad and irregular but to the north, the fold narrows abruptly due in part to a northwest trending cross fold – the Cross Creek Syncline. The crest line of the Claysville Anticline gently undulates forming a series of domes and saddles. As with the Finney Syncline, the southern section of the Claysville Anticline is broad and indistinct. The Westland Dome, a feature related to the Cross Creek Syncline, truncates the northern part of the Claysville Anticline.

4.3.3 Joint Systems

Fractures are breaks that occur in rocks when stress induces mechanical failure within a rock unit. A "joint" is a type of fracture. A joint is a fracture or separation in rock without displacement of the sides of usually plane (flat) surfaces that greatly increase the surface area of rock exposed to weathering processes. Jointing increases the ratio of surface area to volume of a rock body. The orientations of the joints are typically parallel or perpendicular to the layers forming the rock unit.

Joints typically occur as regular sets and it is possible to measure their orientation and spacing. Two dominant joint orientations are discernable within the county--N 25°E and N 65°W. The angular relations between joint sets are maintained with consistency over large areas. The joint traces can cross fold without altering angular relationship to the fold axes. However, the fold axes do in some cases lie more or less parallel to the regional joint pattern. Within Washington County, sandstone has the largest spacing, approaching 8 feet followed by shale and limestone with spacing intervals of 5.5 and 2.5 feet respectively. Coal beds typically display the tightest joint spacing, on the order of 0.2 feet.

The release of rock pressure from the formation valleys can induce another fracture pattern other than the regional joint sets. Studies have recognized stress-relief fracture patterns that extend horizontally beneath valley floors and vertically along valley walls. The removal of compressional stress on underlying rocks by the erosion of overlying rocks during valley formation results in horizontal stress-relief fractures beneath the valley floor. In comparison, stress-relief fractures within upland areas and slope areas are generally vertical. The number of fractures decreases from the valley floor towards the upland as well as with increasing depth.

4.3.4 Lineaments

Transverse linear morphological features, or lineaments, are manifested on topographic or drainage maps both on regional and local scales. In the geologic sense, a lineament is a linear topographic feature that may depict crustal structure or may represent a zone of structural weakness. In cases, lineaments can be used to locate joint sets and fracture zones. The coincidence of anomalously high gas flows or groundwater yields with lineament traces suggests that these traces are zones of weakness. Short lineaments and fracture traces are expressed on aerial photographs and topographic maps by the alignment of stream segments, valleys, swales, wind/water gaps, and changes in vegetative patterns. In southwestern Pennsylvania, most lineaments are regions of fractures with little or no cumulative displacement and generally represent vertical zones of increased porosity and permeability.

Lineament analysis of remote-sensing imagery remains one of the most commonly used reconnaissance tools for assessing potentially transmissive zones in the bedrock. The technique used for both region-wide studies and small-scale site investigations. However, the method is inherently subjective and certainly not all lineaments guarantee finding highly transmissive discontinuities in the bedrock. The main assumption in performing any lineament analysis is that these alignments represent fracture zones or other discontinuities.

The distribution and orientation of lineaments can be plotted on “rose diagrams.” Within the study area, the orientation of valleys and streams mimic the measured joint sets within the bedrock (see Sheets 6 and 7).

4.3.5 Very Low Frequency Survey

The location and orientation of fracture zones is important for modeling fluid flow in fractured rocks. Surface geophysical methods are a rapid, inexpensive addition to drilling for determining the locations and orientation of fractured zones in bedrock. Surface geophysics can be used in conjunction with geologic, hydrologic, and borehole-geophysical investigations to predict subsurface aquifer characteristics. The VLF method is a passive electromagnetic (EM) method that utilizes powerful transmitters as the primary EM wave source. VLF methods can be used to determine the locations of saturated, subvertical conductive zones in which the primary EM wave induces current flow. In the VLF process, water-bearing bedrock fractures are detected by identifying the magnetic fields generated in the water, which conduct electricity, by the VLF broadcasts.

A suspected bedrock fracture is found by taking VLF readings at regular points along a straight line, or transect, along the possible location of the fracture. Results of this work will not only quantify the relationship between lineaments and subsurface fractures but will also evaluate whether or not fracture characteristics observed in surface outcrops can be extrapolated into the third dimension with any degree of certainty.

