Assessment of Fluvial Geomorphology Projects at Abandoned Mine Sites in the Anthracite Region of Pennsylvania[1]

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ABSTRACT

Some watersheds have been so severely impacted by mining that the streams do not support aquatic life and can no longer accommodate flows or transport sediment. To fully recover the environmental resource of these scarred landscapes the land must be reclaimed and the streams reconstructed. As abandoned mine sites are being reclaimed to their approximate original contours, the hydrology of the watersheds will be returning to pre-mining conditions and generating base flows and storm discharges that residents may not have experienced in many years. A stable system will have to be designed to transport the flows and sediment while preventing erosion and flooding. Traditionally, rigid systems have been implemented that are rectangular or trapezoidal in shape and are constructed entirely of rock and concrete. These systems have a good survival rate but do not replace the resource that was lost during mining.

In an attempt to reclaim the watersheds that were destroyed during mining to a natural state, the application of Fluvial Geomorphologic (FGM) techniques has been embraced at several sites in the Anthracite Region of Pennsylvania. These sites have had various degrees of success. All of the sites were designed based on bankfull conditions and were immediately successful in creating habitat for a wide variety of species. Some sites remained stable until damaged due to extreme discharge events where design, construction, or implementation flaws were revealed in regions above the bankfull elevation. Other sites were not damaged at all even though they were hit by a storm of over a 100 year return interval. The cause of much of the damage has been determined but the solutions still need to be worked out. Only through further use of FGM will the answers be revealed.

This paper is an update of the paper presented by Dave Greenfield and Ron Ryczak at the 2008 NAAMLP conference in Durango, Colorado.

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INTRODUCTION

In the Anthracite Region of Pennsylvania, the mining of coal has been conducted since the mid 1800's, first by deep mining and later by surface mining. Many streams that were in the path of these mining operations were relocated numerous times as the mining progressed. When the mining ended these sites were abandoned, leaving the streams in an unnatural condition that caused aggradation or degradation, flooding, and other environmental problems. Some streams were directed into the abandoned strip pits and deep mine workings, adding to the mine pool volume and causing acid/alkaline mine drainage pollution. Other streams have been completely obliterated and encroached upon by development. These are some of the challenges the designers face in reclaiming and restoring streams.

Using a variety of effective and proven methods, engineers have been solving many of the problems that have been associated with abandoned mine lands. Designs for the backfilling of strip pits, grading of embankments, and the construction of wetlands have used innovative methods to restore these lands. The sealing of mine openings, rediversion of channels, construction of engineered channels, and sealing of streambeds above fractured strata have already restored a large volume of fresh water back to our waterways.

Controlling the flows from an abandoned mine site has always been a significant obstacle to overcome. The solution has often been to channelize the water and get it off the site as quickly as possible while ignoring the resource the water once provided to the watershed. Naturally this water may have once meandered through the watershed forming pools and riffles that were relied on by fish, birds, and mammals of the region.

To completely recover the environmental resources that were lost during mining, the streams should be restored to a natural state. The lack of a mathematical method to calculate the forces exerted by storm flows throughout the newly constructed channel or ditch, and the lack of science that can predict how the stream will react at a reclamation site may cause many engineers to shy away from experimenting with new methods.

Fluvial Geomorphology (FGM) is promising methodology to predict what type of natural channel was at the site before mining. FGM is the study of streams that are at equilibrium with their watershed. These naturally occurring streams are called reference reaches. This data is used to determine the dimension, pattern, and profile of the stream before mining.

The design data is collected at the reference reach that has been identified for the restoration site. Cross sections and profiles should be surveyed to prepare for extraction of geomorphological data. At the cross section, one will be able to determine the stage at which the channel is being formed, which is called *bankfull*. This stage or elevation is the single most important parameter used in classification, because bankfull is a function of the dimension, pattern, and profile of the stream.

CHALLENGES

The application of FGM at abandoned mine sites has many obstacles that do not exist at traditional FGM applications. The landscape is often void of any remnants of the stream that once existed there. Floodplains, rock outcrops, and vegetation that once helped to control the channel have all been removed. Very infertile and erosive mine spoils are used as soil to regrade the floodway. High runoff and erosion rates on newly reclaimed sites compromise the integrity of the channel. Most sites have other mining features above ground and below that change the dynamic altering the expected flows. Encroachment by property owners, developers and municipalities has blocked the location of the waterway.

