DESIGN REPORT
FOR
QUITTIE NATURE PARK
STREAM RESTORATION PROJECT
ANNVILLE TOWNSHIP,
LEBANON COUNTY, PENNSYLVANIA

PREPARED FOR
QUITTAPAHILLA WATERSHED ASSOCIATION

PREPARED BY

CLEAR CREEKS CONSULTING
1317 Knopp Road, Jarrettsville, Maryland 21084 (410) 692-2164

In collaboration with

SKELLY AND LOY
ENGINEERING - ENVIRONMENTAL CONSULTANTS

May 2012

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PROJECT BACKGROUND

On behalf of the Quittapahilla Watershed Association, this Design Report has been prepared by Clear Creeks Consulting LLC and Skelly and Loy, Inc. as part of the application requirements for a Joint Pennsylvania Department of Environmental Protection Water Obstruction and Encroachment Permit and U. S. Army Corps of Engineers Section 404 Permit for the proposed Quittie Park Stream Restoration Project located along Quittapahilla Creek in Annville Township, Lebanon County, Pennsylvania. The project reach is located in an area locally known as Quittie Nature Park.

Funded by Growing Greener grants an interdisciplinary team of consultants and government agencies conducted a detailed watershed assessment of the Quittapahilla Creek Watershed. The assessment included: field reconnaissance surveys, geomorphic stream assessments, in-stream habitat assessments, sampling of fish and macroinvertebrate communities, water quality monitoring, developing a sediment-discharge rating curve, and hydrologic and water quality modeling. Sixty five miles of tributaries were assessed and mapped utilizing a method similar to the USDA-NRCS Stream Visual Assessment Protocol. Eighteen miles of Quittapahilla Creek were assessed utilizing Level II, III, and IV Rosgen stream classification and channel stability assessment methods. The location, nature and causes of channel instability, habitat, and water quality problems were identified. The fieldwork was completed between 2001and 2004.

Based on the findings of the watershed assessment a Restoration and Management Plan was developed for the Quittapahilla Creek Watershed. The restoration and management strategies outlined in the Plan were developed to achieve the overall project objectives of improving the water quality and habitat of the Quittapahilla Creek watershed. The Plan presents strategies designed to address existing hydrologic, water quality, in-stream habitat, and channel stability problems. These include best management practices for controlling runoff from agricultural land, best management practices for controlling runoff from urban land and channel stabilization measures focused on restoring and stabilizing stream reaches impacted by livestock grazing, urban runoff and channel alterations along Quittapahilla Creek and its tributaries. The project presented in this document is the first stream stabilization project identified in the Quittapahilla Creek Watershed Restoration and Management Plan.

The results of the watershed assessment indicated that the stream reaches through the Quittie Creek Nature Park are laterally and vertically unstable. Stability problems include high width to depth ratio, moderate to moderately high bank erosion, heavy sedimentation and aggradation (lateral and mid-channel bars) throughout. Bank erosion is a source of sediment to downstream reaches along Quittapahilla Creek, as well as Swatara Creek. The lack of sediment transport capacity is contributing to the streambank erosion. Undermined trees fall into the creek creating debris jams which further accelerate sedimentation and bank erosion. Increased sedimentation has significantly degraded in-stream habitat resulting in few, shallow pools and riffles that are highly embedded with fine sediments.

TECHNICAL REPORT

I. Study Area

The project proposes to restore 3450 linear feet along Quittapahilla Creek from a point 450 feet above the old dam in the Quittie Creek Nature Park to a point immediately upstream of the Route 934 Bridge. In addition, approximately 100 linear feet of an unstable tributary within the Park will be stabilized (Fig. 1).

II. Scope of Studies

Topographic surveys and field studies were conducted to: develop base maps for the design; evaluate the current conditions along the project reaches; determine the extent of the restoration effort required; develop reliable estimates of the design discharge(s) and other design parameters that guided the preparation of restoration design plans, and satisfy permitting requirements. This study also included wetland delineations, identification of significant plant or animal habitat, archeological or historical studies, and other environmental studies that may be required by local, state or federal permitting agencies.

Existing conditions information was collected as part of the comprehensive watershed assessment conducted between 2001 and 2004. This data included: topographic, soils, geology, and land use maps; meteorological data, ecological, biological and water quality data. The hydrologic and hydraulic data was developed specifically for the project area. The following characterization of Quittapahilla Creek watershed was developed from this information.

III. Watershed Characterization

A. Climate

Lebanon County lies too far inland for the climate to be strongly affected by the Atlantic Ocean, and therefore, it has a humid continental climate. Most weather systems that affect the County develop in the Central United States and are modified considerably before reaching the area. The average annual precipitation of 42.3 inches is distributed throughout the year, most of which is in the form of rainfall. May – August are the periods of highest precipitation, which usually occurs as afternoon or evening showers or thunderstorms. There are about 37 thunderstorms each year, and most occur during this period. January – February are the periods of lowest precipitation. Average annual snowfall is 27 inches. The first significant snowfall is usually in December and the last snowfall normally occurs in March.

