Fairfield Run: An Evaluation of Stream Habitat Restoration at the UD Experimental Watershed

March 31, 2004

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Acknowledgements

This research report was prepared by Kristen Sentoff to fulfill the requirements for the Undergraduate Interships in Water Resources funded by the Delaware Water Resources Center. The author would like to thank Dr. Tom Sims and Amy Boyd for their guidance and support. The Water Resources Agency provided matching funds, equipment, and workspace. The Delaware Geological Survey also loaned surveying equipment for use on the project. Gerald Kauffman developed the idea for the research and was the project advisor. Martin Wollaston also provided support for this project. Many thanks to Vern Svatos and Andrew Homsey for their help with GIS analysis. Water Resources Agency Graduate Research Assistants Kevin Vonck, Sara Wozniak, and David Levitt, provided many hours of assistance in the field. Undergraduates Alex DeWire and Marlyse Williams provided assistance in the field and with data analysis. Finally, Undergraduate Research Assistants Judith Walker and Kathleen Cormier provided a great deal of assistance and collaboration for this research project.

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Abstract

Previous research has delineated the University of Delaware (UD) Experimental Watershed for educational purposes and has determined that surrounding land use negatively impacts the streams in it. The purpose of this project is to conduct research into stream restoration techniques and collect the necessary data for restoration implementation on Fairfield Run in the UD Experimental Watershed. The researchers chose a reference stream reach and candidate sites for restoration. They then conducted water quality, habitat, and stream geomorphology surveys. This data was incorporated into stream restoration designs. The candidate restoration sites were found to be impaired in comparison to the reference condition in terms of both water quality and habitat. The restoration and reference stream reaches had similar geomorphology classifications. The researchers selected vortex rock weirs, branch packing, single vanes, tree revetments, stone toe protection, live stakes, and cross vanes from the restoration techniques for use on Fairfield Run. Many viable restoration techniques are available that utilize natural materials already found in the UD Experimental Watershed. Fairfield Run is impaired and could be improved through use of some of these restoration techniques. Furthermore, its geomorphology classification suggests that it is a good candidate for restoration. The restoration project can be used to further the educational mission of the UD Experimental Watershed by involving students and the public in an effort to improve on-campus stream quality and watershed health.

CHAPTER 1
BACKGROUND AND JUSTIFICATION

Introduction

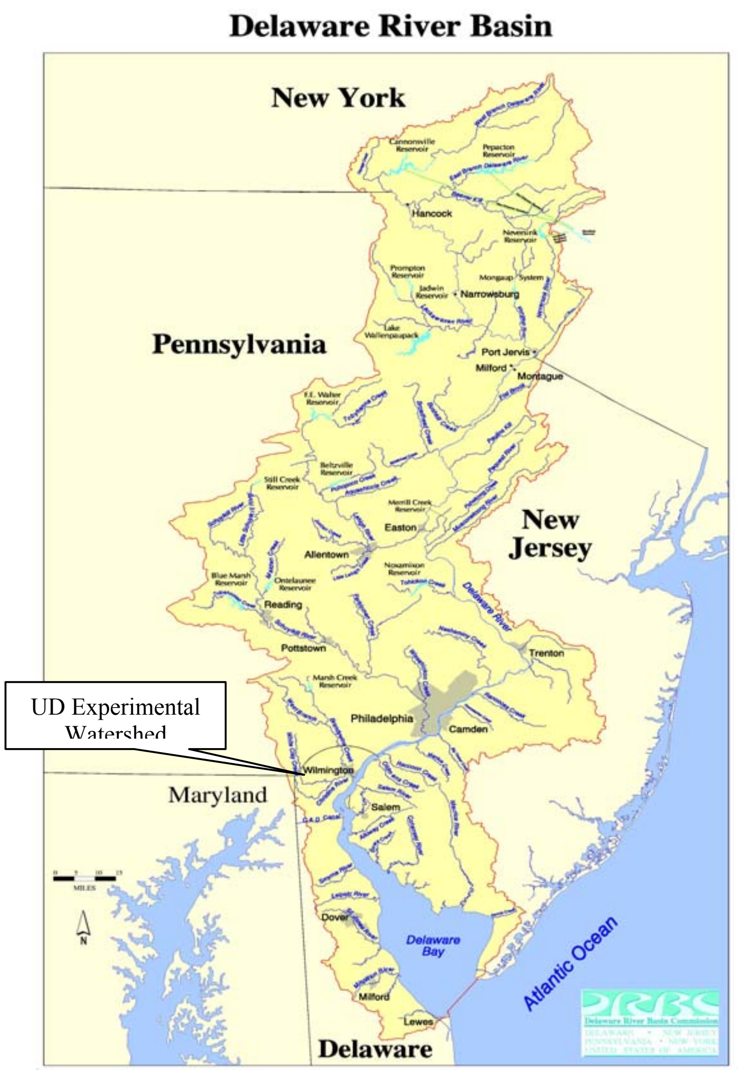
Stream restoration has been identified as a preferred watershed restoration technique in the Piedmont of the Christina Basin in northern Delaware and Southeastern Pennsylvania (Kauffman, Wozniak, and Vonck, 2003). The purpose of stream restoration is to return structure and function to a system that has been altered by natural or human disturbances (FISRWG, 2001). Streams, however, are dynamic ecological systems. Therefore, the goal of restoration should be to return the stream to a state of dynamic equilibrium, or one in which the stream is able to change, but remains stable over the long run.

A stable stream channel has been defined as one that is neither aggrading nor degrading (Gore, Bryant, and Crawford, 1995). An aggrading stream reach is depositing a greater amount of material than it transports so that the bed elevation is increasing over time. A degrading stream is incising into the channel to decrease bed elevation over time. Either situation has negative effects on the physical habitat of a stream and therefore on the ecological diversity of the system. An aggrading reach will contain deposits on the streambed, which homogenize habitat and eliminate interstitial spaces for fish and invertebrate cover. A degrading stream may be subject to erosion, which can threaten property, reduce habitat quality, and increase downstream sedimentation. Therefore, restoration efforts that return a stream to a stable condition can have benefits for human neighbors, stream and riparian ecology, and downstream waterways.

Previous Research

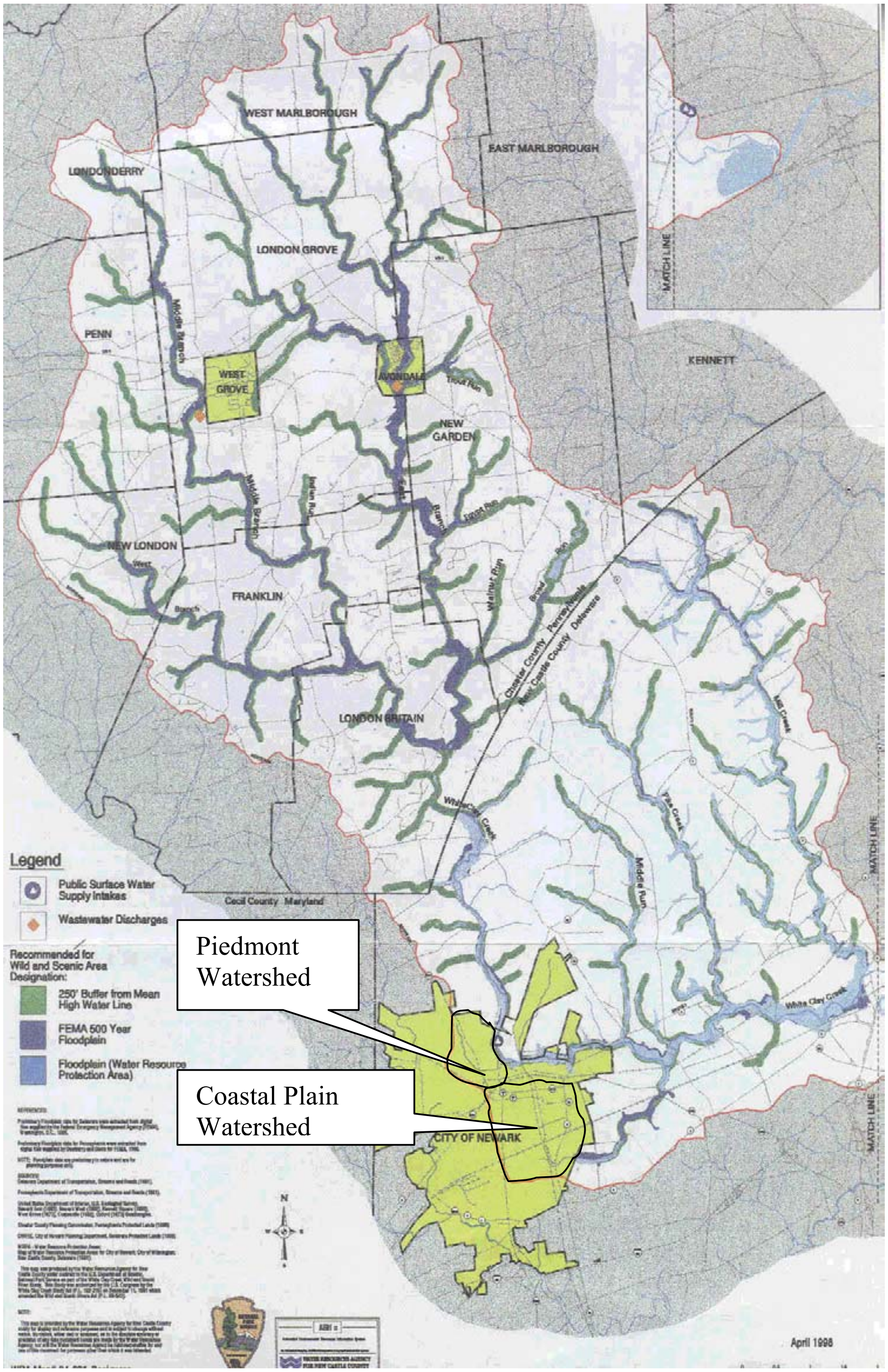
The University of Delaware Experimental Watershed was designed and delineated in 2001 by student researchers under the direction of project advisor Gerald Kauffman with funding from the Delaware Water Resources Center (Campagnini 2001). The purpose of the project was to provide a forum for research and 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 watersheds were delineated. The Piedmont 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 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



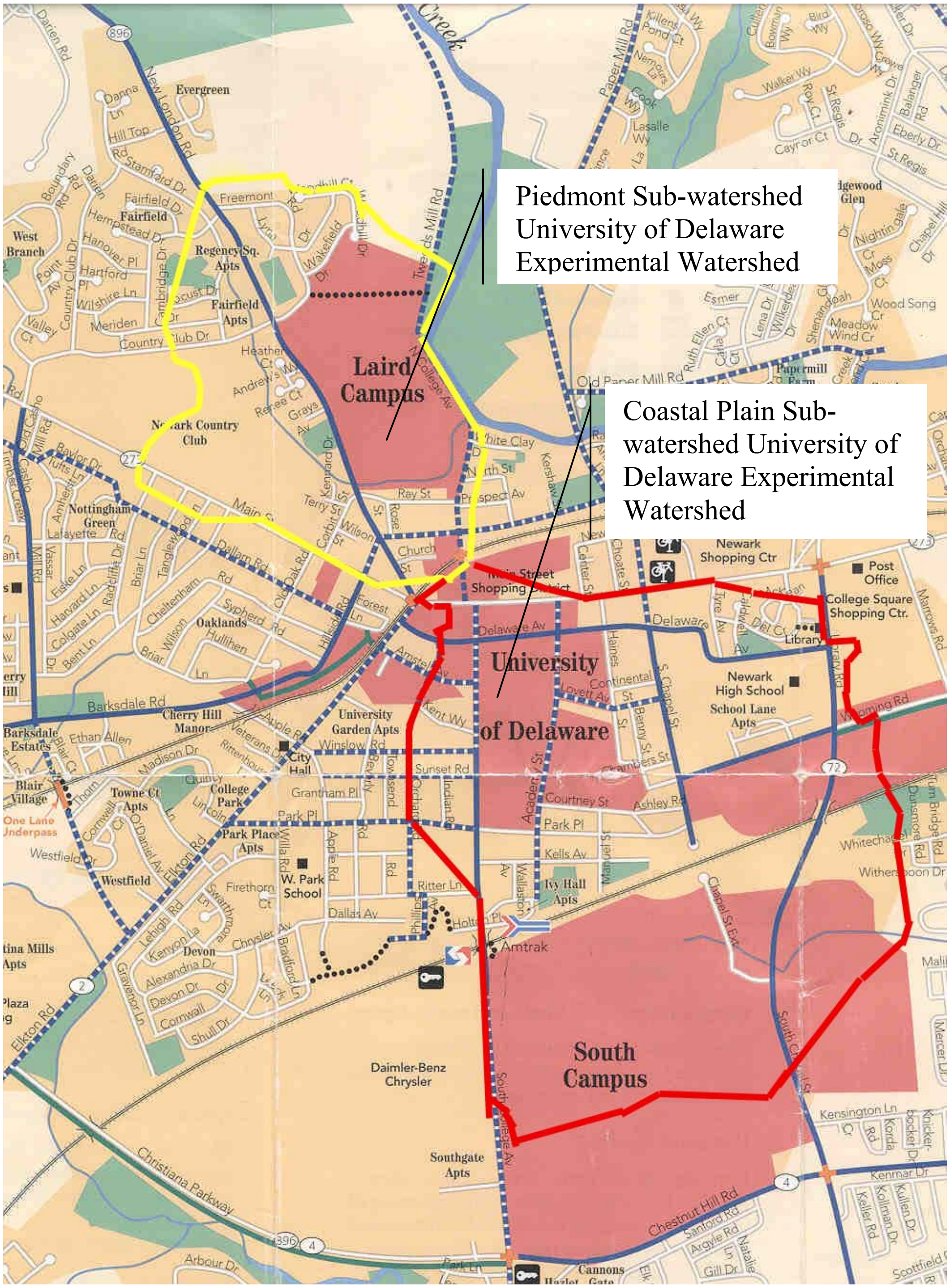
(Campagnini, 2001)