This study included conducting a VLF survey along two separate reaches of Robinson Fork. The objectives of the VLF are to verify that some lineaments mapped from aerial photographs and topographic maps are fractures, or fracture zones. VLF readings were recorded at 1-meter intervals along the two transects, along the mined (800 meters) and unmined (900 meters) reaches of Robinson Fork.

- *Mined Section Transect:* At several points along the mined section transect strong positive VLF signatures were recognized. The location of two of the strongest signatures coincided with the intersection of a tributary/gully with the main channel of Robinson Fork. These same areas were identified during the lineament evaluation performed as part of this study. Three other positive signatures were identified as possible fractures, although these signatures did not correspond to any identifiable surface features. However, the location of the three VLF signatures coincides with the boundary between a longwall panel and adjacent gate.

- *Unmined Transect:* Six strong positive VLF signatures were identified within the unmined section of Robinson Fork. Four of the signatures corresponded to overhead utility lines do not indicate the presence of fractures. The location of two remaining strongest signatures coincided with the intersection of a tributary/gully with the main channel of Robinson Fork.

The VLF signatures in the mined area may be a result of brittle and ductile fracture of the bedrock units due to differential settlement (cantilever failure) between the panel and the gate. Brittle fracture is characterized by rapid crack propagation with low energy release and without significant plastic deformation whereas ductile fracture is characterized by tearing of bedrock and significant plastic deformation. The appearance of fractures above the gates (or barrier pillars) is not unexpected. Tensile stresses are often greater above these areas due to overlapping stress fields from the adjacent mined-out areas. The results of the VLF survey are presented in Sheet 8.

4.4 Soils

4.4.1 Washington County Soil Survey

The U.S. Soil Conservation Service (SCS) mapped the soils within the county, including the study area, during the period of 1963 to 1978. Final approval of the names and description of the soils within the county occurred in 1979. The results of the survey are presented in the SCS publication, “Soil Survey of Greene and Washington Counties, Pennsylvania” (Soil Survey). The publication presents aerial photographs of the county superimposed with soil names and descriptions of the soil types. According to the SCS, conditions represented in the Soil Survey refer to those that existed in the county during 1979.

Soils that have similar profiles comprise a soil series that can be mapped. Individual soil types within the series are map units. The following soil series were identified within the study area by the SCS and included in the Soil Survey:

- *Brooke Series:* Brooke Series soils are moderately deep, well-drained, and developed in upland areas from the in-place weathering of limestone bedrock. Brooke Series soils within the study area include the "BoB" mapping unit. The clay percentage and bedrock depth limits the use of these soils. Only discrete areas of Brooke Series soils were mapped within the study area.

- *Culleoko Series:* According to the Soil Survey, Culleoko soils are moderately deep, well drained, and moderately permeable soils developed on upland (interfluve) areas. The soils resulted from the in-place weathering of underlying bedrock. Culleoko Series soils identified within the study area include map units "CaB", "CaC", and "CaD." These maps units are considered to be silt loam and are distinguished by the degree of slope each are found. For the most part, areas are used for cultivated crops or hay. Although these soils are susceptible to erosion and runoff, cultivation reduces this effect.

- *Dormont Series:* Dormont soils are deep, moderately well drained with slow to moderately slow permeability. These soils occur on upland and colluvial areas forming from the weathering of underlying bedrock. The source of the soils is considered to be the finer-grained lithologic units – limestone, siltstone, and shale. Two maps units were identified within the study area, "DoD" and "DtF." The "DoD" unit consists of silt loam forming on slopes usually in short strips encompassing between 2 to 150 acres. Most of the land included in the "DoD" unit is used for pasture or woodland within the county. The "DtF" unit represents an association between Dormont and Culleoko Series. "DtF" soils occur within elongate strips and develop on steep to very steep slopes. Runoff from these soils is rapid resulting in a severe erosion hazard. Brushland or woodland occupies most areas included in the "DtF" unit. Slope and erosion hazard potential in this unit is severe, limiting use.

- *Huntington Series:* Huntington soils are deep, well-drained, moderately drained developed on floodplains. The soils are derived from alluvium formed by the erosion of sedimentary bedrock. Occurrences of these soils are limited to nearly level elongate strips along streams. Most of the areas occupied by the map unit "Hu" are used for cultivated crops, hay, and pasture. The primary limitation in this soil unit is the potential for flooding.