Winters are cold, but cloudiness is not persistent because of the moisture lost in the more western counties as the air masses approach. Mean daily temperatures range from 27.3 – 32.2ºF in winter. In summer, 60 percent of possible sunshine is received. Mean daily temperatures range from 67.8 – 72.2ºF in summer. Extended periods of hot humid weather occur with temperatures hotter than 90º F. Spring and fall are transition periods. High temperatures in April and October are in the 60's.

Table 1 presents the monthly averages of temperature and precipitation in Lebanon from available records covering the last 50 years.

Parameter	Table 1 – Monthly Averages of Temperature and Precipitation in Lebanon, PA											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (F°)	27.3	29.9	39	49.2	59.0	67.8	72.2	70.0	62.6	51.4	41.3	32.2
Precipitation (Inches)	3.19	2.56	3.31	3.72	4.61	4.04	4.57	3.48	4.08	3.32	3.62	3.19

B. Physiography

The Quittapahilla Creek Watershed is situated in the Ridge and Valley physiographic region in Lebanon County, Pennsylvania. Quittapahilla Creek is a tributary to Swatara Creek and is part of the Susquehanna River Basin. Its headwaters begin just southeast of Lebanon, Pennsylvania and it enters the Swatara Creek near North Annville, Pennsylvania.

The Quittapahilla Creek watershed area is 44.9 square miles (28,736 acres) at the project site. From its headwaters south of the City of Lebanon (elevation 500 feet) Quittapahilla Creek flows approximately 22 stream miles to its confluence with Swatara Creek in the North Annville Township (elevation 350 feet). The average slope of the mainstem is 0.13%. The high point of the watershed is situated at Furnace Hills in Cornwall Township (elevation 1120 feet), giving the basin an average longitudinal gradient of 1.0%.

The southern boundary of the watershed divide includes numerous ridges and knobs with elevations ranging from 700 to 960 feet. The steeper headwater areas of the tributaries draining these southern ridges range in slope from 2 to 4%. After flowing off the ridges these tributaries meander for several miles across the valley floor before reaching the mainstem. As a consequence, the gradients of their lower reaches are much flatter, with average slopes ranging 0.1 to 0.5%. Most ridges and knobs along the northern boundary of the watershed are less than 600 feet in elevation. With the exception of Brandywine Creek, these northern tributaries flow off the ridges directly into the mainstem. The average slopes of these tributaries range from 1.0 to 2.0%.