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 watershed are shown in Tables 1.1 and 1.2. The current research into stream restoration on the streams of the Piedmont 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	3.1	1.0	2.7	2.3
P2PC	2.6			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	3.3	1.0	3.1	2.5
P6FR	2.6			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 Watershed Report Card 2002

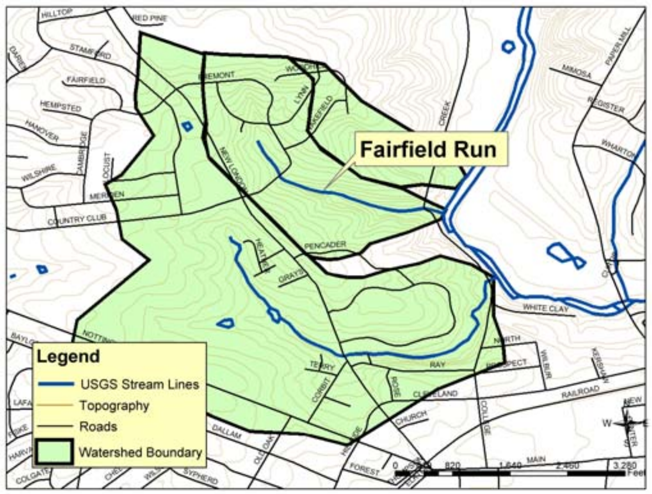
PIEDMONT WATERSHED REPORT CARD					
STREAM	WATER QUALITY	HABITAT ANALYSIS	LANDUSE	IMPERVIOUS COVER	FINAL GRADE
BLUE HEN CREEK					C
P1PC	2.69	1.9	3.1	1.0	2.2
P2PC	3.1	2.4			2.4
P3PC	2.8	1.8			2.2
FINAL GRADE	2.8	2.0	3.1	1.0	2.2
FAIRFIELD RUN					C
P5FR	3.1	2.0	3.3	1.0	2.4
P6FR	3.1	2.8			2.6
P7FR	2.9	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)

Description

Fairfield Run, located in the Piedmont watershed of the University of Delaware Experimental Watershed, has become unstable due to human and natural disturbances. Fairfield Run begins in the Fairfield Crest residential housing development and flows southeast through a wooded part of the University of Delaware Laird Campus, eventually draining into the White Clay Creek. The Fairfield Run watershed has a drainage area of 108.8 acres. The primary land uses in the watershed are residential (41.33%), forested/open (37.33%), and commercial/institutional (21.33%). These land uses give the watershed an estimated 29.93% impervious cover, which is considered to be non-supportive of aquatic life (Campagnini, 2001). The hope of the present research is that stream restoration efforts will help to mitigate the impact of this development.

Figure 1.4: Location of Fairfield Run in the Piedmont Watershed



Residential development in the headwaters of this stream is the main human disturbance. Impervious cover from roofs, driveways, and streets reduces infiltration of rainwater and causes more water to be transported overland into streams, especially during storm events. A stream undisturbed by development is equipped to transport the sediment and water produced by storm flows without aggrading or degrading. When development occurs the increased flows may destabilize the system. Another human impact on Fairfield Run has been the construction and recent expansions of a utility access road under power lines adjacent to the stream. This disturbance has removed some riparian vegetation, but its effect on in-stream habitat and flow remains to be seen.

Weather events over the course of the past year have also created natural disturbances in Fairfield Run. The White Clay Creek experienced a 50-year flood event this September, followed by more flooding and high flows associated with Hurricane Isabel. As a result of these storms, water from White Clay Creek back-flooded tributaries, including Fairfield Run. This natural disturbance has been exacerbated by the human disturbance of a DelDOT culvert under Creek Road, which has prevented normal flows from removing sediment deposited during floods.

Objectives

The objective of this project is to conduct research into methods to restore impaired Fairfield Run 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 Fairfield Run 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.

Restoration designs will be implemented and monitored by future researchers in order to improve the stream quality and educational potential of the UD Experimental Watershed and to determine the applicability of restoration techniques to other Mid-Atlantic Piedmont streams of the Christina River Basin.

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 Restoration Reaches, 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. The researchers gathered books, manuals, and articles on stream restoration from the University of Delaware Morris Library, the Internet, and Water Resources Agency materials. Table 2.1 summarizes the sources reviewed.

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 relatively short length of Fairfield Run and human disturbances in the upstream sections, choosing a nearby stream rather than a reach of Fairfield Run as a reference site was preferable.

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) ArcMap 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

Fairfield Run 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 Fairfield Run were chosen using field notes and photographs from each 100-foot reach.

Task 3.1: Measure Fairfield Run 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. Researchers numbered the stations 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 Fairfield Run and reference stream. Notes were taken for each 100-foot reach on Fairfield Run in order to select candidate restoration sites. Photographs were taken upstream and downstream at each station marker on both Fairfield Run and reference stream.

Task 3.3: Choose candidate reaches for restoration on Fairfield Run. Using photographs and notes, researchers chose 3 candidate restoration reaches on Fairfield Run. The sites were chosen based on presence of bank erosion, lack of sufficient vegetative cover or stabilization, and channel stability. Researchers used City of Newark tax parcel maps 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). Water quality tests were conducted using LaMotte Company Water Testing kits. Tests were conducted in conjunction with Habitat Surveys on the candidate restoration areas of Fairfield Run 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). Habitat surveys were conducted on candidate restoration reaches on Fairfield Run 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 showed 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 Fairfield Run 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 Fairfield Run. 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.

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 compiled all of the literature reviewed into the usable, comprehensive format of 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 are 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.

Reference Stream

The stream selected as a reference condition for stream restoration on Fairfield Run is located in the White Clay Creek State Park, just north of the UD Experimental Watershed. Like Fairfield Run, this stream is a small tributary to White Clay Creek. The reference stream (Panther Run) drains into the White Clay Creek near Creek Road just south of Wedgewood Road. The reference stream watershed is dominated by forest and agricultural land uses. This stream was also easily accessible for sampling from foot and bike paths. Figure 3.1 shows the location of the reference stream in relation to the Piedmont streams of the UD Experimental Watershed. Figures 3.2 and 3.3 show the reference watershed and Piedmont Sub-watershed with orthophotos, illustrating the contrast between development in the UD Experimental Watershed and the predominance of forest and agricultural land uses in the reference stream watershed.

Figure 3.1: Reference Stream Map

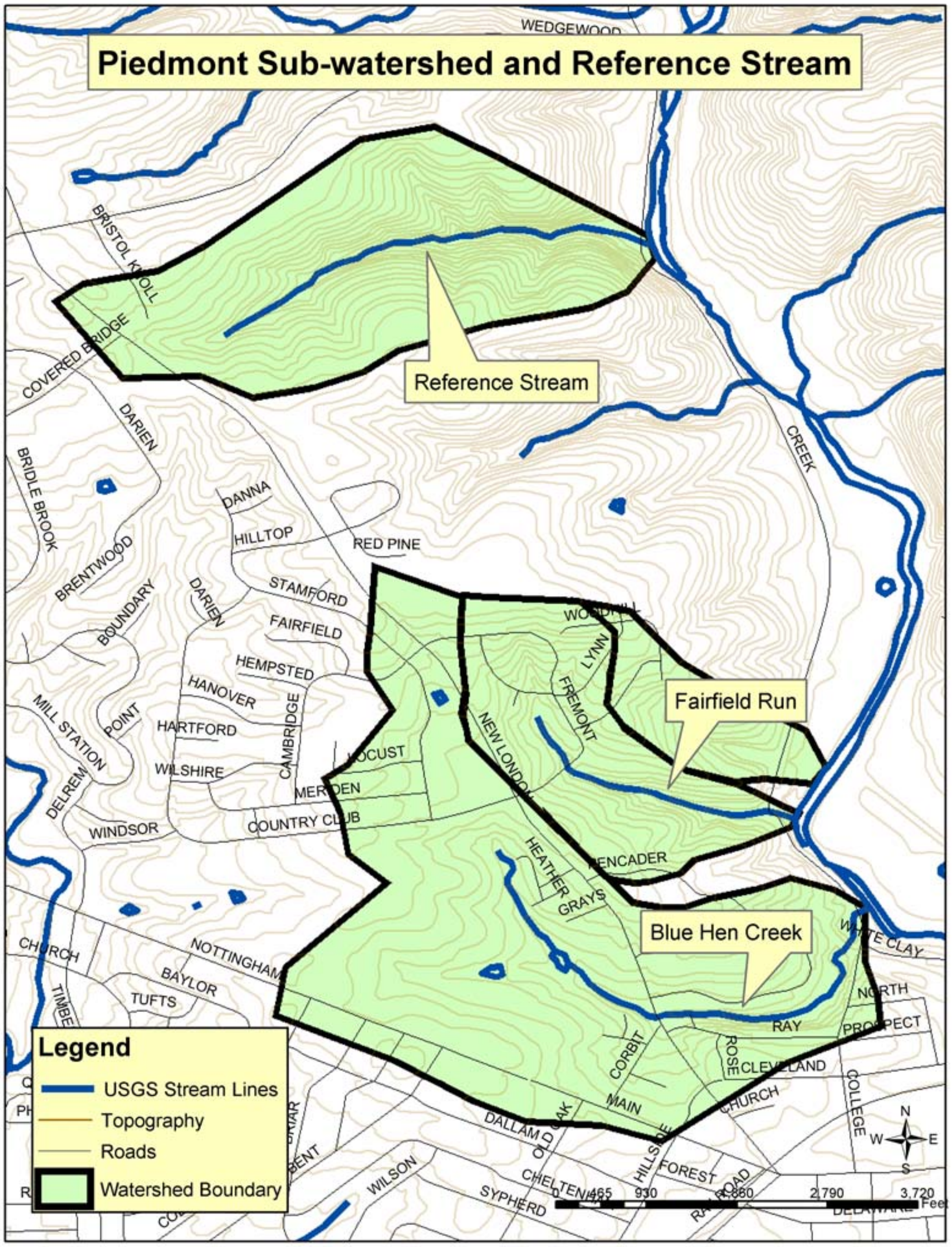


Figure 3.2: Reference Stream Watershed with Orthophoto Base Layer

1997 orthophoto

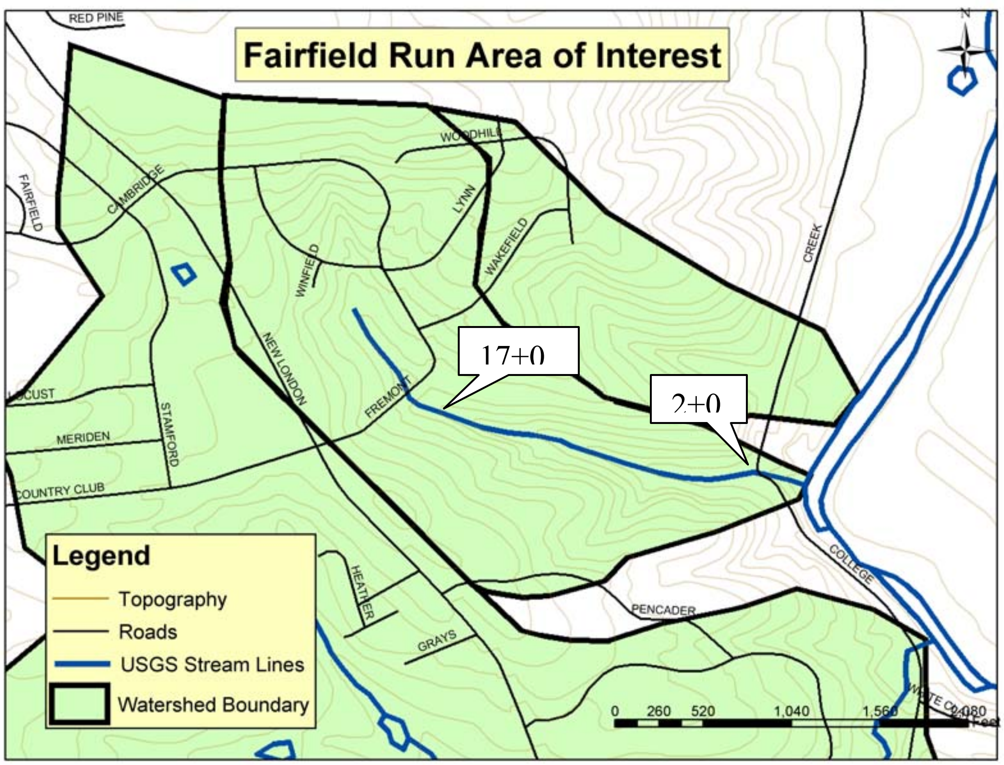
Figure 3.3: Piedmont Sub-watershed with Orthophoto Base Layer

