

**Restoration of Great Meadow Run
at Fort Necessity National Battlefield**

A Report to the National Park Service

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INTRODUCTION

Great Meadow Run flows through Fort Necessity National Battlefield in southwestern Pennsylvania, draining a meadow in the central portion of the park. The meadow and stream have historical significance dating back to a battle between troops commanded by George Washington and French and Indian troops in 1754. The meadow currently comprises about 80 acres. Numerous changes since Washington's time have significantly impacted the physical and biological characteristics of the meadow and stream. Drain tiles, filling, ponding, and channel straightening were all implemented over the years in an attempt to dry out the meadow.

The objective of this one-year study was to determine alternatives for the restoration of the function of the Great Meadow Run (and portions of Indian Run within the study area) to a stable stream channel typical of channels in the same physical setting. The primary function of this stream was to supply adequate water to the floodplain to maintain the wetland meadow by frequent flooding or overtopping of its banks. Although it would be desirable to return the stream to its 1754 condition, tracing the historic channel has been found to be rather difficult given the number of both natural channel movements and human modifications to the channel (National Park Service, 1998a).

SITE DESCRIPTION

Great Meadow Run lies in the Appalachian Plateau physiographic region. It runs approximately 2 km from an upstream pond north of Route 40, through the park to where it again intersects Route 40 (see Figures 1 and 2). Great Meadow Run is a first-order stream from Route 40 until just downstream of the fort where it is joined by Indian Run and becomes a second-order stream. At the upstream end, flow is interrupted by several instream ponds followed by culverts at Route 40 and at the amphitheater entrance. In the park, the stream flows under one pedestrian bridge and one historic automobile bridge. Portions of the stream are deeply entrenched, at least in part due to several feet of fill placed in the meadow prior to the purchase of the park by the National Park Service. Drain tiles can be located throughout the floodplain area draining the meadow toward the stream. The stream is relatively straight due to prior channelization efforts in the mid 1800's. The stream banks are lined with very thick vegetation such that it is difficult to see the stream in some locations. Near the fort, the bank vegetation has been undercut by fluvial erosion and the stability of the banks appear to be highly dependent on the existence of the vegetation.

STREAM RECONNAISSANCE AND STABILITY ANALYSIS

An initial stream reconnaissance was conducted to assess processes on-going within the watershed and the current physical condition of the stream. The method and field forms developed by Thorne (1998) were used, as this method provides a thorough and systematic framework for data collection that includes all aspects of the stream corridor and watershed. The data (primarily qualitative) collected through this procedure provide essential background

information from which to create a sustainable stream restoration design. The field forms are divided into five sections, including: scope and purpose, region and valley description, channel description, left bank survey, and right bank survey. Each of the sections, except the scope and purpose section, guide the user through the data collection process, gradually yielding information at greater detail. Interpretation processes based on observations are also recorded along with the level of confidence in those interpretations.

Figure 2 shows the Great Meadow Run and the locations of structures and cross sections surveyed. The stream reconnaissance began at the culvert upstream of the park boundary (at the amphitheater entrance) and continued to the historic automobile bridge downstream of the fort. The following paragraphs summarize the observations based on the reconnaissance. In these descriptions, the reach is divided into three subsections: the upstream end through the wooded area upstream of and just into the park, the middle section entering the upper end of the meadow, and the downstream end which contains the fort.

The upstream portion of Great Meadow Run from just downstream of the culvert at the amphitheater entrance through the wooded area to a short distance into the park is stable. The stream is relatively wide and shallow in this portion compared with the downstream reach. Bed material consists of silt, sand and gravel. Within the park, the right bank is forested, with a variety of sizes and species of trees. The vegetation on the left bank is primarily meadow grasses and shrubs.

In the middle section of the reach, undercutting of the left and right bank was observed; however, geotechnical failures and failure planes were not observed, and it was concluded that undercutting and bank failure was not a significant problem. The bed material consisted primarily of silt and clay. The stream channel becomes narrower in this section, but remains relatively shallow. Bank vegetation in this reach consists of meadow grasses and honeysuckle with sparse trees.

The downstream end of the reach (which contains the fort) appeared to be relatively stable. Although deeply entrenched, the bed does not appear to be degrading at an accelerated rate. The stream is deep and narrow. The banks appear to be stable, though there were some cases of undercutting, especially on the right bank near the fort. The bed was mostly silt and clay, but there were areas where the channel was lined with large rocks. The source of these rocks may be an old rock road or bridge that crossed the stream in the 1800's. The banks of the downstream reach are covered with a single row of alders. Beyond the alders is meadow grass. Throughout the meadow in the downstream section, holes mark locations where drainage tiles, placed in the 1950's, have likely failed.

In addition to the reconnaissance, five cross sections were surveyed along the reach. Figure 2 shows the locations of the cross sections in the park. Figure 3 shows the individual cross sections. It is clear from the cross-sectional shape that the channel is entrenched. The average width to depth ratio for the five cross sections is 4.0, measured at the approximate top of banks, indicating a deep and narrow channel, typical of incision. A longitudinal survey was also conducted to determine the channel slope. The longitudinal channel slope through the meadow is 0.0038.

Piezometers were placed at cross sections 1 and 2 in the meadow so that several groundwater readings could be taken to qualitatively determine how the stream and subsurface water interact. This interaction will influence the creation of wetlands in this area. Readings were taken on two different days, 6/28/00 (no recent heavy rain activity) and 7/29/00 (immediately following a rain event of unknown magnitude). The readings showed that the groundwater, at least in part, is being fed by water from the stream. However, because the channel is incised, the groundwater table is relatively deep. This creates difficulty when trying to recreate wetlands because it is difficult to maintain the saturated surface that is periodically needed to support a wetland.

REFERENCE REACHES

Reference reaches are stable channel reaches that are either adjacent to or nearby the project site. Reference reaches can provide a "blueprint" for the cross sectional and planform geometry of the restoration design. Topographic maps, aerial photographs, and discussions with park employees were used to locate potential reference reaches. Site visits were conducted to assess the stability and applicability of the reach as a reference for Great Meadow Run. Table 1 provides the sites that were selected and visited for this purpose; the locations of these sites are shown in Figure 4.

As shown by Table 1, none of the streams were considered undisturbed reference reaches. The two most likely candidates, Smiley Run #2 and Meadow Run, have both been altered or otherwise disturbed. These reaches have adjusted to the disturbances, but are not currently in their natural pre-disturbance state. Thus, morphological and hydraulic characteristics of these streams may not be representative of the stream type in Great Meadow Run. In addition to being disturbed, the reaches were very difficult to survey. Smiley Run #2 is located on private land in a farm pasture. Although the site seemed acceptable for use as a reference, there was extensive hoof damage along the banks. In addition, the owner would not grant permission for us to survey because he has bulls on the property and feared for our safety. At Meadow Run, extremely soft channel bottom material made it impossible to wade or set equipment in the channel. However, at each of these two locations, rough estimates were made of average width, depth, and sinuosity. Table 2 provides these estimates. Average widths and depths in Table 2 are estimated for the approximate bankfull stage.

Table 1. Streams considered for reference reaches.

Stream	Location	Suitability as Reference
Smiley Run #1	Fayette County, PA near Deer Lake 39° 51' 26.74", 79° 35' 43.12"	Possible. Excessive thick vegetation does not permit surveying.
Smiley Run #2	Fayette County, PA near Deer Lake 39° 51' 28.11", 79° 35' 31.89"	Possible, but limited. Extensive hoof damage to banks limits usefulness.
Sandy Run	Fayette County, PA south-east of Fort Necessity 39° 45' 35.61", 79° 31' 42.93"	Not suitable. Beaver dam has changed stream characteristics extensively.
Wolf Swamp	Garrett County, MD 39° 40' 08", 79° 05' 13"	Not suitable. No well defined banks. Stream type not appropriate.
Meadow Run	Garrett County, MD near High Point 39° 41' 43.05", 79° 05' 37.52"	Suitable, but disturbed. Similar vegetation and character to Great Meadow Run. Was likely straightened in past.

Table 2. Approximate reference reach parameters.

Stream	Width (ft)	Depth (ft)	Width-Depth Ratio	Sinuosity	Channel Bed Material
Smiley Run #2	15	1.5	10	1.1	Silt
Meadow Run	30	3	10	1.05	Silt

In addition to not having a reliable reference stream to use as a design template for restoring the form of the stream, the many modifications that have been made over the years to Great Meadow Run, such as drainage, straightening, filling, and ponding, may render the use of a reference stream ineffective. In this case, it is unlikely that the use of a reference stream will help to achieve the objective of this study, which is to determine options that will restore the function of the stream (rather than the form or appearance) to that which occurred during the time of Washington. Even if the stream were returned to its original state in terms of form, it may not function in a similar way due to the extensive modifications to the channel and the upstream area.

DISCHARGE CALCULATIONS FOR GREAT MEADOW RUN

Discharges for present time and 1754 were estimated for the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms at the following locations: (1) just downstream of the culvert at the amphitheater

entrance, (2) the historic auto bridge, and (3) just upstream of the Route 40 culvert at the downstream crossing of Great Meadow Run. Calculations were made using PSU-IV (Aaron et al., 1981) and available land use information. PSU-IV is a set of regional regression equations used to estimate flood peaks for watersheds between 1.5 and 250 square miles. The equations account for flood storage and urbanization and provide discharges for the 1.1 to 200-year discharges. Table 3 provides the estimates for Great Meadow Run. The discharges have changed little over this period of time, primarily due to the relatively minor land use changes in the watershed.

Table 3. Estimated discharges for 1754 and 2000 for Great Meadow Run.

Return Period (years)	1754 Discharge (ft ³ /s)			2000 Discharge (ft ³ /s)		
	Culvert	Auto Bridge	Rt. 40	Culvert	Auto Bridge	Rt. 40
1	50	61	89	54	65	95
2	59	80	109	63	86	117
5	75	126	193	80	135	207
10	130	167	293	139	179	314
25	177	212	319	189	227	341
50	223	274	389	239	293	416
100	250	307	450	268	328	482

The entrenched nature of the channel made it difficult to evaluate a bankfull or effective discharge (assuming that the two discharges are the same for the channel in its stable form). From Table 3, assuming that the bankfull discharge is *at most* the 1.5-year event and that discharge increases linearly between the 1- and 2-year events, then under non-incised conditions, the bankfull discharge can be estimated as $\frac{1}{2} (54+63) = 58.5$ ft³/s at the fort and $\frac{1}{2} (65+86) = 75.5$ ft³/s downstream of Indian Run. For cross section 1 upstream of the fort, the discharge that is contained within the channel banks can be approximated from the Manning flow resistance equation:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2} \quad (1)$$

where Q = discharge (ft³/s), n = Manning roughness coefficient, R = hydraulic radius (ft), and S = slope (ft/ft). Assuming n = 0.045 and S = 0.0038 (from the reconnaissance), Q = 115 ft³/s. Thus, it is clear that the channel contains well in excess of the bankfull discharge. Referring to Table 3, it is seen that the channel just upstream of the fort contains approximately an eight-year flood before overtopping its banks. This stream in its natural state likely overtopped its banks around the one to 1.5-year flood.

