Characterization of Miller Run and Conceptual Plan for Watershed Restoration

Final Report for a Class Research Project

UNIV 298/GEOL 298/BIOL 298/ENST 298
Stream Restoration -- Spring 2009

(sponsored by the Henry Luce Foundation Grant to the Bucknell University Environmental Center)

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Chapter 1. Introduction

Miller Run is located at a latitude of 40^o 57' 36'' North and longitude of 76^o 53' West in Lewisburg, Pennsylvania (Fig. 1-1). Bucknell University owns approximately eighty percent of its watershed. The watershed consists of an urbanized college campus, a golf course, a new housing development, and some medium-density suburbs on its fringe. Miller Run is a small stream extending 1.90 km with a drainage area of 2.28 km^2. It has a 157.90 m mean basin elevation with a mean basin slope of 3.12^o. The stream receives about 1.04 m of annual precipitation. The average depth to bedrock is only 1.44 m, leaving very little room for large quantities of water. Miller Run is a tributary to Limestone Run, which is locally known as Bull Run. The watershed is underlain by northward dipping sedimentary rocks from the Silurian age (Fig. 1-2). From South to North, is underlain by the reddish Bloomsburg shale and sandstone. The bedrock then transitions to the Wills Creek shale and sandstone, which has a greenish-yellow hue. The bedrock then transitions to the Keyser-Tonoloway limestone. Much of the watershed has a surficial layer of unconsolidated Pleistocene sediment; mostly yellow-tan wind-blown silt called loess. Thickness of the loess ranges from a few inches to eight feet. There are also scattered gravelly till and outwash sediments.

Figure 1-1 Aerial Photo of Miller Run Watershed

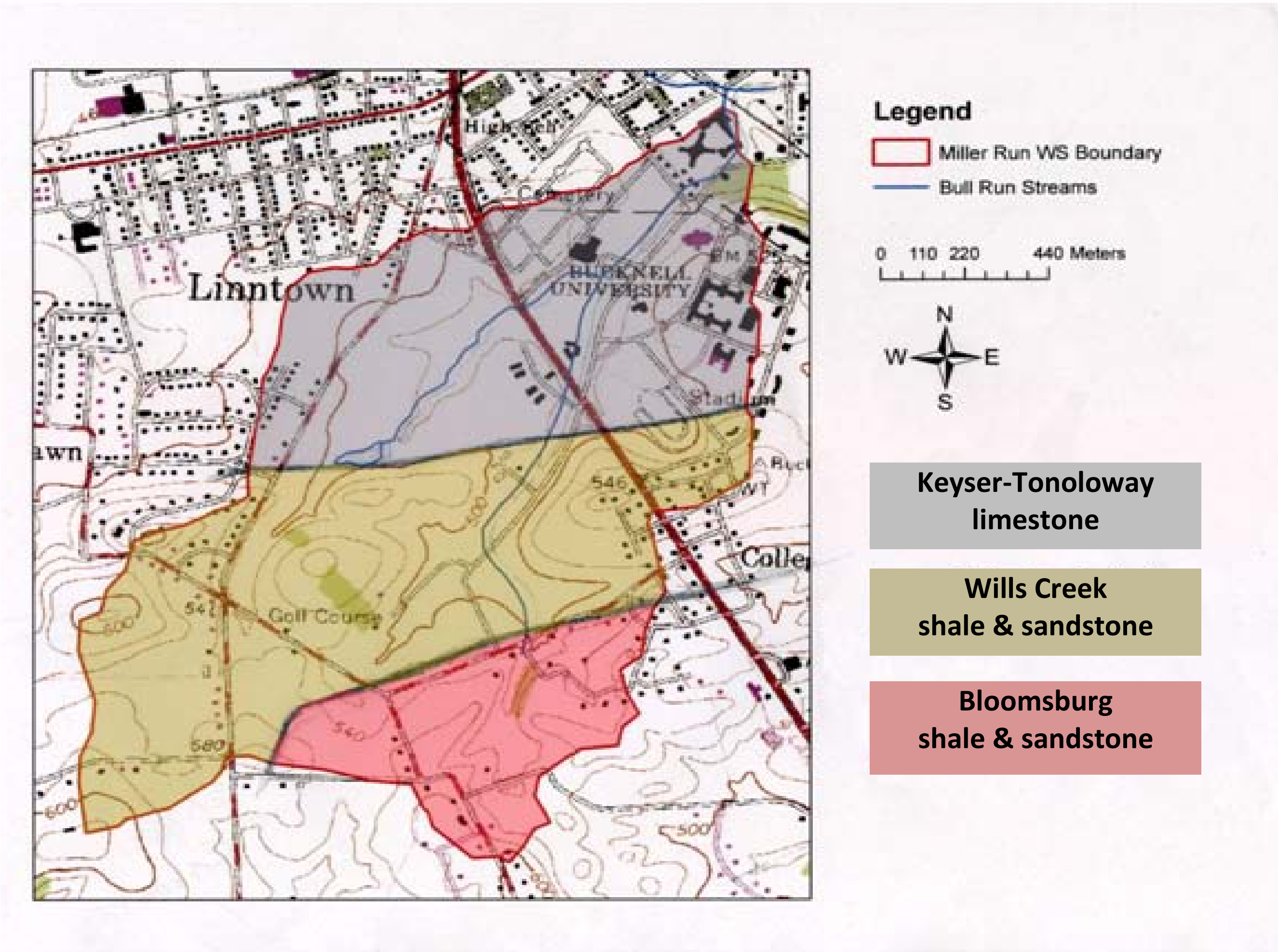


Figure 1-2 Geologic Map of Miller Run

The Miller Run Project was initiated to coincide with the Campus Greening and Susquehanna River Initiatives of the Bucknell University Environmental Center (BUEC) as well as the Campus Master Plan. This project serves as a focused class research project for Stream Restoration (UNIV/GEOL/BIOL/ENST 298); the second of the experiential team-taught courses sponsored by the Henry Luce Foundation Grant to the BUEC. The most significant goal of the Miller Run Project is to restore Miller Run by Bucknell taking a lead role in ecological stewardship. If implemented, this plan will beautify Bucknell's campus as well as decrease the impact of flood events.

The Miller Run report has been divided into two main sections: 1) to focus on the results of our research and the characterization of Miller Run as it now occurs in its degraded state; and, 2) to provide a conceptual plan for improvements and restoration of the Miller Run watershed. Although not discussed in this report, a concurrent investigation into the routing of treated effluent from the Lewisburg Area Joint Sewer Authority College Park Treatment Plant into the upper part of Miller Run watershed would blend favorably with the restoration plans presented in this report. The addition of sewage effluent (whether it was used by the Bucknell Golf Course to reduce groundwater well pumping or discharged directly into Miller Run after treatment in a wetland on the driving range) would significantly enhance efforts to restore year-round flow to the stream.

Our watershed restoration plan was created to accomplish five main goals. These include: flood control, aesthetic appeal, environmental education, ecological health and sustainability, and channel sustainability.

I. In order to promote flood control, there must be implementation of storm water management within the channel-floodplain area as well as off-channel sites. In-channel improvements include wetlands and floodplain storage basins, while off-channel designs include increasing campus infiltration to restore the regional water table. These include permeable surfaces (to increase infiltration) and retention basins such as rain gardens to reduce the amount of runoff directly into the stream).

II. Miller Run currently does not display any sort of aesthetic appeal. In order to beautify the area in and around the channel, we wish to introduce native species, riparian vegetation, and recreational trails and other usages to the stream. The Miller Run Greenway would serve as a logical connector to regional plans for greenways and hiking/biking trails in the Lewisburg area.

III. Environmental education is a goal very important to the university. We would like Miller Run to be an outdoor classroom that could teach biology, geology, and engineering students alike as well as about watershed management and sewage recycling. This outdoor classroom would set the example for other universities and towns to follow. Local grade schools would also be likely to develop instructional programs focused on Miller Run and the ecology of its restoration. Connecting Miller Run to regional green spaces and recreational programs also provides an opportunity to educate the public about stream restoration and watershed management.

IV. Ecological health and sustainability is vital to the restoration of Miller Run. This requires re-establishing year-round flow, habitat diversity and continuity, improved water quality and the introduction of a variety of target aquatic species.

V. Channel sustainability is also imperative to the lasting health of the stream. Long-term ecological sustainability is only possible if natural geomorphic processes involved in channel flow and evolution are made possible. We hope to remove unneeded structures, give the channel space for migration and evolution, re-create the connection between the channel and floodplain, and investigate its geomorphic history and use this as a template for re-establishing channel form and process.

The class was divided into five groups, overseen by the project managers, and supervised by the two faculty instructors from Geology and Biology. The hydrology group established two stream flow-gauging stations; researched current trends in Miller Run's flow hydrology (storm flow and low-flow) and produced a wealth of data proving the Miller Run is in a degraded state. The storm runoff group identified the impact of storm water runoff from the campus on the stream and researched possible solutions to the amount of runoff coming from the campus. The channel design team analyzed the profile of the stream and determined problem areas. They then created a conceptual plan as to how to implement channel sustainability for the future and to accommodate some of the storm runoff by suggesting a design to provide for low-flow augmentation. The water quality group analyzed water samples to find pollutants and assessed biological diversity to determine possible impairment of ecological integrity. Lastly, the aesthetics and economics group provided historical information on Miller Run and general cost options for implementing proposed restoration approaches.

MR-2 Gaging Station and ISCO Sampler

Chapter 2. Geomorphic and Ecological Characteristics of Miller Run: A Degraded Watershed

The Hydrology of Miller Run

Introduction

The prospects of Miller Run as a healthy biotic habitat, a consistently flowing stream, and an aesthetically pleasing attribute to Bucknell University are all inexorably linked to the stream's hydrology. By studying the manner in which the flow of Miller Run behaves, we can begin to address the problems that it faces.

The current state of Miller Run's hydrology is very off balance. There are large portions of the year, regardless of drought (but certainly amplified during dry years), where the downstream reaches of Miller Run do not contain permanent flow. Clearly, a stream that does not consistently flow is not only an unsightly feature on campus, but also a lethal obstacle to a healthy aquatic habitat. Miller Run appears as a solid blue line on the U.S. Geological Survey 7.5' Quadrangle, indicating that it formerly existed as a perennial (permanently-flowing) stream.

Miller Run also suffers from problems on the other end of the spectrum – during periods of high flow, water from snowmelt and rainstorms quickly enters and exits the stream system in an exceedingly flashy manner. This results in enhanced flooding during these events, but leaves the stream dry at most other times. This flow pattern is unsustainable and adversely affects both the University and the biological habitat.

In addition to the flow patterns, it is also vital to understand the geomorphology of the Miller Run watershed, including the types, quantities, sources, and distributions of sediment. Knowledge of a stream's sediment transport is critical to a successful restoration because sediment can redirect the intended flow of water, destroy or bury restoration structures, and harm the biota of the stream – all of which can result in floods, failed restoration projects, or unhealthy ecosystems.

In order to effectively restore Miller Run, the flow of the stream must be restored to a continuous state, the extreme flow variability must be moderated, and the sediment load must be reduced. In this section of the report, we will show how various aspects of the flow and sediment transport are having a negative impact on Miller Run and how Bucknell University is contributing to and perpetuating these problems.

Methods

In order to measure the discharge of the stream, or the flow of the stream over time, two gauging stations that measure the height of the water in Miller Run, referred to as stage, were established at two critical sites. The first gauging station, MR-1, was set up at an upstream location near the Bucknell University Art Barn, while the second gauging station, MR-2, was set up at a downstream location by the Hunt Hall Parking Lot (Fig. 2-1). The upstream gage (MR-1) allowed us to observe the activity of the watershed where it is not directly affected by the main part of campus, where rip-rap is not stabilizing the banks, and where there is a sub-optimal concentration of riparian vegetation buffering the stream. The downstream gage (MR-2) allowed us to observe the activity of the watershed that contains most of the stormwater runoff pipes from campus, runs through the main part of Bucknell University, and has its banks stabilized by rip-rap and concrete walls. Establishing two gauging stations upstream and downstream was vital to our study as it allowed us to directly observe the effects of the campus on Miller Run. In addition to the data collected by our team, data from Allison Schaffer's senior thesis (Schaffer, 2008), and hydrologic data that dates back to October of 2007 were also used to study the flow characteristics of Miller Run.

To measure the source and transport of sediment in Miller Run, two time-delayed sampling devices known as ISCOs were set up at both gauging stations to collect suspended sediment in the stream water during rain and snowmelt event periods in one hour intervals. In addition to these devices, a storm response team was assembled, led, and aided by Christine Kassab and Professor Kochel in order to quickly mobilize and collect sediment and suspended sediment samples at 10 locations throughout the watershed and at various stormwater pipes along Miller Run during rain and snowmelt events.

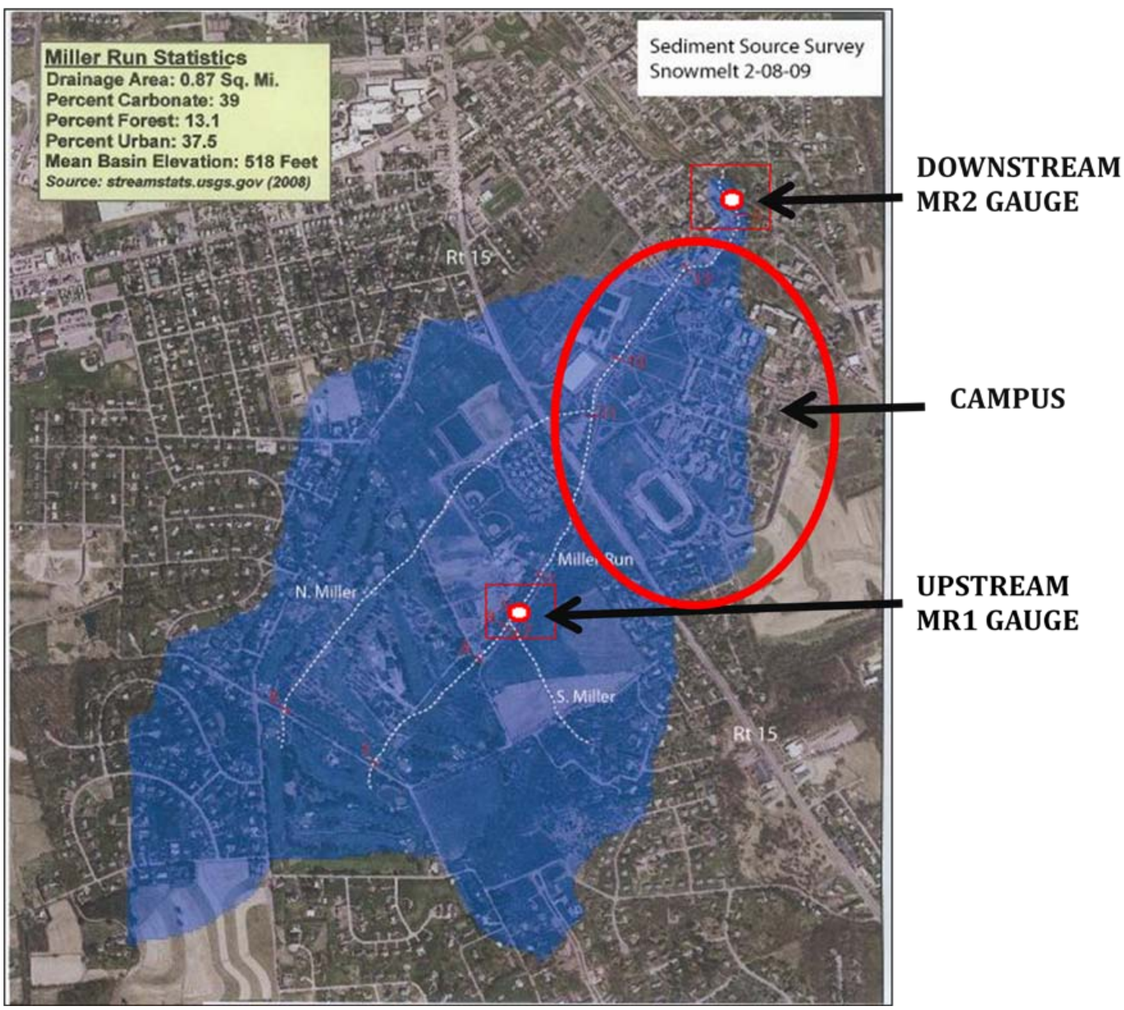


Figure 2-1 Location of Upstream and Downstream Gauges

Flow Patterns and Problems

A.) Base-flow

In order to demonstrate the severity of Miller Run's flow deficit, we first derived the base-flow of Miller Run through a comparison to Penns Creek, a nearby stream with a U.S.G.S. gage, that is in a similar hydrogeomorphic setting (The Ridge and Valley Province) to Miller Run, albeit a larger watershed. Since Miller Run is topographically similar and in the same region, we made the assumption that it would be at base-flow as well during the time periods when Penns Creek was flowing at base-flow discharge. Figures 2-2 and 2-3 show the hydrographs for Penns Creek during Spring 2009. The circled base-flow periods were selected as surrogates for periods when streams in the region were likely at base-flow. We took the flow of Miller Run at both gages on those same dates to estimate a mean base-flow. As you can see from Figures 2-4 and 2-5, this value was approximately **0.005 m^3/s.**

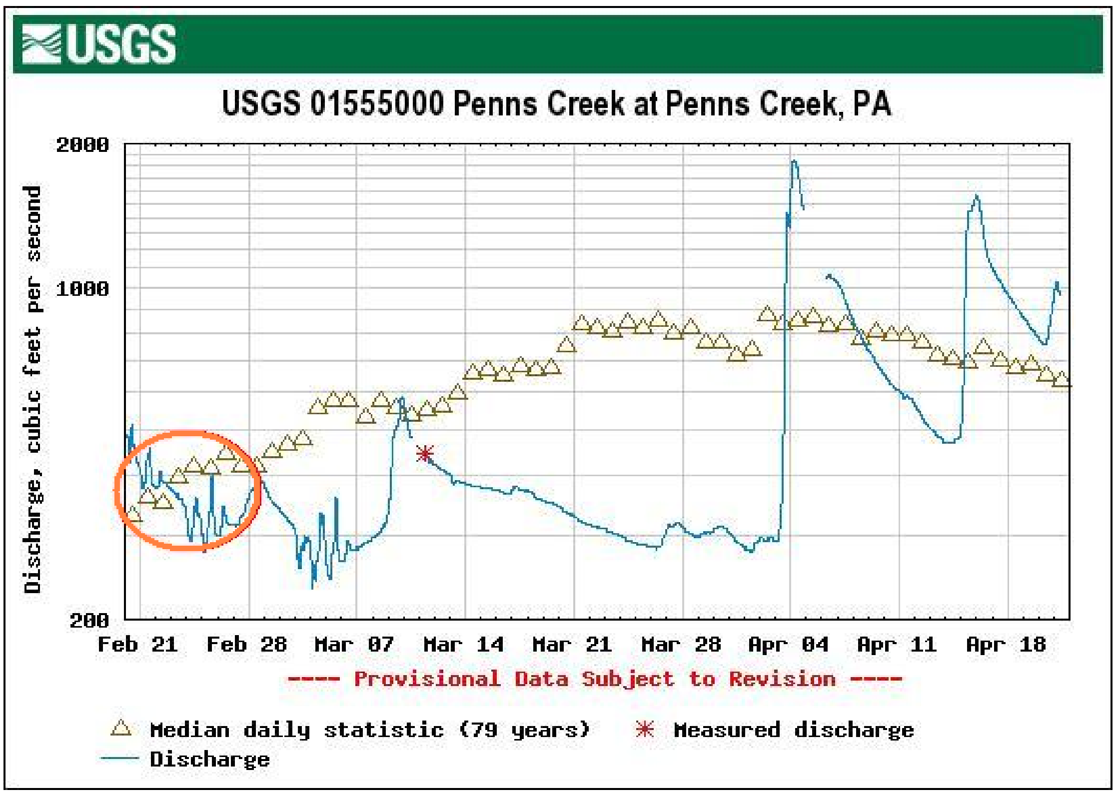


Figure 2-2. Penns Creek Mean Discharge Estimate

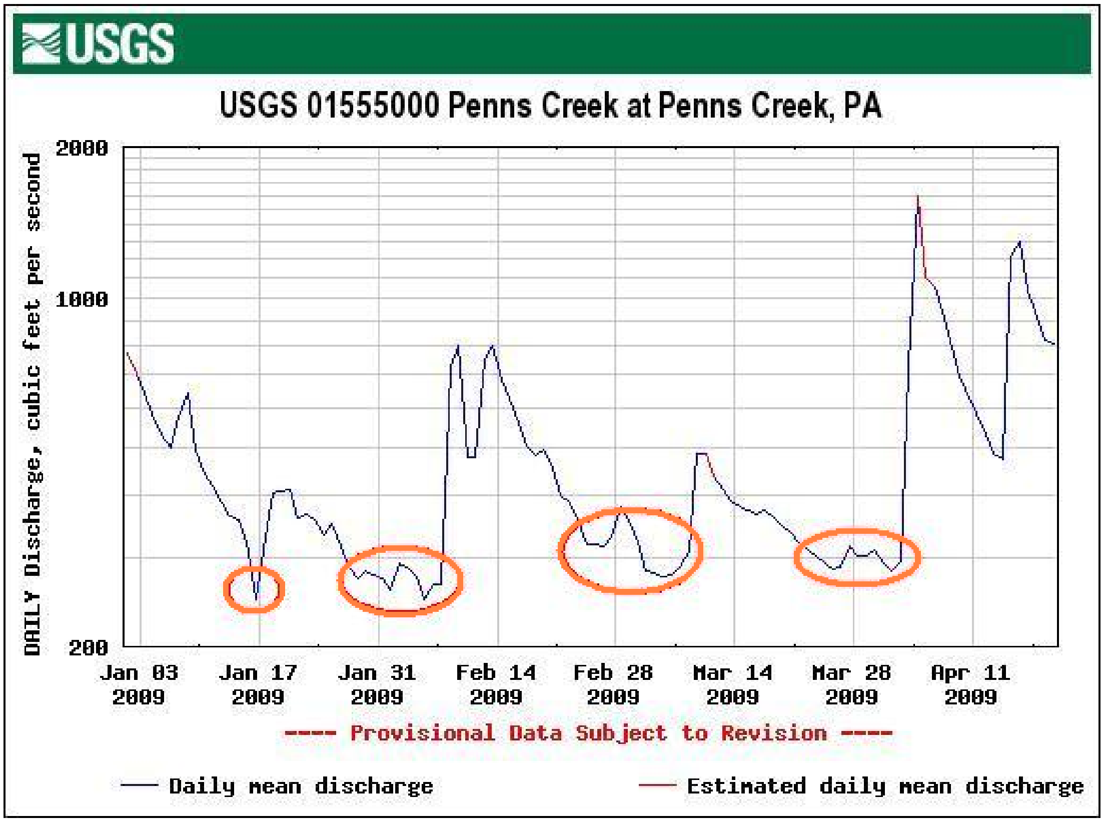


Figure 2-3. Base-flow Dates of Penns Creek for Comparison to Miller Run

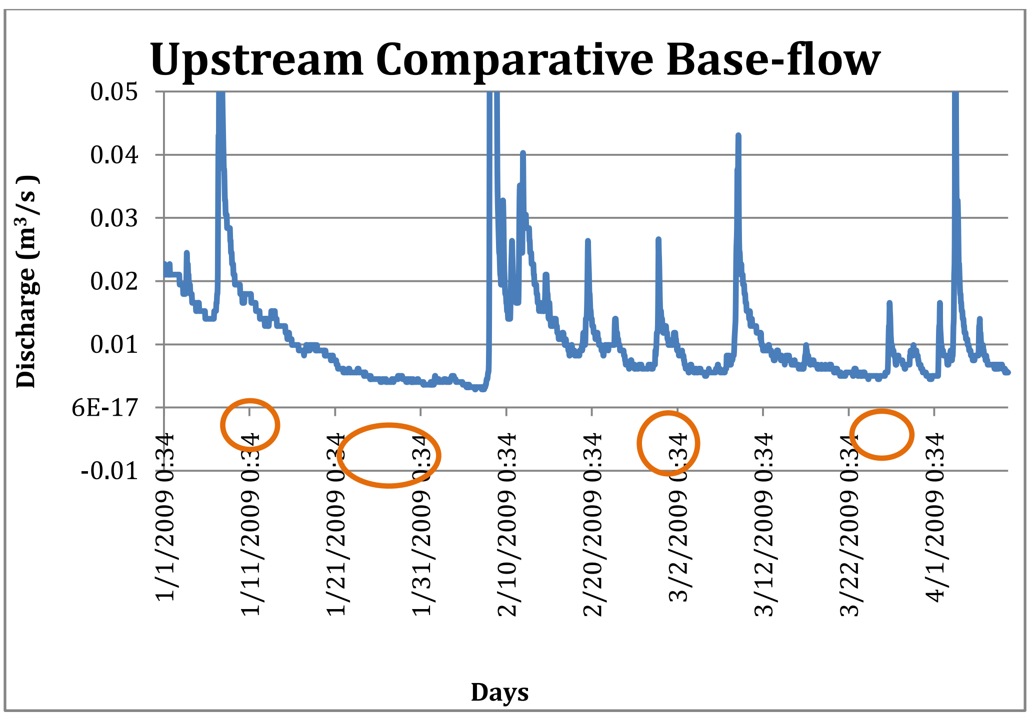


Figure 2-4. Estimated Base-Flow of Miller Run MR 1

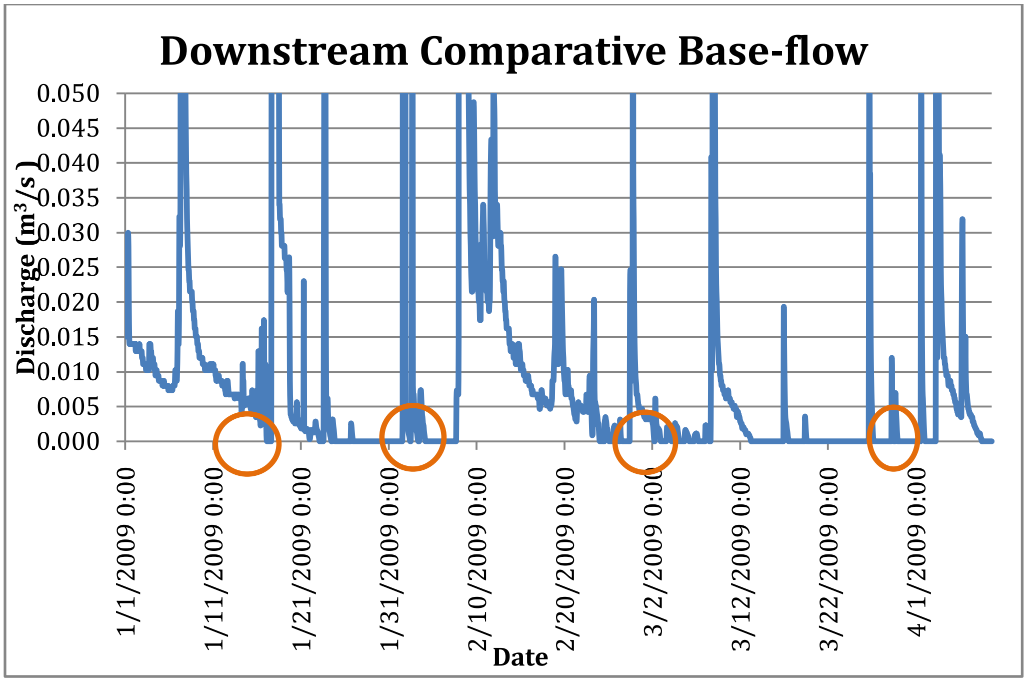


Figure 2-5. Estimated Base-Flow of Miller Run MR2

B.) Flood events

The behavior of Miller Run during flood events such as snowmelt or rainstorms does not correlate with the hydrologic behavior of a normal, healthy stream. For a standard storm event, such as the April 3rd rain event with a total of 0.66 in. of rain, the runoff per unit area for upstream was 2460 m^3/km^2 while the runoff per unit area for downstream was 1760 m^3/km^2. For a normal stream, runoff enters the stream through its low-order tributaries, moving from upstream to downstream, and eventually exits the system. This pattern of flow concentration can be seen in a typical hydrograph as the discharge for a normal stream peaks upstream before it eventually peaks downstream, in a more protracted rise (Figure 2-6). Travel time to the measurement site (gauge) should increase with distance downstream (i.e., Ritter, Kochel, Miller 2002). However, Miller Run consistently exhibits the exact opposite behavior. Not only does discharge in the downstream reach peak before the upstream reach, it also often peaks multiple times (Figures 2-7 to 2-11). This unusual phenomenon can be explained by the immense quantity of water delivered to the stream from campus via storm drains and runoff from impermeable surfaces. This water from the Bucknell campus swiftly enters the downstream system, resulting in a peak before the upstream gage (MR-1) has peaked. After most of this water has already exited the system, the majority of the flow from upstream finally arrives, causing the second of the peaks at the downstream gage (MR-2) (Figure 2-8).

The real problem caused by these flow patterns is that Miller Run's water table has become severely depleted. Since water is rushed off of campus before it has a chance to infiltrate into the groundwater, the water table does not get properly recharged. Therefore the stream goes dry almost immediately after many rainfalls are over and remains dry until more rain occurs. Interception of the normal infiltration processes by campus storm drainage systems has caused Miller Run to become a losing stream (one where the water table does not intersect the stream). Losing streams are not common in the humid eastern USA. We could combat this effect in a variety of ways, such as storing water from events in retention ponds, rain gardens, wetlands, or floodplains so that it has more time to infiltrate and provide the stream with constant flow – all of which will be discussed later in this report. Future research should focus on understanding the water table and groundwater structure of the Miller Run watershed, which was beyond the scope of this project.

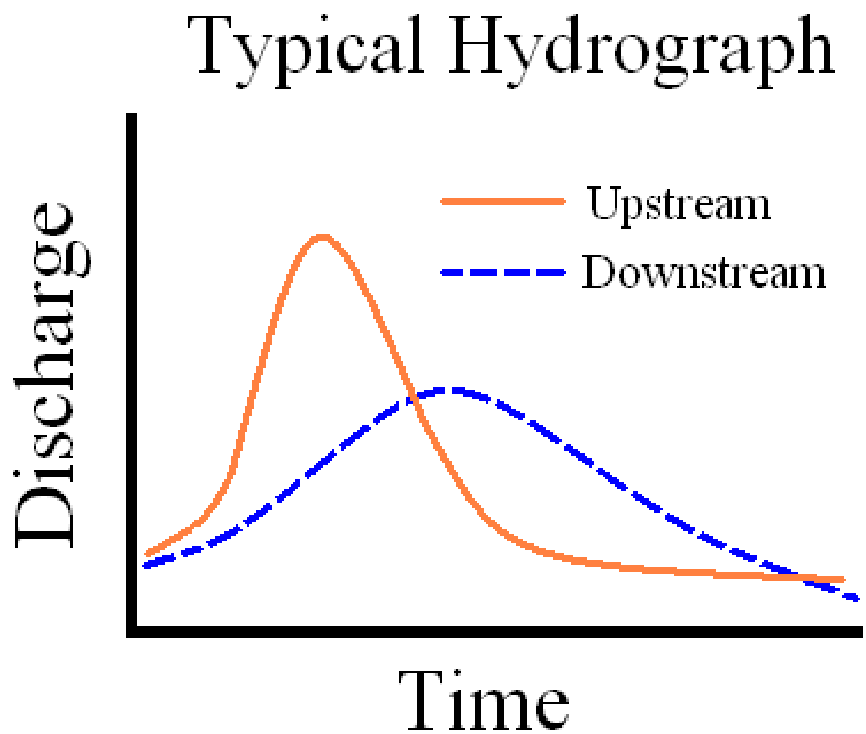


Figure 2-6. Typical Hydrograph Showing Proper Peak Sequence

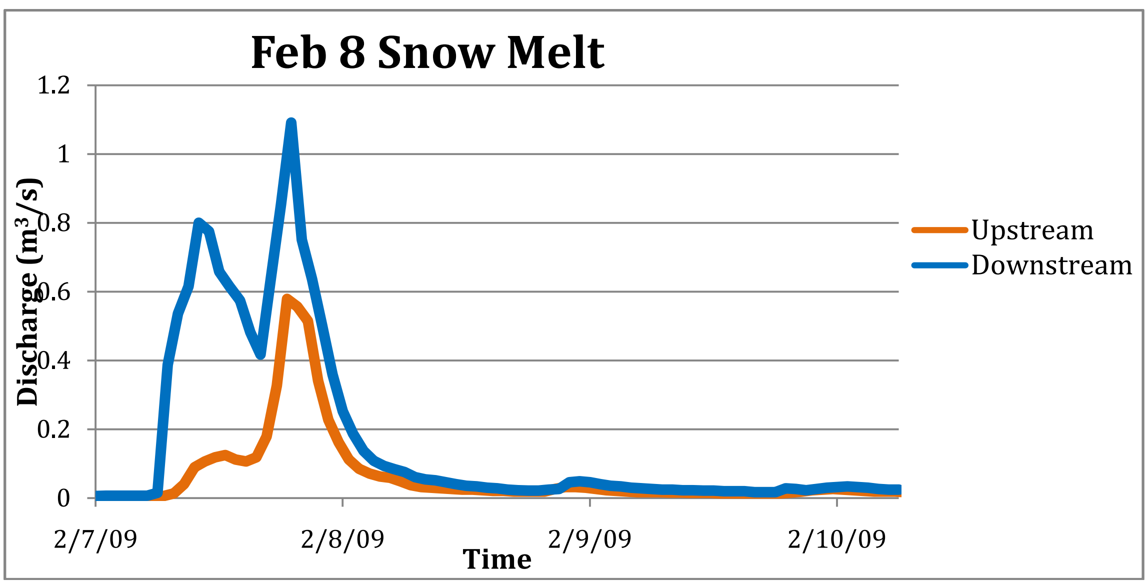


Figure 2-7. Hydrograph Showing Reverse Peak Sequence for a Feb 8 Snowmelt Event

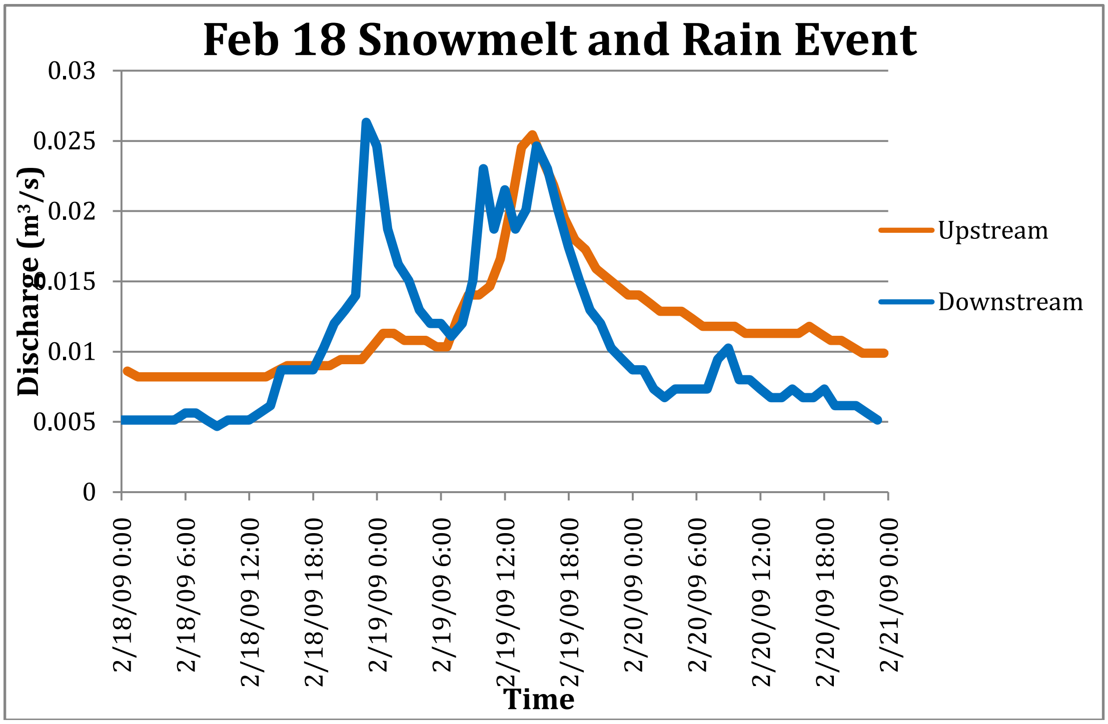


Figure 2-8. Hydrograph Showing Reverse Peak Sequence for a Feb 18 Snowmelt and Rain Event

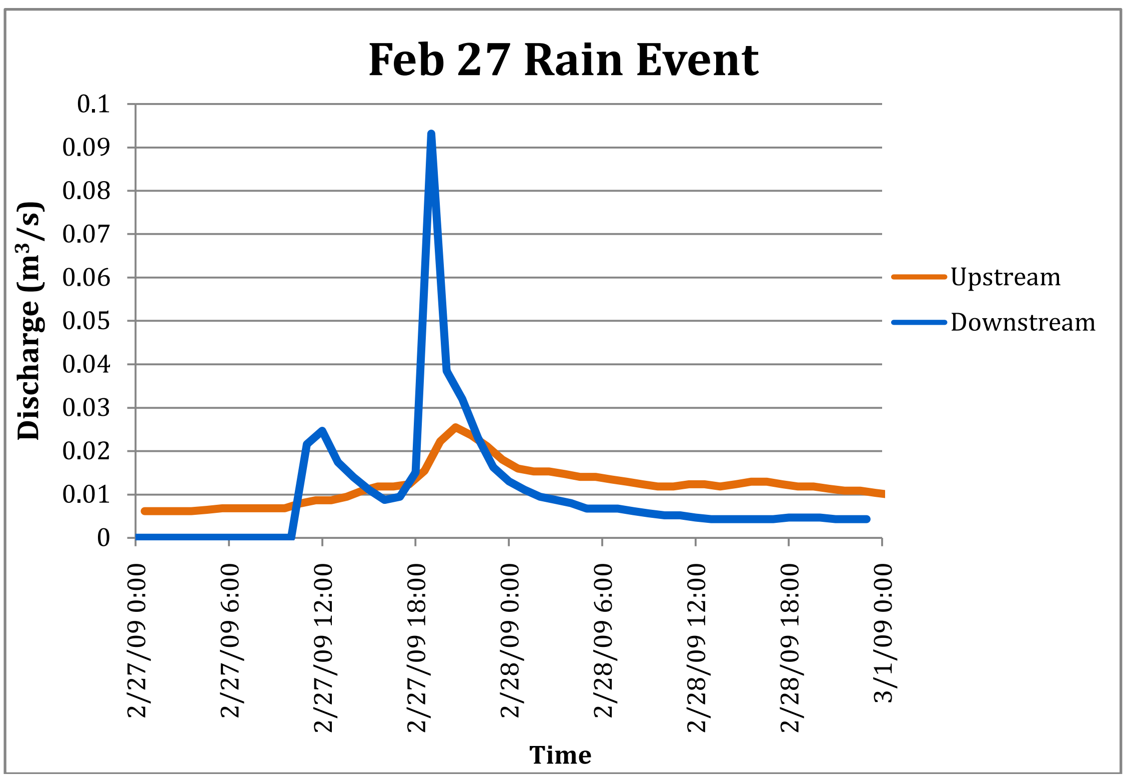


Figure 2-9. Hydrograph Showing Reverse Peak Sequence for a Feb 27 Rain Event

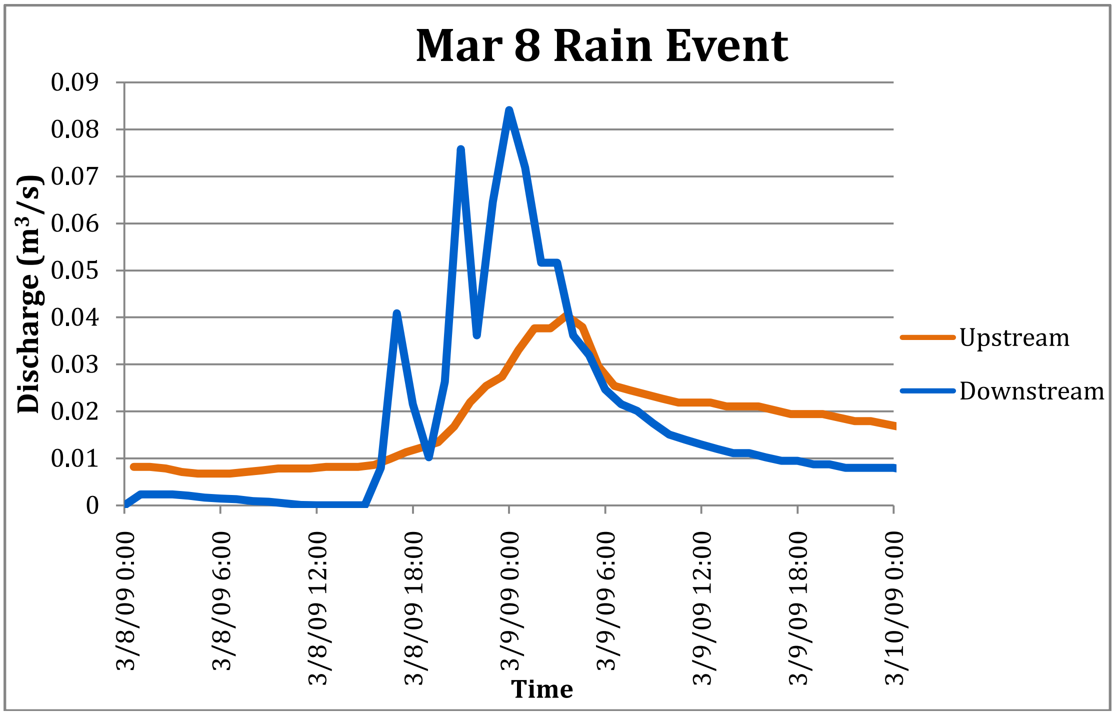


Figure 2-10. Hydrograph Showing Reverse Peak Sequence for a Mar 8 Rain Event

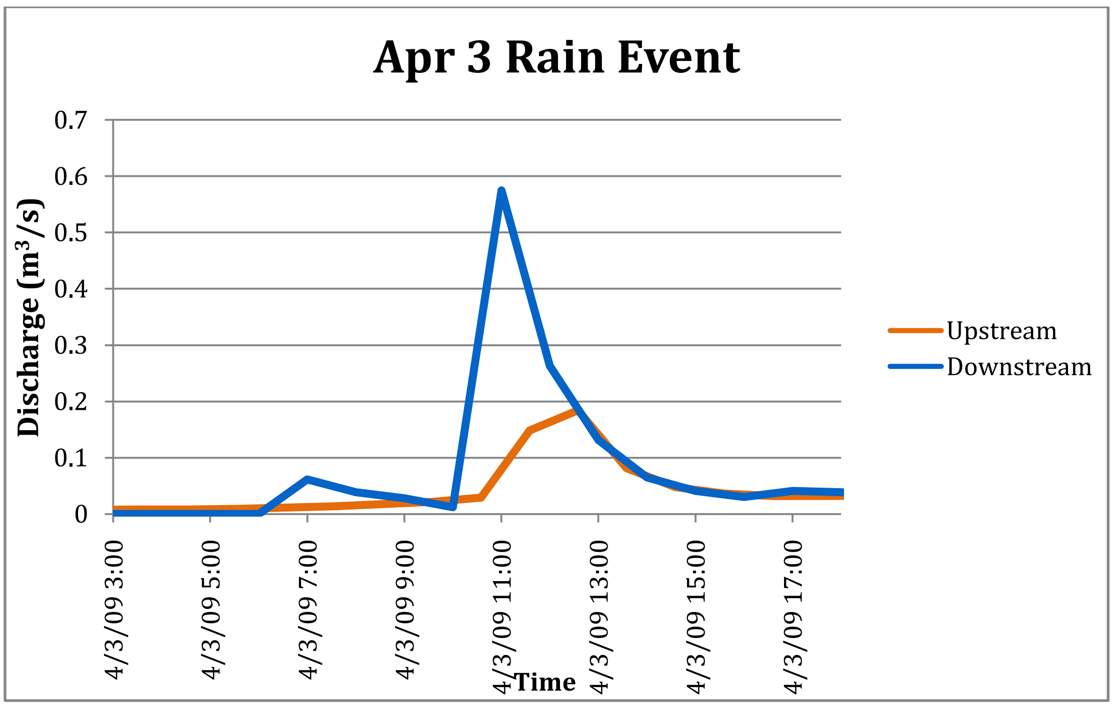


Figure 2-11. Hydrograph Showing Reverse Peak Sequence for an Apr 3 Rain Event

C.) Rain-Discharge Lag

This semester we experienced a variety of intensities of rain events. There were small events, with rainfall per hour peaking at 0.02-0.04 in., and larger events peaking at approximately 0.4 in/hr. During a rain event in a normal stream system, there should be an interval of time between the peak of rainfall and the peak of discharge. This is referred to as time of concentration, which is the time it takes for the rainwater to travel through the watershed to the stream. This normal behavior is clearly demonstrated in Figures 2-12 & 2-14, the upstream rain-discharge lag graph for Miller Run. Here, the time of concentration (the time between rainfall peak and stream hydrograph peak) for the upstream gage (MR-1) is approximately 4 hours. This is appropriate, since very little of the watershed surrounding the upstream reach is urbanized. Therefore, the water takes a slow and natural course to the stream. However when the downstream reach is examined during the same storm (Figures 2-13 & 2-15), the lag between rainfall and discharge peaks is minimal (Time of concentration at the downstream gage, MR-2, is nearly zero). This reduction of lag time is further amplified during a large rain event because of the tremendous amount of runoff that is compensating for the usual lag interval (Figures 2-16 & 2-17). This shows the dramatic impact that the University's impermeable surfaces and stormwater drainage pipes have on the hydrology. This storm water management system directs rainwater into the stream so quickly that it reduces the lag time between the rainfall and the discharge dramatically. This is well displayed in Figure 2-11 where the upstream gage peaks two hours after the downstream gage in the April 3rd rainfall event.