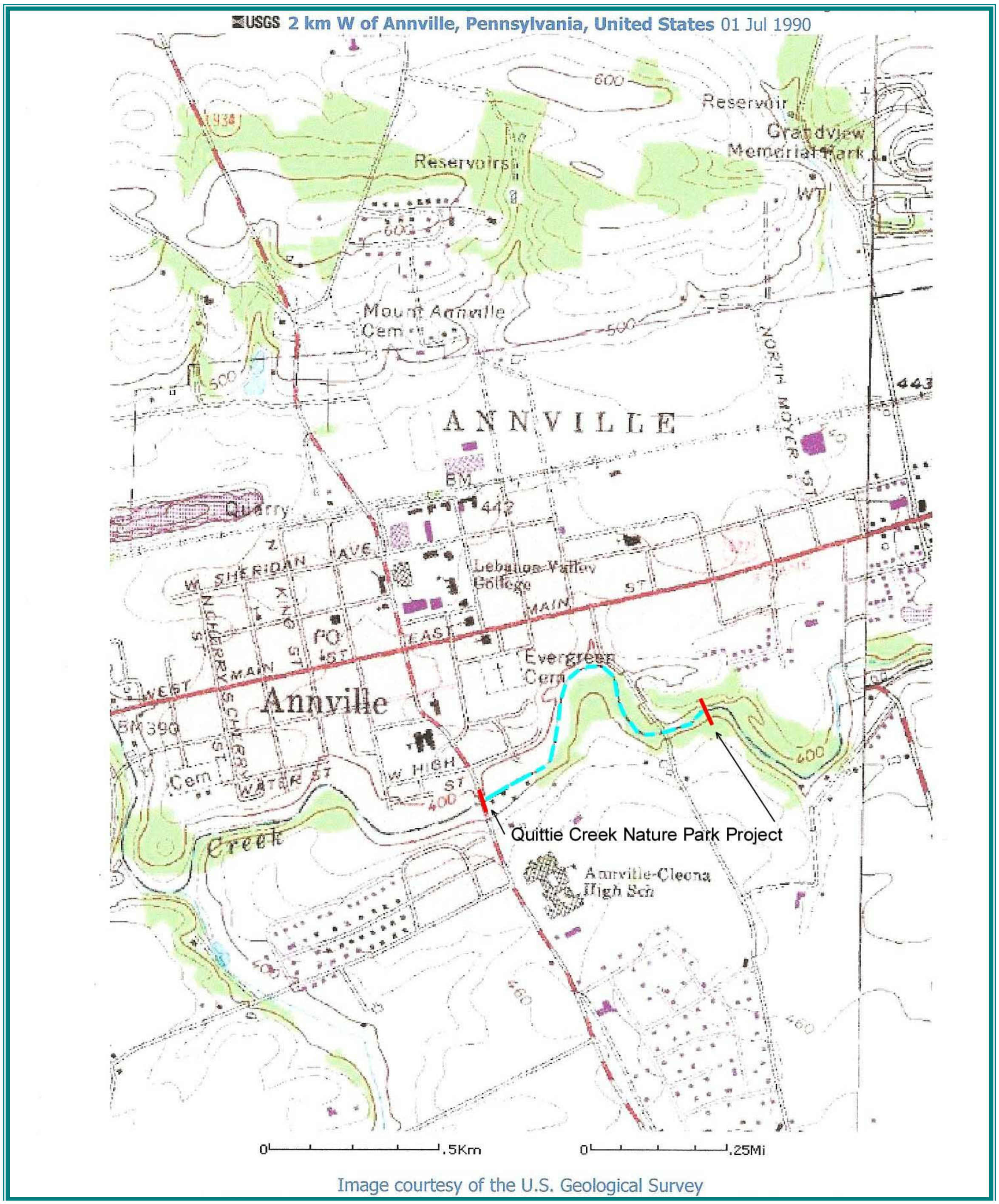

Fig. 1 Quittie Creek Nature Park – Stream Restoration Project Site

C. Geology

The landforms of the Ridge and Valley region are dramatic for their regularity if not for their topographic relief (Miller, 1995). Northeast-southwest trending mountains and valleys characterize the Ridge and Valley region. Folding and differential erosion of sedimentary rocks created the landforms of this region. The region was deformed and pushed westward by the Appalachian Orogeny of the Late Paleozoic Period.

The less resistant rocks, such as dolomite and limestone, brought to the surface by this geologic process eroded rapidly and became lowland valleys, while the more resistant rock, such as shale and sandstone, formed the ridges and high valleys. The Quittapahilla Creek watershed is situated almost entirely in the Great Valley, one of several subregions of the Ridge and Valley characterized by broad limestone valleys. In the Lebanon County area elevations range from over 1600 feet on Second Mountain to 400 feet in the Lebanon Valley.

The headwaters of the southern tributaries drain a ridgeline along the southern boundary of Lebanon County that is situated in the northern portion of the Triassic Lowlands. This area is underlain by Triassic sandstone, conglomerate, and diabase. The Triassic diabase intrusion has been mined for iron ore. The Cornwall mines, the oldest continuously operated mines in the Western Hemisphere, were important producers of high-grade ore from 1742 until 1972.

The majority of the land area in the watershed is situated in the Great Valley section of the Ridge and Valley region. This area is underlain by bedrock of Lower Paleozoic shale, limestone, and dolomite formations. The upper and middle reaches of the mainstem Quittapahilla Creek as well as the middle and lower reaches of the major tributaries flow across the carbonate rocks of the valley. Sinkholes and solution cavities are common in these carbonate rocks. Quarries in the carbonate rock are mined for concrete aggregate, cement, flux stone, and paint filler.

The lower reaches of the mainstem Quittapahilla Creek, as well as the headwaters of the northern tributaries, are underlain by interbedded sedimentary rock and shale.

D. Soils

According to the Penn State Online Soil Mapping Tool (http://soilmap.psu.edu), the dominant soils along the upper reaches of Quittapahilla Creek include those in the Hagerstown-Duffield-Clarksburg map unit. They are deep, well drained to moderately well drained silt loam soils in limestone valleys. They formed in residuum and colluvium from limestone with some sandstone and shale. The dominant soil types located in the project area include:

Hagerstown silt loam (HaB - 3 to 8% slopes). This map unit consists of gently sloping, deep, well drained silt loam soils on uplands. Permeability is moderate and the available water-holding capacity is high. Surface runoff is medium. Water table is greater than 6 feet and depth to bedrock greater than 40 inches. Hagerstown-Rock outcrop complex (HeC - 8 to 25% slopes). This map unit consists of sloping and moderately steep, deep, well drained silt loam soils on uplands. Permeability is moderate and the available water-holding capacity is high. Surface runoff is medium to rapid. Water table is greater than 6 feet and depth to bedrock greater than 40 inches. Lindside silt loam (Ls - 0 to 3% slopes). This map unit consists of nearly level, moderately well drained silt loam soils on floodplains and upland drainageways. Permeability is moderate to moderately slow and the available water-holding capacity is high. Surface runoff is medium. Soil is subject to flooding and seasonal high water table (1.5 – 3.0 feet). Depth to bedrock is greater than 60 inches. Melvin Variant silt loam (Me - 0 to 3% slopes.) This map unit consists of nearly level, deep poorly drained silt loam soils on floodplains adjacent to small streams in the limestone valley. Permeability is moderate and the available water-holding capacity is high. Soil is subject to flooding and seasonal high water table (0.0 – 1.0 foot). Depth to bedrock is greater than 48 inches. Nolin Variant silt loam (No - 0 to 3% slopes). This map unit consists of nearly level, deep, well drained silt loam soils on floodplains and in low areas between higher slopes on uplands. Permeability is moderate and the available water-holding capacity is high. Surface runoff is slow. Soil is subject to flooding and of short duration. Water table is greater than 3 feet and depth to bedrock is greater than 40 inches.