ALTERNATIVES FOR RESTORING GREAT MEADOW RUN

Several alternatives for restoring Great Meadow Run were explored. These included both passive and aggressive methods. Relatively passive methods have the advantage of minimizing the disturbance to the stream corridor and existing ecosystem. In addition, these methods let the stream do the work of restoration gradually over time. The disadvantage is that they may take a longer period of time to attain project objectives. Aggressive methods have the advantage of obtaining immediate design objectives. However, they are generally more expensive, are highly disruptive and destructive to the current habitat and stream environment, introduce sediment to the waterway, and may cause the channel to respond in an unpredictable and undesirable way. Thus, frequent monitoring and maintenance is often associated with aggressive methods.

Regardless of the method, an important component in restoring wetland characteristics to the meadow is the removal or destruction of the drain tiles throughout the park. These terra cotta drains and drainage tiles were placed in the late 1800's, and again in the 1950's, to drain the Great Meadow. Unfortunately, there are no markers or mappings of the tiles; however, there is some field evidence, mainly scour holes above the tiles, of their existence. The tiles could be dug up and removed, although this would involve the excavation of either the entire drainage network, or the main pipeline to which the drains are attached. The exact location of the main pipeline is unknown at this time; blueprints or shop drawings of the original project are unavailable. Alternatively, the drain tiles could be crushed in place, perhaps by driving heavy trucks over them. Although this method should work due to the age and poor condition of the drains, it has no guarantee.

Below we briefly describe each of the options for restoring Great Meadow Run and make recommendations for the most feasible options. For each option, estimated costs are given for the actual construction based on King et al. (1994) and Johnson and Brown (1999). Costs of design, monitoring, and maintenance are not included. In every case, the changes described are only for the channel downstream of the wooded area; upstream of this reach, where large trees grow along the banks, the channel is in a more natural state and is recovering on its own. In addition to each of these design alternatives, removal or destruction of the drain tiles should be considered. Estimated costs do not include drain tile removal.

Passive Approaches

The options described in this section (with the exception of option 1) involve encouraging desirable stream channel adjustments without causing major disturbances. The goal of each option is to increase flooding of the stream so that a one- to 1.5-year storm or greater will overtop the banks, leading to the possible creation of more permanent wetlands, while minimizing disturbances to the stream corridor. These options will involve the least amount of construction work and will have a relatively short recovery period. However, achieving the project objectives may, in some cases, take a number of years as the channel slowly adjusts to its new conditions.

In these options, it is desirable to cause increased flooding primarily on the left bank (facing downstream) of Great Meadow Run throughout the majority of the wetland sites. Flooding of the left bank will protect the fort from excessive moisture and keep the areas near the

pedestrian paths relatively dry to facilitate visitor accessibility. At the park entrance the left bank has long, uncut grasses while the right bank is forested. The vegetation in the forested section is not conducive to a wetland environment; thus, flooding will be encouraged to occur primarily over the left bank.

Option 1 - No Change

Under this option no changes would be made to Great Meadow Run stream corridor. Although the stream channel is deeply entrenched and the banks are locally undercut, the stream does appear to be stable, showing no stress cracks or bank failures. The magnitude of the entrenchment of the stream does not allow for frequent out of bank flooding which is required to maintain the wetlands. Depending on the stream location, the stream will overflow during certain storm events and create temporary marshy areas adjacent to the stream. Upstream of the fort, this occurs for the five-year and greater floods. Downstream of the fort to the park entrance, flooding occurs for return periods greater than about the two-year flood. However, the surrounding lands remain relatively dry for the majority of the year.

Advantages. The main advantage of using the “no change” option is the lack of disruption to the variety of vegetation and wildlife that now resides in the battlefield area. Leaving the site untouched would also guarantee that there would be no construction work needed; thus, the battlefield aesthetics would be kept intact.

Disadvantages. Due to the deep entrenchment of the stream and the drainage in the fields, it is very unlikely that the site will readjust to the 1754 condition, nor will permanent wetlands ever be restored within the next several decades. Another disadvantage of leaving the site untouched is the continued invasion of exotic vegetation in the area.

Estimated Cost of Construction: \$0

Option 2 - Engineered Debris Jams

Method and Purpose. An engineered debris jam consists of several variously sized logs in combination with smaller pieces of wood, silt, and debris to create a jam across a portion of, or the entire, stream channel. The jams cause excess flooding by increasing the channel roughness and meandering planform (Bilby et al., 1987; Hartman et al., 1987; Robison and Beschta, 1990; Shields and Smith, 1991; Gippel, 1995). Fish passage is maintained throughout the stream (Beschta and Cherry, 1989; Sullivan et al., 1987; O’Neal et al., 1999) and habitat is generally improved. Through careful placement of the debris jams, the stream channel will very gradually achieve sinuosity and widening which will, in turn, increase resistance and flooding.

Design Approach. Debris jams can be created using materials closely resembling the natural vegetation in the area. The jams can be designed to resist displacement by interlocking the logs, keying them into the banks, anchoring them in the stream, and inducing sediment deposition (Shields et al., 2001). In order to encourage silt and debris to build up at the jam, a screen can be placed around the upstream side of the logs and below the banks. Since the introduction of debris jams in a stream can increase the abundance and diversity of fish (O’Neal et al., 1999), the screen is attached in such a way as to not completely extend to either bank or the bottom to allow

for fish passage. Debris, including silt from the channel, grasses from the surrounding area, and wood up to 5 inches in diameter should be placed at the upstream side of the jam against the screen. The two support logs should be between 12 and 14 inches in diameter.

Based on the location of the debris jams, one of four basic alignments could be chosen (see Figure 5) (Beschta and Cherry, 1989). The debris jams can be placed at different angles with respect to the banks (vertical angle) and the flow direction (horizontal angle) in order to cause diverse flooding conditions or erosional patterns. To promote flooding on the left bank, alternatives C and D in Figure 5 can be used in an alternating pattern (Figure 6). Setting the jams at these positions will help form meanders in the stream while also protecting the right bank. In order to assure the safety of the bridge and the efficiency of the culvert at Route 40, the area immediately upstream of the bridge and the road should be kept clear of any debris jams for a distance of at least two bridge or roadway widths upstream. The area from downstream of the bridge to the beginning of the meadow at the park entrance should also remain free of engineered jams. Pool spacing in most freely meandering streams is about five to seven channel widths (Leopold, 1994). Pools formed by debris jams are more randomly spaced (Myers and Swanson, 1997). Based on these two observations and the narrowness of the stream channel, the jams should be placed no closer than about 75 to 100 feet apart. Debris jams should be located based on current meanders and locations of bank cutting. The exact location would have to be surveyed at the time of design. The jams can also be angled such that bank cutting by the flowing water will take place away from the fort. After construction of the jams is completed, the banks should be compacted and revegetated with native grasses and shrubs.

Disadvantages. The major disadvantage of debris jams is their potential to wash downstream during a large rain event. If a large discharge occurs in conjunction with bank erosion, the jam may shift from its original position or wash downstream. Another possible drawback of the jams is the potential for them to become an obstruction. Under normal flow conditions this should never happen due to the low rate of sediment transport that the stream carries, but during a high flow velocity, there is the possibility that significant amounts of sediment could be deposited in front of the debris jams.

Estimated Cost of Construction: \$2500

Option 3 - Placed Boulders

Method and Purpose. This method involves the placement of boulders along the length of Great Meadow Run. Strategic boulder placement can result in more out-of-bank flooding by increasing the flow resistance. It can also facilitate widening of the stream or the formation of meanders by constricting the flow area and thereby encouraging bank widening. An example of this can be seen in the current stream in the vicinity of the fort. The channel bottom width upstream of the boulder is approximately 1.5 feet. At the boulder and for a short distance downstream the width increases to almost 10 feet. The stream widening at this naturally placed boulder is a good example of how placed boulders will cause the stream to adjust.

Design Approach. Boulders one to two feet in diameter will be placed in the stream throughout the park entrance and fort vicinity (D'Aoust and Millar, 1998). Given the narrowness of the

stream, boulders will be placed every 50 to 100 feet. Due to the fact that wetland creation is desired only on the left side of the channel, boulders will be placed in an alternating pattern along the right bank and the middle of the channel. This arrangement should encourage both the formation of meanders (boulders on the right bank) and stream widening (boulders in the middle). In order to assure the safety of the bridge and the efficiency of the culvert at Rt. 40, boulders should not be placed within the influence of these structures, about two bridge or roadway widths upstream.

This method requires very little construction in the channel. Light machinery will be needed in order to haul and place the boulders. A small amount of excavation may be required to set the boulders in place.

Disadvantages. A disadvantage of boulder placement is the possibility of a boulder becoming displaced during a large storm event. Given that the boulder diameter is large in comparison with the stream width, displacement of one of more boulders should not greatly alter the original purpose of the boulder. Another possible disadvantage is the aesthetics of this option. The wetlands are to be recreated within a grassy meadow in stream channel material consisting mostly of clay and silt. The boulders might have an awkward appearance and could potentially detract from the 1754 look that the National Park Service is trying to achieve.

Estimated Cost of Construction: \$840

Option 4 - Change in Stream Channel Boundary Roughness

Method and Purpose. The purpose of this option is to increase flow resistance (in terms of the resistance coefficient n in Eq. 1) in the stream channel to decrease flow conveyance.

Design Approach. Cross section 1 has long, uncut grasses on the banks and silty material on the stream bottom. Cross section 2 also has vegetated banks, but the bottom material contains gravel and larger clasts. The park entrance, cross sections 3 to 5, has a silty bottom, but the banks are cut nearly vertical and have no vegetation. The grass and rocky channel bed material are substantially rougher than the silty material and increase the flow resistance, thereby decreasing flow velocity (see Eq. 1). Vegetation in the floodplain is similar throughout the reach, containing scattered trees and shrubs, and long, uncut grasses.

