Blue Hen Creek:
An Evaluation of Stream Habitat Restoration at the UD Experimental Watershed

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Prepared to fulfill the requirements of:

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CHAPTER 1

BACKGROUND AND JUSTIFICATION

Introduction

There are several techniques available to use when restoring a watershed, the best technique depends on the contributing factors to the degradation of the watershed. The Christina Basin is a Piedmont Watershed located in Northern Delaware and Southern Pennsylvania and has been selected for restoration by the state and federal governments (Kauffman, Wozniak, and Vonck, 2003). Before President Clinton left office he signed legislation designating the White Clay Creek as Delaware and Pennsylvania's first Wild and Scenic River (USNPS, 2001). This designation placed a certain amount of importance on restoring the White Clay Creek, a part of the Christina River Basin, to more ideal conditions. One way to improve the conditions of the White Clay Creek is to restore its tributary streams.

Stream restoration was chosen as the primary restoration technique for the White Clay Creek and the Christina River Basin. The biggest factor when performing any type of restoration is deciding the desired end result of the restoration. Especially with changes in the surrounding land use, restoring a stream to its historic conditions may not be successful because of changes in the hydraulic needs of the area; the stream needs to be restored to the stream type that will be the most stable under the present conditions regardless of the historic stream type (Gracie, 2003). Streams are not static entities but are dynamic systems that naturally make lateral movements and these lateral movements are part of a healthy, stable stream. Changes in the grade of the stream channel leads to stream instability.

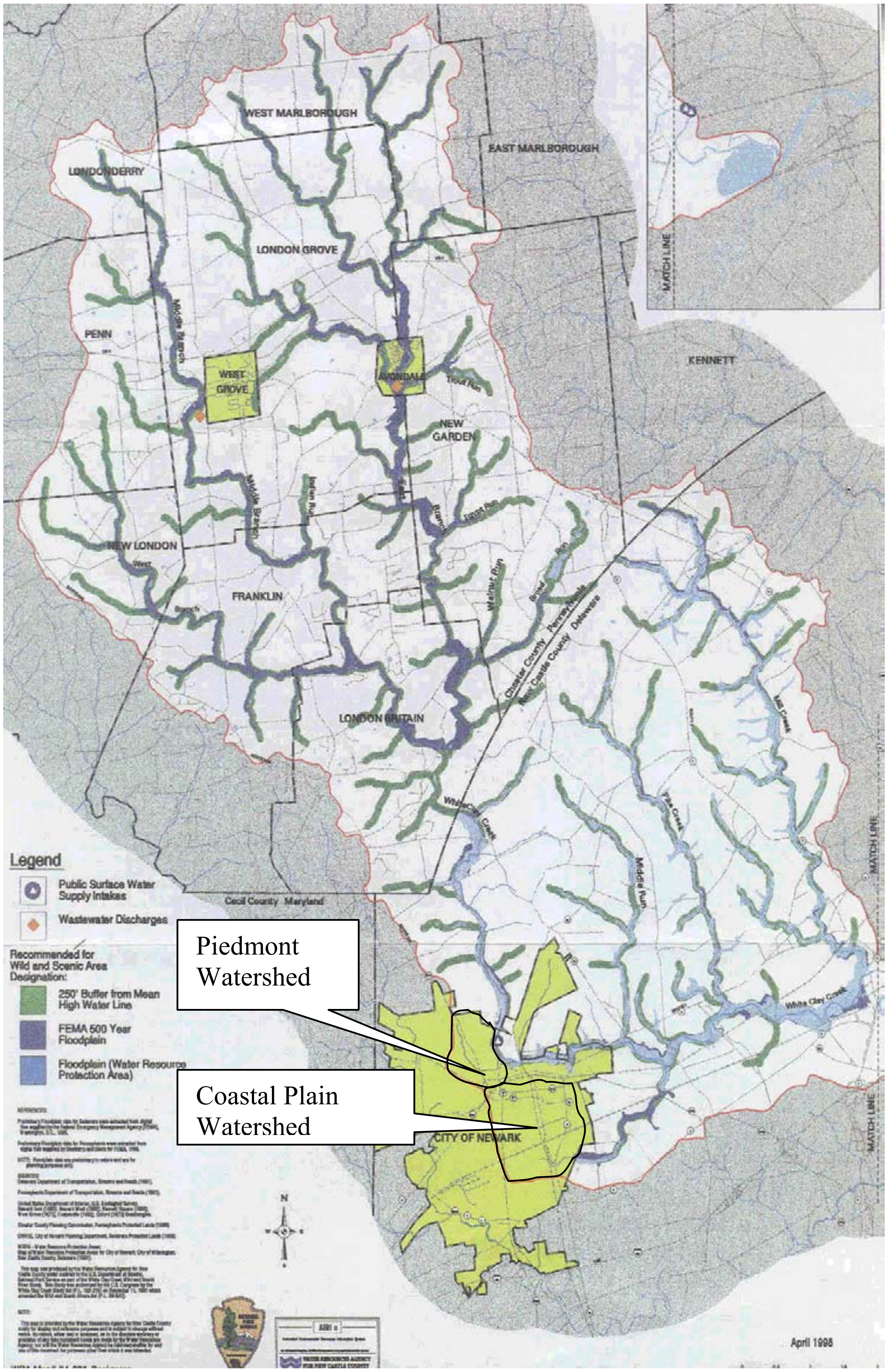
Previous Research

The University of Delaware Experimental Watershed was designed and delineated in 2001 by student researchers under the direction of project advisor Gerald Kauffman with funding from the Delaware Water Resources Center (Campagnini 2001). The main goal of the project was to provide a foundation for the research and educational use of the watersheds on the campus. Because the University of Delaware campus sits on the fall line between the Piedmont and Coastal Plain physiographic provinces, two subwatersheds were delineated. The Piedmont sub-watershed comprises three tributaries to the White Clay Creek: the Lost Stream, Fairfield Run, and Pencader Creek (later renamed Blue Hen Creek). The Coastal Plain sub-watershed comprises a portion of Cool Run and four of its unnamed tributaries. Figures 1.1, 1.2, and 1.3 show the location of the University of Delaware Experimental Watershed.

Figure 1.1: Location of the UD Experimental Watershed within the Delaware River Watershed

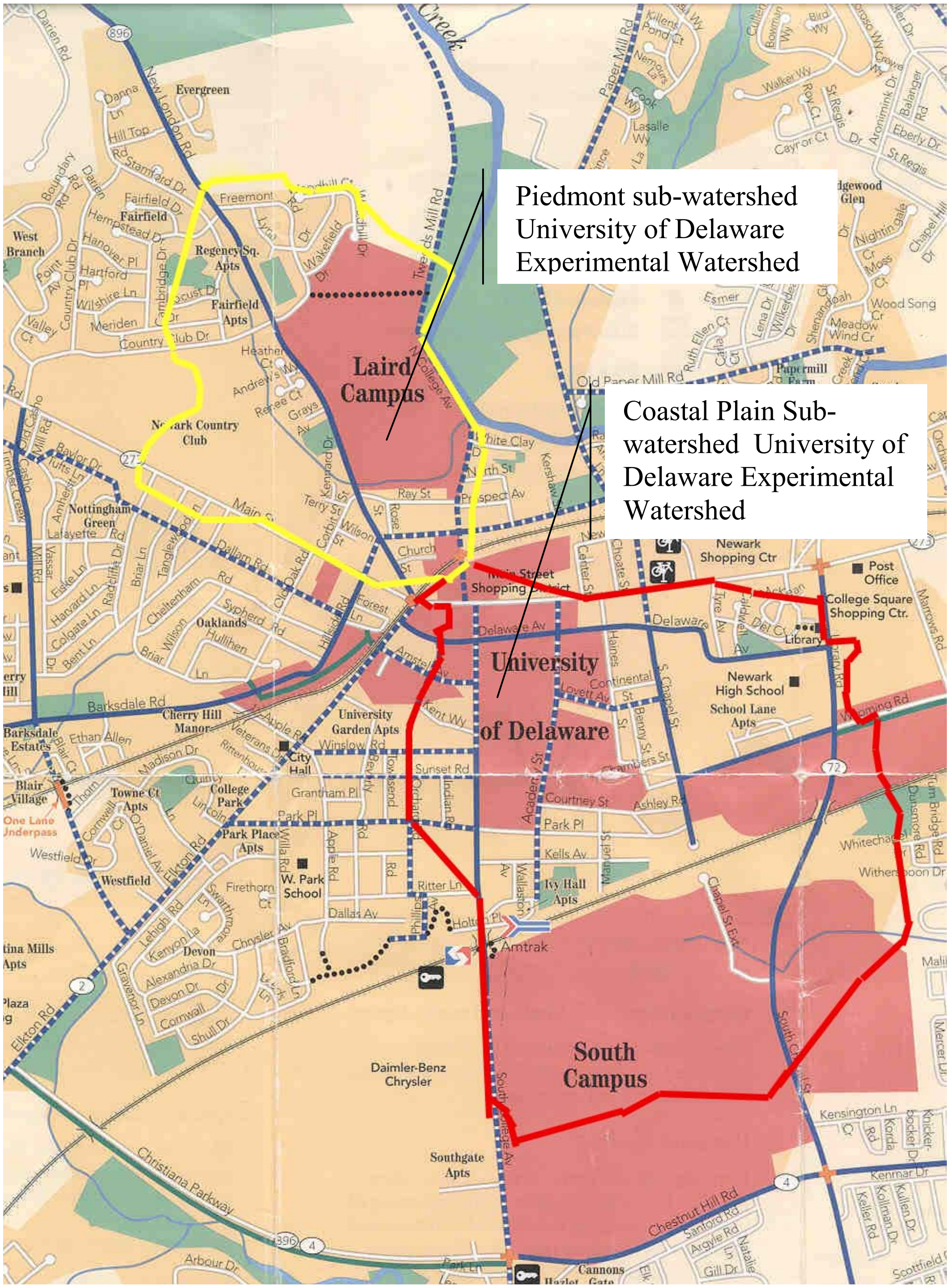
(Campagnini, 2001)

Figure 1.2: The White Clay Creek Watershed



(Campagnini, 2001)

Figure 1.3: The University of Delaware Experimental Watershed



(Campagnini, 2001)

The first phase of the UD Experimental Watershed project developed a watershed report card, which graded overall watershed quality based on Water Quality, Land Use, Impervious Cover, and Habitat Analysis (Campagnini, 2001). Research in the second phase of the UD Experimental Watershed updated the report cards and found that land use significantly impacts stream quality and watershed health (Harrell 2002). The results of the watershed report cards for the Piedmont sub-watershed are shown in Tables 1.1and 1.2. The current research into stream restoration on the streams of the Piedmont sub-watershed is based on the results of this previous research.

Table 1.1: Piedmont Watershed Report Card 2001

PIEDMONT WATERSHED REPORT CARD					
STREAM	***WATER QUALITY***	***LANDUSE***	***IMPERVIOUS COVER***	***HABITAT ANALYSIS***	***FINAL GRADE***
PENCADER CREEK					C
P1PC	2.5			2.7	2.3
P2PC	2.6	3.1	1.0	2.9	2.4
P3PC	2.5			2.4	2.2
FINAL GRADE	**2.5**	**3.1**	**1.0**	**2.7**	**2.3**
FAIRFIELD RUN					C+
P5FR	2.8			3.1	2.5
P6FR	2.6	3.3	1.0	2.5	2.3
P7FR	2.6			2.7	2.4
FINAL GRADE	**2.7**	**3.3**	**1.0**	**2.8**	**2.4**
LOST STREAM					B
P9LS	2.9	3.8	3.0	3.0	3.2
FINAL GRADE	**2.9**	**3.8**	**3.0**	**3.0**	**3.2**
WATERSHED FINAL GRADE	**2.7**	**3.4**	**1.7**	**2.8**	**2.6**
WATERSHED FINAL LETTER GRADE*	**B-**	**B+**	**C-**	**B-**	**B-**

(Campagnini 2001)

Table 1.2: Piedmont sub-watershed Report Card 2002

PIEDMONT WATERSHED REPORT CARD					
STREAM	WATER QUALITY	HABITAT ANALYSIS	LANDUSE	IMPERVIOUS COVER	FINAL GRADE
BLUE HEN CREEK					C
P1PC	2.69	1.9	3.1	1.0	2.2
P2PC	3.1	2.4			2.4
P3PC	2.8	1.8			2.2
FINAL GRADE	2.8	2.0	3.1	1.0	2.2
FAIRFIELD RUN					C
P5FR	3.1	2.0	3.3	1.0	2.4
P6FR	3.1	2.8			2.6
P7FR	2.9	2.3			2.4
FINAL GRADE	3.0	2.4	3.3	1.0	2.4
LOST STREAM					B+
P9LS	n/a	n/a	3.8	3.0	3.4
FINAL GRADE	n/a	n/a	3.8	3.0	3.4
WATERSHED FINAL GRADE	2.9	2.2	3.2	1.7	2.5
WATERSHED FINAL LETTER GRADE*	B-	C	B	C	C+

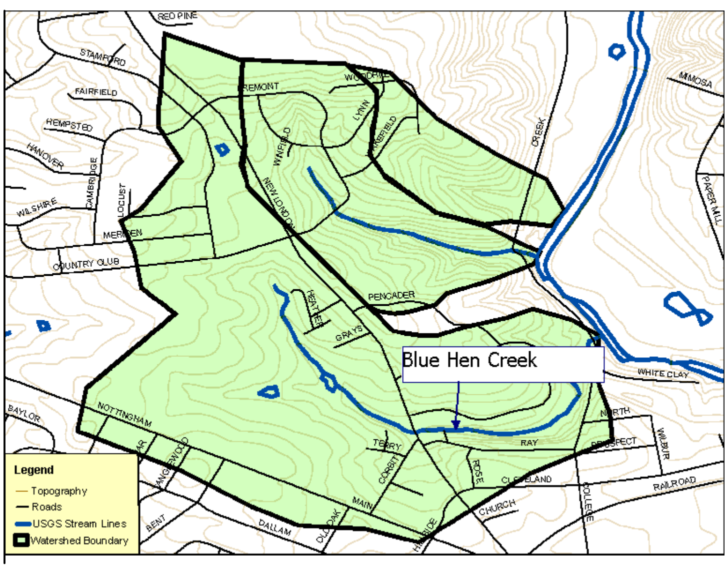
(Harrell 2002)

Previous researchers have found that the Experimental Watershed scores low for sediment deposition, channel flow status, bank stability, and riparian vegetation zone in habitat surveys (Harrell 2002). These findings combined with the current conditions of Blue Hen Creek in the University of Delaware's Experimental Watershed makes the stream a good candidate for successful restoration.

Description

The Blue Hen Creek, located in the Piedmont sub-watershed of the University of Delaware Experimental Watershed, has been selected for restoration because of the current conditions in the stream. At the headwaters of Blue Hen Creek is The Newark Country Club Golf Course and the creek flows in a southeasterly direction through the University of Delaware's Laird Campus and continues on until it reaches the White Clay Creek. The creek is also downstream of Rte 896 (New London Road). Blue Hen Creek is responsible for draining 281.6 acres of the Experimental Watershed. The primary land uses in the watershed are Residential (47%), Forested/Open (39%), and Commercial/Institutional (15%). These land uses give the watershed an estimated 33% impervious cover, which is considered to be non-supportive of aquatic life (Campagnini, 2001).

Figure 1.4: Location of Blue Hen Creek in the Piedmont Watershed



A large portion of the stream bank is structurally sound except for an area where it appears that someone dumped broken slabs of concrete down one side of the bank to keep the bank from falling in and another area of extreme erosion near 896. However, large areas of the stream banks are covered in multiflora rose, in some areas crossing the stream channel and connecting with multiflora rose on the opposite bank. The rose does provide bank stabilization but it is a highly invasive exotic species that has forced out most of the natural vegetation and habitat. There is also an unusually high quantity of algae in the stream, which could be coming from a variety of sources including the large residential areas along the stream and the Newark Country Club Golf Course. Both of which would produce high quantities of nutrient runoff due to fertilization practices associated with lawn maintenance and turf management practices of golf courses. Along the stream are several developments and University of Delaware property, which could also be making significant contributions to the creation of the high amounts of algae. With a considerable portion of the stream on the University's North Campus near the Pencader Dorms, trash is a separate issue that will be harder to counter act but is at a level that it cannot be overlooked in this report. Researchers have found numerous grocery carts lying in the stream, and combined with the other trash found litter is making a significant negative impact to the quality of the stream.

Objectives

The objective of this project is to conduct research into methods to restore impaired Blue Hen Creek in the Piedmont province on the University of Delaware campus.

1. **Conduct literature review-** Conduct research to compile a literature review to summarize and select various candidate stream habitat restoration techniques appropriate for streams in the mid-Atlantic Piedmont.
2. **Identify candidate restoration reaches-** Identify and field locate 4 to 6 stream segments (200 to 300 feet long) as candidates for experimental stream habitat restoration techniques.
3. **Conduct a field habitat survey-** Conduct a field habitat survey of Blue Hen Creek at the University of Delaware Experimental Watershed utilizing methods derived by the US Environmental Protection Agency and the New Zealand Ministry of the Environment.
4. **Prepare restoration designs-** Prepare conceptual designs for the recommended stream habitat restoration techniques.

5. **Prepare a research report**- Prepare a research report summarizing the field habitat survey, literature review, selection of candidate stream restoration segments, and recommended stream restoration designs.