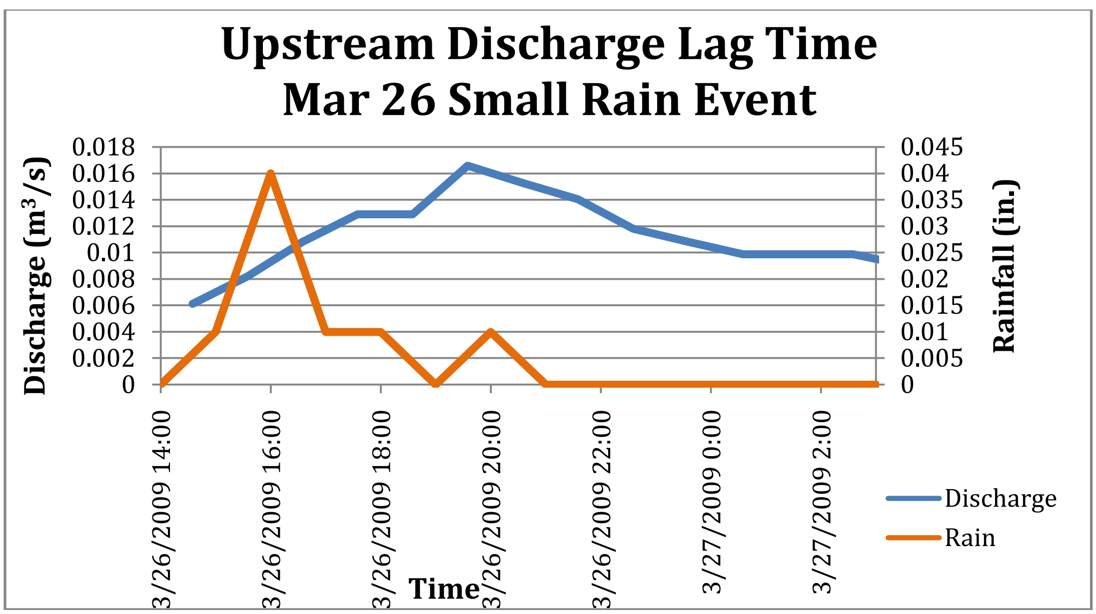


Figure 2-12. Lag between Rainfall and Upstream Discharge for a Small Mar 26 Rain Event

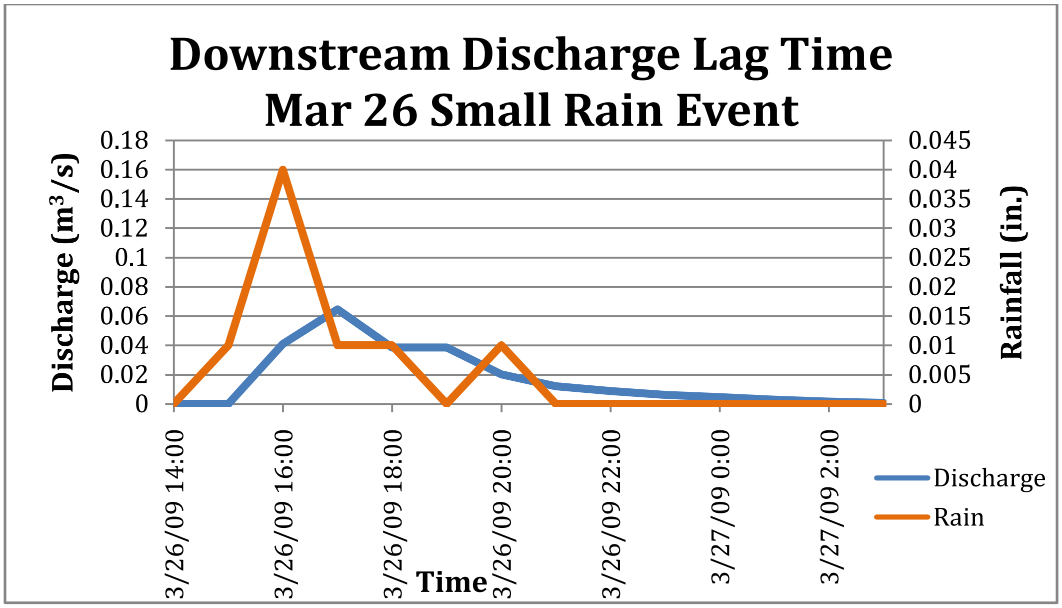


Figure 2-13. Lag between Rainfall and Downstream Discharge for a Small Mar 26 Rain Event

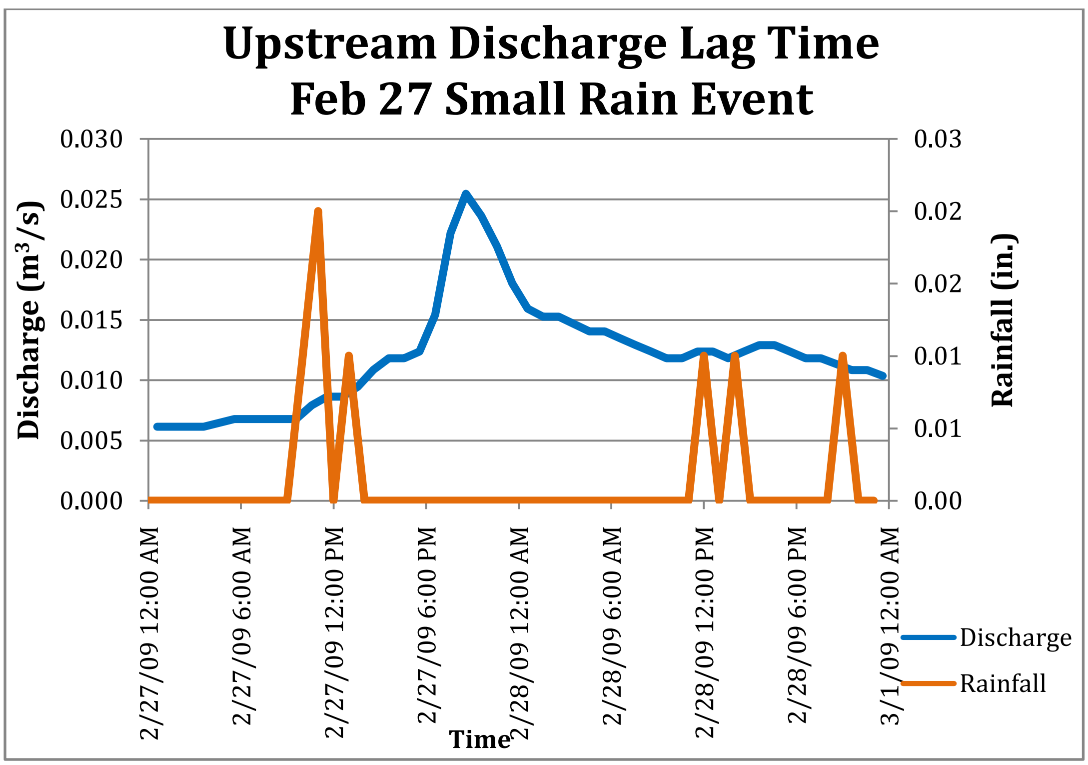


Figure 2-14. Lag between Rainfall and Upstream Discharge for a Small Feb 27 Rain Event

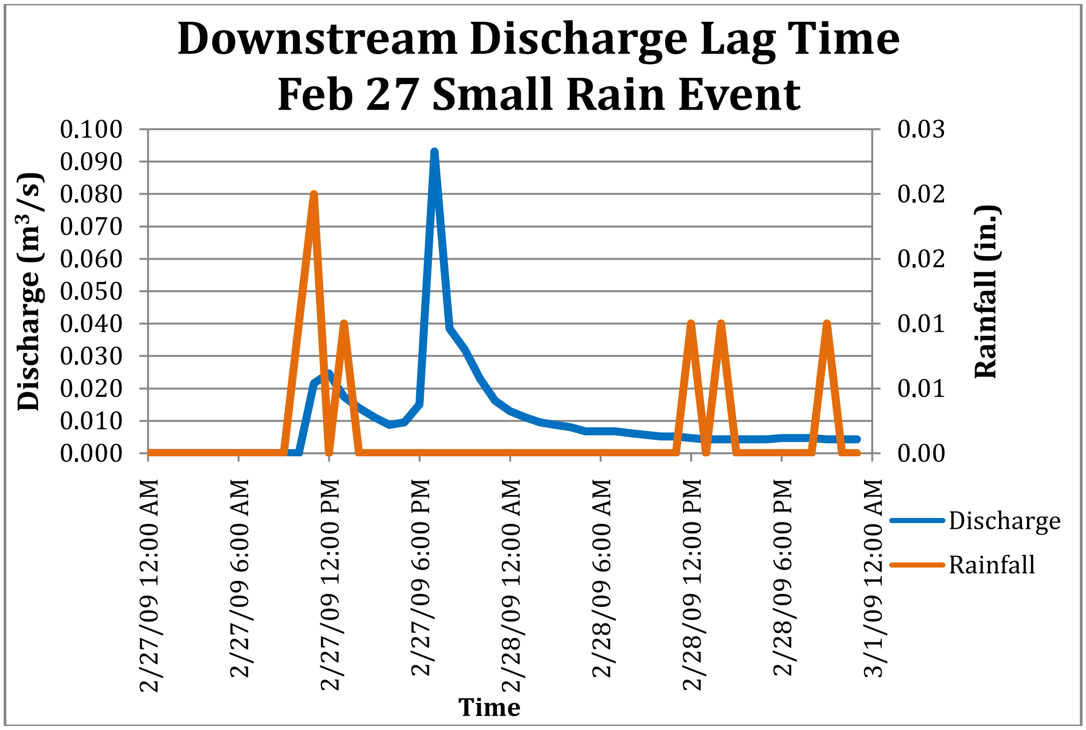


Figure 2-15. Lag between Rainfall and Downstream Discharge for a Small Feb 27 Rain Event

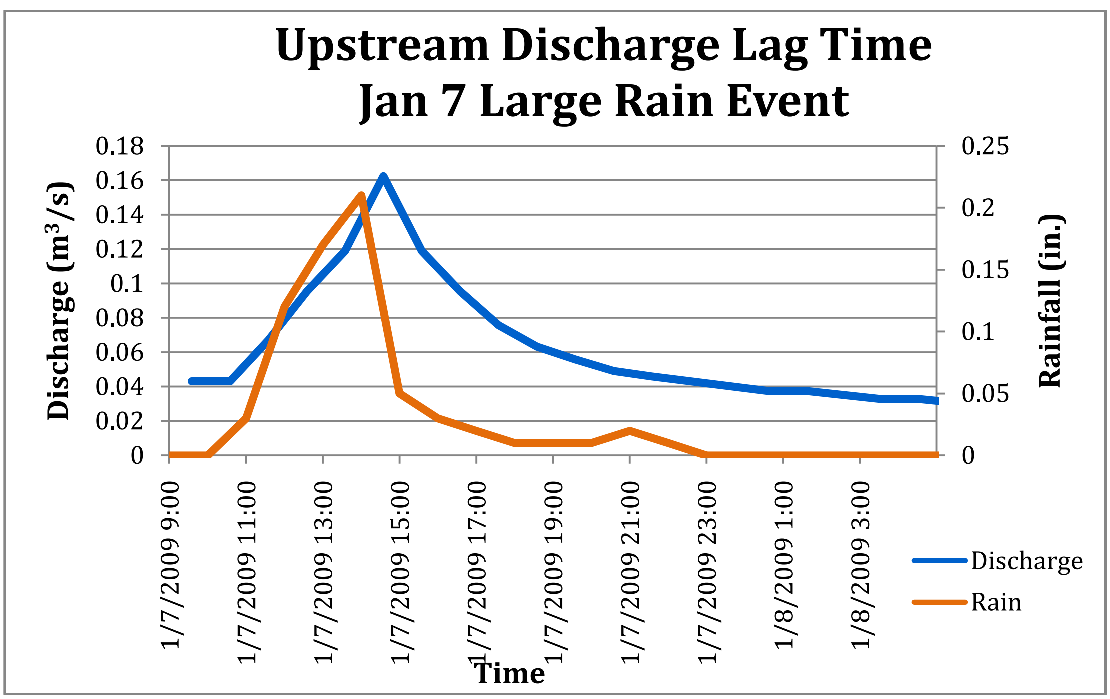


Figure 2-16. Lag between Rainfall and Upstream Discharge for a Large Jan 7 Rain Event

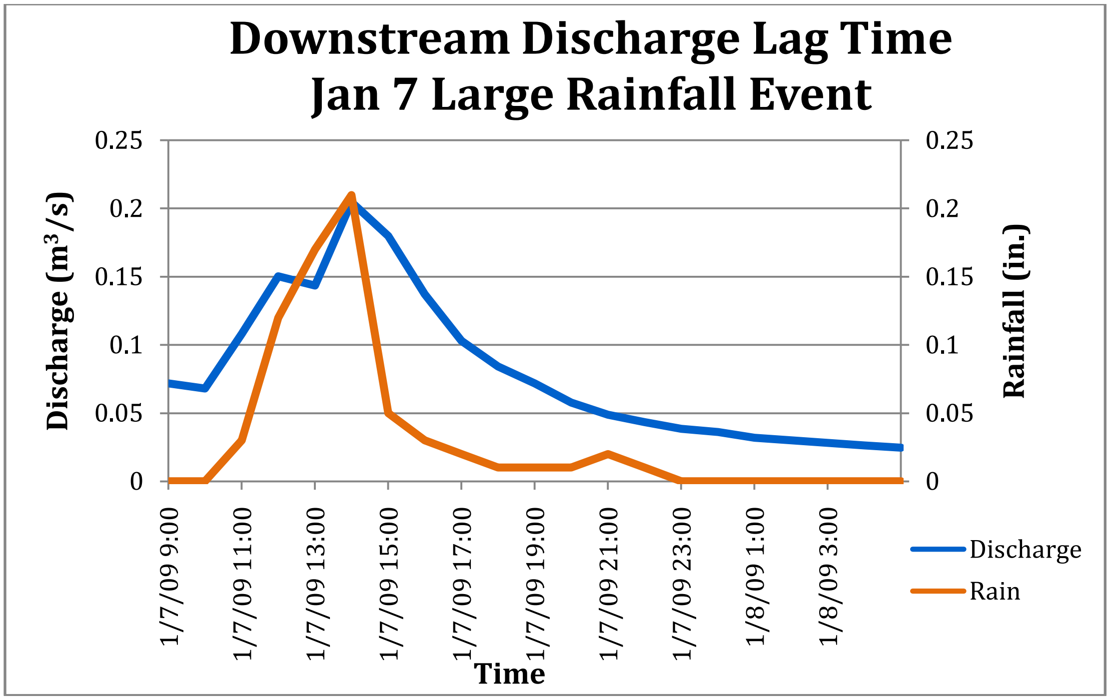


Figure 2-17. Lag between Rainfall and Downstream Discharge for a Large Jan 7 Rain Event

D.) Sediment

Streams carry three types of load: 1) bedload – which is the coarse material predominantly found on the stream bed; 2) suspended sediment – which is mostly fine-grained silt and clay transported in the water column; and 3) dissolved load – which is the amount of chemical salts dissolved and transported by the stream. The natural bedload of Miller Run has been significantly disrupted by channelization, especially downstream of Route 15. Much of the current bedload is related to erosion of artificial fill and rip-rap. Above Route 15, bedload is significantly finer. Sampling and discussion of the substrate is presented in the Channel Character section of this report. The suspended sediment loads transported by a stream are an extremely important part of its hydrology. High concentrations of sediment can clog culverts, bury structures maintaining flow, and choke out biota.

<u>Suspended Sediment</u>

In order to trace the source and concentration of the suspended sediment, additional special sampling was done during flood events for various tributaries that flow into North and South Miller Run (Figure 2-18), as well as the system of stormwater drainage pipes from campus (Figures 2-19). For comparison, Buffalo Creek is a stream system that is notorious for extensive sedimentation problems. During flood events of bankfull flow or greater, the sediment concentration averages between 150 and 350 ppm (Professor Kochel, personal communication of unpublished data). Buffalo Creek is known to be impaired significantly by agricultural runoff in places. As can be seen from the sediment distribution maps (Figures 2-18 & 2-19), during below-bankfull rain events, Miller Run has transported sediment loads of up to

2287 ppm, a value more than ten times the amount of Buffalo Creek. When we examine graphs of the discharge and suspended sediment concentration at the upstream and downstream sites (Figures 2-20 to 2-23), there is an interesting phenomenon – the upstream site has a higher concentration of sediment than the downstream site. This could be interpreted that the campus is not contributing highly to the sediment load. However, this is not the case for two reasons. First, we must note that the downstream sites have significantly greater discharge than the upstream sites. This results in a dilution effect that lowers the sediment concentration. Second, the stormwater pipe samples (Figure 2-19) also provide ample evidence that the campus is a major contributor of sediment, sourced directly from campus. The concentrations of sediment were observed to be over 1700 ppm at points during the spring storms. While the concentrations did vary between different times of the year, different storm pipes sampled, and different types of precipitation events, it is still clear that the campus is often a significant source of suspended sediment. However, more studies must be done in this regard to determine the specifics of when and where the campus plays the biggest roles.

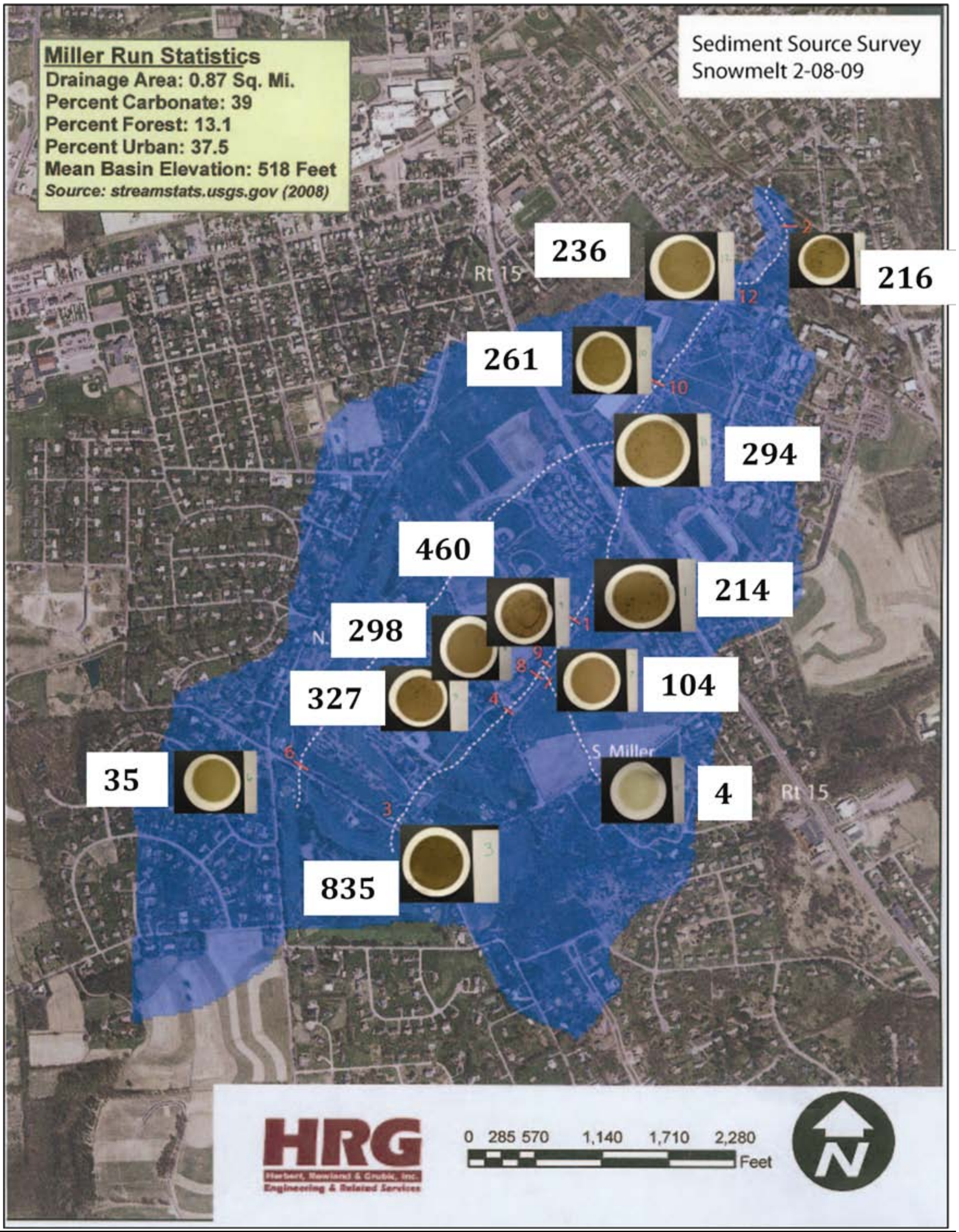


Figure 2-18. Sediment Contributions from Various Tributaries from the February 8-9, 2009 snowmelt event. Numbers show sediment concentrations in ppm.

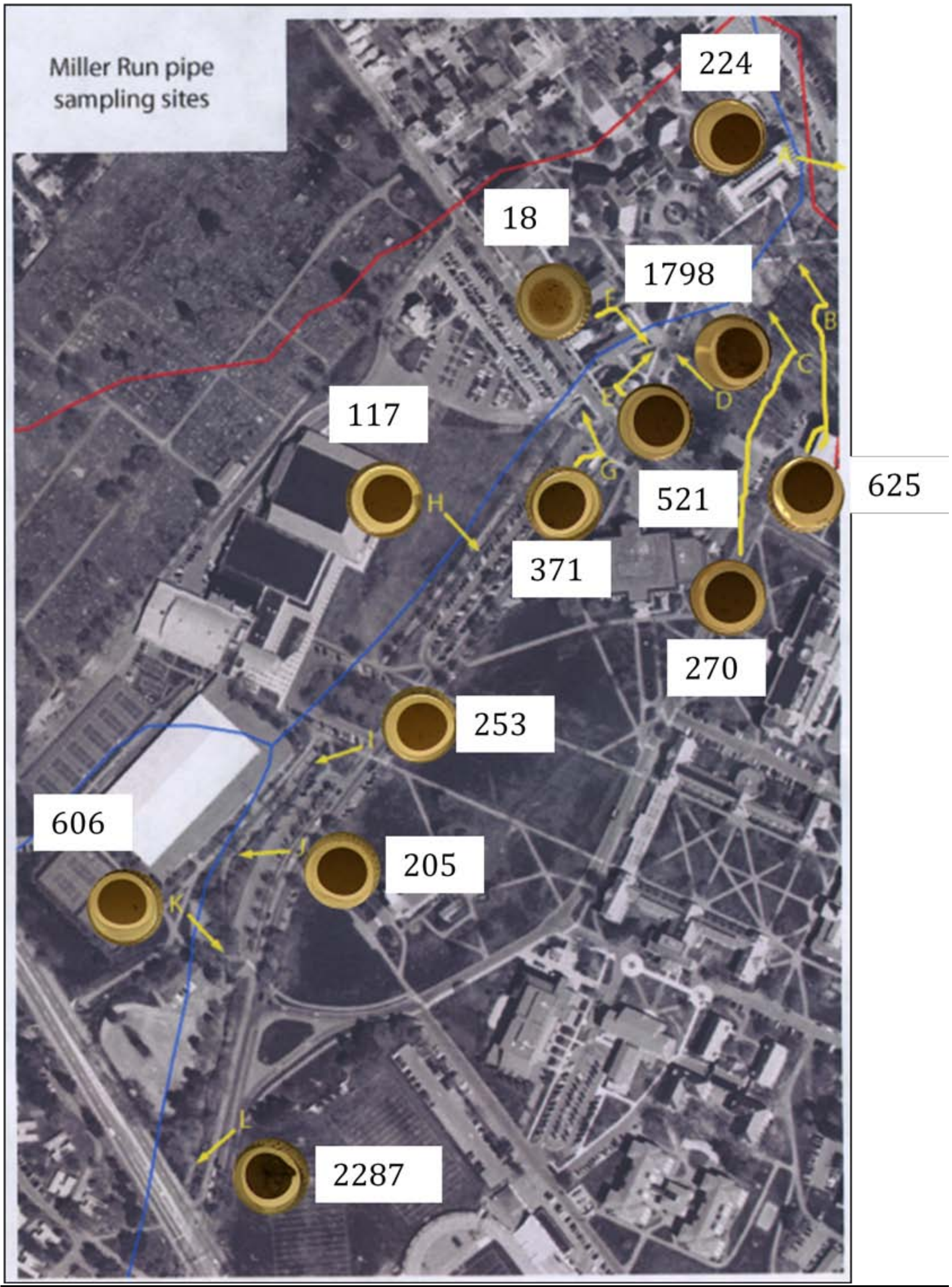


Figure 2-19. Sediment Contributions from Various Drainage Pipes, April-3 Event. Numbers show sediment concentrations in ppm.

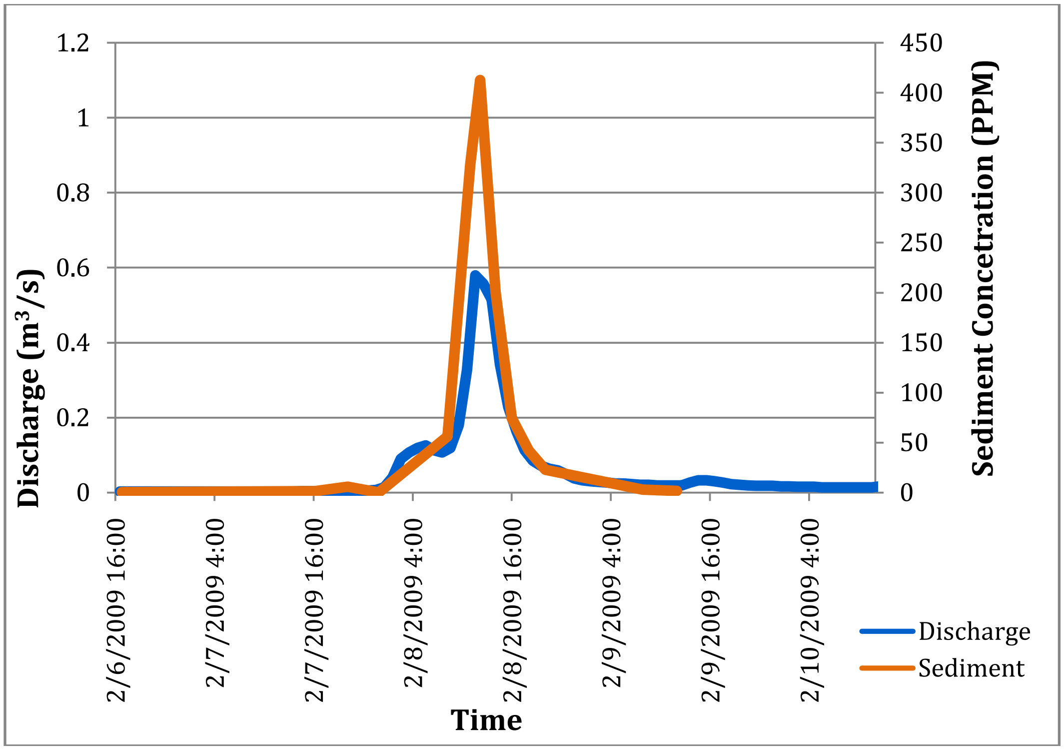


Figure 2-20. Upstream Sediment Concentration and Discharge for 2/7 Rain and Snowmelt

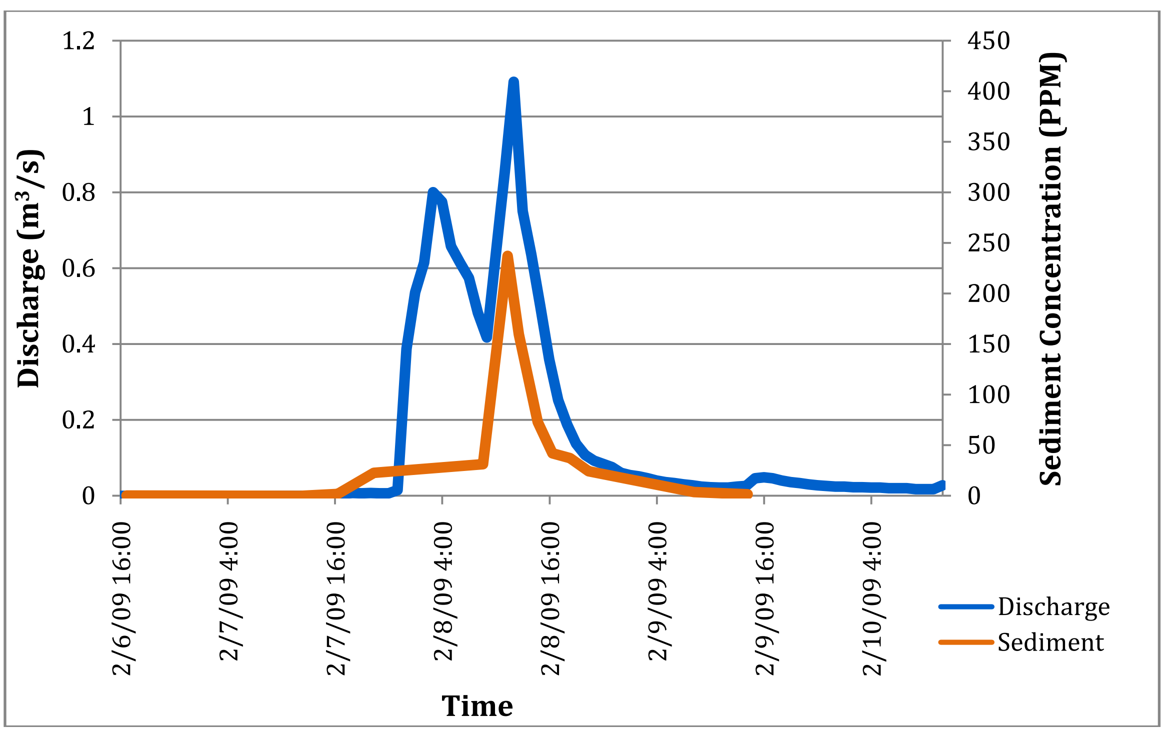


Figure 2-21. Downstream Sediment Concentration and Discharge for Feb 7 Rain and Snowmelt

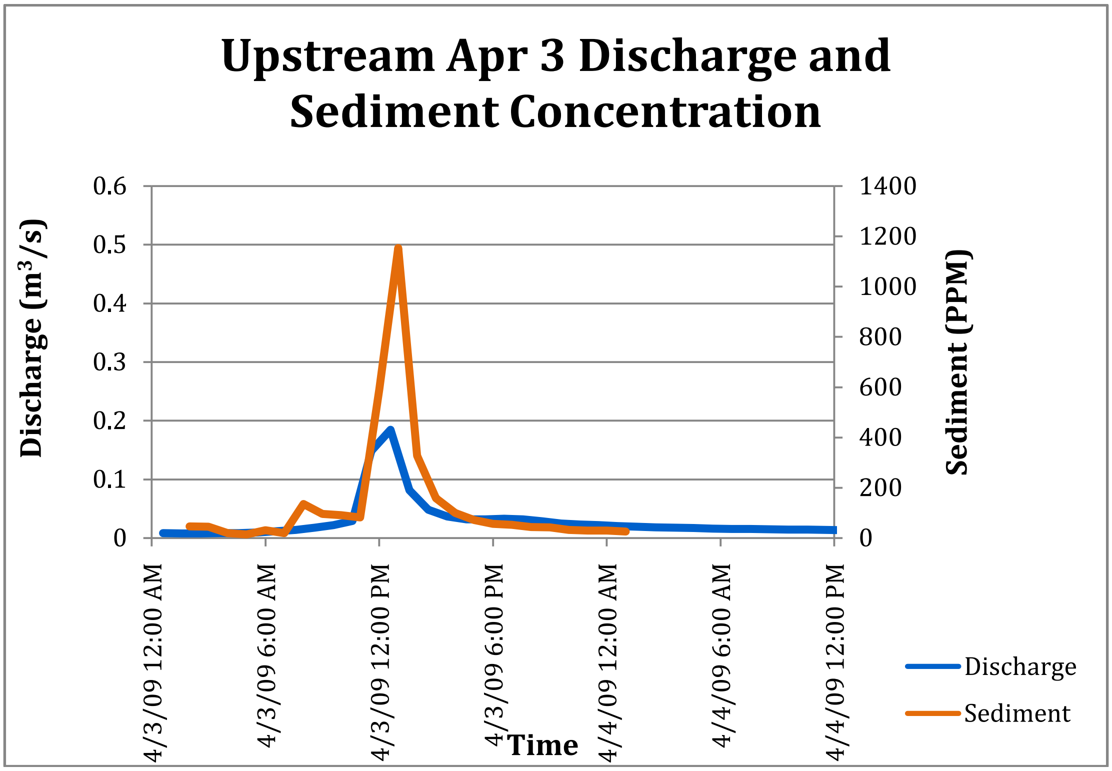


Figure 2-22. Upstream Sediment Concentration and Discharge for Apr 3 Rain Event

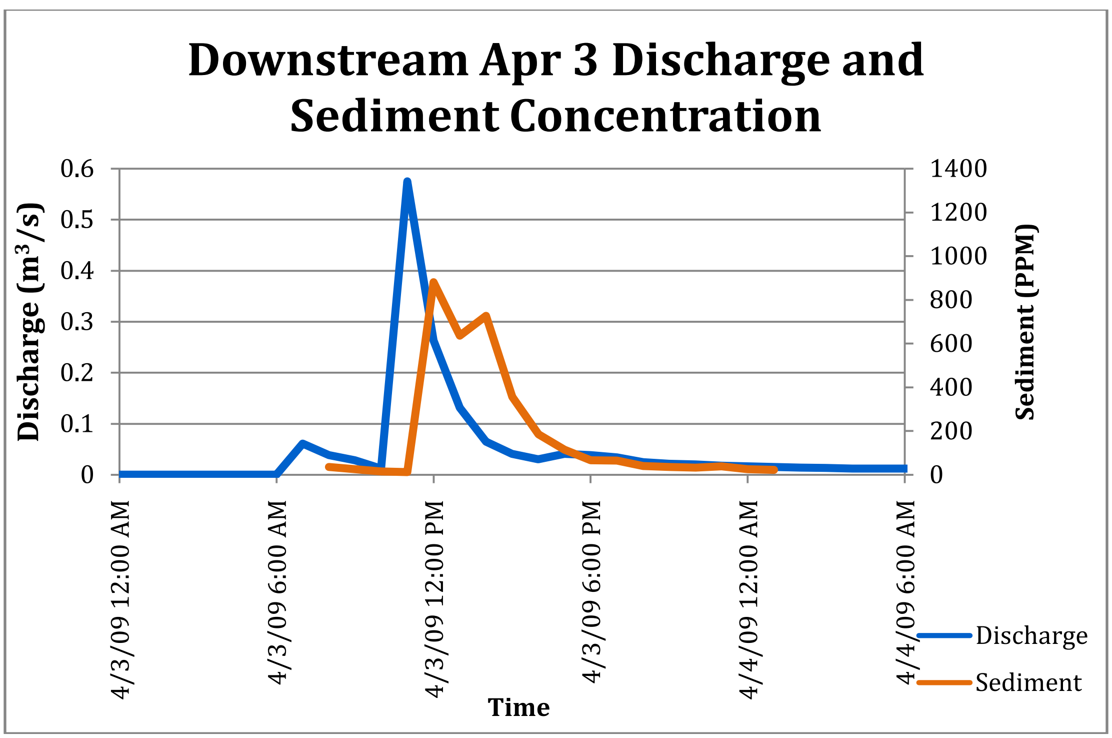


Figure 2-23. Downstream Sediment Concentration and Discharge for Apr 3 Rain Event

Storm Water Runoff

Storm water runoff in the Miller Run watershed, specifically the Bucknell University campus is a major problem for the stream. Storm water increases the amount of sediment load in Miller Run. Runoff from buildings, parking lots, and walking paths, for the most part feed directly into storm drains, which in turn feed directly into Miller Run at a high velocity. New structures could be applied to the existing storm water management system to help reduce and slow water runoff and recharge the water table through infiltration.

Increasing infiltration is the main goal of implementing the structures recommended in later sections in this document. Allowing storm water to be absorbed into the watershed as opposed to shooting it out off of campus at high velocity in storm drain pipes will decrease erosion and sedimentation as well as possibly contribute to year round flow which is one of the main goals of this project. Figure 2-7 shows the disrupted lag period between peaks at the upstream and downstream gauges in Miller Run. The main contributor to the distorted hydrographs in Miller Run is the unchecked runoff from Bucknell University's storm drains and surface runoff. These issues should be thoroughly addressed if the current condition of Miller Run is to improve.

Some suggestions to control storm water runoff (from the Pennsylvania Stormwater Best Management Practices Manual 2006) on Bucknell's campus are permeable pavements, rain gardens, and infiltration trenches. These structures would significantly reduce the amount of runoff on campus and could be used in partnership with wetlands created to retain storm runoff and augment flow to Miller Run. The main issue with campus is that it is moderately urbanized and there are not enough natural permeable surfaces to soak up rain in large storms. There are many ways that Bucknell could implement storm water management practices and maintain aesthetic appeal.

As you can see in the Figure 2-24 it is not an exaggeration to state that this area is extremely developed. With the help of ArcGIS the campus walkways, parking lots, and buildings were digitized from an aerial photo of campus (Fig 2-24). These numbers are a rough estimate but the total impermeable surface area came out to be 8,488,157 square feet. In addition, several buildings and parking lots located outside the topographic watershed boundaries of Miller Run (e.g., Gateways) are linked to the underground storm drains, which feed into Miller Run, so the effective drainage area of Miller Run exceeds its natural drainage divides.

Ground water recharging mechanisms could be used to help to cut down the surface runoff and increase infiltration in the Miller Run watershed. Consideration of mechanisms to reduce surface runoff by improving infiltration and groundwater recharge are essential to restoring Miller Run ecologically, which would dramatically improve campus aesthetics and reduce Bucknell's environmental footprint. Such steps will require a change in viewpoint to treat Miller Run as a functioning ecosystem instead of a drainage ditch to convey storm water. These solutions will be addressed in detail in a later section of this report.

Figure 2-24 GIS map showing buildings, walkways, and parking lots on Bucknell's campus.

Channel Characterization: Physical Assessment of Channel Morphology

Introduction

Miller Run is an urbanized stream that is not appealing on the University campus and can be dangerous to University property during times of high flow. The stream has been affected by past farming in the area, channelizing and ditching it to create more space for crops. More recently the University has created different types of stream obstacles, such as culverts, parking lots, concrete channelization and buildings. These efforts increase campus functionality but denaturalize the stream and increase flood event effects. Past reconstruction of the stream, using rip-rap installments and channelized beds are not attractive as well. In such an urbanized area, structures such as footbridges, roads and municipal piping are necessary factors to consider when planning restoration, to make the stream functional as well as natural, attractive and educational. This section will characterize the current condition of the Miller Run channel and provide a foundation for the restoration guidelines suggested later in the report.

Longitudinal Profile

The longitudinal profile of Miller Run (Fig. 2-25) shows the gradient of the stream from the mouth where it enters Bull Run to its source at Smoketown Road and the Bucknell Golf Course. The overall gradient of the stream over its ~2 km course is 11.36 meters per kilometer. The elevation changes ~23.8m from the mouth to headwaters. In a regular stream the highest gradient is usually in the headwaters, closest to the source and lessens as the stream reaches its mouth. Miller Run functions similarly with the two highest gradients still in the reaches closest to the source (Fig. 2-25) until it hits campus property at the upstream start of the Bucknell West Mods. At this point gradient decreases, only to increase in Reach 1 again, the reach closest to the mouth. By ranking the reach gradients, highest to lowest, it is easy to see the disparity: Reach 5, Reach 4, Reach 1, Reach 3 and Reach 2. While the stream may not be natural in this aspect, it does help in terms of our restoration ideas, which include low-lying, low gradient wetland areas in both Reach 3 and Reach 2.

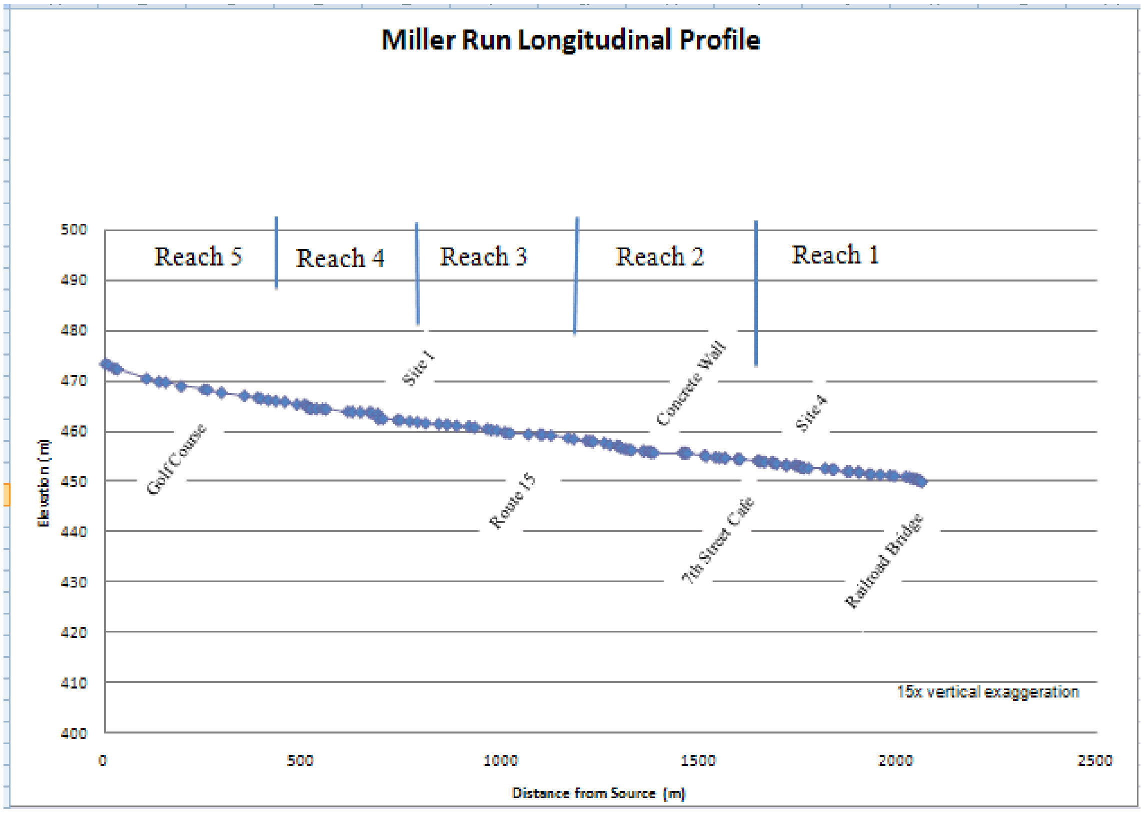


Figure 2-25 Miller Run Longitudinal Profile

<u>Reaches</u>

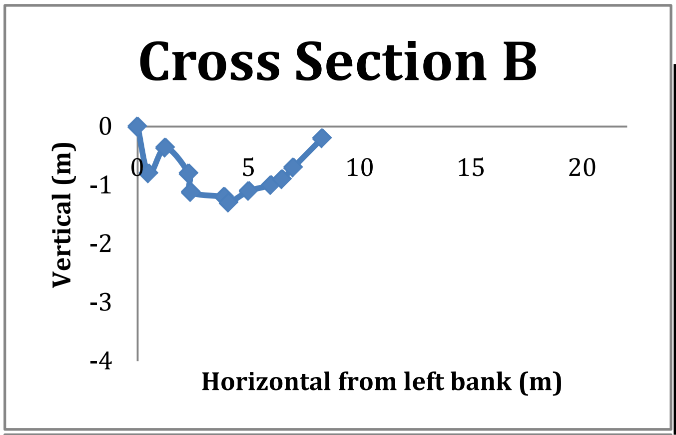
Table 2-1 illustrates the extent of modification that the Miller Run channel has experienced. Each reach is described in more detail in the sections below. All cross-sections can be found in Appendix A.

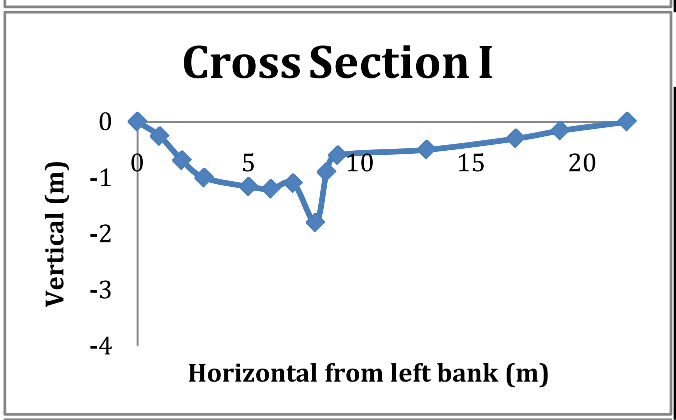
Table 2-1: Stream corridor conditions along Miller Run from its mouth (Reach 1) to Smoketown Road (Reach 5)

Problem	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Lack of Riparian Vegetation	X	X	X	X	X
Aesthetically Unappealing	X	X	X	X	X
Rip-rap Instability	X	X			
Lack of Flow	X				
Highly Channelized	X	X			X
Lack of Floodplain Connection	X	X			
No Habitat Diversity	X	X	X		X
Bank Instability	X	X	X		
Unnecessary Obstructions	X	X	X	X	X

Reach 1 – Downstream reach – RR Underpass to 7th Street (Figure 2-26)

Throughout Reach 1, the stream is contained by steep banks, rip-rap, and has some pools. Cross Section B has a much lower bank and is not that deep. Cross Section I is similar to E and G, but has gradual banks that are very flat on each side with a steep drop in the middle. The cross sections continue this pattern until Cross Section M where the banks are steep on both sides with a narrow bottom near 7th Street Café.





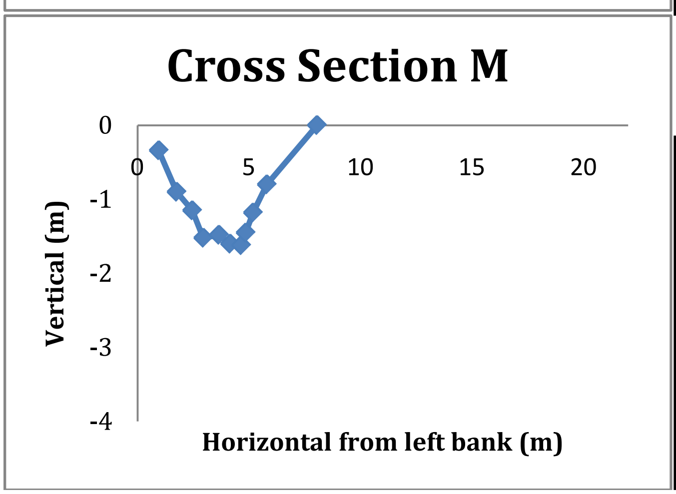
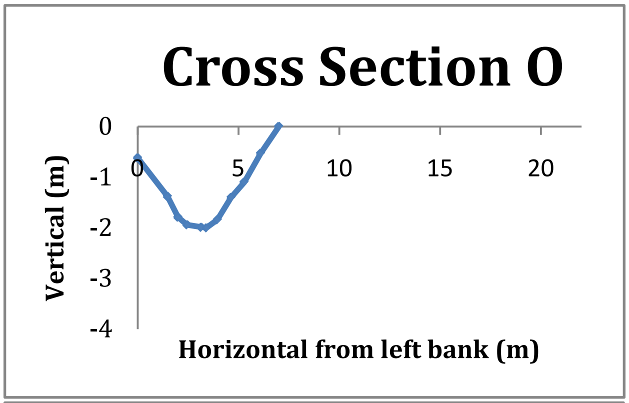
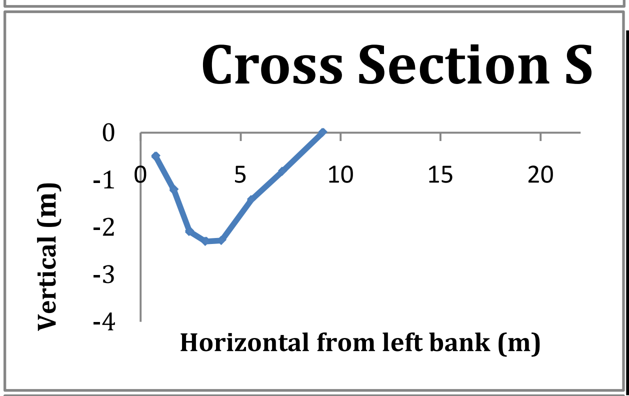


Figure 2-26 Reach 1

Reach 2 – 7th Street to Route 15 along the Athletic Complex (Figure 2-27)

Reach 2 then spans from Cross section N-Z which follows in front of the athletic buildings and is very channelized. Cross section O and P follow a pattern deep pools and steep banks due to the cement wall on the left side. Upstream, the cross sections up R-T follow the same general pattern on steep banks. Cross section Y and Z, before Route 15, both have steeper banks with narrow deep bottoms.





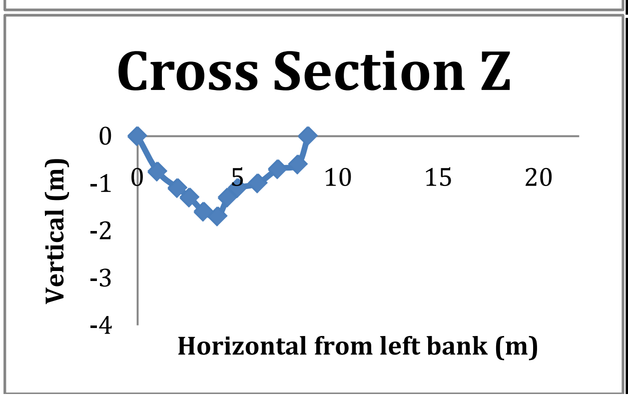


Figure 2-27 Reach 2

Reach 3 – Route 15 to the Art Barn along the Mods (Figure 2-28)

At Reach 3, staring after Route 15, the area is wide open with Smoketown Road near the right bank. Cross section AA is shallow with a steep bank on the right side due to the road. The horizontal measurement is very low throughout this reach. All of the cross sections only go to -0.5m vertically in this reach and the banks start to decrease in slope by cross section KK.

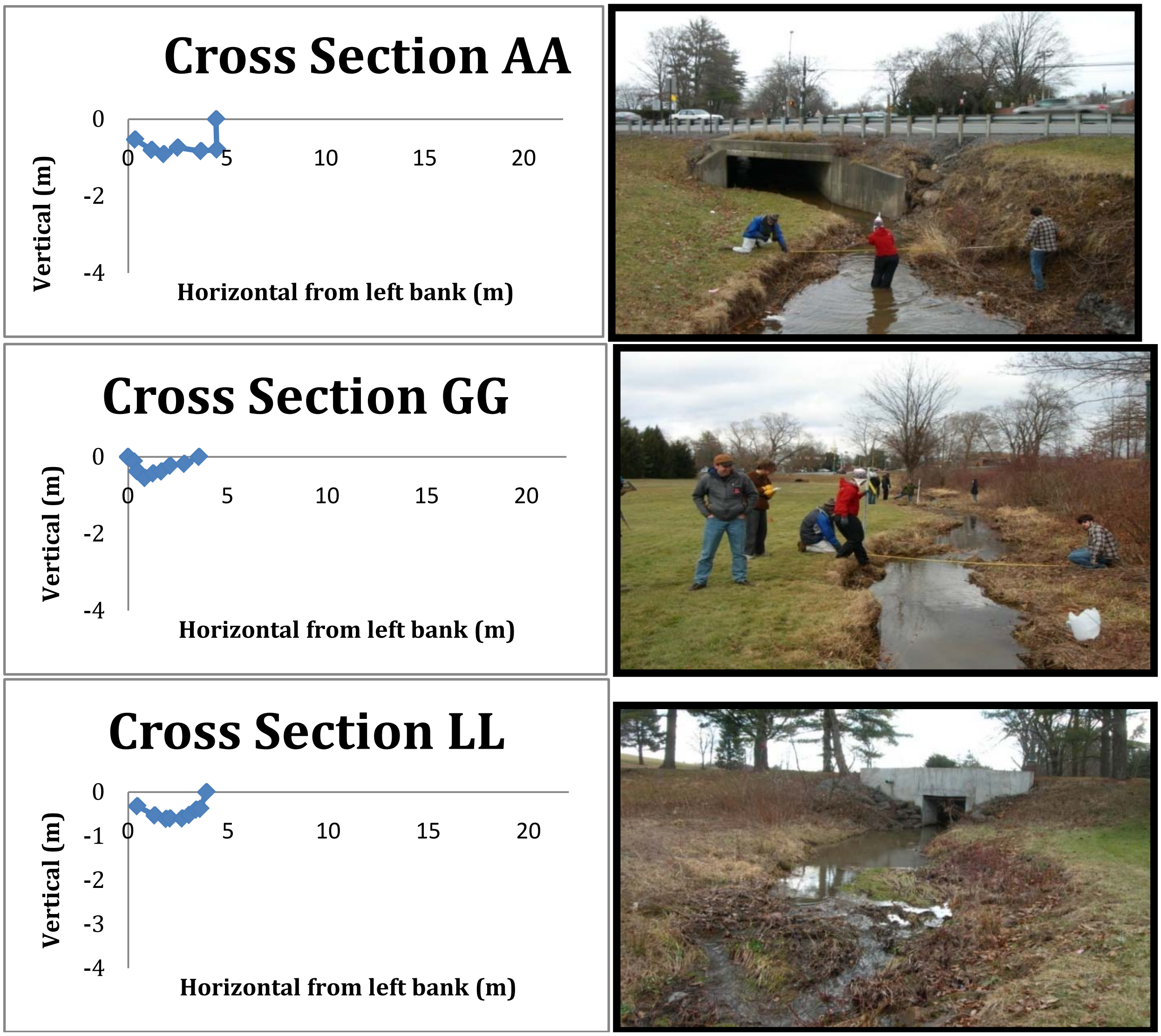


Figure 2-28 Reach 3

Reach 4 – Art Barn to Sunflower (Figure 2-29)

At Reach 4, near the Art Barn and coming into the most untouched part of the stream, the cross sections start at MM, but at Cross section NN the stream hits a flat area where the difference in vertical measurement is only -0.5 from bank to bank. Cross section QQ follows a similar pattern to Reach 1 cross sections by having gradual slops on the left bank and a steeper slope on the right side. The bottom is very flat and is maintained. Cross section UU is deeper while Cross section VV has a very gradual slope on the left side then a steep slope on the right bank.