There are essentially two ways to increase the stream channel boundary roughness to achieve more frequent out-of-bank flooding: (1) increase the sediment size on the channel bed and (2) increase the roughness of the banks. The Manning's resistance coefficient (Eq. 1) is proportional to the channel bed material sediment size as:

$$n \propto D^{1/6} \quad (2)$$

where D = sediment diameter. From Eq. 1, the roughness coefficient n will have to be doubled to reduce the discharge by half, or approximately the bankfull discharge. From Eq. 2, increasing the sediment size from a very fine sand, 0.1 mm in diameter, to 6.4 mm in diameter (fine gravel), will provide this increase in n . The shear stresses should also be checked to determine whether

the new bed material, in this example fine gravel 6.4 mm in diameter, will be eroded at flow conditions that just fill the banks. The average boundary shear stress is given by:

$$\tau = \gamma RS \quad (3)$$

where τ = average boundary shear stress, γ = specific weight of water, R = hydraulic radius, and S = slope. For cross section 1, $\tau = 0.311 \text{ lb/ft}^2$. The sediment diameter that can just stay on the bed without movement is given by the Shield's equation:

$$\tau_c = 0.06(\gamma_s - \gamma)D \quad (4)$$

where τ_c = critical shear stress for particle movement, γ_s = specific weight of sediment, γ = specific weight of water, and D = particle diameter. For a shear stress of 0.311 lb/ft^2 Eq. 4 yields a sediment diameter of 19.3 mm. Thus, if the particle size of 6.4 mm calculated earlier is the largest particle size or if a uniform sediment size of 6.4 mm or smaller is used, it will be eroded. The use of a graded sediment will overcome this problem. For example, if the D_{86} size is 19.3 and the D_{50} (median) size is 6.4 mm, then the sediment will not be eroded (D_i = particle size for which i^{th} % of the total material is finer than that size). For this arrangement, the sediment gradation is 3.47, $D_{86} = 19.3 \text{ mm}$, $D_{50} = 6.4 \text{ mm}$, and $D_{16} = 1.6 \text{ mm}$.

In addition to changing the bed material size, roughness can be added by changing the bank roughness, for example, by installing fascines near the toes of the banks. Live fascines are long bundles of plant cuttings that are wired together and placed horizontally in shallow trenches (Brown and Johnson, 1999). Fascines can be secured into a streambank using live or dead stakes. The roots quickly grow and provide a dense, but shallow, network for stabilizing shallow bank failures. This is a particularly useful technique in areas where shallow erosion is a problem. This may also decrease the cross sectional area somewhat, providing additional assistance in lowering the return period for overbank flows.

Disadvantages. The primary disadvantage of this method is the change in bottom substrate as habitat. The soft, silty bed will be changed to a gravel bed. The implications of such a change should be addressed before using this method. There is also potential for new vegetation to be washed away if a large storm event occurs before the plants have completely taken root. If this happens, the channel would regain some of its former potential to carry more discharge, leading to heavier flows downstream that could cause the uprooting of new vegetation on the downstream banks.

Estimated Cost of Construction: \$56,000

Aggressive Approaches

The options described in this section involve significant construction and disruption of the current stream corridor and ecosystem. The goal of each option is to change the stream morphology to increase flooding of the stream so that a one- to 1.5-year storm or greater will overtop the banks, leading to the possible creation of more permanent wetlands, while minimizing disturbances to the stream corridor. These options will involve significant

construction work. Achieving project objectives is more immediate than for passive methods, but often requires frequent monitoring and maintenance as the stream adjusts to its new form, especially until vegetation has re-established. Due to the abrupt nature of these approaches, native vegetation could be destroyed along with exotics. In addition, sediment may be added to the stream flow and current aquatic and riparian habitats could be destroyed or damaged. Thus, these alternatives require very careful consideration and precautions.

Option 5 - Full Reconstruction of 1754 Wetlands

Method and Purpose. The purpose of this option is to completely restore the function and form of the Great Meadow Run stream corridor to its 1754 appearance, as described in the Cultural Landscape Report (National Park Service, 1998b). Restoration to approximate conditions at the time of the battle will include removal of the two to four feet of fill that has been added to the meadow area near the fort since the time of Washington and removal of the earthen levees that were built upstream of the fort. Removal of these features will yield a non-entrenched stream which will flood more frequently.

Design Approach. To estimate the amount of fill that was placed throughout the Great Meadow and park entrance, original surveys or additional studies (such as pollen studies) are needed. A rough estimate of the volume to be excavated can be made using the approximate area of the wetlands to be restored, about 20 acres based on the Cultural Landscape Report (National Park Service, 1998b) map, at an average depth of about two and a half feet, or 80,000 cubic yards. The longitudinal slope of the floodplain should closely approximate the current slopes of the overbank area and channel. The lateral slope should be gentle and follow the general terrain.

The stream would be widened to achieve a width to depth ratio of about 10. Based on the estimated bankfull discharge of 58.5 cfs at the fort, a rectangular channel would be approximately one foot deep by 10 feet wide. The affected areas should then be compacted and replanted with vegetation that was native to the meadow in 1754 (see National Park Service, 1996).

Disadvantages. The most apparent disadvantage of fully restoring the estimated conditions of the meadow is the amount of damage that will be done to the current stability and ecosystem of the stream corridor by the construction. Removing the fill will cause a large portion of the meadow to be disturbed. Existing riparian and floodplain vegetation as well as wildlife burrows and shelters will be destroyed. Compacting the area once the excavation is complete will create difficult growing conditions for the grasses and shrubs and the new topsoil may not be suitable for the wetland vegetation that needs to grow. In addition, channel adjustments subsequent to channel modifications may be rapid and undesirable, such as bank widening or channel migration in the vicinity of the fort. The channel could be stabilized with various measures; however, they could detract from the natural appearance of the channel. Construction work could also increase the sediment load to the channel. Finally, the renewal time for vegetation to re-establish following construction could be on the order of years.

Estimated Cost of Construction: \$645,000 for excavation of 80,000 cubic yards. The additional cost of revegetation would be determined by a botanist.

Option 6 - Cut Banks

Method and Purpose. In this option the banks of the stream would be cut back to widen the corridor. In addition, several techniques would be implemented to encourage the formation of meanders.

Design Approach. In this option, only a portion of the fill will be removed to minimize disturbance to the vegetation adjacent to the stream. To increase out-of-bank flooding, the left stream bank will be cut back at a 6H:1V slope above the bankfull estimated in Option 5. The affected areas will then be compacted and revegetated. Fascines will be planted to facilitate a more rapid recovery of vegetation and to provide additional stabilization of the banks and protection from erosion.

Logs will be placed at a downstream angle of 30° (Beschta and Cherry, 1989) throughout the channel, no more frequently than five stream widths apart. This will direct the flow into the banks and around the ends of the logs and will begin the formation of meanders. Since meanders increase flow resistance and reduce flow velocities, they also encourage flooding.

Disadvantages. One of the disadvantages of cutting back the banks of the stream is the removal of the alder trees and grasses that line the banks down to the water's edge. These native trees provide bank stability, and shade, cover, and food for the aquatic habitat. The grasses reduce flow velocities and act as a sediment control measure. The period between removing this vegetation and the complete revegetation of the banks would increase both the water temperature and the sediment flow into the stream and could cause destabilization of the banks if a large rainfall event occurs during this period. Although the area of land disturbed by construction is much smaller than in Option 5, a major part of the stream that is viewed by visitors will be excavated and altered, temporarily disturbing the aesthetics of the battlefield.

Estimated Cost of Construction: \$25,600 for excavation of 3,200 cubic yards plus \$17,000 for fascines.

Option 7 - Two-Stage Channel

Method and Purpose. A two-stage, or compound, channel consists of a deeper central channel that conveys a smaller discharge, such as the 1.5-year or bankfull discharge, and one or two side channels that convey overbank flows up to a design discharge, effectively creating a new floodplain (Myers, 1990). The compound channel is created by cutting the banks of the main channel and lowering the adjacent floodplains. By creating new overbank area, more out-of-bank flooding will occur onto the newly formed floodplain. Although this option is similar to bank cutting (see Option 6), a compound channel creates a new floodplain and lowers the banks, as opposed to cutting the banks back.

Design Approach. Since it is desirable to have more frequent flooding only on the left bank to protect the fort, an asymmetrical channel should be designed with a flood-stage channel cut out of only the left bank. According to Higginson, et al. (1990), constructed floodplains in compound channels are usually one to two times the width of the main channel. For Great Meadow Run, assuming a bankfull channel of 10 feet wide by one foot deep, an approximation

of the channel dimension can be made using Eq. 1 with $n = 0.045$ (some vegetation will be removed initially, but will re-establish in time). Based on the discharges given in Table 3 at the fort, the configuration in Figure 7, and a flood-stage channel width of 20 feet (twice the bankfull channel width), Table 4 gives the flow depth in the flood-stage channel. Following construction, the banks should be compacted and revegetated with native grasses and shrubs. The new stream corridor should be monitored for a period of years to assure channel stability and vegetative regrowth.

Table 4. Flow depths in a flood-stage channel for a two-stage channel design.

Return Period (years)	Flow Depth (y) (feet)
5	0.9
10	1.4
25	1.8
50	2.1
100	2.3

Disadvantages. The design and construction of a two-stage channel at Fort Necessity may result in an undesirable change in the aesthetics of the landscape in the vicinity of the fort. Although wetlands would be encouraged on the left bank, the remainder of the meadow would not receive any benefits due to the depth of entrenchment of the main channel. The asymmetrical design could result in the loss of soil moisture from the right bank, shifting vegetation further toward non-native species.

Similar to the other options that require significant construction, the alder trees and grasses that line the banks down to the water's edge will have to be removed on the left bank, possibly resulting in reduction of bank stability, and shade, cover, and food for the aquatic habitat. In addition, a major part of the stream that is viewed by visitors will be excavated and altered, temporarily disturbing the aesthetics of the battlefield.

Estimated Cost of Construction: \$28,000 for excavation of 3490 cubic yards plus vegetation costs.

CONCLUSIONS

Great Meadow Run is a first-order stream in the Appalachian Plateau of south-western Pennsylvania. It runs through a natural wetland meadow that is the site of an historic battle in 1754. Since the time of this battle, changes to the meadow and stream channel have resulted in a straighter, deeply entrenched stream which can no longer flood the meadow with a frequency needed to maintain the wetlands. Native vegetation has been replaced with exotics. It was the purpose of this project to examine alternatives for restoring or partially restoring the stream to

the time of Washington's battle so that the native vegetation can once again survive in at least a portion of the meadow.

The hydrology of the watershed has changed little since the 1700's. Slight changes in discharge are due to the highway (US Route 40) and other drainage from the visitor's center and other paved surfaces. Despite the many changes to the stream and meadow, such as the addition of several feet of fill, placement of drain tiles, and straightening of the channel, Great Meadow Run is relatively stable even though it is deeply entrenched. The dense vegetation at the banks and the nature of the bank material helps to maintain slow channel adjustments over a range of flows.

Seven options were developed as possibilities for restoring, at a minimum, the function of Great Meadow Run. Four of the options were classified as passive in that they require relatively little earth movement and adjustments to the stream channel would be fairly slow. Three options were classified as aggressive in that significant construction and excavation would be required. Although the use of a reference channel was explored, suitable reference channels were not found and because of the modifications within the Great Meadow Run channel and meadow, it is unlikely that the use of a reference channel will produce the desired results in terms of maintaining the wetland meadow.

Recommendations

It is the opinion of these authors that aggressive methods should be avoided for this project. Aggressive methods will result in a very abrupt disruption to the current ecosystem and channel stability. It is preferable to encourage a gradual response to a minimal change that, in time, yields the desired results for the ecosystem as well as the form and function of the stream. In addition, all aggressive methods will require post-construction monitoring and maintenance over a period of years to assure that the channel is stable while waiting for vegetation to mature. The stream channel could become unstable due to the disturbance of soils during construction.