Future researchers will implement and monitor the recommended restoration designs to improve the stream quality, educational potential of the UD Experimental Watershed, and to determine the effectiveness of stream restoration techniques on smaller tributaries of Mid-Atlantic Piedmont waterways.

CHAPTER 2
METHODOLOGY

The research project had several steps to reach completion so the report is separated in subsections for organizational purposes. The subsections are organized as follows: Task 1- Literature Review, Task 2- Identification of Reference Stream Reach, Task 3- Candidate Restoration Reach Selection, Task 4- Chemical Water Quality Tests, Task 5- Stream Habitat Surveys, Task 6- Stream Geomorphology Surveys, and Task 7- Restoration Design.

Task 1 - Literature Review

The student researchers conducted a review of the literature on stream restoration techniques in order to identify the techniques best suited to the streams in the UD Experimental Watershed. The information collected was then used to create a matrix to compare the many techniques side by side.

Task 1.1. Collect resources on stream restoration. Gather books, manuals, and articles on stream restoration from the University of Delaware Morris Library, the Internet, and University of Delaware Water Resources Agency materials. Table 2.1 summarizes the review of literature sources.

Table 2.1 Stream Restoration Literature

Citation	Description
Gracie, J. W., 2003. "Geomorphic considerations in Stream Restoration." Wet Weather Flow in the Urban Watershed: Technology and Management. Eds. Richard Field and Daniel Sullivan, Pp. 343-368.	A detailed description of and procedure for the Rosgen classification of streams with photographs of some of the stream types; also included are applications of the Rosgen classification to problems and restoration design.
Gore, J. A., Bryant, F.L., and Crawford, D. J., 1995. "River and Stream Restoration." In Cairns, J. Jr. Rehabilitating Damaged Ecosystems, Second Edition, Pp. 245-270	Provides general descriptions and evaluations of techniques for restoration of hydrology, water quality, bank stability (including both hard and soft engineering techniques, macroinvertebrate habitat, and fish habitat.
Schult, D. T. and Cundy, Dr. T. W., 1996. "Stream Stuctures for Fish Habitat Restoration in Potlatch Creek, Idaho." American Water Resources Association. Watershed Restoration Management: Physical, Chemical, and Biological Considerations. Pp. 57-67.	Discusses the placement of structures including log deflectors, rock weirs, rock islands, stumps, and revetments. Success rates, measurements of pools created, changes in fish populations, and suggestions for future projects are included.
Miller, D. E., 1999. "Deformable Stream Banks: Can We Call It Restoration Without Them?" American Water Resources Association. Wildland Hydrology, Pp. 293-300.	Describes the use of deformable stream banks, or those that are stabilized for the short term but able to migrate over time, in restoration design.
Doll, B. A. et. Al., 2003. Stream Restoration: A Natural Channel Design Handbook. North Carolina Stream Restoration Institute and North Carolina Sea Grant. <http://www5.bae.ncsu.edu/programs/extension/wqg/sri/stream_rest_guidebook/sr_guidebook.pdf>, Pp. 1-128.	Detailed instructions all levels of the Rosgen Classification System, describes specific calculations for "natural channel design" in major stream reconstruction projects.
The Federal Interagency Stream Restoration Working Group, 2001. Stream Corridor Restoration: Principles, Processes, and Practices. <http://www.usda.gov/stream_restoration>, Pp. 1-1-B-1.	Comprehensive guide to stream restoration including background on processes, planning and coordination, design, and monitoring including the human dimension of restoration planning.
Tjaden, B. and Weber, G. W., 1999. "Riparian Buffer Management: Soil Bioengineering or Streambank Restoration for Riparian Forest Buffers." University of Maryland Publications. FS-729. <http://www.agnr.umd.edu/MCE/Publications/Publication.cfm?ID=91>, Pp. 1-4.	Outlines six soil bioengineering techniques: live staking, conventional plantings, live fascines, branch packing, brush layering, and brush mattressing.
Tennessee Valley Authority, 2003. "Using Stabilization Techniques: To Control Erosion and Protect Property." <www.tva.gov/river/landandshore/stabilization>, Pp. 1-4.	Describes in detail several different types of restoration techniques with design drawings and organized chart of details of the techniques included.

Task 1.2. Create a stream restoration technique matrix. The sources collected were used to create a table of stream restoration techniques to visually compare those techniques side by side. The table was formatted with the following headings:

- Type/Purpose - General purpose of the restoration technique (e.g. bank stabilization or habitat improvement). While many restoration techniques serve multiple functions, grouping techniques by primary purpose allowed the researchers to choose from a smaller group of techniques when addressing a specific problem.
- Technique - The specific stream restoration technique (e.g. root wads or gabions).
- Use- The specific purpose of the restoration technique and preferences and/or limitations for placement.
- Description - Physical description of the structures or methods used.
- Labor Requirement - Labor required to implement the technique. Whether or not construction can be done by hand was included. Techniques with low labor requirement and that can be implemented by hand (possibly by university students) were preferred for stream restoration in the UD Experimental Watershed.
- Materials - The building materials required to implement the restoration technique. Techniques using natural materials and those available on-site are preferred.
- Cost - The general range of costs for each technique. While costs can vary widely depending on the source of materials, techniques with lower costs were preferred for this project.
- Sources - The source of information on the restoration technique. This also provided a reference for the researchers to refer to original sources for more detailed information and diagrams while selecting restoration techniques.

Task 2 - Identification of a Reference Stream Reach

A review of the relevant literature found that the identification of a reference reach or a reference stream is recommended for stream restoration projects (FISRWG, 2001). This stream or reach then serves a reference condition to compare with restoration areas. The area chosen should be relatively undisturbed and should therefore exhibit physical, chemical, and habitat characteristics that are closer to the ideal for the region. Because of the human disturbances in both the upstream and downstream sections of the creek, choosing a nearby stream rather than a reach of Blue Hen Creek, as a reference site was preferable especially considering the large amount of litter found in and around the stream. The researcher chose a tributary of the White Clay Creek in White Clay Creek State Park that met the criteria to be used as a reference stream. The reference stream itself is located downstream from Wedgewood Road, near Creek Road, and approximately 1.5 miles north from the City of Newark.

Task 2.1: Identify a candidate reference stream - The researchers chose a stream that exhibited a stable condition and was accessible for data collection.

Task 2.2: Delineate reference stream watershed - The researchers delineated the watershed of the reference stream using Geographic Information System (GIS) Arc Map software and the procedure described by the previous researchers (Campagnini, 2001). Orthophotos were used to confirm the relatively undisturbed condition in the reference watershed.

Task 3 - Candidate Restoration Reach Selection

Blue Hen Creek and the chosen reference stream were flagged at 100-foot intervals in order to provide points of reference for restoration reach selections, stream quality surveys, and restoration design. Candidate sites for restoration on Blue Hen Creek were chosen using field notes and photographs from each 100-foot reach.

Task 3.1: Measure Blue Hen Creek and reference stream. Beginning at the mouth of each tributary, the researchers measured 100-foot intervals along the stream channel. Tying a flag with the station number to nearby vegetation marked each interval. Stations were numbered in the following manner: station 0 + 0 is the mouth of the stream; station 1 + 0 is 100 feet upstream of the mouth, etc.

Task 3.2: Gather field notes and photographs on Blue Hen Creek and reference stream. Notes were taken for each 100-foot reach on Blue Hen Creek in order to select candidate restoration sites. Photographs were taken upstream and downstream at each station marker on both Blue Hen Creek and reference stream.

Step 3: Choose candidate reaches for restoration on Blue Hen Creek. Using photographs and notes, one candidate restoration reach was chosen on Blue Hen Creek. The site was chosen based on presence of bank erosion, lack of native vegetative cover or stabilization, and channel stability. City of Newark tax parcel maps were also used to ensure candidate restoration reaches were within University of Delaware property boundaries.

Task 4 - Chemical Water Quality Tests

Chemical properties of water are an important aspect of stream health because the aquatic life of the stream depends on a specific chemical balance to survive (Harrell 2002). Two sets of chemical water quality tests were taken using LaMotte Company Water Testing kits. The first was taken at the Blue Hen Creek sampling sites chosen by the previous researchers and three sites on the reference stream. The second set was taken in conjunction with Habitat Surveys on the candidate restoration areas of Blue Hen Creek and on a single site on the reference stream. This set of tests will serve as a base line for comparison with restoration reaches after restoration techniques have been implemented.

Table 2.2 shows the rating system used for the results of chemical water quality tests. This system, devised by the previous researchers, gives a rating of 4 for levels within the recommended daily limits. There is then a one-point decrease in the rating for each 25% deviation in the quantity of pollutant from the guideline (Harrell 2002).

Table 2.2. Water Quality Grading by Parameter

PARAMETER	4	3	2	1	Max. Limit
Alkalinity (ppm)	<20-50	50-100	100-150	>150	200
Ammonia (ppm)	<1	2-2.9	3-4	>5	10
Chloride (ppm)	<40	40-60	60-150	>150	250
Chlorine (ppm)	<0.1	0.1-0.2	0.2-0.4	>0.5	0.5
Chromium (ppm)	<0.003	0.003-.01	0.01-0.03	>0.04	0.05
Copper (ppm)	<0.03	0.03-0.3	0.3-0.6	>0.6	<1
Dissolved Oxygen (ppm)	5-6	4	3	<2	5-6
BOD (ppm)	5-6	4	3	<2	5-6
Hardness	<60	60-120	120-180	>180	180
Iron (ppm)	<0.1	0.1-0.15	0.5-0.2	>0.2	0.3
Nitrate (ppm)	<4	4-5	6-8	>8	40
pH	7	6.5-6.9 or 7.1-7.5	6.0-6.4 or 7.6-8.0	<6.0 or >8.0	5.0-8.5
Phosphate (ppm)	<0.01	0.01-0.02	0.02-0.03	>0.03	0.03
Turbidity	clear	slightly turbid	turbid	opaque	
Odor	no			yes	
Sheen	no	trace	some	thick	
Hydrocarbon	no	no		yes	
Conductivity	>50	50-100	100-150	>200	

(Campagnini, 2001)

Task 5 - Stream Habitat Surveys

Assessment of habitat quality is a key component of stream restoration because one of the goals of restoration is the improvement of aquatic and riparian habitat. The suitability of stream habitat depends on both chemical water quality and other physical and biological aspects. Therefore, a system of measuring habitat quality is needed in addition to chemical testing to determine overall stream health. According to the recommendation of the previous researcher, the New Zealand National Institute of Water and Atmospheric Research Stream Health Monitoring and Assessment Kit (NZ-NIWA SHMAK) was used to conduct habitat surveys (Harrell 2002). Researchers conducted habitat surveys on candidate restoration reaches on Blue Hen Creek and on the reference stream. Table 2.3 shows the parameters measured in the NZ-NIWA SHMAK. The parameters in Part C: Habitat Quality are given point values, which can be totaled and correlated to a rating of Very Good (60-100 points), Good (40-60 points), Moderate (20-40 points), or Poor (-50-20 points) (Biggs 2001).

Table 2.3. NZ-NIWA Stream Health Assessment and Monitoring Kit Parameters

Categories
A. Recent Flow Conditions
B. Recent Catchment Cond.
Inputs/Disturbances
Activites w/in 500m
C.Habitat Quality
Flow Velocity (m/s)
Water pH
Water Temperature ('C)
Water Conductivity (mS/cm)
Water Clarity (cm)
Composition of Stream Bed
Deposits
Bank Vegetation

(Harrell 2002)

Task 6 - Stream Geomorphology Surveys

Review of the literature determined that stream geomorphology is an important aspect of stream restoration (Gracie, 2003). Surveys of the stream channel and flood plain can help to determine its current stability and the possibility of improvement through restoration techniques. Furthermore, a clear picture of the stream's physical characteristics is important for matching restoration techniques with appropriate locations. The student researchers surveyed stream cross-sections at each station (every hundred feet) along Blue Hen Creek and the reference stream. Microsoft Excel software was then used to graph the elevation data and produce cross sections and a profile for each stream.

These surveys were then combined with other data collected to complete the Rosgen stream classification system. The Rosgen method is used to classify streams in an objective manner that is mathematical and reproducible (Doll et. al, 2003). Once the classification is known the stream can be more accurately compared to other streams with known classifications. The researchers calculated the stream's classification using the Level II analysis of the Rosgen method. This level has six separate steps the results of which are charted to lead to a classification (Doll et. al, 2003).

Task 6.1: Determine single or braided channel. Through aerial photographs or field observation the number of distinct channels is determined. For a channel to be considered braided there must be at least three channels.

Task 6.2: Calculate entrenchment ratio. The entrenchment ratio provides the measure of channel incision. Divide the flood-prone width by the bank full width. The bank full width is determined in the field by the edge of vegetation or the water level when the channel is full but not flooding.

Task 6.3: Calculate width-to-depth ratio. The bank full width divided by the mean bank full depth using the cross-sectional data collected through field observations.

Task 6.4: Determine sinuosity. Divide the stream channel length by the valley length of the stream.

Task 6.5: Measure water-surface slope. Use the profile graph created from the stream geomorphological cross-sections to calculate the slope. Divide the difference in elevation by the length as measured at the center of the channel between two similar features in the stream (riffle to riffle).

Task 6.6: Determine the median size of the bed material. Through field observations determine whether bedrock, boulder, cobble, gravel, sand, or silt/clay is the dominant feature of the stream bed material.

Task 7 - Restoration Design

The researchers created a conceptual restoration plan using the stream restoration technique matrix and the field data collected.

Task 7.1: Select preferred restoration techniques. Using the restoration techniques matrix, the researchers chose techniques that were best suited to the Piedmont sub-watershed streams and had minimal labor and cost requirements.

Task 7.2: Select locations for chosen techniques. Based on the field data collected, techniques were matched with suitable locations within the candidate restoration reaches on Blue Hen Creek. Techniques and locations were verified in the field and photographs were taken to aid future researchers in locating sites and to compare with post-restoration photographs in later phases of the project.

Task 7.3: Create map of restoration plan. The latitude and longitude of each marked station on Fairfield Run was recorded during stream geomorphology surveys using a Global Positioning System (GPS) receiver. Latitude and longitude data was added to ArcMap Geographic Information System (GIS) software to create maps for use in stream restoration planning. This enabled the researchers to correlate field stations with maps for restoration planning.

CHAPTER 3

RESULTS and DISCUSSION

Literature Review

Table 3.1 compiles all of the literature reviewed in a usable, comprehensive format a stream restoration technique matrix. The techniques are broken down by use, cost, materials, required labor, etc. From this matrix, the researchers could easily eliminate certain techniques based on budget constraints or ability to apply the techniques to the stream. For example, techniques requiring heavy machinery were eliminated because most of the restoration sites are inaccessible to machinery such as a backhoe.

Table 3.1: Stream Restoration Technique Matrix

Type/Purpose	Technique	Use	Description	Labor Requirement	Materials	Cost	Sources
Bank Stabilization	Bank Shaping	Stabilize slope to increase the success rate of the other restoration techniques being applied.	Removal of soil to reduce the slope of very steep banks to a more stable angle.	Hand tools or power machinery	Place to put the removed soil	Moderate to high	TVA. "Using Stabilization Techniques"
	Vanes: single and J-hook	Direct flow away from banks towards the center of the channel. Single vanes protect the bank. J-hooks protect bank and create a scour hole by flow convergence to dissipate energy and create habitat.	Single vanes are spaced along the outside of a meander bend at an angle of 20-30 degrees with the bank. J-hook is similar to single vanes, but the last 2-3 rocks are spaced 1/2 rock diameter apart in a J shape.	Hand tools or power machinery	Flat boulders and smaller footer rocks	Moderate	Gracie 360. Doll et. al. 87-88.
	Stone Toe Protection	Deflects flow from the bank, stabilize the slope, and promote sediment deposition.	Ridge of quarried rock or stream cobble placed at the toe of the streambank.	Hand tools	Rocks	Low	FISRWG A-16.
	Root Wads	Protect outside of meander bends from high flows. Most successful for gentle meanders upstream of vegetation to prevent back eddy erosion.	Part of tree with is inserted in bank with root wad towards stream so that flow intersects root wad at a 90-degree angle.	Track hoe with hydraulic thumb or hand tools	Root wad with 10-24 in basal trunk diameter and 10-15 ft trunk remaining, footer logs, boulders	Moderate to high	Gracie 360. Doll et. Al. 84-86.