These factors make estimating the bankfull discharge of a mined watershed very difficult, and planning for an historic event harder. Over estimating the flows will result in a channel that will not function properly and underestimating could result in a disaster.

DESIGN

The design data is collected at the reference reach that has been identified for the restoration site. Cross sections and profiles should be surveyed to prepare for extraction of geomorphological data. At the cross section, one will be able to determine the *bankfull* discharge of the watershed. This stage or elevation is the single most important parameter used in classification, because bankfull is a function of the dimension, pattern, and profile of the stream.

Bankfull discharge is associated with a momentary maximum flow that, on the average, has a recurrence interval of 1.5 years as determined using a flood frequency analysis (Dunne and Leopold, 1978). This interval may vary from 1 – 2 years for most watersheds, to a 1.2 year return for highly developed urban watersheds. A universally accepted definition of bankfull was also provided by Dunne and Leopold in 1978. "The bankfull stage corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphological characteristics of channels."

Determining bankfull can be accomplished by various methods. First, if a reference reach is available, measurements can be taken as described previously. Second, if a USGS gaging station for a similar channel in the watershed or adjoining watershed exists, data from that station can be analyzed to determine bankfull and other parameters to be utilized in the stream design. Last, if a reference reach or gaging station is not available (which more than likely happens in disturbed mining areas), a *regional curve* may be used. These curves have been developed for various hydro-physiographic provinces in the United States. The curves compare drainage areas to bankfull width, cross-sectional area, and mean depth. Ideally, a regional curve should be developed for each local region to provide a more accurate determination of the characteristics of streams in that region. In Pennsylvania, the regional curve developed by Dunne and Leopold for South Eastern Pennsylvania is being utilized. Additional curves that are more specific to the particular hydro-physiographic regions within Pennsylvania are presently being developed. Reclamation of mine sites and the construction of natural stream channels will provide sites for future regional curve development data collection. Bankfull is also being estimated by computer models. Sophisticated software that has been developed for erosion and sedimentation control purposes, and considers many site specific variables can accurately predict bankfull. This resource is an excellent tool to verify bankfull.

Once bankfull discharge is known, one can begin to determine the stream type with which one is dealing with by identifying the five (5) primary criteria used for the Rosgen Classification. The five "Rosgen" criteria are the following:

1) Entrenchment

Entrenchment (ER) is generally the ratio of the width of the existing flood prone area (W_{fpa}), divided by the width of the bankfull stage (W_{bkf}),

$ER = W_{fpa} / W_{bkf}$

where the bankfull width (W_{bkf}) at the bankfull stage elevation and the flood prone area width (W_{fpa}) is the width at twice the maximum depth of the bankfull stage.

2) Width/Depth Ratio

The width/depth (W/D) ratio is the stream's width at bankfull (W_{bkf}), divided by its mean depth (d_{bkf}) at bankfull.

$W/D = W_{bkf} / d_{bkf}$

The width/depth ratio determines the velocity and shear stress distributions within the channel during channel-forming bankfull flows. An improperly dimensioned channel will not be able to transport sediment, and will be susceptible to problems such as bank erosion, aggradation, and degradation because the energy is not properly distributed.

3) Sinuosity

Sinuosity (K) is the stream length (SL) divided by the valley length (VL).

K = SL / VL

Sinuosity is the result of the path a stream takes to dissipate energy. In nature, a channel strives to reach a form where the dissipation of energy is simplest.

4) Channel Materials

The composition of the channel bed and banks influences the stream's sediment transportation capability and its resistance to erosion. The analysis of bed materials is done by a "pebble count", which measures the size distribution of the bed material at the bankfull stage.

5) Slope

The slope of a channel is measured as the difference in water surface elevations along a length of stream. A profile taken along the reference reach will identify the slope. The slope of the channel plays a major role in determining the stream classification.

The results of the field work and calculations will enable values for the five (5) criteria to be determined. Then a stream type can be chosen using the Rosgen Classification of Natural Rivers. (Figure 1, see Page 12) This will show the range of values for which the criteria could have fallen within the same stream type. Now, knowing the range, the proper channel can be geometrically fit into the project. The criteria are interdependent. A change in sinuosity will affect the slope, which could change the bankfull dimensions, thereby changing the width/depth ratio and the entrenchment. The proper channel type will be stable at the restoration site only within the ranges of the classification criteria; and will rely on the proper installation of in-stream grade controls and placement of stabilization structures. Site-specific design decisions will be necessary to prevent any portion of the project from deviating out of range.