We believe that Option 2 (Engineered Debris Jams), a relatively passive option, will provide the gradual change that is desirable, will have minimal impact on the aesthetics of the park during construction, will cause minimal disruption to the current physical system, and will produce the desired results with the majority of the work being performed by the stream itself. It should be kept in mind that the results will not be immediate, but rather will be produced over a period of time. The plates attached at the end of this report illustrate the progression of the channel and vegetative adjustments over time.

Our recommendations are based on the results of our study of the river mechanics and geomorphology associated with Great Meadow Run, although we also made every attempt to consider the aesthetics of the park. Other factors that may be considered in the selection of a preferred alternative by the National Park Service include economics, politics, priorities, and other physical factors associated with the park.

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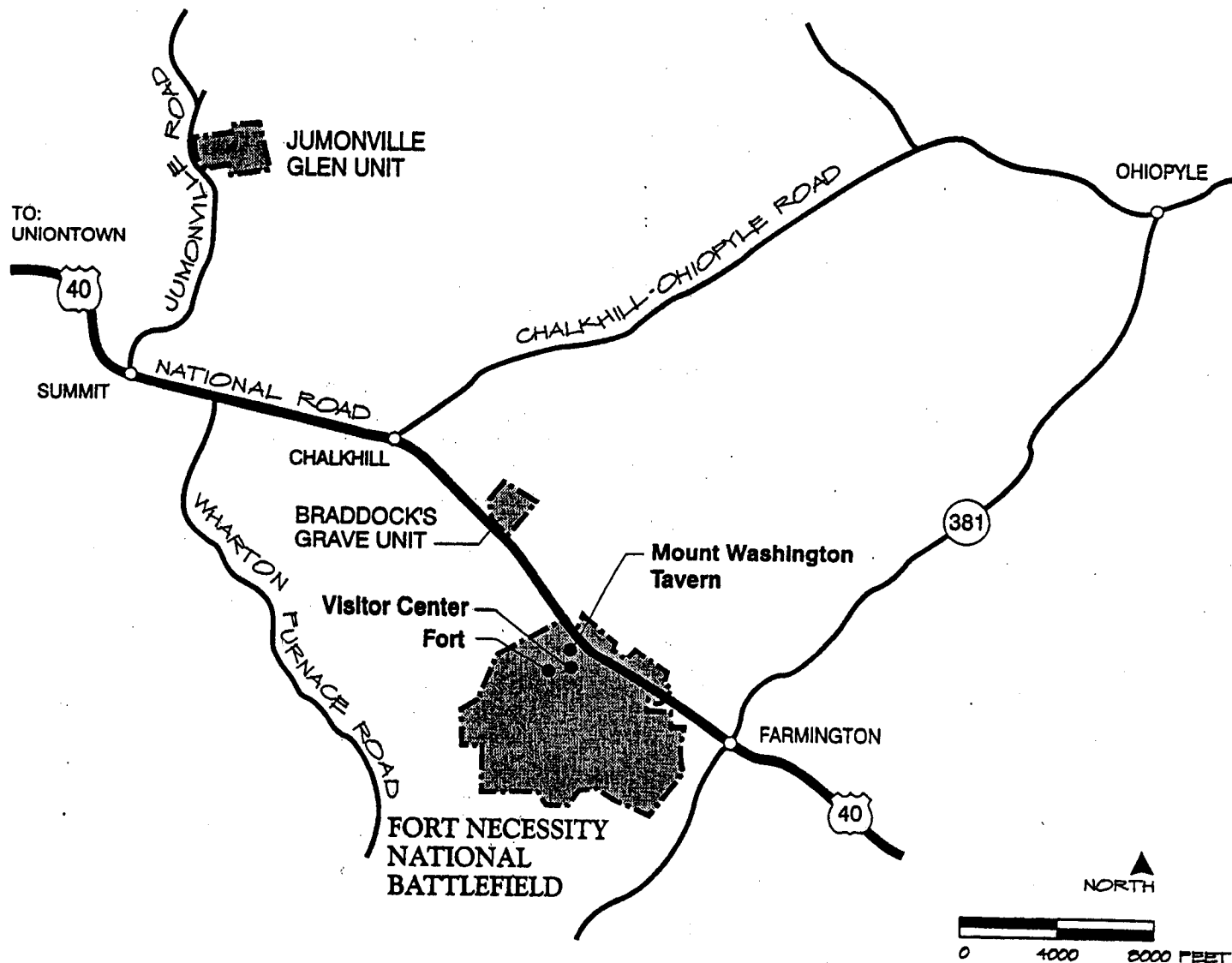


Figure 1. Location of Fort Necessity National Battlefield, Pennsylvania

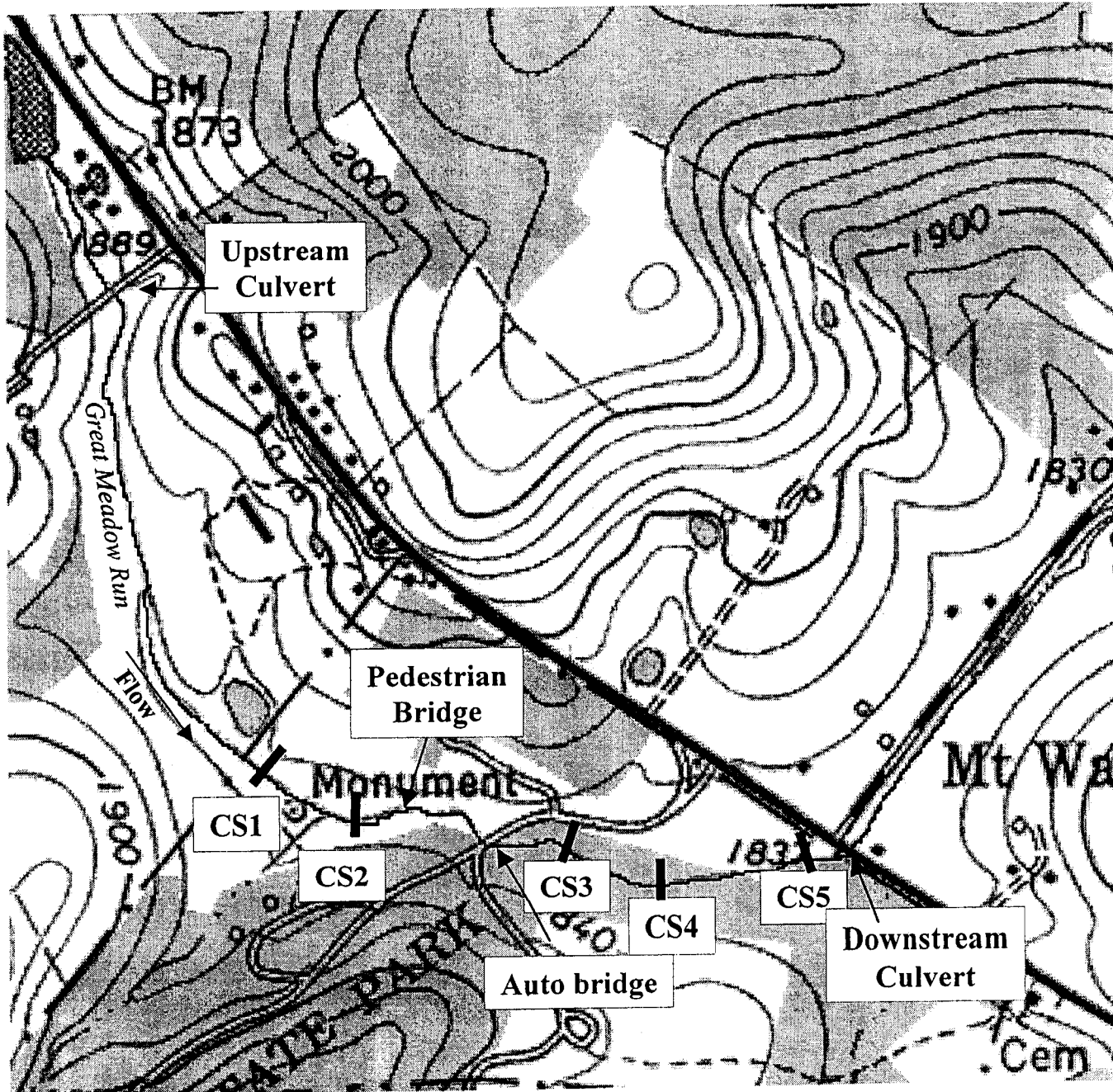


Figure 2. Great Meadow Run with locations of cross sections (CS) and structures.