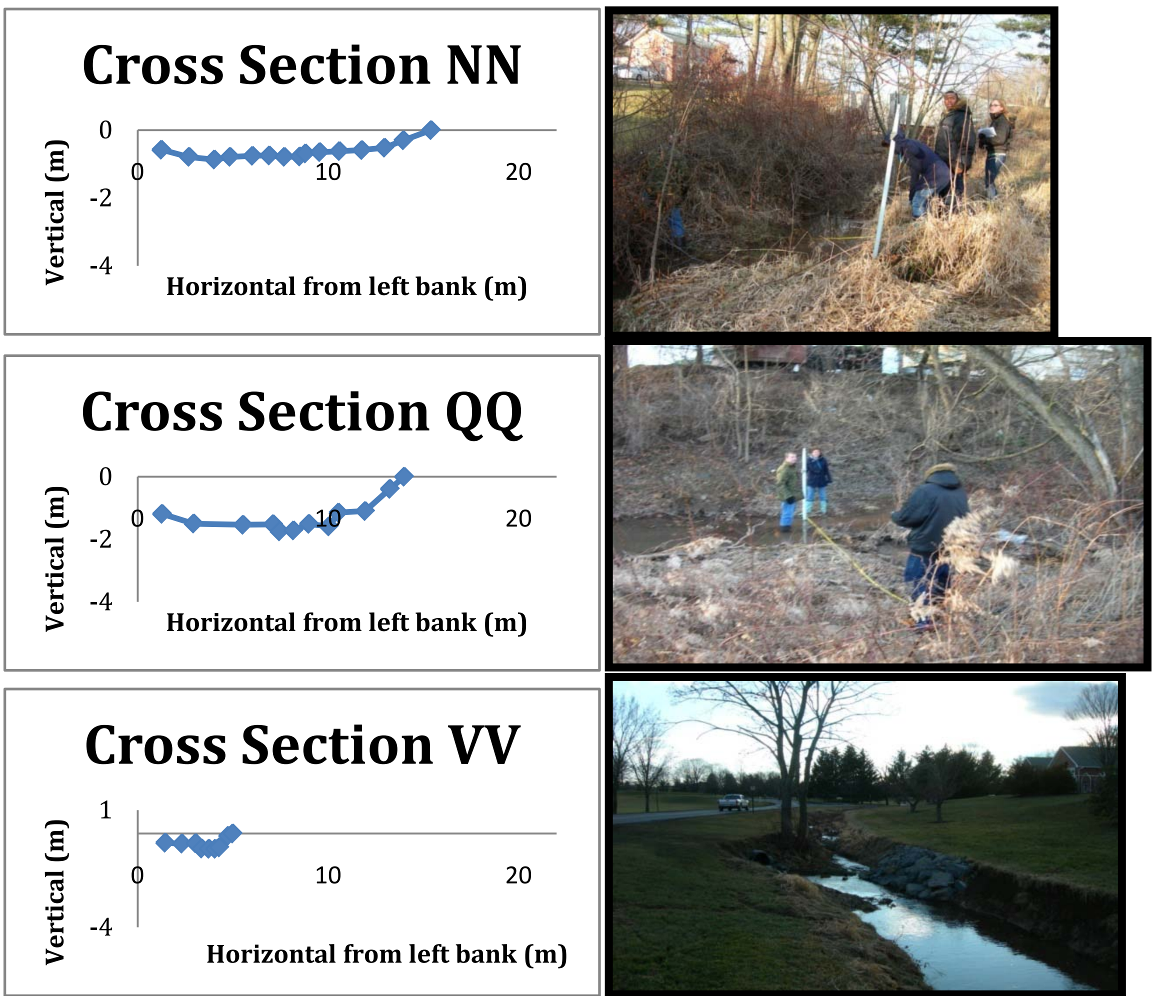


Figure 2-29 Reach 4

Reach 5 – Sunflower Daycare Access Road to Smoketown Road though the Golf Course (Figure 2-30)

Reach 5, which runs throughout the golf course has cross sections that follow the same pattern of gradual steep slopes with narrow shallow bottoms. Cross sections AAA - DDD especially show the small widths and shallow bottoms clearly. The majority of the stream is run through a series of corrugated metal pipes, under fairways. The last cross section in this reach, Cross section EEE, shows the pool that occurs right after the culvert under Smoketown Road.

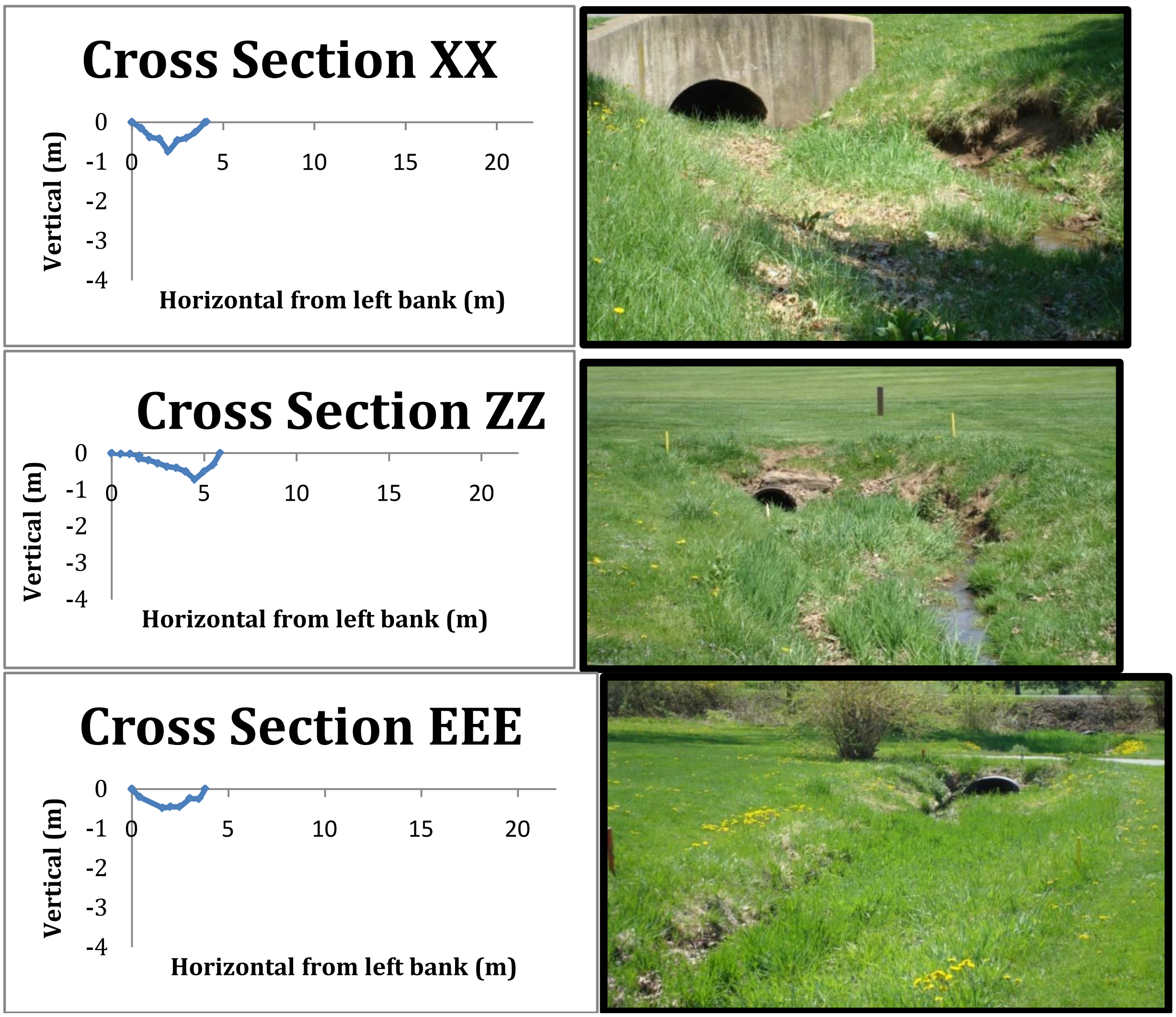


Figure 2-30 Reach 5

Bedload Sediment

In general, Miller Run carries two types of bedload sediment, above Route 15 the bedload is notably finer – mostly silt and sand with scattered pebbles – probably the natural load of the stream, while below Route 15 it is coarse, probably sourced as erosion from a variety of artificial fills and riprap. There were two different areas of sediment measured in the stream. Site 1 was upstream near the Art Barn in Reach 4. Here the average grain size was 12.08 mm with the 85^{th} percentile (D_{85}) being 16.15 mm. Pebbles measuring smaller than 2 mm composed nearly 50% of the sediment samples found in that site. The largest grains that were found were about 90 mm; however, they constituted less than 5% of the overall sediment. Site 4 was located near the Art Building in Reach 1. Here the average grain size was 126.63 mm, much larger than its upstream counterpart. The 85^{th} percentile (D_{85}) was 252 mm. There were few grains found that were less than 2 mm, about 1%.

The observed changes in sediment size may be due to the channelization efforts of the Bucknell campus. The non-channelized site downstream of the Art Barn (site 1) exhibited small sediment size, mostly sand to clay sized with some larger rocks as well (Figure 2-31). The downstream site near the Art Building (site 4), along the constructed rip-rap and gravel features had obviously larger grain sizes, pebble to cobble (Figure 2-32). The average base flow of Miller Run is 0.005 m^3/s. At site 1 (Art Barn, corresponding to gage MR-1) the depth required to move the average bedload particles, according to Costa's tractive force equation, is 1.32m (Figure 2-33). The bankfull depth of the channel at the same point is 1.1 m, indicating that average sized sediment will move at just over bankfull stage, such as in conditions seen in the February snowmelt event. At site 4 (Art Building, corresponding to gage MR-2) the depth required to move the average bedload clast (126.63 mm) is a staggering 13.93 m. The bankfull depth of the channel in this reach is only 1m, demonstrating that only a very large flood could move the average sediment. Obviously this size sediment is not natural to the stream, and may have been part of eroded channelization efforts in the past. The survey illustrates Bucknell's profound influence on altering the current substrate of the stream.

Average: 12.078 mm
85%: 16.15 mm

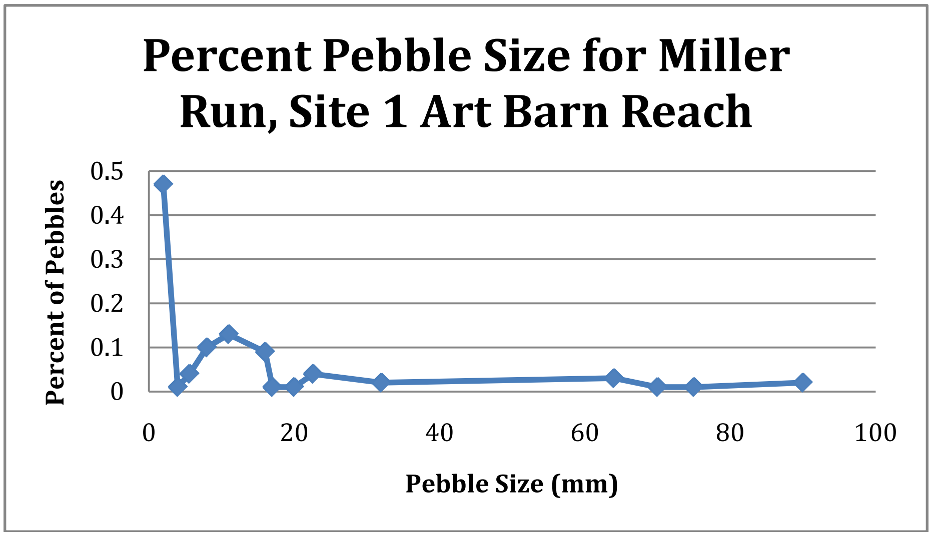


Figure 2-31 Site 1 Percent Pebble Size

Average: 126.6296 mm
85%: 252 mm

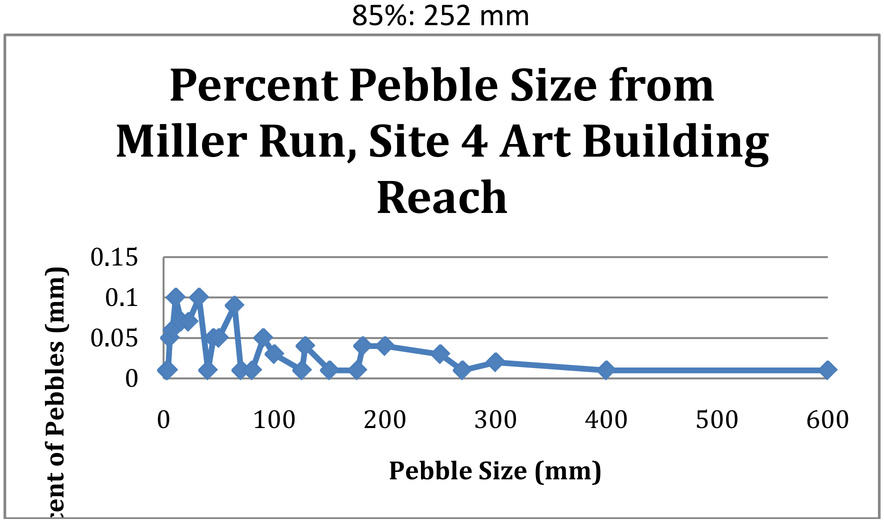


Figure 2-32 Site 4 Percent Pebble Size

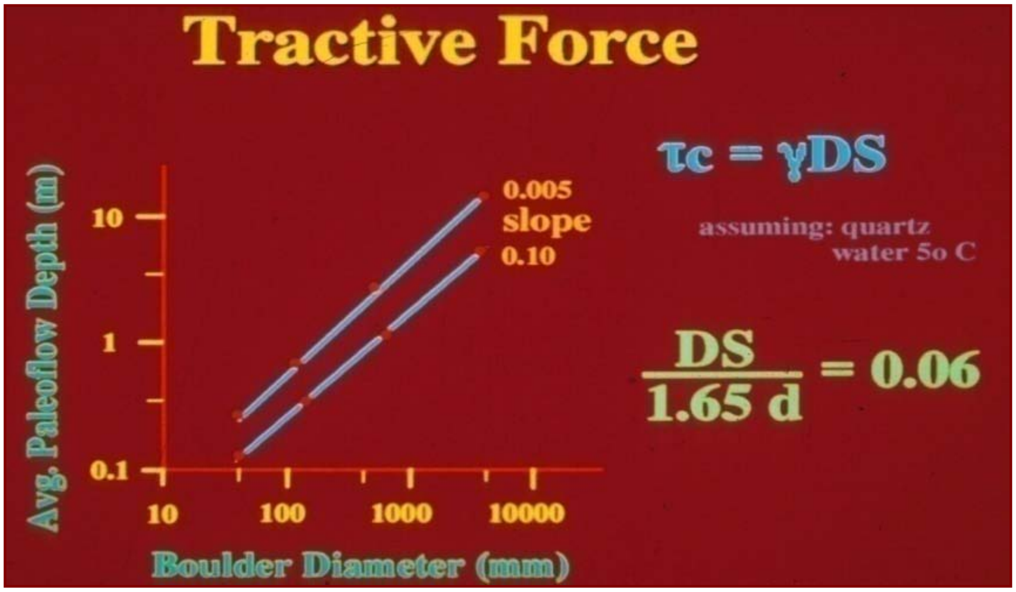


Figure 2-33 Equation for the Tractive Force

Water Quality

Introduction

Water quality, perhaps one of the most significant determinants of the health of an ecosystem, encompasses everything ranging from ion and dissolved oxygen concentrations, temperature, and pH. Along with structural habitat, these water quality conditions play a critical role in determining the overall health of aquatic ecosystems. Water quality is also an important factor in defining various ecological realtionships that exist in a given stream by identifying the types of aquatic organisms (algae, microbes, macroinvertebrates, and fishes) present. Furthermore, water quality can indicate the influence that humans have on a particular stream; for example, one would expect to find different organsims in a polluted stream than in a stream with little human interaction. Unfortunately, aquatic ecosystems have been neglected by humans for quite some time: streams and rivers have been continually treated as landfills and an open place in which to dump garbage and chemicals. Other destructive anthropogenic factors include runoff from impervious surfaces (such as blacktop), construction, farming, and recreation, which all have visibly adverse effects on the overall health of a stream and its aquatic biota.

More specific examples that can impact water quality include salts, nutrients, pesticides, and various sediments. Salts are important in that they determine the hardness of water but they also present aquatic organisms with osmoregulatory challenges. At high concentrations, certain salts, such as chloride, can become toxic to various aquatic organisms, thus limiting the biodiversity of a stream. At high enough concentrations, nutrients such as nitrogen and phosphorous, which determine aquatic plant growth, can cause excessive plant growth at high enough concentrations in a process known as eutrophication. Eutrophication can result in plant life consuming all of the dissolved oxygen in a stream, which deprives aquatic organisms of a vital element for life. The most vivid example of eutrophication can be seen in the Gulf of Mexico each year, when excess nutrients are transported via the Mississippi due to farming and irrigation. Upon reaching the Gulf of Mexico, they create huge algael blooms that deprives the water of dissolved oxygen, thereby creating a "dead zone" in which no aquatic life can be found. Also affecting the stream's health are pesticides, used most often to preserve crops from different organisms. However, these pesticides will often be carried via runoff into streams, where they become toxic to a variety of aquatic organisms. Finally, sedimentation can also impact habitat directly. Increases in sedimentation can destroy habitat of aquatic insects by burying the gravelly substrates that they need. Fish species can also be affected by large amounts sedimentation when eggs laid by spawning fish are covered by sediment.

An understanding of the impact that the aforementioned human processes have on aquatic ecosystems is imperative if they are to be restored to a more natural state. The objective of this study is to present the water quality conditions of Miller Run, including habitat and macroinvertebrate analyses, in its current state. The data will then be presented in a general overview showing what needs be done in order to restore Miller Run from a water quality standpoint.

Part 1: Water Chemistry
Methods

The water chemistry analysis included measuring various ion concentrations from water samples collected from Miller Run as well as measuring temperature, specific conductivity, pH, and dissolved oxygen concentrations. Ion chromatography was used to measure cation (ammonium, calcium, magnesium, potassium, and sodium) and anion (chloride, nitrate, and sulfate) concentrations. Metal (aluminum, cadmium, copper, iron, manganese, nickel, and zinc) concentrations were determined from an ion-coupled plasma spectrometry analysis. Various standards were run initially in order to asses any drift of the instrument. Soluble reactive phosphorous was measured using a spectrophotometric assay. Temperature, specific conductivity, pH, and dissolved oxygen concentrations were measured using two separate data loggers with probes that were placed in an upstream reach near the Art Barn (gage site MR-1) and a downstream reach located near Hunt Hall (gage site MR-2). These instruments collected data at 5-minute intervals and were deployed during high flow events to compare water quality flow changes at base flow with high flows from snow melt or rain.

Results/Discussion

A. Baseline Water Quality Data

Baseline data were gathered for Miller Run to allow for comparison of storm events. These baseline data illustrate the current conditions of Miller Run and the role that natural processes, such as photosynthesis, has on the fluctuations of the different variables that were analyzed. The temperature, pH, and dissolved oxygen concentration data and the patterns that were observed for each can be explained by naturally occurring processes related to weather, geology, and biological processes. The temperature (Figure 2-34) will fluctuate throughout the day depending on the location of the sun. Likewise, the pH (Figure 2-35) and dissolved oxygen concentrations (Figure 2-36) will be higher during the day due to an increase in photosynthesis relative to respiration by aquatic biota. During the night, without photosynthesis to compensate, respiration consumes dissolved oxygen and produces carbon dioxide, which causes pH to drop. Specific conductivity on the other hand can also vary depending on various biological processes, but it will tend to remain relatively similar without major fluctuations during the day.

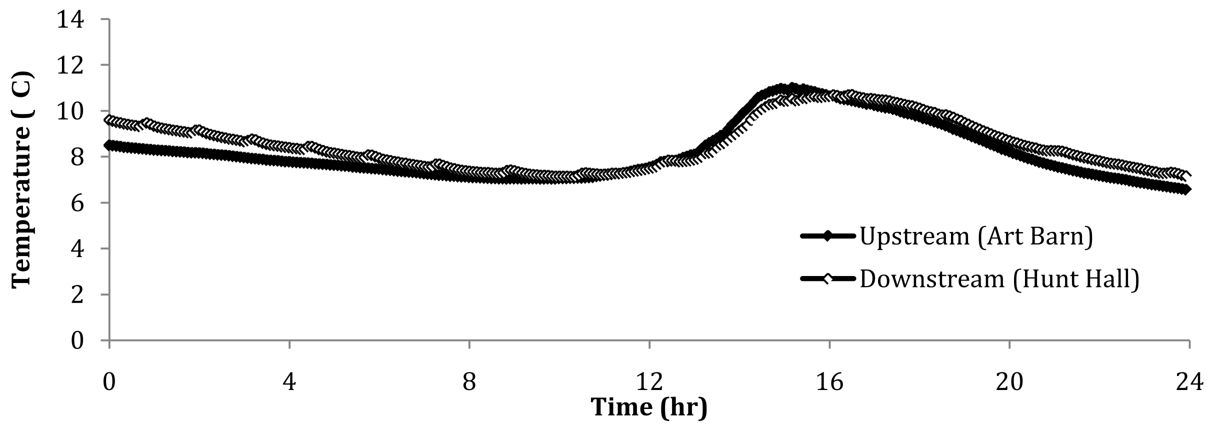


Figure 2-34 Baseline temperature analysis for upstream and downstream reaches of Miller Run (April 4, 2009 at 12:01 A.M. – April 4, 2009 at 11:56 P.M.)

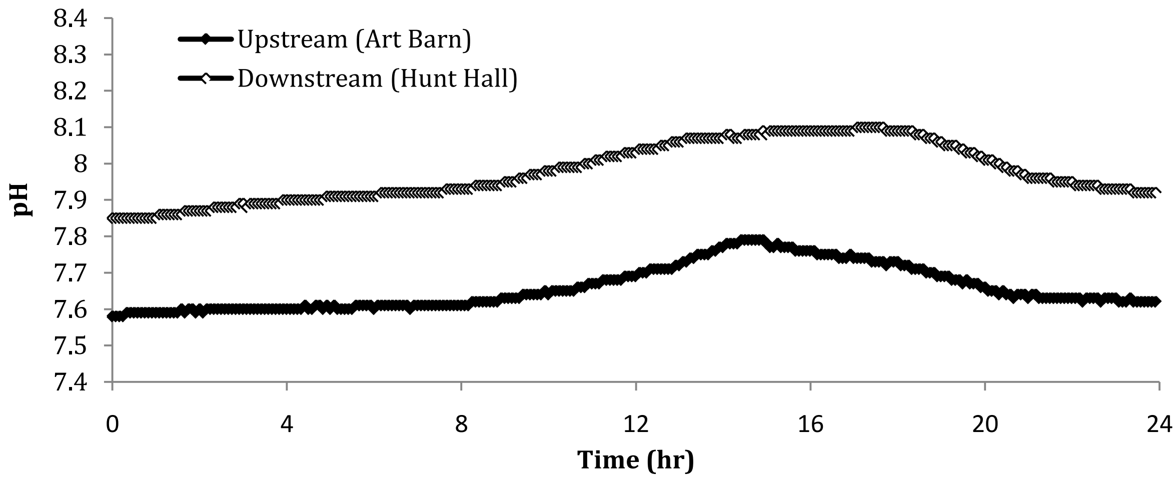


Figure 2-35 Baseline pH analysis for upstream and downstream reaches of Miller Run (April 4, 2009 at 12:01 A.M. – April 4, 2009 at 11:56 P.M.)

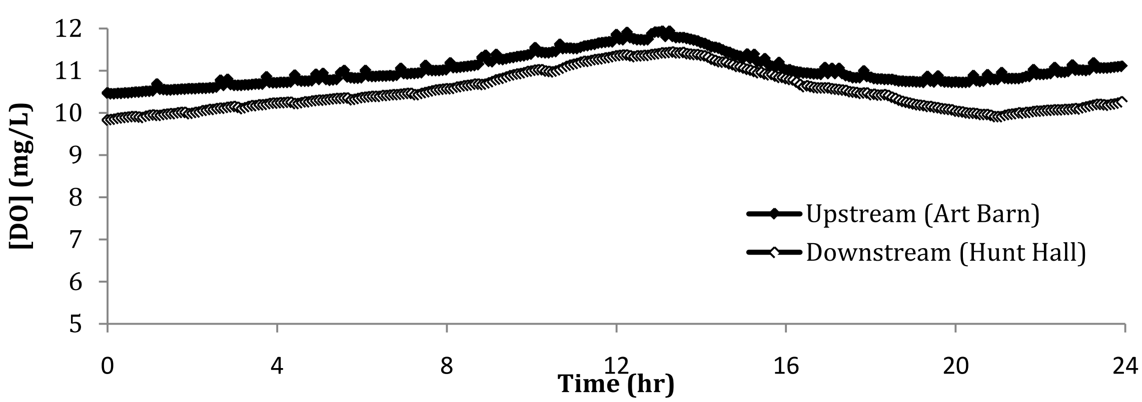


Figure 2-36 Baseline dissolved oxygen concentration analysis for upstream and downstream reaches of Miller Run (April 4, 2009 at 12:01 A.M. – April 4, 2009 at 11:56 P.M.)

The ion and metal concentrations (Table 2-2) were indicative of what normally is observed in Miller Run. It was assumed that during normal flow, the ion and metal concentrations would remain relatively constant. The ion concentrations at the upstream site were higher than the downstream site, which is likely attributable to farming, irrigation, and runoff from construction. The specific conductivity analysis (Figure 2-37) supports this assumption. Higher concentrations of ions will lead to higher specific conductivities. In contrast, temperature, pH, and dissolved oxygen remained relatively constant.

	Upstream (Art Barn)	Downstream (Hunt Hall)
Dissolved Solid	Concentration (mg/L)	Concentration (mg/L)
Ammonium	<10	<10
Sulfate	34	48
Chloride	81.7	47.9
Nitrate	1.9	1.98
Phosphorous	<0.1	<0.1
Sodium	32.2	21.9
Potassium	3.2	2.8
Magnesium	9.7	9.9
Calcium	57.9	53.5
Manganese	0.05	<0.03
Iron	0.2	0.23
Lead	<0.01	<0.01
Zinc	<0.02	<0.02
Chromium	<0.004	<0.004
Copper	<0.04	<0.04
Nickel	<0.005	<0.005
Cadmium	<0.001	<0.001
Arsenic	<0.005	<0.005

Table 2-2 Baseline ion concentration analysis for upstream and downstream reaches of Miller Run (February 17, 2009)

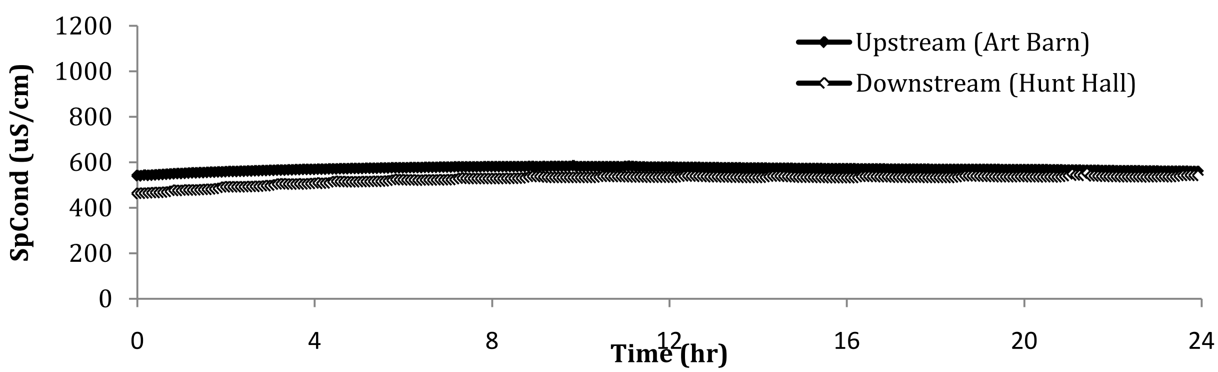


Figure 2-37 Baseline specific conductivity analysis for upstream and downstream reaches of Miller Run (April 4, 2009 at 12:01 A.M. – April 4, 2009 at 11:56 P.M.)

B. Snowmelt Event- February 7-9, 2009

Chloride, sodium, and potassium concentrations (Figures 2-38 to 2-40) all had significantly higher concentrations at the downstream site than at the the upstream site. In general, the sodium, chloride, and potassium concentrations initially increased during the event, but decreased after the initial peaks. However, there was a significant spike in the potassium concentration 25 hours into the event at the upstream site. Furthermore, the ion concentrations also peaked faster at the downstream site. This suggests that at some point during the snowmelt event, large amounts of these ions were transported into the stream between the upstream and downstream sites via runoff or infiltrating groundwater. Since this snowmelt event took place in February, the roads, parking lots, and walkways were covered with salt due to a number of snow events as well as in preparation for future events. There are a number of different salts that Bucknell and the Pennsylvania Department of Transporation use, and these salts likely contain sodium, potassium, and chloride. Thus, the runoff that occurred during this event may have transported these various salts into Miller Run. Also, the downstream site had higher concentrations, since it is in a more urbanized area where these salts are applied to roads, parking lots, and walking paths. The watershed upstream of Campus has more vegetation, which makes it harder for ions to be carried into Miller Run via runoff. Miller Run exhibited higher concentrations of the aforementioned ions when compared to similar streams that are not as affected by urbanization. As a result, one can conclude that Bucknell University has a large impact on Miller Run, and it has contributed to the current degraded water quality conditions.

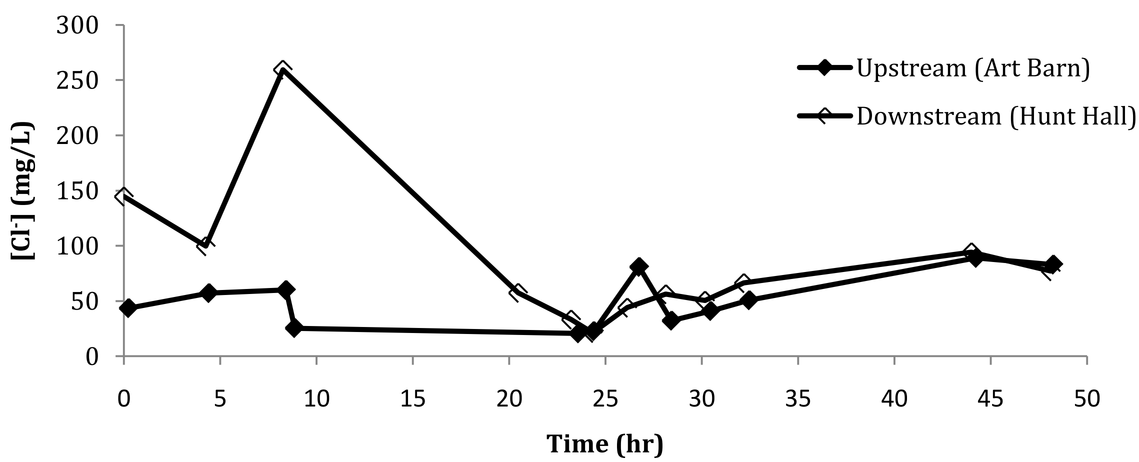


Figure 2-38 Comparison of upstream and downstream chloride concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

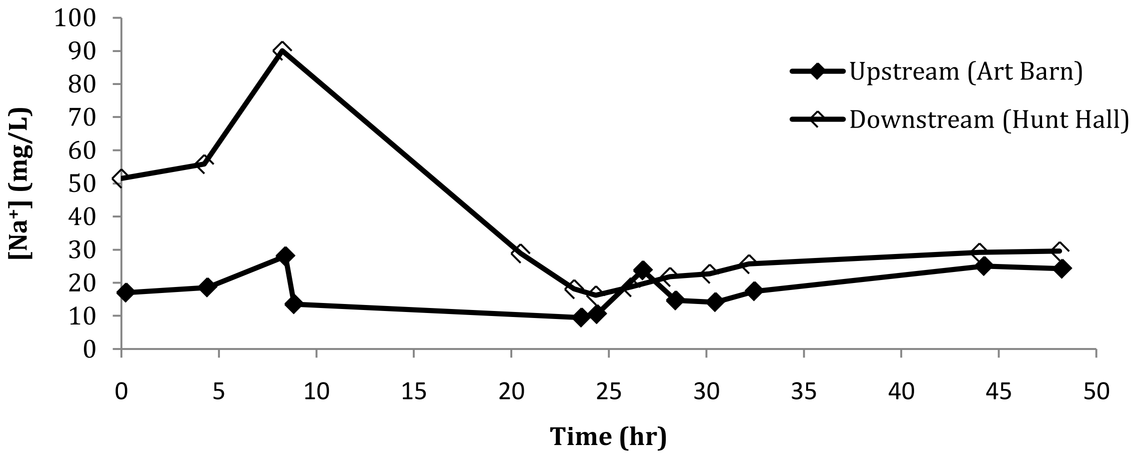


Figure 2-39 Comparison of upstream and downstream sodium concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

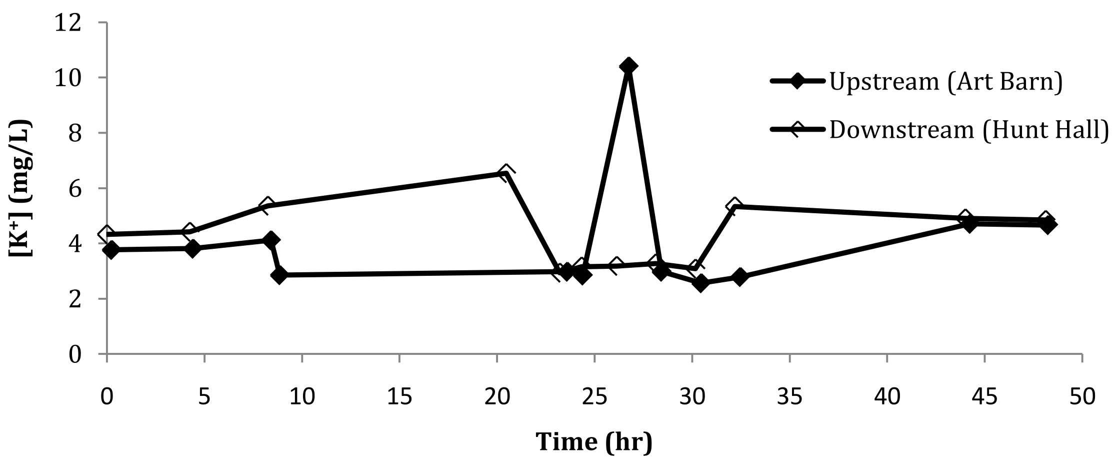


Figure 2-40 Comparison of upstream and downstream potassium concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

Magnesium and calcium concentrations (Figures 2-41 & 2-42) were higher at the upstream site than at the downstream site. In general, the concentrations of these two ions decreased during the first half of the snow melt until peak flow was reached. The upstream site reached minimum concentration of both ions first although it took longer for the initial decrease to occur. By comparison, calcium and magnesium concentrations decreased at a slower rate at the downstream site. The calcium and magnesium concentrations started to increase half-way through the event. The pattern that was observed for the calcium and magnesium ions can be explained via a dilution effect. Calcium and magnesium are typically derived from geological sources and require contact time with water for chemical weather to dissolve minerals containing these ions. Precipitation and surface runoff are typically very low in calcium and magnesium, so higher flows derived from precipitation (snow melt, in this case) will dilute these chemicals in the stream and cause lower concentrations. The reason why the ion concentrations were higher at the upstream site than the downstream site is that the downstream area receives more runoff and rainwater from Bucknell's underground drainage system that flow directly into Miller Run. Therefore, more of a dilution effect will be seen at the downstream site. Although calcium and magnesium are naturally occurring ions in streams due to the weathering of rocks and soils, the elevated levels suggest possible human sources. For example, calcium may be coming from $CaCl_2$, a de-icing salt that is commonly used to treat road and walking surfaces. The data are not conclusive though, and the elevated ion concentrations may be due to natural processes and the human-altered hydrology of the stream.

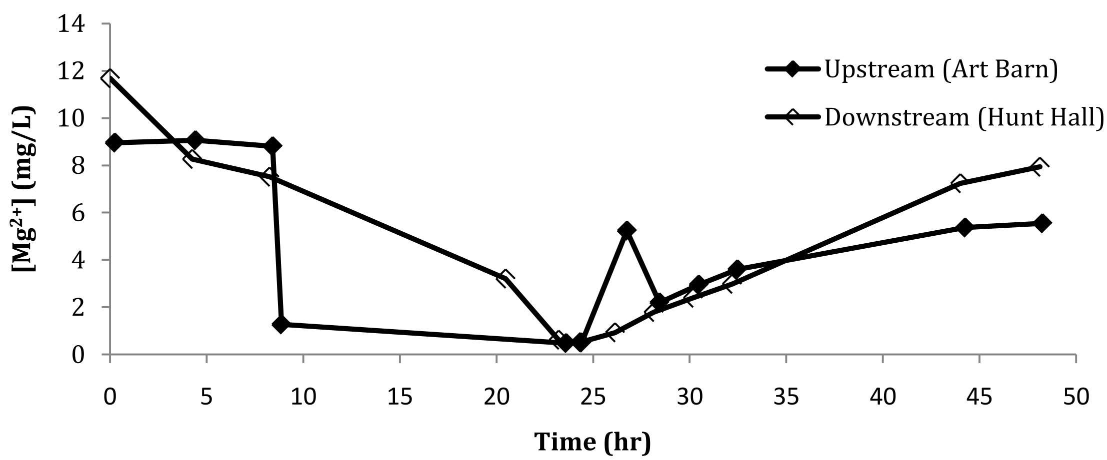


Figure 2-41 Comparison of upstream and downstream magnesium concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

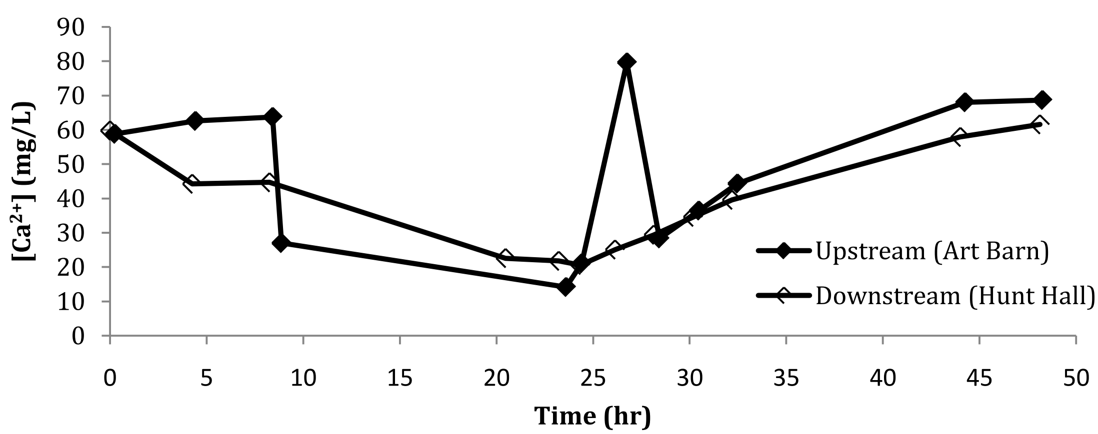


Figure 2-42 Comparison of upstream and downstream calcium concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

Nitrate and sulfate concentrations (Figures 2-43 & 2-44) followed a similar pattern to that of calcium and magnesium, in that their concentrations decreased during the first half of the event. Similarly, the upstream site reached minimum nitrate and sulfate concentration faster than the downstream site. Like calcium and magnesium, these ions are also diluted by runoff. Thus, one would expect to see higher concentrations of these ions upstream where the dilution is not as great. The elevated levels of these two ions can possibly hint at the use of fertilizers throughout the watershed. Nitrates and sulfates are often found in fertilizers, which Bucknell may use on its lawns as well as the golf course. Therefore, these ions can be carried by runoff into Miller Run. Sulfate though can be found naturally with the weathering of different rocks, so elevated concentrations can be somewhat misleading. In addition, sulfate could be leaching from coal piles that are buried under fill near entrance to the golf course. Sampling could be performed upstream of the sampled site at the Art Barn, possibly in the South Branch of Miller Run, to determine whether the elevated sulfate concentrations are natural or due to leaching of the buried coal piles.

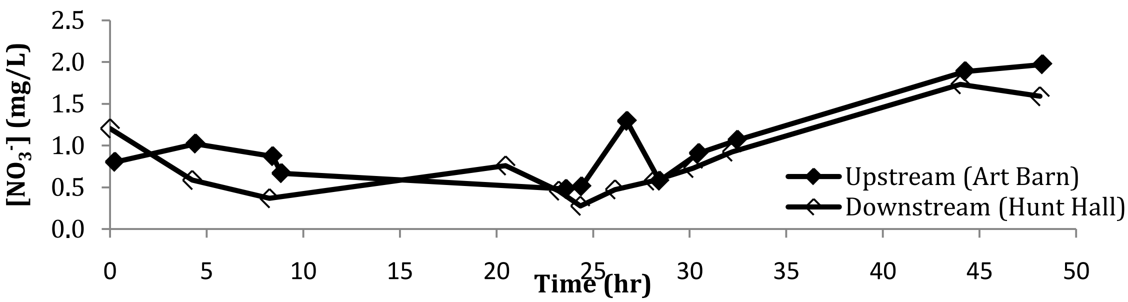


Figure 2-43 Comparison of upstream and downstream nitrate concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

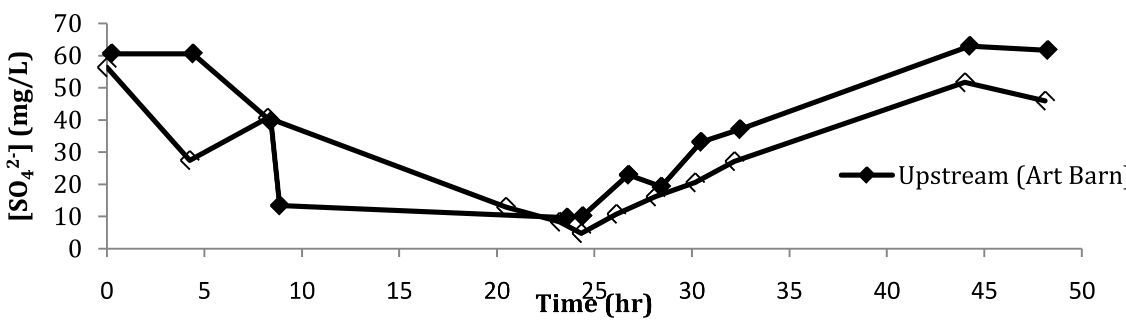


Figure 2-44 Comparison of upstream and downstream sulfate concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

One of the most intriguing ion data that was collected was that of ammonium (Figure 2-45). A dilution effect similar to that of calcium and magnesium and nitrate and sulfate should have been observed. However, ammonium was not detected until several hours into the event. Surprisingly, the ammonium concentrations were higher downstream than upstream where it may have been found in fertilizers used on the golf course. The ammonium concentration remained relatively constant after the initial detection but increased slightly, however, the concentrations returned to zero a few hours after it had first appeared. It is also important to note that ammonium concentrations did not appear elevated until the flood stage reached peakflow. This pattern can be explained either by the use of fertilizers, ammonium storage that gets flushed out druing a snowmelt/rain event, or a sewage leak. The use of fertilizers by Bucknell may be the most likely culprit, but a sewage leak is also a real possibility. Ammonium is found in sewage, and a leak in a pipe that is near Miller Run could allow ammonium to leach into the stream, but only when there is enough interflow to transport materials leaking from the pipes. In order to draw a more concrete conclusion about ammonium, it is necessary to have more sampling sites along the channel.

In addition to ammonium concentration, concentrations of other ions are relatively high when compared to other streams the size of Miller Run. This too can also hint at impairment, some of which is explained by runoff or by erosion occuring along the banks to introduce these ions into the stream. The high ion concentrations are representative of what one would expect to see based on the land use around the watershed, such as with suburbanization and golf development upstream and urbanization downstream. However, it is important to note that the concentrations of the heavy metals analyzed are insignificant.

Soluble reactive phosphorus concentrations (Figure 2-46) were similar at both sites throughout the storm. Furthermore, the concentration at each site remained constant for the most part at both sites. However, it did peak 25 hours into the storm. The upstream site had a relatively larger peak than the downstream site although the downstream site peaked prior to the upstream site. Phosphorous is often found in fertilizers as well as in sewage. As a result, this could indicate of the use of fertilizers by Bucknell that somehow enter into Miller Run via runoff. Also, a correlation was found between soluble reactive phosphorus concentrations (Figure 2-46) and ammonium concentrations (Figure 2-45), since they peaked at relatively the same time during the event. Thus, it is likely that they entered the stream in a similar manner, and they may have come from the same source. During baseflow, there is an insignificant amount of phosphorous present in Miller Run either upstream or downstream. Consequently, this provides more data that phosphorous and ammonium come from an area that only contributes water to Miller Run during higher flows.

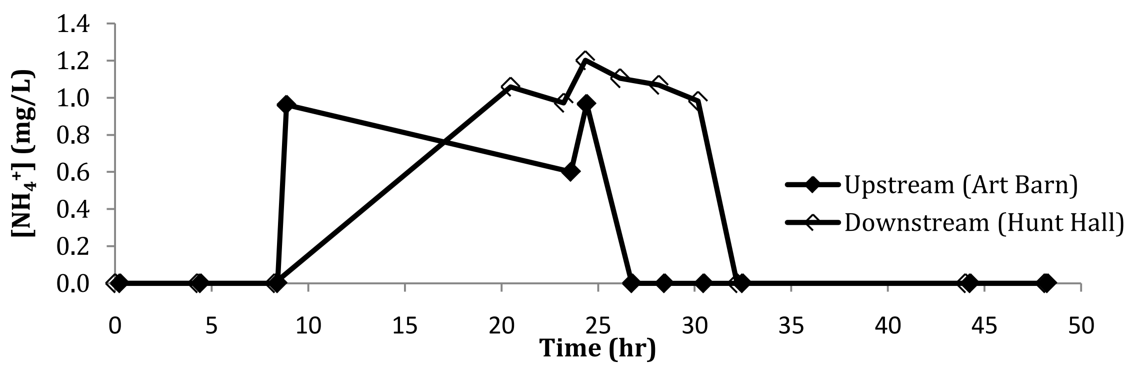


Figure 2-45 Comparison of upstream and downstream ammonium concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

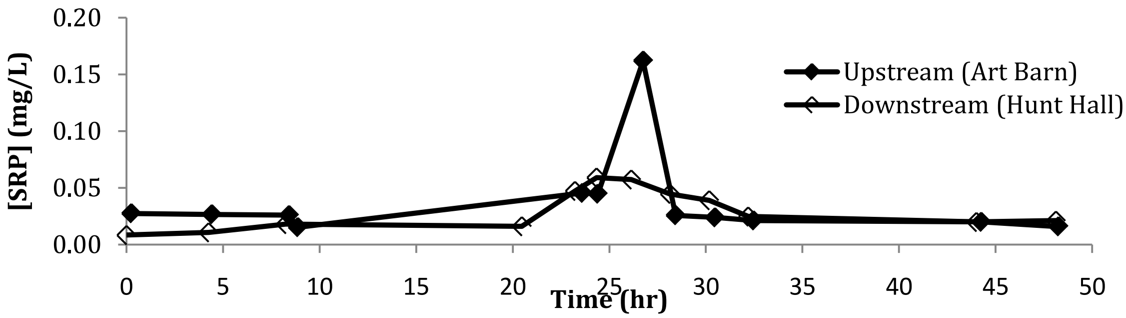


Figure 2-46 Comparison of upstream and downstream soluble reactive phosphorous concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

For the most part, the heavy metal concentrations were either insignificant during the snowmelt event or were below detection limits, including cadmium, copper, manganese, nickel, and zinc. However, aluminum (Figure 2-47) and iron (Figure 2-48) concentrations showed interesting patterns during the snowmelt. The patten of aluminum concentration was similar to that of calcium (Figure 2-42). In general, aluminum decreased during the first half of the event. The upstream site reached minimum concentration first although it took longer for the initial decrease to occur. The aluminum concentration began to increase half-way during the event, which occurred rapidly at the upstream site. The most likely culprit for the presence of aluminum in Miller Run is from the erosion of pipes or trash that people tend to throw into Miller Run.

The iron concentration (Figure 2-48) by comparison had a very unique pattern. Initially, iron decreased at the upstream site, and was undetectable at the downstream site. Then the iron concentrtaion had a significant increase at the upstream site, while the same occurred at the downstream site later. The iron concentration peak was higher at the downstream site than at the upstream site. Eventually, iron concentration leveled off at both sites. The iron likely came from groundwater sources or from natural processes, such as erosion. However, the iron may also have been transported via runoff from different sources of polution, especially on the Bucknell campus. Iron can come from automobiles and parking lots as rust, which can explain the trend as to why the downstream site had a higher iron concentration than the upstream site.

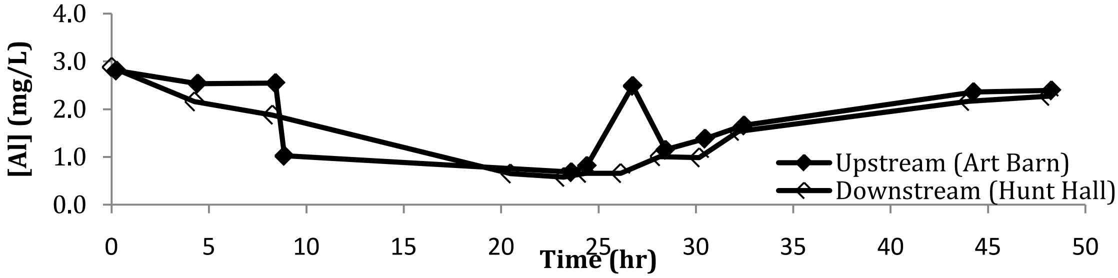


Figure 2-47 Comparison of upstream and downstream aluminum concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

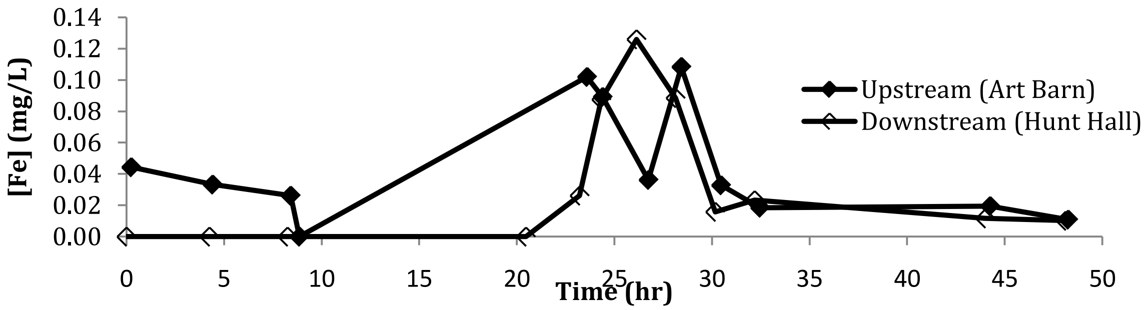


Figure 2-48 Comparison of upstream and downstream iron concentrations for snowmelt event (February 7, 2009 at 11:55 A.M. – February 9, 2009 at 12:10 P.M.)