According to the Penn State Online Soil Mapping Tool (http://soilmap.psu.edu), the following soil types within the project area contain major or minor hydric components: Lindside silt loam, Melvin Variant silt loam, and Nolin Variant silt loam. In addition, seven wetland areas were identified during the course of a routine wetland delineation on the project site. Refer to the plan drawings for the location of these wetland areas within the project site.

E. Land Use

Quittapahilla Creek starts as a small spring on a dairy farm in the South Lebanon Township. The surrounding land that drains the headwaters to the south and east is still fairly rural and includes large farms with cropland and pasture. However, as the Quittapahilla flows north toward the City of Lebanon farmland quickly gives way to residential subdivisions and commercial properties.

Flowing beneath Route 422 the creek turns west and flows through the center of Lebanon. Storm drains carry runoff from densely developed neighborhoods to the north and south into a highly altered channel that was first modified in the 18th century. As a result of the flood mitigation projects that the City initiated in the late 1970's Quittapahilla Creek is conveyed in a concrete flume from 3rd Street to 19th Street. The land on either side of the channel includes typical urban uses characterized by high percent impervious surfaces all routed via storm drains to the creek.

After leaving the City of Lebanon the creek flows in a direction that roughly parallels the intensely developed corridor along Route 422 through West Lebanon, Cleona, and Annville. On its way west it meanders along its natural floodplain where a surprising amount of area has been maintained in forest cover in spite of the adjacent land use. These wooded areas are most often associated with steep, rocky slopes or wet seeps and springs, and other areas with saturated soil conditions. With the exception of the Lebanon Wastewater Treatment Plant, cropland is the predominant land use along the left (south) floodplain and adjacent slopes. In some areas crops have been planted to within a few feet of the bank. Land use along the right (north) floodplain and adjacent slopes is more variable and includes old and new residential subdivisions, parking lots of businesses that front on Route 422, schools and athletic fields.

At the western end of Annville the Quittapahilla Creek flows under Route 422 and heads in a northwest direction. Immediately downstream of the Annville Wastewater Treatment Plant the creek enters a concrete flume that conveys it through a land area pocked with abandoned quarries. The creek empties into a natural channel on a large farm upstream of Clear Spring Road. From this point to its confluence with Swatara Creek, farms and homesteads on large parcels border the Quittapahilla.

The entire restoration project area is located in the Annville Township. The upper section of the project area is situated on publically owned land in the Quittie Creek Nature Park. This area is characterized by a mature forest along both sides of the floodplain. Walking trails and a sanitary sewer easement follow the creek along most of the length of the project. With the exception of a tract owned by the Board of Education, most of the middle and lower sections of the project area include privately owned tracts with single family homes. The riparian corridor along these sections includes mature forest (upland and floodplain), meadow, and mowed yards. No permanent structures are situated within the proposed limit of disturbance.

F. Hydrology

1. Peak Discharge Estimates

Peak discharge estimates for were developed for the project reaches by Skelly & Loy, Inc. The results of their analysis are presented in a separate report included in the appendix of this document.

2. Bankfull Discharge Estimates

Three methods were used to develop bankfull discharge estimates. These included 1) bankfull regional regression equations, 2) a probability of exceedence analysis, and 3) Manning's equation and field data.

a. Bankfull Regional Regressions

The U. S. Geological Survey and Pennsylvania Department of Environmental Protection, Canaan Valley Institute, and Susquehanna River Basin Commission cooperated to develop regional curves for streams in Pennsylvania and selected areas of Maryland, 2005).

b. Probability of Exceedence Analysis

A probability of exceedence analysis was conducted to develop an estimate of the 1.01-yr, 1.01-yr, 1.11-yr, 1.5-yr, 2-yr recurrence interval (RI) flows for the project site. To accomplish this peak discharge estimates for the 2-yr and greater recurrence interval storms were developed using the regression equations in Regression Equations for Estimating Flood Flows at Selected Recurrence Intervals for Ungaged Streams in Pennsylvania (USGS SIR – 2008-5102). These peak discharges were plotted on a probability of exceedence table. Peak discharges were then developed from a flood frequency analysis of the maximum annual peaks recorded at the USGS stream gaging station on Quittapahilla Creek near Bellegrove. These were also plotted on the same table. Finally, peak discharge estimates developed using the HEC-HMS model were developed and plotted on the same table. A comparison of the slopes of the three lines indicated that a line of best fit could be extended downward from the initial plot to obtain estimates of the more frequent peak discharges. The probability of exceedence table with the three plots is included in the appendix to this report.

c. Manning's Equation

Bankfull discharge estimates were developed using Manning's equation and cross-sectional data collected in the crossover (riffle) of relatively stable reaches along the project area. The slope used was the bankfull slope of the overall reach, and estimates of Manning's n were developed utilizing visual observations of the channel bottom and banks throughout the reach.