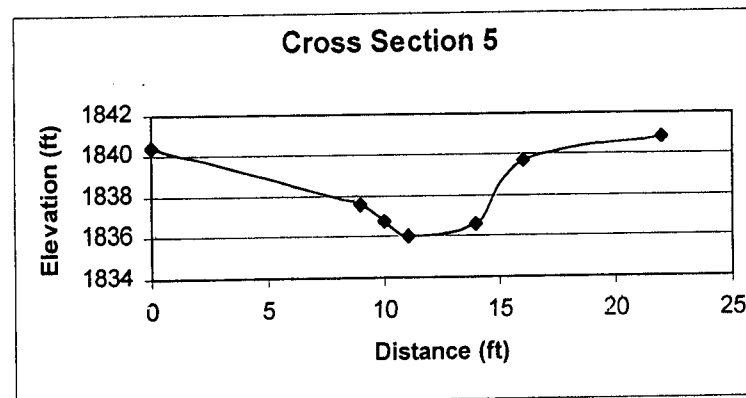
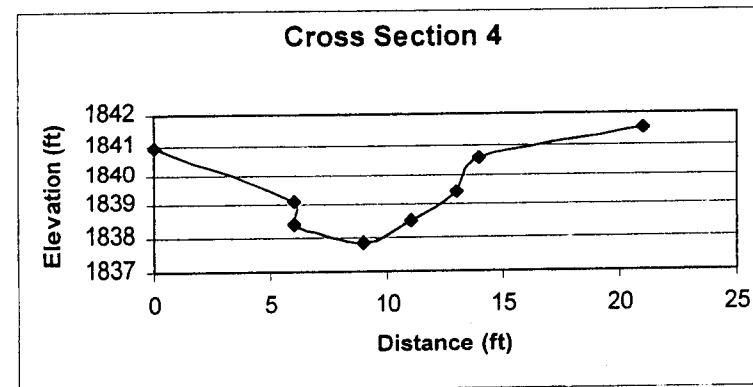
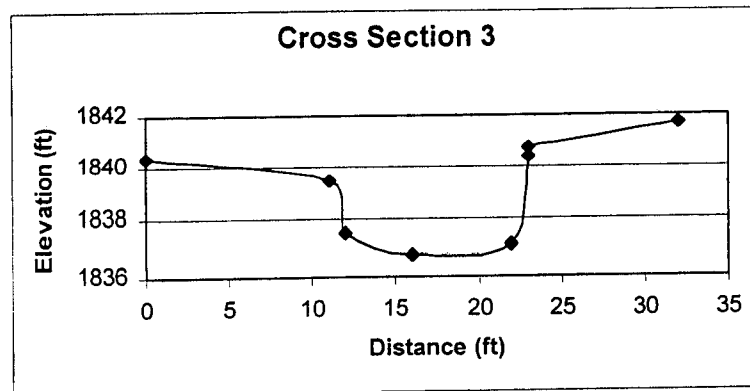
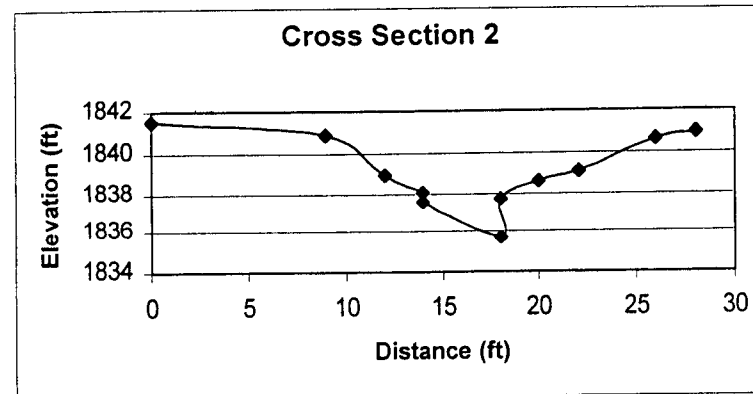
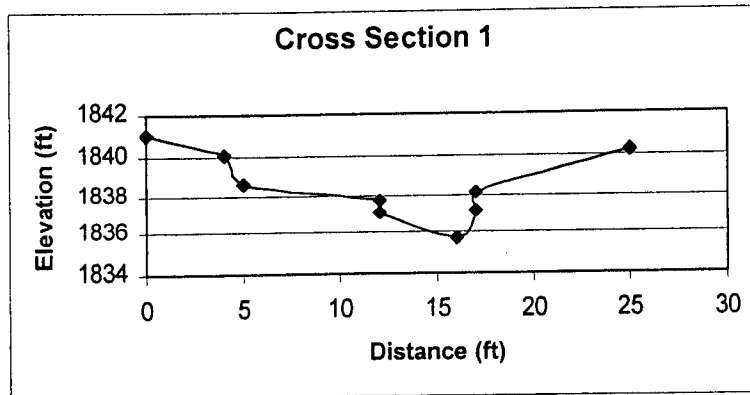


Figure 3. Cross sections with Distance = 0 at left bank facing downstream.

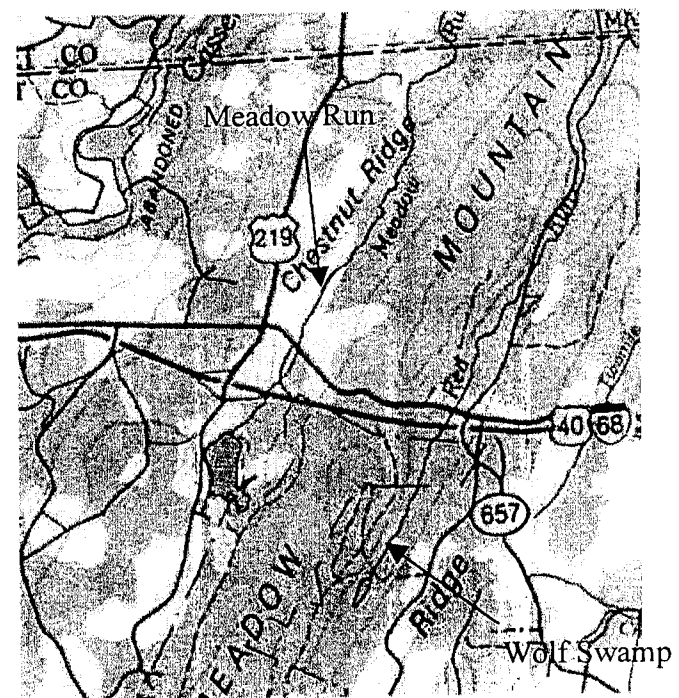
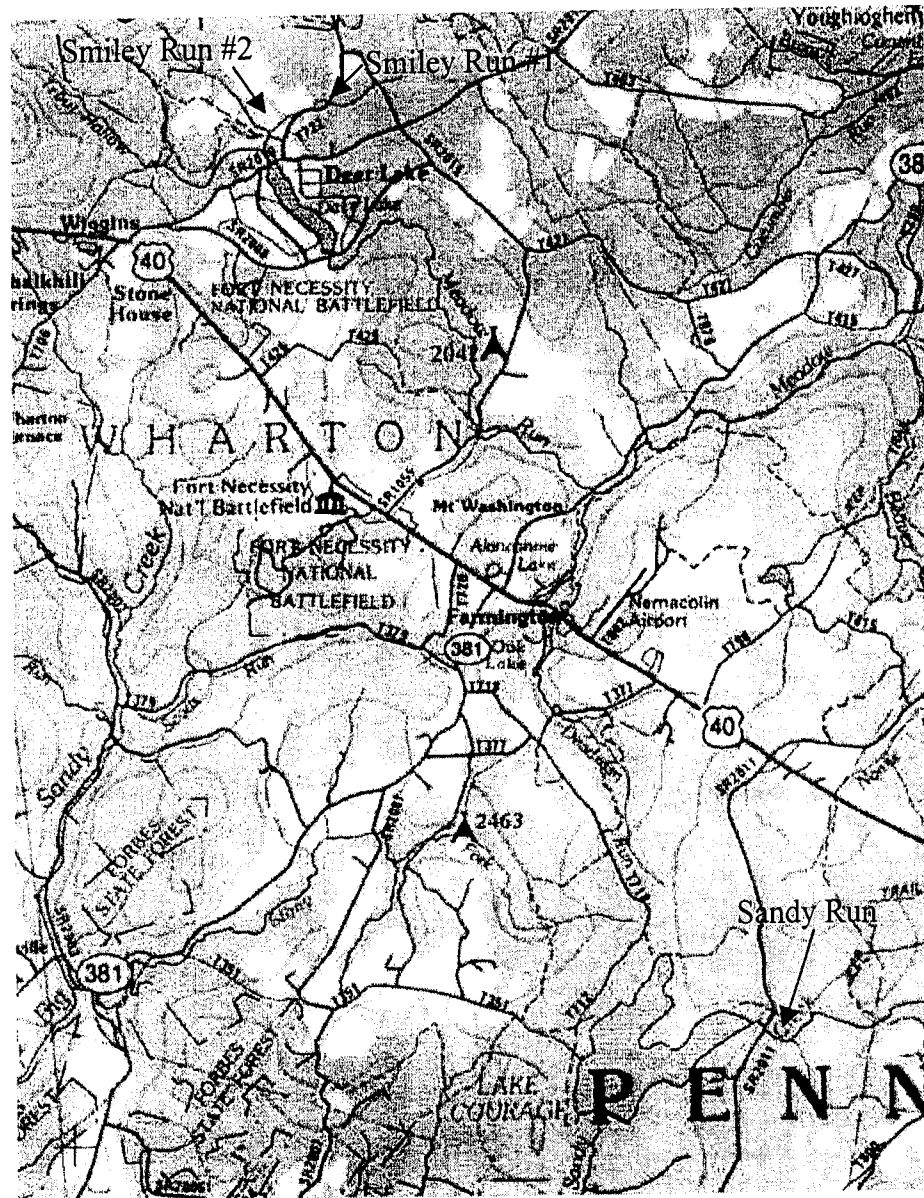


Figure 4. Locations of reference reaches.

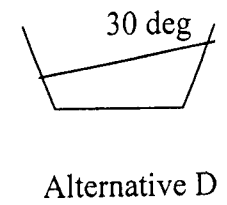
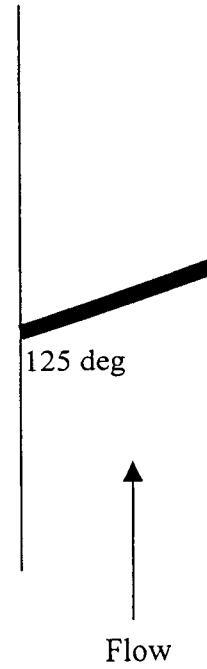
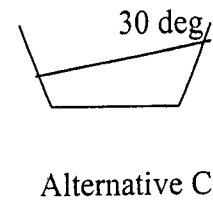
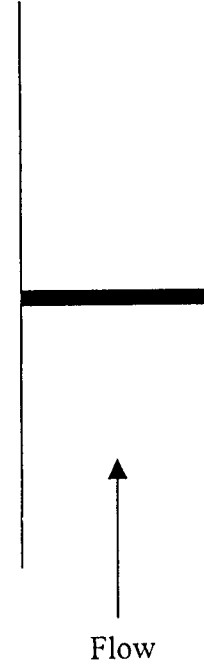
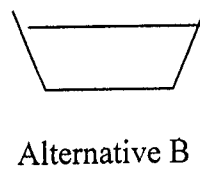
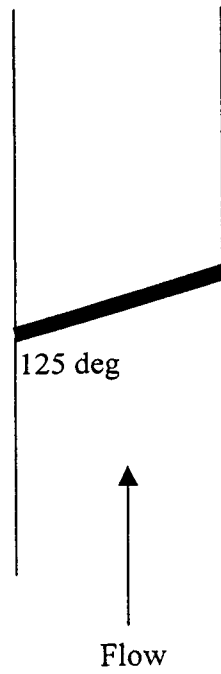
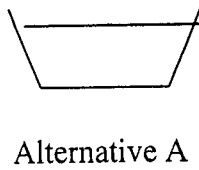
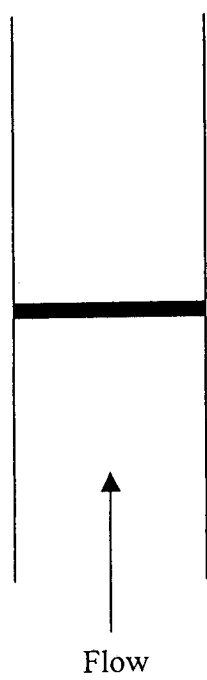


Figure 5. Four alternative alignments for debris jams.