Table 3.1: Stream Restoration Technique Matrix

Type/Purpose	Technique	Use	Description	Labor Requirement	Materials	Cost	Sources
	Rock Riprap	Provides toe protection, upper bank protection, and run-off control. Requires good design and construction.	Large stones along the slope of a bank to stabilize the soil.	Light to heavy power machinery	Rocks	Moderate to high	TVA. "Using Stabilization Techniques"
	Gabions	Provides toe protection, upper bank protection, and run-off control. Can reduce or eliminate the need for bank sloping by creating a vertical wall.	Wire baskets filled with rocks placed along bank.	Light to heavy power machinery	Wire and rocks	High to very high	TVA. "Using Stabilization Techniques"
Bank Stabilization/ Re-vegetation	Tree Revetments	Provides toe protection and usually used in combination with other techniques.	Rows of cut trees (usually cedar or something similar) and anchored to the toe of the bank.	Hand tools or light power machinery	Trees, anchoring material	Low	TVA. "Using Stabilization Techniques"
	Live Stakes	Stabilize the upper banks preventing further erosion	Branches of rootable plants inserted into the bank	Hand tools	Plant parts	Low	TVA. "Using Stabilization Techniques"
	Live Vegetation Planting	Stabilize slope and prevent further erosion. Provides toe protection, upper bank protection, and run-off control.	Planting of native trees, shrubs, and grasses to stabilize banks. May require some protections during root establishment.	Hand tools or light power machinery	Native plants of choice	Low	TVA. "Using Stabilization Techniques"

Table 3.1: Stream Restoration Technique Matrix

Type/Purpose	Technique	Use	Description	Labor Requirement	Materials	Cost	Sources
	Live Fascines	Stabilize banks with vegetation. Provides upper bank protection and run-off control and enhances conditions for colonization with native vegetation.	Bundles of live cuttings buried in a trench and staked.	Hand tools	Live cuttings of appropriate native vegetation, stakes	Moderate	Gracie 360. FISRWG A-14. TVA, "Using Stabilization Techniques"
	Biologs/Coconut fiber roll	Stabilize banks and create a planting medium.	Coconut fiber rolled into tubes is laid along banks, staked, and planted with appropriate vegetation.	Hand tools	Commercially produced biologs, stakes, seedlings or cuttings to plant	Moderate	Gracie 361.
	Branch Packing	Upper bank protection and provides run-off control by filling in depressions in the soil.	Live branch cuttings incorporated into compacted soil.	Hand tools	Plant material (and soil only if necessary)	Moderate	TVA. "Using Stabilization Techniques"
	Brush Mattress	Provides upper bank protection, run-off control. Provides immediate complete cover and long-term stabilization.	Live branch cuttings covering entire stream bank and secured in place.	Hand tools	Branch cuttings	Moderate to high	TVA. "Using Stabilization Techniques"

Table 3.1: Stream Restoration Technique Matrix

Type/Purpose	Technique	Use	Description	Labor Requirement	Materials	Cost	Sources
	Vegetative Geogrids	Provides toe protection, upper bank protection, and run-off control. Can be installed for steeper and higher slopes; useful in restoring outside bends where erosion is a problem.	Alternating layers of live branch cuttings and compacted soil layers wrapped in geotextile fabric to rebuild and vegetate eroded banks.	Hand tools	Soil, geotextile	High	TVA. "Using Stabilization Techniques"
Grade Control	Cross Vanes	Keep thalweg in the center of the channel, prevent down cutting, and protect bank from erosion.	Consist of two vanes on each bank connected by a central structure placed perpendicular to flow. Used at the head of riffles in small streams.	Hand tools or power machinery	Boulders or logs, footer rocks, geotextile fabric recommended	Moderate to high	Gracie 361. Doll et. Al. 88-89.
	Vortex Rock Weirs	Create downstream velocity differentials to improve habitat.	Footer rocks are placed in a V upstream and vortex rocks are spaced 1/2 diameter and leaned against footer rocks.	Hand tools or power machinery	Rocks	Low	Gracie 362.
	Step Pools	Stabilize channels on steep reaches, stabilize headcuts, and maintain fish passage in steep reaches.	A pool is created by lining the entire bottom with rocks. Usually used on steep slopes (greater than 4%).	Power machinery	Boulders with diameter of 20-28 inches	Moderate	Gracie 362.

Table 3.1: Stream Restoration Technique Matrix

Type/Purpose	Technique	Use	Description	Labor Requirement	Materials	Cost	Sources
Habitat Improvement	Log/Brush/Rock Shelters	Enhance fish habitat, encourage food web dynamics, prevent stream bank erosion, and provide shading.	Log, brush, and rock structures installed in the lower portion of stream banks.	Hand tools	Logs, brush, rocks (usually available on site)	Low	FISRWG A-6.
	Large Woody Debris	Provides snag habitat for fish and traps leaf packs.	Woody debris placed in pools or lodged under boulders.	Placed by hand	Woody debris	Low	Doll et. Al. 93.
	Boulder Clusters	Create cover, scour-holes, and areas of reduced velocity. Not recommended to sand or finer bed or for aggrading or degrading streams. Best in areas with flow >2 ft per second.	Boulders are placed in clusters in the base flow channel.	Hand tools or power machinery	Boulders	Moderate	FISRWG A-5.
	Weirs and Sills	Create pool habitat, control bed erosion, collect and retain gravel. Undermining can occur in sand bottom streams.	Log, boulder, or quarrystone structures placed across the channel and anchored to the streambank and/or bed. Can be perpendicular, diagonal, upstream or downstream V or U.	Hand tools or power machinery, rock most easily constructed	Logs, boulders, or quarrystone; cable for anchoring if necessary	Moderate	FISRWG A-5. Gore, Bryant, and Crawford 261-263.
	Wing Deflectors	Deflect flow away from bank and scour pools.	Rock or rock filled log structures that protrude from the bank but do not extend fully across the channel.	Hand tools or power machinery	Logs or rocks, geotextile fabric	Moderate	FISRWG A-8.

Table 3.1: Stream Restoration Technique Matrix

Type/Purpose	Technique	Use	Description	Labor Requirement	Materials	Cost	Sources
Reforestation	Riparian Buffers	Provide detritus and large woody debris, improve habitat, and reduce sediment, organic material, and pollutants.	Streamside vegetation.	Hand tools or light to heavy power machinery	Native plants of choice	Low to high	FISRWG A-6.
Removal of Invasive Species	Hand cutting	Allow native vegetation to become established, and promote diverse riparian community.	Multiflora rose: hand cutting or mowing 6 times per season for 2-4 years.	Hand tools or mower	None	Low	The Nature Conservancy 1.
	Herbicide	Allow native vegetation to become established, and promote diverse riparian community.	Multiflora rose: Apply glyphosate directly to plants, cut branches or stumps.	Sprayer	Glyphosate	Moderate	The Nature Conservancy 1.

Identification of a Reference Stream Research

A stream (in the process of being named Panther Run) located within White Clay Creek State Park was selected in a forested Piedmont Watershed near Blue Hen Creek and met all of the required characteristics of a reference stream. The stream selected is in an almost completely undeveloped watershed and also drains into the White Clay Creek near Creek Road and just south of Wedgewood Road. The development in the watershed is for single-family land use which creates run-off from lawn and garden fertilizers but not the extent of agricultural development. This developed section is a small area in the top corner of the watershed; however, there is a considerable forested buffer between the developed section and the selected reference stream. Therefore, almost all of the effects of the developed area are mitigated before reaching the reference stream. Figure 3.1 shows a map of the reference stream in spatial relation to Blue Hen Creek and Fairfield Run. Figures 3.2 and 3.3 show the reference and experimental watersheds with orthophotos from 1997 illustrating the forested buffer and the relatively small amount of development that is found within the reference watershed.

Figure 3.1 Reference Stream Map

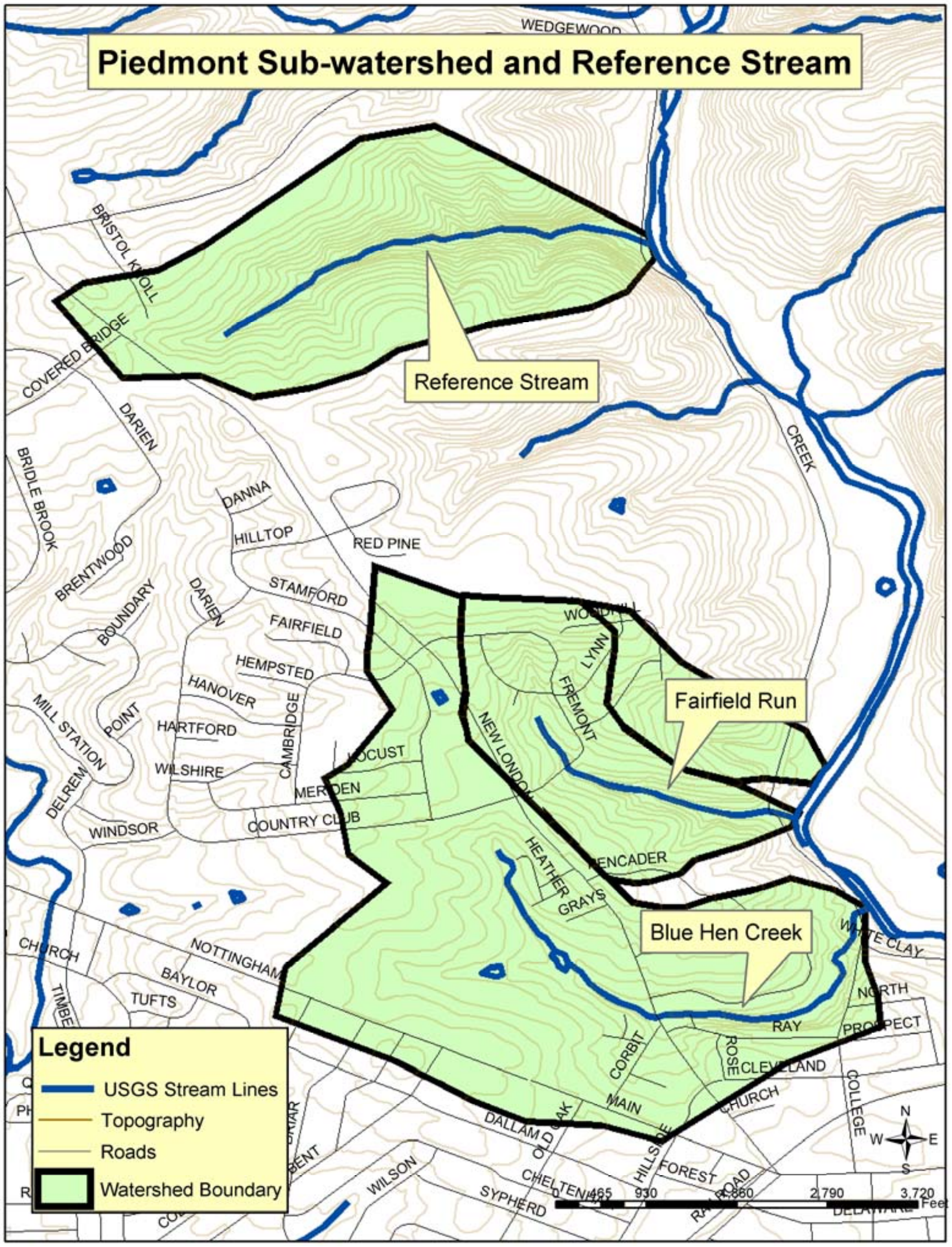


Figure 3.2: Reference Stream Watershed with Orthophoto Base Layer

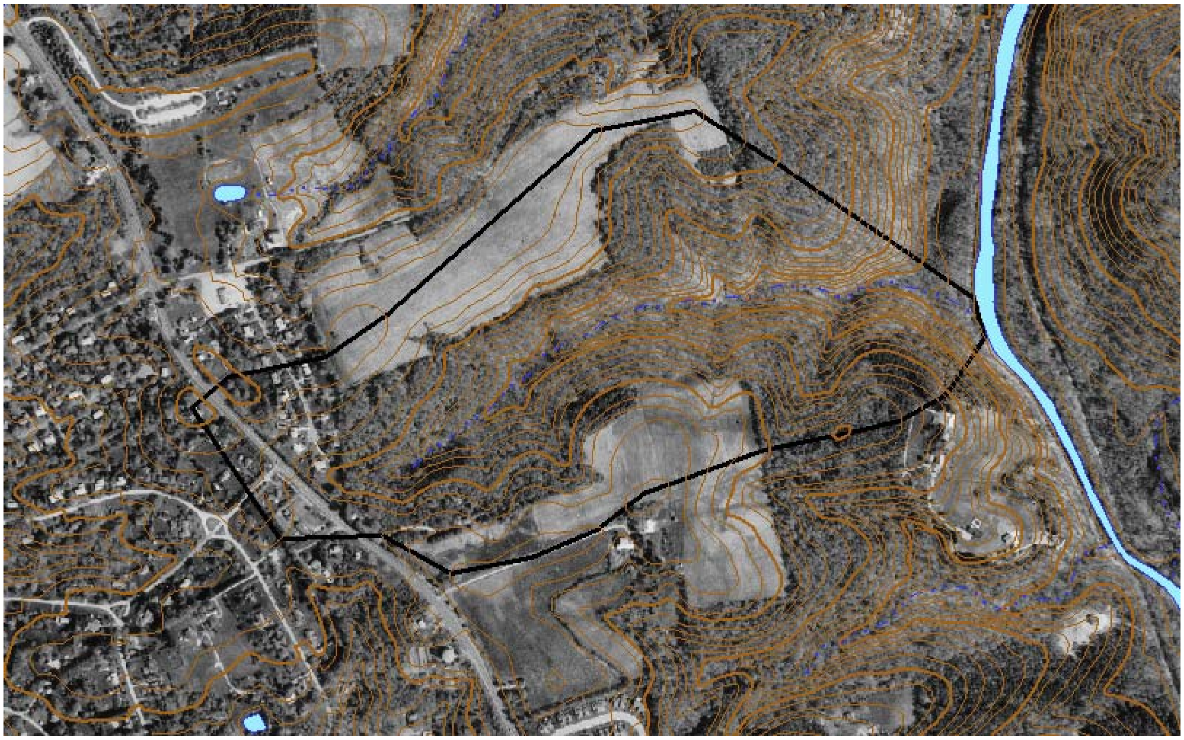
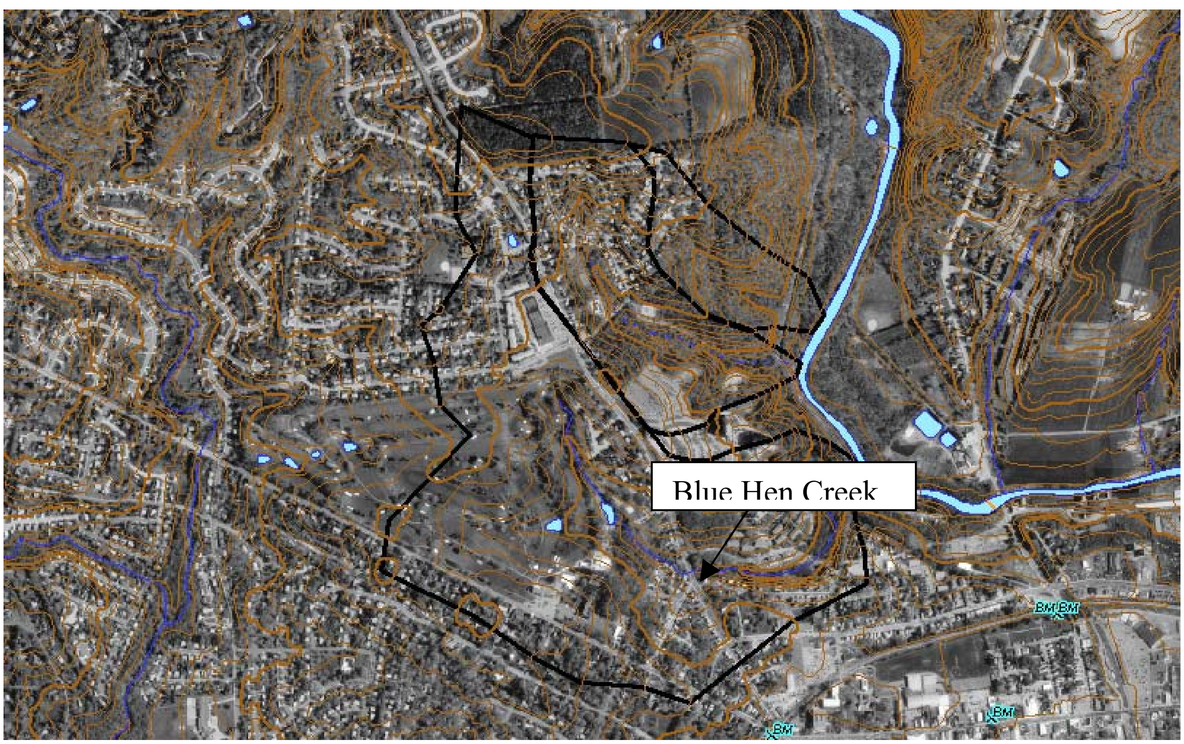


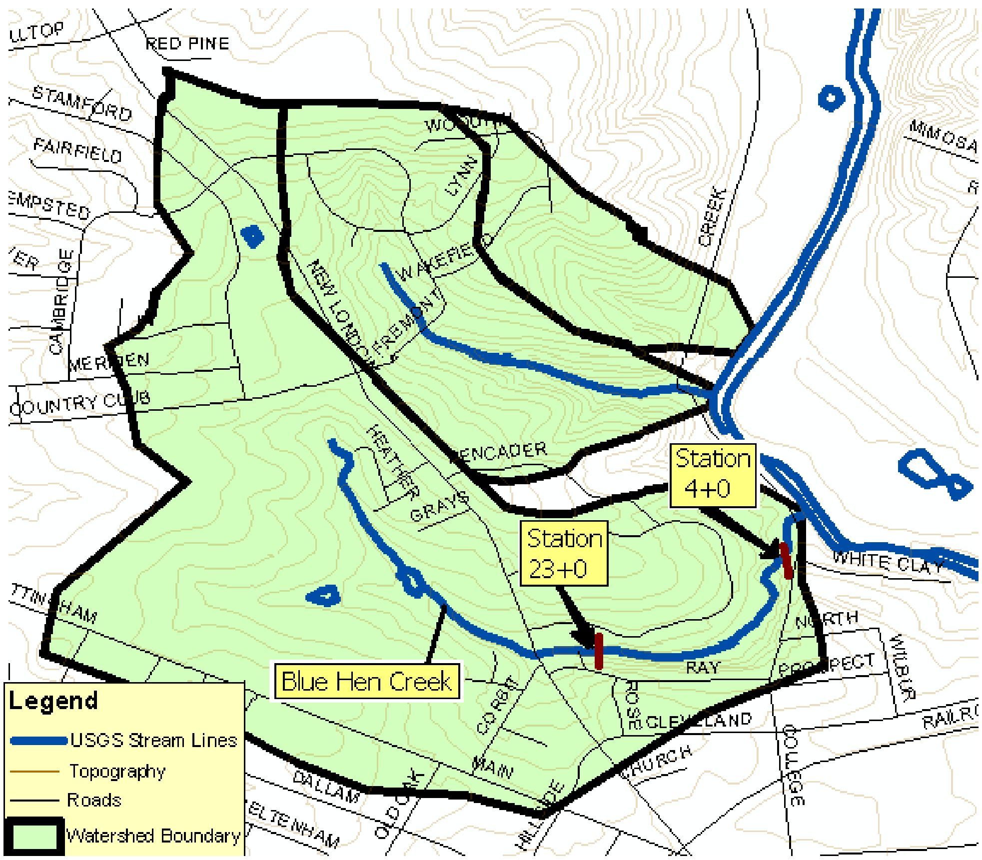
Figure 3.3: Piedmont sub-watershed with Orthophoto Base Layer



Candidate Restoration Reach Selection

Blue Hen Creek was measured with a marked station being placed at every 100 feet, beginning at 4 + 0, or 400 feet from the mouth of the stream, and ending at 23 + 0, or 2300 feet from the stream's mouth. Figure 3.4 illustrates the station endpoints of 4 + 0 and 23 + 0 in spatial reference. At each of these stations photographs, observations of erosion, vegetation, water quality, channel stability, and habitat quality were recorded. These records were then used to select the sites most in need of restoration and to select the best restoration technique to help repair the section of the stream. The areas of Blue Hen Creek that were determined to be in need of restoration are sites 11 + 0 to 23 + 0. This section of the stream has the greatest need for restoration and stations 4 + 0 to 10 + 0 are in favorable conditions considering the surrounding land uses.