As shown in Table 2, the bankfull discharge estimates developed for the Quittapahilla Creek project reaches using the bankfull regional regressions compare favorably with the estimates developed using Manning's equation and field data. Both estimates fall within the range of discharges bound by the 1.11 and 1.5 -YR interval flood flows developed from the probability of exceedence analysis.

Project Reach Location	Drainage Area (mi^2)	Bankfull Regional Regression (cfs)	Probability of Exceedence Analysis 1.11 YR/ 1.5 YR (cfs)		Manning's Equation (cfs)
UPS	43.5	484.3	ND	ND	484.0 – 492.9 (487.9)
DS	44.9	494	280	540	489.6 – 500.0 (496.2)

Based on this analysis it was determined that utilizing the bankfull regional regression estimate provides a reliable method for estimating bankfull discharge for the proposed project design.

G. Hydraulic Analysis

A hydraulic analysis was conducted for the project reaches by Skelly & Loy, Inc. The hydraulic model was developed for existing and proposed conditions for the 100- year flow event. The methodology, findings, and figures showing the 100-year water surfaces, cross-section profiles and summary tables are presented in a separate report included in the appendix of this document.

IV. Existing Resources and Environmental Conditions

A. Wetlands

Existing wetland resources along the project reaches were identified and delineated by Skelly & Loy, Inc. during Summer 2009. The results of their field work and a description of the wetland areas are presented in a separate report included in the appendix of this document.

B. In-Stream Biological Communities

1. Methods

The benthic macroinvertebrate communities in the project area were assessed during Winter 2003. The biological sampling effort utilized the U.S. EPA Rapid Bioassessment Protocol (RBP) and included: taxonomic identification; development of Functional Group and Tolerance Indices for macroinvertebrate communities. The fish communities were assessed during Summer 2004. This biological sampling effort also utilized the U.S. EPA Rapid Bioassessment Protocol (RBP) and included: taxonomic identification; determination of tolerance value and trophic level; and calculation of Indices of Biotic Integrity (IBI) for fish communities. The biological sampling station was located on Quittapahilla Creek in Quittie Creek Nature Park immediately downstream of the old dam spillway.

2. Results

This sampling station produced 163 benthic macroinvertebrates from at least 10 taxa. The dominant taxon by far was the scud *Gammarus*, which accounted for 73.6% of all organisms collected. Scuds are typically dominant in most limestone creeks in the region. The next most numerous organisms were midge larvae and the exotic invasive Asiatic clam (*Corbicula fluminea*). This invasive hard-shell clam is often deleterious to native bivalve molluscs, none of which were found at any sampling location, and is very tolerant of most types of pollution.

Collectors were the strongly dominant functional feeding group at 98.8 % of the sampled organisms, suggesting high levels of FPOM. This may be due to increased levels of primary production, suggesting nutrient enrichment. Other functional feeding groups were minimally present, and no predators were collected. The biotic index was moderately high at 6.04, suggesting fair water quality conditions. The dominance of the relatively pollution tolerant scuds, midges, and Asiatic clams contribute to the high score.

The fish community was less dense and diverse than expected, with the fewest species produced of any sampling station at five. Although 219 fish were collected, 213 of these (97.2 %) were the dominant slimy sculpin. Only one or two individuals of the other species present were collected, with one stocked brown trout. More trout would be expected in this reach due to stocking patterns and excellent pool habitat. However, angling pressure is likely high in this public park reach, and high turbid flows with excellent root and debris cover certainly impeded collection efficiency. This station produced an IBI score of 29.

C. In-stream Habitat

1. Methods

Existing in-stream habitat was mapped during Summer 2001. Because this part of the assessment was focused on habitat criteria for naturally reproducing trout populations, habitat parameters relevant to spawning and sustaining embryos, fry, juvenile and adult fish were emphasized in the mapping/evaluation process.

The habitat mapping effort focused on characterizing and documenting existing habitat including depth of pools and riffles/runs; percent of the total stream area that provides adequate cover for adult trout during the low flow period; an evaluation of channel substrate relative to potential spawning areas, fry and juvenile escape cover and resting areas, macroinvertebrate habitat in riffles/runs, and the % fine sediment (embeddedness) in riffles/runs; percent of stream length that is pools; a rating of the quality (i.e., size, depth, structure) of the pools;

dominant stream bank vegetation; percent of the stream bank covered by vegetation; and the percent of the stream area shaded.