During the snowmelt event, temperature (Figure 2-49) was very low (0-2°C) and remained relatively constant at both sites. The upstream site had a slightly higher temperature than the downstream site. Therefore, the temperature analysis are not that informative, since the data were collected during winter. Thus, one would expect to see colder temperatures during winter months. The only reason as to why the upstream site would have a higher temperature would be due to the influx of groundwater that is slightly warmer than snowmelt.

Specific conductivity (Figure 2-50) on the other hand changed dramatically during the course of the event. At both sites, it showed an initial increase, but dropped significantly a few hours into the event due to the high flow experienced then. After the mimimum was reached, a gradual increase was observed at both sites. Unlike the baseline data (Figure 2-37), the downstream site had a higher specific conductivity during the event than the upstream site. This can be explained by the downstream site experiencing more of a dilution effect due to Bucknell's drainage system. During storm events, stormwater travels through this system at high rates and volumes, which creates high amounts of dilution downstream, after possible pulses of inputs at the start of storms.

The pH (Figure 2-51) was distinct at both sites. The upstream site remained relatively constant even though a small gradual decrease in pH was observed during the snowmelt. The downstream site had an initial increase, but had a noteworthy decrease 5 hours into the event. Gradual decreases in pH were observed after that until it finally began to increase 30 hours into the event and level off at baseline levels. The pH likely varied due to biological processes although to a lesser extent during this snowmelt event. The decrease in pH at the downstream site is probably due to the snowmelt that was released into Miller Run, particularly by the drainage system. It is important to note that the pH fluctuations were minimal overall.

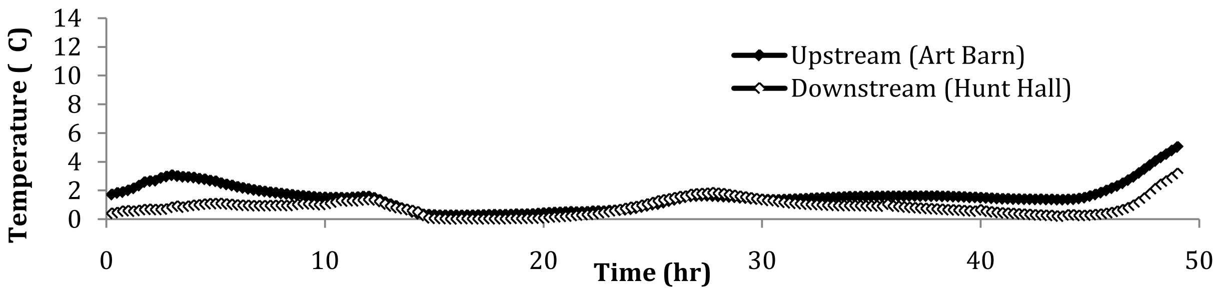


Figure 2-49 Temperature analysis for upstream and downstream reaches of Miller run for snowmelt event (February 7, 2009 at 12:01 P.M. – February 9, 2009 at 12:46 P.M.)

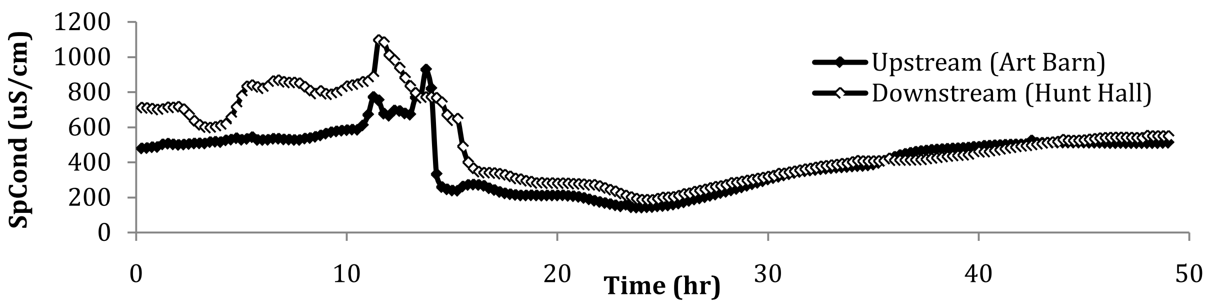


Figure 2-50 Specific conductivity analysis for upstream and downstream reaches of Miller run for snowmelt event (February 7, 2009 at 12:01 P.M. – February 9, 2009 at 12:46 P.M.)

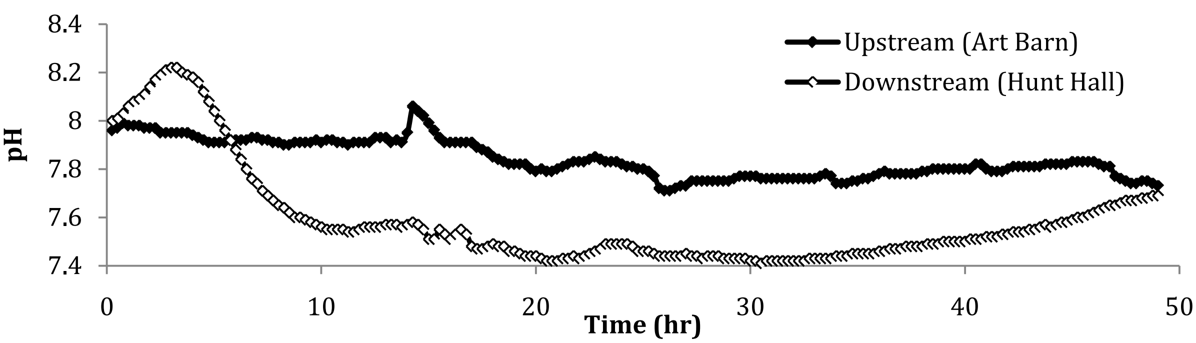


Figure 2-51 pH analysis for upstream and downstream reaches of Miller run for snowmelt event (February 7, 2009 at 12:01 P.M. – February 9, 2009 at 12:46 P.M.)

C. Rain Event- April 1, 2009

Bucknell University experienced significant amounts of rain on April 3, 2009. Sampling was done throughout and after the event. For a more information on the April 3 rainfall event, see the Hydrology section. Temperature, specific conductivity, pH, and dissolved oxygen concentrations were collected for this event. The temperature data (Figure 2-52) for this event did not show any fluctuations and remained relatively constant. When compared to the snowmelt event (Figure 2-49), the temperature at both sites are higher due to the time of year, but the downstream temperature is higher than the upstream temperature. This is most likely the result of hot water and steam pipes that Bucknell has that goes into Miller Run, which would have allowed the temperature downstream to be greater than that upstream.

The specific conductivity (Figure 2-53) for this event is similar to that of the snowmelt event. It was on a smaller scale though, since it was a smaller event. Specific conductivity remained relatively constant at the upstream site, while it dropped initially during the event and gradually returned to baseline levels at the downstream site. Thus, the specific conductivity was higher at the upstream site than at the downstream site. Once again the decreases were due to the dilution of ions by the flow.

The pH (Figure 2-54) by comparison had minor fluctuations during the event. It initially increased at both the upstream and downstream sites, and eventually returned to pH levels before the storm. The downstream site had a higher pH than the upstream site, which is similar to what was observed at baseline pH. This may have been the case due to the size of the rain event. Since it was a smaller event, the dilution factor at the downstream portion may have been negligible.

The dissolved oxygen concentration (Figure 2-55) remained constant at the upstream site, and was higher than at the downstream site. The downstream site though had a dramatic increase in dissolved oxygen concentration in a 1 hour period. It eventually leveled off, and slowly approached levels that were seen before the storm. The dissolved oxygen concentration is somewhat surprising though, since it increases with the gradual increase in temperature (Figure 2-52). Typically, colder water holds more oxygen than warmer water. Thus, it was astonishing to see that an increase in temperature corresponded to an increase in dissolved oxygen. The most likely explanation for this is that during storm events, oxygen saturated rain and runoff along with turbulence caused by high flows lead to higher dissolved oxygen at the downstream site. Upstream waters that are more saturated with oxygen are flushed through the channel, which will exhibit an increase in dissolved oxygen concentrations downstream where it is normally depleted due to respiration. When comparing the baseline dissolved oxygen concentration (Figure 2-35) to that of this rainfall event, it may be misleading. This is due to the baseline data being gathered after the two rainfall events analyzed for Miller Run. The baseline data is to depict what normal levels of dissolved oxygen concentrations would be like if Miller Run experienced normal flow on a daily basis, instead of drying up in some parts along the stream. Therefore, during storm events the dissolved oxygen concentration should increase at the downstream site, since the water from the upstream site with higher baseline dissolved oxygen concentrations will be flushed through the system. Also, this could be due to a stagnant water issue from the irregular flows that Miller Run experiences. However, it could also be a biochemical oxygen demand issue, since there is less riparian vegetation at the downstream site. Consequently, there will be more in-stream photosynthetic organisms at the downstream site.

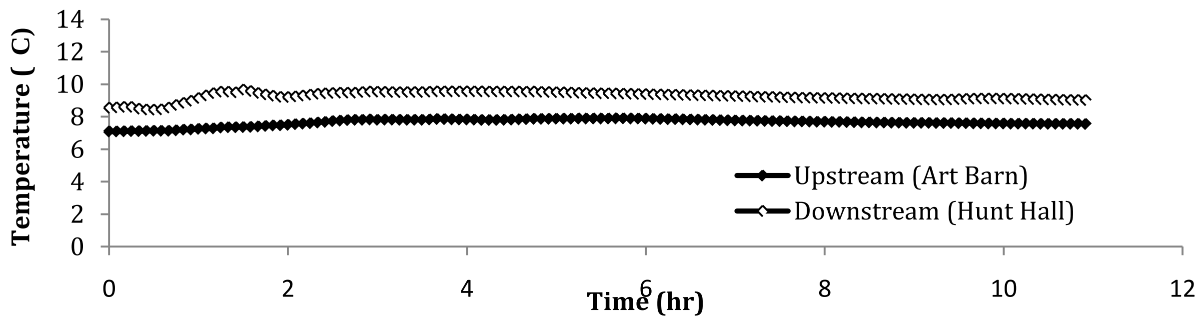


Figure 2-52 Temperature analysis for upstream and downstream reaches of Miller run for snowmelt event (April 1, 2009 at 1:01 P.M. – April 1, 2009 at 11:56 P.M.)

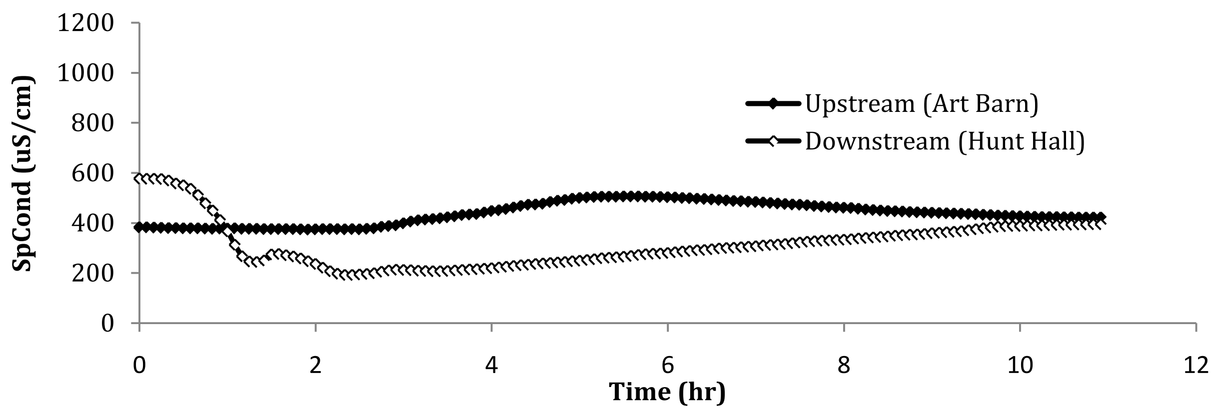


Figure 2-53 Specific conductivity analysis for upstream and downstream reaches of Miller run for snowmelt event (April 1, 2009 at 1:01 P.M. – April 1, 2009 at 11:56 P.M.)

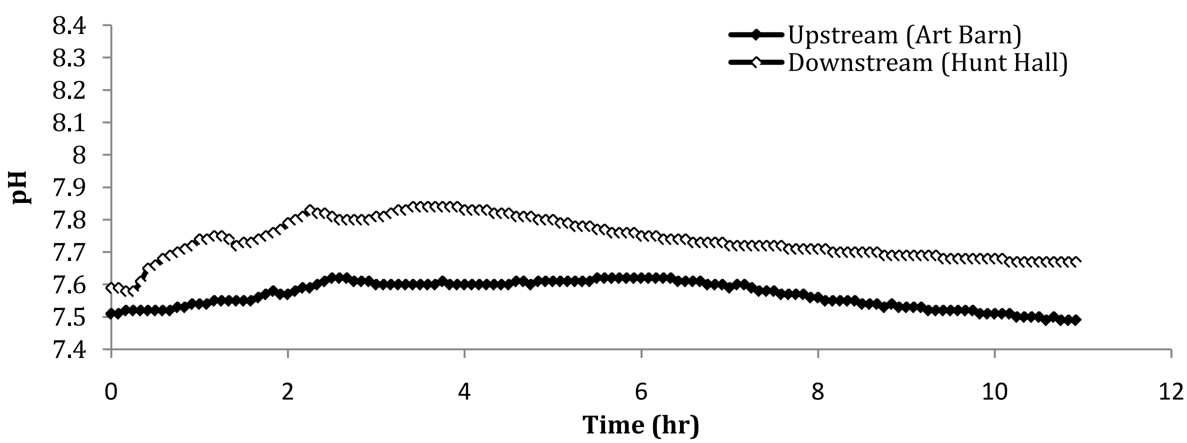


Figure 2-54 pH analysis for upstream and downstream reaches of Miller run for snowmelt event (April 1, 2009 at 1:01 P.M. – April 1, 2009 at 11:56 P.M.)

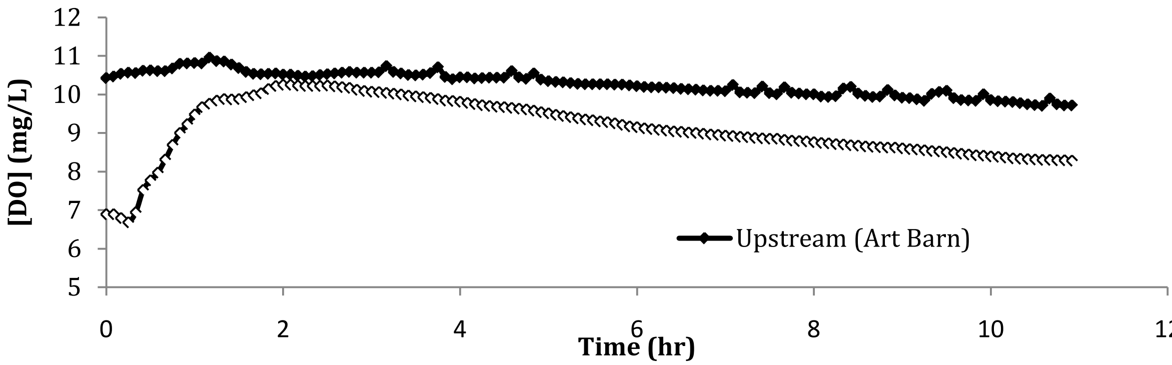


Figure 2-55 Dissolved oxygen concentration analysis for upstream and downstream reaches of Miller run for snowmelt event (April 1, 2009 at 1:01 P.M. – April 1, 2009 at 11:56 P.M.)

D. Rain Event- April 3, 2009

Temperature, specific conductivity, pH, and dissolved oxygen concentrations were also collected for this rain event. The temperature (Figure 2-56) was not as illustrative as the other variables. The temperature remained constant through the first-half of the storm at both the upstream and downstream sites. It gradually decreased during the second-half of the storm. Also, the temperature was higher at the downstream site. The downstream portion also had a higher temperature likely due to the increase in flow during storm events. Groundwaters that have slightly higher temperatures that flow in at the upstream site are transported through the channel to the downstream site, which will cause minor fluctuations in temperature at the downstream site.

This rain event was signifiicant and it more vividly illustrated the patterns that were shown by the first two events we analyzed. The specific conductivity data (Figure 2-57) were distinct for both sites. At the upstream site, specific conductivity remained unchanged through the first 8 hours of the storm. It then had a small increase during the next 4 hours. At 12 hours though, there was a sharp decrease in specific conductivity, but it rebounded to the initial levels observed rather quickly. Likewise, conductivity at the downstream site remained constant through the first 8 hours of the storm. Unlike the upstream site, a significant decrease in specific conductivity was observed, but conductivity leveled out until a smaller decrease occurred a few hours later. It then began to increase although at a slower rate than the upstream site. This was likely due to the dilution of ions by the flow. The downstream portion was impacted to a greater extent, which validates the role of the drainage system on Bucknell's campus. As previously stated, stormwater travels through the drainage system at high rates and volumes, which creates high amounts of dilution downstream, after possible pulses of inputs at the start of storms.

The pH (Figure 2-58) displayed a similar pattern to that of the first rainfall event on April 1st. The pH remained relatively constant for the first-half of the event at both sites. Then half-way into the storm, a sharp increase in pH took place. The pH would then decrease and level off at both the upstream and downstream sites. It is important to note though that pH leveled off at both sites at a higher pH than before the event. Furthermore, the pH was higher at the downstream site than at the upstream site, especially the peak that was observed half-way into the event. Although photosynthesis can cause pH to increase by removing CO_2 from the water, there is likely little photosynthesis occurring during storm events when the stream waters are turbid. Consequently, something else is causing the increase in pH during storms. It may be the result of mobile groundwaters flowing into the stream, or from inputs of other alkaline materials, especially since calcium and magnesium concentrations go down during higher flows.

The dissolved oxygen concentration (Figure 2-59) displayed a similar pattern to that of the first rain event on April 1, 2009 (Figure 2-55). The dissolved oxygen concentration remained constant at the upstream site, and was higher than at the downstream site. The downstream site though had a dramatic increase in dissolved oxygen concentration in a 1 hour period. It eventually leveled off, and slowly approached levels that were seen before the storm. The reasoning behind this is similar to what was observed in the previous rain event. Increases in dissolved oxygen concentrations at the downstream site were due to turbulence and a flush of more oxygen saturated waters from the upstream site through the system.

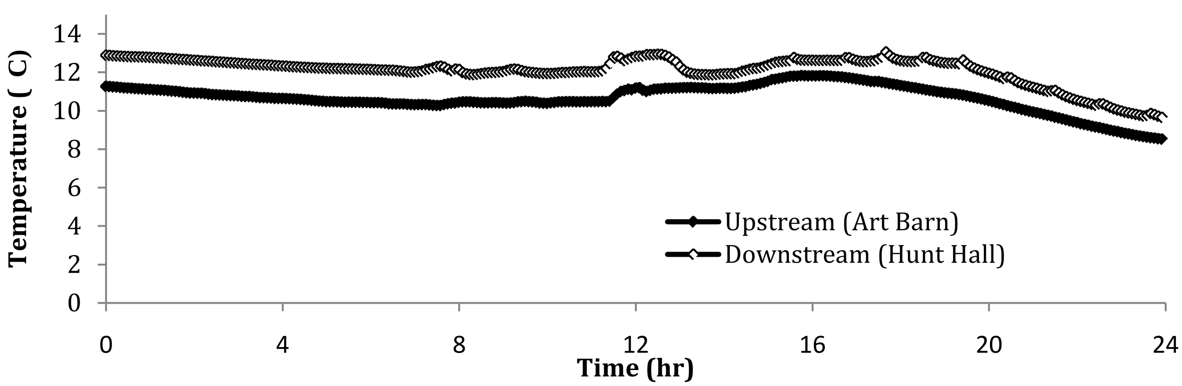


Figure 2-56 Temperature analysis for upstream and downstream reaches of Miller run for snowmelt event (April 3, 2009 at 12:01 A.M – April 3, 2009 at 11:56 P.M.)

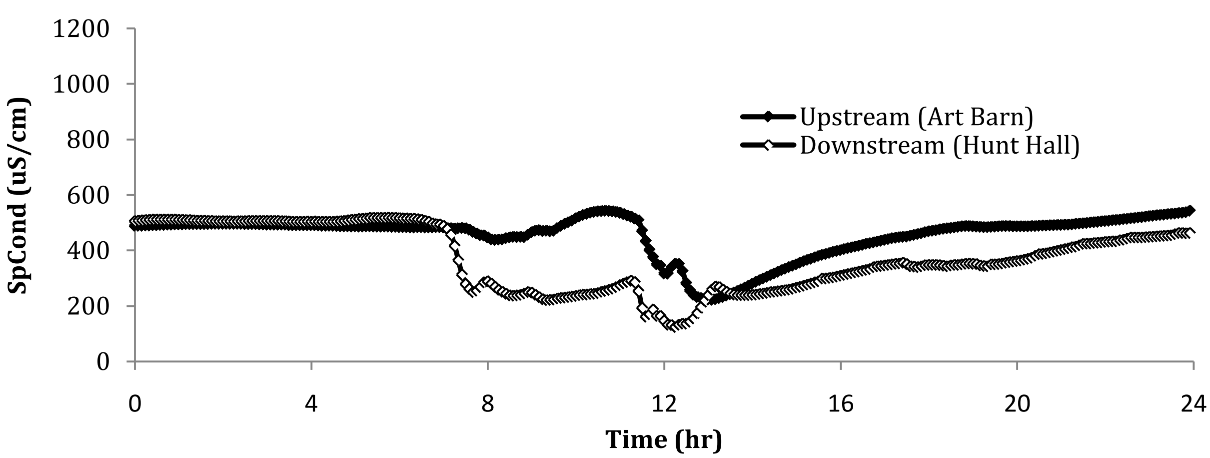


Figure 2-57 Specific conductivity analysis for upstream and downstream reaches of Miller run for snowmelt event (April 3, 2009 at 12:01 A.M – April 3, 2009 at 11:56 P.M.)

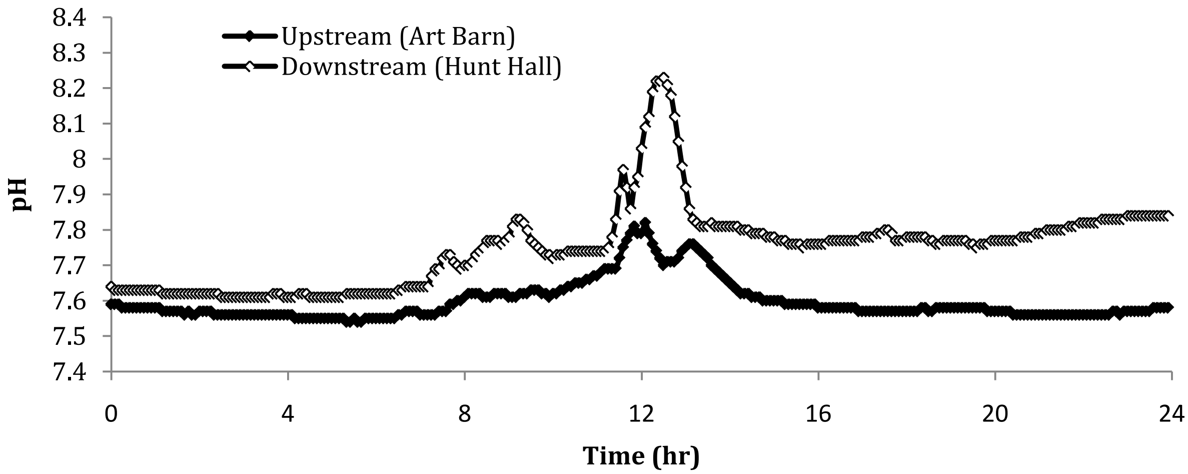


Figure 2-58 pH analysis for upstream and downstream reaches of Miller run for snowmelt event (April 3, 2009 at 12:01 A.M – April 3, 2009 at 11:56 P.M.)

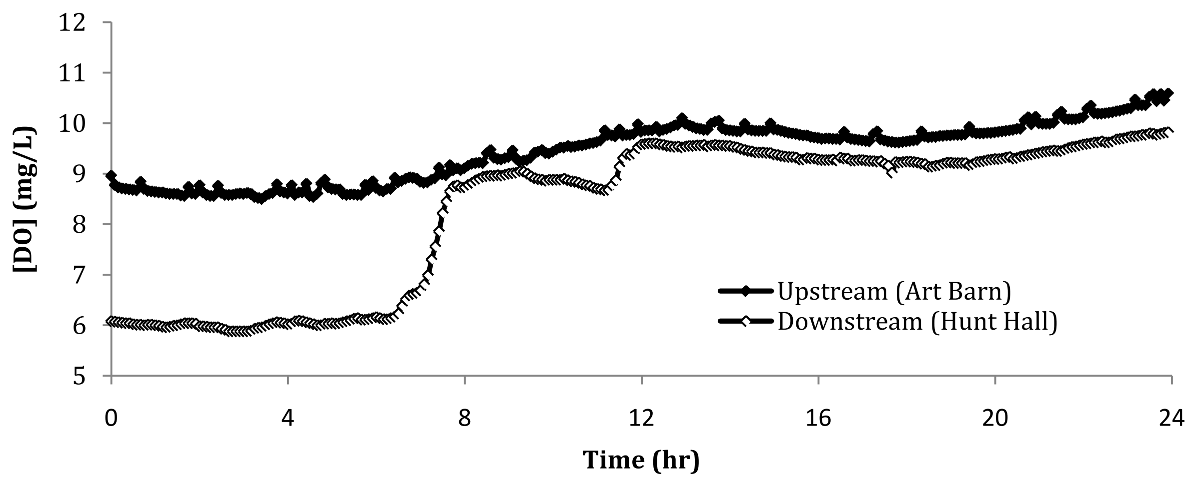


Figure 2-59 Dissolved oxygen concentration analysis for upstream and downstream reaches of Miller run for snowmelt event (April 3, 2009 at 12:01 A.M – April 3, 2009 at 11:56 P.M.)

<u>Conclusion</u>

As seen by the water chemistry data, Miller Run has been greatly impacted by human use, especially by Bucknell University. There are several problems that are associated with Miller Run from a water chemistry perspective. Ion concentrations are significantly higher in Miller Run than in streams that are similar in size. Salts, such as sodium, potassium, and chloride at the levels observed in Miller Run can have serious impacts on aquatic biota. One of which relates to the important process of osmoregulation. When salts reach high concentrations, they tend to place stress on the organisms that live in streams. This is due to aquatic biota having certain tolerance levels to different ion concentrations. When this tolerance level is exceeded, the organism is no longer able to maintain a normal physiological state. This stress can cause aquatic biota to become more susceptible to the toxicity of other ions, such as ammonium. Thus, when concentrations of toxic ions and metals are present in high enough concentrations as in Miller Run, they can lead to disease and/or death.

There are several other factors that can place stress on aquatic organisms as well, including temperature, pH, and dissolved oxygen concentrations. This is similar to what was already mentioned with the ion concentrations. Different organisms have different tolerance levels to various factors. An excellent example is the classification that is used to denote as either cold-water or warm-water fishes. Certain fish species are better adapted to live in cold-waters, while others are adapted to live in warmer waters. Therefore, if an alteration in temperature were to occur, stresses can be placed on these organisms and can lead to death. This is also true for pH and dissolved oxygen. If the pH is too acidic or alkaline different stresses will be placed on aquatic biota. Similarly, aquatic biota can be placed under stress if dissolved oxygen concentrations are too high or low.

Therefore, in order to see the impact of Miller Run's water quality on aquatic biota, it was pivotal to do additional analyses. These analyses included a habitat assessment, algae analysis, and aquatic biota characterization as outlined in a protocol established by the Pennsylvania Department of Environmental Protection.

Part 2: Habitat Assessment

Introduction

A habitat assessment was performed for Miller Run for several reasons. The most significant reason is due to the current state of Miller Run. For the past several decades, Miller Run has been severely impacted by human intervention. The most obvious impairments can be seen from construction near or around the stream as well as the channelization of the stream itself, particularly through Bucknell University's campus. This has greatly decreased the amount of viable habitat suited for aquatic biota to flourish throughout Miller Run. Furthermore, various sections of the stream have been "rip-rapped" destroying the habitat necessary for aquatic biota. Streams naturally interact with their riparian (i.e. streamside) environments. These interactions can be direct, like during overbank flows, or indirect, like how terrestrial vegetation can moderate in-stream water quality or provide dead organic material (e.g., leaves) for aquatic organisms to consume. These linkages are critical components of healthy stream ecosystems and have been dramatically altered along Miller Run. Therefore, a thorough characterization of Miller Run was necessary in order to assess what types of habitat are located in Miller Run for aquatic biota. The primary objective of this habitat assessment was to illustrate the poor conditions currently in Miller Run, and to create a plan of action to increase the habitat diversity of Miller Run.

Methods

The habitat assessment for Miller Run was performed using a standard protocol for water quality network habitat assessment as established by the Pennsylvania Department of Environmental Protection (PA-DEP 2007). This assessment was performed through the in-depth analysis of four different reaches of Miller Run (Figure 2-60). The most important issues considered by the Commonwealth of Pennsylvania are "in-stream cover," such as for fish, "epifaunal substrate," "embeddedness," "sediment deposition," and the "overall condition of the banks." Other factors that were assessed included: velocity/depth regimes, channel alterations, riffle frequency, flow status of the channel, bank vegetative protection, grazing or other disruptive pressures, and the width of the riparian vegetative zone. The above variables were each categorized on a scale of 2-20: Ratings of 2-5 were considered poor, 6-10 marginal, 12-15 suboptimal, and 16-20 optimal. The individual ratings were then tallied to give overall scores to each site, which were then used to categorize the habitat along each stream reach as optimal (192-240), suboptimal (132-180), marginal (72-120), or poor (60 or less), with gaps between each category left up to the discretion of the investigators.

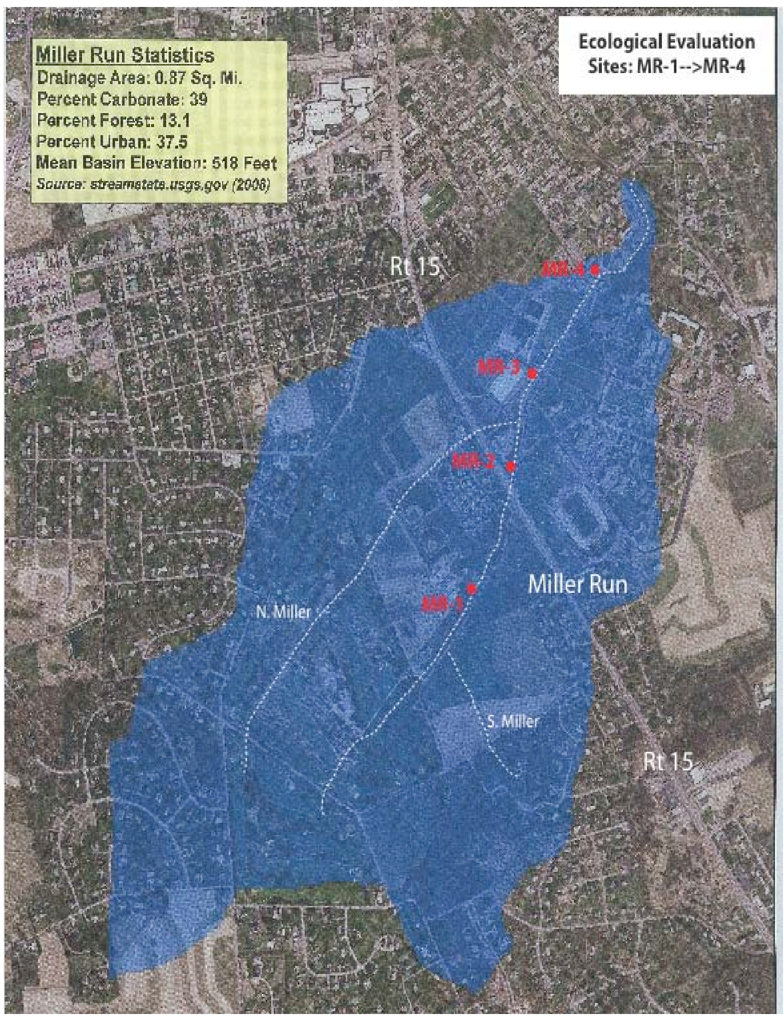


Figure 2-60 Map of Biological Test Sites

Results/Discussion

Table 2-3 Habitat assessment scores evaluated using a protocol established by the Pennsylvania Department of Environmental Protection

Site	MR-1 (Art Barn)	MR-2 (Gerhard Fieldhouse - U.S. 15)	MR-3 (Langone Athletics and Rec Center)	MR-4 (Loomis Street – Art Building)
In-stream Cover(fish)	6 (Marginal)	8 (Marginal)	10 (Marginal)	7 (Marginal)
Epifaunal Substrate	8 (Marginal)	12 (Suboptimal)	7 (Marginal)	8 (Marginal)
Embeddedness	18 (Optimal)	3 (Poor)	3 (Poor)	3 (Poor)
Velocity/Depth Regimes	7 (Marginal)	7 (Marginal)	9 (Marginal)	8 (Marginal)
Channel Alteration	14 (Suboptimal)	3 (Poor)	1 (Poor)	3 (Poor)
Sediment Deposition	13 (Suboptimal)	7 (Marginal)	10 (Marginal)	8 (Marginal)
Frequency of Riffles	8 (Marginal)	12 (Suboptimal)	10 (Marginal)	3 (Poor)
Channel Flow Status	16 (Optimal)	14 (Suboptimal)	14 (Suboptimal)	7 (Marginal)
Condition of Banks	10 (Marginal)	14 (Suboptimal)	11 (Suboptimal)	7 (Marginal)
Bank Vegetative Protection	9 (Marginal)	5 (Poor)	1 (Poor)	1 (Poor)
Grazing or Other Disruptive Pressure	10 (Marginal)	6 (Marginal)	3(Poor)	3 (Poor)
Riparian Vegetative Zone Width	3 (Poor)	4 (Poor)	1 (Poor)	1 (Poor)
Total	122	95	80	59
Habitat Assessment	Marginal	Marginal	Marginal	Poor

Site 1:

The first site that was sampled, MR-1, was located near the Art Barn. Although this site outperformed the other three, its habitat score was still "marginal" with a total score of 122, primarily due to its less urbanized area and an abundance of riparian vegetation.

The in-stream cover at this site received a marginal score (6). There were some boulders which could act as a habitat for aquatic organisms, but not enough to make it particularly desirable. The epifaunal substrate also received a marginal rating (8) due to lack of a good riffle system and the abundance of gravel and boulders. The embeddedness of this site received an optimal rating (18), because the gravel and cobble present were minimally surrounded by fine sediment. The sediment deposition by comparison, received a suboptimal rating (13). It was noted that some point bars were increasing in size as well as some minor deposition occurring near the pool locations. The condition of the banks received a marginal score (10). The banks were unstable, evidenced by the presence of new grasses located within the channel. Significant amounts of erosion occur at this site, but there were still a few areas that looked moderately stable. The velocity/depth regimes received a marginal rating (7). Fast-deep, slow-deep, fast-shallow, and slow-shallow regimes were not all represented, but the site was not solely dominated by one particular regime. A suboptimal score (14) was received for the channel alteration, in part due to the minimal amount of channelization throughout the reach. Several bridges and culverts represented what little channelization was found, indicating that most of the channel was affected by natural processes. The riffle frequency received a marginal rating (8). Some riffles were present, which could act as habitat for aquatic biota; however, there were not significant numbers of riffles in the reach. The channel's flow status received an optimal score similar to that of the embeddedness; water was able to reach the base of both lower banks with a minimal amount of substrate being exposed. The bank's vegetative protection received a marginal score, (9) due to the fact that grasses make up the majority of the vegetation, and there is little plant diversity. The grazing/other disruptive pressures also received a marginal score (10) because again, although some vegetation is present, it is mostly grasses. There is also obvious erosion occurring along the banks, which causes some grasses to fall into the channel, thus exposing soils on top of the bank. Finally, the riparian vegetation width received a poor rating (3) due to human activities on either side of the bank; parking lots on one side, and a roadway on the other.

Site 2:

The second sample site, MR-2,located between Gerhard Fieldhouse and US-15, performed worse than the first site that was assessed, but was still able to obtain an overall "marginal" rating (95). Notably, the habitat scores suggest progressive physical degradation as one moves further downstream from the Art Barn onto campus.

The in-stream cover at this site received a marginal score (8). There were a few areas that could provide cover for aquatic biota, yet they were less than desirable, just as in the first sample site. The epifaunal substrate was given a suboptimal rating (12), primarily due to the abundance of cobble and gravel. However, it is obvious that this is the result of channel modification as noted below. The embeddedness of this site received a poor score (3) in part due to the gravel and cobble that were completely surrounded by fine sediments. The sediment deposition, by comparison, received a marginal rating (7) due to the obvious channel modifications and rip-rap. Furthermore, there were no point bars present in the stream, and so far only moderate sedimentation has occurred. The condition of the banks received a suboptimal score (14) which is somewhat misleading, since the banks had been rip-rapped with boulders. However, the banks seem to be fairly stable due to lack of erosion in this reach. The velocity/depth regimes received a marginal rating (7), similar to the first site near the Art Barn because there were no fast-deep or slow-deep regimes present in this reach. The channel alteration category received a poor rating of 3, again due to the significant amount of heavy riprap present on the banks. The riffle frequency received a suboptimal rating (12). There were more riffles present in this site compared to Site 1. However, the riffles were still infrequent overall. The flow status of the channel also received a suboptimal score (4), because the majority of the channel was filled with water and a minor amount of substrate was exposed. The bank vegetative protection received a poor score (5), due to the scarcity of vegetation on the stream bank and heavy rip-rap along the bank. The grazing/other disruptive pressures received a marginal score (6), again due to the lack of vegetation in this reach. The riparian vegetation width got a poor rating (4) since there were obvious human activities occurring in the reach. There were culverts and bridges present, a roadway, several sidewalks, and a few drainage pipes.

Site 3:

The third sample site, MR-3, was located just downstream of the entrance to Kenneth G. Langone Athletics and Recreation Center and upstream of 7th Street. This site performed relatively worse than the previous two sites, thus validating the trend mentioned earlier of worse ratings as you go downstream, but it was still able to obtain an overall rating of "marginal" with a total score of 80.

The in-stream cover at this site received a marginal score (10). There were a few areas in this reach that could act as cover for aquatic biota, so it was less than desirable, and performed similarly to the first two sample sites. The epifaunal substrate also received a marginal rating (7). This was primarily due to the fact that there was some cobble and gravel, but very little. The embeddedness of this site received a poor score (3). This partly due to the fact that the gravel and cobble present was not as significant as the fine sediments that were found. The sediment deposition, by comparison, received a marginal rating (10). There are several reasons for this, including the obvious modification of the channel through grade control in culverts and channelization, going as far as constructing a cement wall on the left stream bank. This modification has resulted in increased sedimentation with significant deposition occurring in the pools, as sediments are rapidly transported through culverts and are deposited after grade declines. However, it is significant to note that even though there was a lot of sedimentation occurring, there were no point bars forming, likely due to intense channel straightening and confinement through this reach. The condition of the banks received a suboptimal score (11). This score may be somewhat inflated, because the lack of bank erosion is due to the fact that the banks are lined with a concrete wall on the left bank and rip-rap on the right bank. The velocity/depth regimes received a marginal rating (9) similar to the two previous sites. There were no fast-deep or slow-deep regimes present in this reach. The lowest rating (1) was given for channel alteration because of the obvious channel straightening, significant amount of rip-rap, and the concrete wall. Riffle frequency got a marginal rating (10). There were some riffles present which could provide habitat, but these were very isolated from one another by long pools and runs. Riffle-pool sequences appear to be disrupted along this reach by several structures that artificially control stream gradient. These structures, such as concrete-bottomed culverts, prevent Miller Run from reaching grade by interfering with natural erosion and deposition processes. The flow status of the channel received a suboptimal score (11). This too can be misleading, because there is no visible evidence of erosion, but the channel is radically modified by a concrete wall. The bank vegetative protection also received the lowest score possible (1). There was no vegetation present along either bank. The grazing/other disruptive pressures received a poor score (3), which relates to the bank vegetation protection. There is no stream-bank vegetation, and it has been replaced with the concrete wall. What little vegetation exists in the bank below the cement wall or on the riprapped right bank is obviously mowed or clipped annually or more often. The riparian vegetation width also got a poor rating (1), since there are obvious human activities occurring in this reach. There are a few culverts present, a roadway, a few sidewalks, multiple large drainage pipes, and a concrete wall.

Site 4:

The fourth sample site, MR-4, was located between Loomis Street and the Art Building. This site performed the worst overall, receiving a poor rating (59). There were multiple problems located within this reach, especially with erosion and the fact that this reach often does not experience any flow at all. All of the parameters received a rating of either poor or marginal.

The in-stream cover at this site received a marginal score (7). There were a few areas that could act as cover for aquatic biota, but generally, habitat was very limited. The majority of this reach was comprised solely of fine sediments. The epifaunal substrate also received a marginal rating (8). This slightly higher score is due to the presence of a minute amount of cobble and gravel, though it was still lacking overall and was largely comprised of entrained rip-rap from the banks. The embeddedness of this site received a poor score (3), due to the overabundance of fine sediments surrounding the gravel. The sediment deposition, by comparison, received a marginal rating (10). Significant sedimentation occurs here, especially fine grains. One of the most likely causes of this sedimentation is the irregular flow that is seen here, since this section of the stream can dry up at times. The condition of the banks received a marginal score (7). Significant amounts of erosion have been occurring on the banks of this site, consequently reducing their stability. The velocity/depth regimes received a marginal rating (8). Similar to the previous sites, several of the major flow regimes was absent. The channel alteration parameter received a poor score (3), mostly because of the presence of culverts such as the one that goes beneath the art building itself. Riffle frequency received a poor rating (3) as well. There were few, if any, riffles present. Most of the channel had flat water, which also relates to the irregular flow that this reach of Miller Run experiences. The flow status of the channel received a marginal score (7), since the water was able to fill the channel. This score may be misleading, because of the aforementioned flow irregularities. The bank vegetative protection received the lowest score possible (1), since there was very little vegetation along the banks of the stream due to the amount of erosion that was occurring. The grazing/other disruptive pressures received a poor score (3), primarily due to the amount of erosion and obvious vegetation maintenance (e.g., mowing) along this section of Miller Run. Finally, the riparian vegetation width also got a poor rating (1) because there are obvious human impacts, such as art building's location directly over Miller Run, as well as a few culverts, bridges, and sidewalks being present.

Conclusion

Miller Run has been greatly impacted by urbanization in general and by Bucknell University specifically. When the habitat was characterized using an adopted protocol from the Pennsylvania Department of Environmental Protection, most reaches of Miller Run received ratings of marginal or worse. Furthermore, most of the parameters that were used in the assessment received ratings that were somewhat misleading, such as the reach near the Athletics and Recreation Facility. It is obvious that little to no erosion will occur on a large concrete wall in a stream the size of Miller Run. However, this is not conducive to healthy habitat for aquatic biota. The habitat assessment further illustrated the impact that Bucknell

University has on Miller Run. This can be seen in the way that the stream received worse ratings as we moved downstream through campus. Therefore, it is important that the stream be restored, so aquatic biota can flourish in the Miller Run watershed. The ecological impact that the current state of Miller Run has on aquatic biota can be seen in both the algae and aquatic macroinvertebrate analyses.

Part 3: Algae

Introduction

We determined algal biomass by measuring amounts of chlorophyll a on rocks from several sites in Miller Run in order to gain information about availability of algae as a food resource and relative nutrient and light conditions promoting algal growth, which may be related to water chemistry and conditions of riparian vegetation.

Methods

Three rocks were collected from each of the four sites in Miller Run (Figure 2-60) and preserved in plastic bags filled with water. Rocks were completely submerged in 90% basic acetone to extract chlorophyll from algae on the rock surfaces. Rocks were then dried and wrapped in foil to determine surface area. Foil was weighed and converted to rock surface area using a weight-area conversion for the foil used. Chlorophyll *a* concentration was quantified from the acetone extraction by measuring absorbance of each extract at 664 nm (adjusting for absorption by turbidity at 750 nm), acidifying the extract to remove chlorophyll *a*, and measuring absorbance at 665 nm to adjust for absorption by other pigments (adjusting for absorption by turbidity at 750 nm). Absorbance values and surface areas were used to calculate chlorophyll *a* concentration using the following formula:

$$\text{Chlorophyll } a \ (\mu g/cm^2) = \frac{26.7\ (664_b - 665_a) \times V_{ext}}{SA \times L}$$

*Chlorophyll formula provided by Dr. McTammany

Results/Discussion

Chlorophyll *a* concentration varied from approximately 2 $\mu g/cm^2$ in the upstream site near the Art Barn (Site 1) to approximately 12 $\mu g/cm^2$ in the downstream site near Loomis Street (Site 4). Chlorophyll abundance was highly variable at each site, which led to non-significant differences (Figure 2-61). At all sites, algae are present and potentially available as a food resource. However, the data show a general trend of increasing algal biomass downstream, which may indicate increasing nutrient or light availability along Miller Run. Alternatively, lower algal biomass in upstream reaches of Miller Run might be caused by grazing by benthic macroinvertebrate “scrapers” (e.g., some chironomids) or herbivorous fishes (e.g., stonerollers).

Although not assessed directly, algal species composition likely shifts dramatically from upstream to downstream. For example, we observed tuft-like blooms of algae growing in Miller Run, from the Fieldhouse to the Art Building (below which intermittent flows prevent accumulation of algae). These tuft-like growths of algae are the genus *Cladophora*, which can indicate “eutrophic” conditions caused by high nutrient concentrations and light availability. *Cladophora* is considered a nuisance algal taxon and suggests nutrient enrichment in Miller Run. A healthier algal assemblage of diatoms and non-blooming green algae would support more natural benthic macroinvertebrate and fish communities in downstream reaches of Miller Run.

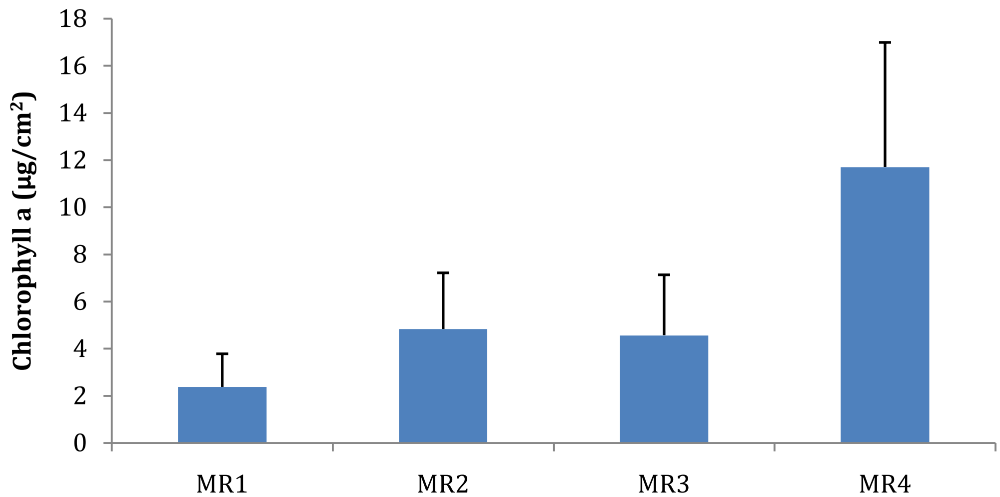


Figure 2-61 Average chlorophyll a for each site in Miller Run. Bars are means + 1 standard error from 3 rocks collected on 19 March 2009. [MR-1 (Art Barn), MR-2 (Gerhard Fieldhouse - U.S. 15), MR-3 (Kenneth G. Langone Athletics and Rec Center), MR-4 (Loomis Street – Art Building)]

Part 4: Aquatic Macroinvertebrate and Fish Analysis

Introduction

The purpose of biotic evaluation is to determine the extent to which a stream has been impaired, using information known about the species living within the waters. Aquatic macroinvertebrates are highly variable in their sensitivity to water pollution. Differences in types of benthic macroinvertebrates between sites can be used by biologists to evaluate the overall health of a stream because we know many important ecological relationships of specific types of organisms. For example, ecologists can assign pollution sensitivity values to particular macroinvertebrate taxa and use these scores and relative abundance of different taxa to determine the health of each section of stream.

In addition to algae and benthic macroinvertebrates, fish abundance and species composition can indicate stream health and ability to support organisms of a high trophic level.

Regulatory agencies in Pennsylvania categorize streams by the types of fishes they expect to find in a given location (e.g., cold-water fishery, warm-water fishery). Obviously, the link between fish species composition to habitat and water quality provides an important assessment of stream ecosystem health. We expected that if any fish were found, most species found in Miller Run would be warm-water species, due to its proximity to the Susquehanna River and classification as a "warm-water fishery" by Pennsylvania Department of Environmental Protection.

<u>Methods</u>

Benthic macroinvertebrate samples were taken at four sites along Miller Run, (See above site map) by using the methods described by the Pennsylvania Department of Environmental Protection's (PA-DEP) "*A Benthic Index of Biotic Integrity for Wadeable Freestone Streams in Pennsylvania*" (Chalfant 2007). Macroinvertebrate assemblage data from these samples was used to calculate an index of biotic integrity (IBI) for each site using the PA-DEP protocol. Six D-frame kick net samples were taken from each of the four sample sites, and preserved in ethanol. In the laboratory, material from all 6 samples from a given site was combined in a gridded plate and spread evenly across the grids. Four grids were randomly selected, and macroinvertebrates contained within those grids were counted and identified. Additional grids were selected if at least 200±40 macroinvertebrates were not found. This process was repeated for the remaining three sites, and their respective macroinvertebrate counts were recorded for evaluation. Each of the macroinvertebrate samples was evaluated for the Beck's Index, EPT Taxa Richness, Total Taxa Richness, Shannon Diversity Index, Hilsenhoff Biotic Index, and Percent Intolerant Individuals. Scores of these 6 metrics were relativized based on PA-DEP's assessment of scores from "reference" streams across the Commonwealth. The average of the 6 relativized metric scores was calculated and multiplied by 100 to obtain the IBI Score for each site. A description of calculating the metrics and IBI values for each site is presented in Appendix B.