1997 orthophoto

Candidate Restoration Reach Selection

Fairfield Run was measured with a marked station being placed at every 100 feet, beginning at the mouth of the stream, and ending at 17+0, or 1700 feet from the stream's mouth. Reaches upstream of 17+0 were not considered as candidates for restoration due to a lack of accessibility and the stream crossing from University of Delaware property into the Fairfield Crest subdivision. Figure 3.4 shows the downstream and upstream extent of the area of interest for Faifield Run. At each of the measured stations photographs and visual 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.

Figure 3.4: Area of Interest for Fairfield Run



The first restoration site chosen on Fairfield Run was the reach from 0+2 to 0+5. The downstream end of this reach was degraded by sediment backwashed from the White Clay Creek during storm events. The area from 4+0 to 5+0 was severely eroded on the right bank. The apparent cause of this erosion is that high flows are diverted towards the steep right bank by a sanitary sewer connection adjacent to the normal channel. The second reach chosen as a candidate for restoration was from 0+8 to 0+11. This area also had severe right bank erosion on the outside of meanders. The third reach chosen was from 14+0 to 16+0. This reach had poor bank stability with erosion on outside of meander bends on both banks and a narrow, downcutting channel. Figure 3.5 shows some of the photographs taken at the time of restoration reach selection.

Figure 3.5: Sample Photos of Candidate Stream Restoration Reaches

Candidate restoration reaches (clockwise from top left): sedimentation at 3+0, sewer connection and right bank erosion between 4+0 and 5+0, right bank erosion at 10+0, undercut bank at 16+0.

Chemical Water Quality Tests

The student researchers conducted a round of chemical water quality tests within each of the candidate restoration reaches during October and November 2003. The results of water quality tests were then compared with results from a site on the reference stream. The candidate restoration sites received a 3.06, 3.33, and 3.13, all of which translate to a B using the grading scale devised by the previous researchers (Campagnini 2001). The reference stream received a 3.50, or an A-. Table 3.2 shows the results of the chemical water quality tests.

All three sites on Fairfield Run had scores below the recommendation for alkalinity, while the reference stream fell within the recommended daily limit. Fairfield Run 2+0 to 5+0 and the reference stream had received scores of 3 for dissolved oxygen. Also, all four sites fell below the recommendation for biochemical oxygen demand (BOD). These results suggest either that low dissolved oxygen can be a problem even in undisturbed watersheds or that there was some degree of error in this testing kit. The Fairfield Run sites received grades of 2, 2, and 3 respectively for hardness, while the reference stream received a 4, indicating a greater amount of leaching of calcium and magnesium from the soil in the Fairfield Run watershed. Only Fairfield Run 14+0 to 16+0 had elevated levels of iron, possibly because of a point source pipe in this reach. All sites received low scores for phosphate, again indicating either a pervasive phosphate problem in both disturbed and undisturbed watersheds or an error in testing. An odor and a trace sheen, indicating the presence of oils, were detected at the site on Fairfield Run from 2+0 to 5+0. Finally, all the Fairfield Run sites received the lowest possible score of 1 for conductivity, while the reference stream received a 3. This indicates elevated salinity or nutrient levels on Fairfield Run (Biggs 2001).

The differing chemical water quality results between the reference condition and Fairfield Run reinforce the need for restoration. These results can be used in future stages to see if and how the restoration techniques are improving the quality of the water.

Table 3.2: Chemical Water Quality Test Results

Water Quality Results								
Site	Reference		Fairfield 2+0 to 5+0		Fairfield 8+0 to 11+0		Fairfield 14+0 to 16+0	
Parameter	Result	Grade	Result	Grade	Result	Grade	Result	Grade
Alkalinity	40	4	80	3	80	3	80	3
Ammonia	0	4	0	4	0	4	0	4
Chloride	0	4	14	4	0	4	8.4	4
Chlorine	0	4	0	4	0	4	0	4
Chromium	0	4	0	4	0	4	0	4
Copper	0	4	0	4	0	4	0	4
Dissolved Oxygen	4	3	4	3	6	4	6	4
BOD	2	1	4	3	-2	1	2	1
Hardness	40	4	160	2	120	3	120	3
Iron	0	4	0	4	0	4	0.5	1
Nitrate	1	4	0	4	2	4	2	4
Phosphate	2	1	1	1	2	1	3	1
Turbidity	clear	4	clear	4	clear	4	clear	4
Odor	none	4	yes	1	none	4	none	4
Sheen	no	4	trace	3	no	4	no	4
Conductivity	100	3	360	1	300	1	340	1
Average Score		3.50		3.06		3.33		3.13

Stream Habitat Surveys

Stream habitat surveys were conducted on the candidate restoration reaches of Fairfield Run as well as on the reference stream and compared to one another. The reference stream received a very good rating, while the three sites on Fairfield Run received a moderate, good, and very good, respectively. The results of the habitat surveys are shown in Table 3.3.

All three candidate restoration sites were impaired with regard to temperature, conductivity, and bank vegetation. All three received high ratings for clarity. The reference stream received a much higher rating for bank vegetation because it had well vegetated stream banks and native plants and trees, while Fairfield Run had many bare, eroded banks and a higher percentage of scrub and non-native vegetation. The sampling site between 2+0 and 5+0 received very low ratings for bed composition and deposits because of the heavy sedimentation in that reach (See Figure 3.2). The reach from 8+0 to

11+0 was impaired by slow flow velocities, low (acidic) pH, and low scores for bed composition and deposits because of sand and exposed bedrock in eroded areas. The reach from 14+0 to 16+0 was also impaired by slow flows. The third candidate restoration reach actually had the highest score for bed composition. The reference stream received a low score for bed composition because 30% of the bed was sand, which receives a negative score in the NZ-NIWA SHMAK system. This may indicate that the natural condition in Piedmont streams does contain some sand and that Fairfield Run 14+0 to 16+0 is lacking in pool habitat or is overly scoured. Although this reach received a very good overall rating, it was determined to still be a candidate restoration site based on field observations and chemical water quality results.

Table3.3: Habitat Quality Results

NZ-NIWA SHMAK Part C: Habitat Quality Results				
Site	Reference	Fairfield 2+0 to 5+0	Fairfield 8+0 to 11+0	Fairfield 14+0 to 16+0
Parameter (max. score)	Score			
Flow Velocity (10)	8	10	1	1
pH (10)	5	10	5	10
Temperature (10)	5	5	5	5
Conductivity (20)	16	6	6	6
Clarity (10)	10	10	10	10
Stream Bed Composition (20)	4.5	-7	6	10
Deposits (10)	5	-10	5	10
Bank Vegetation (20)	19.5	12.5	10	10
Total (100)	77.5	29.5	54	72
Habitat Score	Very Good	Moderate	Good	Very Good

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 cross section 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 cross sections show the shape of the stream channel and flood plain at each 100 foot interval. This data was used to complete a Rosgen stream classification for Fairfield Run and the reference stream. Table 3.4 shows the results of this analysis.

Fairfield Run was found to be a C4b stream type, while the reference stream was found to be a C3b stream type. The different numbers result from the higher percentage of cobble in the bed of the reference 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 Fairfield Run 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 Stream Classification

	Reference Stream		Fairfield Run	
	Raw Score	Evaluation	Raw Score	Evaluation
Channel Type	1	single	1	single
Entrenchment Ratio	2.2	slightly	1.7	moderate
Width to Depth Ratio	12	moderate	7.5	very low
Sinuosity	1.2	moderate	1.1	moderate-high
Water-Surface Slope	0.026	low	0.03	low
Bed Material	3	cobble	4	gravel
Classification	C3b		C4b	

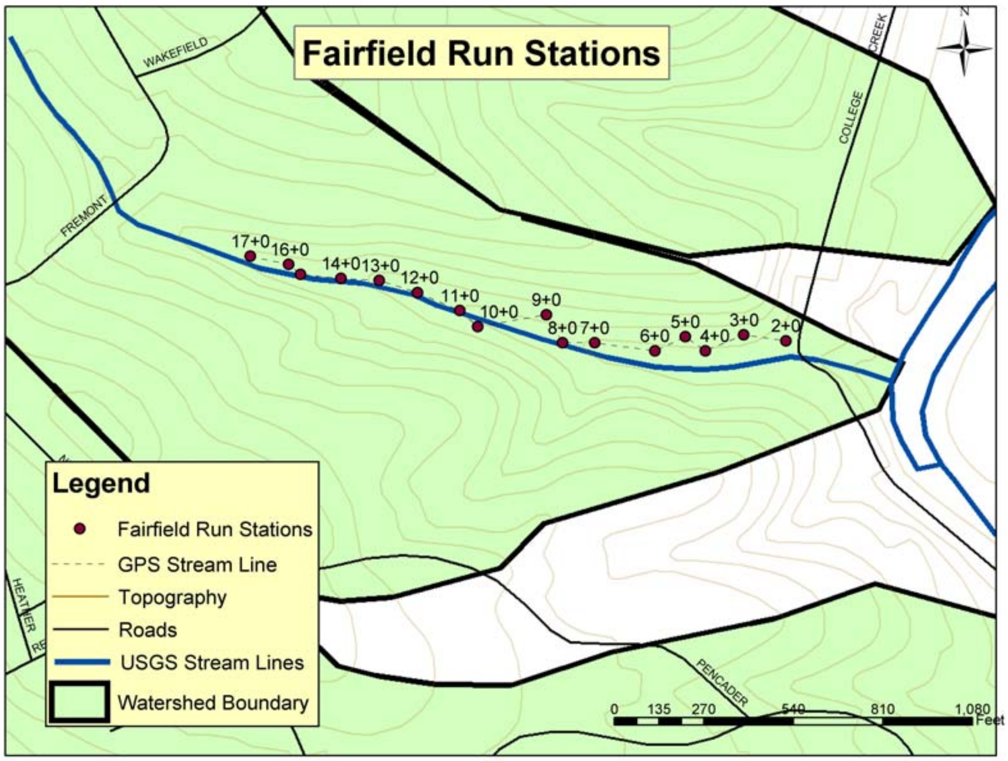
Restoration Design

Using the matrix, the researchers determined that stone toe protection, root wads, tree revetments, live stakes, coconut fiber rolls, branch packing, vortex rock weirs, wing deflectors, removal of invasives by hand cutting, removal of invasives by herbicide, and reforestation were the preferred restoration techniques for the streams of the UD Experimental Watershed. A variety of techniques were chosen in order to increase the research value of the restoration project. The techniques selected use mainly natural materials and will improve the aesthetic appeal of the streams as well as providing habitat improvement. Techniques that could be installed by hand and had lower costs were preferred.

Using the other data collected, the researchers paired these methods with specific locations on Fairfield Run and Blue Hen Creek. On Fairfield Run it was determined that a vortex rock weir would be used at 3+0, branch packing would be used at 4+0 to 5+0, a tree revetment and live stakes would be used at 8+0, stone toe protection and live stakes would be used at 10+0, and cross vanes would be used between 14+0 and 16+0. The remaining selected techniques would be implemented on Blue Hen Creek. Results and recommendations for Blue Hen Creek are provided in a separate report. The conceptual designs for Fairfield Run will be discussed in greater detail in the Recommendations chapter of this report.