Figure 3.4: Station Endpoints on Blue Hen Creek



Almost the entire bank of Blue Hen Creek from station 11+0 to station 23+0 is covered in multiflora rose. In many cases the rose has or is in the process of choking the native trees to death. This type of habitat is inappropriate for native fauna and needs to be restored to a native vegetation habitat for the health of the stream and to re-create suitable habitat for native wildlife. Other areas along this section of Blue Hen Creek had other stream health problems that need to be addressed through restoration, which is why stations 11+0 to 23+0 were chosen as candidate restoration reaches for this project. Figure 3.5 shows some photographs of areas along Blue Hen Creek that are in need of restoration to bring the stream to its ideal conditions.

Figure 3.5: Candidate Stream Restoration Sites

Clockwise from top left: multiflora rose along stream bank (14+0), vertical bank (18+0), erosion with litter from dormitories (23+0), longer look at extensiveness of the erosion (23+0).

Chemical Water Quality Tests

Researchers selected three sites along Blue Hen Creek to collect water samples for chemical water quality tests. The results of water quality tests were then compared with results from three sites along the reference stream, see Table 3.2. The highest grade Blue Hen Creek received for an individual collection site was a B and the lowest grade received was a B-. The grades on the reference stream ranged from a B to an A-. The overall, Blue Hen Creek received a water quality score 3.03 or a B- and the reference stream received 3.56 or an A-. These results reinforce the need for restoration techniques to be applied to the stream and can be used in future stages to gauge how effective the restoration techniques are at improving the quality of the water of small tributaries in a Piedmont Watershed. The results are also positive in the respect that the low scores are high enough that applying restoration to degraded areas of the stream will be effective in bringing the water quality levels to a more acceptable level.

Table 3.2: Chemical Water Quality Results for Blue Hen Creek and Reference Stream

Stream Sampling Site	Blue Hen Creek 8-21-03								Reference Stream 9-10-03							
	WCC-PC		P1PC		P2PC		P3PC		WCC-RS		1RS		2RS		3RS	
Parameters	Result	Grade	Result	Grade	Result	Grade	Result	Grade	Result	Grade	Result	Grade	Result	Grade	Result	Grade
Alkalinity (ppm)	160	1	240	1	200	1	240	1	200	1	40	4	40	4	40	4
Ammonia (ppm)	0	4	0	4	0	4	0	4	0	4	0	4	0	4	0	4
Choride (ppm)	0	4	39.2	4	33.6	4	39.2	4	0	4	0	4	0	4	0	4
Chlorine (ppm)	0	4	0	4	0	4	0	4	0	4	0	4	0	4	0	4
Chromium (ppm)	0	4	0	4	0	4	0	4	0	4	0	4	0	4	0	4
Copper (ppm)	0	4	0	4	0	4	0	4	0	4	0	4	0	4	0	4
Dissolved Oxygen (ppm)	4	3	2	1	4	3	4	3	6	4	4	3	4	3	3	2
BOD (ppm)	5	4	2	1	5	4	0	1	2	1	n/a		n/a		n/a	
Hardness (ppm)	120	3	160	2	160	2	160	2	160	2	40	4	40	4	80	3
Iron (ppm)	0	4	1	1	0	4	3	1	0	4	0	4	0.5	2	0	4
Nitrate (ppm)	4	3	1	4	2	4	0	4	2	4	0	4	1.5	4	0	4
Phosphate (ppm)	1	1	0.5	1	4	1	4	1	1	1	4	1	4	1	1	1
pH	8	2	8	2	8	2	7	4	8	2	8	2	8	2	7	4
Turbidity	Clear	4	Clear	4	Clear	4	Clear	4	Clear	4	Clear	4	Clear	4	Clear	4
Odor	No	4	No	4	No	4	No	4	No	4	No	4	No	4	No	4
Sheen	No	4	No	4	No	4	No	4	Trace	4	No	4	No	4	No	4
Hydrocarbon	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Conductivity	310	1	450	1	430	1	450	1	290	1	100	2	110	2	110	2
Overall Grade	B	3.18	B-	2.71	B	3.31	B-	3.06	B	3.19	A-	3.6	B+	3.47	A-	3.6
Stream Grade	3.03								3.56							

Stream Habitat Surveys

Stream habitat surveys were conducted on the selected restoration reaches of Blue Hen Creek as well as on the reference stream and compared to one another. Blue Hen Creek only received a moderate score while the reference stream received the high rating of Very Good, the results are shown in Table 3.3. Only one habitat survey was completed on Blue Hen Creek because at the time of data collection a large area of the stream was inaccessible due to felled trees and banks covered in multi flora rose. Based on later fieldwork, when the stream was more accessible, the amount of litter alone gives the stream a habitat score on the low end of the scale.

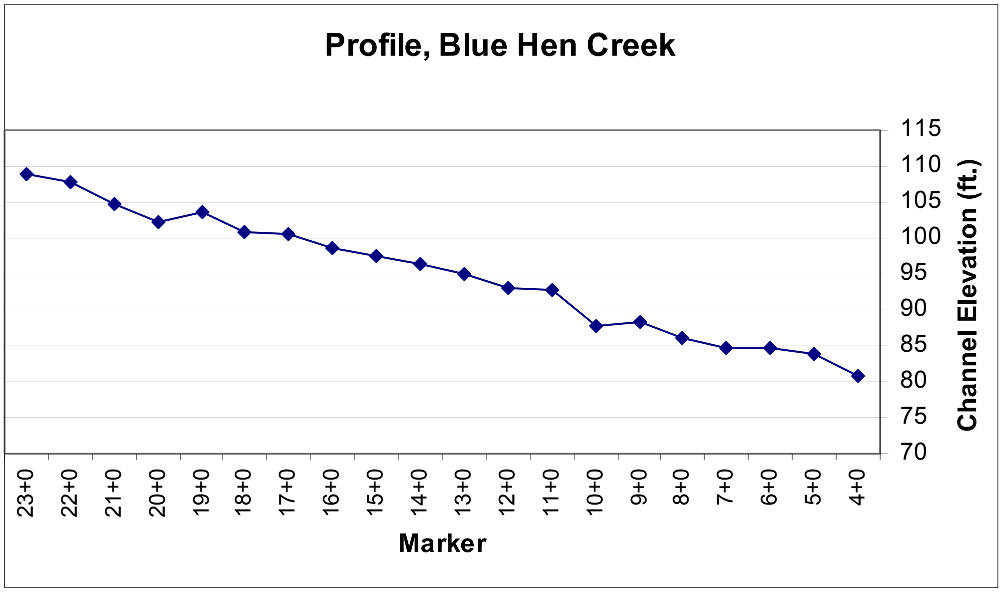
Table 3.3: Habitat Quality Survey for Blue Hen Creek and Reference Stream

NZ-SHMAK Part C: Habitat Quality Results		
Site	Reference	Blue Hen
Parameter (max. score)	Score	
Flow Velocity (10)	8	1
pH (10)	5	10
Temperature (10)	5	5
Conductivity (20)	16	6
Clarity (10)	10	10
Stream Bed Composition (20)	4.5	3
Deposits (10)	5	-5
Bank Vegetation (20)	19.5	8
Total (100)	73	38
Habitat Score	Very good	Moderate

Stream Geomorphology Surveys

An important step in restoring streams is to survey the stream's geomorphology. The survey data collected by the researchers was organized and analyzed in Microsoft Excel. Excel was also used to generate the final graphs of each stream field station as well as the stream profile. The stream profile illustrates the changes in elevation of the midpoint of the stream flow, giving the grade of the stream and showing if there are any sudden changes in the stream grade that need to be addressed through restoration. The profile of Blue Hen Creek did not give an indication of a major change in the stream gradient and sloped down in a reasonable manner, see Figure 3.6.

Figure 3.6: Profile of Blue Hen Creek



The results of the Rosgen method of stream classification are quite positive. As shown in Table 3.4, the reference stream and Blue Hen Creek received very close scores. This means that the reference stream is a good indicator of what Blue Hen Creek would be without human disturbances and that Blue Hen Creek is an excellent candidate for restoration. The main differences in the streams lie in the width to depth ratio and the water surface slope, both of which are being addressed partially through restoration. Both the reference stream and Blue Hen Creek have single channels that received entrenchment ratios that were very close with Blue Hen Creek bordering on being a slightly entrenched stream. Streams with G or F classification are severely incised and subject to erosion and downcutting, while B, C, and E streams are moderately incised and may have an increased risk of instability from disturbances. Restoration efforts that rebuild the stream channel usually try to achieve a C or E stream type (Doll et. Al., 2003). The C classification of Blue Hen Creek demonstrates that it is at risk of instability, but is not so severely incised that localized measures will be insufficient. Furthermore, the similar classification obtained for the reference stream indicates that major channel reconstruction (to obtain a different stream classification) is probably unnecessary.

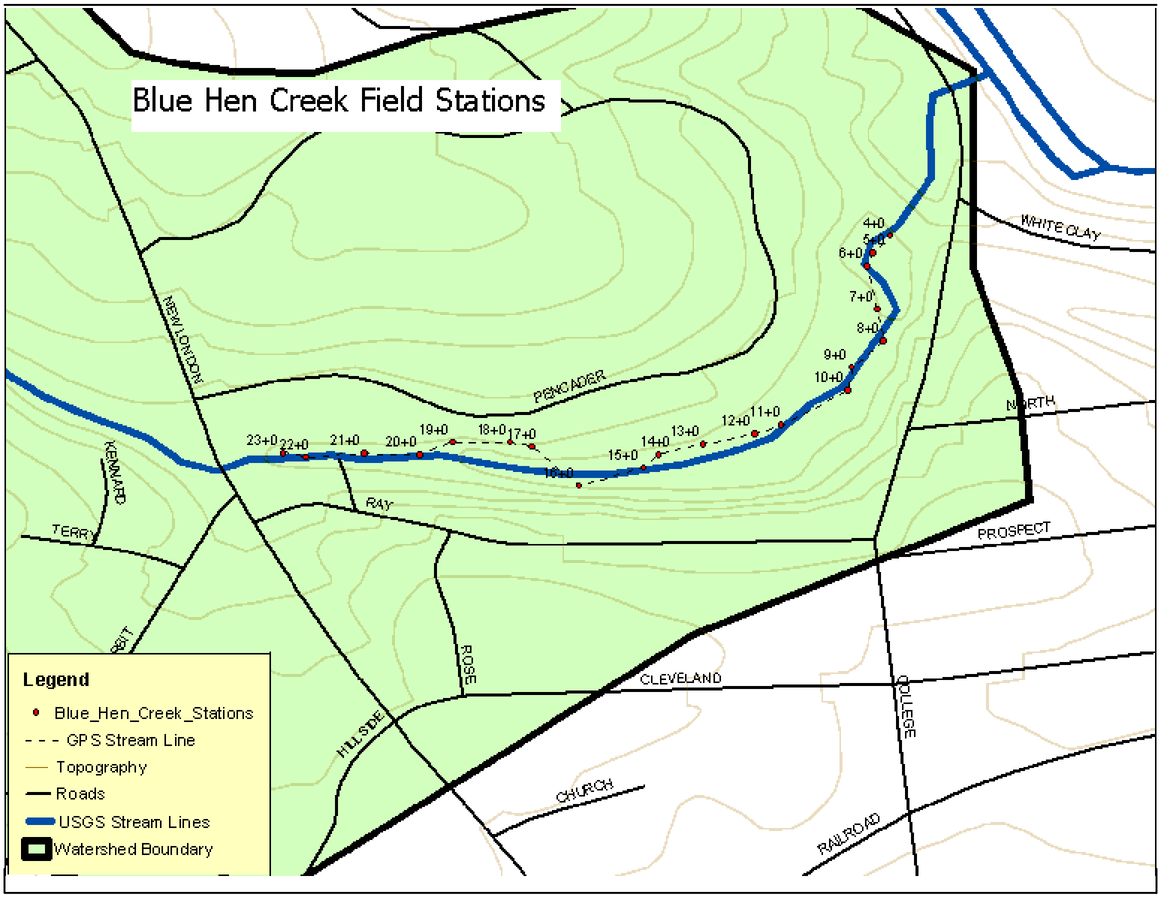
Table 3.4: Rosgen Score for Blue Hen Creek and Reference Stream

	Blue Hen Creek		Reference Stream	
	Raw Score	Evaluation	Raw Score	Evaluation
Channel Type	1	single	1	single
Entrenchment Ratio	2	moderate	2.2	slightly
Width to Depth Ratio	7.1	very low	12	moderate
Sinuosity	1.12	moderate-high	1.2	moderate
Water-Surface Slope	0.015	moderate	0.026	low
Bed Material	5	sand	3	cobble
Classification	C5		C3b	

Restoration Design

The matrix was used to determine that bank shaping, root wads, coconut fiber rolls, removal of the invasive species multiflora rose by hand cutting and by herbicide, and reforestation were the preferred restoration techniques for Blue Hen Creek. A variety of techniques were chosen in order to increase the research value of the restoration project. Information gathered during the implementation and monitoring of stream restoration techniques in the UD Experimental Watershed could be used to plan other stream restoration projects on Piedmont streams in the Christina Basin. Combining this information with field data collected, the researchers later paired these restoration methods with specific locations on Blue Hen Creek. This enabled the researchers to correlate field stations with maps for restoration planning. Figure 3.7 gives a spatial illustration of Blue Hen Creek with the GPS marked field stations. More detailed descriptions of the specific restoration plans can be found in a later section of this report.

Figure 3.7: Blue Hen Creek with GPS Marked Field Stations



CHAPTER 4
CONCLUSIONS

The researchers collected information on stream restoration and collected the data necessary to plan a stream restoration project on Blue Hen Creek in the UD Experimental Watershed. The results of the data collected reinforced the need for stream restoration and helped to identify specific problems to address with restoration techniques.

1. **Restoration Techniques** - A large variety of stream restoration techniques have been developed to address many of the problems created by human impacts on aquatic ecosystems. Techniques using natural materials are preferred for their aesthetic and habitat values. Using techniques that can be installed by hand will lower costs and improve the educational value of restoration by allowing student, faculty, and the public to participate. Figure 4.1 is a pictorial representation of each of the sites designated for restoration.

Figure 4.1: Recommended Stream Restoration Sites

Clockwise from top left: Station 14+0-removal of multiflora rose by hand cutting and reforestation, Station 16+0- wing deflectors, Station 17+0-wing deflectors, Station 19+0-removal of multiflora rose by herbicide and reforestation, Station 23+0-root wads, Station 21+0- live stakes, and Station 18+0-coconut fiber roll and bank shaping

2. **Need for Restoration** - The results of chemical water quality tests and stream habitat surveys indicate that Blue Hen Creek is impaired in comparison to the reference condition but is not too far degraded to make restoration pointless. These results can be used with future monitoring results to determine if restoration has helped return Blue Hen Creek to a more ideal condition, see Table 4.1.