Electro-fishing was used to sample and identify fish species within Miller Run. Electro-fishing involves the use of DC electricity, applied directly to the water, to induce galvanotaxis in fish species. Galvanotaxis is the uncontrolled muscular movement that results when a fish is temporarily stunned by the electrical current. This causes fish to rise to the surface of the water, where they can be easily collected via hand-netting. Organisms were placed into buckets with stream water to recover and identified before returning them to the stream segment from which they were collected. We electro-fished 2 reaches of Miller Run: upstream between the Art Barn entrance and Route 15 and downstream between 7th Street and the Art Building.

Results/Discussion

Benthic macroinvertebrate counts are shown in Table 2-3. The IBI scores found at all four sampling sites were extremely low (Figure 2-62). The threshold IBI score to designate impairment in a stream with "warm-water fishery" designation (like Miller Run) is 63.0 on a scale of 100 (scores below 63 indicate impaired water quality). The IBI scores found in Miller Run ranged from 28.52 in the upstream reach near the Art Barn to 14.47 in the downstream reach below Loomis Street. These scores indicate poor water quality and habitat conditions and can be used to petition DEP to consider adding Miller Run to its "303d Impaired Stream List", which could open the possibility of state or federal funding for restoration work through the Federal Clean Water Act or State's Clean Streams Law.

Biodiversity of macroinvertebrates within Miller Run is also very low, with Shannon Diversity Index values ranging from 1.726 to 0.607 (Figure 2-63). Increasing biodiversity is one of the primary goals of any restoration project, and Miller Run presents a prime opportunity for dramatic improvement. Improving stream flow and water quality will increase the biotic potential of the stream, as well as invite more desirable (e.g., pollution-sensitive) macroinvertebrates into the ecosystem. However, individuals from "pollution-tolerant" taxa only comprised 25 % of the benthic macroinvertebrates in Site 1 and less than 5 % of benthic macroinvertebrates in Site 4 (Figure 2-64). Bucknell's impact on Miller Run is clearly visible in the severe reduction in macroinvertebrate biodiversity (especially pollution-sensitive species).

Water quality downstream from Bucknell's campus is severely impaired to induce such a radical decrease in pollution-sensitive life forms.

Table 2-3a. MR-1 (Art Barn) Macroinvertebrate Counts

Order	Family	Genus/Species	Count
Amphipoda	Crangonyctidae	Crangonyx	68
Coleoptera	Elmidae	Stenelmis	1
Coleoptera	Haliplidae	Peltodytes	1
Diptera	Chironomidae	Chironomidae	85
Diptera	Simuliidae	Simulium	47
Diptera	Simuliidae	Prosiumulium	5
Diptera	Tabanidae	Chrysops	1
Isopoda	Asellidae	Caecidotea	24
Mollusca:Bivalvia	Sphaeriidae	Pisidium	1
Mollusca:Gastropoda	Physidae		1
Oligochaeta			3
Turbellaria	Planariidae	Planaria	58
Total			**237**

Table 2-3b. MR-2 (Gerhard Fieldhouse - U.S. 15) Macroinvertebrate Counts

Order	Family	Genus/Species	Count
Amphipoda	Crangonyctidae	Crangonyx	14
Diptera	Chironomidae		104
Diptera	Simuliidae	Simulium	22
Diptera	Simuliidae	Prosimulium	3
Isopoda	Asellidae	Caecidotea	1
Oligochaeta			1
Total			**145**

Table 2-3c. MR-3 (Kenneth G. Langone Athletics and Rec Center) Macroinvertebrate Counts

Order	Family	Genus/Species	Count
Amphipoda	Crangonyctidae	Crangonyx	17
Decapoda	Cambaridas	Cambarus	1
Diptera	Chironomidae		143
Diptera	Simuliidae	Simulium	10
Diptera	Simuliidae	Prosimulium	1
Diptera	Tabanidae	Chrysops	1
Isopoda	Asellidae	Caecidotea	1
Turbellaria	Planariidae	Planaria	2
Total			**147**

Table 2-3d. MR-4 (Loomis Street – Art Building) Counts

Order	Family	Genus/Species	Count
Amphipoda	Crangonyctidae	Crangonyx	5
Coleoptera	Elmidae	Stenelmis	1
Diptera	Chironomidae		157
Molluska:Bivalvia	Sphaeriidae	Pisidium	1
Turbellaria	Planariidae	Planaria	7
Total			**164**

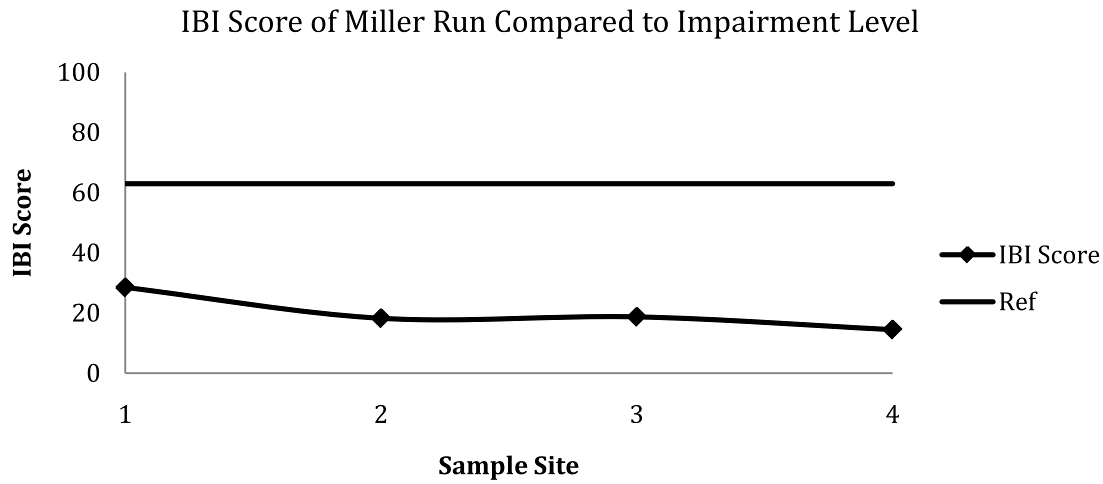


Figure 2-62 Comparison of Miller Run to impairment values by IBI

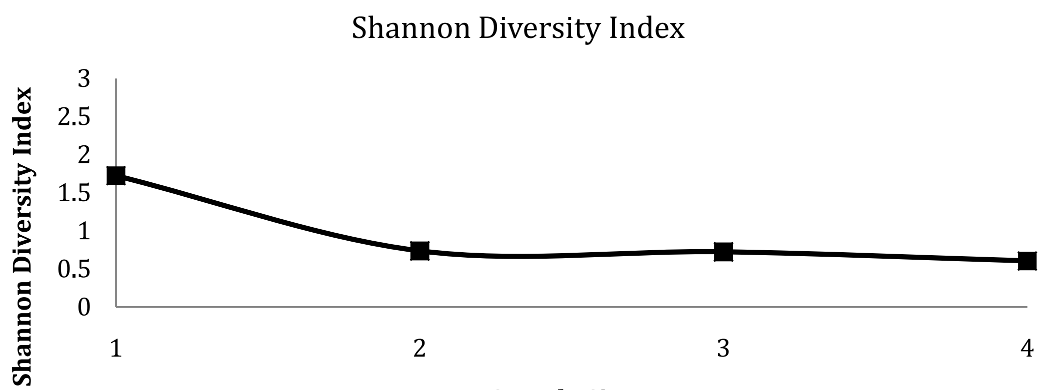


Figure 2-63 Variation in species diversity as a function of sample location

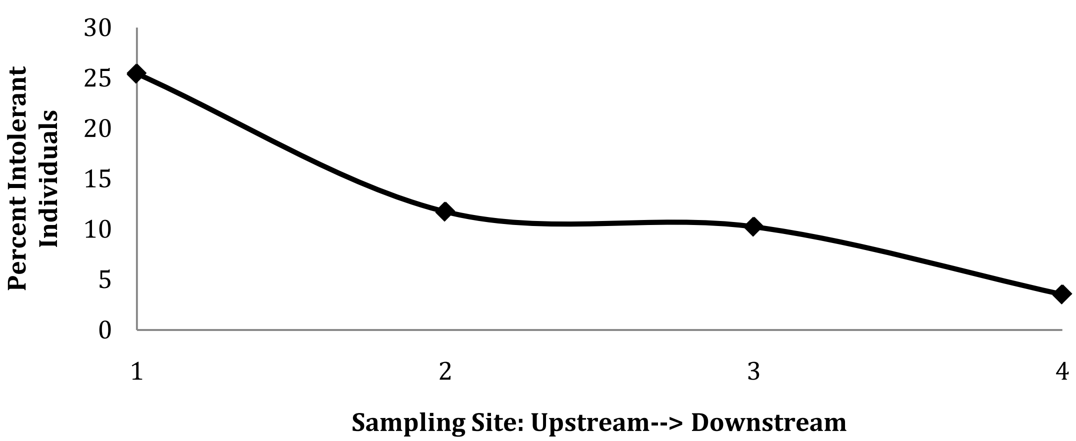


Figure 2-64 Percent of pollution-sensitive macroinvertebrates at each sample site.

Electro-fishing revealed the presence of 23 fish at Site 1 (Art Barn) and Site 4 (Loomis Street), with six species represented; *Lepomis macrochirus* (bluegill sunfish), *Campostoma anomalum* (central stoneroller), *Semotilus atromaculatus* (creek chub), *Exoglossum maxillingua* (cutlips minnow), *Luxilus cornutus* (common shiner), and *Lepomis gibbosus* (pumpkinseed sunfish). These species are consistent with Miller Run's designated use as a "Warm-Water Fishery." The fish collected were distributed very unevenly between sites we surveyed. At the downstream site (MR-4), we only collected 3 fish, all creek chubs, while at the upstream site, we found all of the taxa listed above and 20 individual fish (Table 2-4). These findings run counter to expected patterns, because the downstream site is much closer to Bull Run and the Susquehanna River, which have high potential as sources for colonizing fishes to Miller Run. The dramatic decrease in fish numbers and diversity indicate a substantial difference in the quality of habitat available at downstream versus upstream locations. Essential to the improvement of Miller Run's sustainability as fish habitat are the establishment of flow permanence, improved flow volume, and stabilization of thermal gradients. Native indicator species whose presence would confirm a successful restoration process include darters (Family *Percidae*), sculpin (Family *Cottidae*), and members of the Family *Salmonidae*.

Table 2-4a. Fishes found at upstream site (Art Barn)

Family	Genus	Species	Adults	Juveniles	**Total**
Centrarchidae	*Lepomis*	*macrochirus*	1	3	**4**
		gibbosus	1	0	**1**
Cyprinidae	*Campostoma*	*anomalum*	1	0	**1**
	Semotilus	*atromaculatus*	11	0	**11**
	Exoglossum	*maxillingua*	2	0	**2**
	Luxilis	*cornutus*	1	0	**1**
Total			**17**	**3**	**20**

Figure 2-4b. Fishes found at downstream site (Loomis Street – Art Building)

Family	Genus	Species	Adults	Juveniles	**Total**
Cyprinidae	*Semotilus*	*atromaculatus*	3	0	**3**
Total			**3**	**0**	**3**

Campus Aesthetics

Introduction

The aesthetics component of this restoration process is a vital part for the physical appeal of Miller Run. The introduction of this section gives a great outline of what we are doing to transform this stream into something we can be proud to look at. Along with the channel design solutions in the restoration plan, the aesthetic character of the stream is highly important to both the community and students on campus. Therefore, we have developed a plan that will improve the existing aesthetics problems from which Miller Run already suffers.

The plan will look to add aesthetic value to the campus while promoting the growth of vegetation natural to the Susquehanna valley. With the help of the channel design group we have come up with ideas that will bring both educational value and visual interest for students, faculty, visitors, and the general public.

Funding a project such as this will do nothing but benefit the University. Both the University and Miller Run will receive a great deal of national publicity that may in fact serve as an example for other universities looking for a successful restoration plan. Also, the restoration of Miller Run will integrate well with Bucknell's Master Plan. Further, it is obvious that Miller Run will become an educational resource for classes on campus.

Methods

In order to take the correct approach in improving the appearance of Miller Run, we first searched for any historical photos of Miller Run and its condition during the growth of Bucknell (See Figs. 2-65 to 2-68). These figures show sections of Miller Run along Moore Avenue and near Bucknell Hall. We spoke with town historians at the Union County Historical Society and the special collections office in the Bertrand Library.

Figure 2-65 Campus Aerial 1930s
At the bottom left of the photo you can see the aerial view of Miller Run in the 1930's near the current junction of Moore Avenue and Highway 15.

Figure 2-66 Bucknell Hall 1930s
This is a picture of Miller Run in the downstream area next to Bucknell Hall. This photograph shows that the channel and floodplain have already been terraced and channelized to elevate the building above the floodplain.

Figure 2-67 Davis Gymnasium 1940s
This print is of Miller Run in front of the old Davis Gymnasium. This is a part of Miller Run where the data for Reach #2 was collected. In the 1940's it is evident that there was yet to be the placement of rip rap in Miller Run. It is evident that Miller Run has already been straightened and channelized.

Figure 2-68 Bucknell Commencement 1950s
This graduation photo from the 50's shows the existence of numerous culverts and channelization.

Miller Run has a long history of modification and channelization by Bucknell to enhance its ability to convey stormwater rapidly from the campus. However, these changes have come with major ecological degradation of the stream and a major eyesore which conflicts with the park-like aesthetic of campus.

Other resources useful in the evaluation of the state of Miller Run include restoration projects designed by other universities. The photos below are from a stream restoration project at Villanova University.

Figure 2-69 Pennypack Watershed (Villanova University)
The stream in this photograph looks rather healthy. The continual growth of shrubs along the banks is a good sign of biotic diversity. This is an ideal look of what we want Miller Run to eventually adopt.

Figure 2-70 Pennypack Ecological Restoration Trust
Another snap shot of the biological success that Villanova is having with their stream. The native Wingstem flower shown in the photo is encouraging to see. This stream seems to have a natural appearance to it rather than man made.

Figure 2-71 Villanova Stormwater Wetlands

This is the wetland constructed at Villanova University which is used as a stormwater filtration system and floodplain. Again there is a wide variety of shrubs and vegetation that is both pleasing to the eye and helpful to habitat. A wetland such as this can serve as an educational tool for biology classes and or even art classes. The amount of biological diversity you find is a positive factor, and this will be a useful example for other universities.

Miller Run is suffering from numerous factors that include problems with vegetation and the placement of rip rap. Flow is not year round and Miller Run is plagued with imposing structures that are sore to the eye. The Villanova example illustrates the kind of improvements that could be made to channel structure, riparian vegetation, and stormwater management in Miller Run.

Chapter 3: Conceptual Plan for Miller Run: Watershed Restoration

Introduction

Our research illustrates that Miller Run is in a thoroughly degraded state. Here we will proposea conceptual planthat will alleviate the issues identified in our report. Our watershed restoration plan is designed to accomplish five main goals: flood control, aesthetic appeal, environmental education, ecological health and sustainability, and channel sustainability.

The group has come up with several major conceptual approaches to the watershed restoration, including off-channel and in-channel solutions. A key element in the overall design for restoring Miller Run is reconnecting its channel with its floodplain. Based on observations of other basin streams in nearby agricultural areas, we have concluded that Miller Run would likely have an anastamosing channel, consisting of multiple channels with stable and vegetated bars. The channel complex would be embedded in a broad wetland-like area forming the floodplain of Miller Run. This anastomosing channel form is consistent with observations made by Walter and Merritts (2008) for low-gradient agricultural streams, prior to post-colonial sedimentation.

A major impediment in restoring the ecology of Miller Run is its lack of year-round flow permanence. A series of low-flow augmentation strategies will help provide year-round flow. One solution is working with the local water treatment facility to re-route excess effluent and create constant flow. An additional solution is building wetlands in key locations along the stream to capture flood flows and slowly discharge them into the channel. In addition, off-channel approaches scattered throughout the campus would allow rainwater and runoff to recharge groundwater to reestablish campus water table conditions and reduce stormflow.

The appearance of Miller Run does not fit in with the campus' aesthetic appeal. By making Miller Run more natural, reducing storm runoff, and instituting year-round flow, the biotic potential will increase greatly. Miller Run will become a more appealing habitat for aquatic biota and wildlife.

Off-Channel Recommendations

Introduction

The following recommendations are for structures off the immediate channel of Miller Run. While they are not a part of the channel itself, they are vital to improving the overall health of Miller Run.

Permeable pavement

There are many types of permeable pavements ranging from porous asphalts and concretes, to block pavers. Each is very effective in its groundwater recharging capabilities. Factors one should think about while choosing the correct porous pavement for an area are the aesthetic appeal for the designated area, the slope of the land, and the underlying geology (Fig. 1-2). Intricate designs can be made by block pavers to enhance visual beauty if that is the goal. Porous asphalt and concrete are better suited for large surface areas where aesthetic beauty is not a top priority. It has been said that porous pavements are three to four times more expensive than regular pavement (Dennis Hawley, personal communication). The University of Rhode Island (from 2002-2003) installed two porous asphalt parking lots and stated that the cost of conventional parking lots would have been approximately equal (McNally 2003). The porous asphalt and the recharge bed of crushed rock are more expensive than just laying out regular asphalt. However, impervious asphalt requires expensive storm water pipes and retention areas whereas areas drained by porous pavement do not.

As you can see from Figure 3-1 there are opportunities for Bucknell to reduce its storm water impact by possibly replacing asphalt walkways and parking lots with permeable pavements. It has already been shown by our hydrologic and water quality data, storm runoff from campus has caused flow in Miller Run to peak rapidly and to contain many harmful chemicals. Take note of the typical hydrograph (Fig. 2-6) in the steam hydrology section where the downstream peaks after the upstream. In Miller Run, however, discharge peaks downstream at or before the upstream peak (Fig. 2-7) because the stormwater management systems are so efficient. The hydrologic modifications caused by the runoff also harm in-stream habitat by transporting large amounts of sediment, eroding channel banks, and creating unstable substrate. Beyond the ecological benefits provided by reduced storm water runoff, Bucknell should consider how responsible environmental stewardship and improved “green” image will offset slight differences in the direct costs of implementing permeable pavement as a best-management practice for storm water management.

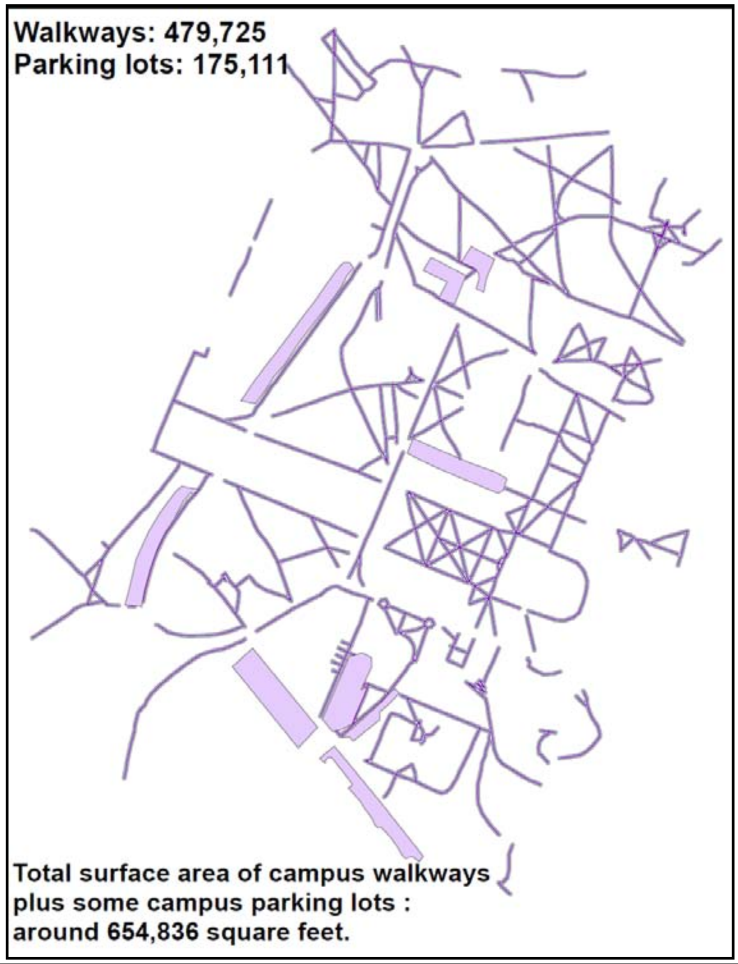


Figure 3-1 Map showing parking lots and walkways on Bucknell's campus.

Rain Gardens/Bio-retention

Rain gardens are ideal for collecting, storing, and even infiltrating surface water runoff from parking lots and other impermeable surfaces. Runoff can be directed into rain gardens using cut curbs or natural grading to collect sheet flow over grassed areas. The gardens collect runoff and filter it through soil and plant material. They can also discharge runoff during large storm events when subsurface/surface storage capacity is exceeded through raised storm drains hidden in the middle of the garden as shown in Figure 3-2. The term "positive overflow" describes the system of drainage that becomes active as the rain garden is overwhelmed with high water. This prevents them from becoming submerged in storm water. Rain gardens could be used at several locations on campus in place of or in conjunction with existing landscaping, as they are aesthetically pleasing around parking lots (Figure 3-3). Some of the possible sites are shown in Figure 3-4 in green; these are current storm drain locations on campus. They could also be placed over existing storm drains in an attempt to increase infiltration. Rain gardens can be created as ornamental flowerbeds or planted with native vegetation to mimic other natural ecosystems, or even wetlands.

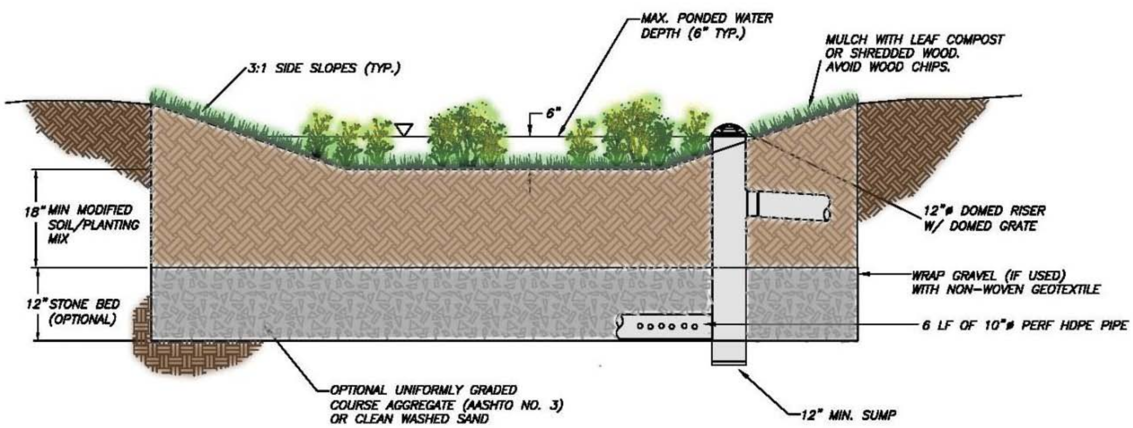


Figure 3-2 Cross-section through a rain garden, showing depression to collect storm water and the overflow pipe connected to underground sump and perforated pipe connected to storm water drainage system. On this diagram, water would enter the overflow pipe once it reaches 6 inches deep.

Figure 3-3 Rain gardens could be an aesthetically appealing component of Bucknell's overall landscaping.

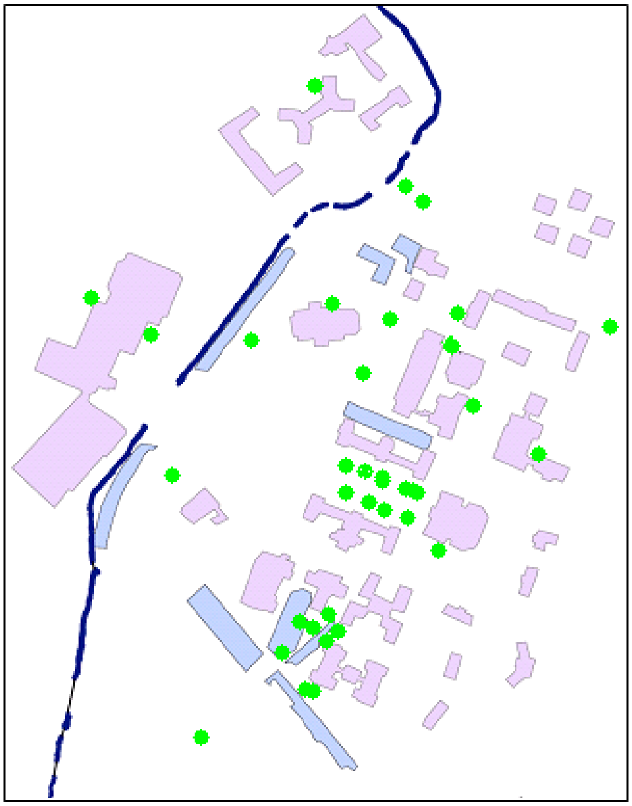


Figure 3-4 Locations where rain gardens could be aligned with Bucknell's storm drainage system.

Infiltration Trenches

Infiltration drains are ideal for improving infiltration of roof runoff and other runoff reaching the centralized campus storm drains. Instead of just piping rainwater from roofs directly into Miller Run in areas where rain gardens are not applicable, infiltration trenches could be used. Infiltration trenches are perforated pipes laid in uniformly graded course aggregate. When these pipes are stepped (Figure 3-5), in low flows they maximize infiltration but still allow for efficient discharge in high flows when it would act like a conventional storm drain pipe. This structure seems to fit well with the KLARC athletic complex's situation. The KLARC center has a large roof area all piped into Miller Run. If those pipes were converted to infiltration trenches, it would reduce the amount of water being directly discharged into the stream. Figure 3-6 shows the main storm drain pipes, which transport the majority of runoff into Miller Run. These pipes should be targeted first to achieve the most efficient increase of infiltration.

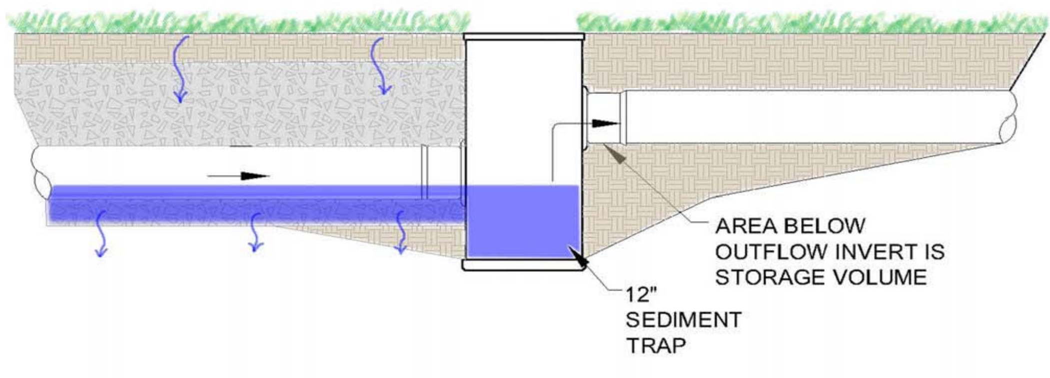


Figure 3-5 Cross-section diagram of an infiltration trench. Water would flow along the deep pipe, which is perforated to allow infiltration, and be stored in the trap to allow sediment deposition and further infiltration. Water would only reach the shallow pipe when enough runoff entered the system to elevate the level in the trap.

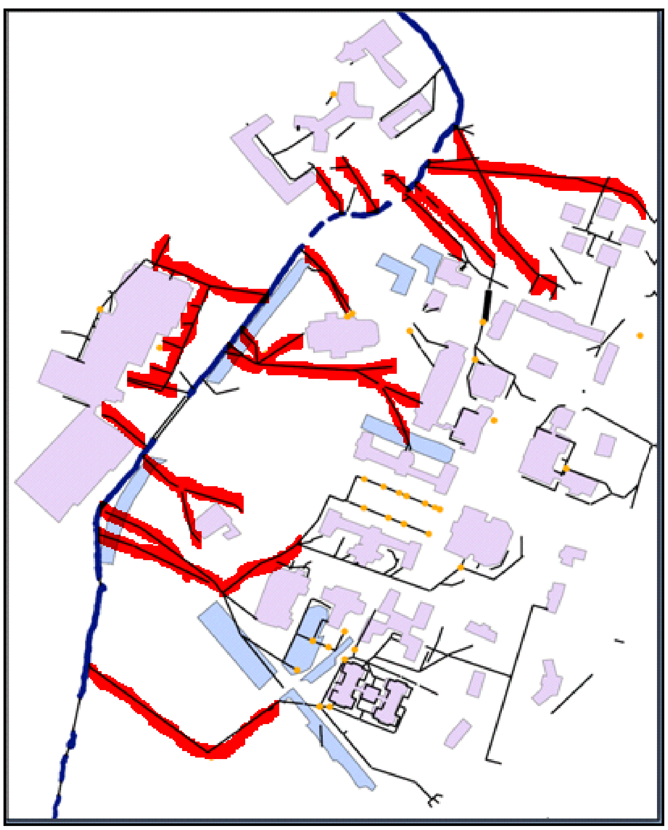


Figure 3-6 Cross-section diagram of an infiltration trench. Water would flow along the deep pipe, which is perforated to allow infiltration, and be stored in the trap to allow sediment deposition and further infiltration. Water would only reach the shallow pipe when enough runoff entered the system to elevate the level in the trap.

In-Channel Recommendations

Introduction

In this section, we will describe structural modifications along the channel reaches defined for Miller Run. These recommendations, in conjunction with our off-channel recommendations, will help restore the overall health of Miller Run.

Channel Design by Reach

Reach 1 (Cross Sections A-M)—Railroad Culvert to 7th Street

Reach 1 is the area that runs from the railroad bridge crossing up to where Miller Run meets 7th Street (Figure 3-7). The most prominent problem in this area is that the stream must make ~ 90^{0} turn the stream to enter the culvert. The culvert is small (< 2 year flood) and cannot allow for much water to pass through it during high flow events (Figure 3-8). The best possible solution would be to remove the railroad bridge all together. However, this is highly unlikely so the widening of the already existing culvert or the addition of another culvert could solve the problem. The culverts should have the capability to convey a 100-year flood, similar to the culvert at the stream's intersection with Route 15 (Figure 3-8). A widened or added culvert of this capacity could prevent flooding of Hunt parking lot, as water could move swiftly out of the area. The removal of the Hunt/Harris Hall parking lots, in general, would also help this problem and aid in floodplain-stream reconnection. This would allow the stream to have a more natural floodplain, connecting it to the upland Grove with a blended transition, and permit water storage during flooding.

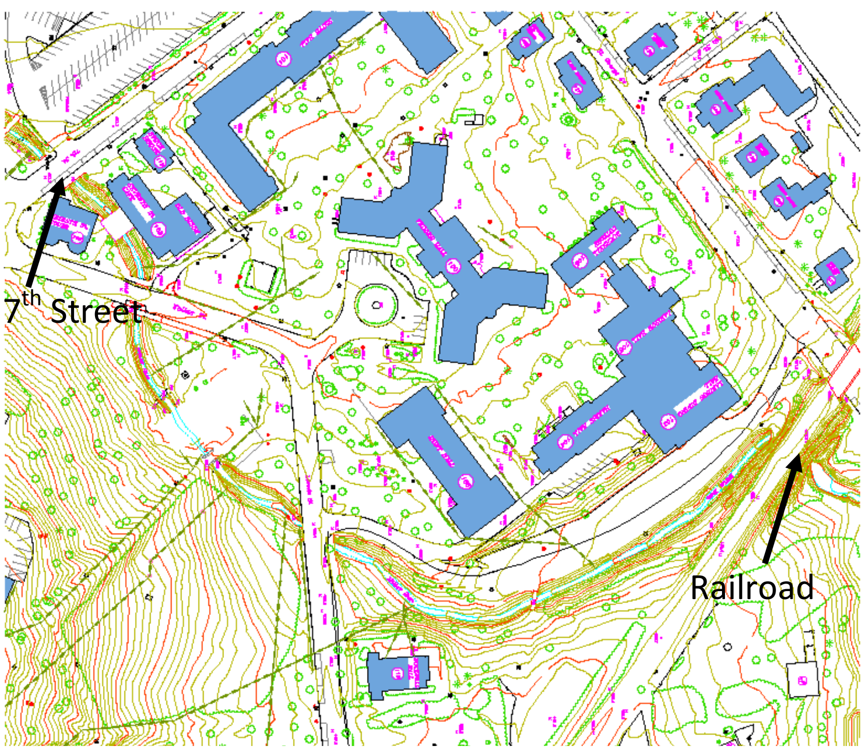


Figure 3-7 Reach 1 with Art Building removed (blank rectangle).

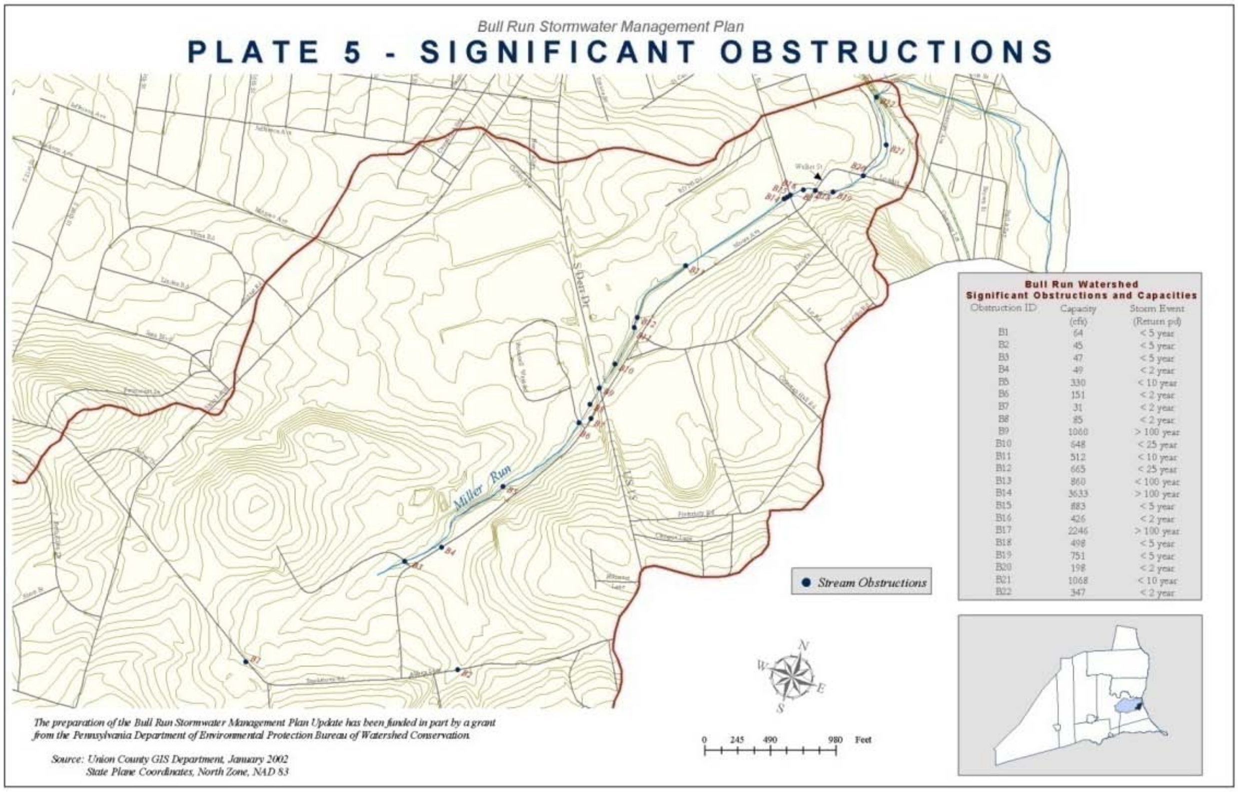


Figure 3-8 Bull Run stormwater management plan, showing obstructions along Miller Run and the conveyances for each (Union County Planning Commission, GIS Department 2002).

For more aesthetic appeal as well as encouragement of riparian growth most of the rip-rap in this reach also needs to be removed, except on the banks nearest to the intersection of Loomis Street and Miller Run culvert (~10 feet on both banks and both sides of the culvert). Other obstructions that should be removed include the Art Building (already destined to disappear according to the Campus Master Plan). This section between the Art Building and Loomis Street includes a gravel plot, rip-rap, and footbridge as well. If possible, relocating the footbridge to where the pipes cross the stream would prove to be more aesthetically pleasing. The longitudinal profile of the reach shows a very low grade, especially at this point, and flow oftentimes stops right underneath the Art Building. The area currently occupied by the Art Building would make for a great scenic, park-like area. Vegetation and park benches would be a great addition. The culvert at the intersection of Walker Street and Miller Run is necessary, but may have to be rebuilt to contain more than just the current <5 year storm event (Figure 3-8). Unfortunately for the stream, 7th Street Café and the 7th Street House are not going to move. Therefore, the stream must be channelized here to prevent undercutting of the structures. We suggest leaving the current rip-rap in place but adding more riparian vegetation between the boulders for a more aesthetic approach. Alternatively rip rap could be replaced with more aesthetic log cribbing.

Reach 2 (Cross Sections N-Z) – 7th Street to Route 15

Reach 2 starts at 7th Street Cafe and continues until Miller Run crosses Route 15 (Figure 3-9 & 3-10). The intersection of 7th street and Miller Run has a <2-year culvert (Figure 3-8), which may prove to be a problem during high flows. Maintaining the rip-rap at the culvert entrance as well as widening it may be the best possible method of increasing flow capacity. The next major area is the highly channelized, straight "chute" provided by the left bank concrete wall and right bank large sized rip-rap. Concrete in or near the stream impedes any formation of a floodplain, riparian vegetation or livable habitat for stream biota. The field currently held back by the concrete wall is also a possible area for a wetland. The grade of Reach 2 is very lowest gradient of all reaches, making it a natural area for deposition of both sediment and water (Figure 2-25). A wetland offers many advantages, especially as a store of excess water during storm events (and subsequent low-flow augmentation), an area for vegetation, biota and habitat diversity and as a filter, cleaning the water as it travels through. The proposed wetland area takes into account structures planned in the Campus Master Plan, and is set to cover most of the Sojka Pavilion field. The proposed wetland area (width of 40m length of 200m), according to our low estimates, could hold up to 16,000 m^3 of water. This would allow us to augment flow at 430 m^3/day to maintain the baseflow of 0.005 m^3/s for 35 days. The area would be lower in elevation than surroundings and the stream could flow in embedded anastamosing channels within the newly-constructed wetland. Riparian restoration should occur along the east bank, an area currently acting as parking along Moore Avenue. The area in total would create a visually appealing, recreational (i.e. trails) and educational area ("outdoor classroom") in a true natural setting.

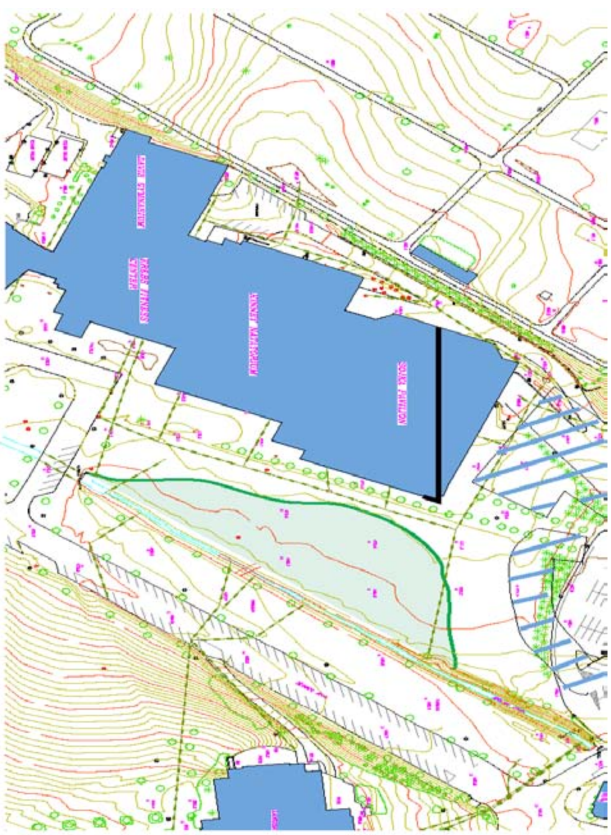


Figure 3-9 Reach 2a showing the proposed Bucknell Inn (cross-hatched) and proposed wetland (green area on Sojka Lawn) for stormwater retention and low-flow augmentation of Miller Run.

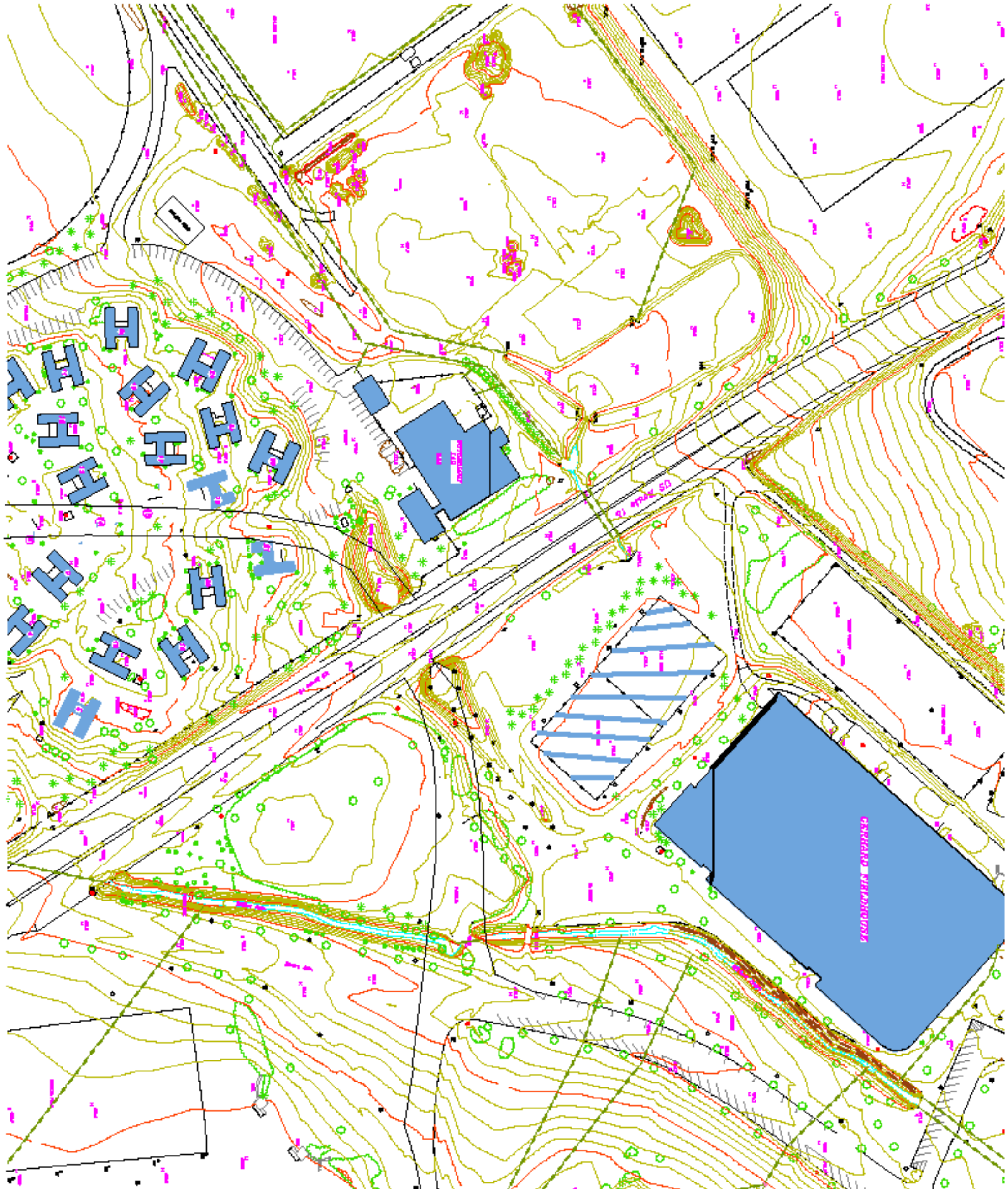


Figure 3-10 Reach 2b showing proposed realignment of the junction of Moore Avenue and Route 15 (black lines) and proposed log cribbing along the Gerhard Fieldhouse (brown).

At the entrance of the athletics complex (the KLARC U) we propose one of two possible culvert redesigns. The first idea uses a bottomless culvert or span bridge, decreasing contact between concrete or metal and the biota and allowing fish species to travel both downstream and upstream. The second proposed solution is to retrofit the current box culverts, often the best choice for high traffic volume areas. To make it more fish friendly, it would be best to install current deflectors and remove the plunge pool, allowing fish a better chance of migrating upstream.

The stream is again channelized between cross sections R-U (Figure 2-27), using large rip-rap to protect Gerhard Fieldhouse from Miller Run's undercutting migration. The most natural and aesthetically pleasing way to do slow the stream's migration towards Gerhard is to replace the rip-rap with log-cribbing. This would allow for bank stabilization by structure and future riparian vegetation. We also propose the removal of the Moore Avenue parking spaces and a nearby basketball court to provide space for the Miller Run channel to move and establish natural floodplain areas. This area could again serve as a park like educational area with picnic tables and park benches and trails. The redesign of the campus roads is an opportunity to build more stream-friendly culverts and bridges. The low grade of the stream (Fig. 2-25) makes bottomless or ellipse culverts the best choice to encourage fish spawning and movement, as well as make the area eye-pleasing.

Reach 3 (Cross Sections AA-LL) – Route 15 to the Art Barn

Reach 3 consists of the area between Route 15 and the bridge at the Bucknell Art Barn (Figure 3-11). The Campus Master Plan proposes moving Smoketown Road further north, as well as the demolition of the West Bucknell Mod structures along with its access roads. We propose building another major wetland here in the remaining open land south of the Mods. While the gradient is relatively high for Miller Run, it is still low enough to propose a wetland that will provide water storage and low-flow augmentation as well as a place for research and education. The proposed wetland should have an area 70 m wide and 220 m long with a depth of 2 m. This would allow up to 30,000 m^3 of water to be held here. This would augment flow to our target 0.005 m^3/s baseflow allowing this particular wetland to add 430 m^3 /day from one event for up to 17 days, greatly aiding in flood control. With the current discharge, mean sediment size and slope, an anastomosing stream could form within the wetland. Properly placed dirt bike/pedestrian pathways with benches could provide the population with a recreational, natural setting.

Figure 3-11 Reaches 3 and 4 from Route 15 (lower right) to Golf Course entrance road (upper left). Note the extensive green ellipse upstream of Route 15, proposed as a major wetland for stormwater retention and low-flow augmentation.

Reach 4 (Cross Sections MM-VV) – Art Barn to Sunflower Day Care

Reach 4 consists of the area of Miller Run that runs from the Art Barn Bridge to the Sunflower Daycare Center (Figure 3-11). This is currently the most recently untouched part of the stream. But it is one of the most disturbed areas because it contains the fill from a former coal handling operation, its clay cap, and old culverts – creating a major knickpoint in the longitudinal profile and a problem spot for fish migration (Figure 2-25, 3-12). The fill has induced a zone of enhanced sedimentation which is now colonized by dense invasive vegetation – albeit woody. Another problem spot in Reach 4 is the junction with Miller Run's south branch, storm-piped in from under the driving range. The angle at which south branch comes in encourages bank erosion on the left bank of Miller Run. Currently there is rip-rap trying to prevent the wear down of the bank, however a more aesthetically pleasing and habitat-supporting method of bank stabilization could be log-cribbing. The dimensions of the structures themselves would be small, no more than 10 feet in width across. If log-cribbing is not a viable option for the small area, highly vegetated rip-rap may be used instead.

Figure 3-12 Knickpoint at downstream edge of the fill covering coal handling deposits.

Reach 5 (WW-EEE) – Sunflower Daycare Access Road to Smoketown Road (Golf Course)

Reach 5 consists of the Sunflower Daycare Center through the golf course, up to Smoketown Road (Figure 3-13). The reach is has very little flow (due to its headwater nature) and is very narrow. The entire reach has been straightened to suit the needs of the surrounding golf course, with long stretches of the stream piped. The best case scenario should remove the pipes and daylight the stream. In talks with some golfers, the newly created water feature would not pose a threat to their enjoyment of the course and would allow the stream and its biota to move more naturally. Small cart-worthy bridges or bottomless culverts should be built to allow passage over the stream. The stream has a very low discharge flow at this point (Fig 2-3), and any migration of its channel will not extend far from its current position

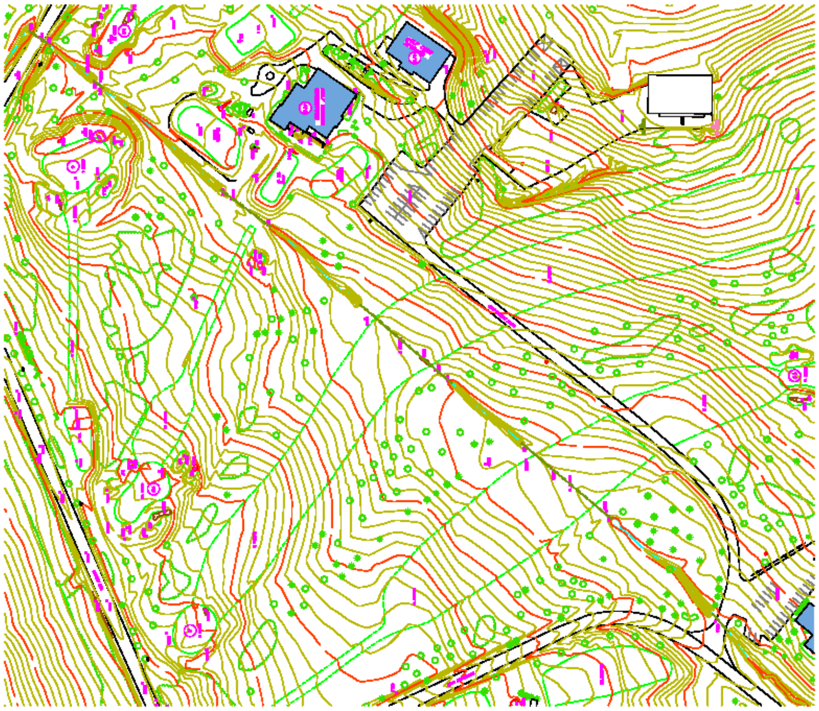


Figure 3-13 Map of Reach 5, from Golf Course entrance road (lower right) to Smoketown Road (upper left), showing the channelized stream through the golf course.