The final step in restoration design was to plot latitude and longitude data collected in the field with a GPS receiver. These points were then added to the base map of the UD Experimental Watershed. Adding the coordinates to GIS allowed the researchers to correlate points in the field with maps. This information will also help future researchers locate positions in the field for restoration implementation and monitoring. USGS topographic maps tend to underestimate stream meandering. Therefore, a line connecting the points was added to show a more realistic approximation of the channel shape. While closer than the USGS stream line, coordinates taken only at every 100 feet still may underestimate meandering. Figure 3.6 shows the coordinate points and the new stream line. This map was used as an overview for restoration planning.

Figure 3.6: Fairfield Run Stations Map



CHAPTER 4
CONCLUSIONS

The researchers collected information on stream restoration and collected the data necessary to plan a stream restoration project on Fairfield Run in the UD Experimental Watershed. The results of the data collected reinforced the need for stream restoration, helped to identify specific problems to address with restoration techniques, and determined the potential for improvement through small scale restoration efforts.

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.

2. **Need for Restoration**- The results of chemical water quality tests and stream habitat surveys indicate that Fairfield Run is impaired in comparison to the reference condition. These results can be used with future monitoring results to determine if restoration has helped return Fair Field Run to a more ideal condition.

Location	Chemical Water Quality	Habitat
Reference	A-	Very Good
FFR 2+0 to 5+0	B	Moderate
FFR 8+0 to 11+0	B	Good
FFR 14+0 to 16+0	B	Very Good

3. **Restoration Potential-** Fairfield Run and the reference stream are C type stream channels in the Rosgen stream classification system. This classification indicates that there is a strong potential for improvement through restoration on Fairfield Run because it threatened with instability, but has not yet become severely incised.

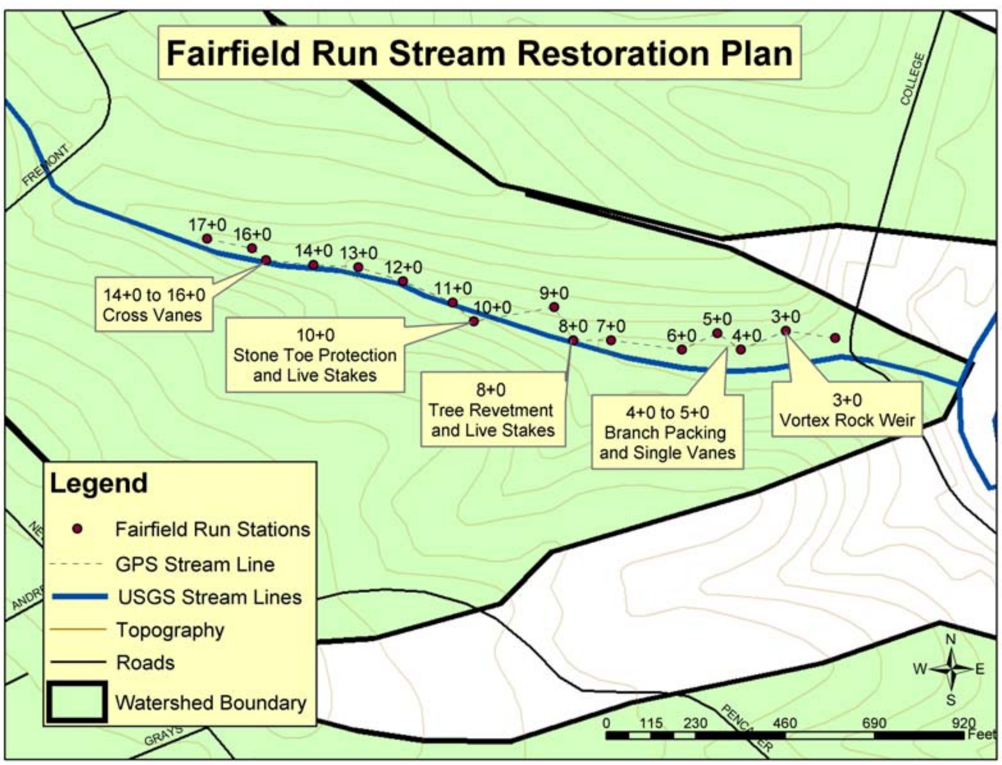
4. **Applicability of Restoration and Research-** Information gathered during the implementation and monitoring of stream restoration techniques in the UD Experimental Watershed could be used to plan other stream restoration projects on Piedmont streams in the Christina Basin.

CHAPTER 5
RECOMMENDATIONS

Stream Restoration

The student researchers selected sites and techniques for stream restoration on Fair Field Run. Seven different techniques are recommended for use on five treatment areas. Figure 5.1 shows an overview of the restoration plan for Fair Field Run.

Figure 5.1: Recommended Stream Restoration Plan Along Fairfield Run



Treatment 1: Vortex Rock Weir at 3+0- A vortex rock weir will be placed at 3+0 in order to differentiate habitat and prevent further down-cutting of the stream bed toward the Creek Road culvert.

Figure 5.2: Site for Proposed Vortex Rock Weir

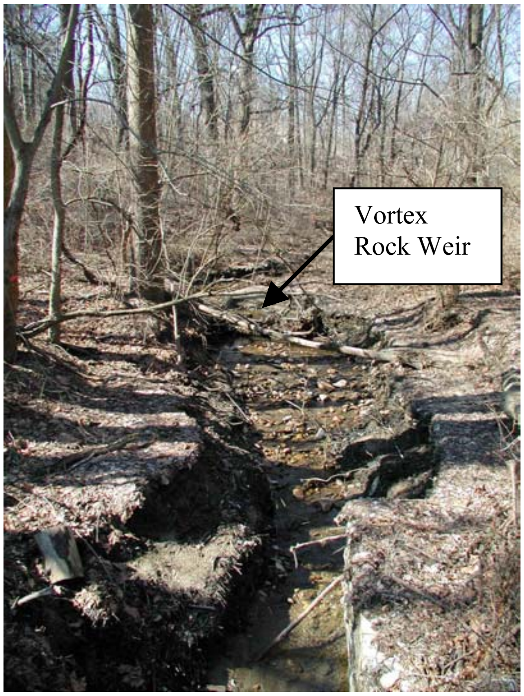
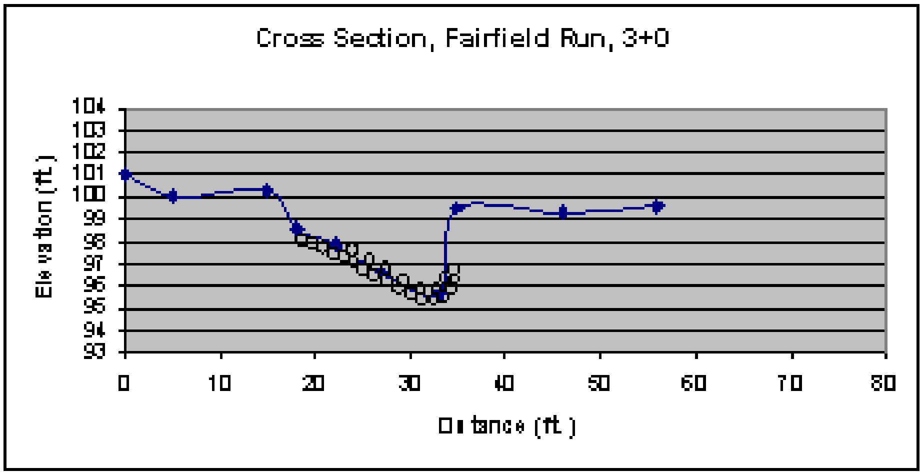


Figure 5.3: Cross Section of Vortex Rock Weir at 3+0



Treatment 2: Channel Block and Single Vanes at 4+0 to 5+0- Branch packing will be used to fill in the wash-out between 4+0 and 5+0 and revegetate the slope. Alternating layers of soil and live branch cuttings will be placed between the sewer connection and the washed out bank. Additionally a series of single vanes will be placed along the outside of the bend where the channel splits to direct high flows away from the side channel and the unstable bank.

Figure 5.4: Location of Branch Packing (left) and Single Vanes (right).

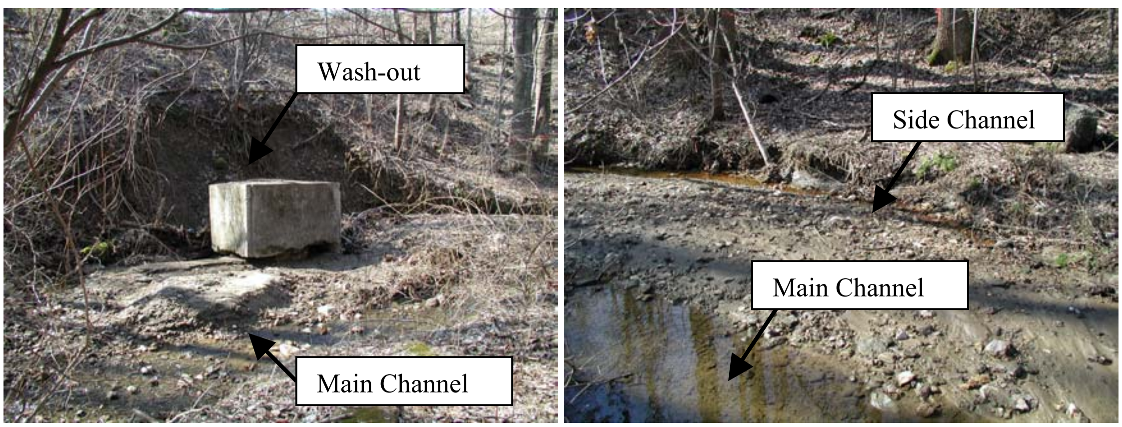


Figure 5.5: Cross Sections at 4+0 with Branch Packing

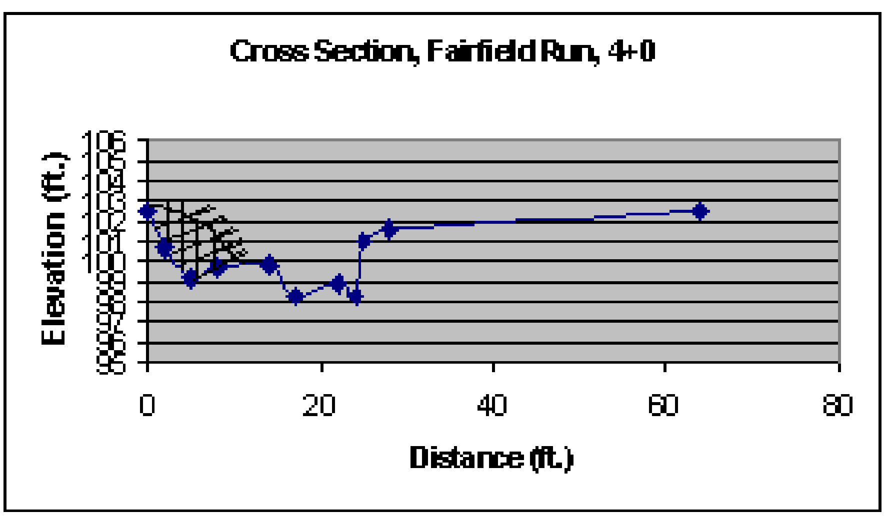
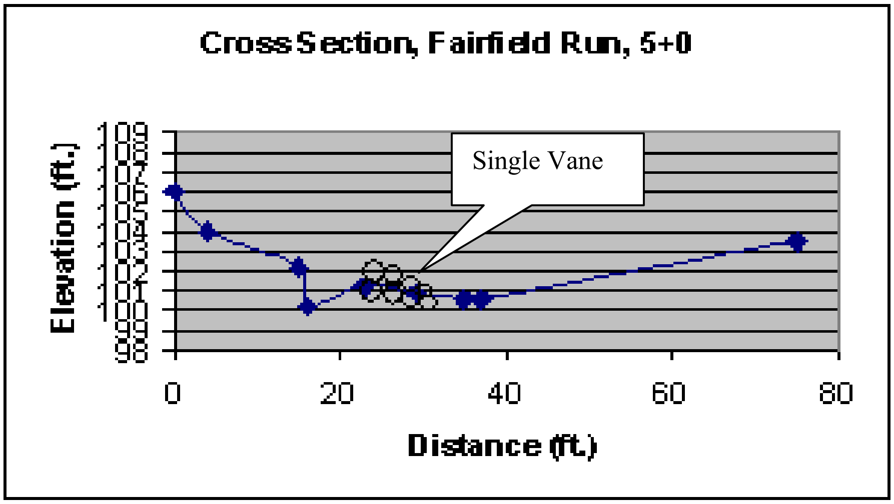


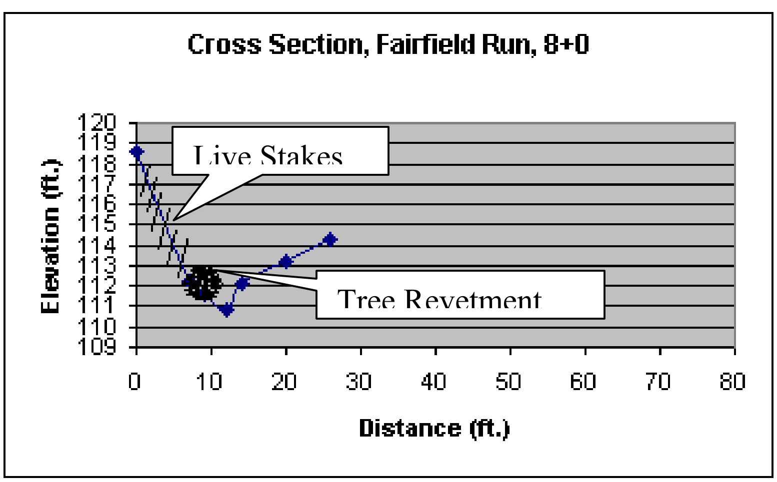
Figure 5.6: Cross Sections at 5+0 with Single Vane



Treatment 3: Tree Revetment and Live stakes at 8+0- A tree revetment will be placed along the outside of the meander at 8+0 to provide toe protection on the eroding right bank. Live stakes will be placed in the upper bank to provide additional stabilization and revegetation.