Table 4.1: Reference Stream Compared to Blue Hen Creek

Location	Chemical Water Quality	Habitat	Rosgen
Reference	A-	Very Good	C3b
Blue Hen Creek	B-	Moderate	C5

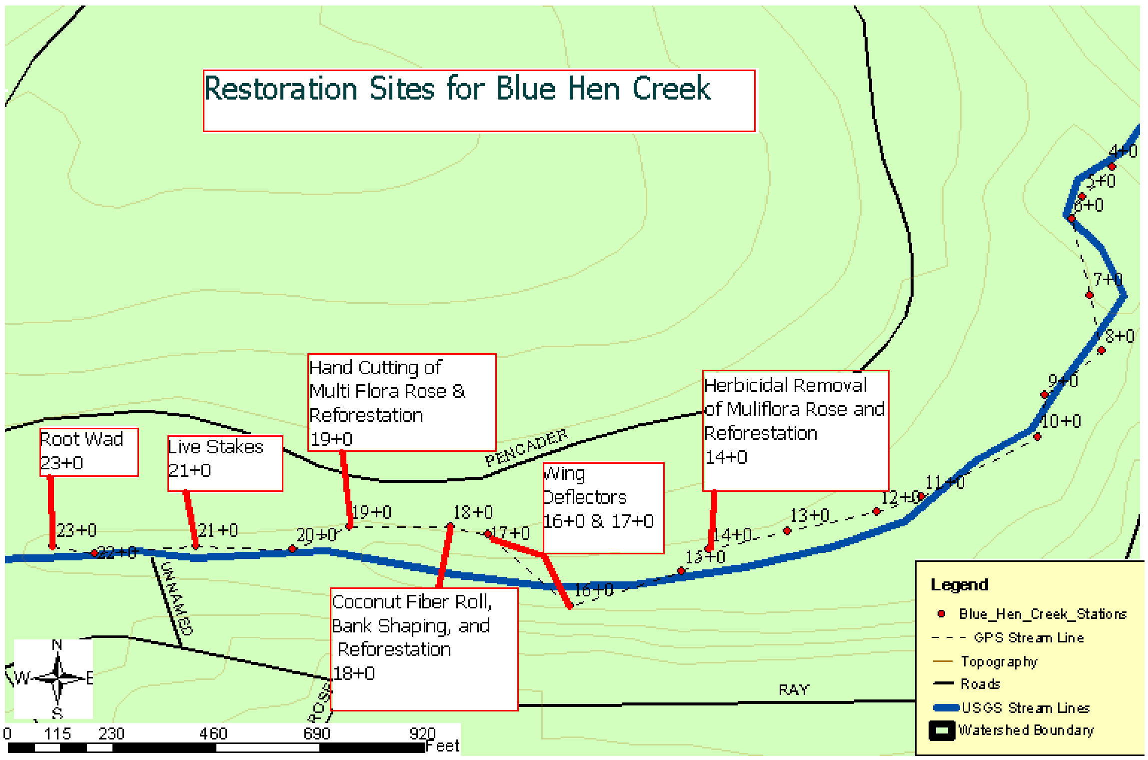
CHAPTER 5

RECOMMENDATIONS

Restoration Designs

The researchers chose field stations and restoration techniques for application on Blue Hen Creek. Nine restoration techniques are recommended for implementation on either the entire length of the stream or on specific field stations along the stream as marked in Figure 5.1.

Figure 5.1: Recommended Restoration Sites Along Blue Hen Creek



Treatment 1: Litter Removal by UD Facilities Management, Faculty/Staff, and Student Groups. Blue Hen Creek is covered in litter and it is strongly recommended that a stream clean-up be implemented as soon as possible and have the stream monitored closely in the future to prevent the stream from getting so littered again. The litter by students and local residents has only been compounded by the construction taking place on the hotel and the amount of litter greatly increases near the construction site. With the

hotel opening soon, this area of campus should be well maintained for University pride as well as for the health of Blue Hen Creek.

Treatment 2: 20ft Wide Forested Buffer. After completion of construction of the hotel and dormitories on Laird Campus a 20ft forested buffer of native trees such as maples and poplars should be placed from station 11+0 to 23+0. The buffer would bring many benefits to the stream and to the aesthetic value of this part of campus. First it would further stabilize the stream bank and help in the removal of the multiflora rose (the researchers found little to no multiflora rose along stream banks in areas of greater shade.) Secondly it would help with the litter problems facing the stream because access to the stream banks would not be so open to dumping of waste. The trees themselves would help beautify the area surrounding the hotel adding to the aesthetic value of hotel room views. However, it is not recommended that the buffer be implemented until construction on that section of Laird Campus be completed because close construction could cause the trees to become stressed and therefore increase the mortality of the planted trees unnecessarily.

Treatment 3: Herbicidal Removal of Multiflora Rose and Reforestation at Station 14+0. Multiflora rose is a highly invasive exotic species that is very hard to remove from an area once it has been established. The rose is currently choking many of the native trees currently along the stream banks to death so removal of this species needs to happen. Two types of removal treatments are recommended for Blue Hen Creek to determine which type is better suited for this area and what removal procedures are feasible given the resources available. Removal treatments must be reapplied three to four times a year for four to five years for the treatments to be effective. Station 14+0 was selected for herbicidal treatments because of its dense population of the rose. The area along the stream bank that has the multiflora rose removed needs to be reforested for two reasons. One, if the bank is left bare it will be subject to erosion problems and two, with nothing taking its place the multiflora rose will simply re-establish itself along the bank.

Figure 5.2: Muliflora Rose at Station 14+0

Treatment 4: Wing Deflectors at Stations 16+0 and 17+0. This stretch of Blue Hen Creek has been channelized and needs more variation in the stream flow. A series of deflectors will help to scour pools creating more wildlife habitat within the stream and decrease the channelization that has occurred. Deflectors can either be made out of logs or stones depending on the resources available.

Figure 5.3: Wing Deflectors at Stations 16+0 and 17+0

Figure 5.4: Cross Section of 16+0 with Wing Deflector

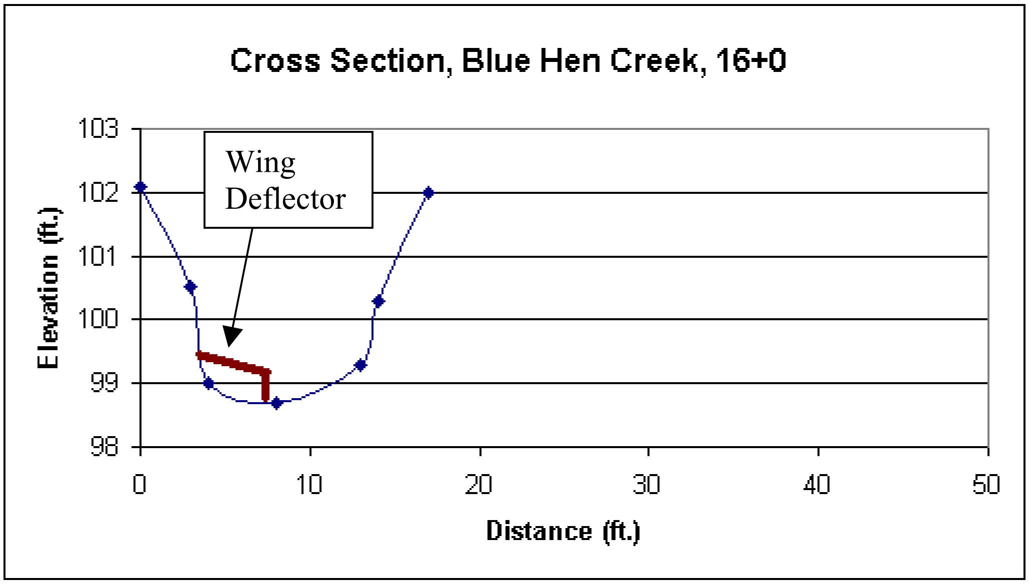
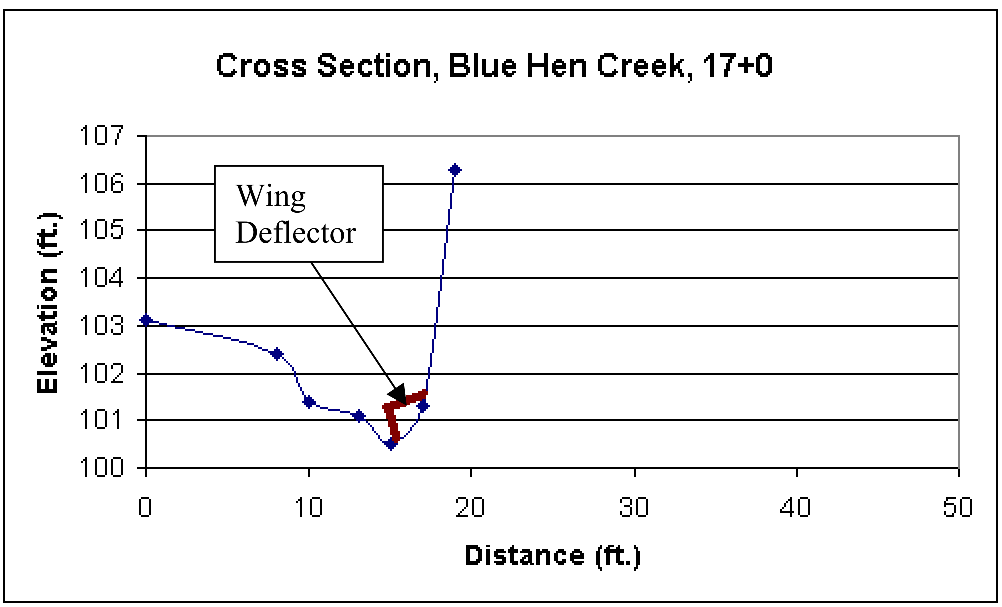


Figure 5.5: Cross Section of 17+0 with Wing Deflector



Treatment 5: Bank Shaping, Coconut Fiber Roll, and Reforestation at Station 18+0. The bank at this station is a shear drop down to the stream. Some bank shaping will be necessary to increase the effectiveness of the other restoration techniques being applied at

this station. The coconut fiber roll will help protect the bank from further erosion problems from the bottom up and reforestation will provide erosion protection from the top down.

Figure 5.6: Bank Shaping, Coconut Fiber Roll, and Reforestation at18+0

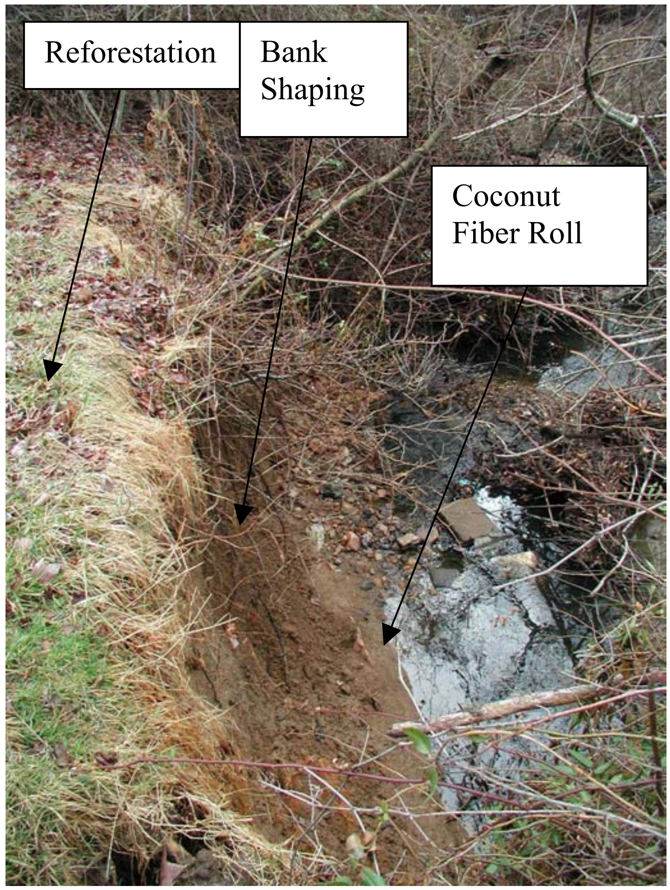
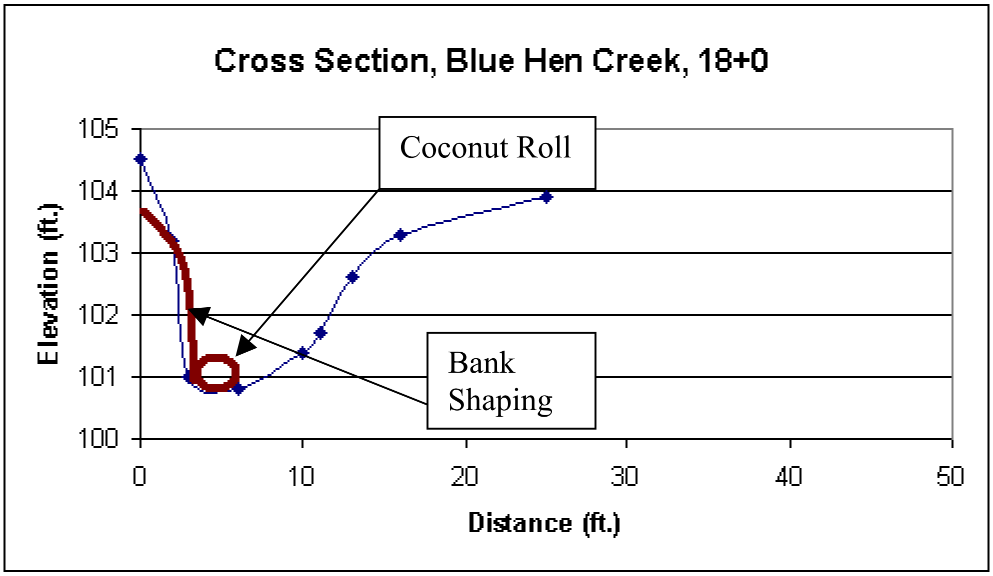


Figure 5.7: Cross Section of 18+0 with Coconut Fiber Roll and Bank Shaping



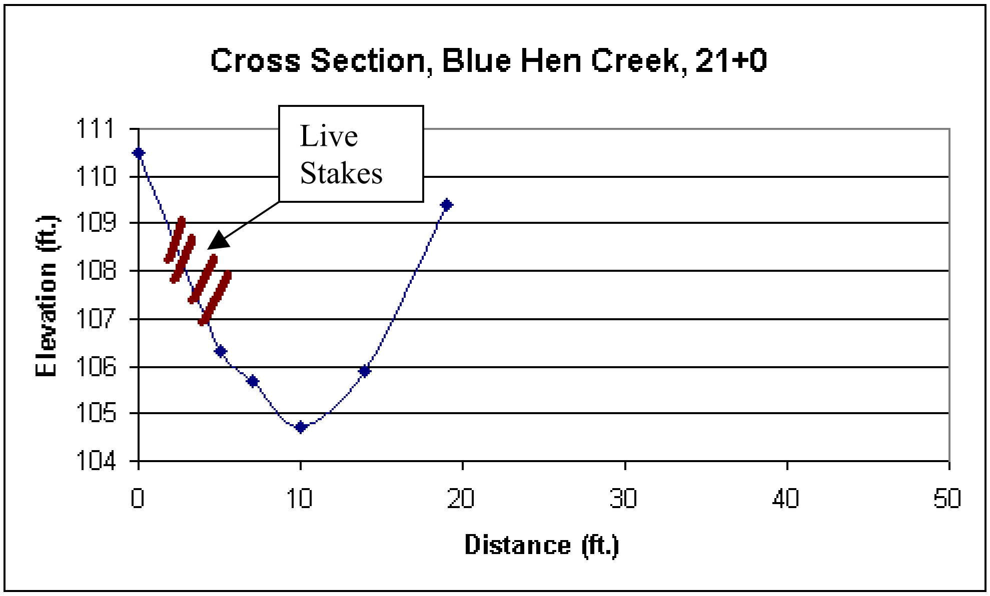
Treatment 6: Hand Cutting of Multiflora Rose and Reforestation at Station 19+0. Multiflora rose is a highly invasive exotic species that is very hard to remove from an area once it has been established. The rose is currently choking many of the native trees currently along the stream banks to death so removal of this species needs to happen. Two types of removal treatments are recommended for Blue Hen Creek to determine which type is better suited for this area and what removal procedures are feasible given the resources available. Removal treatments must be reapplied three to four times a year for four to five years for the treatments to be effective. Station 19+0 was selected for hand cutting treatments because of its dense population of the rose and because it is a decent distance from station 14+0. The stations with different treatments should not be too close together to allow for clearer observations of treatment effectiveness. The area along the stream bank that has the multiflora rose removed needs to be reforested for two reasons. One, if the bank is left bare it will be subject to erosion problems and two, with nothing taking its place the multiflora rose will simply re-establish itself along the bank.

Figure 5.8: Multiflora Rose along Station 19+0

Treatment 7: Live Stakes at Station 21+0. At some point small concrete slabs were placed along the bank at station 21+0. It provides poor wildlife habitat but with some vegetation placed in and around the slabs it could provide habitat as well as providing bank stability for the stream.