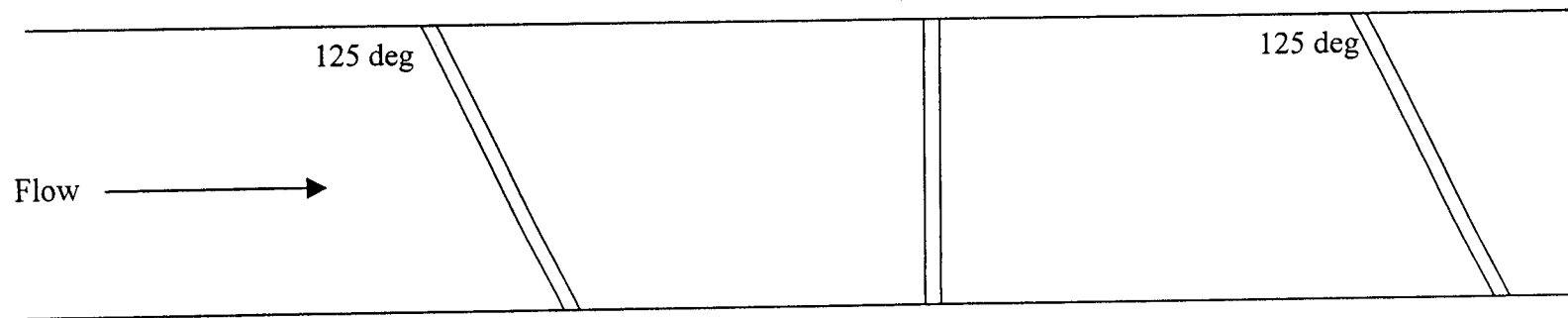


Figure 6. Alternating pattern for debris jams to promote flooding on left bank.

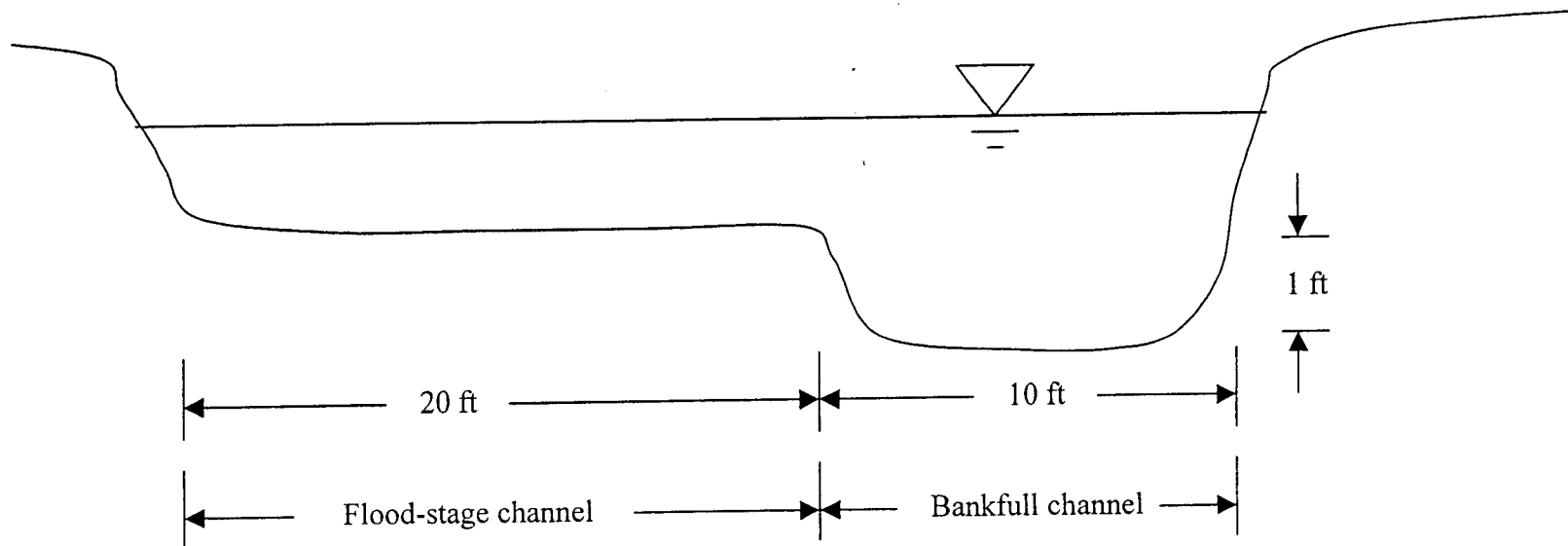


Figure 7. Two-stage channel configuration (Option 7).

**Restoration of Great Meadow Run
at Fort Necessity National Battlefield**

A Report to the National Park Service

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September 12, 2002

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INTRODUCTION

Great Meadow Run flows through Fort Necessity National Battlefield in southwestern Pennsylvania, draining a meadow in the central portion of the park. The meadow and stream have historical significance dating back to a battle between troops commanded by George Washington and French and Indian troops in 1754. The meadow currently comprises about 80 acres. Numerous changes since Washington's time have significantly impacted the physical and biological characteristics of the meadow and stream. Drain tiles, filling, ponding, and channel straightening were all implemented over the years in an attempt to dry out the meadow.

The objective of this one-year study was to determine alternatives for the restoration of the function of the Great Meadow Run (and portions of Indian Run within the study area) to a stable stream channel typical of channels in the same physical setting. The primary function of this stream was to supply adequate water to the floodplain to maintain the wetland meadow by frequent flooding or overtopping of its banks. Although it would be desirable to return the stream to its 1754 condition, tracing the historic channel has been found to be rather difficult given the number of both natural channel movements and human modifications to the channel (National Park Service, 1998a).

SITE DESCRIPTION

Great Meadow Run lies in the Appalachian Plateau physiographic region. It runs approximately 2 km from an upstream pond north of Route 40, through the park to where it again intersects Route 40 (see Figures 1 and 2). Great Meadow Run is a first-order stream from Route 40 until just downstream of the fort where it is joined by Indian Run and becomes a second-order stream. At the upstream end, flow is interrupted by several instream ponds followed by culverts at Route 40 and at the amphitheater entrance. In the park, the stream flows under one pedestrian bridge and one historic automobile bridge. Portions of the stream are deeply entrenched, at least in part due to several feet of fill placed in the meadow prior to the purchase of the park by the National Park Service. Drain tiles can be located throughout the floodplain area draining the meadow toward the stream. The stream is relatively straight due to prior channelization efforts in the mid 1800's. The stream banks are lined with very thick vegetation such that it is difficult to see the stream in some locations. Near the fort, the bank vegetation has been undercut by fluvial erosion and the stability of the banks appear to be highly dependent on the existence of the vegetation.

STREAM RECONNAISSANCE AND STABILITY ANALYSIS

An initial stream reconnaissance was conducted to assess processes on-going within the watershed and the current physical condition of the stream. The method and field forms developed by Thorne (1998) were used, as this method provides a thorough and systematic framework for data collection that includes all aspects of the stream corridor and watershed. The data (primarily qualitative) collected through this procedure provide essential background

information from which to create a sustainable stream restoration design. The field forms are divided into five sections, including: scope and purpose, region and valley description, channel description, left bank survey, and right bank survey. Each of the sections, except the scope and purpose section, guide the user through the data collection process, gradually yielding information at greater detail. Interpretation processes based on observations are also recorded along with the level of confidence in those interpretations.

Figure 2 shows the Great Meadow Run and the locations of structures and cross sections surveyed. The stream reconnaissance began at the culvert upstream of the park boundary (at the amphitheater entrance) and continued to the historic automobile bridge downstream of the fort. The following paragraphs summarize the observations based on the reconnaissance. In these descriptions, the reach is divided into three subsections: the upstream end through the wooded area upstream of and just into the park, the middle section entering the upper end of the meadow, and the downstream end which contains the fort.

The upstream portion of Great Meadow Run from just downstream of the culvert at the amphitheater entrance through the wooded area to a short distance into the park is stable. The stream is relatively wide and shallow in this portion compared with the downstream reach. Bed material consists of silt, sand and gravel. Within the park, the right bank is forested, with a variety of sizes and species of trees. The vegetation on the left bank is primarily meadow grasses and shrubs.

In the middle section of the reach, undercutting of the left and right bank was observed; however, geotechnical failures and failure planes were not observed, and it was concluded that undercutting and bank failure was not a significant problem. The bed material consisted primarily of silt and clay. The stream channel becomes narrower in this section, but remains relatively shallow. Bank vegetation in this reach consists of meadow grasses and honeysuckle with sparse trees.

The downstream end of the reach (which contains the fort) appeared to be relatively stable. Although deeply entrenched, the bed does not appear to be degrading at an accelerated rate. The stream is deep and narrow. The banks appear to be stable, though there were some cases of undercutting, especially on the right bank near the fort. The bed was mostly silt and clay, but there were areas where the channel was lined with large rocks. The source of these rocks may be an old rock road or bridge that crossed the stream in the 1800's. The banks of the downstream reach are covered with a single row of alders. Beyond the alders is meadow grass. Throughout the meadow in the downstream section, holes mark locations where drainage tiles, placed in the 1950's, have likely failed.

In addition to the reconnaissance, five cross sections were surveyed along the reach. Figure 2 shows the locations of the cross sections in the park. Figure 3 shows the individual cross sections. It is clear from the cross-sectional shape that the channel is entrenched. The average width to depth ratio for the five cross sections is 4.0, measured at the approximate top of banks, indicating a deep and narrow channel, typical of incision. A longitudinal survey was also conducted to determine the channel slope. The longitudinal channel slope through the meadow is 0.0038.

Piezometers were placed at cross sections 1 and 2 in the meadow so that several groundwater readings could be taken to qualitatively determine how the stream and subsurface water interact. This interaction will influence the creation of wetlands in this area. Readings were taken on two different days, 6/28/00 (no recent heavy rain activity) and 7/29/00 (immediately following a rain event of unknown magnitude). The readings showed that the groundwater, at least in part, is being fed by water from the stream. However, because the channel is incised, the groundwater table is relatively deep. This creates difficulty when trying to recreate wetlands because it is difficult to maintain the saturated surface that is periodically needed to support a wetland.

REFERENCE REACHES

Reference reaches are stable channel reaches that are either adjacent to or nearby the project site. Reference reaches can provide a "blueprint" for the cross sectional and planform geometry of the restoration design. Topographic maps, aerial photographs, and discussions with park employees were used to locate potential reference reaches. Site visits were conducted to assess the stability and applicability of the reach as a reference for Great Meadow Run. Table 1 provides the sites that were selected and visited for this purpose; the locations of these sites are shown in Figure 4.

As shown by Table 1, none of the streams were considered undisturbed reference reaches. The two most likely candidates, Smiley Run #2 and Meadow Run, have both been altered or otherwise disturbed. These reaches have adjusted to the disturbances, but are not currently in their natural pre-disturbance state. Thus, morphological and hydraulic characteristics of these streams may not be representative of the stream type in Great Meadow Run. In addition to being disturbed, the reaches were very difficult to survey. Smiley Run #2 is located on private land in a farm pasture. Although the site seemed acceptable for use as a reference, there was extensive hoof damage along the banks. In addition, the owner would not grant permission for us to survey because he has bulls on the property and feared for our safety. At Meadow Run, extremely soft channel bottom material made it impossible to wade or set equipment in the channel. However, at each of these two locations, rough estimates were made of average width, depth, and sinuosity. Table 2 provides these estimates. Average widths and depths in Table 2 are estimated for the approximate bankfull stage.