Figure 5.7: Location of Tree Revetment and Live Stakes

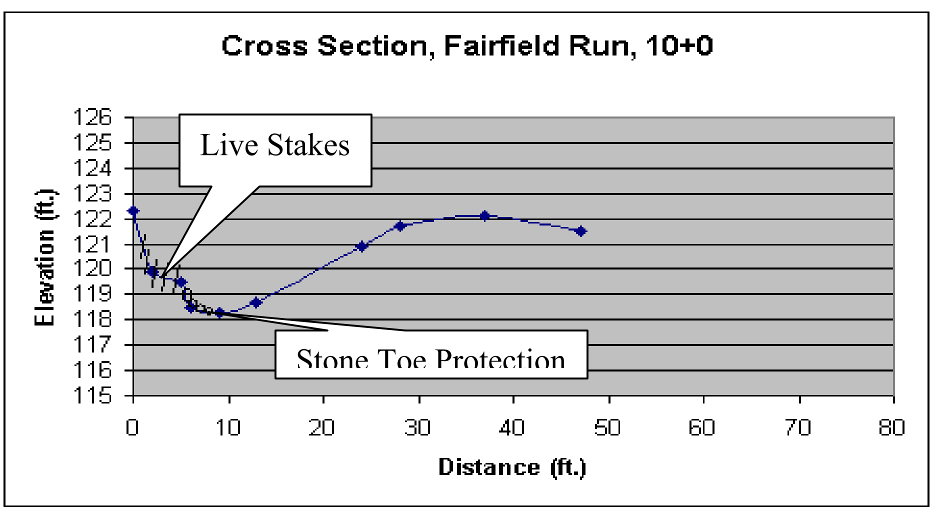
Figure 5.8: Cross Section at 8+0 with Treatment



Treatment 4: Stone Toe Protection and Live Stakes at 10+0- Rocks will be placed along the base of the right bank to provide bank toe stabilization. Live stakes will be placed in the upper bank to provide revegetation and upper bank stabilization. Similarities between this treatment and the treatment used at 8+0 will provide a means for comparison of the toe protection techniques (Stone Toe Protection versus Tree Revetment).

Figure 5.9: Location of Stone Toe Protection and Live Stakes

Figure 5.10: Cross Section at 10+0 with Treatment



Treatment 5: Cross Vanes from 14+0 to 16+0- Cross vanes should be placed at the head of riffles between stations 14+0 and 16+0 (approximately 4 to 6 cross vanes). The head of the riffle is the area where the water surface begins to be broken by rocks. Cross vanes will prevent degrading of the channel and will protect the banks from further undercutting without losing the beneficial cover and shade provided by the undercut banks.

Figure 5.11: Sample Location of Cross Vane

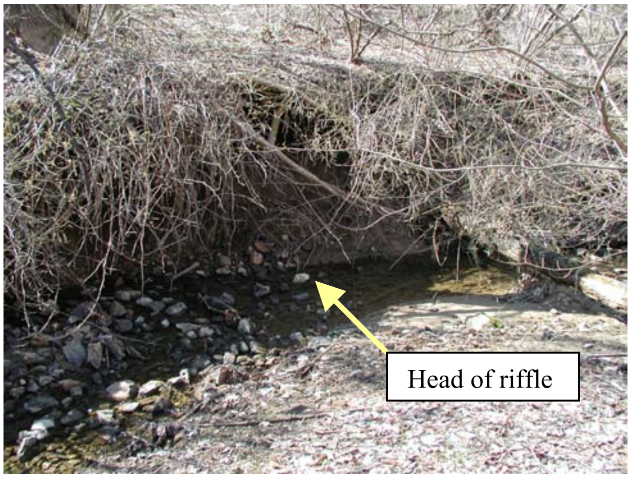
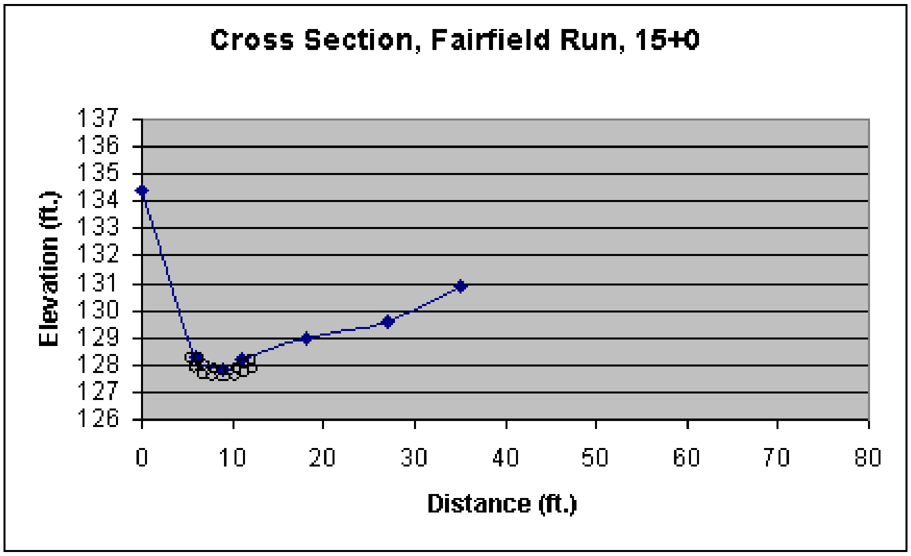


Figure 5.12: Cross Section at 15+0 with Cross Vane



Education and Outreach

In order to improve the educational value of the UD Experimental Watershed, signs should be erected near roads and walkways that explain the watershed concept and the purpose of the UD Experimental Watershed. The signs should have a simple slogan such as "Now Entering the University of Delaware Experimental Watershed." The previous researchers recommended placement of signs at Creek Road, Route 896 near Clayton Hall, the wetland BMP on Laird Campus, the UD main campus mall, the Main St./College Ave. intersection, the UD Agricultural Farm, the stream BMP near Trabant Parking Garage, and the stormwater pond on East Campus (Campagnini, 2001).

In addition, public outreach and educational opportunities in the UD Experimental Watershed could be enhanced through the implementation of the stream restoration project. University students, community organizations, and the public should be invited to participate in a "Stream Clean-Up" prior to restoration and to help with the implementation and monitoring of restoration techniques. Coordination of volunteers will lower restoration costs and is consistent with the educational mission of the UD Experimental Watershed.

Report Card Update

Water quality and habitat data gathered for this project were obtained from candidate restoration reaches rather than at the sampling sites designated by the previous researchers to collect data for the watershed report cards. The report cards, therefore, were not updated. In addition to monitoring of restoration reaches, the watershed report cards should be updated using the sampling sites and methods used by the previous researchers in order to observe temporal changes in overall watershed health during and after stream restoration.

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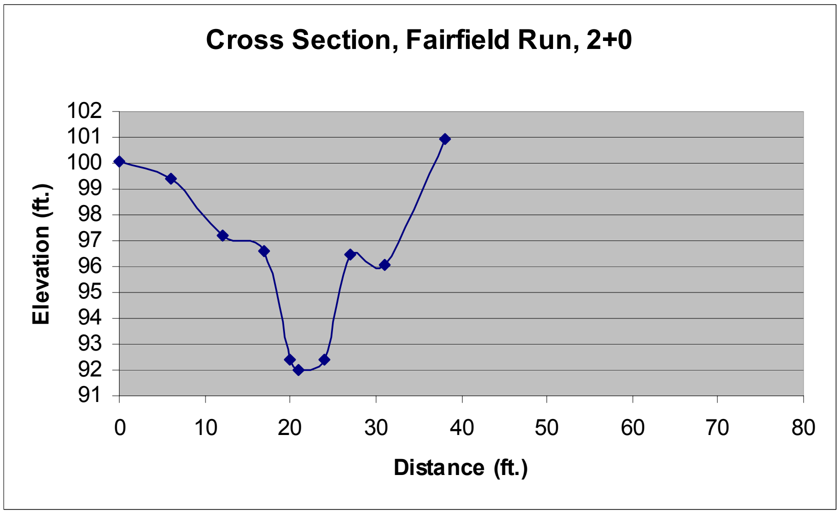
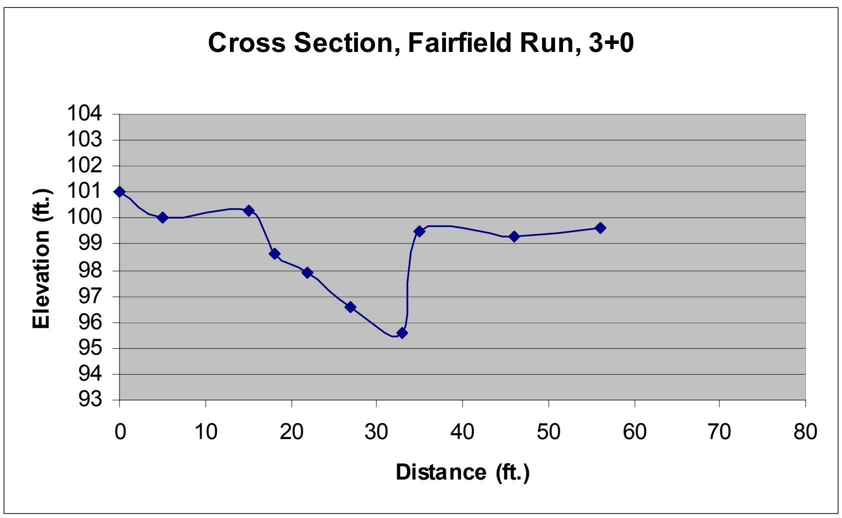
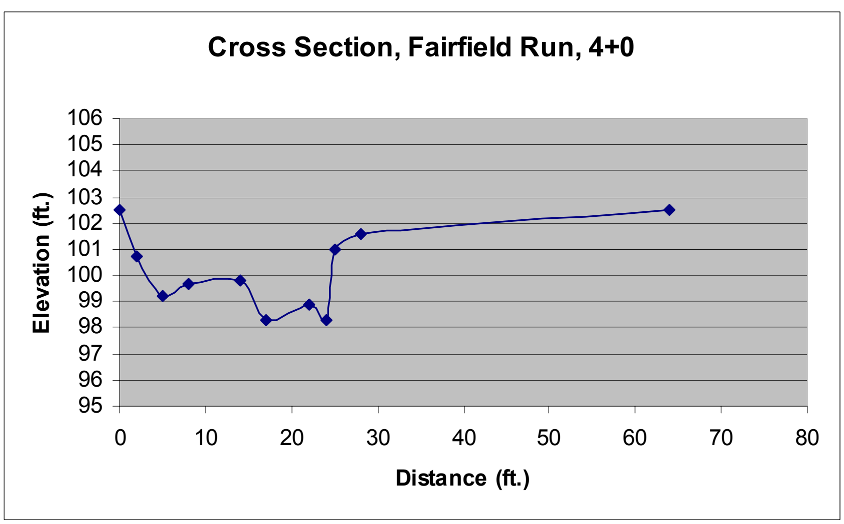
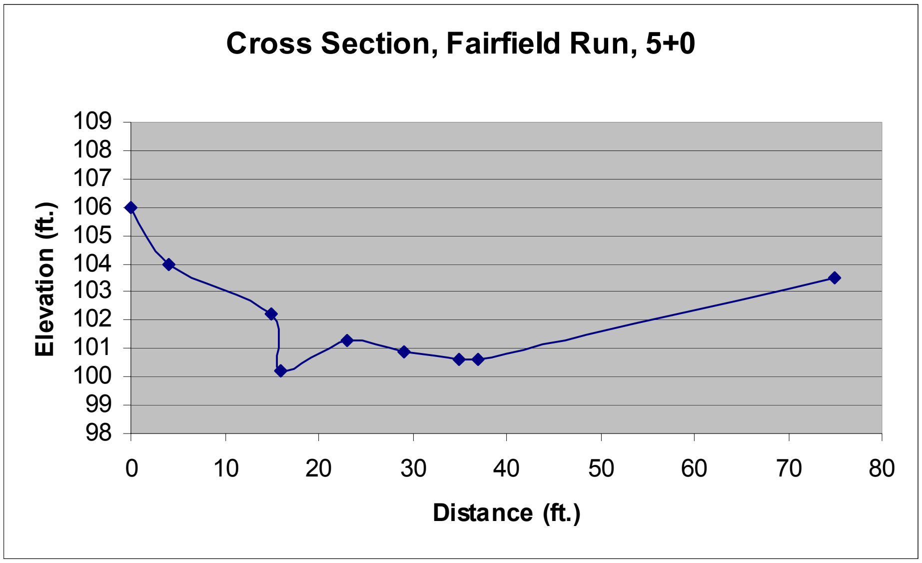
Exhibits