Figure 5.9: Live Stakes at Station 21+0

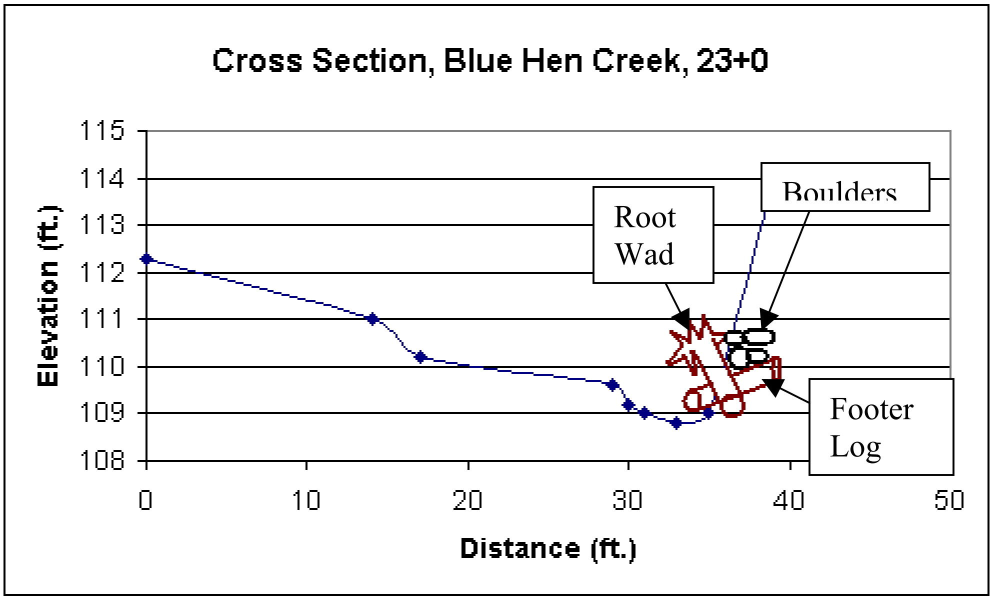
Figure 5.10: Cross Section of 21+0 with Live Stakes



Treatment 8: Root Wads at Station 23+0. The bank at station 23+0 is severely eroded and will continue to do so without pushing the stream away from the right bank.

Figure 5.11: Root Wads at Station 23+0

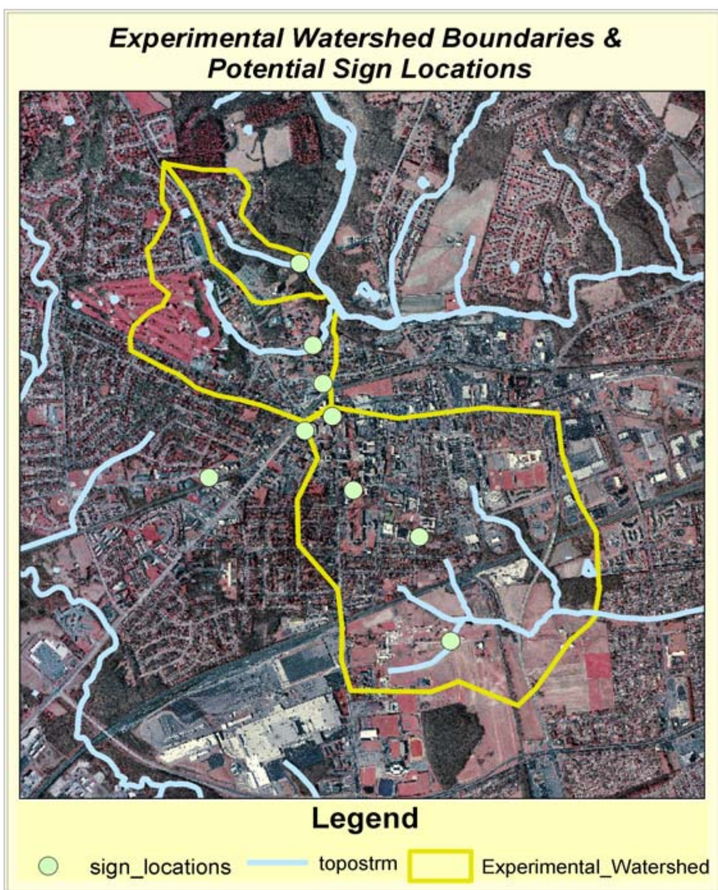
Figure 5.12: Cross Section of 23+0 with Root Wads



Education and Outreach

The University of Delaware Experimental Watershed has excellent educational outreach potential. On the university level classes on land survey, field identification of plant and animal species, as well as research projects such as this one are all feasible educational uses for this watershed. The general public could also get involved in the Experimental Watershed with stream clean ups, stream watches, and 4-H or Scout activities. This watershed is a valuable resource and tool that the University of Delaware should exploit to its fullest extent. However, no educational outreach will be that effective if no one knows the Experimental Watershed even exists. It is highly recommended that signs be placed designating the watershed for awareness purposes, see figure 5.13 for possible locations. A possible slogan for the sign is "Now Entering the University of Delaware Experimental Watershed."

Figure 5.13: Potential Sign Locations for Experimental Watershed



Habitat Surveys

To further assess the overall health of the stream it is recommended that surveys be taken of both overstory and understory vegetation all the full length of the stream. This data would be very helpful in determining how close the vegetation is to the native habitat that should be found in Mid-Atlantic Piedmont streams. The comprehensive survey could reveal other exotic species that are forcing out native species besides multiflora rose. In addition animal surveys, including macroinvertebrates, should be taken to determine the desirability of the riparian habitat to wildlife life. If the stream is not being used as a wildlife corridor, there may be other problems that need to be addressed in further phases of this project.

Watershed Report Card

To monitor how the University of Delaware Experimental Watershed is being affected over the years by the amount of development taking place throughout the Newark region, the watershed report card should be updated at least every couple years. After the restoration plan has been implemented, updates on the report card may reveal how effective the restoration has been on mitigating the effects of human disturbances.

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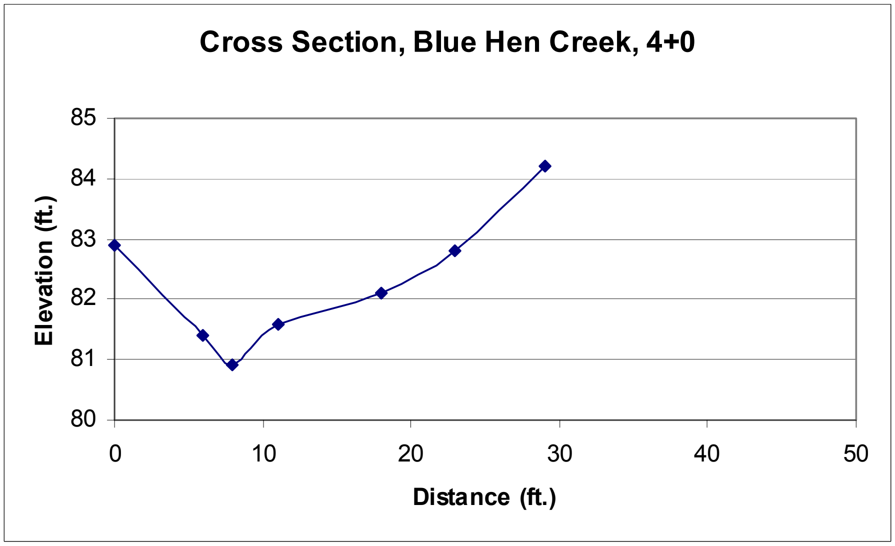
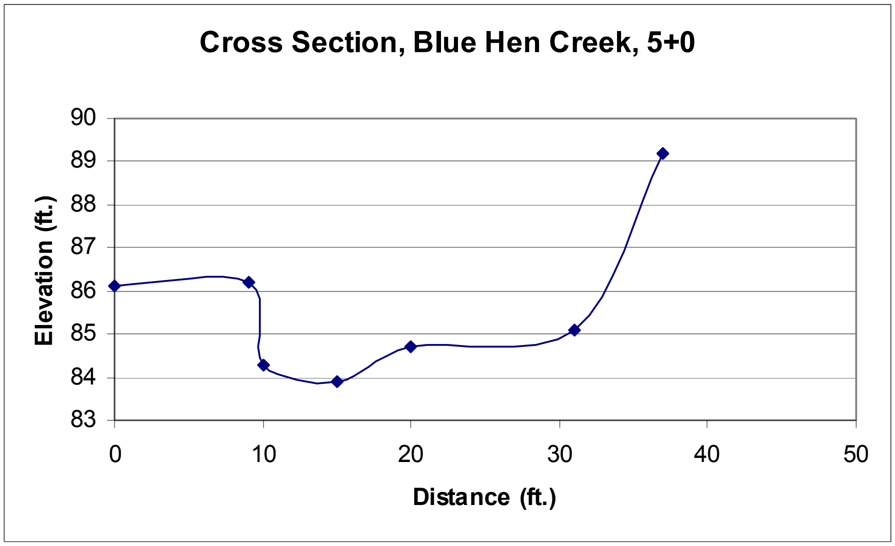
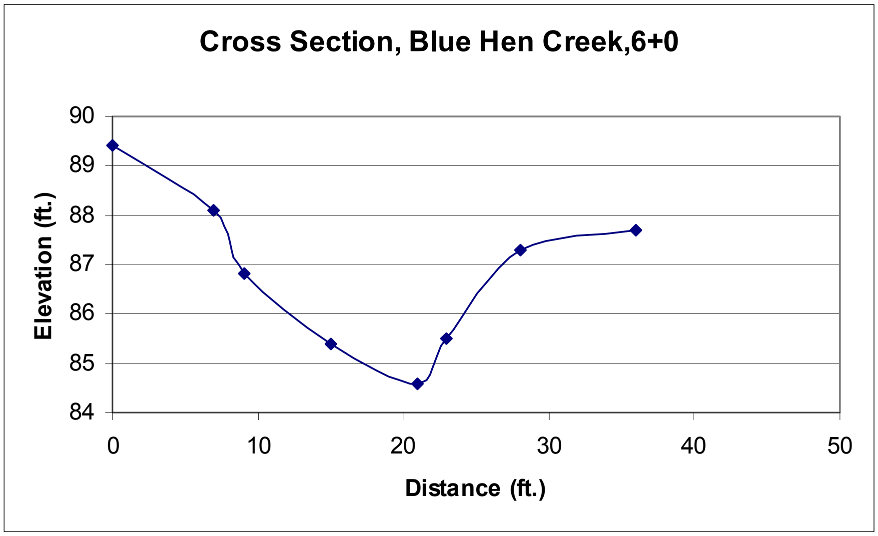
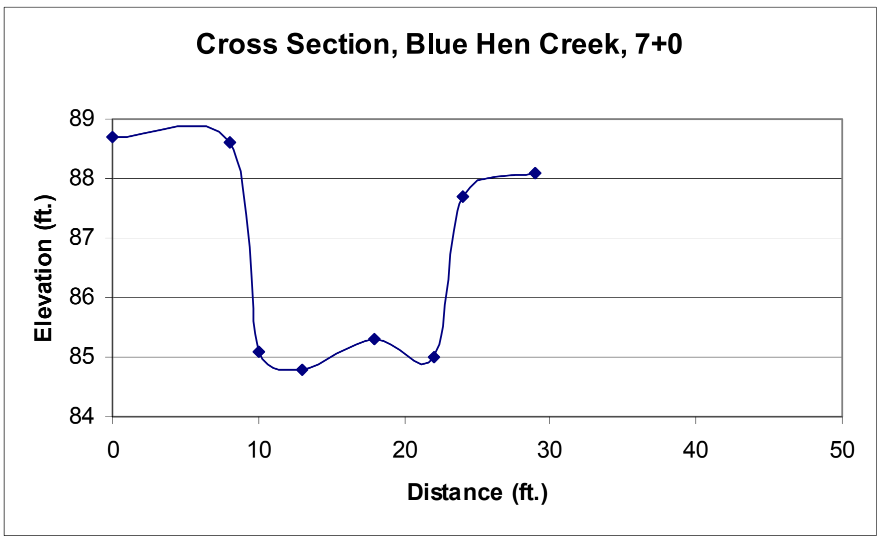
EXHIBITS

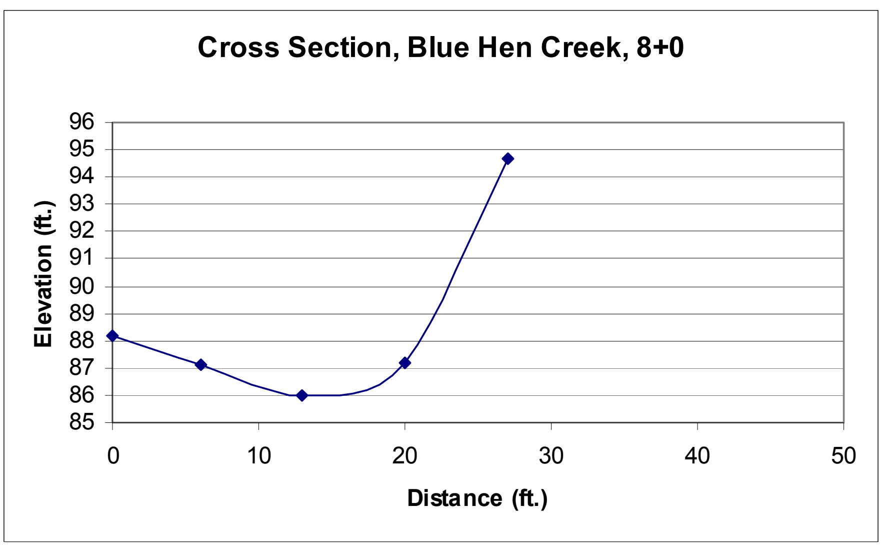
Exhibit 1: Stream Cross Sections for Blue Hen Creek Field Stations

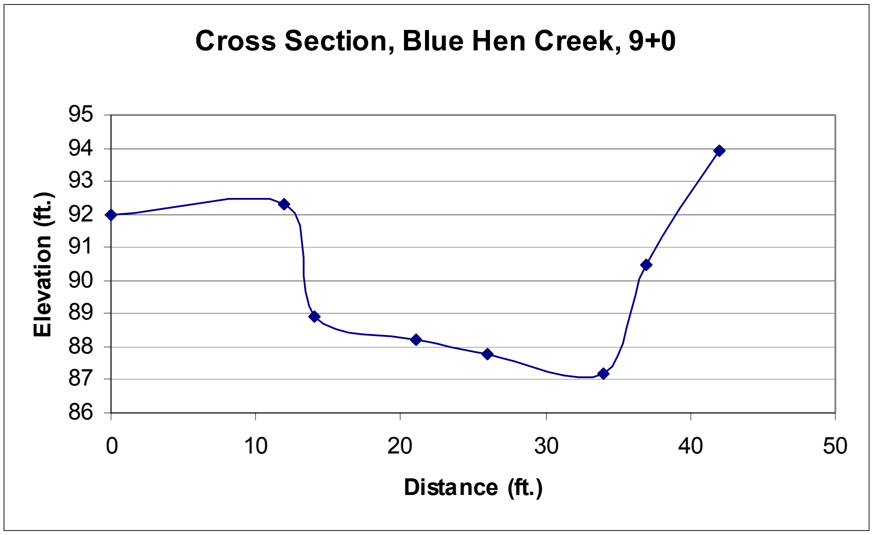


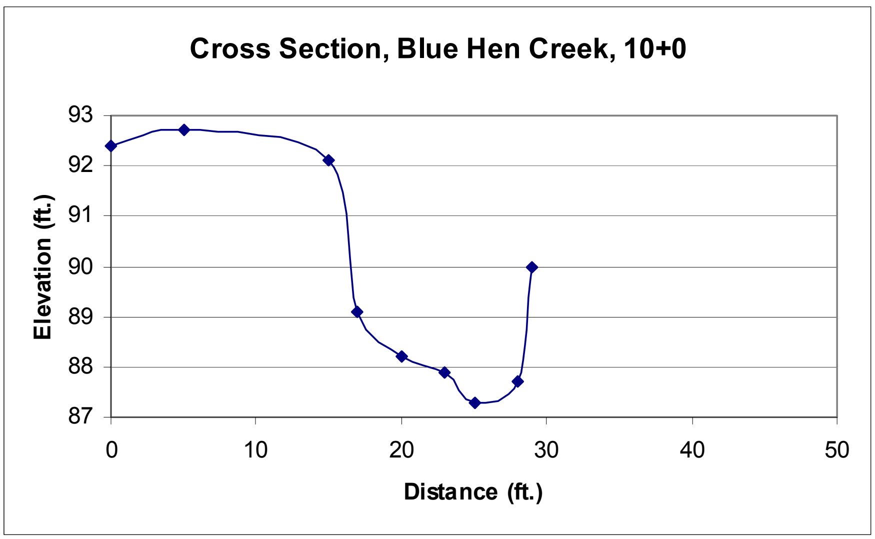


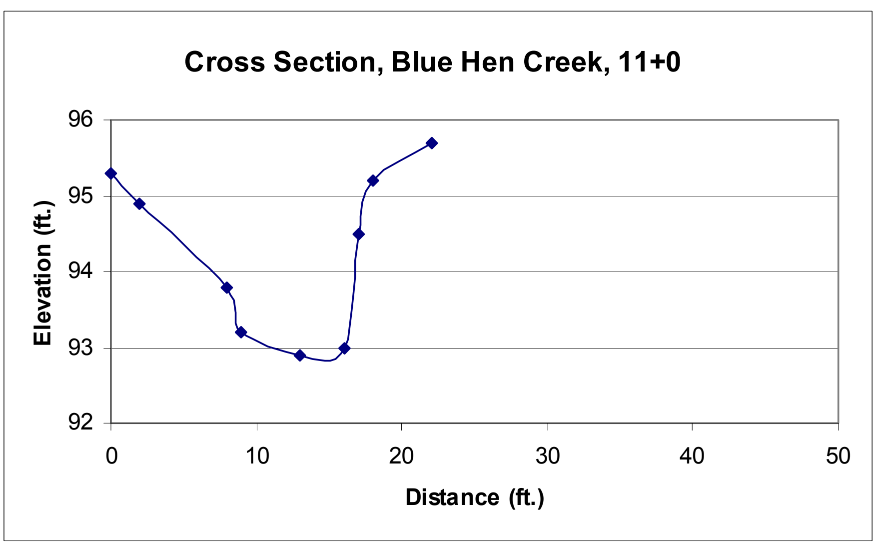

Cross Section, Blue Hen Creek,6+0
90
89
88
87
86
85
84
Elevation (ft.)
0
10
20
30
40
50
Distance (ft.)