- *Newark Series:* Newark soils are deep, but poorly drained that develop on floodplains, typically in association with Huntington Series soils. The soils are derived from alluvium formed by the erosion of sedimentary bedrock. The Newark Series soils within the study area include the map unit, "Nw." Most of the soils described as "Nw" are used for pasture, hay, woodland, or brushland; although some area include cultivated ground or community development.

- *Weikert Series:* Weikert Series soils are shallow, well-drained soils that develop on upland areas. The soils are derived from the in-place weathering of underlying sedimentary bedrock, excluding limestone. The Weikert Series soils within the study area include the map units, "WeB", "WeC", and "WeD." The primary difference between the units is the steepness of the slopes on which they develop. The slopes and shallow bedrock depth generally limit the use of these soils to pasture, hay, or woodland.

Sheet 9 presents the SCS Soil Survey data superimposed on the USGS topographic maps.

4.4.2 Colluvial Deposits

Colluvium is poorly sorted debris that has accumulated at the base of slopes, in depressions, or along small streams through gravity, soil creep, and local wash. It consists largely of material that has rolled, slid or fallen down the slope under the influence of gravity. Accumulations of rock fragments are called talus. The rock fragments in colluvium are usually angular, in contrast to the rounded, water-worn cobbles and stones in alluvium and glacial outwash.

The USGS performed a mapping project within the county in 1978 to delineate landslide deposits. According to the USGS information, landslide deposits cover between 30 to 60 percent of the study area. The map also depicts the location of landslides (recent and historic). The valley walls for Robinson Fork and its tributaries are the location for numerous landslide areas. Some of these areas may still be active.

4.5 Hydrogeology

4.5.1 General

Groundwater is part of a hydrologic (water) cycle that is in a dynamic equilibrium. Recharge in the form of infiltrating rainwater and snowmelt is continually replenishing groundwater supplies. The amount of recharge in a given area is determined by the permeability of the soils and the amount, duration and intensity of rainfall. Where soils are finer grained, infiltration rates through the earth's surface are less; more of the total precipitation runs off to nearby streams and rivers. If there is less rainfall, infiltration amounts will be less. In the soil zone and underlying unsaturated zone (vadose zone), water movement is vertical in response to the pull of gravity. Water in this zone would be called vadose water. Movement continues downward until reaching the water table, below which all pores are saturated. Below the water table, the water is now called *groundwater*, and movement can be in any direction depending on energy gradients. Discharge areas for groundwater are represented by local topographic low features such as lakes and by regional features such as major river systems. The water table is a subdued reflection of the surface topography.

Heterogeneities (fine-grained and coarse-grained sediment in a single area, such as alternating layers of shales and sandstones) have significant impacts on groundwater flow systems and movement of contaminants. Flow of groundwater is much faster through highly permeable sediments, such as sand and gravel, compared to silts and clays. The essential difference is in particle size and consequently the size of the pore spaces between particles. There is much greater resistance to groundwater flow where pore spaces are very small, as in silts and clays. Permeability is a measure of resistance to flow, or the relative ease with which the aquifer can transmit water. The permeability that is formed as sediments are deposited is referred to as *primary permeability*. *Secondary permeability*, when developed, can be extremely important in the movement of groundwater and contaminants. Where fractures or joints occur in mudstones, shales, limestones, secondary permeability can be the path for very rapid movement of groundwater. There is little resistance to flow along fractures or joints because of the large openings.

4.5.2 Aquifer Characteristics

As stated in the previous section, primary permeability is related to the rock type, or lithology, prior to any fracturing. However, in Washington County, the dominant component of aquifer permeability is related to the number, size, and extent of interconnected fractures – secondary permeability. Coal beds commonly display the greatest number of fractures and consequently the highest hydraulic conductivity. Sandstone typically also has a high hydraulic conductivity due in part to fractures and their incipient primary permeability. The presence of primary and secondary permeability in the sandstone units results in the greatest groundwater yields within the county. The permeability of siltstone and shale is attributed to fractures, however due to infilling of these lithologies typically have comparatively low hydraulic conductivity. Limestone, barring development of karst features, typically displays the lowest hydraulic conductivity as a result of high density and clay content.