Summary

Stream channel issues discussed here illustrate the detrimental effects of urbanization and channelization on the health and sustainability of the stream. Removing specified culverts, parking lots, buildings and rip-rap throughout the first reach would decrease the possibility of flooding, as well as be more attractive. In the second reach, near the athletic centers, removing the concrete wall would improve campus aesthetics and allow the establishment of a water storage and slow augmentation wetland feature. The third reach should also be considered a possible wetland location, because of its low gradient and amount of free space. Both wetland areas could be spaces for recreation with well-placed bike/walk paths and benches, as well as "outdoor classrooms," places where classes could learn and research the native biota of Central Pennsylvania. In the last two upstream reaches, rip-rap should be removed and piped-stream sections exposed to encourage vegetation growth as a method of bank stabilization. Over time, Miller Run could be and should an example of Bucknell University's environmental stewardship practices, a place where the natural world and the educational world join together and serve as a beautiful and instructive place for all Bucknellians to enjoy.

Stormwater Pipe Diffusers

One problem associated with storm water flushing through drainage pipes is the high velocity and power with which this water enters Miller Run. Often, drainage pipes are elevated above the active channel to avoid backing up when stream stage increases. However, high velocity water creates severe channel instability at the outlets of storm drains (Figure 3-14). Some of the largest pools in Miller Run are scour pools at the mouths of storm drains (near the Gerhard Fieldhouse, for example). Diffusers could be installed at the ends of storm drain pipes to slow and filter runoff before it enters the stream. Some of the designs which look the most promising consisted of vegetated riprap fans (Figure 3-14). These types of diffusers eliminate scour, which causes erosion. Redesign of the channel of Miller Run would create the opportune moment for diffusers to be created out of excavated rip rap that might otherwise be discarded.

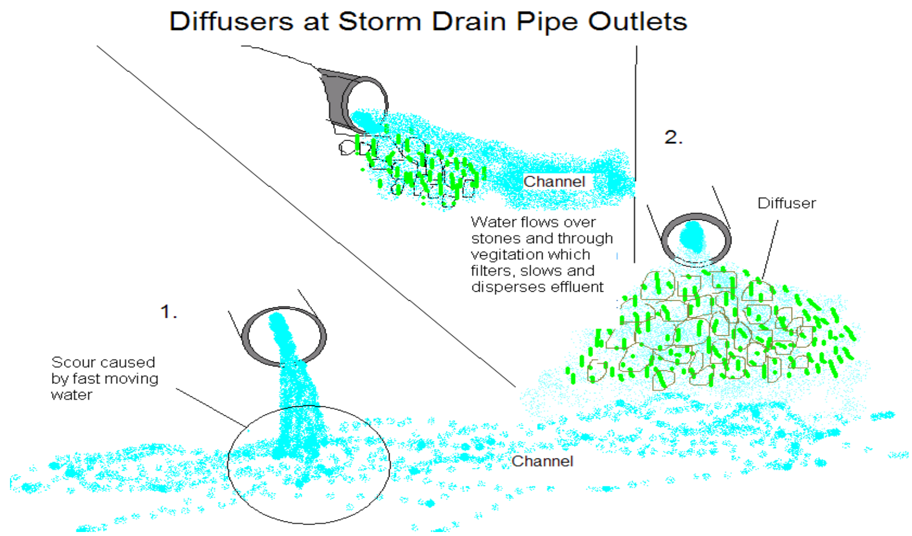


Figure 3-14 Depiction of pipe scour (1.), the problem that diffusers attempt to rectify and a theoretical design of a vegetated storm water pipe diffuser shown from the front and side (2.)

Riparian Corridors

The section of Miller Run that runs through campus is currently characterized by steep rip-rapped banks, which lead into mowed grass fields or parking lots. Neither of these bank conditions is ideal for bank stabilization, runoff filtering, mitigation, aesthetics or natural stream ecosystem function. In problem areas for erosion, the banks are built up so high that when they reach the stream there is a four-foot down-cut from storm water (Figure 3-15). The entire stretch along Moore Avenue has banks that are much too steep for a stream of this size and gradient. As a result, the banks are only held in place by rip-rap and cement walls. These could all be adjusted, vegetated, and beautified. The stream banks of Miller Run should be graded down to provide a gentler slope. This would allow vegetation to be planted and maintained with the goal of stabilizing the banks naturally. In addition, this would be a great opportunity to incorporate human interaction with Miller Run. Streamside benches or walkways meandering through Miller Run's floodplain would be very popular with all members of the Bucknell community as well as guests and prospective students. All areas of Miller Run require some work on their riparian zones, but extensive vegetated riparian zones could replace the parking lots along Moore Avenue and the area behind Hunt Hall. This parking becomes more expendable as the "Plan for Bucknell" proceeds through its goals (Campus Master Plan as communicated by Dennis Hawley). Additional "naturalization" of the riparian zones between the stream channel and parking lots will allow runoff to be slowed and filtered before it enters the stream. In addition to bank stabilization and improved aesthetics, vegetated riparian zones along streams moderate stream temperature by providing shade, provide a source of food through input of detritus, and serve as habitat and corridors for a variety of amphibians, birds, reptiles, and mammals. As a result, natural vegetation along Miller Run could enhance regional biodiversity and ecological connections among surrounding landscape green spaces.

Figure 3-15 Erosion of Miller Run stream banks on the west side of Route 15

The Economics of Restoration

<u>Costs</u>

The costs delineated in this section are likely extremely conservative and do not account for the extensive planning that would be required if the project were undertaken. Significant research remains to be done to more accurately project costs associated with the restoration projects.

Previous sections in this report went into great depth explaining the various measures proposed to restore Miller Run to a healthy state; this portion of the report looks to quantify the cost associated with the proposed project, as well as outline some of the intangible benefits of the project. The numbers presented in this section were derived using construction estimator databases, case studies, previous project reports, as well as industry experts (a detailed list of references can be found in Appendix C).

The cost analysis of this project covers the proposed alterations to the stream channel as delineated in the *Channel Design Plan*, as well as a 'state of the art,' storm management system already designed by Bucknell University's Facilities department. To briefly summarize what has already been described in great detail in earlier sections of this report, it is the intention of this project to recommend modifications, which would reduce many of the problems associated with Miller Run. The *Channel Design Plan*, calls for the removal of rip-rap which acts as a bank stabilizer, the concrete retaining wall in front of Sojka, and various culverts which impede flow. In addition, the plan calls for the construction of log cribbing to replace the rip-rap along the banks, as well as two wetlands for storm water retention. All proposed renovations are planned within Bucknell's property, and therefore do not require additional land acquisition. The 'state of the art' storm management system was designed and compiled by Facilities; therefore, this report includes this project in its cost analysis budget (Table 3-1).

The total cost for the project comes in at just under $1.3 million with nearly two thirds of the entire cost stemming from the storm water management system. Included in this budget are all of the proposed alterations made in the *Channel Design Plan*, as well as a number of miscellaneous inputs associated with construction. The costs in this budget all include labor and equipment. Without the burden of the storm management system, the cost of restoring Miller Run falls 68 % to just over $416k.

The cost of the rip rap removal covers both banks of Miller Run in front of Davis Gym as well as the banks adjacent to the Art Building. Parking surfaces includes the cost associated with the removal of the parking lot in front of the ELC on Moore Ave. The *Channel Design Plan* calls for the removal of additional parking space and the Art Building itself, but these plans are also included in the *Campus Master Plan*, and therefore not associated with the costs of the Miller Run project. The budget above also covers the cost of removing the retaining wall in front of Sojka, as well as numerous vestigial culverts and pipes impeding the flow of the stream.

Table 3-1 Cost Analysis including stream restoration and 'state of the art' stormwater management system as proposed by Bucknell's Facilities department.

COST ANALYSIS				
Channel Restoration				
Demolition:		**Unit Cost**	**Units est.**	**Total Cost**
	Rip Rap:	$ 42	2,400	$ 100,440
	Parking Surfaces:	0	2,250	923
	Concrete Walls:	150	300	45,000
	Culverts and Pipes:	290	20	5,791
	Sub Totals:	**$ 482**		**$ 152,154**
Construction:				
	Log Cribbing:	$ 286	315	$ 90,090
	Culvert:	289.5	2	579
	Wetlands: Sojka	150000	1	75,000
	Wetlands: Mods	57100	1	57,100
	Sub Totals:	$207,676		$ 222,769
	Grand Total:	**$208,157**		**$ 374,923**
Storm Water Management				
	Bucknell Proposal for 'State of the Art SWM':	$ 250	3,400	**$ 850,000**
Misc. Inputs				
	Permits:			8,500
	Legal Council:			4,250.00
	BU Facility Cost:			17,000.00
	Sub Totals:			**$1,254,673**
	Escalation & Contingency:			37,640.18
	Grand Total:			**$1,292,313**

In addition to demolition, the budget details all of the costs associated with constructing structures proposed in earlier sections of the report. The two wetlands vary greatly in cost due to the scale of earth that needs to be moved to accommodate their construction. Wetlands cannot be built on an area with significant gradient; therefore the land in front of Sojka must have a great deal of sediment removed in order to sustain wetland growth. The necessary leveling of the site in front of Sojka accounts for the drastic difference in price between the two wetlands. The stream restoration project has many peripheral costs that must be included in the budget, including the cost of permits, legal counsel, BU facility costs and escalation and contingency. These numbers cover many of the formalities associated with construction. A detailed reference sheet can be found in Appendix C.

In addition to the costs associated with the actual construction of Miller Run, there are many unquantifiable benefits the project will bring to Bucknell's campus. First and foremost, a healthy Miller Run will allow for the efficient handling of storm water, decreasing the damage caused to cars, property and University buildings during times of intense flooding. Besides decreasing the damage inflicted upon cars and buildings, the restoration project will be an invaluable educational site for university students, members of the community and school children in the Lewisburg area. They will be afforded the opportunity to see a functioning restoration project, as well as a unique place to learn about fluvial systems. Complimenting the educational nature of the stream restoration project will be the wetlands on campus. Very few wetlands still exist in central Pennsylvania, and none will be as accessible nor as learner friendly to students and community members as the two proposed to be constructed on Bucknell's campus. In addition to having exceptional sites to educate people about the importance of responsible environmental practices, the wetland and restoration project will provide an opportunity for Bucknell to set itself apart from its peer schools. Having a place to bring visitors on tours to demonstrate the ingenuity and forward-mindedness of Bucknell students will be invaluable when recruiting new students to attend the University. A healthy stream and wetlands system will attract a diverse group of animals and vegetation, adding further natural beauty to the campus, and making it a unique and exciting atmosphere to both live and work.

In the effort to structurally recreate Miller Run into a healthy stream, there are a number of required permits and regulations that need to be signed and followed. The meetings with officials from East Buffalo Municipal Building, Union County Planning, and the Conservation District were helpful in our attempt to follow regulations for the restoration of the stream. The Pennsylvania Department of Environmental Protection and Bureau of Watershed Conservation must also clear a waiver before the progress of Miller Run starts.

Conclusion

Restoring Miller Run offers some unique and exciting benefits to Bucknell University. Making the stream healthy will not only provide a more efficient and effective means to deal with storm water, but will provide a site on campus to educate students and members of the community about the importance of being respectful and responsible toward our surroundings. In addition to creating an outdoor classroom, the project will be a perfect showcase of the caliber of student found at Bucknell and the opportunities afforded to them, when bringing prospective students on tours of the University. Along with restoring bio diversity and increasing the aesthetic appeal, the project proposed in this report will set Bucknell apart from its peer schools and make it a unique place to attend University. The costs associated with the project are no small barrier to overcome, but when the benefits are weighed against the cost of building and maintaining Miller Run, it is clear the restoration of the stream not only dovetails with the Campus Master Plan, but will increase the overall value of the University.

Summary

Several measures are needed to restore both the biological and ecological integrity of Miller Run. The first and most important of these measures is the restoration of flow permanence. Without a permanent connection to Bull Run and the greater Susquehanna, Miller Run lacks the potential for colonization by fish and aquatic macroinvertebrate species. Although some macroinvertebrates are able to survive in the hyporheic zone, without a permanent connection to Bull Run there is no potential for Miller Run to sustain significant perennial populations of aquatic biota.

Just as flow permanence is necessary for colonization, improved water chemistry is imperative if aquatic biodiversity is to become sustainable. A wide, densely vegetated riparian buffer zone is necessary to reduce the sediment load in Miller Run. This riparian zone will serve three purposes: sediment entrapment, bank stabilization, and habitat. By reducing the velocity of incoming surface runoff, a riparian zone will allow sediments and chemicals to settle out of solution and be taken up by vegetation. The root systems of these native plants will also lend much needed stability to the banks of Miller Run, which suffer from chronic erosion and sediment release. Finally, this riparian vegetation will provide habitat for many aquatic and terrestrial organisms, thus increasing the biodiversity of the Miller Run Watershed. When all these benefits are considered, it becomes quickly evident that investing in native streamside plant life is the single most beneficial improvement possible for the cost.

Related to flow stabilization is the control of runoff that enters into Miller Run during storm events. Perhaps the best way to deal with the massive influx of water from the upper portion of campus during a high-water event is to build retention basins that store storm water for a limited time, allowing it to percolate naturally into the inflow region of the subsoil. These basins will then release water slowly into the stream, which will limit the risk of flash flooding, such as the 1999 flood event. Also, wetlands can be built in strategic locations along Miller Run to absorb flood outputs, recharge ground water, allow sediments to settle, and provide a controlled release of stored storm water. Wetlands also have the additional benefit of increasing vegetation and overall biodiversity.

Another aspect of water chemistry which requires immediate attention is the late-starting influx of nutrient ions such as sulfate, phosphate, and ammonia during high water events. The magnitude and consistency of this influx conclusively indicates a buried source of contamination. Further research must be done to locate this source and mitigate the damage. The contamination could be explained by a damaged sewer line near the upstream site, contamination from the buried coal near the Art Barn, or fertilizer deposits in the subsoil from the golf course.

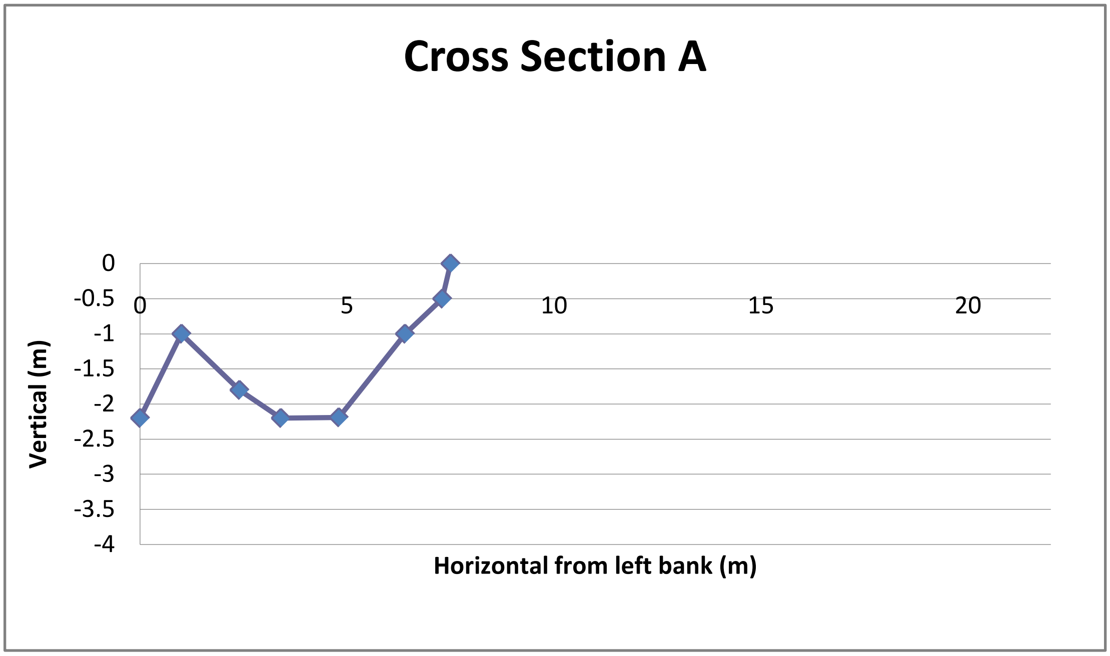
It is also important that various structures such as the concrete wall outside of the Athletics and Recreation Facility be removed. This wall is the most obvious sign of the channelization that has occurred along Miller Run for decades. Therefore, if the administration of Bucknell is committed to the restoration of the Miller Run watershed, the immediate removal of channelized structures should be the first order of business. Not only would it set the tone for better watershed management, but the removal of these structures would also carry benefits for the University. The removal of these structures would be aesthetically pleasing, an issue that is of perennial interest to University administration and prospective students alike. Instead of a crumpling concrete wall, visitors and students will see beautiful, natural vegetation growing along the gentle, pastoral banks of Miller Run, enriching the already considerable dividends of Bucknell University's steadfast devotion to campus aesthetics.

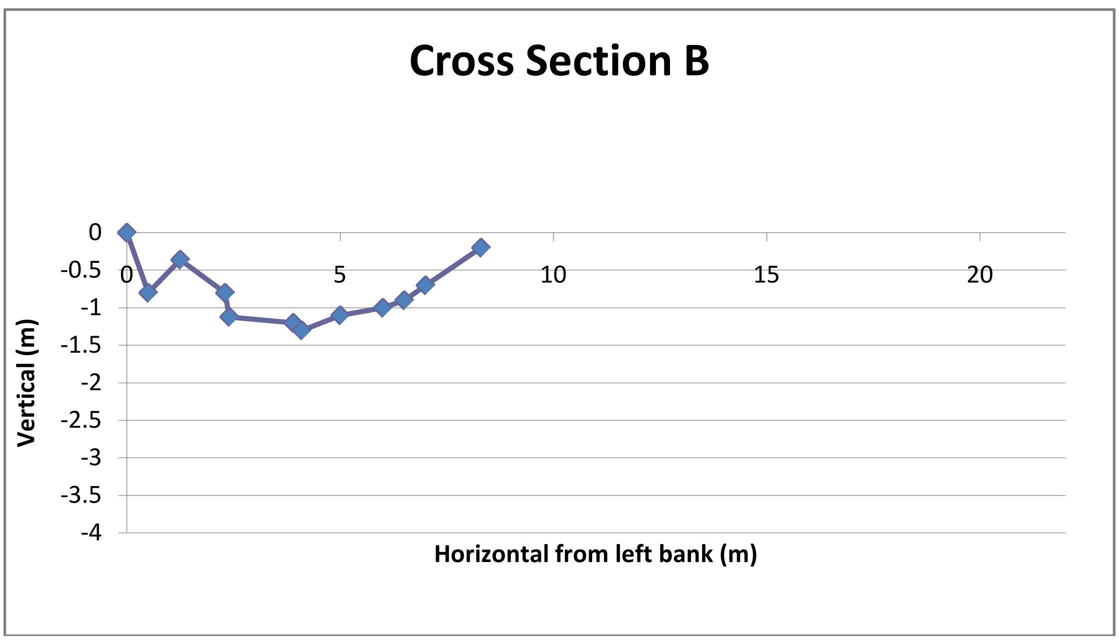
Several in-stream modifications should also be used to improve the quality of Miller Run. Once the flow permanence has been established, riffle-pool sequences can be created using soft structures to provide habitat for aquatic organisms and log cribbing will stabilize the banks during floods. The introduction of more diverse native aquatic plant species can also increase both the aesthetic appeal of the stream and its overall quality as habitat.

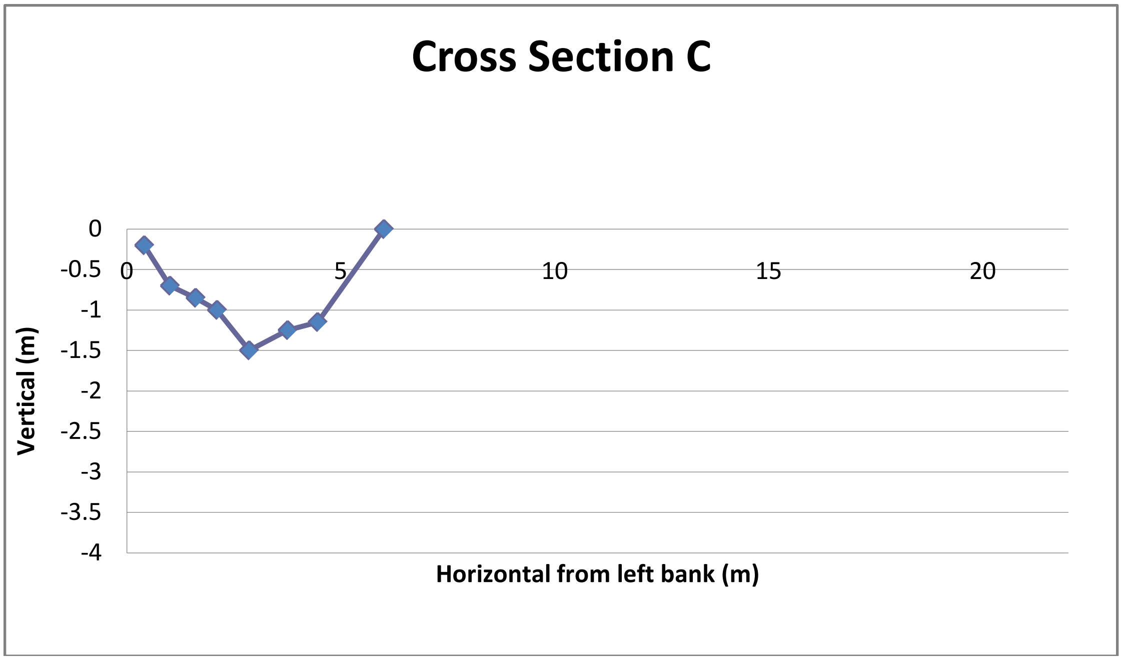
One overlooked benefit of creating a healthier Miller Run is the opportunity for wholesale enrichment of the educational experience here at Bucknell. Once Miller Run is restored, it can be used as an outdoor classroom by professors from all disciplines and majors. The presence of a truly natural space near the main campus offers countless opportunities for scientific research, hands-on ecological lessons, and meditative reflection for artists and writers. The intrinsic beauty of Miller Run will serve as both inspiration and scientific achievement.

The potential benefits of the restoration guidelines given above are innumerable. Not only will Bucknell's restoration of Miller Run earn the University a healthy reputation for setting an example of responsible environmental stewardship, it will also serve to distinguish Bucknell University from its peers in the eyes of prospective students. For these reasons as well as those listed above, it is pivotal that Miller Run be restored immediately to a more natural state. As the main contributor to Miller Run's current state of impairment, it is the responsibility of Bucknell University to atone for its previous neglect through a proactive approach to the future management of the watershed. If the restoration of Miller Run is successful, not only will it restore the ecological integrity of the stream, it will also provide an opportunity for Bucknell University to distinguish itself as one of the elite environmental universities in the United States.

Appendix A: Cross Sections



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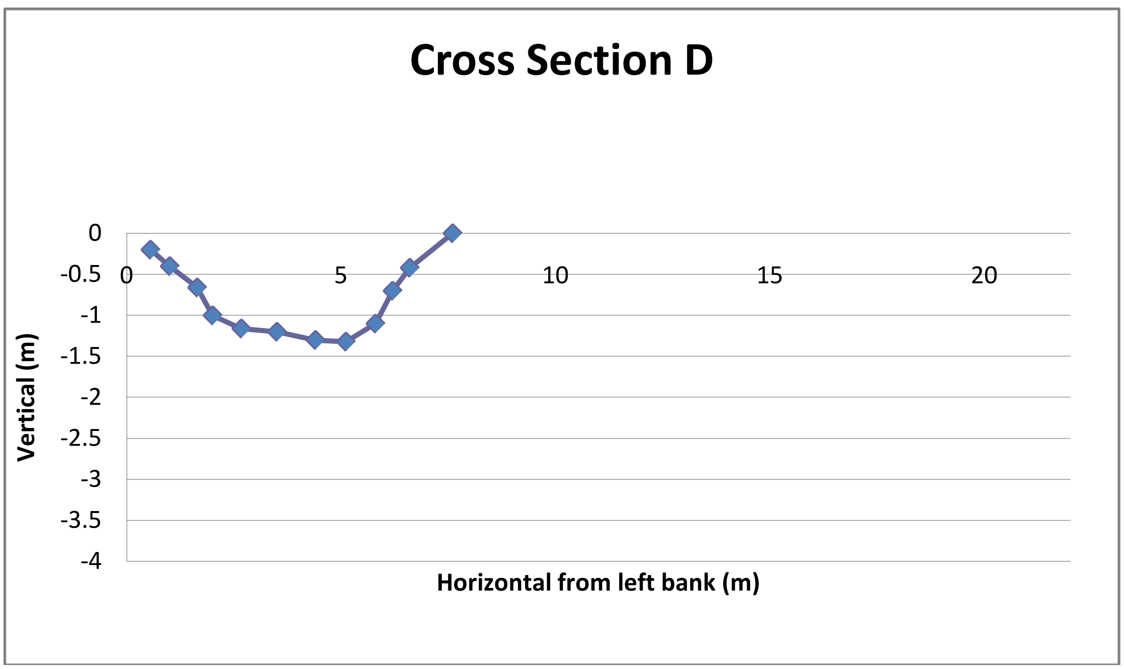
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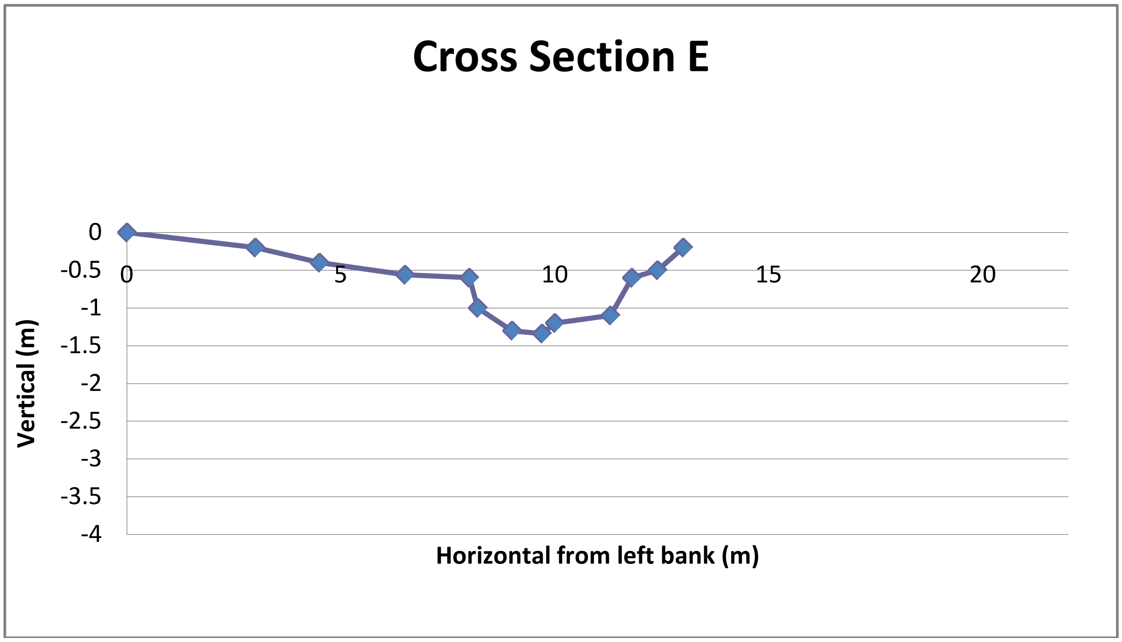
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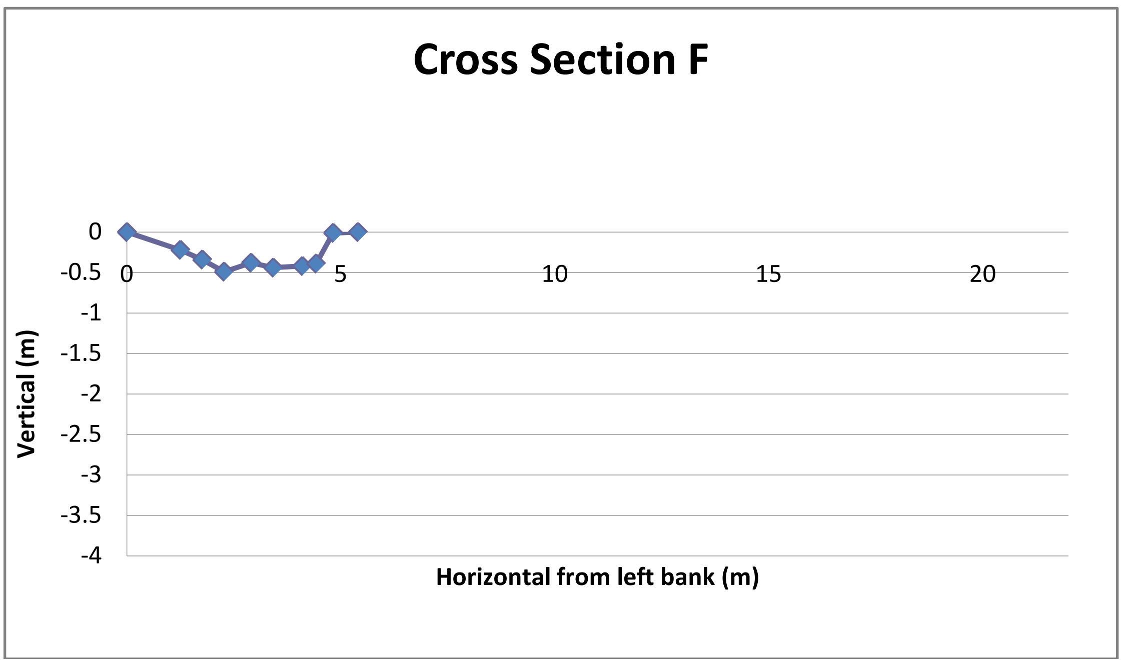
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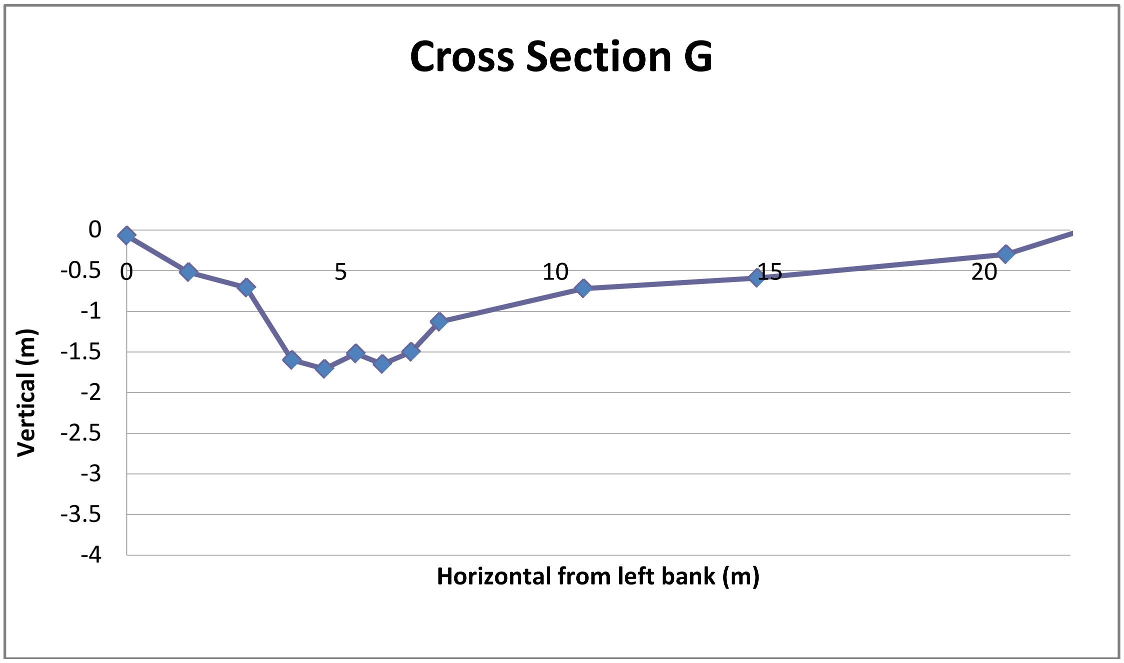
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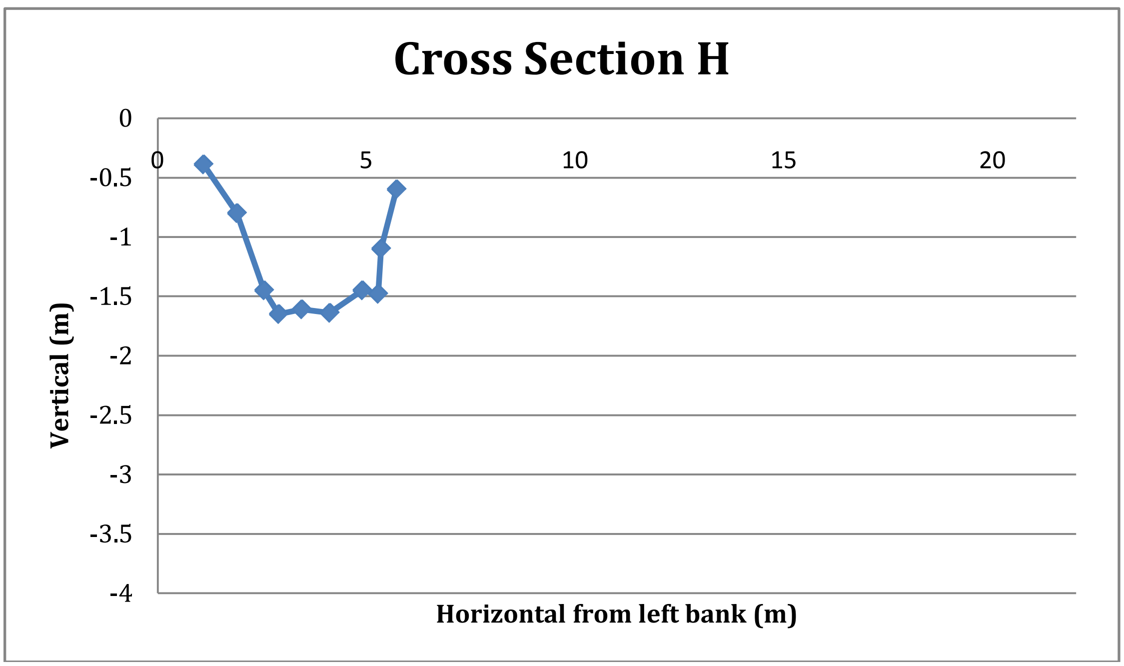
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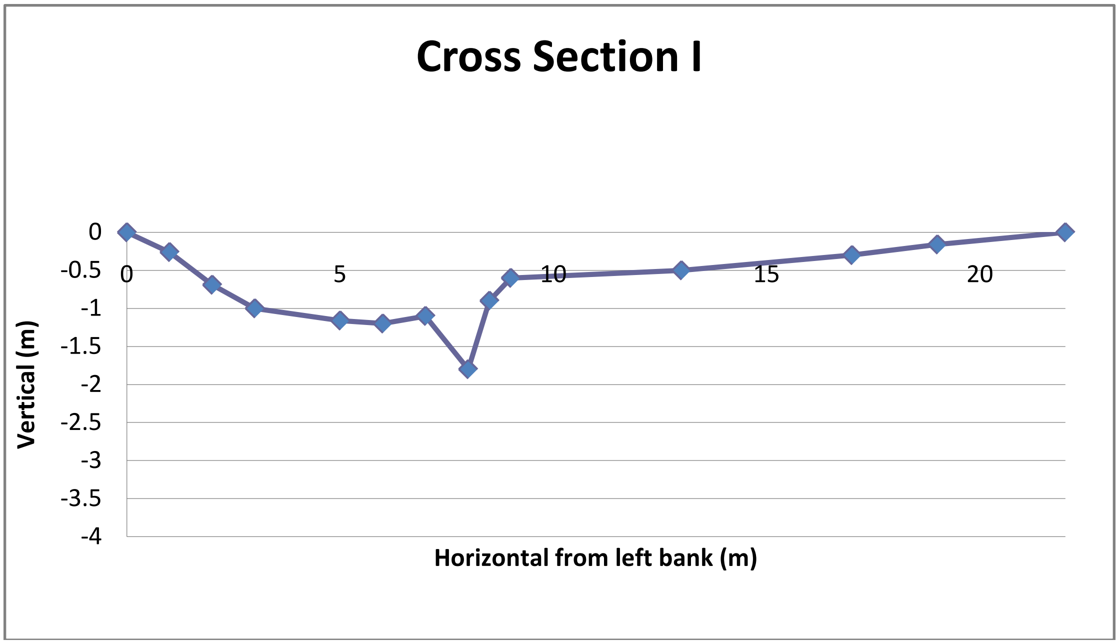
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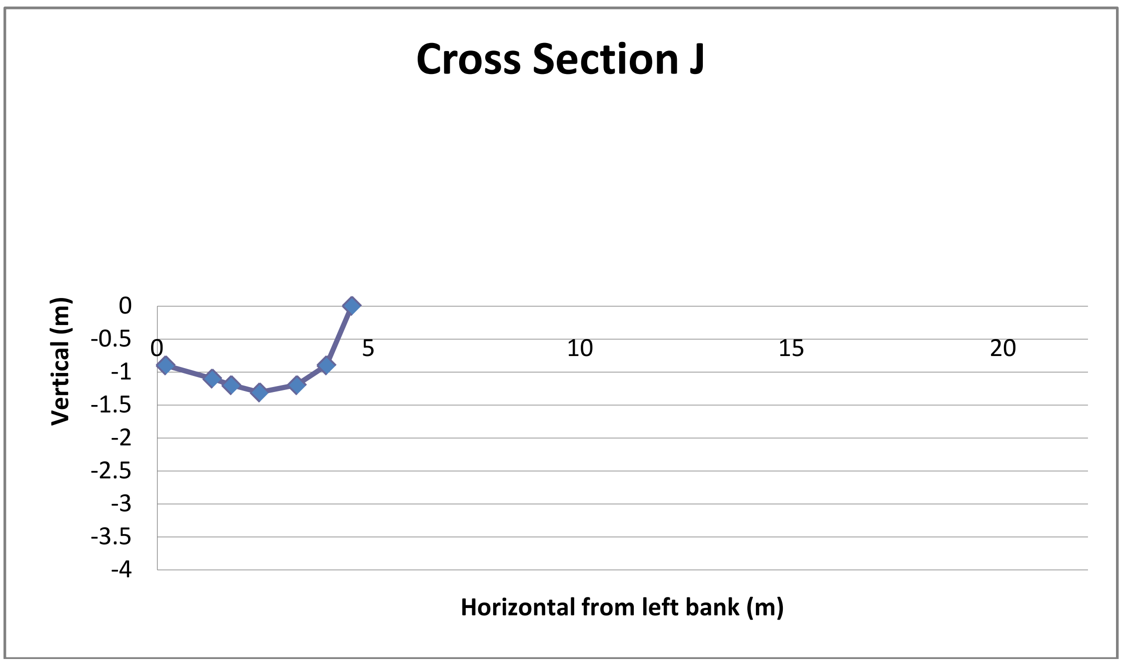
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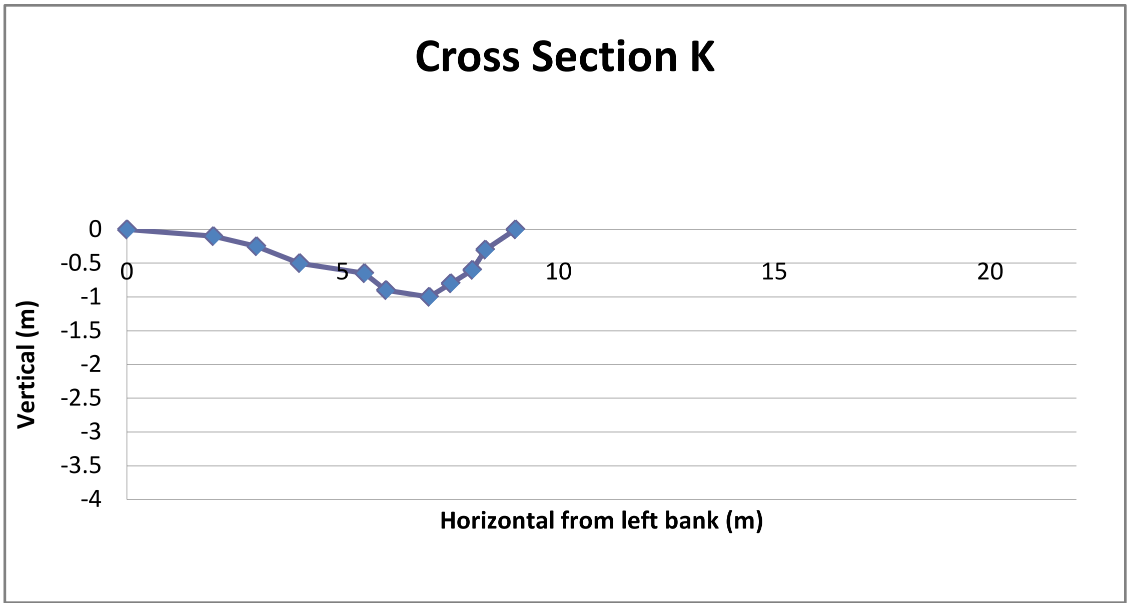
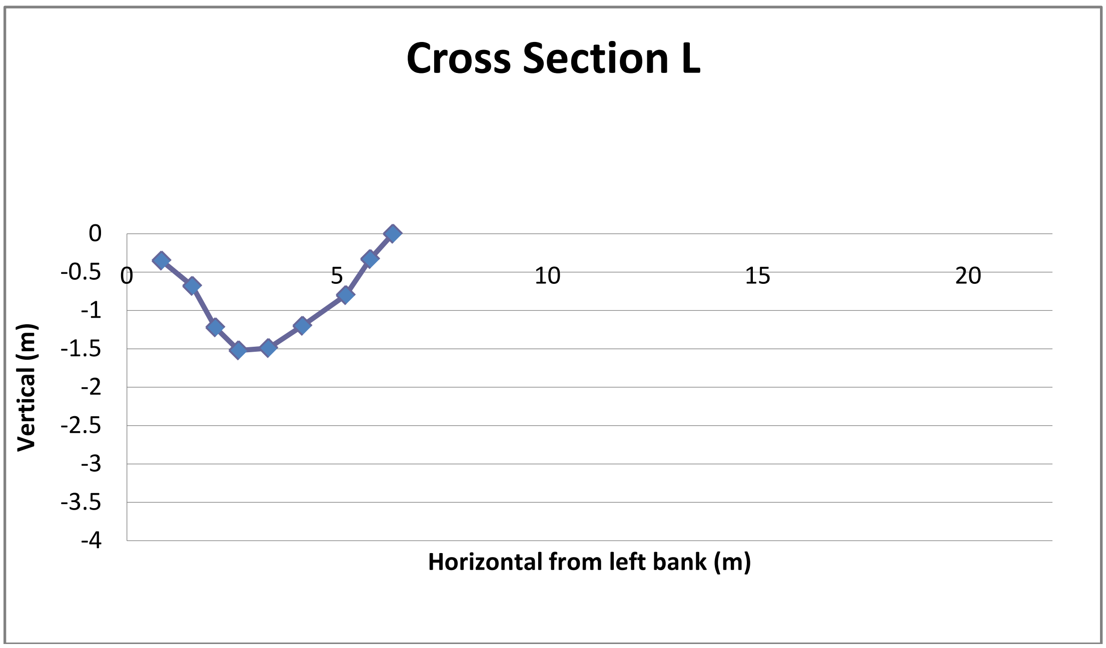
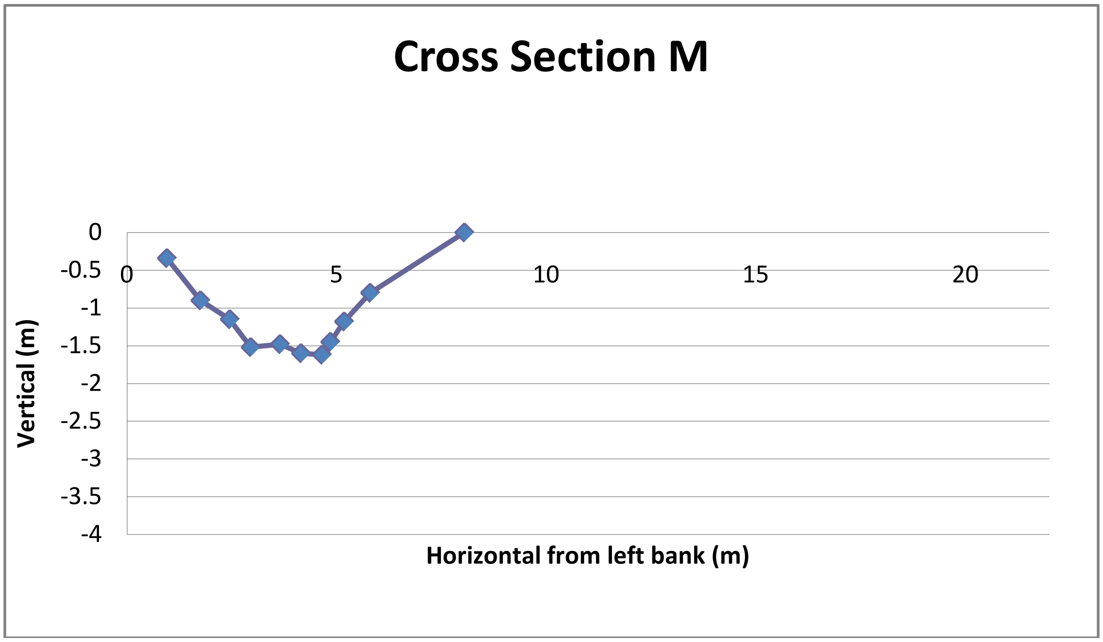
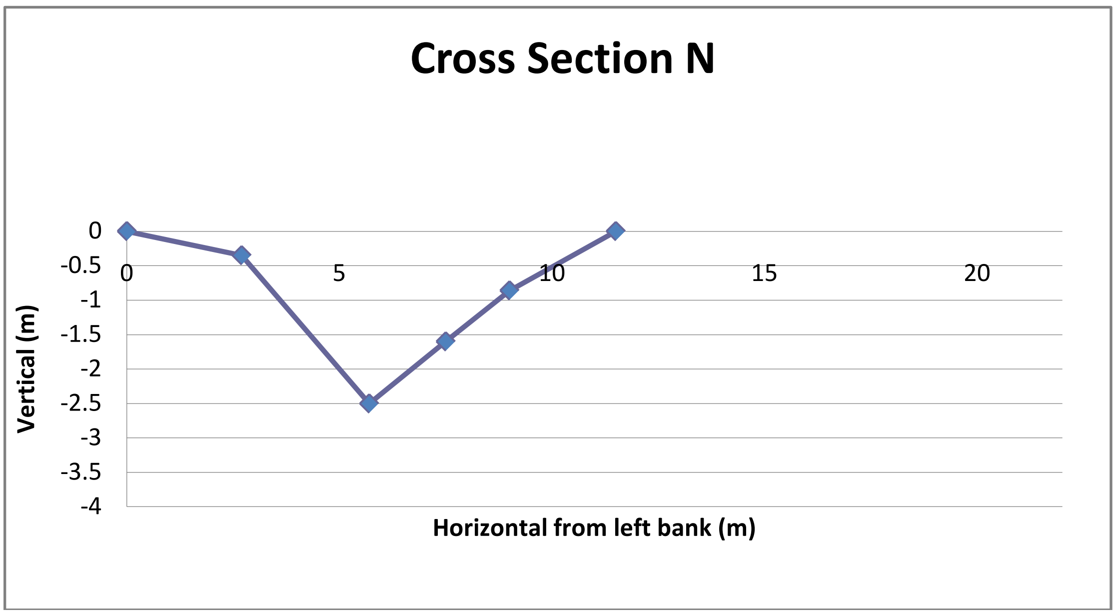


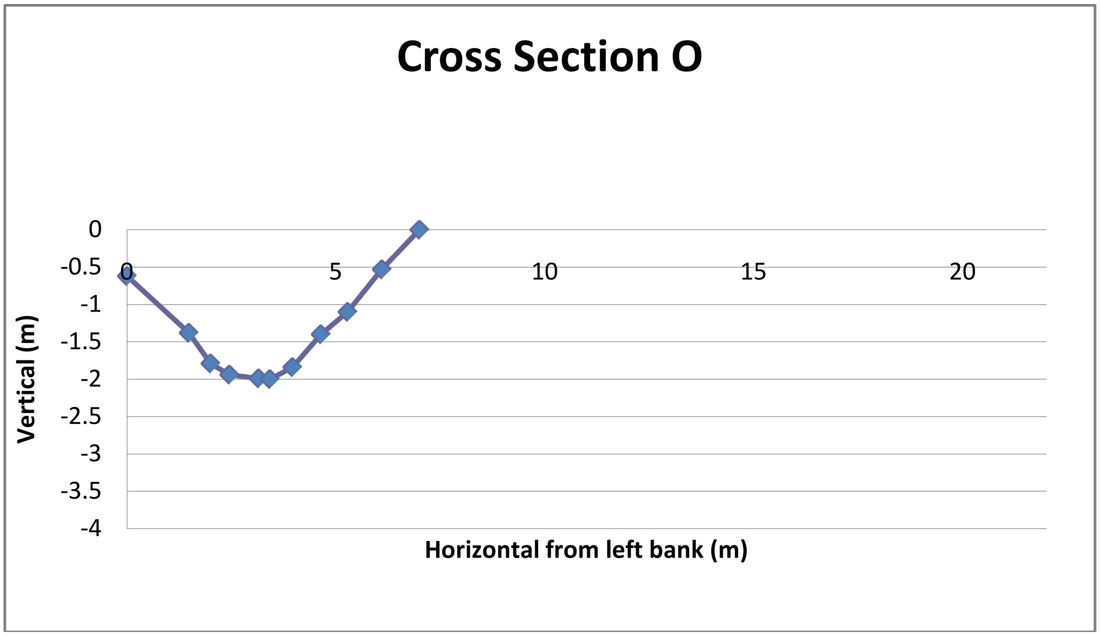
Cross Section K
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