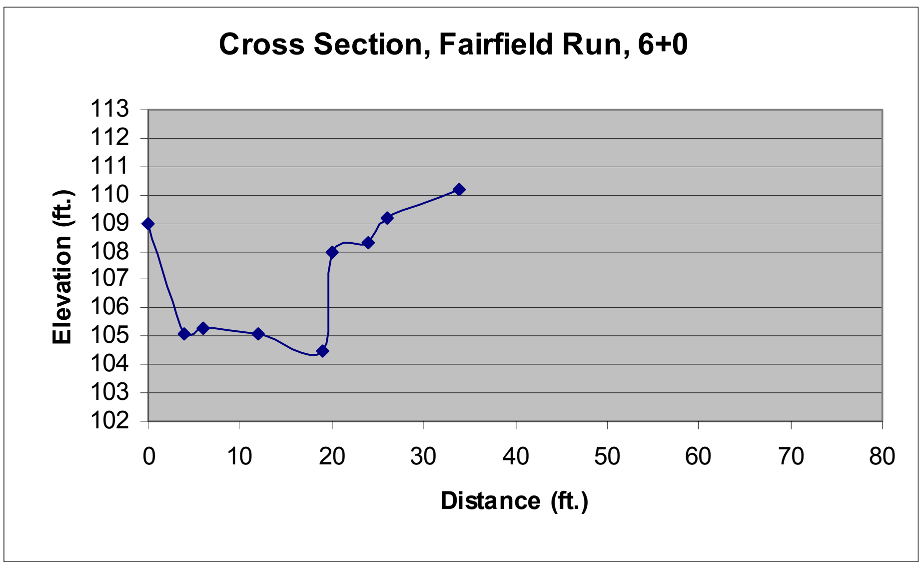
Exhibit 1: Fairfield Run Cross Sections

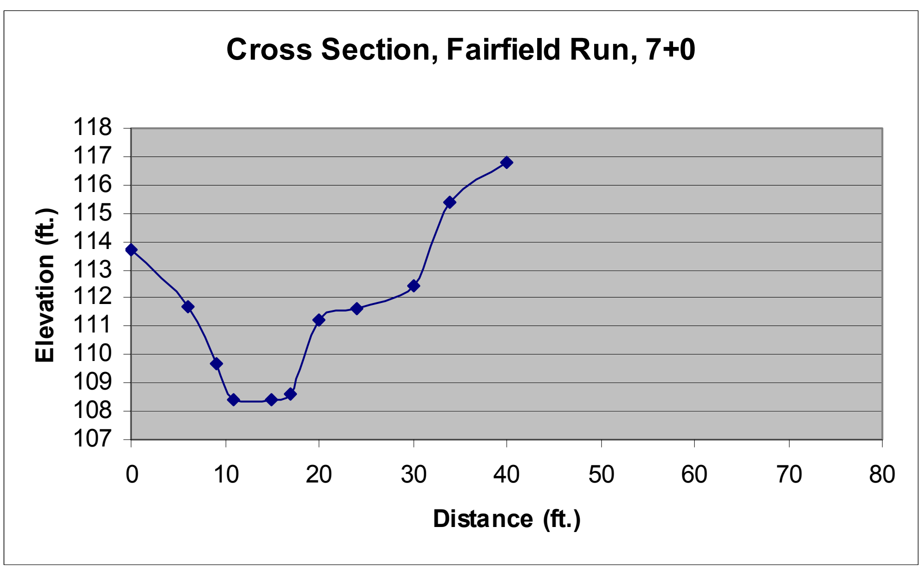


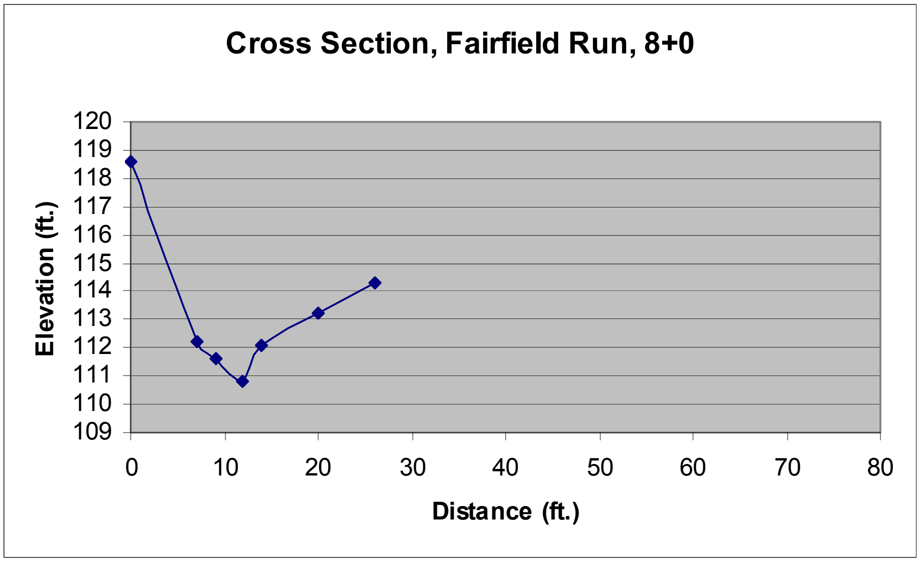


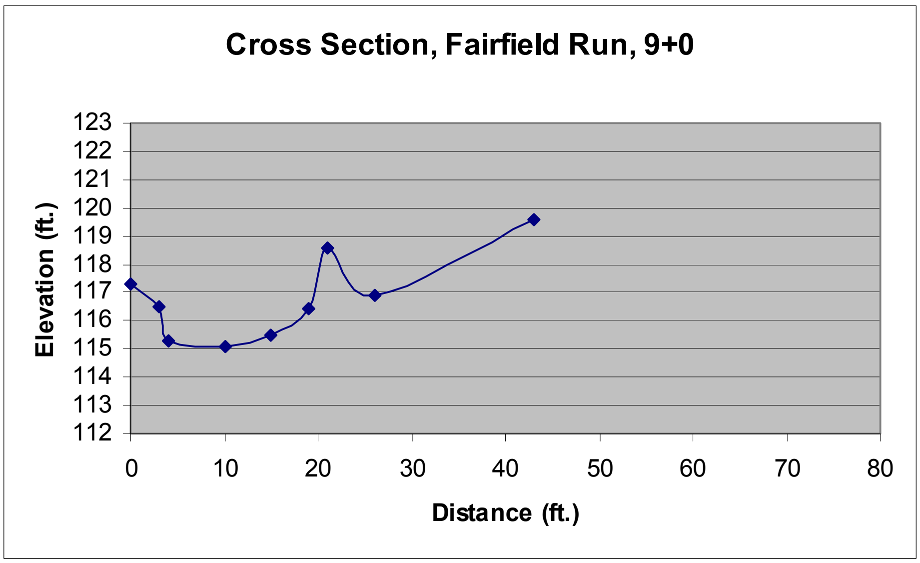


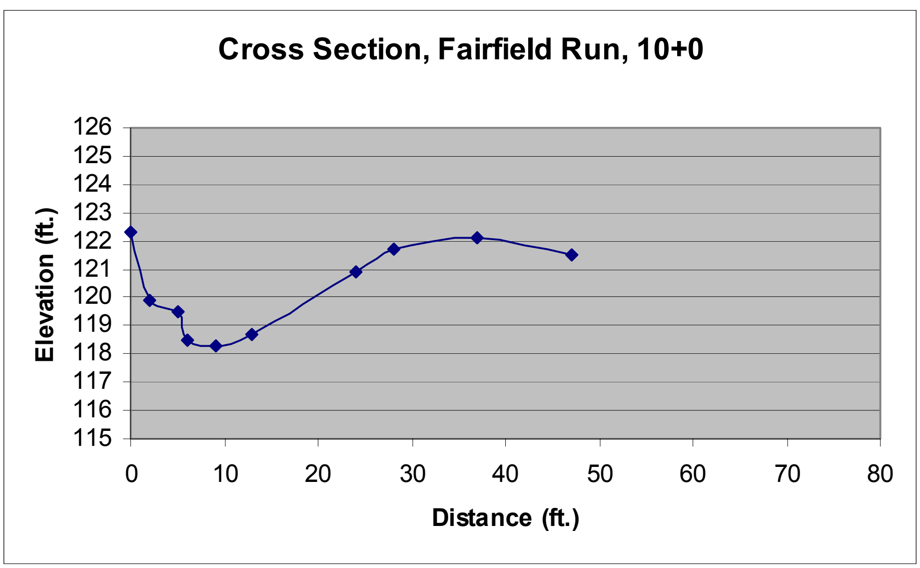

Cross Section, Fairfield Run, 5+0
Elevation (ft.)
Distance (ft.)
109
108
107
106
105
104
103
102
101
100
99
98
0
10
20
30
40
50
60
70
80

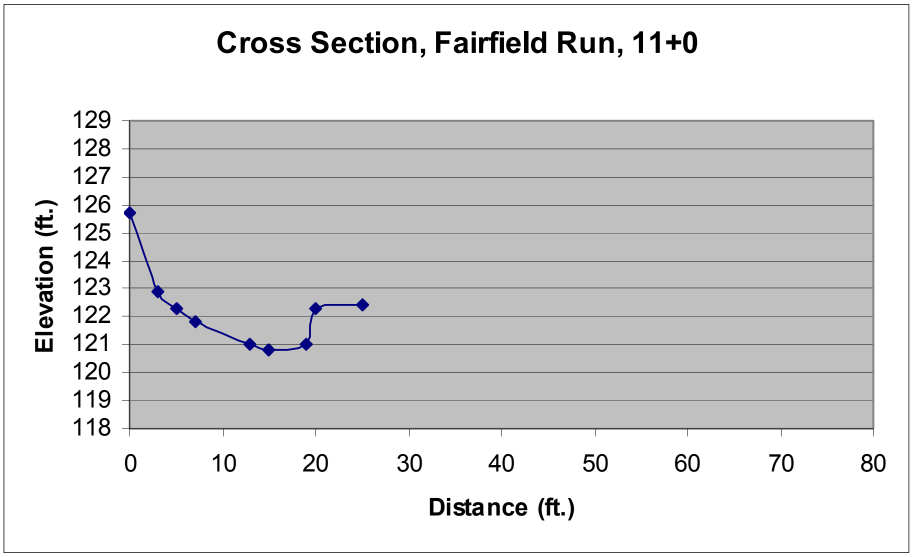

Cross Section, Fairfield Run, 6+0
Elevation (ft.)
Distance (ft.)
113
112
111
110
109
108
107
106
105
104
103
102
0
10
20
30
40
50
60
70
80


Cross Section, Fairfield Run, 7+0
Elevation (ft.)
Distance (ft.)
118
117
116
115
114
113
112
111
110
109
108
107
0
10
20
30
40
50
60
70
80