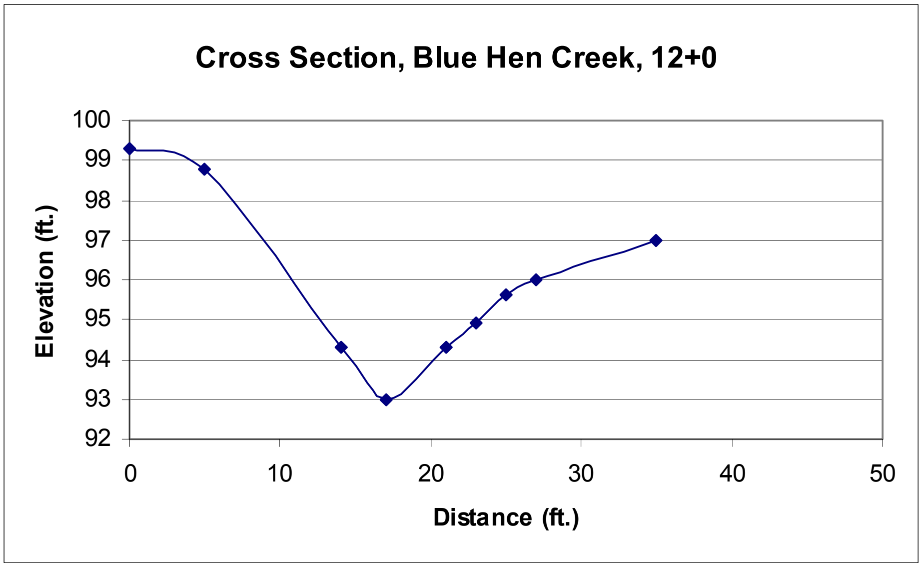

Cross Section, Blue Hen Creek, 7+0
89
88
87
86
85
84
Elevation (ft.)
0
10
20
30
40
50
Distance (ft.)

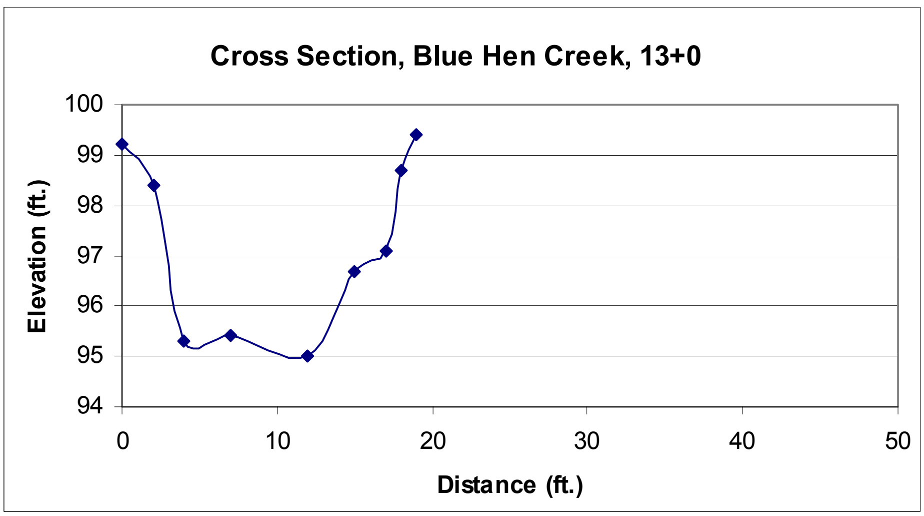

Cross Section, Blue Hen Creek, 8+0
96
95
94
93
92
91
90
89
88
87
86
85
Elevation (ft.)
0
10
20
30
40
50
Distance (ft.)

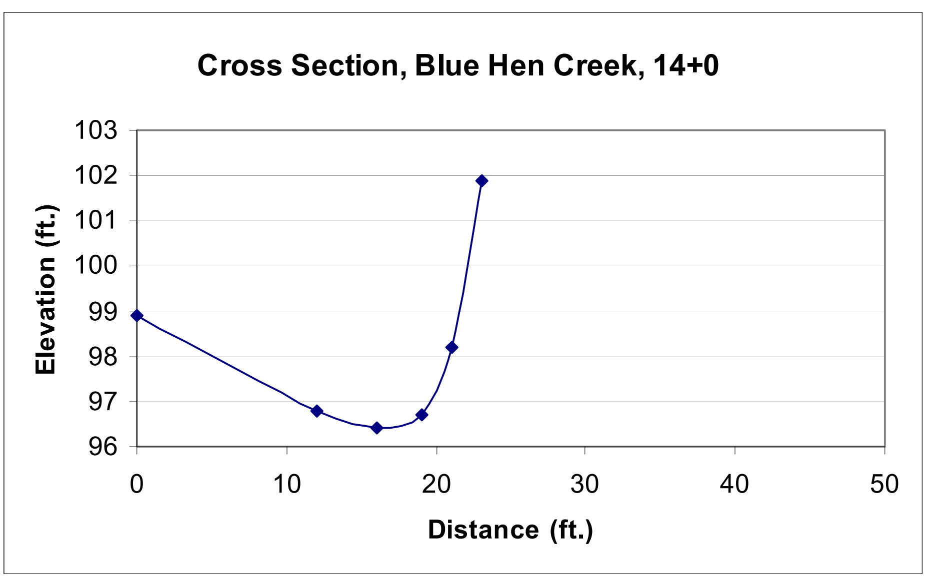

Cross Section, Blue Hen Creek, 9+0
Elevation (ft.)
95
94
93
92
91
90
89
88
87
86
0
10
20
30
40
50
Distance (ft.)

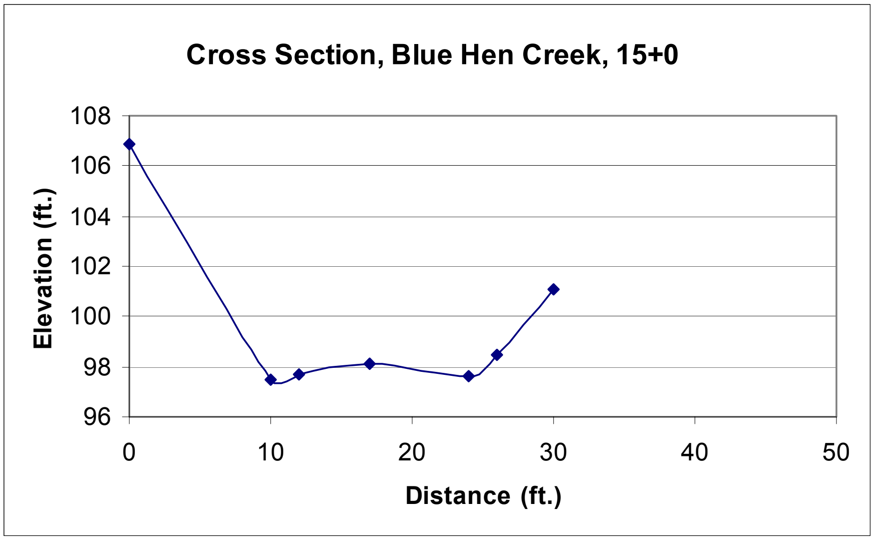

Cross Section, Blue Hen Creek, 10+0
Elevation (ft.)
93
92
91
90
89
88
87
0
10
20
30
40
50
Distance (ft.)

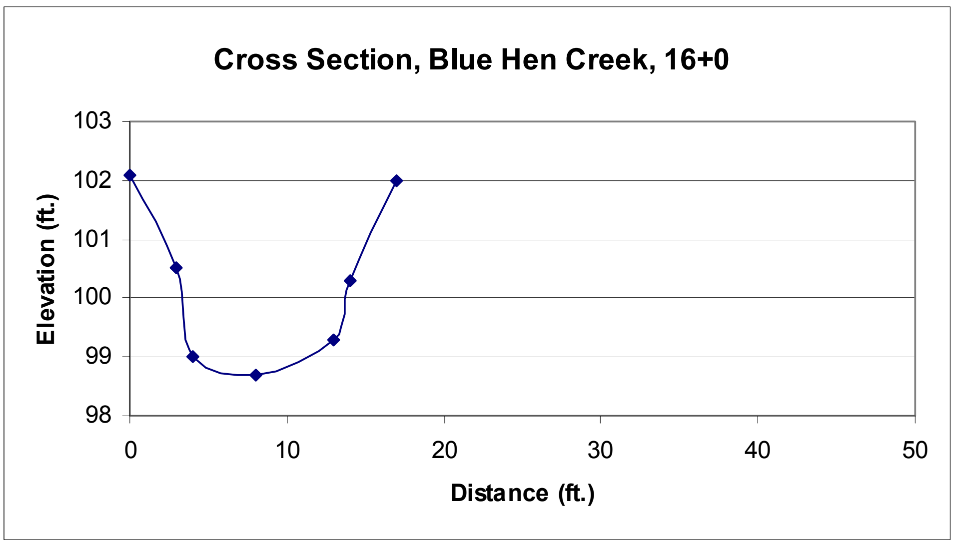

Cross Section, Blue Hen Creek, 11+0
Elevation (ft.)
96
95
94
93
92
0
10
20
30
40
50
Distance (ft.)

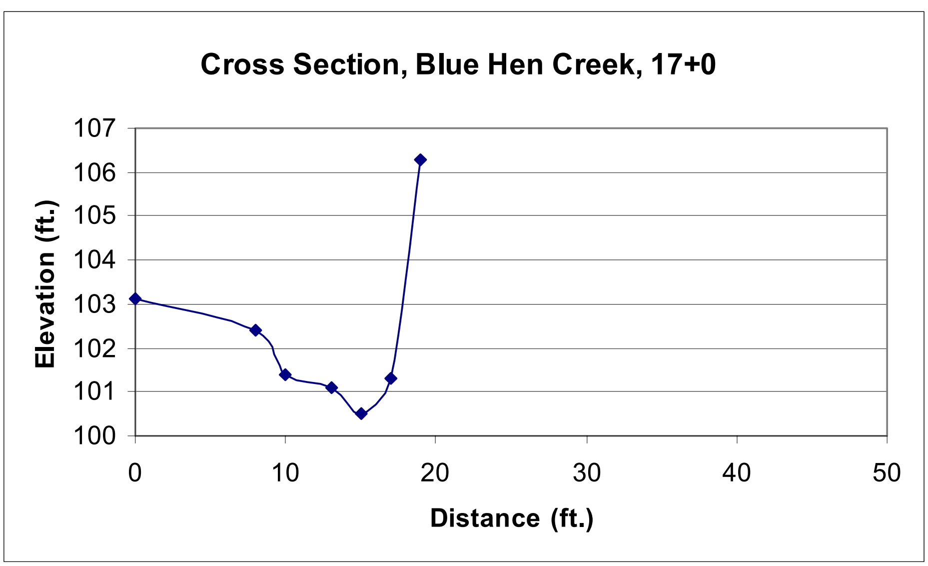

Cross Section, Blue Hen Creek, 12+0
Elevation (ft.)
100
99
98
97
96
95
94
93
92
0
10
20
30
40
50
Distance (ft.)

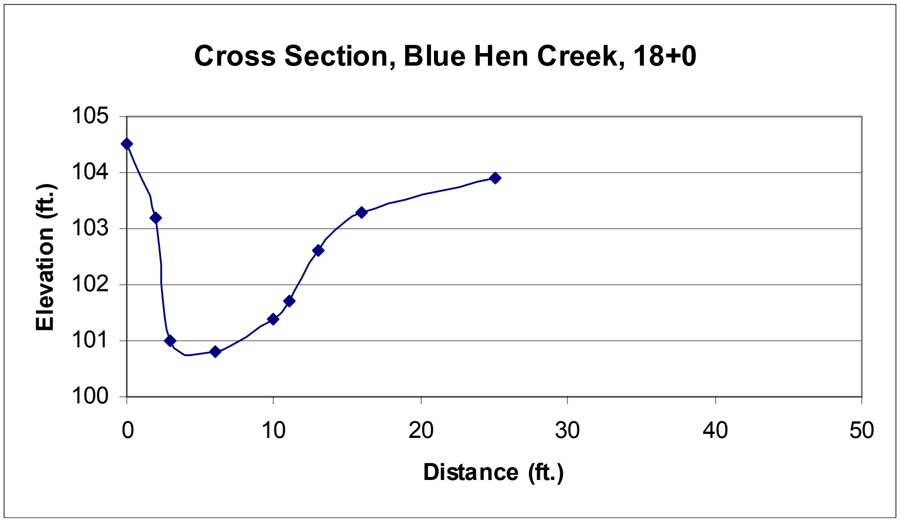

Cross Section, Blue Hen Creek, 13+0
Elevation (ft.)
100
99
98
97
96
95
94
0
10
20
30
40
50
Distance (ft.)


Cross Section, Blue Hen Creek, 14+0
Elevation (ft.)
103
102
101
100
99
98
97
96
0
10
20
30
40
50
Distance (ft.)

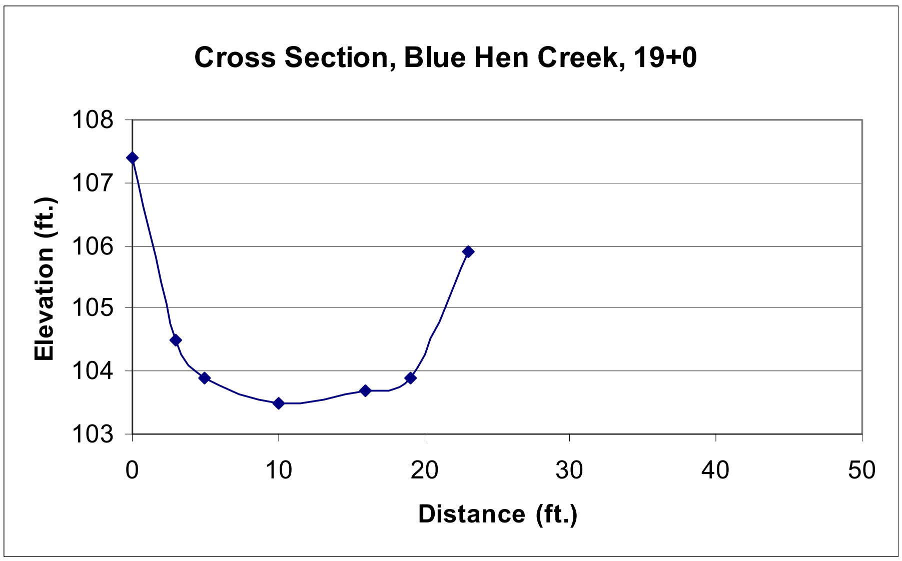

Cross Section, Blue Hen Creek, 15+0
Elevation (ft.)
108
106
104
102
100
98
96
0
10
20
30
40
50
Distance (ft.)


Cross Section, Blue Hen Creek, 16+0
Elevation (ft.)
103
102
101
100
99
98
0
10
20
30
40
50
Distance (ft.)

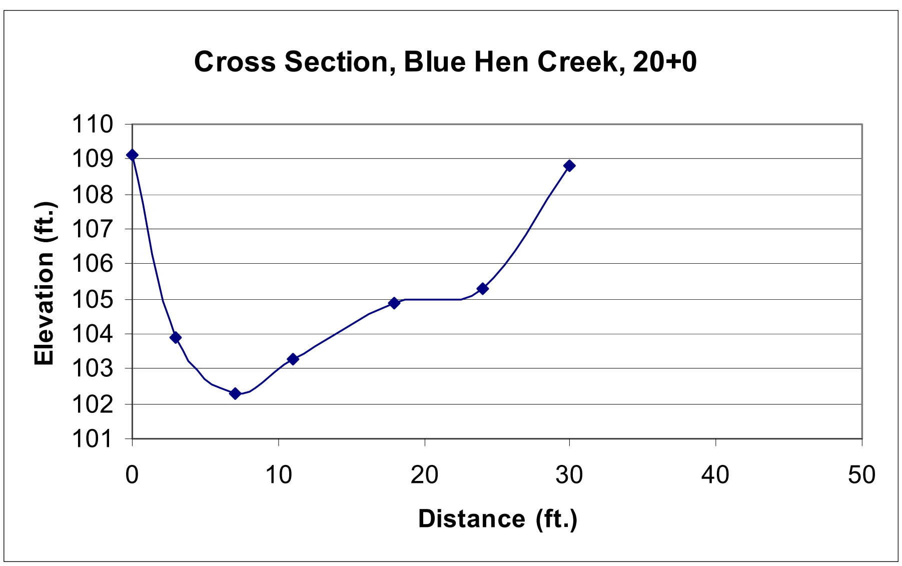

Cross Section, Blue Hen Creek, 17+0
Elevation (ft.)
107
106
105
104
103
102
101
100
0
10
20
30
40
50
Distance (ft.)