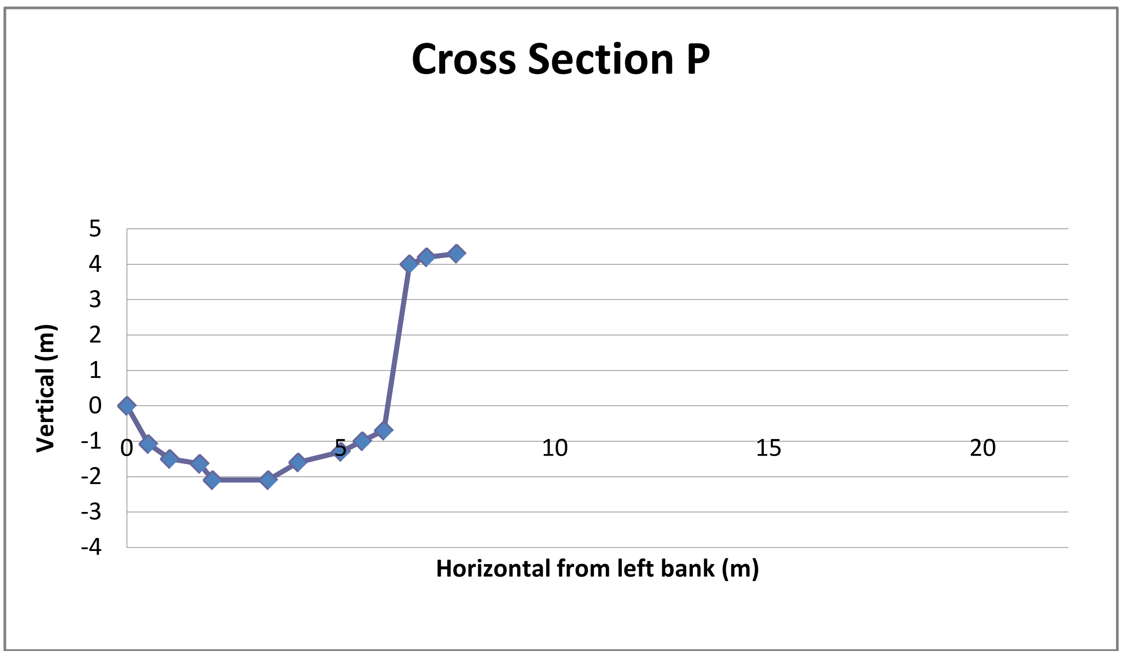


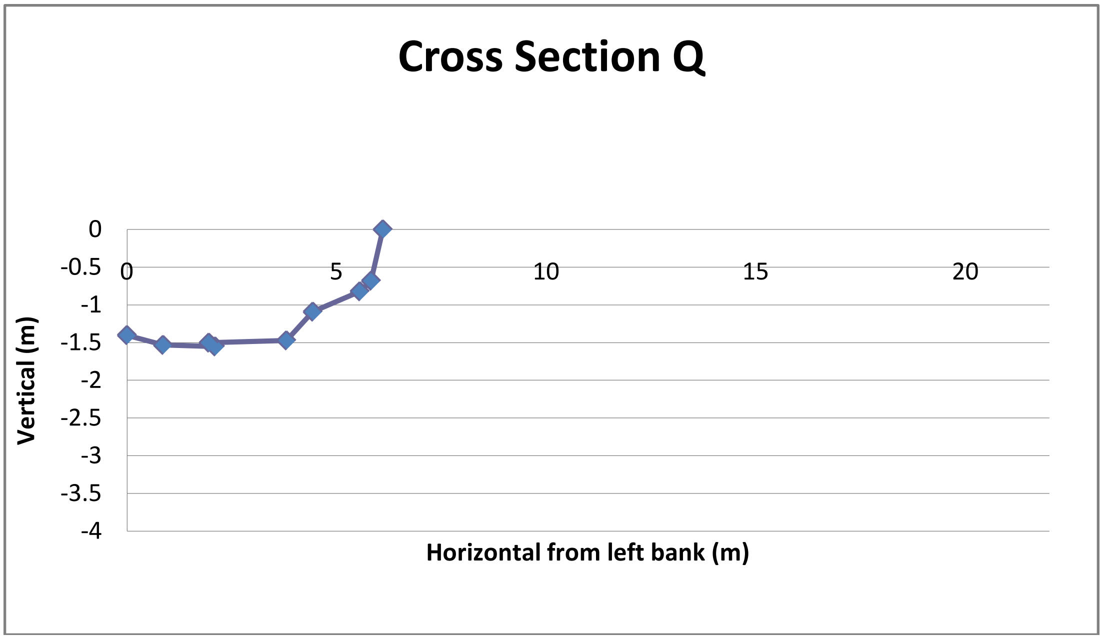
Cross Section L
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

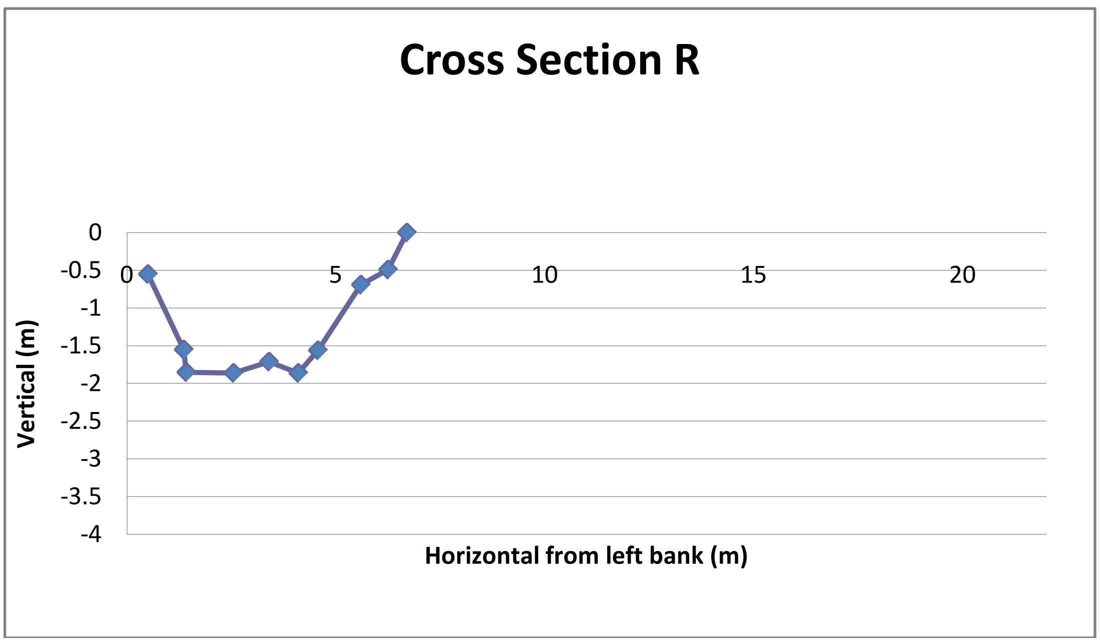

Cross Section M
Vertical (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Horizontal from left bank (m)

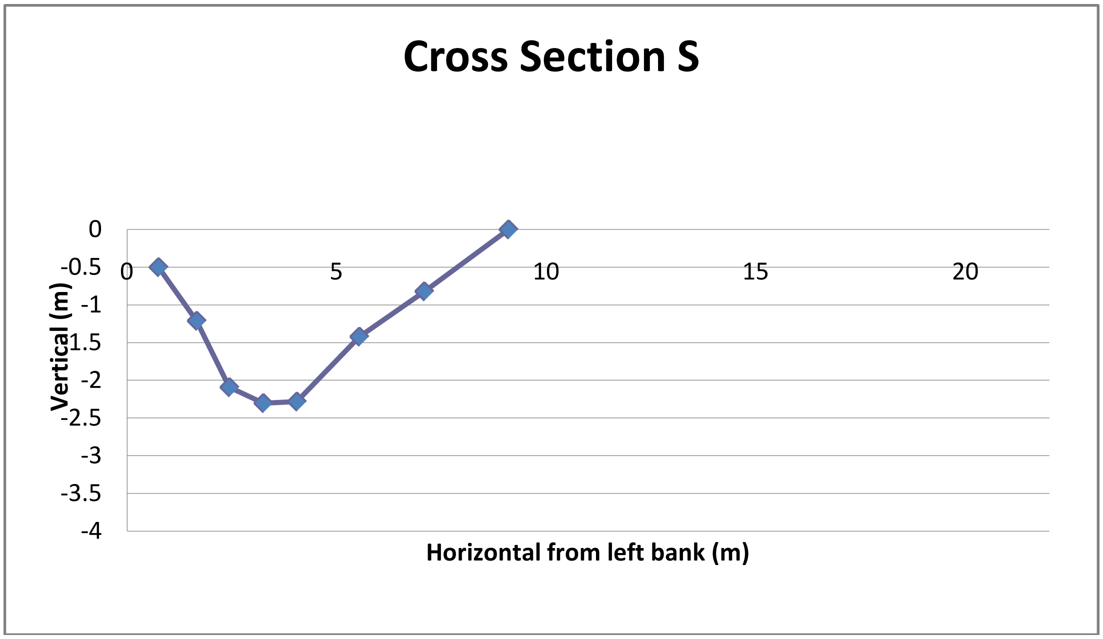

Cross Section N
Vertical (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Horizontal from left bank (m)

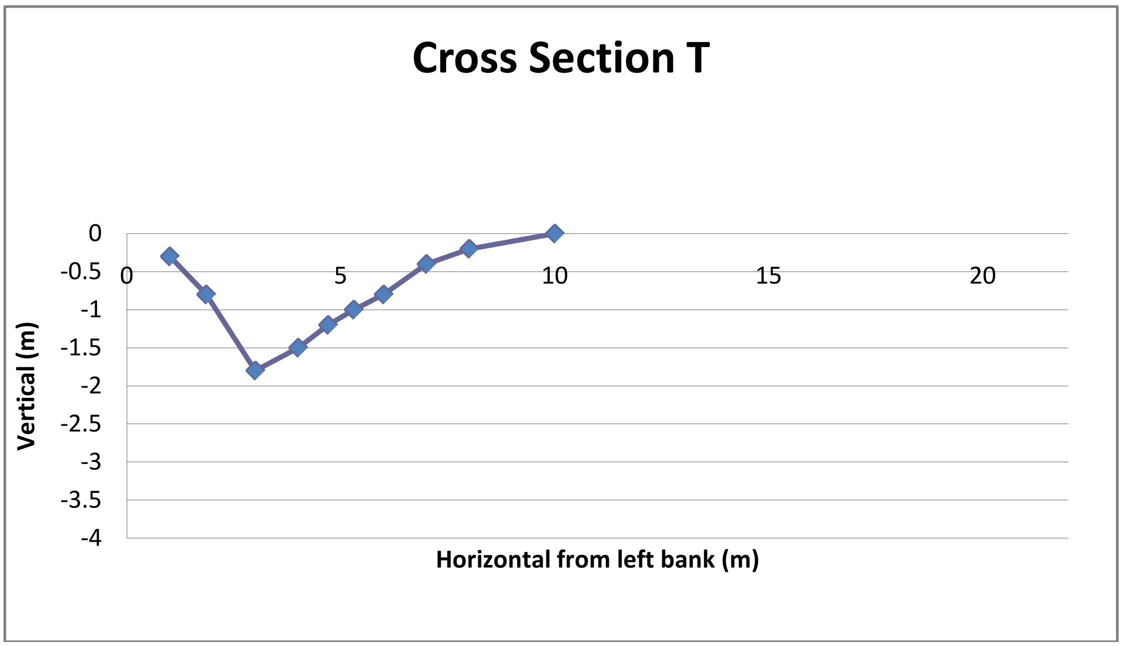

Cross Section O
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

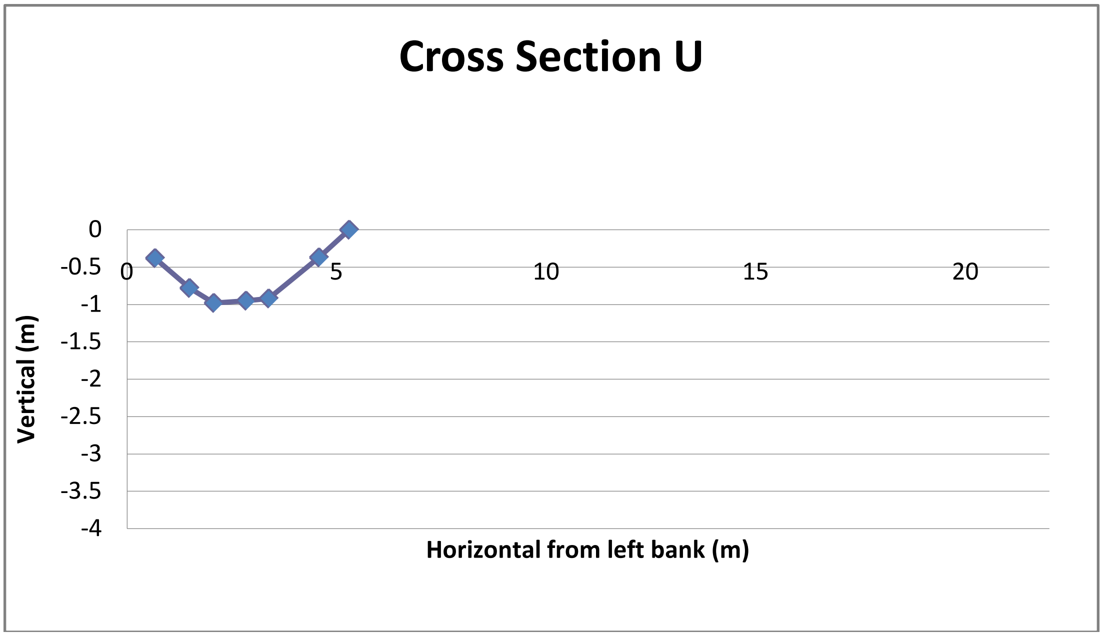

Cross Section P
5
4
3
2
1
0
-1
-2
-3
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

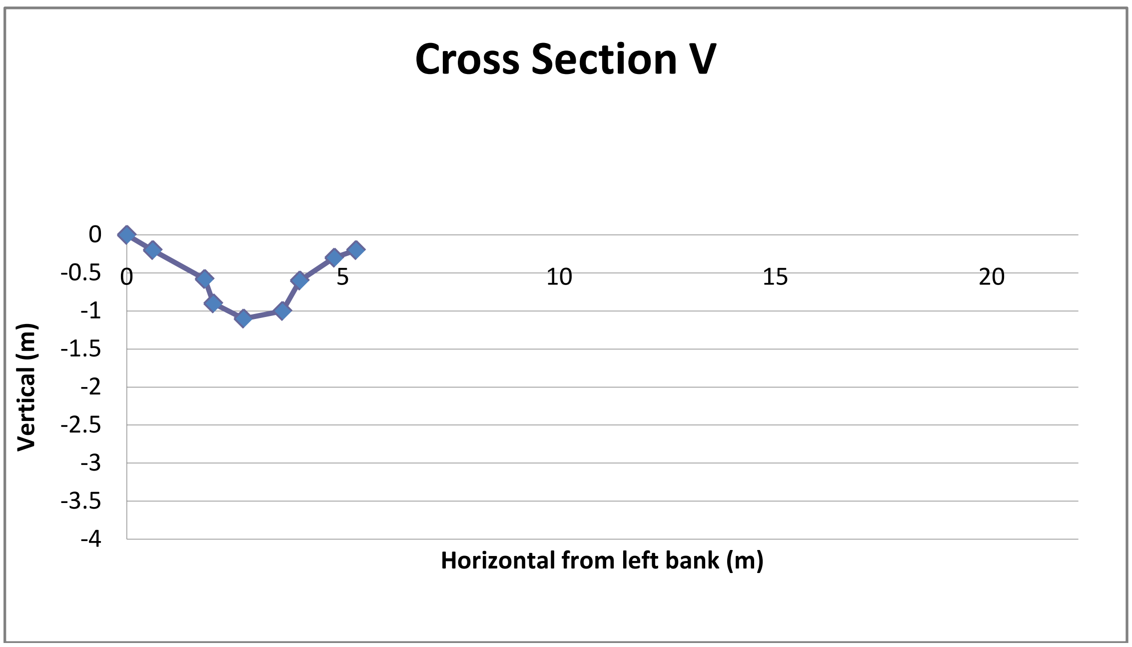

Cross Section Q
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

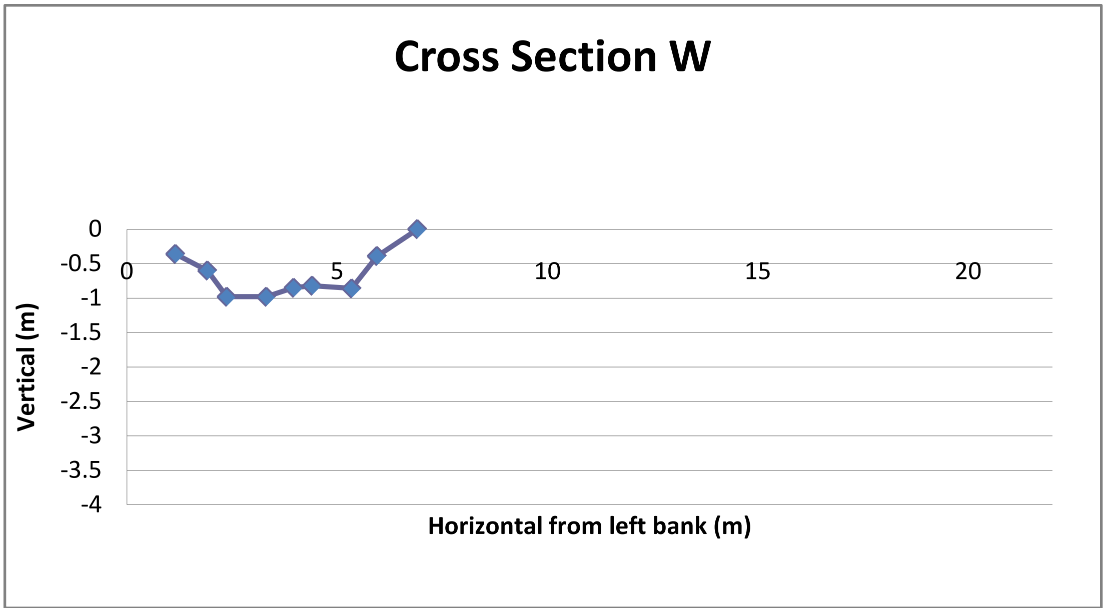

Cross Section R
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

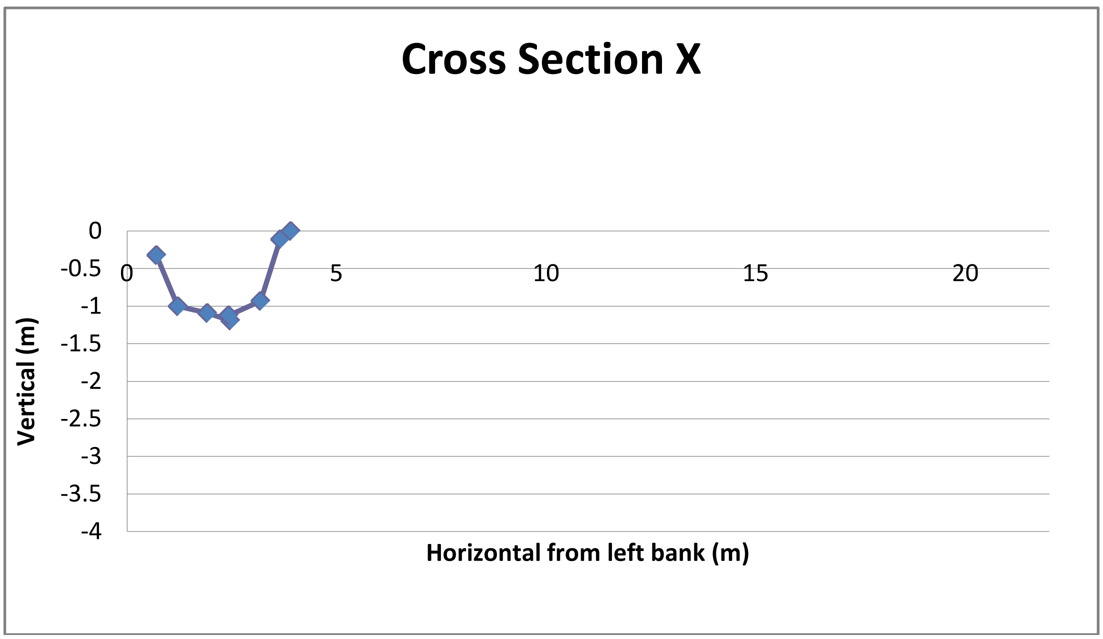

Cross Section S
Vertical (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Horizontal from left bank (m)

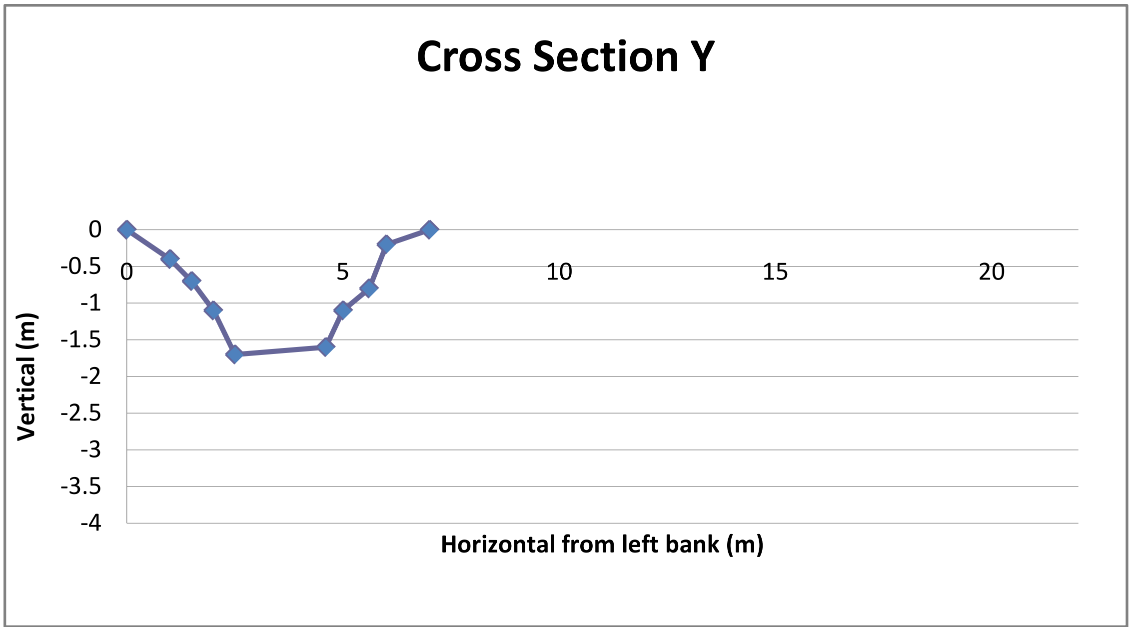

Cross Section T
Vertical (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Horizontal from left bank (m)

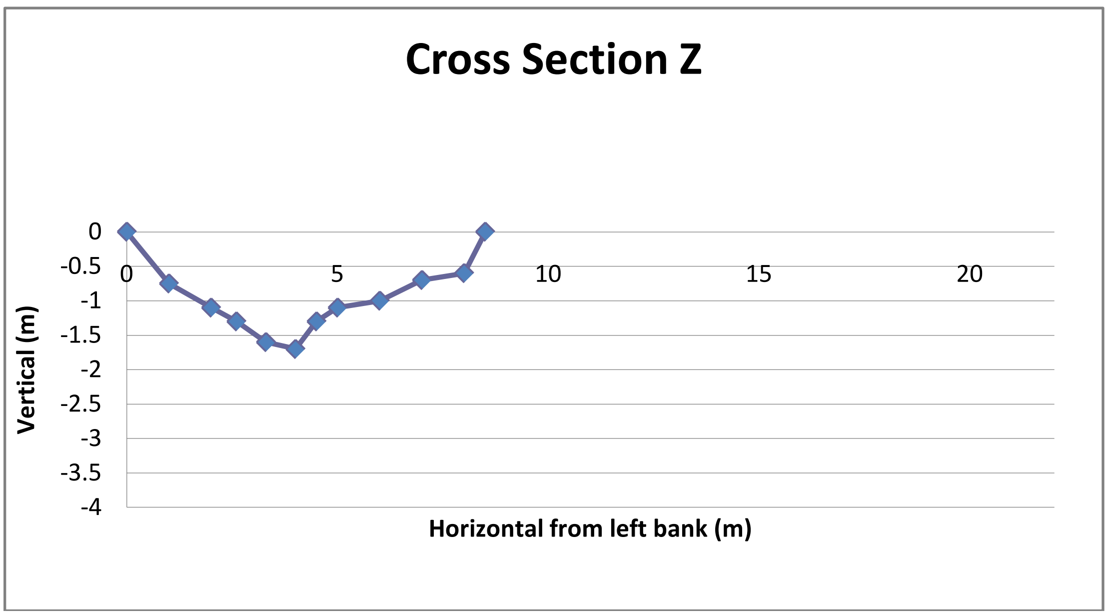

Cross Section U
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

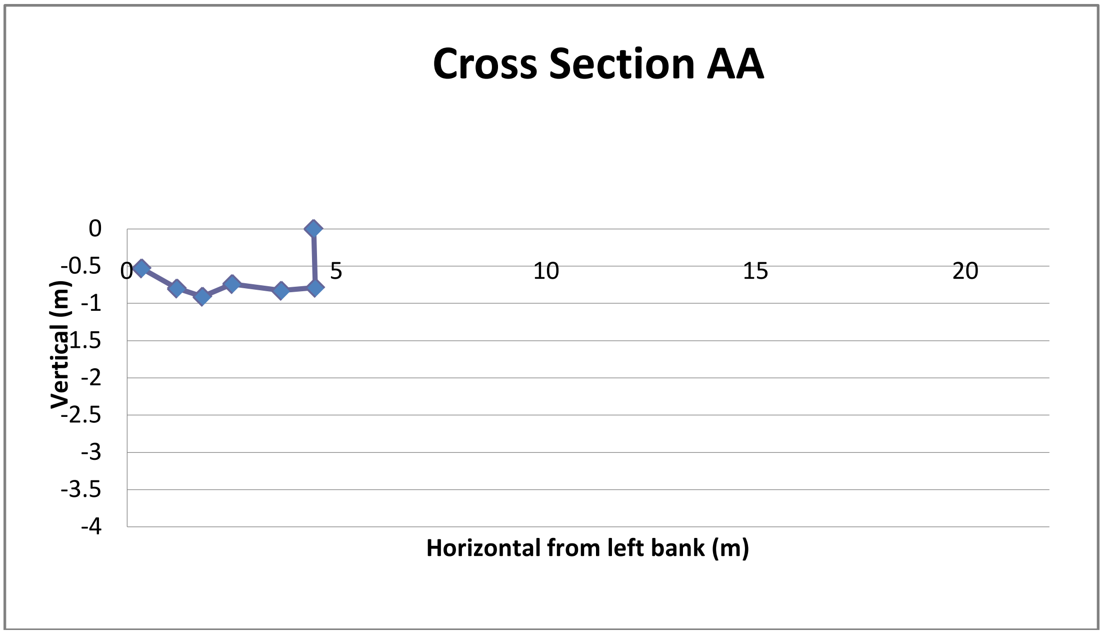

Cross Section V
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

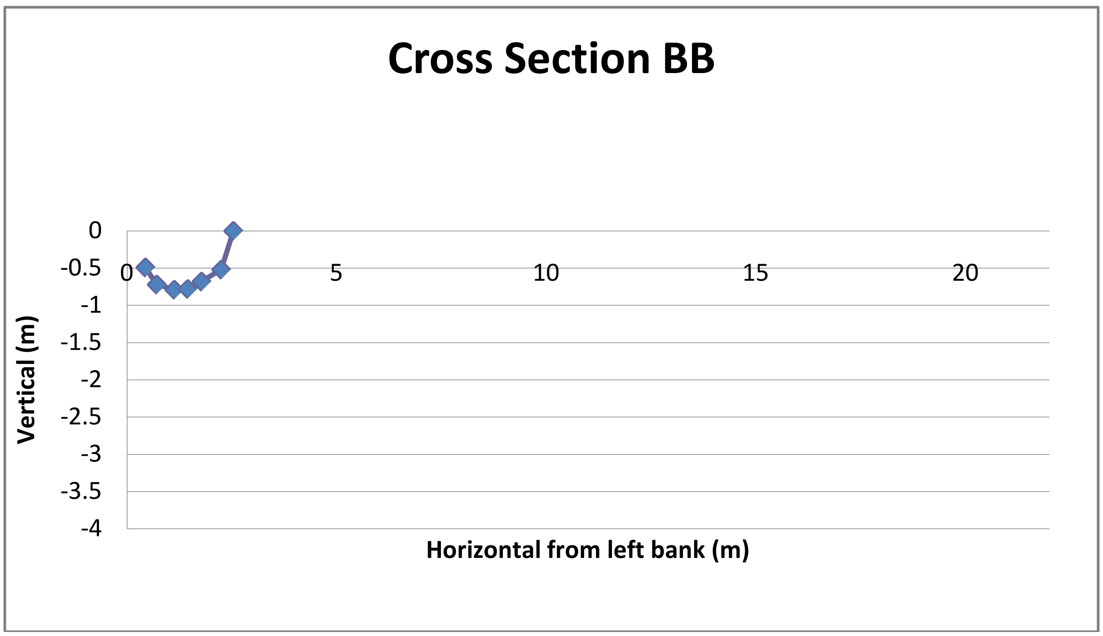

Cross Section W
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

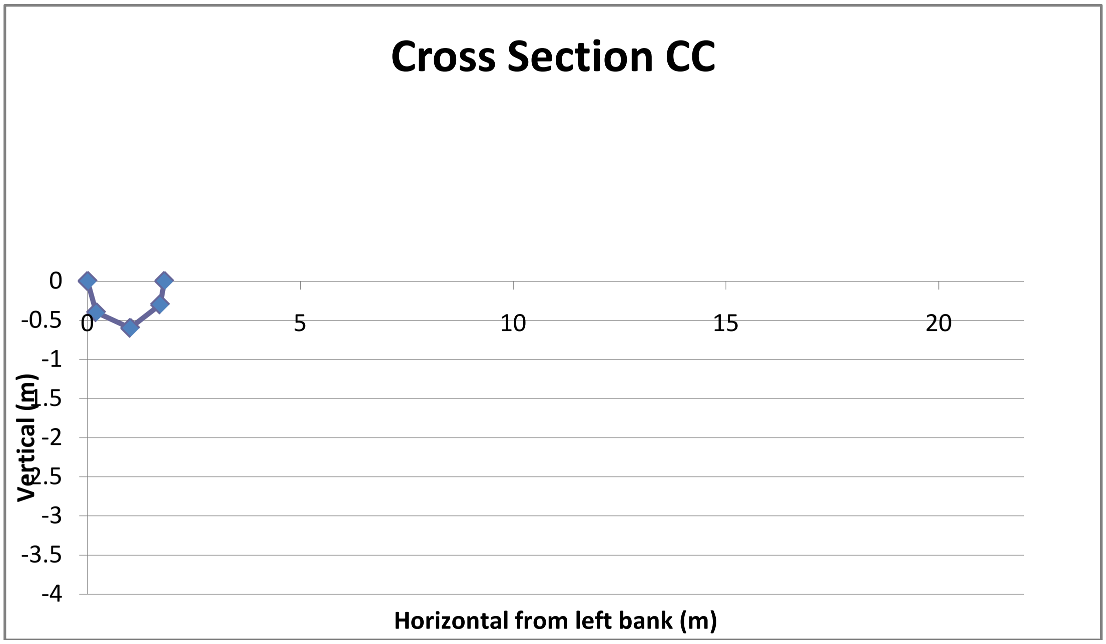

Cross Section X
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

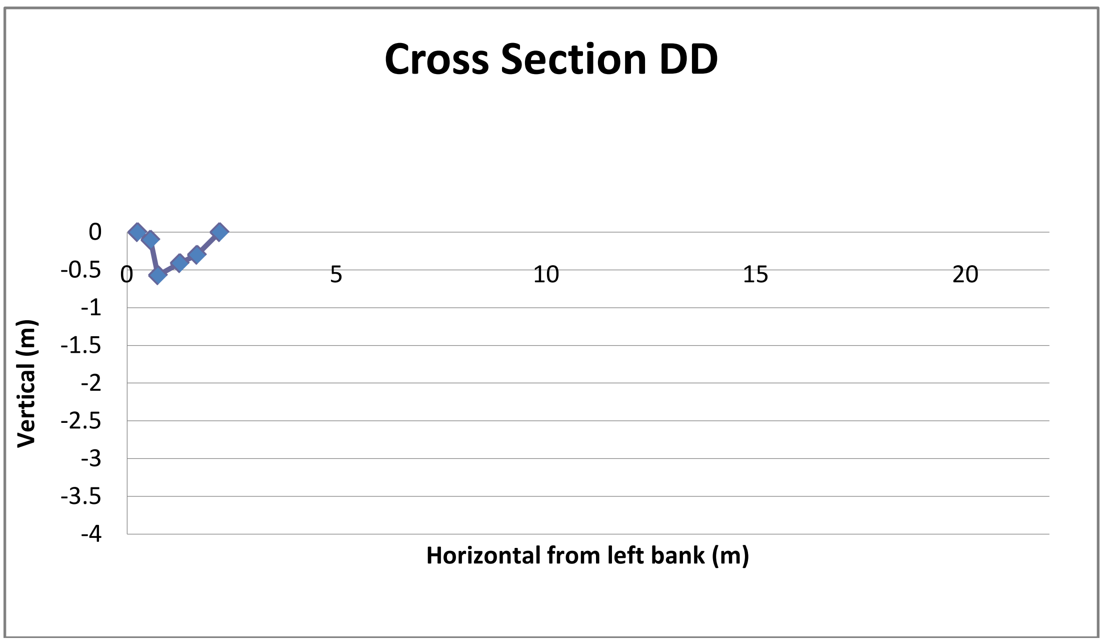

Cross Section Y
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

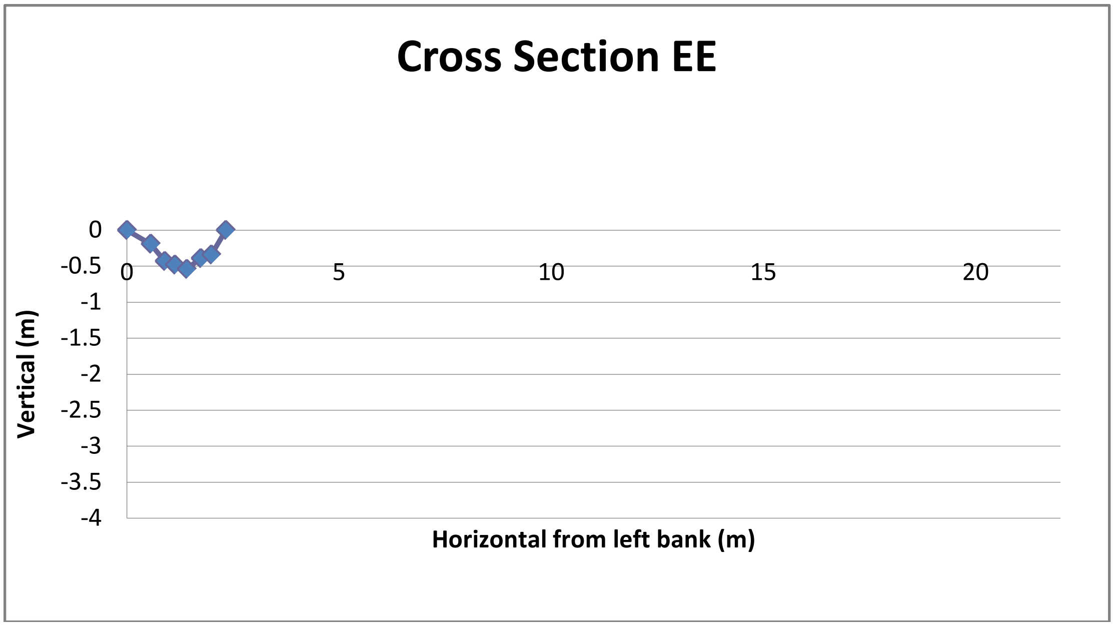

Cross Section Z
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

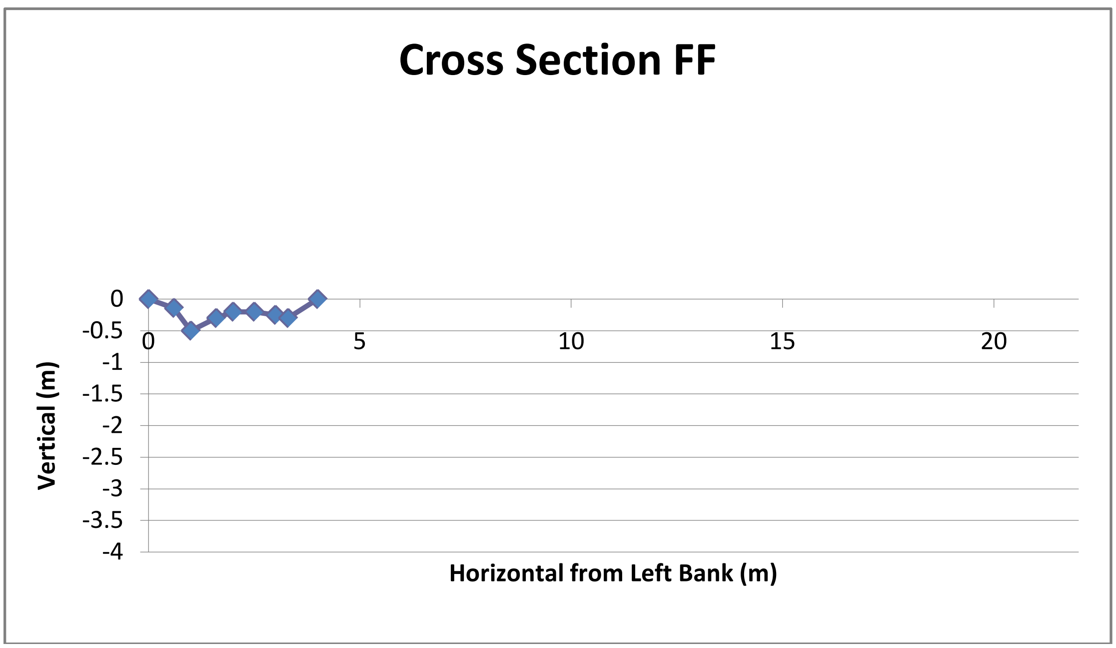

Cross Section AA
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

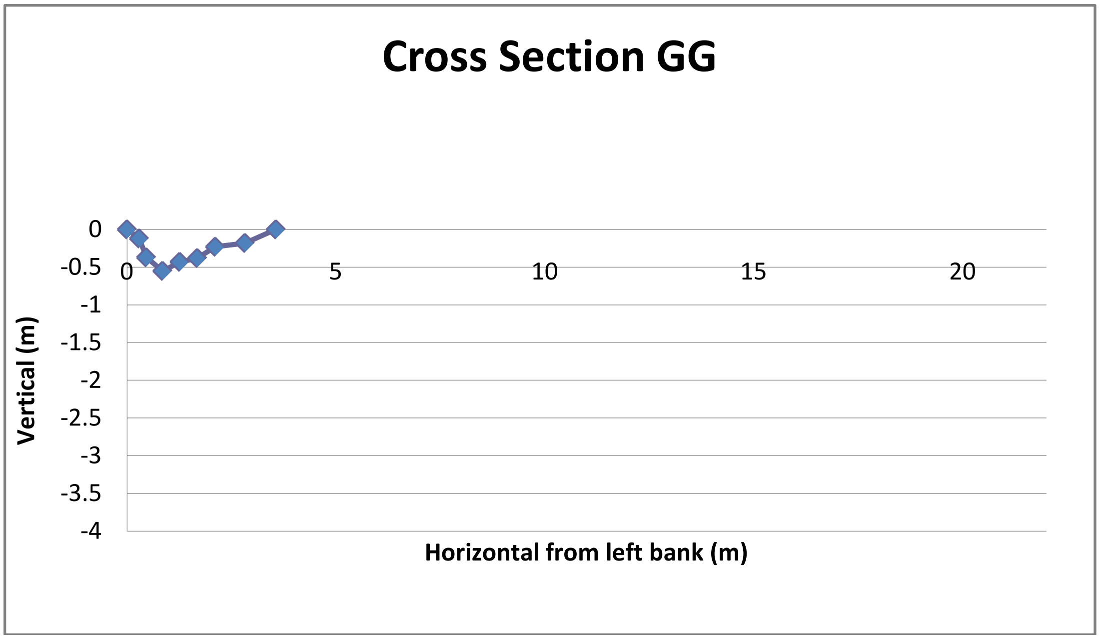

Cross Section BB
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

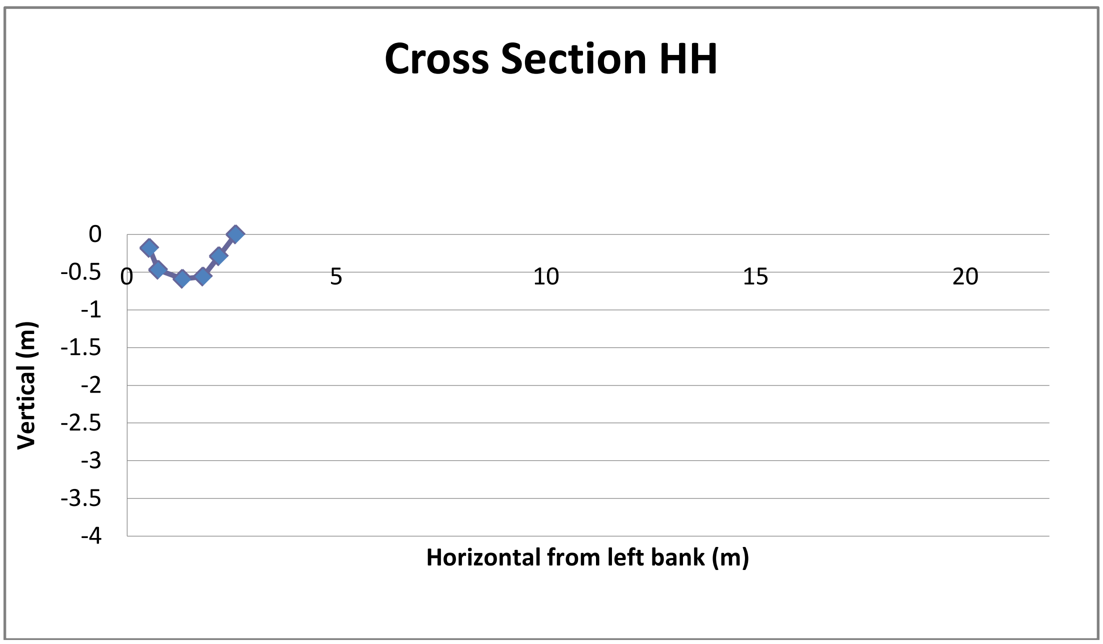

Cross Section CC
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

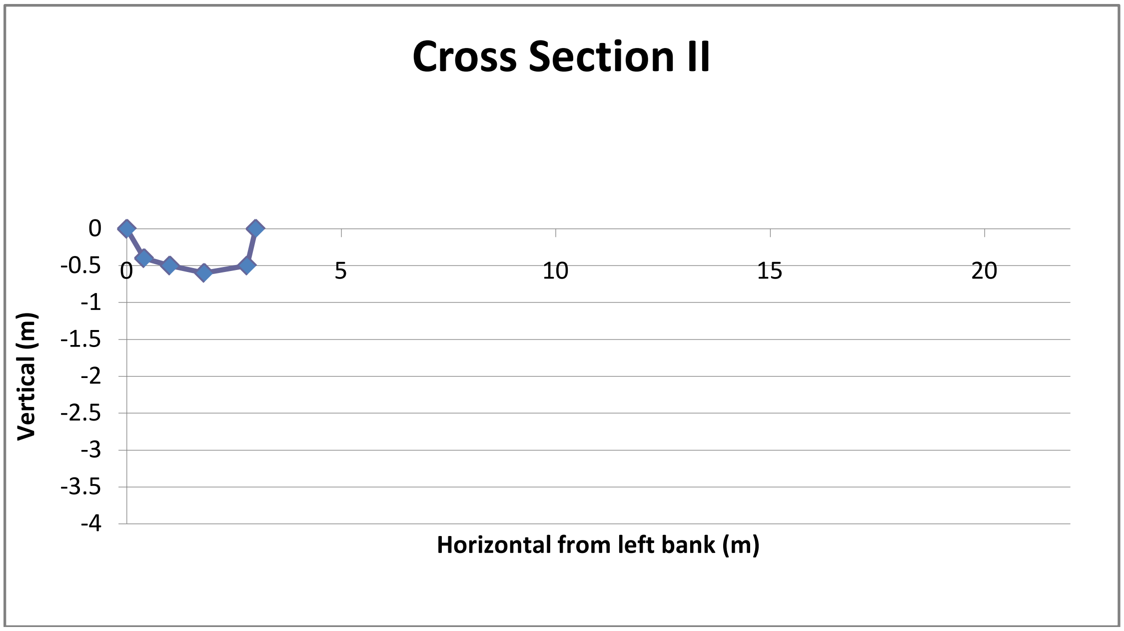

Cross Section DD
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

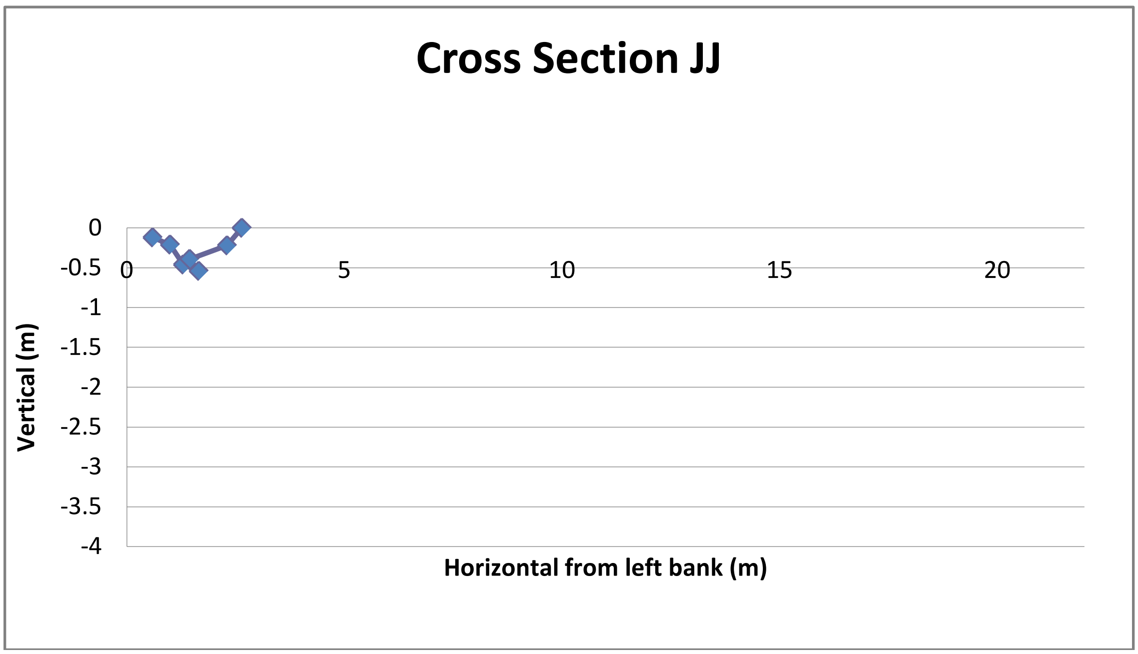

Cross Section EE
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

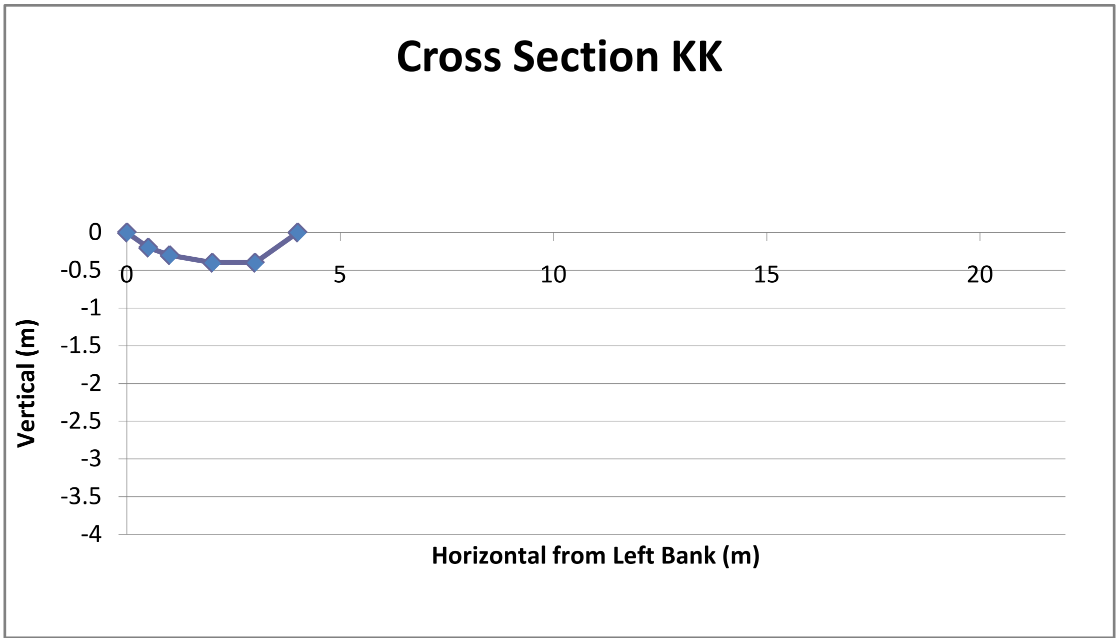

Cross Section FF
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from Left Bank (m)