After the geometry of the proposed channel is laid out, structures for grade control and bank erosion protection must be designed. Pebble count data in the reference reach riffle area is used, along with bedload data from a *point bar* (a depositional feature on the inside bend of "C" type channel) in the stream, to calculate Manning's "n", shear stress, and probable scour depth for the proposed channel.

RESULTS

There have been five projects completed at abandoned mine sites in Pennsylvania that have utilized natural channel design principles. They have had varying degrees of success and some have succumb to various forces of nature. To follow are brief descriptions of the completed projects.

PARDEESVILLE

This project was the first FGM project with construction being completed on December 30, 1998. The project included elimination of three hazardous water bodies and one thousand linear feet of highwall while creating twenty-two hundred linear feet of stream channel that was removed during mining.

The proposed channel was classified as a "C" channel with a bankfull discharge on 30 cfs, a bankfull width of 10 feet, bankfull depth of 1.5 feet and a bankfull cross sectional area of 15 ft^2. This channel was designed at a slope of eight tenths of one percent (0.008 ft/ft). The slope changed along the profile from 0.01 ft/ft to 0.006 ft/ft, to provide for a riffle/pool sequence in the channel. There were nineteen (19) bends incorporated to provide the sinuosity needed to dissipate the stream's energy. At the outside bank of each bend, channel stability and habitat structures comprised of trees from the site, used to deflect flow velocities; or rock veins installed to roll the flows and direct velocity toward the center of the channel were installed to take stress off of the banks. The entire channel was placed inside a 100+ foot wide, grass-lined floodplain at a set meander geometry. This geometry was calculated between 90 feet and 135 feet long for meander length, and between 25 feet and 45 feet wide for meander width. The profile and geometry values were derived as a function of bankfull. The floodplain was designed to contain flows in excess of 800 cfs, the flow expected during a 100 year storm event. Although it is classified as a C3 channel because certain parameters, the width/depth ratio of 6.7 suggests more of an E3 type classification.

The timing of the project's completion was worrisome because it was seeded in late fall, with no chance of vegetative cover being established before the spring thaw. The site was monitored closely as bank erosion continued throughout the spring of 1999 until the summer when the vegetation filled in and the channel appeared to stabilize. Then willow stakes were harvested and planted at the site to further stabilize the banks. The channel has remained stable through many rain events including the historic flood of June 2006 when most lower order streams in Northeastern Pennsylvania sustained significant damage.

KEYSER AVENUE

Construction of the Keyser Avenue project, Lackawanna County, Pennsylvania, was completed on November 30, 2000. This project addressed a section of Lucky Run that was experiencing severe bank erosion and its bed was highly fractured. This portion of Lucky Run was removed during strip mining in the 1940's. A rock-lined channel was constructed to convey flows in the 1970's when the strip pits were reclaimed by Lackawanna County during the construction of a county park that was later named McDade Park.

The valley slope at this site is so severe that velocities in the channel exceeded 20 fps. During storm events and rapid snow melt periods the large, nearly boulder sized riprap was being moved requiring numerous riprap repairs and culvert cleaning projects.

The bankfull discharge was determined by measuring existing conditions, consulting a regional hydrology curve of Eastern Pennsylvania, and developing a computer hydrology model for this 1.1 square mile watershed. Data was collected by delineating the bankfull indicators and then surveying for the cross-sectional area and channel slope. The bankfull cross-sectional area was measured to be approximately 25 square feet. This data was then used to calculate a bankfull discharge of 60 cfs that was confirmed from the regional curve and computer model. The three methods confirmed bankfull, allowing the bankfull dimension to be gleaned from the regional curve for the region. The bankfull width is 16 feet, the bankfull cross-sectional area is 25 square feet, and the mean bankfull depth is 2.5 feet.

The design that was developed was for an "A2" channel with a step pool sequence. The geometry of the channel was planned using a sinuosity of 1.11. The overall channel slope was 8.6% with slopes varying along its profile from up to 18% for the steps and 1% for the pools. The steps were spaced 60 feet apart or 3.75 times bankfull. These values were derived for the site conditions and conformed values for stable conditions found at other type "A" streams.