Groundwater flow in the Upper Ohio-Wheeling watershed is complex. Within the interiors of the upland areas, water is stored and transmitted in intergranular pore spaces of the predominantly sandstone bedrock. Although these rocks are saturated, well yields vary considerably. Saturated sandstone zones are separated by relatively impermeable claystone units associated with major coal seams, which limit the vertical movement of water. These confining layers cause lateral flow to the hillsides where groundwater may discharge as springs or seeps or more vertically downward through the confining zones via secondary porosity consisting of fractures and bedding-plane openings. Bedrock wells monitoring valley walls and bottom usually respond quickly to rainfall events, evapotranspiration, and mining activity. This suggests high hydraulic conductivity and direct connection to infiltration from the surface. Secondary fracture permeability, possibly created by stress-relief fracturing, is responsible for the increased hydraulic conductivity along hillsides and valley bottom, and controls much of the shallow groundwater flow in the basin. Fractures that underlie the valley are interconnected with those along the valley walls, and the interconnected fracture set enhances the permeability of the rock.

4.5.3 Washington County Hydrogeology

Two types of groundwater flow exist in the vicinity of the study area. Near surface alluvial deposits overlie bedrock. The alluvial deposits are porous medium with a relatively high permeability that can transmit water relatively quickly. Flow through alluvium comes mainly from surface infiltration and runoff (e.g., rainfall).

In contrast, the bedrock is a fracture system where most water flows through the fractures. The rock mass is relatively impermeable and only a small amount of water moves directly through the rock. The principal water-yielding geologic units within Washington County are sandstone units of the Permian and Pennsylvanian Dunkard Group. Reported typical yields of wells completed in all these units range from 30- to 300-gallons per minute, but some wells yield as much as 600 gallons per minute. Aquifer testing in sedimentary rocks indicates hydraulic conductivities ranging from 2.4×10^{-6} to 50 feet per day.

4.6 Hydrology

4.6.1 Drainage Basin Characteristics

A small percentage of the water that enters Washington County through precipitation is held as soil moisture and stored in ponds or reservoirs. The remainder of the water leaves as vapor, or as stream flow (including groundwater). The amount of stream flow and the distribution of that flow are dependent on meteorlogic and topographic characteristics of the drainage basin.

A watershed is an area that drains water to a given outlet point on a stream network. Watersheds have traditionally been defined using a topographic map that shows the terrain elevation as contour lines. From the elevation contours on a topographic map, a watershed boundary can be sketched by starting at the outlet point and following the drainage divides from neighboring watersheds around until the boundary is closed back at the outlet.

4.6.2 Upper Ohio – Wheeling Watershed

The subject property is located within the Ohio River Basin; specifically within "Subbasin No. 20." Subbasin No. 20 has a total drainage area of 3,084 square miles. Known as the Ohio Subbasin, it includes the Pennsylvania portion of the Ohio River, from its beginning at the confluence of the Allegheny and Monongahela Rivers in Pittsburgh to the borders of Ohio and West Virginia. The subbasin encompasses all of Beaver and Lawrence Counties, much of Mercer, Butler, Allegheny, and Washington Counties, and small portions of Crawford, Venango, and Greene Counties.

Washington County crosses three watersheds included as part of Subbasin No. 20: the Lower Monongahela, the Upper Ohio, and the Upper Ohio – Wheeling (UOW) (see Sheet 2). The study area, which includes portions of Robinson Fork and its tributaries, is situated entirely within the upper reaches of the UOW watershed. Major streams within the UOW include Wheeling Creek, Enlow Fork, and Buffalo Creek.

Statistics for the UOW watershed (U.S. Environmental Protection Agency):

- Encompasses an area of approximately 1,506 square miles
- Total watershed acres is 1,340.4
- 25 streams
- 82 lakes
- 2,126.5 total river miles
- 1,493 perennial river miles

Water entering Robinson Fork flow southward through the study area, eventually entering Enlow Fork. Water from Robinson Fork entering Enlow Fork proceeds westward from the confluence of those two streams to Wheeling Creek and ultimately to the Ohio River. The applicable portion of the Robinson Fork watershed encompasses approximately 14.4 square miles (9,220 acres) and is depicted in Sheet 2.

4.7 Climatology

Water resources are affected by changes in precipitation as well as by temperature, humidity, wind, and sunshine. Changes in stream flow tend to magnify changes in precipitation. Water resources in drier climates tend to be more sensitive to climate changes. Because evaporation is likely to increase with warmer climate, it could result in lower river flow and lower lake levels, particularly in the summer. If stream flow and lake levels drop, groundwater also could be reduced. In addition, more intense precipitation could increase flooding.