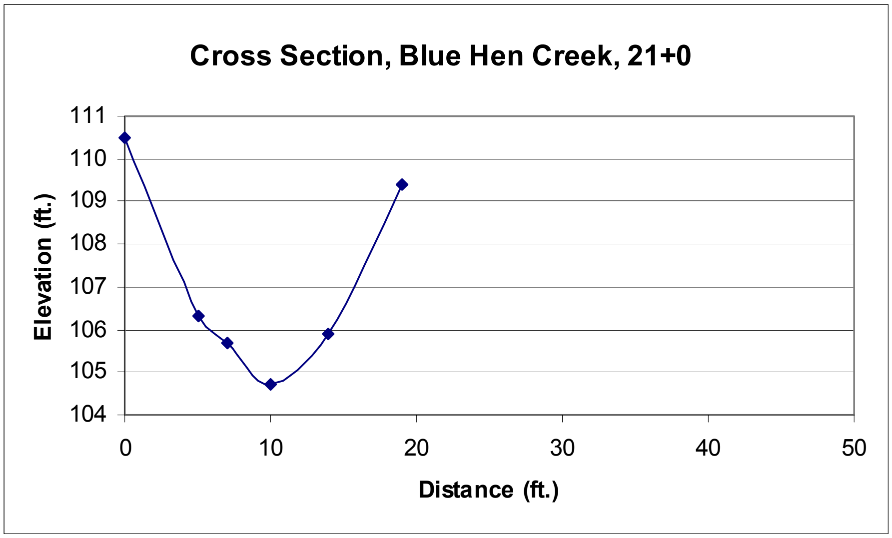
Cross Section, Blue Hen Creek, 18+0
Elevation (ft.)
105
104
103
102
101
100
0
10
20
30
40
50
Distance (ft.)



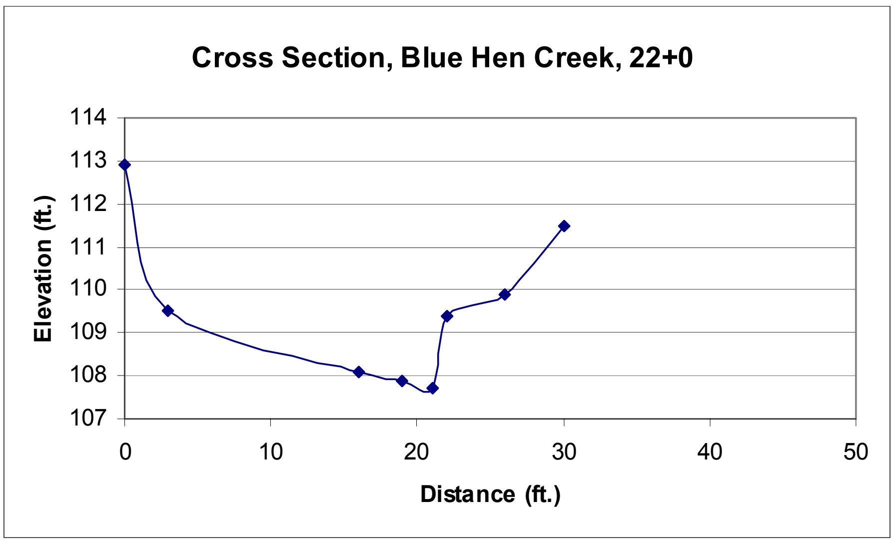
Cross Section, Blue Hen Creek, 19+0
Elevation (ft.)
108
107
106
105
104
103
0
10
20
30
40
50
Distance (ft.)



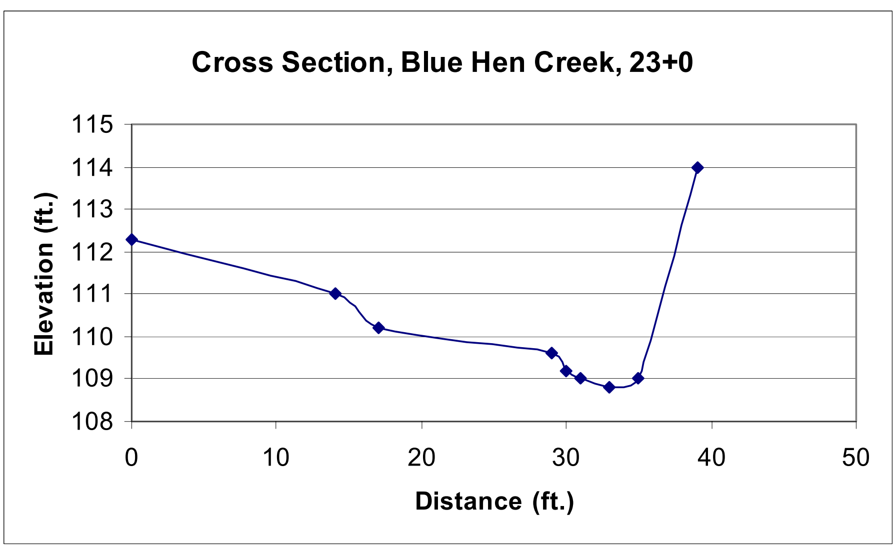
Cross Section, Blue Hen Creek, 20+0
Elevation (ft.)
110
109
108
107
106
105
104
103
102
101
0
10
20
30
40
50
Distance (ft.)



Cross Section, Blue Hen Creek, 21+0
Elevation (ft.)
Distance (ft.)
111
110
109
108
107
106
105
104
0
10
20
30
40
50



Cross Section, Blue Hen Creek, 22+0
Elevation (ft.)
Distance (ft.)
114
113
112
111
110
109
108
107
0
10
20
30
40
50



Cross Section, Blue Hen Creek, 23+0
Elevation (ft.)
Distance (ft.)
115
114
113
112
111
110
109
108
0
10
20
30
40
50

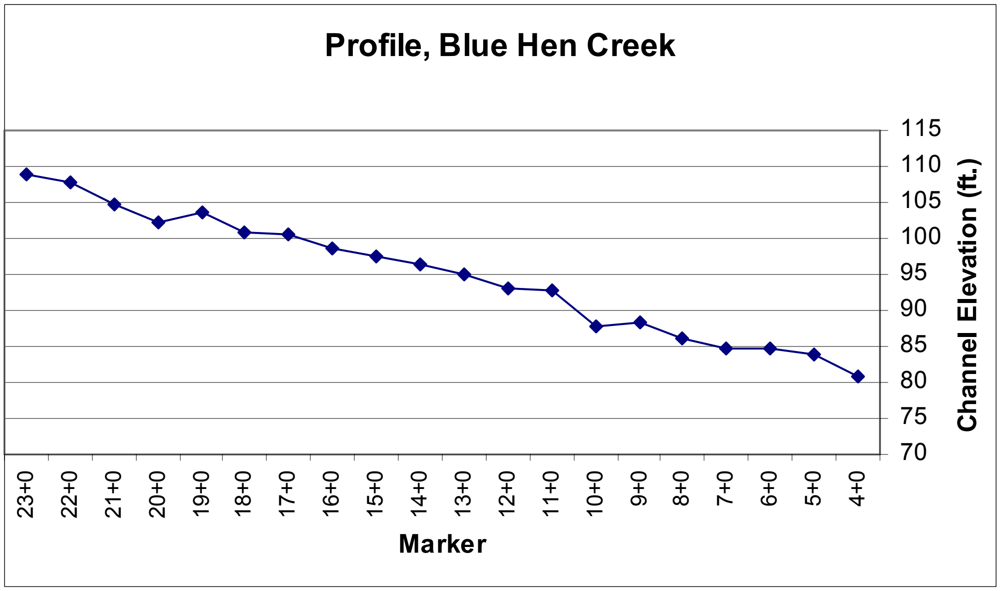
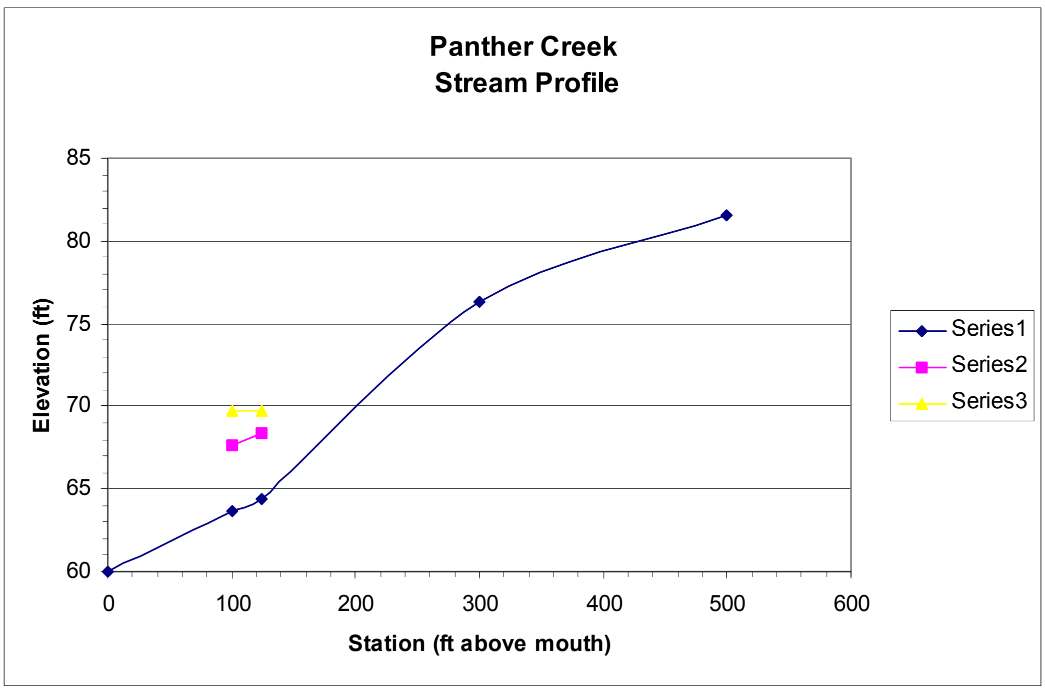


Exhibit 2: Reference Stream Cross Sections



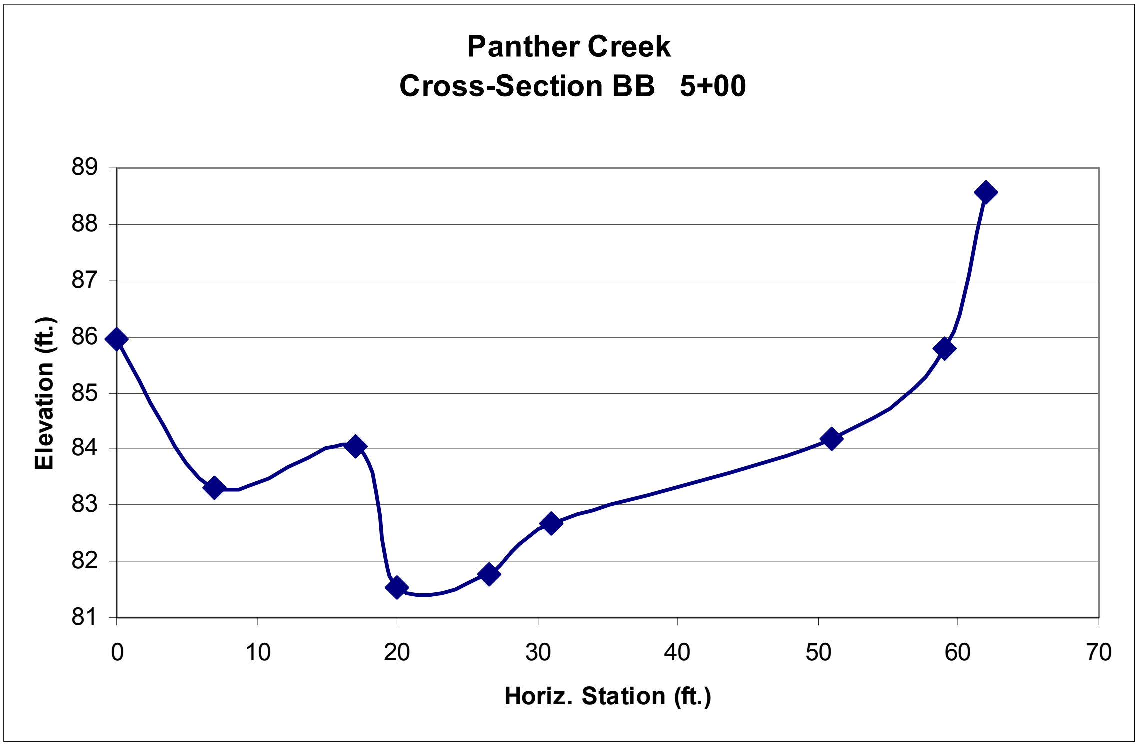

Panther Creek
Cross-Section BB 5+00
89
88
87
86
85
84
83
82
81
Elevation (ft.)
0
10
20
30
40
50
60
70
Horiz. Station (ft.)

Exhibit 3: Rosgen Stream Classification Method

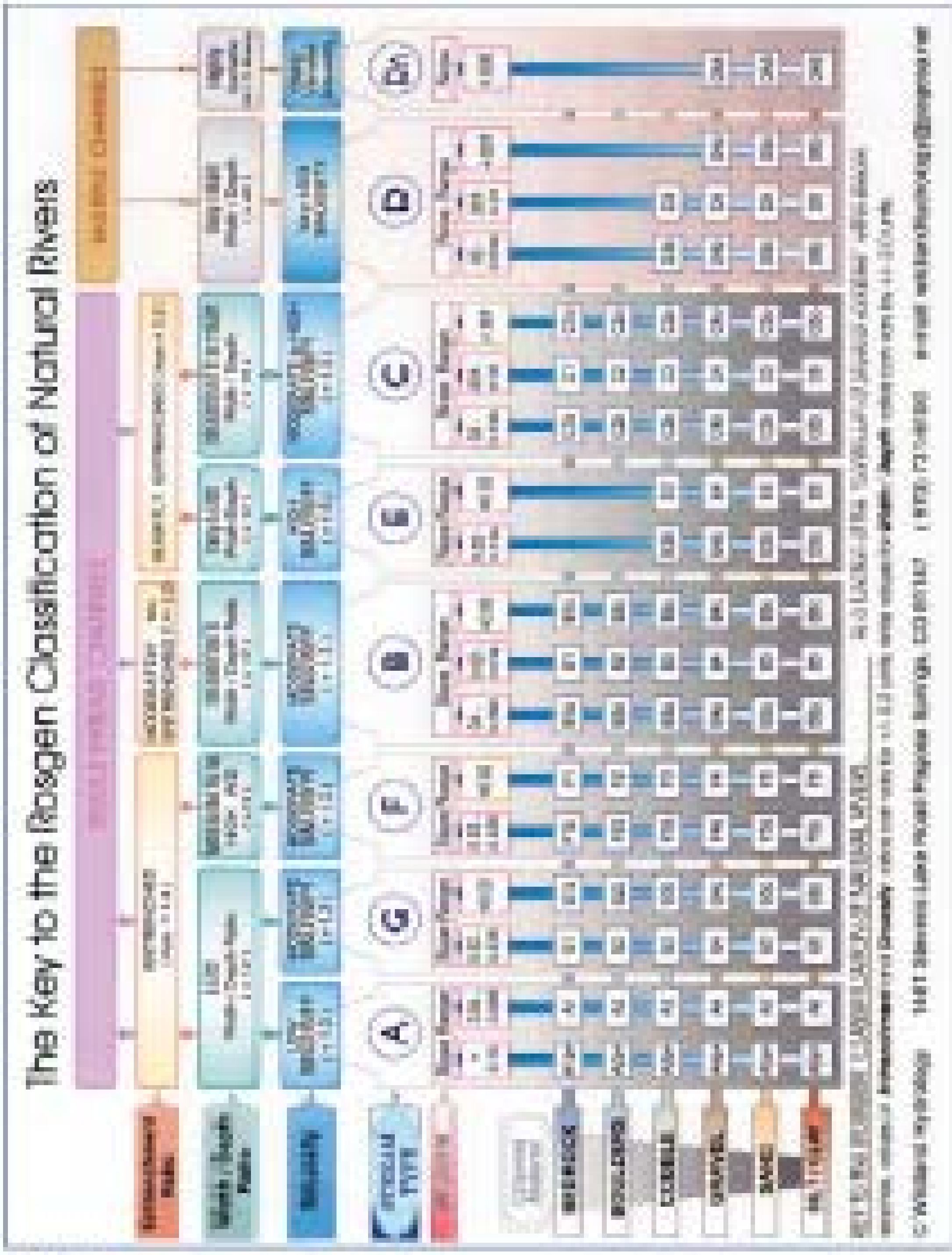


Figure 3.1
Rosgen classification of natural rivers
Rosgen 1996

(Doll et. Al., 2003)