Another key component of the design was to line the entire bankfull channel with a buried PVC liner to prevent infiltration into an underground coal mine tourist attraction situated beneath the project. This technique had been very successful at preventing infiltration in rock lined ditches on numerous AML projects.

The site was closely monitored for stability and morphologic changes. The County planted and landscaped the riparian zone in the spring of 2001. The channel handled many severe rain events over the next several years and seemed indestructible until rain from Hurricane Ivan, in September of 2004, caused several structures to fail. The structures were replaced and improved shortly thereafter by the Department's in-house construction crew. All seemed well with the channel until the historic June 2006 rainfall when most of the structures failed. This time the damage was deemed too significant to handle in-house and before a contract could be let a series of small storms destroyed the channel causing severe downcuts and bank erosion.

<u>MIDDLE CREEK</u>

This was the third project and was completed in 2003 by combining aspects of the first two designs. Over one thousand feet of channel with flood plain was recreated after backfilling two huge strip pits that were trapping the stream flow. The stream was lined with PVC to the bankfull stage as was done at Lucky Run.

The design was developed was for a “B3a” channel. The bankfull discharge was determined to be 115 cfs with a cross-sectional area of 34 square feet, bankfull depth of 1.5 feet and a bankfull width of 22 feet. The floodplain was designed to be 70 feet wide at the bankfull elevation. Slope was 0.06 ft. /ft.

The new section of channel was monitored closely and during the first storm event it was evident that sections of the channel were constructed incorrectly as water was running around the structures and some of the flood plain was well above the bankfull elevation. The poorly constructed structures were reset by the Contractor and it was determined to leave the floodplain as is.

The project vegetated and stabilized quickly. The project remained stable throughout the next several years including being unscathed by hurricane Ivan in 2004. The storms of June 2006 again were the undoing of this channel. The water level rose well above bankfull and got behind the liner and rock structure. This caused several structures to fail and clog the channel. Then during subsequent rainfall events the stream had to abandon the clogged channel and the damage snowballed downstream. Currently there is a large section of channel in the center of project that remains destroyed while other sections remain looking natural.

JESSUP CEMETERIES

The next project that was designed attempted to realign Grassy Island Creek in Lackawanna County, Pennsylvania. The stream cut through a vast mine spoil area and was yearly producing an incredible amount of sediment pollution to the Lackawanna River during storm events. During the rest of the year, the entire base flow was lost to the deep mines. The five square mile Grassy Island Creek watershed was classified as the best tributary to the Lackawanna River, but the resource was being lost to the deep mines.

The design was for a large “B/C” channel with smaller high velocity flows being transported in the main channel in a series of steps and pools (B3) or riffles and pools (C3b), with the larger flows spreading over a constructed 104 foot wide flood plain. The bankfull discharge was determined to be 190 cfs, with a bankfull width of 28 feet, and a bankfull cross-sectional area of 57 feet. Channel bed protection was accomplished utilizing J-hook vanes and cross-vanes. Root wads were installed in the stream to provide a habitat for aquatic wildlife. PVC liner was installed in approximately 1280 feet of the channel where underground mining existed to prevent infiltration into the workings.

This project was constructed in 2004 and was immediately very unstable. The material at the site was mostly mine silts, red ash and shales that were easily transported by flow and not conducive to growing vegetation. Because of the lack of vegetation and the composition of the bed material, sections of the PVC liner were exposed. Another problem that made the channel unstable was that the sections of the floodplain were constructed above the bankfull elevation leaving it disconnected form the channel and unable to function a dissipater of energy. The stream banks eroded rapidly because the pressure on them was not capable of reaching the floodplain.

The following year, the Department's in-house construction crew was used to grade the floodplain to the design elevations and to repair damage to the channel. The vegetation at the site was still very sparse particularly within the channel were the silt had washed away and apparently the seed with it. The channel bed was now nothing but pebbles and boulders with the PVC liner seeming to prohibit any type of vegetation from volunteering and sinking deep roots.

This channel never stabilized as we would have liked, but it did survive the June 2006 storm better than others. It sustained significant damage at the transition areas with only minor damage at the section with a floodplain.