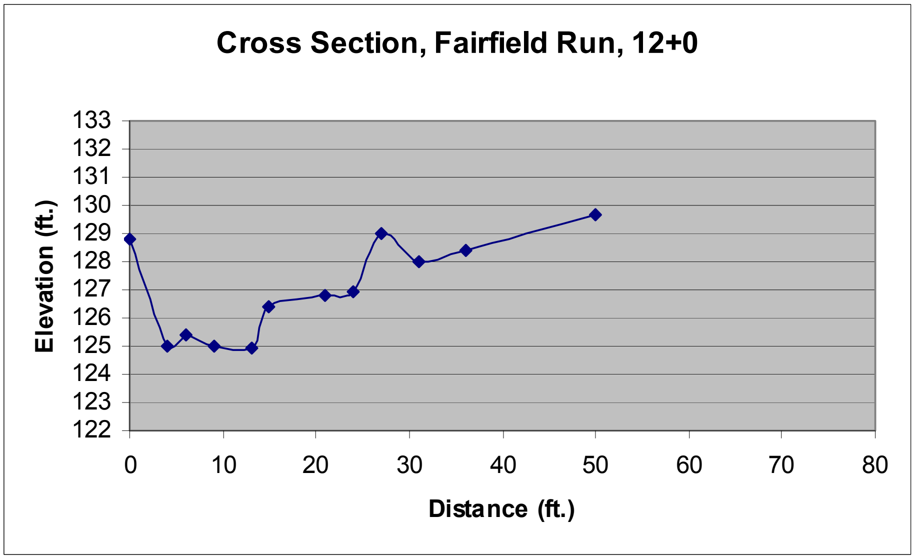

Cross Section, Fairfield Run, 8+0
Elevation (ft.)
Distance (ft.)
120
119
118
117
116
115
114
113
112
111
110
109
0
10
20
30
40
50
60
70
80


Cross Section, Fairfield Run, 9+0
Elevation (ft.)
Distance (ft.)
123
122
121
120
119
118
117
116
115
114
113
112
0
10
20
30
40
50
60
70
80

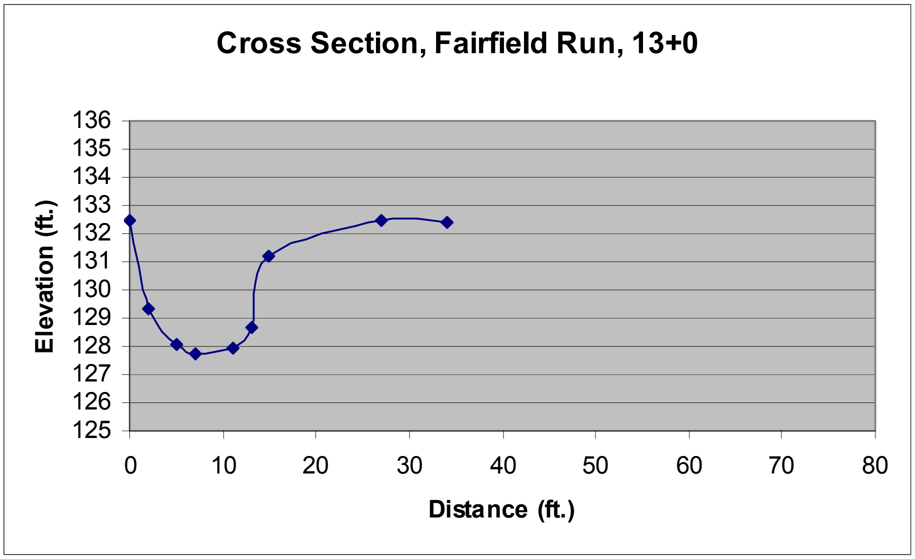

Cross Section, Fairfield Run, 10+0
Elevation (ft.)
Distance (ft.)
126
125
124
123
122
121
120
119
118
117
116
115
0
10
20
30
40
50
60
70
80



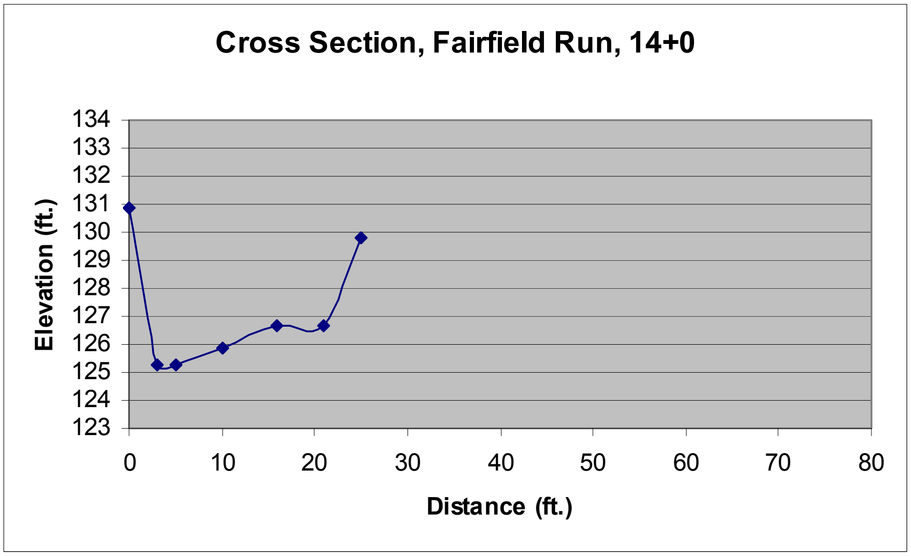
Cross Section, Fairfield Run, 11+0
Elevation (ft.)
129
128
127
126
125
124
123
122
121
120
119
118
0
10
20
30
40
50
60
70
80
Distance (ft.)

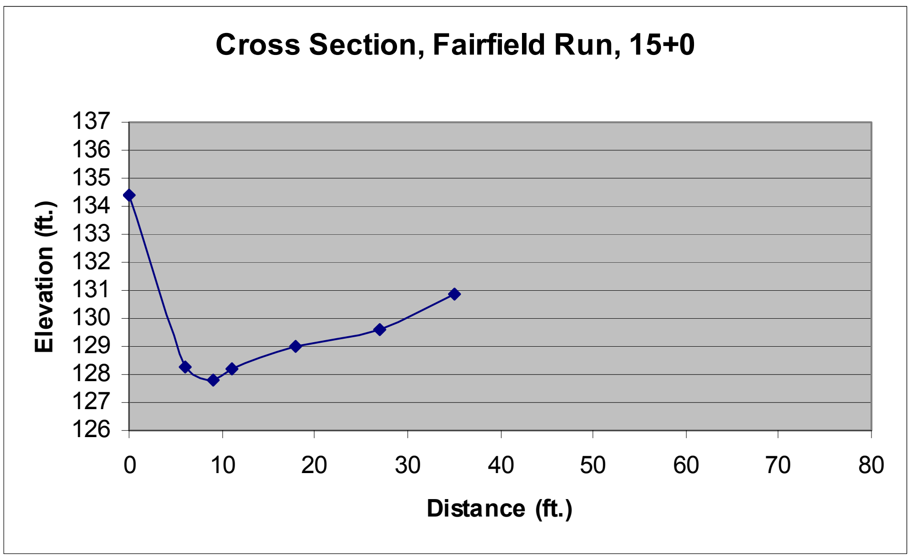


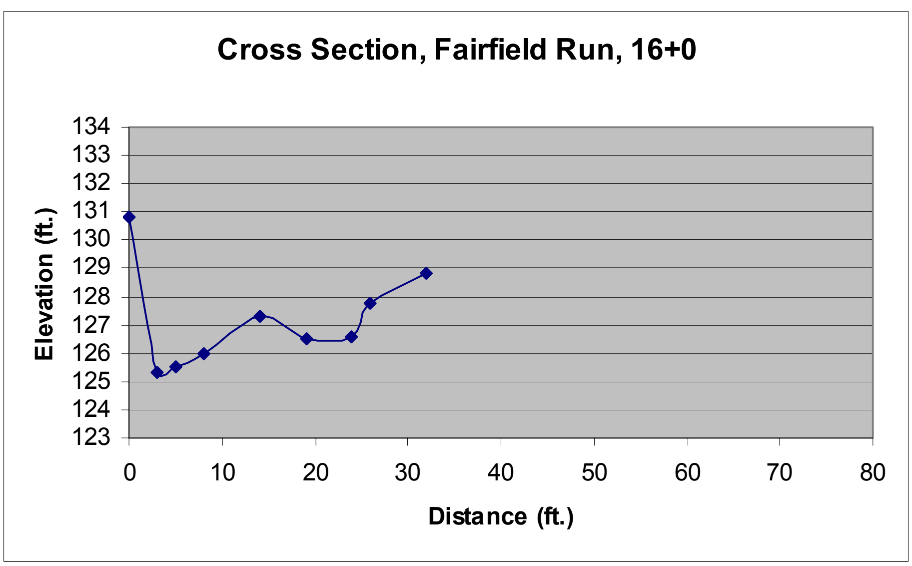
Cross Section, Fairfield Run, 12+0
Elevation (ft.)
133
132
131
130
129
128
127
126
125
124
123
122
0
10
20
30
40
50
60
70
80
Distance (ft.)

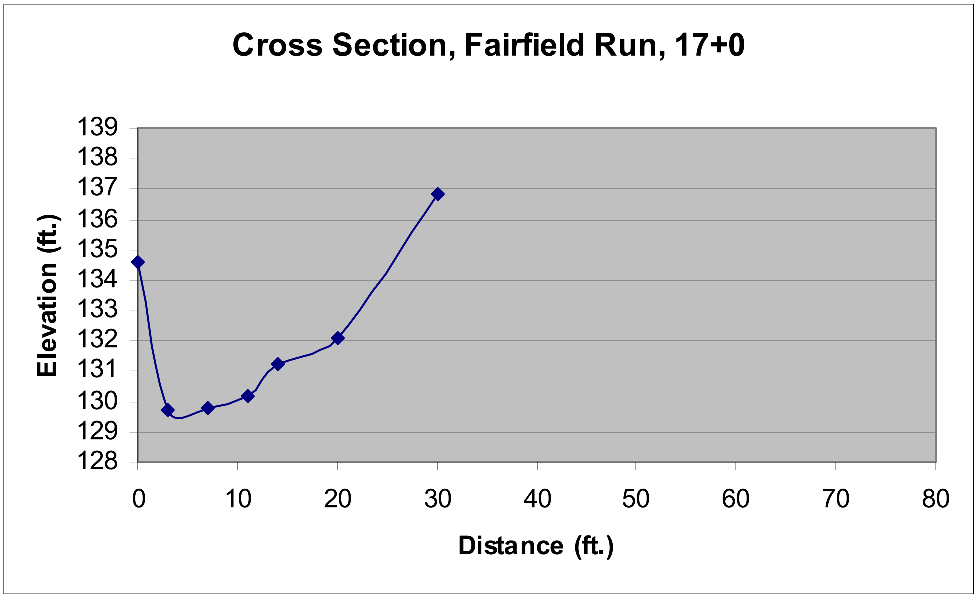


Cross Section, Fairfield Run, 13+0
Elevation (ft.)
136
135
134
133
132
131
130
129
128
127
126
125
0
10
20
30
40
50
60
70
80
Distance (ft.)


Cross Section, Fairfield Run, 14+0
Elevation (ft.)
134
133
132
131
130
129
128
127
126
125
124
123
0
10
20
30
40
50
60
70
80
Distance (ft.)


Cross Section, Fairfield Run, 15+0
Elevation (ft.)
137
136
135
134
133
132
131
130
129
128
127
126
0
10
20
30
40
50
60
70
80
Distance (ft.)


Cross Section, Fairfield Run, 16+0
Elevation (ft.)
134
133
132
131
130
129
128
127
126
125
124
123
0
10
20
30
40
50
60
70
80
Distance (ft.)


Cross Section, Fairfield Run, 17+0
Elevation (ft.)
139
138
137
136
135
134
133
132
131
130
129
128
0
10
20
30
40
50
60
70
80
Distance (ft.)