Table 1. Streams considered for reference reaches.

Stream	Location	Suitability as Reference
Smiley Run #1	Fayette County, PA near Deer Lake 39° 51' 26.74", 79° 35' 43.12"	Possible. Excessive thick vegetation does not permit surveying.
Smiley Run #2	Fayette County, PA near Deer Lake 39° 51' 28.11", 79° 35' 31.89"	Possible, but limited. Extensive hoof damage to banks limits usefulness.
Sandy Run	Fayette County, PA south-east of Fort Necessity 39° 45' 35.61", 79° 31' 42.93"	Not suitable. Beaver dam has changed stream characteristics extensively.
Wolf Swamp	Garrett County, MD 39° 40' 08", 79° 05' 13"	Not suitable. No well defined banks. Stream type not appropriate.
Meadow Run	Garrett County, MD near High Point 39° 41' 43.05", 79° 05' 37.52"	Suitable, but disturbed. Similar vegetation and character to Great Meadow Run. Was likely straightened in past.

Table 2. Approximate reference reach parameters.

Stream	Width (ft)	Depth (ft)	Width-Depth Ratio	Sinuosity	Channel Bed Material
Smiley Run #2	15	1.5	10	1.1	Silt
Meadow Run	30	3	10	1.05	Silt

In addition to not having a reliable reference stream to use as a design template for restoring the form of the stream, the many modifications that have been made over the years to Great Meadow Run, such as drainage, straightening, filling, and ponding, may render the use of a reference stream ineffective. In this case, it is unlikely that the use of a reference stream will help to achieve the objective of this study, which is to determine options that will restore the function of the stream (rather than the form or appearance) to that which occurred during the time of Washington. Even if the stream were returned to its original state in terms of form, it may not function in a similar way due to the extensive modifications to the channel and the upstream area.

DISCHARGE CALCULATIONS FOR GREAT MEADOW RUN

Discharges for present time and 1754 were estimated for the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storms at the following locations: (1) just downstream of the culvert at the amphitheater

entrance, (2) the historic auto bridge, and (3) just upstream of the Route 40 culvert at the downstream crossing of Great Meadow Run. Calculations were made using PSU-IV (Aaron et al., 1981) and available land use information. PSU-IV is a set of regional regression equations used to estimate flood peaks for watersheds between 1.5 and 250 square miles. The equations account for flood storage and urbanization and provide discharges for the 1.1 to 200-year discharges. Table 3 provides the estimates for Great Meadow Run. The discharges have changed little over this period of time, primarily due to the relatively minor land use changes in the watershed.

Table 3. Estimated discharges for 1754 and 2000 for Great Meadow Run.

Return Period (years)	1754 Discharge (ft ³ /s)			2000 Discharge (ft ³ /s)		
	Culvert	Auto Bridge	Rt. 40	Culvert	Auto Bridge	Rt. 40
1	50	61	89	54	65	95
2	59	80	109	63	86	117
5	75	126	193	80	135	207
10	130	167	293	139	179	314
25	177	212	319	189	227	341
50	223	274	389	239	293	416
100	250	307	450	268	328	482

The entrenched nature of the channel made it difficult to evaluate a bankfull or effective discharge (assuming that the two discharges are the same for the channel in its stable form). From Table 3, assuming that the bankfull discharge is *at most* the 1.5-year event and that discharge increases linearly between the 1- and 2-year events, then under non-incised conditions, the bankfull discharge can be estimated as $\frac{1}{2} (54+63) = 58.5$ ft³/s at the fort and $\frac{1}{2} (65+86) = 75.5$ ft³/s downstream of Indian Run. For cross section 1 upstream of the fort, the discharge that is contained within the channel banks can be approximated from the Manning flow resistance equation:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2} \quad (1)$$

where Q = discharge (ft³/s), n = Manning roughness coefficient, R = hydraulic radius (ft), and S = slope (ft/ft). Assuming n = 0.045 and S = 0.0038 (from the reconnaissance), Q = 115 ft³/s. Thus, it is clear that the channel contains well in excess of the bankfull discharge. Referring to Table 3, it is seen that the channel just upstream of the fort contains approximately an eight-year flood before overtopping its banks. This stream in its natural state likely overtopped its banks around the one to 1.5-year flood.

ALTERNATIVES FOR RESTORING GREAT MEADOW RUN

Several alternatives for restoring Great Meadow Run were explored. These included both passive and aggressive methods. Relatively passive methods have the advantage of minimizing the disturbance to the stream corridor and existing ecosystem. In addition, these methods let the stream do the work of restoration gradually over time. The disadvantage is that they may take a longer period of time to attain project objectives. Aggressive methods have the advantage of obtaining immediate design objectives. However, they are generally more expensive, are highly disruptive and destructive to the current habitat and stream environment, introduce sediment to the waterway, and may cause the channel to respond in an unpredictable and undesirable way. Thus, frequent monitoring and maintenance is often associated with aggressive methods.

Regardless of the method, an important component in restoring wetland characteristics to the meadow is the removal or destruction of the drain tiles throughout the park. These terra cotta drains and drainage tiles were placed in the late 1800's, and again in the 1950's, to drain the Great Meadow. Unfortunately, there are no markers or mappings of the tiles; however, there is some field evidence, mainly scour holes above the tiles, of their existence. The tiles could be dug up and removed, although this would involve the excavation of either the entire drainage network, or the main pipeline to which the drains are attached. The exact location of the main pipeline is unknown at this time; blueprints or shop drawings of the original project are unavailable. Alternatively, the drain tiles could be crushed in place, perhaps by driving heavy trucks over them. Although this method should work due to the age and poor condition of the drains, it has no guarantee.

Below we briefly describe each of the options for restoring Great Meadow Run and make recommendations for the most feasible options. For each option, estimated costs are given for the actual construction based on King et al. (1994) and Johnson and Brown (1999). Costs of design, monitoring, and maintenance are not included. In every case, the changes described are only for the channel downstream of the wooded area; upstream of this reach, where large trees grow along the banks, the channel is in a more natural state and is recovering on its own. In addition to each of these design alternatives, removal or destruction of the drain tiles should be considered. Estimated costs do not include drain tile removal.

Passive Approaches

The options described in this section (with the exception of option 1) involve encouraging desirable stream channel adjustments without causing major disturbances. The goal of each option is to increase flooding of the stream so that a one- to 1.5-year storm or greater will overtop the banks, leading to the possible creation of more permanent wetlands, while minimizing disturbances to the stream corridor. These options will involve the least amount of construction work and will have a relatively short recovery period. However, achieving the project objectives may, in some cases, take a number of years as the channel slowly adjusts to its new conditions.

In these options, it is desirable to cause increased flooding primarily on the left bank (facing downstream) of Great Meadow Run throughout the majority of the wetland sites. Flooding of the left bank will protect the fort from excessive moisture and keep the areas near the

pedestrian paths relatively dry to facilitate visitor accessibility. At the park entrance the left bank has long, uncut grasses while the right bank is forested. The vegetation in the forested section is not conducive to a wetland environment; thus, flooding will be encouraged to occur primarily over the left bank.

Option 1 - No Change

Under this option no changes would be made to Great Meadow Run stream corridor. Although the stream channel is deeply entrenched and the banks are locally undercut, the stream does appear to be stable, showing no stress cracks or bank failures. The magnitude of the entrenchment of the stream does not allow for frequent out of bank flooding which is required to maintain the wetlands. Depending on the stream location, the stream will overflow during certain storm events and create temporary marshy areas adjacent to the stream. Upstream of the fort, this occurs for the five-year and greater floods. Downstream of the fort to the park entrance, flooding occurs for return periods greater than about the two-year flood. However, the surrounding lands remain relatively dry for the majority of the year.

Advantages. The main advantage of using the “no change” option is the lack of disruption to the variety of vegetation and wildlife that now resides in the battlefield area. Leaving the site untouched would also guarantee that there would be no construction work needed; thus, the battlefield aesthetics would be kept intact.

Disadvantages. Due to the deep entrenchment of the stream and the drainage in the fields, it is very unlikely that the site will readjust to the 1754 condition, nor will permanent wetlands ever be restored within the next several decades. Another disadvantage of leaving the site untouched is the continued invasion of exotic vegetation in the area.

Estimated Cost of Construction: \$0

Option 2 - Engineered Debris Jams

Method and Purpose. An engineered debris jam consists of several variously sized logs in combination with smaller pieces of wood, silt, and debris to create a jam across a portion of, or the entire, stream channel. The jams cause excess flooding by increasing the channel roughness and meandering planform (Bilby et al., 1987; Hartman et al., 1987; Robison and Beschta, 1990; Shields and Smith, 1991; Gippel, 1995). Fish passage is maintained throughout the stream (Beschta and Cherry, 1989; Sullivan et al., 1987; O’Neal et al., 1999) and habitat is generally improved. Through careful placement of the debris jams, the stream channel will very gradually achieve sinuosity and widening which will, in turn, increase resistance and flooding.

Design Approach. Debris jams can be created using materials closely resembling the natural vegetation in the area. The jams can be designed to resist displacement by interlocking the logs, keying them into the banks, anchoring them in the stream, and inducing sediment deposition (Shields et al., 2001). In order to encourage silt and debris to build up at the jam, a screen can be placed around the upstream side of the logs and below the banks. Since the introduction of debris jams in a stream can increase the abundance and diversity of fish (O’Neal et al., 1999), the screen is attached in such a way as to not completely extend to either bank or the bottom to allow

for fish passage. Debris, including silt from the channel, grasses from the surrounding area, and wood up to 5 inches in diameter should be placed at the upstream side of the jam against the screen. The two support logs should be between 12 and 14 inches in diameter.

Based on the location of the debris jams, one of four basic alignments could be chosen (see Figure 5) (Beschta and Cherry, 1989). The debris jams can be placed at different angles with respect to the banks (vertical angle) and the flow direction (horizontal angle) in order to cause diverse flooding conditions or erosional patterns. To promote flooding on the left bank, alternatives C and D in Figure 5 can be used in an alternating pattern (Figure 6). Setting the jams at these positions will help form meanders in the stream while also protecting the right bank. In order to assure the safety of the bridge and the efficiency of the culvert at Route 40, the area immediately upstream of the bridge and the road should be kept clear of any debris jams for a distance of at least two bridge or roadway widths upstream. The area from downstream of the bridge to the beginning of the meadow at the park entrance should also remain free of engineered jams. Pool spacing in most freely meandering streams is about five to seven channel widths (Leopold, 1994). Pools formed by debris jams are more randomly spaced (Myers and Swanson, 1997). Based on these two observations and the narrowness of the stream channel, the jams should be placed no closer than about 75 to 100 feet apart. Debris jams should be located based on current meanders and locations of bank cutting. The exact location would have to be surveyed at the time of design. The jams can also be angled such that bank cutting by the flowing water will take place away from the fort. After construction of the jams is completed, the banks should be compacted and revegetated with native grasses and shrubs.