Water quality monitoring of storm flow events was conducted during the Summer, Fall and early Winter, 2003. The monitoring effort included installation of staff gauges at each sampling site, installation of continuous-reading digital thermographs at each site; flow measurements and rating curve development for each site; sample collection and analysis for five storm events at each site. The storm water samples were analyzed for: temperature, pH, dissolved oxygen, specific conductance, total acidity, total alkalinity, biochemical oxygen demand, nitrate, orthophosphate phosphorus, total phosphorus, total dissolved solids, total Kjeldahl nitrogen, total nitrogen, total suspended solids, turbidity, hardness, copper, lead, zinc, and fecal coliform.

2. Results

Throughout this segment of Quittapahilla Creek the daily maximum summer water temperatures routinely exceeded the optimum for adult and juvenile Brown Trout. The maximum temperatures recorded during the period were only slightly lower than the upper tolerance limit for this species. These high temperatures are likely a result of the effects of the concrete flume in the upper reaches as well as runoff from the City of Lebanon, and Towns of Cleona and Annville along the middle and lower reaches. By early November, the time during which brown trout would normally begin spawning, water temperatures had fallen into the range at which spawning could occur. In mid-November a maximum daily water temperature peak was recorded that exceeded the upper tolerance limit for brown trout embryos. However, by late November and early December the maximum temperatures had dropped into the optimum range for embryo development. The recorded data suggest that overall the water temperature conditions along this segment would provide a stressful environment for all life stages of trout.

The measured dissolved oxygen and pH levels were consistently within the optimum range. However, measured nitrate-nitrogen levels were well above the optimum. Other water quality parameters of concern include: conductivity, suspended and dissolved solids, turbidity, total nitrogen, total Kjeldahl nitrogen, total phosphorus, ortho-phosphate, alkalinity, hardness, copper, and lead. The extremely high levels of these constituents are indicative of pollution caused by urban runoff from the City of Lebanon the Towns of Cleona and Annville, discharges from the Lebanon WTTP, as well as agricultural runoff contributed by Snitz and Beck Creeks.

Along this segment of the creek the range and average depths of pools and riffles are optimum. However, riffles make up only a small percentage of the total bed features. The majority of the pools are large and deep but lack good structure and in-stream cover (e.g., debris, logs, and boulders) for adult trout under low flow conditions. Spawning habitat was limited and a significant portion of the project area is impacted by a high percentage of fine sediments. There is a minimal amount of substrate of adequate size to provide escape or resting cover for fry or juveniles. The riffles and runs did not include enough coarse substrate material to support an abundant macroinvertebrate community.

Numerous in-stream habitat structures were installed along the reaches upstream of Quittie Creek Nature Park at some time in the past. The design and placement of these habitat structures makes them of questionable value. More recently, in-stream habitat structures were installed along reaches in Quittie Creek Nature Park immediately upstream of the current project area.

The dominant bank vegetation along the project reaches is mature trees and shrubs. The percentage of the banks covered with vegetation is relatively high. The segment is heavily shaded along most reaches. Along the middle reaches, the lack of a riparian buffer is a common problem. In residential neighborhoods along the floodplain mowed lawns with scattered trees are the typical vegetation.

The Pennsylvania Fish and Boat Commission is currently conducting a pre-construction in-stream habitat assessment that will be utilized to evaluate the effectiveness of the restoration effort.

V. Channel Morphology and Stability Assessment

A. Assessment Methods

1. Previous Work Effort

During Summer 2001, the geomorphic features of Quittapahilla Creek were mapped from the headwaters south of the City of Lebanon to the confluence with Swatara Creek. A morphological stream assessment was conducted during Spring 2003. This work included the detailed levels of geomorphic assessment and was critical to evaluating the overall condition and stability of Quittapahilla Creek and completion of the geomorphic component of the overall watershed assessment.

2. Current Study

a. Verifying Bankfull Channel Field Indicators.

The U. S. Geological Survey and Pennsylvania Department of Environmental Protection, Canaan Valley Institute, and Susquehanna River Basin Commission cooperated to develop regional curves for streams in Pennsylvania and selected areas of Maryland, 2005). These regional regressions were utilized to verify field indicators associated with the bankfull channel in conducting the geomorphic stream assessments along Quittapahilla Creek.

b. Level II - Morphological Description.

The reaches along Quittapahilla Creek in the project area were classified into specific categories of stream types (i.e., B4c, C4, F4, etc.) utilizing the standard field procedures recommended by Rosgen (1996).

c. Level III - Assessment of Stream Condition

The geomorphic features of Quittapahilla Creek were mapped and the overall stability assessed. The project reaches were assessed for stream channel condition and influencing factors including riparian vegetation, meander pattern, depositional pattern, debris and channel blockages, sediment supply, vertical stability, and lateral stability.