In 2009, it was decided to design a project to repair sections of the creek that have been compromised, while leaving other sections that appear to be stable alone. Certain portions of the creek that saw severe damage were reconstructed utilizing rock riprap designed to handle a 100 year-24 hour storm event. The remainder of the creek was left at its natural state in most places with rock armoring placed at the outside bends. One two-tier rock riprap channel was constructed to divert the flow around an abandoned railroad stone culvert that is in poor condition. The lower tier conveyed bankfull flows and the upper tier the 100 year flood event. During the storm of 2006, flood flows were redirected around the culvert through a low area, subsequently connecting with the creek downstream of that culvert. Since that path was the path of least resistance, the new riprap channel was constructed in the same location. Another two-tier riprap channel was constructed just upstream of an active railroad stone arch culvert at the terminus of the project to allow a smooth transition of high flows into that culvert. Above that channel, three rock cross vanes were constructed to control grade in that steep reach of the creek. The project was completed in December of 2012.

In June of 2103, a localized storm that was measured between 5 and 6 inches fell in the Jessup Area. The stream channel remained intact with some minor areas that will need repair. The cross vanes worked as designed with the exception of one vane that some of the flow found a low spot and circumvented the vane. This will be raised and armored in the near future.

<u>HOLLARS HILL</u>

This project, completed in the spring of 2008, was a huge earth moving operation to reclaim strip pits and to replace a stream that was removed during mining. The stream had a contributing watershed of 6.4 square miles. The design was for a very flat "C4" type channel with a bankfull discharge of 250 cfs, a bankfull width of 30 feet, a bankfull mean depth of 2.5 feet and a bankfull cross-sectional area of 80 square feet. A 180 foot wide floodplain was constructed along the channel.

No rock structures were used because the expected velocities were less than 3 fps and bank erosion or down cutting are not expected. Towards the western end, about half of the length of the channel was lined through the deep mined area to prevent infiltration into the mine workings.

Due to site restrictions, the sinuosity of the C4 channel was slightly lower (1.03) than the 1.43 – 1.76 low-end range of a C4 type stream. This was expected to not cause any major problems due to the fact that this reach of Cranberry Creek functions as an intermittent stream at present. It should handle only stormwater runoff with minimal baseflow and will operate with less than bankfull conditions for a majority of the time. To address this, an "E4" type channel was constructed inside of the C4 channel to handle the 90 cfs present condition bankfull discharge. This watershed measures 2.1 mi^2 at the present time. This channel will allow stormwater flows to pass through the creek without compromising the integrity of the C4 channel.

Vegetation at the site took off quickly and the stream seems to have stabilized nicely. The site will be closely monitored into the future. It is expected that a naturally stable stream will have been created at this site.

OBSERVATIONS

The past years experimentation with FGM has been very rewarding and very deflating when a portion of the stream failed. Every project had so many successful aspects that have encouraged us to continue designing and monitoring FGM projects. The question has become, what could we have done differently? The following is a list of observations made for the improved implementation of natural channels.

Construction

The channel needs to be constructed according to the plans. Any portion of the plans that is not constructed properly should be immediately corrected. The repair of damage caused because of poor construction is very costly and time consuming.

Vegetation

Getting as much vegetation started as quickly as possible on the site is very important. Vegetation is an important component of any naturally stable channel. The planting of trees and other plants with deep roots should be considered to enhance the stability of the channel.

PVC Liner

It is recommended the use of PVC Liner on natural channels be discontinued. The liner prevents vegetation from sinking deep roots and the liner produces a zone of instability in the stream bank. When the liner is uncovered it can be torn by debris in the channel and if the water gets behind it significant damage can occur.

Structures

Grade control structures and bank stabilization structures that are damaged should be repaired immediately. The damaged channel stability might be compromised to the point that any subsequent storms will continue to pile on the damage.

Design

Consideration should be given to including in the design controls that will address the 100 year flood or even greater. This could include the design of grade control structures that extend well above the bankfull elevation.

Floodplain

Floodplains should be included in the design to allow for pressure relief of the stream banks by having the flows to exit the channel at the bankfull elevation and to re-enter when the storm subsides.

Steep Channel Design

We observed that the “C” and “E” channels held up much better than the “B” or “A” channels on steeper grades. As noted earlier, PVC liner should not be used especially in steep channel design, where large storm events tend to unravel the liner. Although the sinuosity of steep channels was in the parameters of Rosgen’s chart, reducing the K ratio to near 1.00 may reduce bank erosion during super high flows.