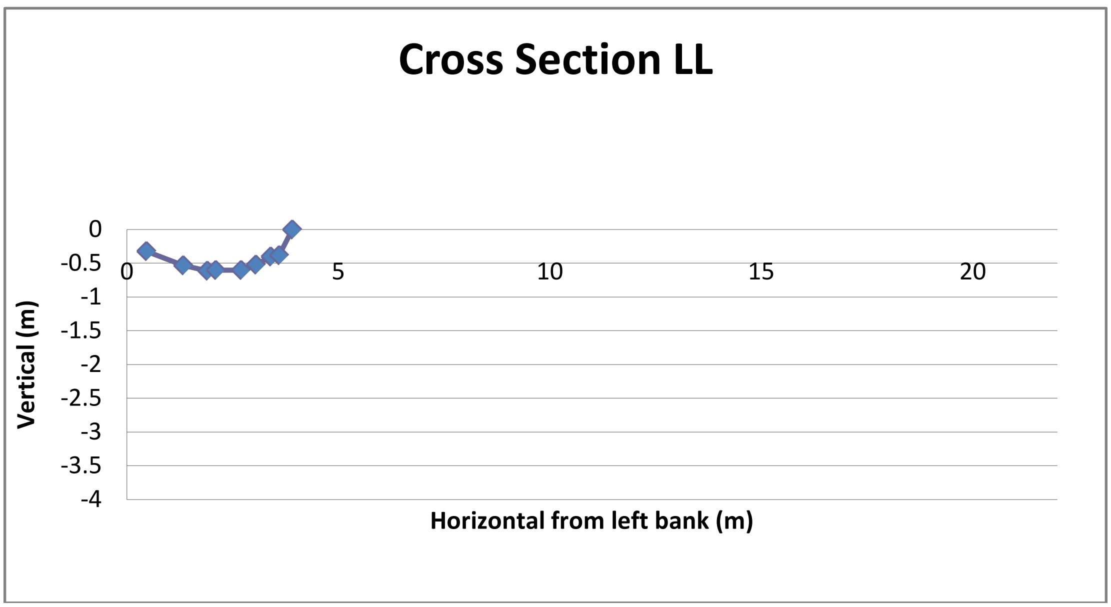

Cross Section GG
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)

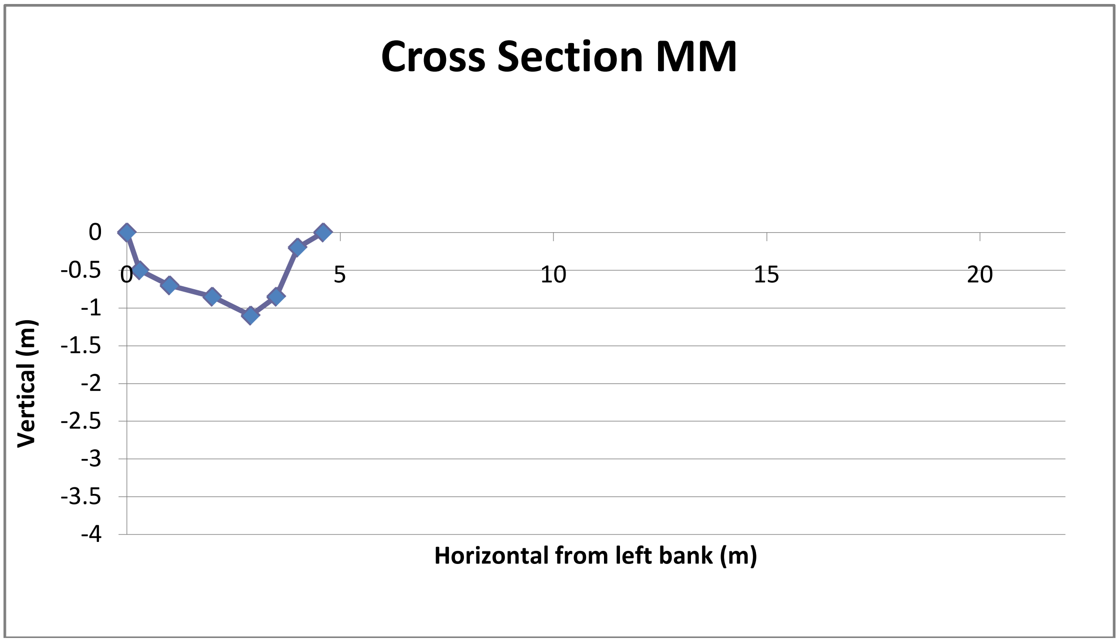

Cross Section HH
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)

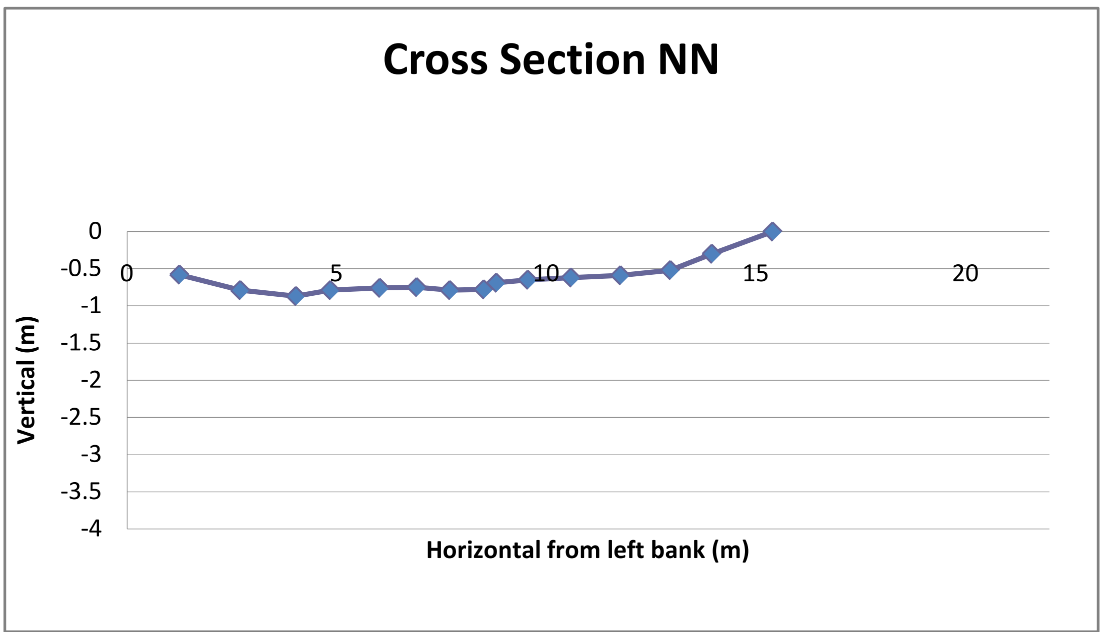

Cross Section II
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

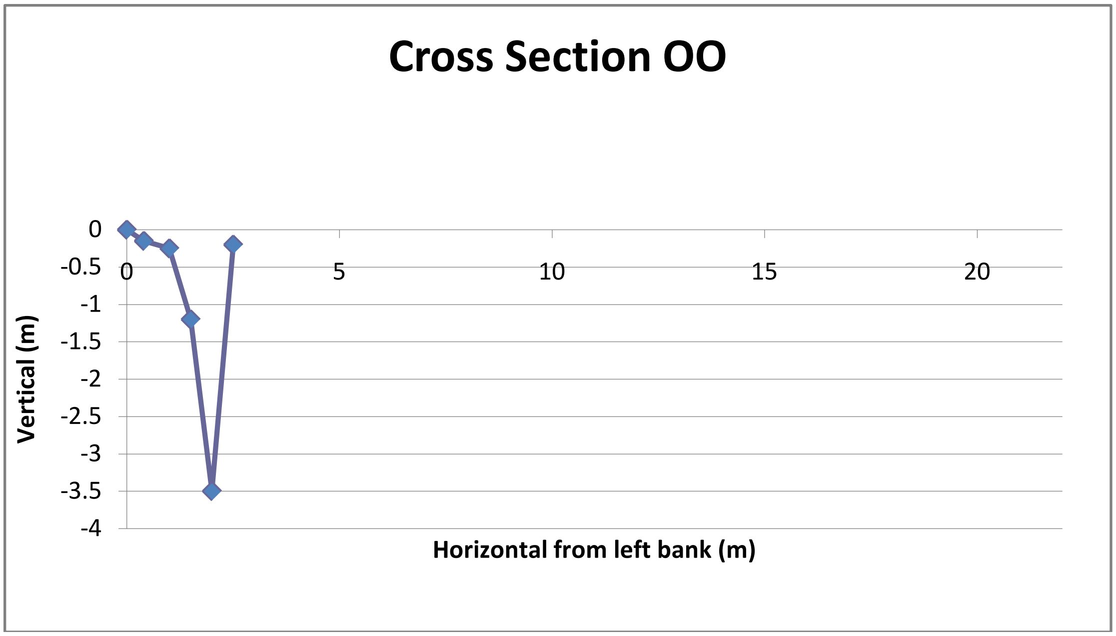

Cross Section JJ
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

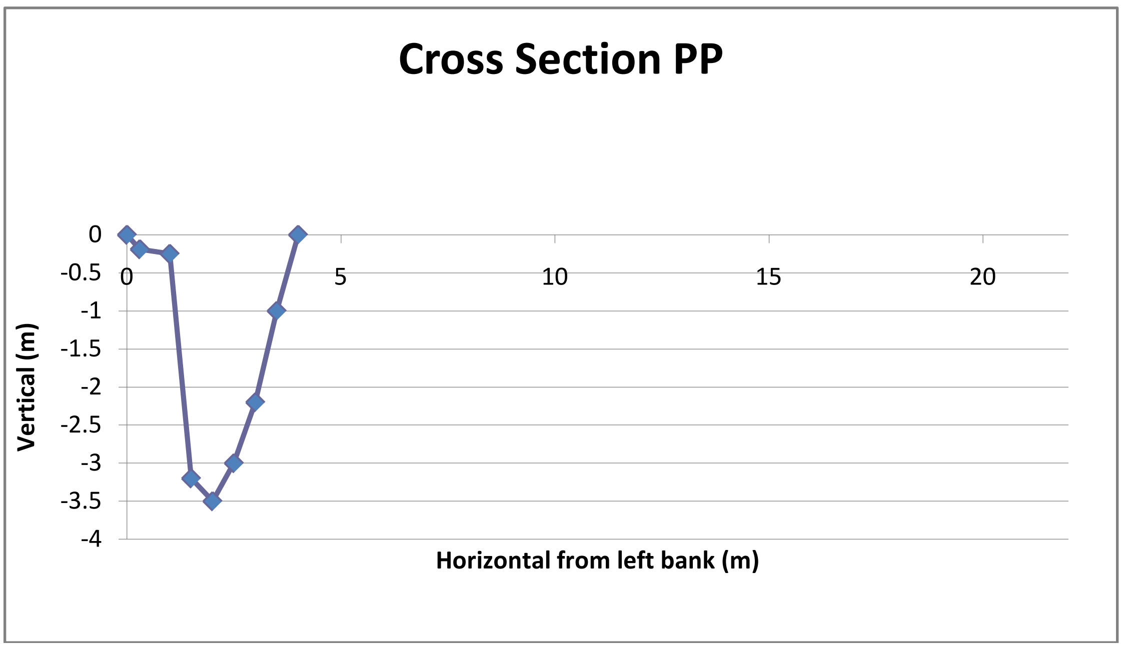

Cross Section KK
Vertical (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Horizontal from Left Bank (m)

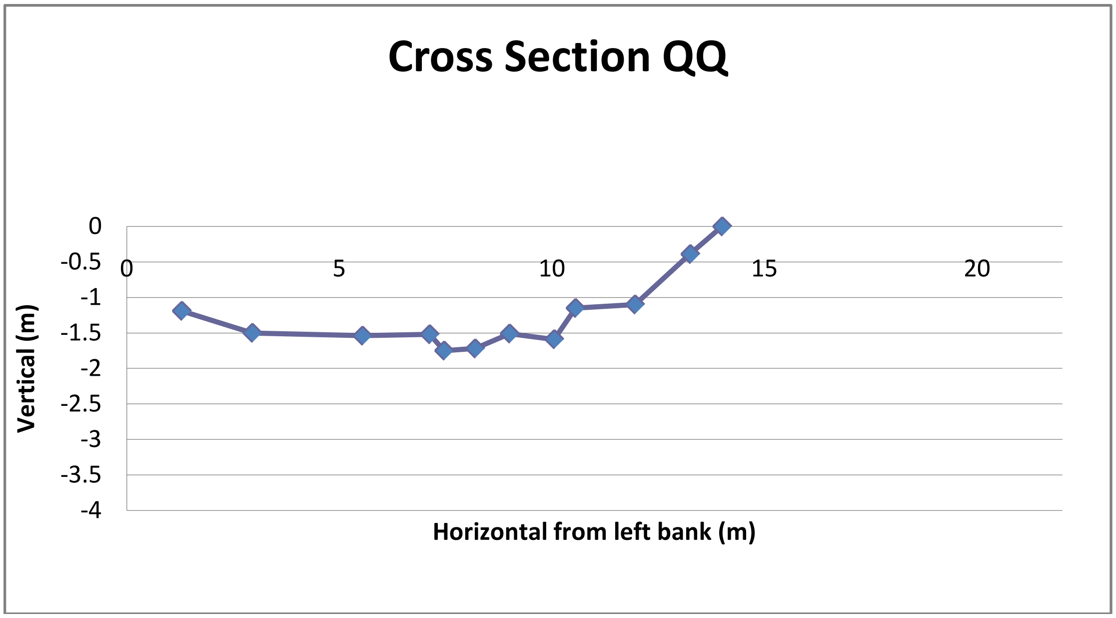

Cross Section LL
Vertical (m)
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Horizontal from left bank (m)

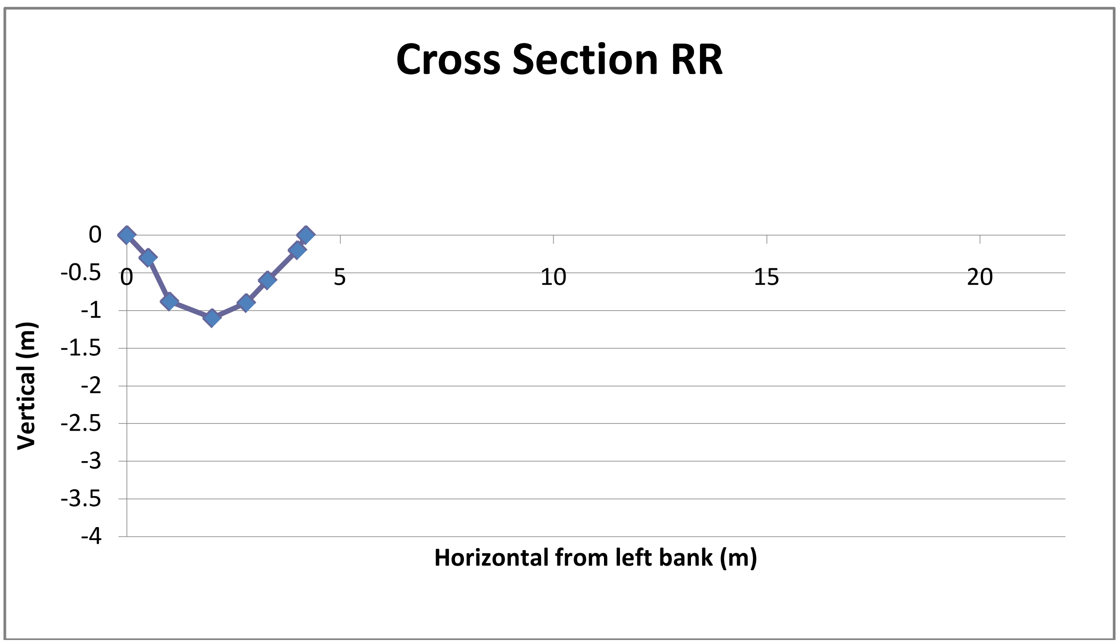

Cross Section MM
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

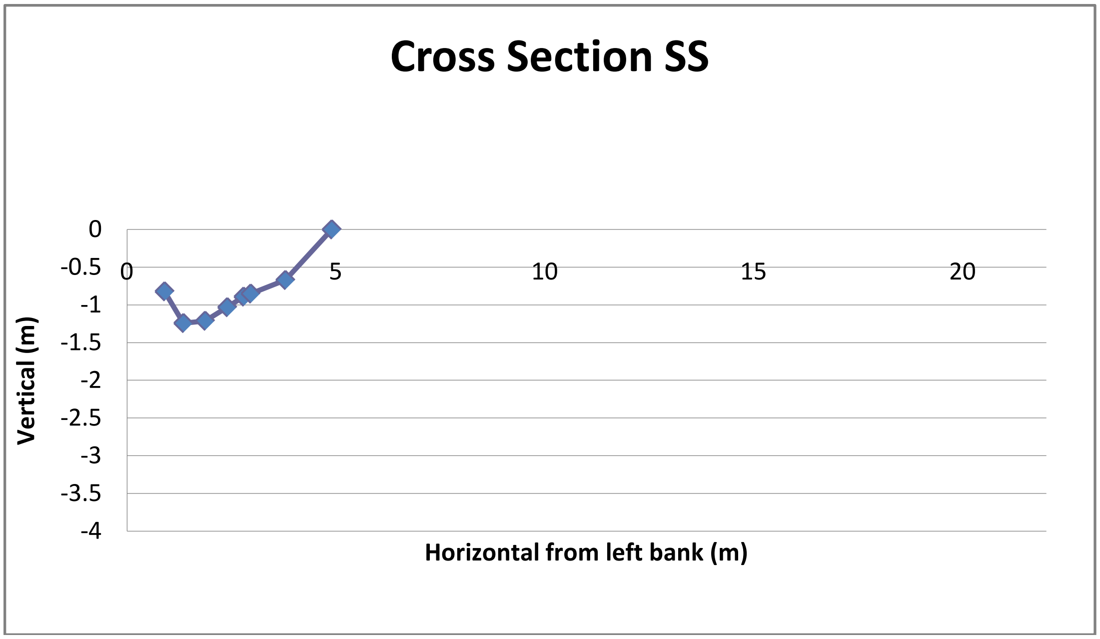

Cross Section NN
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)


Cross Section OO
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

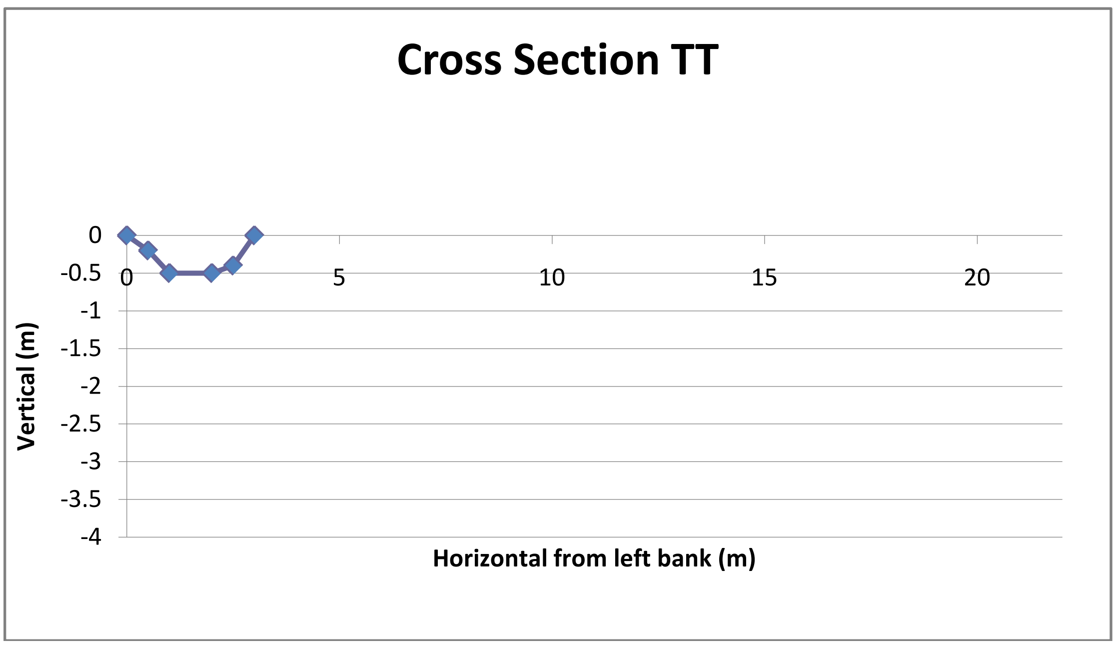

Cross Section PP
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)


Cross Section QQ
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

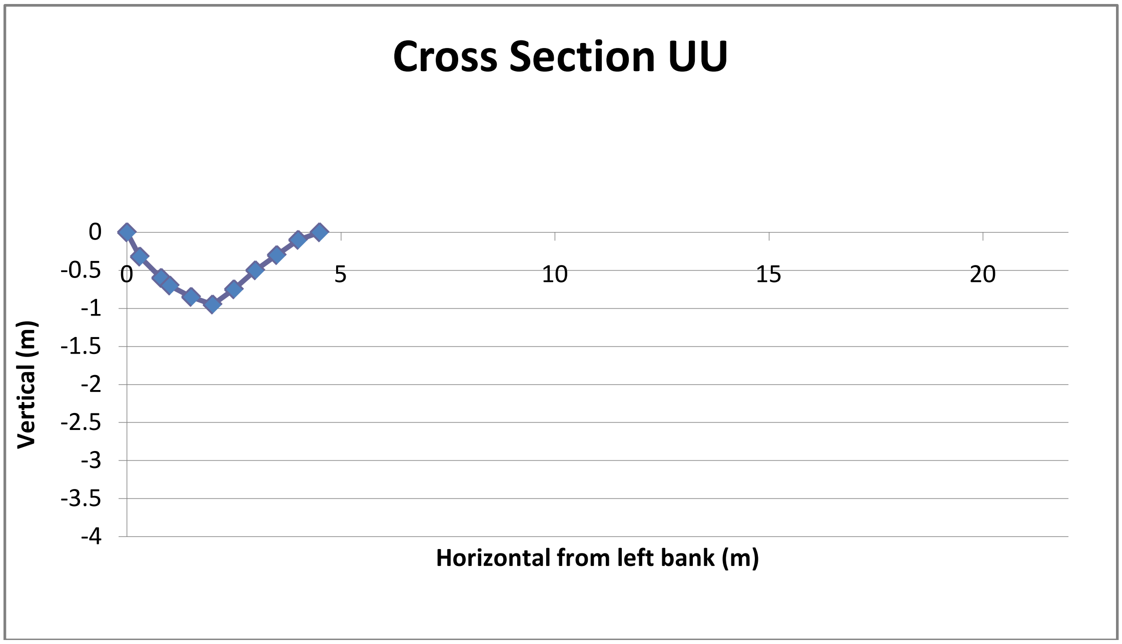

Cross Section RR
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

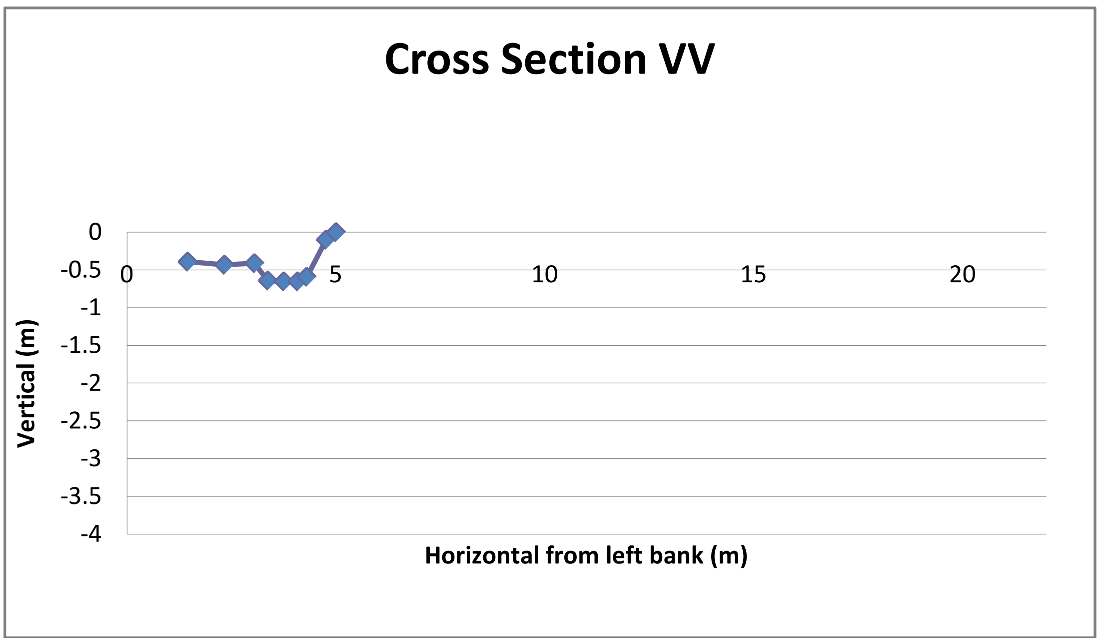


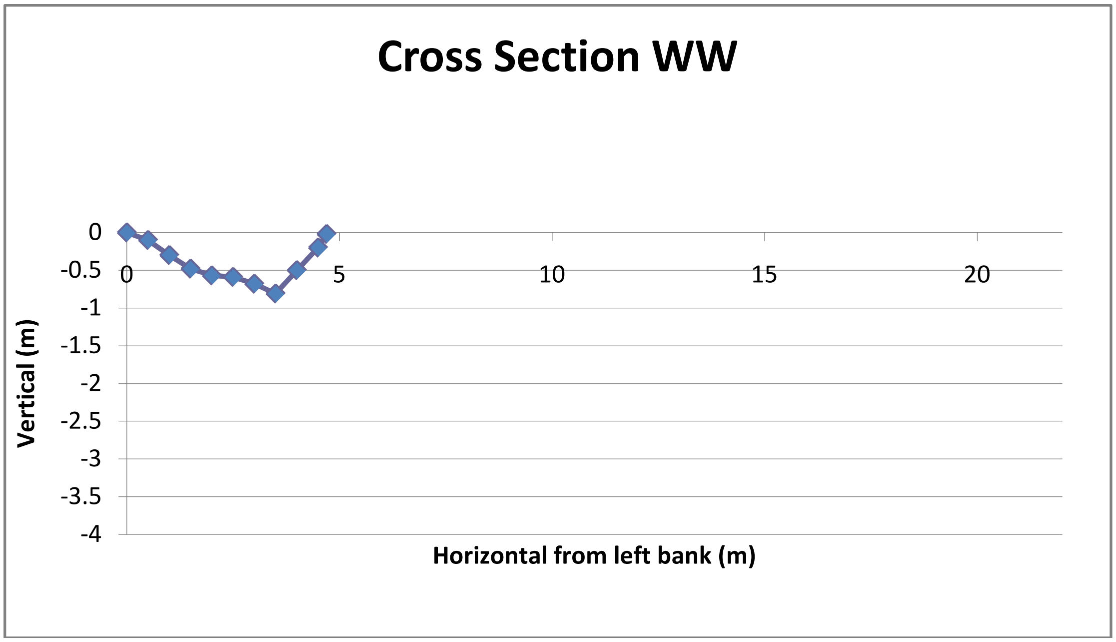
Cross Section SS
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)

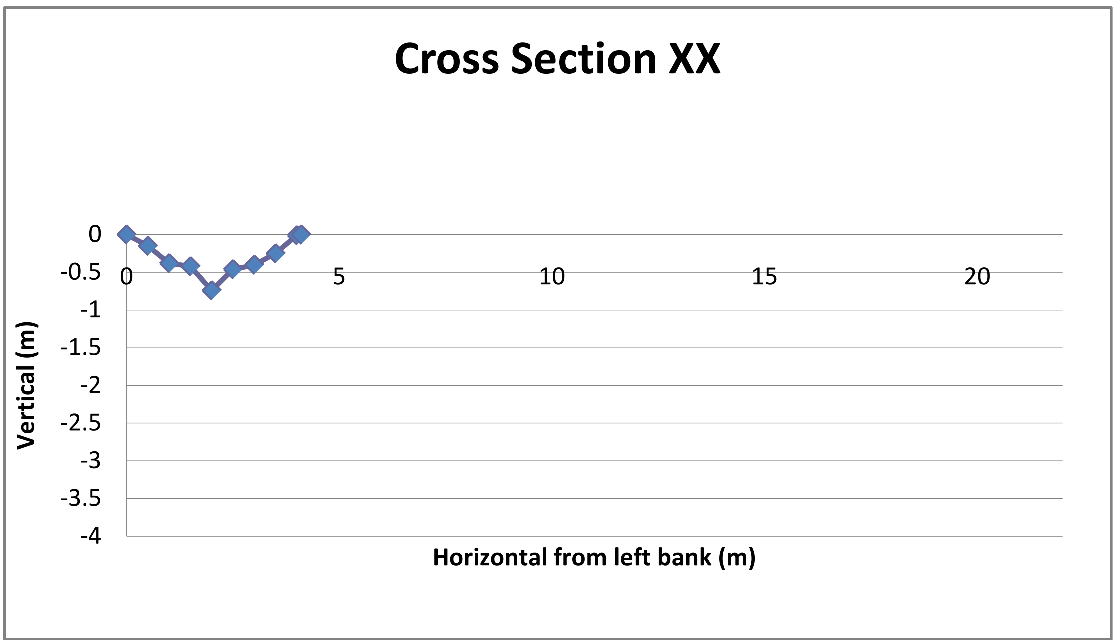


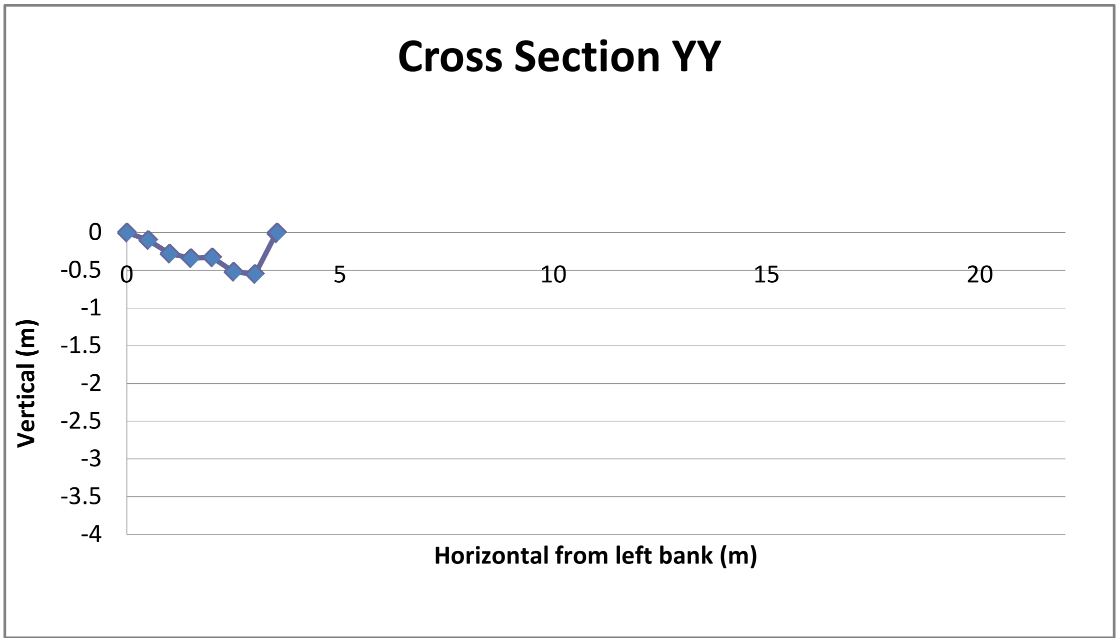
Cross Section TT
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)


Cross Section UU
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

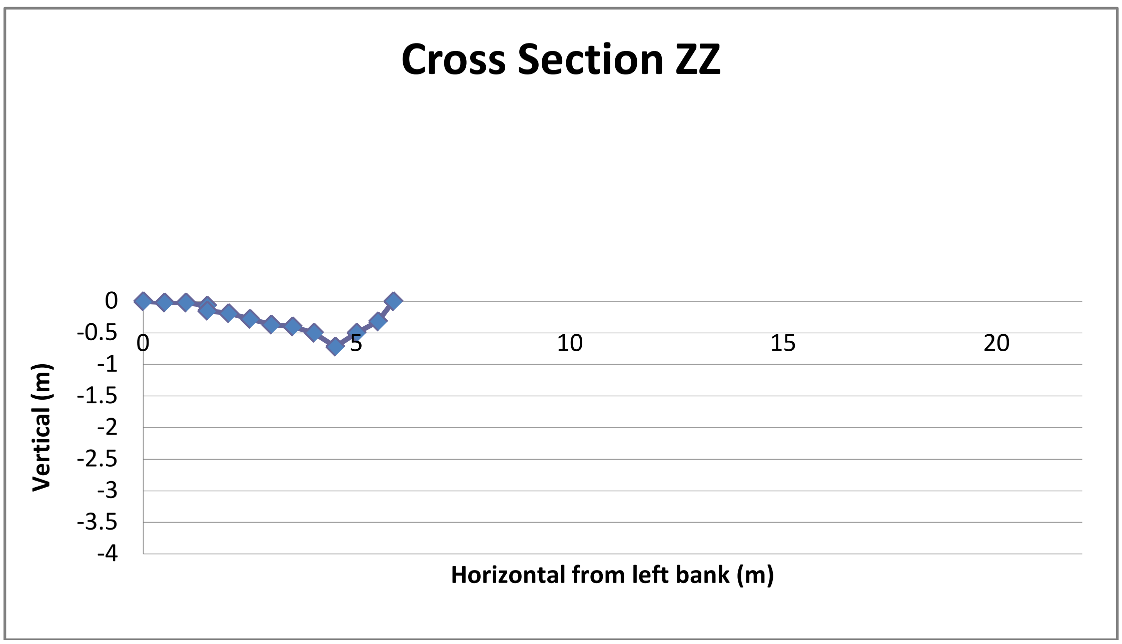

Cross Section VV
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)


Cross Section WW
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)

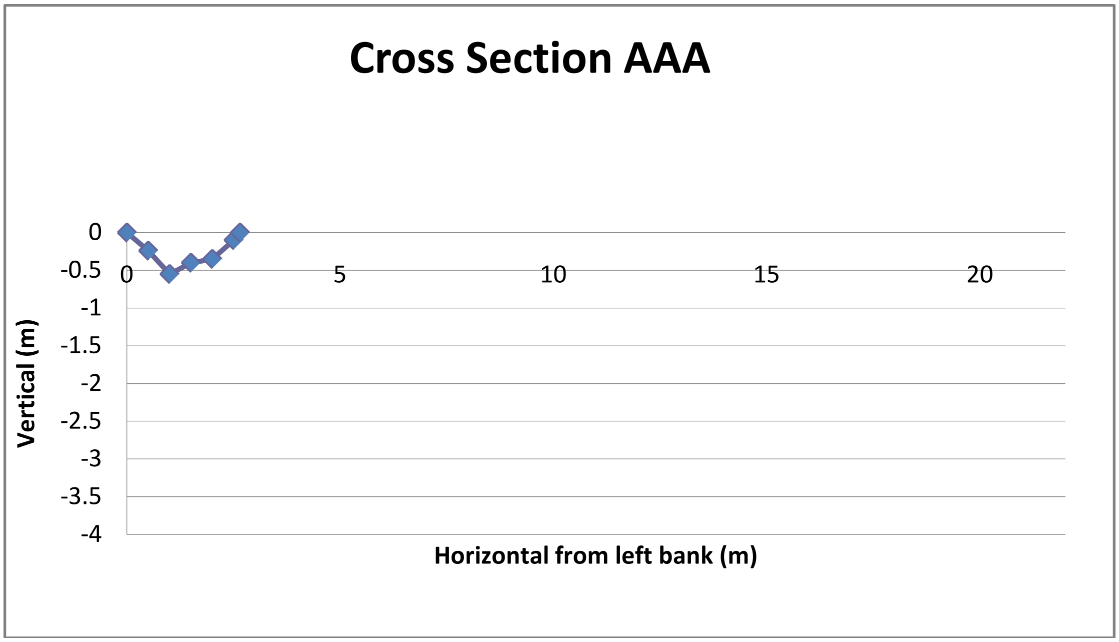

Cross Section XX
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)

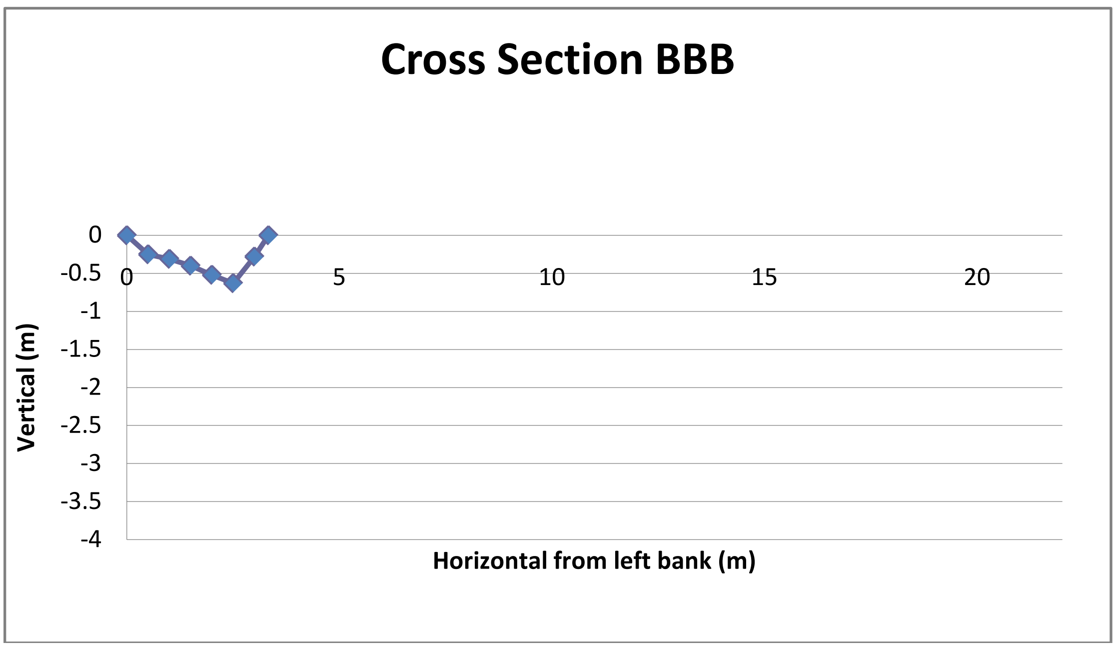


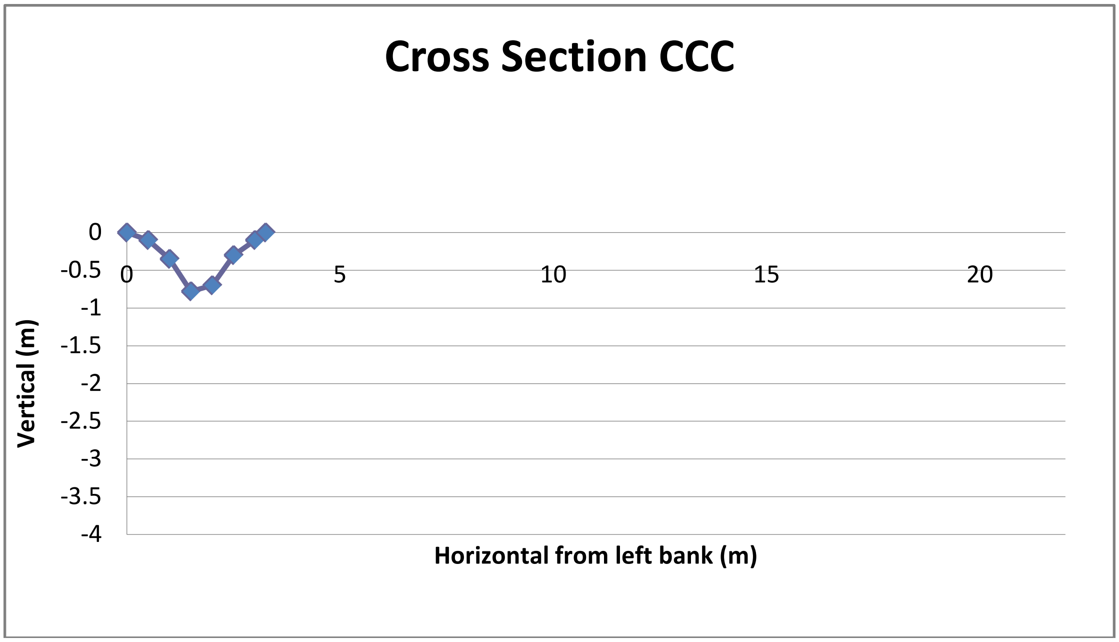
Cross Section YY
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

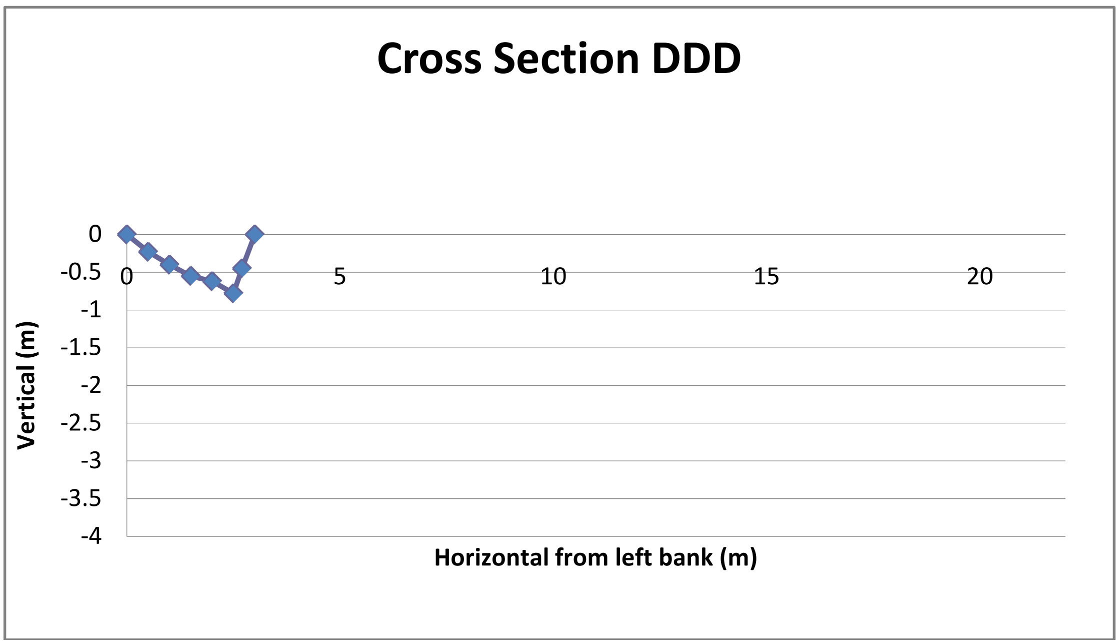


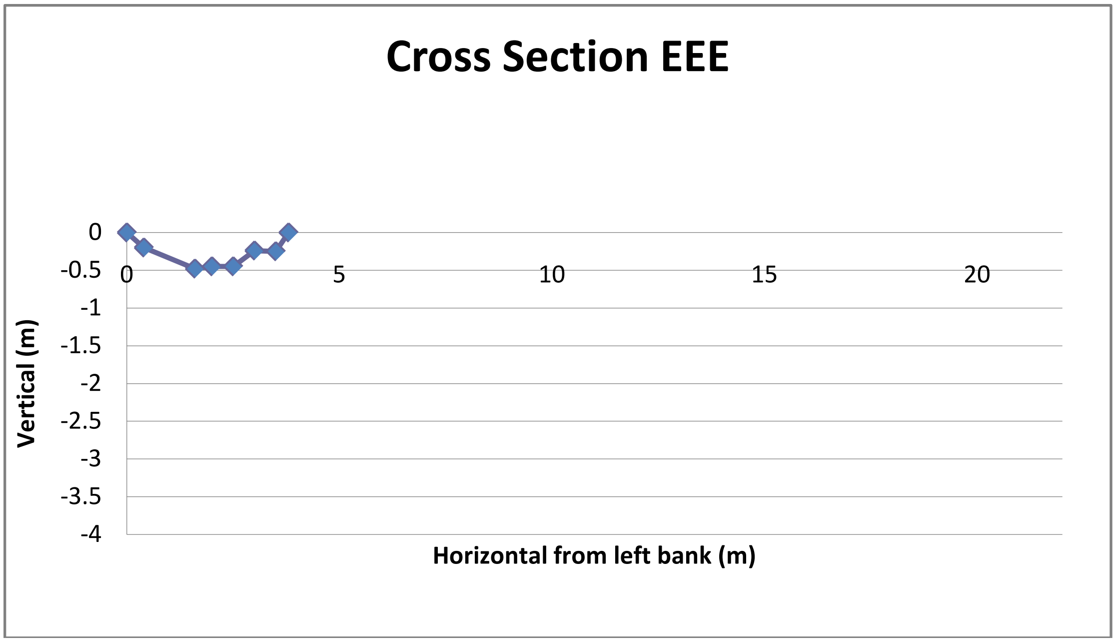
Cross Section ZZ
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)


Cross Section AAA
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)


Cross Section BBB
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)


Cross Section CCC
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)


Cross Section DDD
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
Vertical (m)
0
5
10
15
20
Horizontal from left bank (m)



Cross Section EEE
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0
5
10
15
20
Vertical (m)
Horizontal from left bank (m)

Appendix B: Aquatic Macroinvertebrate Analysis

A. Equations Used

a. Beck's Index
$BI = 3(n_{taxaHILSO}) + 2(n_{taxaHILS1}) + 1(N_{taxaHILS2})$
Where $n_{taxaHILSi}$ = the number of taxa in a sub-sample with a pollution tolerance value (PTV) of i
b. EPT Taxa Richness
EPTTR = # of taxa belonging to the insect orders Ephemeroptera, Plecoptera, or Trichoptera in a sub-sample
c. Total Taxa Richness
TTR = total # of taxa in a sub-sample
d. Shannon Diversity Index
$SDI = -\Sigma(n_i/N)\ln(n_i/N)$
Where n_i = the number of individuals in each taxa, and N = to the total number of individuals in a sub-sample.
e. Hilsenhoff Biotic Index
$HBI = \Sigma[(i * n_{indvPTVi})]/N$
Where $n_{indvPTVi}$ = the number of individuals in a sub-sample with pollution tolerance value (PTV) of I and N = the total number of individuals in a sub-sample.
f. Percent Intolerant Individuals
$PII = (\Sigma n_{indvPTVi})/N*100$
Where $n_{indvPTV}$ = The number of individuals in a sub-sample with PTI of I and N = the total number of individuals in a sub-sample.

B. Macroinvertebrate Metrics

Table B-1 Biotic Indices for MR-1 (Art Barn)

Index	**Raw Output**	**Standardized Output**	**Adjusted Standardized Metric Score**
Beck's Index	1	0.03	0.03
EPT Taxa Richness	0	0	0
Total Taxa Richness	12	0.34	0.34
Shannon Diversity Index	1.73	0.60	0.60
Hilsenhoff Biotic Index	6.11	0.47	0.47
Percent Intolerant Individuals	25.42	0.27	0.27
IBI Score			**28.52**

Table B-2 Biotic Indices for MR-2 (Gerhard Fieldhouse - U.S. 15)

Index	Raw Output	Standardized Output	Adjusted Standardized Metric Score
Beck's Index	1	0.03	0.03
EPT Taxa Richness	0	0	0
Total Taxa Richness	6	0.17	0.17
Shannon Diversity Index	0.74	0.25	0.25
Hilsenhoff Biotic Index	5.75	0.52	0.52
Percent Intolerant Individuals	11.72	0.13	0.13
IBI Score			**18.25**

Table B-3 Biotic Indices for MR-3 (Kenneth G. Langone Athletics and Recreation Center)

Index	Raw Output	Standardized Output	Adjusted Standardized Metric Score
Beck's Index	1	0.03	0.03
EPT Taxa Richness	0	0	0
Total Taxa Richness	8	0.23	0.23
Shannon Diversity Index	0.73	0.25	0.25
Hilsenhoff Biotic Index	5.82	0.51	0.51
Percent Intolerant Individuals	10.23	0.11	0.11
IBI Score			**18.72**

Table B-4 Biotic Indices for MR-4 (Loomis Street – Art Building)

Index	Raw Output	Standardized Output	Adjusted Standardized Metric Score
Beck's Index	0	0	0
EPT Taxa Richness	0	0	0
Total Taxa Richness	5	0.14	0.14
Shannon Diversity Index	0.61	0.21	0.21
Hilsenhoff Biotic Index	6.07	0.48	0.48
Percent Intolerant Individuals	3.51	0.04	0.04
IBI Score			**14.47**

Appendix C: References

References for restoration cost estimates

Demolition:

Rip Rap	R.S. Means-Cost Works Line Item 024113700400
Parking Surfaces:	R.S. Means-Cost Works Line Item 320116715320
Concrete Walls:	R.S. Means-Cost Works Line Item 024113900200
Culverts and Pipes:	R.S. Means-Cost Works Line Item 334113600100

Construction:

Log Cribbing	Delaware County Soil and Water Conservation District. *East Branch Delaware River Stream Corridor Management Plan*.
Culvert	R.S. Means-Cost Works Line Item 334113600100
Wetlands: Sojka	Department of Energy, Brookhaven National Laboratory. *Peconic River Remedial Alternatives: Wetlands Restoration/Constructed Wetlands*
Wetlands: Mods	California Storm Water Quality Association. *California Stormwater BMP Handbook: Constructed Wetlands*

Storm Water Management

2006 Pennsylvania Best Management Practices (BMP) Manuel

Misc. Inputs

Permits:	V.P. of Facilities Mr. Dennis Hawley
Legal Council:	V.P. of Facilities Mr. Dennis Hawley
BU Facility Cost:	V.P. of Facilities Mr. Dennis Hawley
Escalation & Contingency:	Industry Practice

Literature Cited

Chalfant, B. 2007. A Benthic Index of Biotic Integrity for Wadeable Freestone Streams in Pennsylvania. Pennsylvania Department of Environmental Protection.

McNally, C, DeProspo Philo, L, Joubert L. “The University of Rhode Island’s Permeable Parking Lots: A Case Study of Alternative Paving Methods”. University of Rhode Island Cooperative Extension. 2003. 1 May 2009. www.uri.edu/ce/wq/NEMO/Publications/PDFs/PP.uriCaseStudy.pdf

Pennsylvania Stormwater Best Management Practices Manual 2006 Pennsylvania Department of Environmental Protection, Bureau of Watershed Management, Document Number: 363-0300-002.

PA-DEP. 2007. Pennsylvania DEP Multihabitat Stream Assessment Protocol.