Lateral stability was evaluated using the bank erosion hazard index (BEHI), near bank stress (NBS), width/depth ratio state, and meander/width ratio. Vertical stability was evaluated using a measurement of the degree of incision or bank height to bankfull ratio and a sediment entrainment analysis.

B. Findings of Channel Morphology and Stability Assessment

Although there are several broad sweeping meanders in along the project reaches, the overall channel plan form is characterized by relatively low sinuosity indicative of historic channel straightening. Channel constrictions have been created by the old mill dam and the bridge at Oak Street (Route 934) at the upper and downstream ends of the project area respectively, causing backwater conditions under bankfull and higher flows.

The overall conditions are characterized by lateral erosion, high sediment supply, and vertical instability (i.e., aggradation) with lateral and mid-channel bars. Results of the stability assessment show bank height to bankfull ratios along the reaches range from 1.0 – 2.4. The higher banks are susceptible to erosion and gravitational failure. The upper and lower reaches have highest percentage of unstable banks with 30% and 23%of the banks exhibiting high bank erosion potential. The middle reach was considered relatively stable with a Reach Stability Ranking of 1.3. The lower reach was considered unstable with a Reach Stability Ranking of 8.3. The upper reach was considered very unstable with a Reach Stability Ranking 14.5.

Bed aggradation is a problem throughout all reaches as evidenced by a high percent embeddedness of riffles and the development of mid-channel and lateral bars along significant portions of some of these reaches. Although debris jams were generally infrequent partial blockages were observed along the middle reach. With the exception the upper reach which has incising sections, grade control is provided throughout the project area by bedrock ledges. A number of reaches have long sections with bedrock overlain with cobble, gravel and sand.

Channel alterations along this segment include rip-rap armoring, concrete walls, in-stream habitat structures, and the old mill dam. Numerous in-stream habitat structures were installed along the reach immediately upstream of the project area in Quittie Creek Nature Park. Although most of the structures appeared to be functioning as intended, a steep, constructed riffle near the middle of the reach was directing flow into the adjacent right bank causing considerable erosion. This section of stream has been repaired. However, field observations indicate this spot may continue to be a problem. The old mill dam on in the current project area functions as a barrier to fish migration under extreme low flow conditions.

Much of this area has considerable riparian buffer composed of mature woods. However, the lack of a riparian buffer is a common in the residential neighborhood along the floodplain of the lower reach where mowed lawns with scattered trees are the typical condition.

The following photographs were taken along the project area in May 2008 and July 2010.

Eroding banks and debris jam in upper project reach

Eroding banks and debris jam in upper project reach

Eroding banks in middle project reach

Lateral bar along middle project reach

Eroding banks in middle project reach

Eroding banks in lower project reach

Eroding banks in lower project reach

Over-wide channel with algal growth and heavy sedimentation at downstream end of project

Bank erosion along tributary

Remnants of an old mill dam located in the upper section of the project area creates a migration barrier to fish under low flow conditions.

In addition, an old road bed and historic rubble fill have encroached on the floodplain adjacent to the old dam increasing stress on the banks.

The Town of Annville erected a new footbridge over Quittapahilla Creek allowing Park visitors to enter the Park from either side of the creek.

VI. Restoration Design

A. General Approach

As pointed out in the Findings of Channel Morphology and Stability Assessment Section, Quittapahilla Creek was historically impacted by the construction of a low-head mill dam. In addition, the stream reaches upstream and downstream of the old dam are experiencing instability including bank erosion and aggradation.

The restoration objectives for Quittapahilla Creek include:

The objectives of the proposed restoration project are to reestablish a narrower, stable channel cross-section, restore floodplain, stabilize eroding streambanks, reduce sediment loading to downstream reaches contributed by the eroding banks, improve sediment transport through the project area, restore fish passage through the upper project reach and improve in-stream habitat throughout the project area. The project proposes to restore 3450 linear feet of Quittapahilla Creek from a point 450 feet above the old dam to a point immediately upstream of the Route 934 Bridge. In addition, approximately 100 linear feet of an unstable tributary will be stabilized.

The restoration approach involves:

Upper Reach

- Creating a narrower cross-section and improving sediment transport capacity along the over-wide channel by installing toe benches and rebuilding banks along the channel margins
- Grading, reconstructing and stabilizing the eroding streambanks utilizing toe benches and toe wood, erosion control matting, and native grasses, trees and shrubs. In most areas, reconstructing the banks will be accomplished by working channel-ward of existing banks to minimize grading of the banks and the loss of trees and riparian vegetation.
- Modifying the channel profile to create streambed features that increase the pool to riffle ratio and improve overall pool and riffle habitat.
- Providing grade control, diverting flow away from the banks and creating in-stream habitat by installing structures composed of native materials (logs, boulders, cobble and gravel).