CONCLUSION

It took nature thousands of years carve a stream into a stable configuration while it took mankind only a few decades to undo the landscape in the mining regions. There are many abandoned mine sites that have the potential to be restored with a naturally functional stream. One only has to look at the success at few sites to see what can potentially be accomplished. The transformation will not happen over night and the first attempt might not always succeed, but that should not discourage us from recovering the resources that were lost during mining. The alternative is to collect the water and then get it off the site as quickly as possible while losing a valuable natural resource forever.

LITERATURE CITED

Rosgen, D. L. (1996): Applied River Morphology. Printer Media Companies, Minneapolis, Minnesota: 336 pp.

<u>Figure 1. Key to the ROSGEN Classification of Natural Rivers.</u> As a function of the "continuum of physical variables" within stream reaches, values of **Entrenchment** and **Sinuosity** ratios can vary by +/- 0.2 units; while values for **Width/Depth** ratios can vary by +/- 2.0 units. [This table is from "Applied River Morphology" (Rosgen, 1996).]

	Single-Thread Channels														Multiple Channels			
Entrenchment Ratio	Entrenched (Ratio: <1.4)						Moderately Entrenched (1.4-2.2)			Slightly Entrenched (> 2.2)								
Width/Depth Ratio	LOW Width/Depth Ratio (< 12)				Moderate to HIGH W/D (> 12)		MODERATE Width/Depth Ratio (> 12)			VERY LOW Width/Depth (< 12)		Moderate to HIGH Width/Depth (> 12)			Very HIGH Width/Depth (> 40)			LOW W/D (< 40)
Sinuosity	LOW Sinuosity (< 1.2)		MODERATE Sinuosity (> 1.2)		MODERATE Sinuosity (> 1.2)		MODERATE Sinuosity (> 1.2)			VERY HIGH Sinuosity (> 1.5)		HIGH Sinuosity (> 1.2)			LOW Sinuosity (< 1.2)			Low-Hi Sinuosity (1.2-1.5)
Stream Type	**A**		**G**		**F**		**B**			**E**		**C**			**D**			**Da**
Slope	Slope Range		Slope Range		Slope Range		Slope Range			Slope Range		Slope Range			Slope Range			Slope
	> 0.10	0.04-0.099	0.02-0.039	< 0.02	0.02-0.039	< 0.02	0.04-0.099	0.02-0.039	< 0.02	0.02-0.039	< 0.02	0.02-0.039	0.001-0.020	< 0.001	0.02-0.039	0.001-0.020	< 0.001	< 0.005
CHANNEL MATERIAL																		
Bedrock	A1a+	A1	G1	G1c	F1b	F1	B1a	B1	B1c			C1b	C1	C1c-				
Boulders	A2a+	A2	G2	G2c	F2b	F2	B2a	B2	B2c			C2b	C2	C2c-				
Cobble	A3a+	A3	G3	G3c	F3b	F3	B3a	B3	B3c	E3b	E3	C3b	C3	C3c-	D3b	D3		
Gravel	A4a+	A4	G4	G4c	F4b	F4	B4a	B4	B4c	E4b	E4	C4b	C4	C4c-	D4b	D4	D4c-	DA4
Sand	A5a+	A5	G5	G5c	F5b	F5	B5a	B5	B5c	E5b	E5	C5b	C5	C5c-	D5b	D5	D5c-	DA5
Silt/Clay	A6a+	A6	G6	G6c	F6b	F6	B6a	B6	B6c	E6b	E6	C6b	C6	C6c-	D6b	D6	D6c-	DA6

Figure 2. Design Data Table

Project	Type	Width	Depth	W/D Ratio	Entrenchment	Sinuosity	Area	Slope	Bankfull Q	Drainage Area	Width	Liner
Pardeesville	C3/E3	10 ft	1.5 ft	6.7	13.5	1.2	15 ft²	1%	30 cfs	1.1 mi²	135 ft	No
Keyser Avenue	A2	16 ft	2.5 ft	6.4	1.0	1.2	25 ft²	10%	60 cfs	1.1 mi²	N/A	Yes
Middle Creek	B3a	22 ft	1.5 ft	14.7	3.2	1.1	34 ft²	6%	115 cfs	1.25 mi²	70 ft	Yes
Jessup Cemeteries	B3/C3b	28 ft	2 ft	14.0	3.6	1.2	57 ft²	2%	190 cfs	4.9 mi²	100 ft	Yes/No
Hollars Hill	C4/E4	30 ft	2.5 ft	12.0	6.0	1.5	80ft²	0.5%	250 cfs	6.4 mi²	180 ft	Yes/No