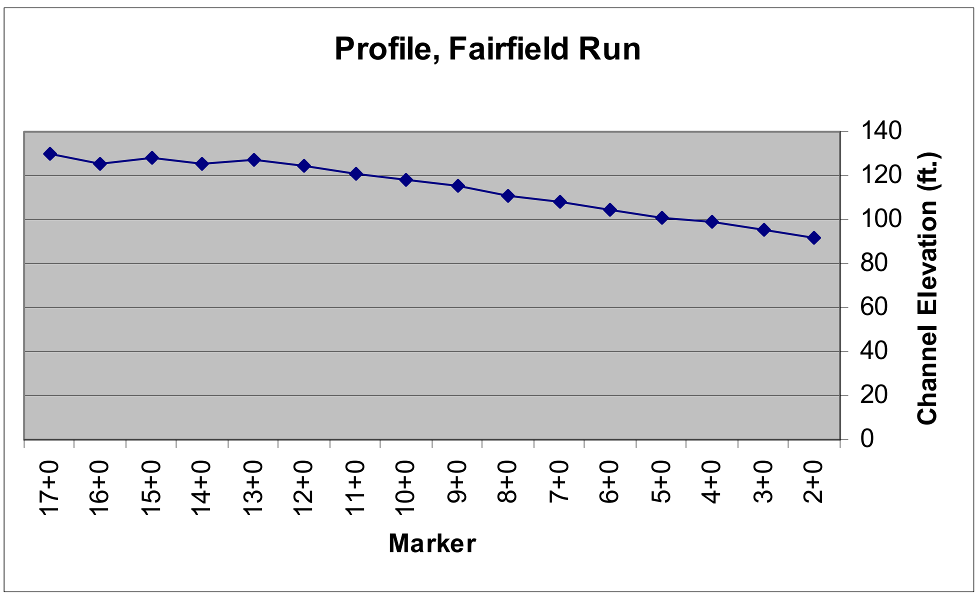
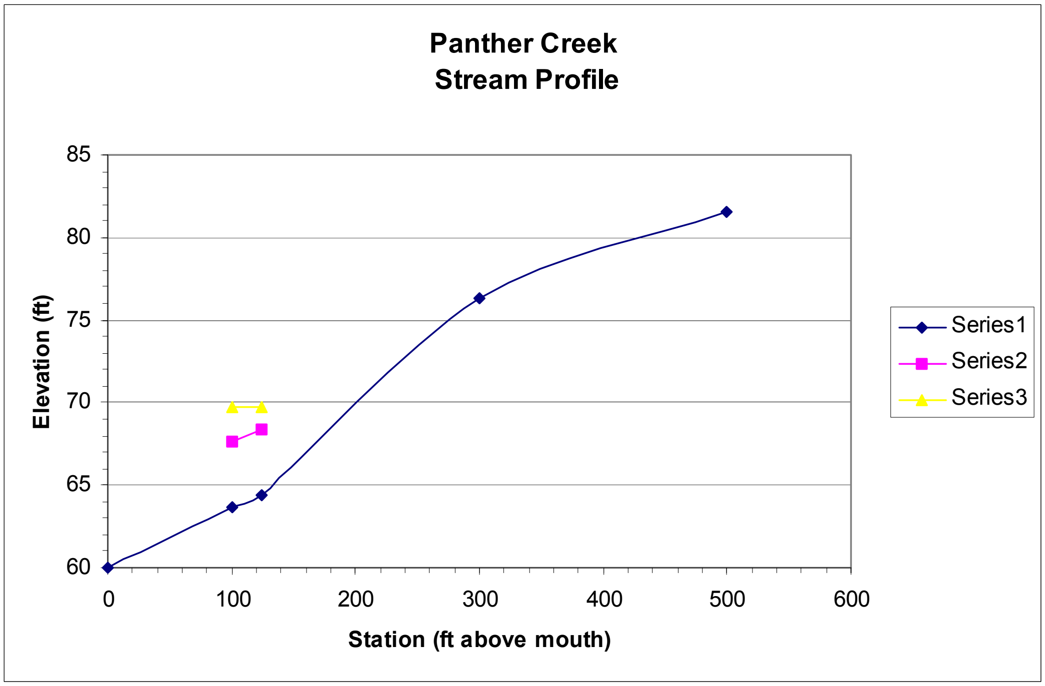
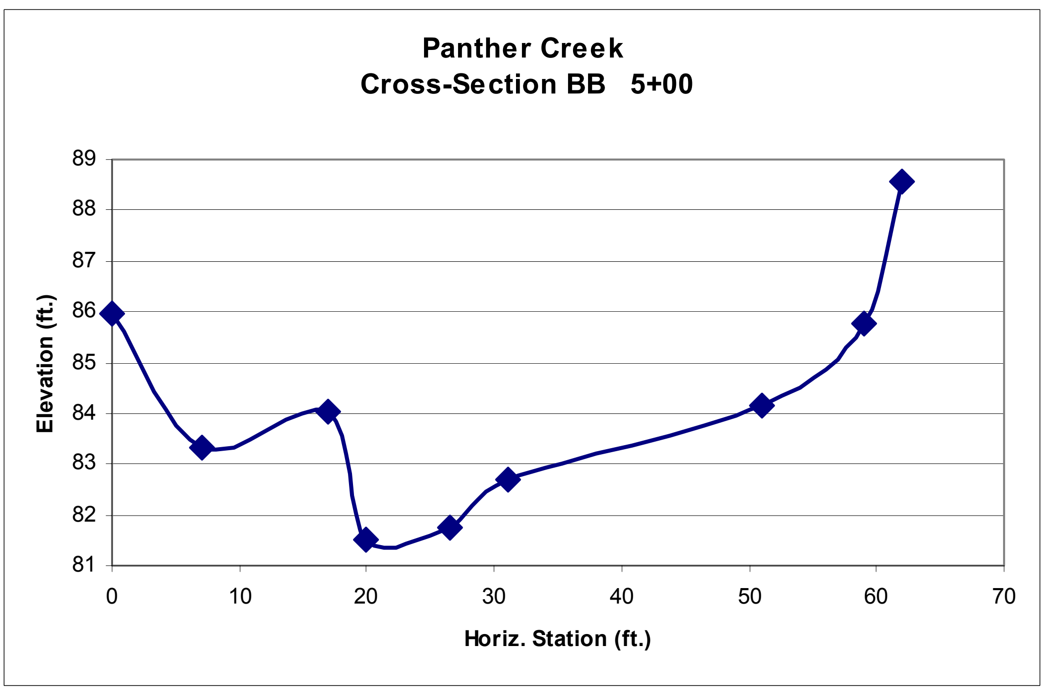

Profile, Fairfield Run
140
120
100
80
60
40
20
0
Channel Elevation (ft.)
17+0
16+0
15+0
14+0
13+0
12+0
11+0
10+0
9+0
8+0
7+0
6+0
5+0
4+0
3+0
2+0
Marker

Exhibit 4: Reference Stream Cross Sections





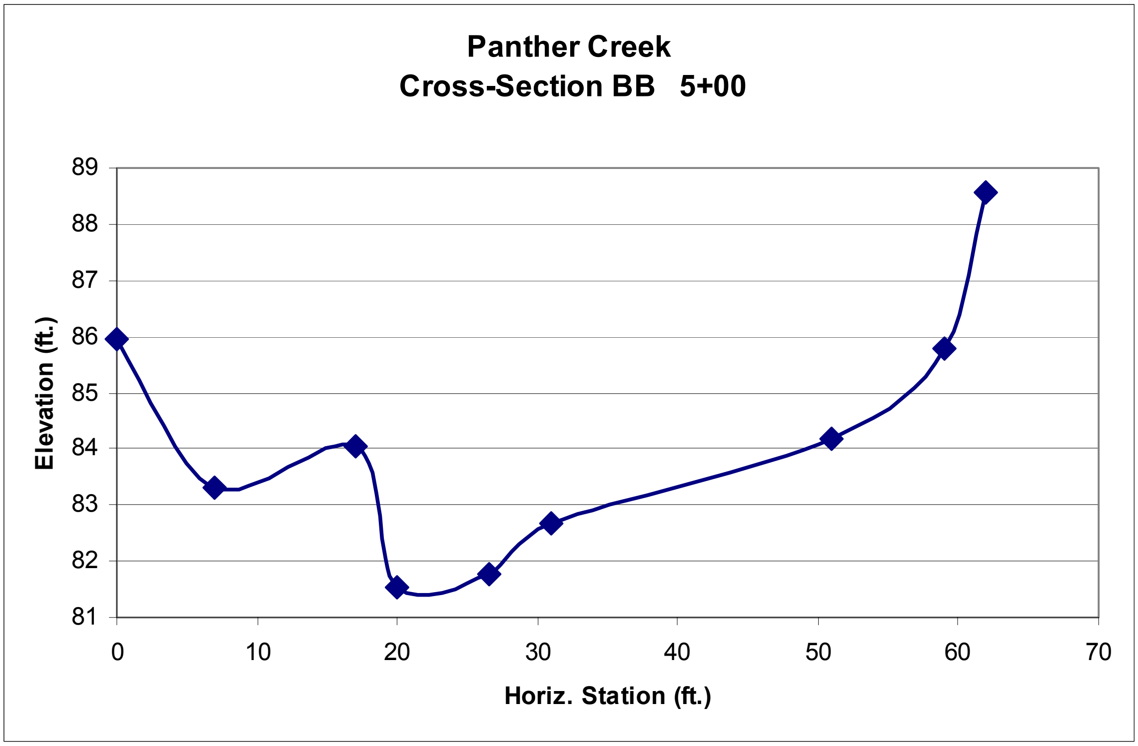
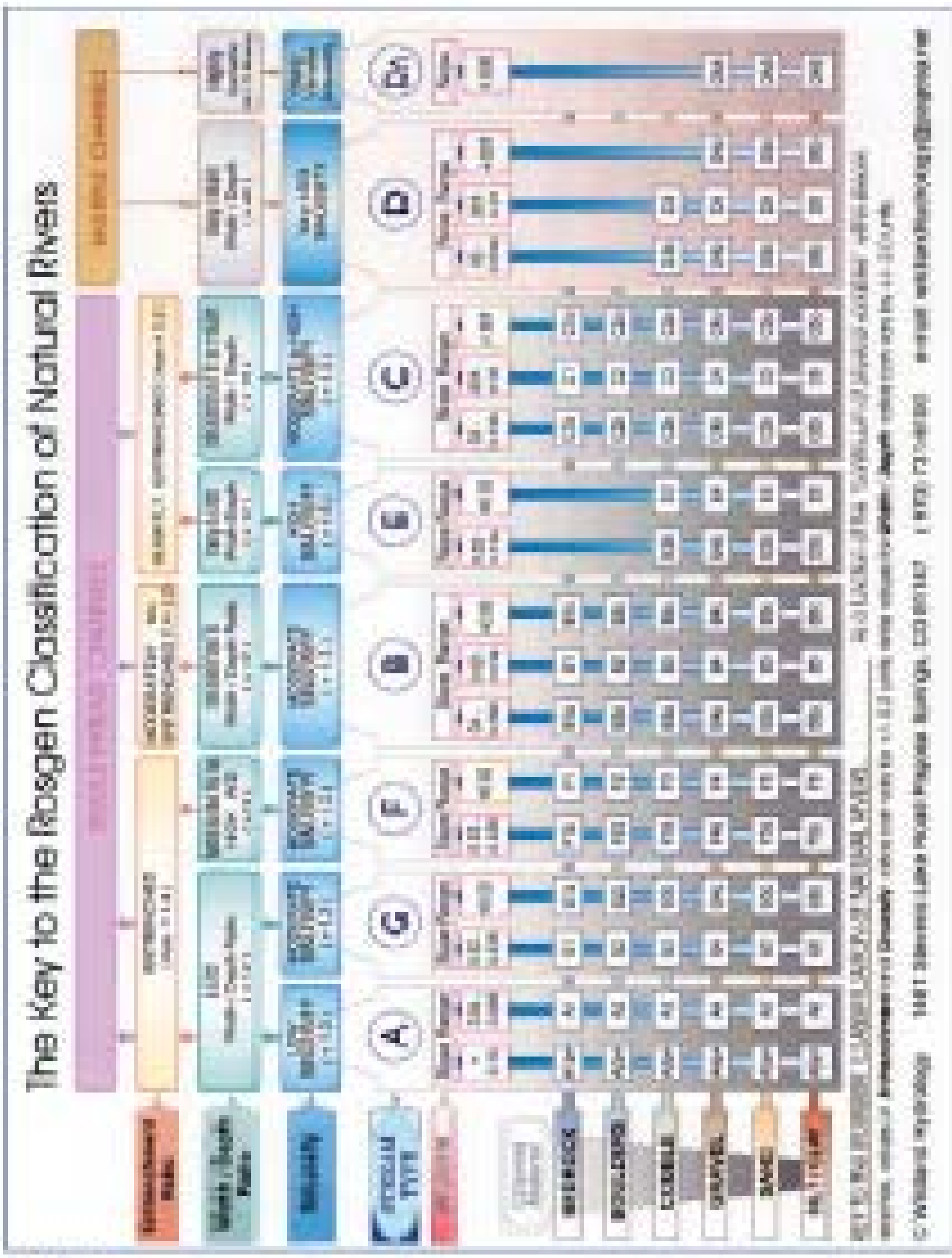

Panther Creek
Cross-Section BB 5+00
89
88
87
86
85
84
83
82
81
Elevation (ft.)
0
10
20
30
40
50
60
70
Horiz. Station (ft.)

Exhibit 3: Rosgen Stream Classification Method



(Doll et. Al., 2003)