Old Mill Dam

- Reconstructing the channel section to provide fish passage by installing boulder step-pools and boulder cascades upstream, through, and downstream of the dam
- Removing the old roadbed and rubble fill
- Grading and stabilizing the banks and floodplain

Middle and Lower Reaches

- Creating a narrower cross-section and improving sediment transport capacity along the over-wide channel by installing toe benches and toe wood rebuilding banks along the channel margins.
- Grading, reconstructing and stabilizing the eroding streambanks utilizing toe benches and toe wood, erosion control matting, and native grasses, trees and shrubs. In most areas, reconstructing the banks will be accomplished by working channel-ward of existing banks to minimize grading of the banks and the loss of trees and riparian vegetation.
- Modifying the channel profile to create streambed features that increase the pool to riffle ratio and improve overall pool and riffle habitat.
- Providing grade control, diverting flow away from the banks and creating in-stream habitat by installing structures composed of native materials (logs, boulders, cobble and gravel).

Tributary

- Grading and stabilizing the eroding streambanks

- Reconstructing the channel section to provide grade control by installing boulder step-pools

Springs

Two of the three springs that enter Quittapahilla Creek along the project area will be enhanced to provide summer temperature refugia for trout.

The restoration approach presented above is illustrated in the design drawings (i.e., plan view, profile, and cross-sections) attached to this report. The design criteria are summarized in the Appendix to this report.

B. Design Criteria

1. Reference Reach Data

After determining the targeted stream types (i.e., stable form for the reaches to be restored) for Quittapahilla Creek, dimensionless ratios were taken from a reference reach data base developed from stable C4 streams in the Piedmont and Mountain Regions of Maryland, Pennsylvania and North Carolina.

2. Design Discharges

As noted in the Hydrology section of this report, three methods were used to develop bankfull discharge estimates. These included 1) bankfull regional regression equations, 2) a probability of exceedence analysis, and 3) Manning's equation and field data.

Based on this analysis it was determined that utilizing the Regional Regression estimates provided a reliable method for estimating bankfull discharge for the proposed project design.

3. Channel Geometry

After the location of streambed features (riffles, pools) and habitat structures (toe wood, log boulder j-hooks) were laid out in plan-view, the longitudinal profile was developed.

After the proposed channel plan form and longitudinal profile were completed, preliminary channel dimensions were developed utilizing the Bankfull Discharge and Hydraulic Geometry Regional Regressions for Streams in Pennsylvania and Selected Areas of Maryland (USGS et al, 2005) to determine channel cross-sectional area (A) based on the drainage area to a given reach. The calculated A and W/D ratios from our reference reach database were used to determine bankfull width Wbf = √(Wbkf / dbkf) (Abkf) and bankfull mean depth Dbf = Wbkf / (Wbkf / dbkf).

The proposed bankfull cross-sectional area, width, depth and width/depth ratios were adjusted using an iterative process that included a sediment entrainment analyses. After the adjustment the channel dimensions were checked against ratios from the reference reach database

4. Sediment Entrainment Analysis

In restoration design, entrainment analysis is utilized to verify that the proposed channel generates the shear stress needed to entrain and transport the sediment expected to be moving through the project reach under bankfull flow conditions. Sediment data gathered from riffle pavement/subpavement samples along the Quittapahilla Creek project reaches was utilized in the entrainment analysis to verify that the project channel dimensions and profile are appropriate to maintain competency of the restored reaches.

Using the following equations, the critical shear stress required to mobilize and transport the largest particle from the riffle subpavement was determined.

1. Determine ratio D_{50}/D_{50}^

   Where: D_{50} = bed material D_{50} of riffle
   D_{50}^ = D_{50} of riffle subpavement

   35.55/16.84 = 2.1

2. If ratio is 3.0 – 7.0, calculate the critical shear stress using:
   $Tci = 0.0834 (D_{50}/D_{50}\hat{}) ^{-0.872}$

3. If ratio D_{50}/D_{50}^ is not 3.0 – 7.0, calculate the ratio of Di/D_{50}

   Where: D_i = largest particle from bar or riffle subpavement
   D_{50} = bed material D_{50} of riffle (100 count in riffle)

   50.8/35.55 = 1.43

4. If ratio of Di/D_{50} is 1.3 – 3.0, calculate the critical shear stress using:

   $Tci = 0.0384 (Di/D_{50})^{-0.887}$

   $Tci = 0.0384 (50.8/35.55)^{-0.887}$

   $Tci = 0.0279$

Once the critical shear stress was determined, the minimum mean bankfull depth and average bankfull slope required to entrain the largest particle in the subpavement was calculated using:

d = Tci (Ss) (Di) / s

Where:

d = minimum mean bankfull flow depth (ft.)
Tci = critical dimensionless shear stress
Ss = sediment density (submerged specific weight)
Di = largest particle from subpavement
s = reach average bankfull slope (ft. / ft.)

d = 0.0279 (1.65) (0.167) / 0.0025
= 0.00768745 / 0.0025
= 3.1 ft.

During the design phase of the project, the critical shear stress developed in these analyses was utilized to verify that the project channel dimensions and profile are appropriate to maintain the competency of the restored reaches.