Disadvantages. The major disadvantage of debris jams is their potential to wash downstream during a large rain event. If a large discharge occurs in conjunction with bank erosion, the jam may shift from its original position or wash downstream. Another possible drawback of the jams is the potential for them to become an obstruction. Under normal flow conditions this should never happen due to the low rate of sediment transport that the stream carries, but during a high flow velocity, there is the possibility that significant amounts of sediment could be deposited in front of the debris jams.

Estimated Cost of Construction: \$2500

Option 3 - Placed Boulders

Method and Purpose. This method involves the placement of boulders along the length of Great Meadow Run. Strategic boulder placement can result in more out-of-bank flooding by increasing the flow resistance. It can also facilitate widening of the stream or the formation of meanders by constricting the flow area and thereby encouraging bank widening. An example of this can be seen in the current stream in the vicinity of the fort. The channel bottom width upstream of the boulder is approximately 1.5 feet. At the boulder and for a short distance downstream the width increases to almost 10 feet. The stream widening at this naturally placed boulder is a good example of how placed boulders will cause the stream to adjust.

Design Approach. Boulders one to two feet in diameter will be placed in the stream throughout the park entrance and fort vicinity (D'Aoust and Millar, 1998). Given the narrowness of the

stream, boulders will be placed every 50 to 100 feet. Due to the fact that wetland creation is desired only on the left side of the channel, boulders will be placed in an alternating pattern along the right bank and the middle of the channel. This arrangement should encourage both the formation of meanders (boulders on the right bank) and stream widening (boulders in the middle). In order to assure the safety of the bridge and the efficiency of the culvert at Rt. 40, boulders should not be placed within the influence of these structures, about two bridge or roadway widths upstream.

This method requires very little construction in the channel. Light machinery will be needed in order to haul and place the boulders. A small amount of excavation may be required to set the boulders in place.

Disadvantages. A disadvantage of boulder placement is the possibility of a boulder becoming displaced during a large storm event. Given that the boulder diameter is large in comparison with the stream width, displacement of one or more boulders should not greatly alter the original purpose of the boulder. Another possible disadvantage is the aesthetics of this option. The wetlands are to be recreated within a grassy meadow in stream channel material consisting mostly of clay and silt. The boulders might have an awkward appearance and could potentially detract from the 1754 look that the National Park Service is trying to achieve.

Estimated Cost of Construction: \$840

Option 4 - Change in Stream Channel Boundary Roughness

Method and Purpose. The purpose of this option is to increase flow resistance (in terms of the resistance coefficient n in Eq. 1) in the stream channel to decrease flow conveyance.

Design Approach. Cross section 1 has long, uncut grasses on the banks and silty material on the stream bottom. Cross section 2 also has vegetated banks, but the bottom material contains gravel and larger clasts. The park entrance, cross sections 3 to 5, has a silty bottom, but the banks are cut nearly vertical and have no vegetation. The grass and rocky channel bed material are substantially rougher than the silty material and increase the flow resistance, thereby decreasing flow velocity (see Eq. 1). Vegetation in the floodplain is similar throughout the reach, containing scattered trees and shrubs, and long, uncut grasses.

There are essentially two ways to increase the stream channel boundary roughness to achieve more frequent out-of-bank flooding: (1) increase the sediment size on the channel bed and (2) increase the roughness of the banks. The Manning's resistance coefficient (Eq. 1) is proportional to the channel bed material sediment size as:

$$n \propto D^{1/6} \quad (2)$$

where D = sediment diameter. From Eq. 1, the roughness coefficient n will have to be doubled to reduce the discharge by half, or approximately the bankfull discharge. From Eq. 2, increasing the sediment size from a very fine sand, 0.1 mm in diameter, to 6.4 mm in diameter (fine gravel), will provide this increase in n . The shear stresses should also be checked to determine whether

the new bed material, in this example fine gravel 6.4 mm in diameter, will be eroded at flow conditions that just fill the banks. The average boundary shear stress is given by:

$$\tau = \gamma RS \quad (3)$$

where τ = average boundary shear stress, γ = specific weight of water, R = hydraulic radius, and S = slope. For cross section 1, $\tau = 0.311 \text{ lb/ft}^2$. The sediment diameter that can just stay on the bed without movement is given by the Shield's equation:

$$\tau_c = 0.06(\gamma_s - \gamma)D \quad (4)$$

where τ_c = critical shear stress for particle movement, γ_s = specific weight of sediment, γ = specific weight of water, and D = particle diameter. For a shear stress of 0.311 lb/ft^2 Eq. 4 yields a sediment diameter of 19.3 mm. Thus, if the particle size of 6.4 mm calculated earlier is the largest particle size or if a uniform sediment size of 6.4 mm or smaller is used, it will be eroded. The use of a graded sediment will overcome this problem. For example, if the D_{86} size is 19.3 and the D_{50} (median) size is 6.4 mm, then the sediment will not be eroded (D_i = particle size for which i^{th} % of the total material is finer than that size). For this arrangement, the sediment gradation is 3.47, $D_{86} = 19.3 \text{ mm}$, $D_{50} = 6.4 \text{ mm}$, and $D_{16} = 1.6 \text{ mm}$.

In addition to changing the bed material size, roughness can be added by changing the bank roughness, for example, by installing fascines near the toes of the banks. Live fascines are long bundles of plant cuttings that are wired together and placed horizontally in shallow trenches (Brown and Johnson, 1999). Fascines can be secured into a streambank using live or dead stakes. The roots quickly grow and provide a dense, but shallow, network for stabilizing shallow bank failures. This is a particularly useful technique in areas where shallow erosion is a problem. This may also decrease the cross sectional area somewhat, providing additional assistance in lowering the return period for overbank flows.

Disadvantages. The primary disadvantage of this method is the change in bottom substrate as habitat. The soft, silty bed will be changed to a gravel bed. The implications of such a change should be addressed before using this method. There is also potential for new vegetation to be washed away if a large storm event occurs before the plants have completely taken root. If this happens, the channel would regain some of its former potential to carry more discharge, leading to heavier flows downstream that could cause the uprooting of new vegetation on the downstream banks.

Estimated Cost of Construction: \$56,000

Aggressive Approaches

The options described in this section involve significant construction and disruption of the current stream corridor and ecosystem. The goal of each option is to change the stream morphology to increase flooding of the stream so that a one- to 1.5-year storm or greater will overtop the banks, leading to the possible creation of more permanent wetlands, while minimizing disturbances to the stream corridor. These options will involve significant

construction work. Achieving project objectives is more immediate than for passive methods, but often requires frequent monitoring and maintenance as the stream adjusts to its new form, especially until vegetation has re-established. Due to the abrupt nature of these approaches, native vegetation could be destroyed along with exotics. In addition, sediment may be added to the stream flow and current aquatic and riparian habitats could be destroyed or damaged. Thus, these alternatives require very careful consideration and precautions.

Option 5 - Full Reconstruction of 1754 Wetlands

Method and Purpose. The purpose of this option is to completely restore the function and form of the Great Meadow Run stream corridor to its 1754 appearance, as described in the Cultural Landscape Report (National Park Service, 1998b). Restoration to approximate conditions at the time of the battle will include removal of the two to four feet of fill that has been added to the meadow area near the fort since the time of Washington and removal of the earthen levees that were built upstream of the fort. Removal of these features will yield a non-entrenched stream which will flood more frequently.

Design Approach. To estimate the amount of fill that was placed throughout the Great Meadow and park entrance, original surveys or additional studies (such as pollen studies) are needed. A rough estimate of the volume to be excavated can be made using the approximate area of the wetlands to be restored, about 20 acres based on the Cultural Landscape Report (National Park Service, 1998b) map, at an average depth of about two and a half feet, or 80,000 cubic yards. The longitudinal slope of the floodplain should closely approximate the current slopes of the overbank area and channel. The lateral slope should be gentle and follow the general terrain.

The stream would be widened to achieve a width to depth ratio of about 10. Based on the estimated bankfull discharge of 58.5 cfs at the fort, a rectangular channel would be approximately one foot deep by 10 feet wide. The affected areas should then be compacted and replanted with vegetation that was native to the meadow in 1754 (see National Park Service, 1996).

Disadvantages. The most apparent disadvantage of fully restoring the estimated conditions of the meadow is the amount of damage that will be done to the current stability and ecosystem of the stream corridor by the construction. Removing the fill will cause a large portion of the meadow to be disturbed. Existing riparian and floodplain vegetation as well as wildlife burrows and shelters will be destroyed. Compacting the area once the excavation is complete will create difficult growing conditions for the grasses and shrubs and the new topsoil may not be suitable for the wetland vegetation that needs to grow. In addition, channel adjustments subsequent to channel modifications may be rapid and undesirable, such as bank widening or channel migration in the vicinity of the fort. The channel could be stabilized with various measures; however, they could detract from the natural appearance of the channel. Construction work could also increase the sediment load to the channel. Finally, the renewal time for vegetation to re-establish following construction could be on the order of years.

Estimated Cost of Construction: \$645,000 for excavation of 80,000 cubic yards. The additional cost of revegetation would be determined by a botanist.

Option 6 - Cut Banks

Method and Purpose. In this option the banks of the stream would be cut back to widen the corridor. In addition, several techniques would be implemented to encourage the formation of meanders.

Design Approach. In this option, only a portion of the fill will be removed to minimize disturbance to the vegetation adjacent to the stream. To increase out-of-bank flooding, the left stream bank will be cut back at a 6H:1V slope above the bankfull estimated in Option 5. The affected areas will then be compacted and revegetated. Fascines will be planted to facilitate a more rapid recovery of vegetation and to provide additional stabilization of the banks and protection from erosion.

Logs will be placed at a downstream angle of 30° (Beschta and Cherry, 1989) throughout the channel, no more frequently than five stream widths apart. This will direct the flow into the banks and around the ends of the logs and will begin the formation of meanders. Since meanders increase flow resistance and reduce flow velocities, they also encourage flooding.

Disadvantages. One of the disadvantages of cutting back the banks of the stream is the removal of the alder trees and grasses that line the banks down to the water's edge. These native trees provide bank stability, and shade, cover, and food for the aquatic habitat. The grasses reduce flow velocities and act as a sediment control measure. The period between removing this vegetation and the complete revegetation of the banks would increase both the water temperature and the sediment flow into the stream and could cause destabilization of the banks if a large rainfall event occurs during this period. Although the area of land disturbed by construction is much smaller than in Option 5, a major part of the stream that is viewed by visitors will be excavated and altered, temporarily disturbing the aesthetics of the battlefield.

Estimated Cost of Construction: \$25,600 for excavation of 3,200 cubic yards plus \$17,000 for fascines.

Option 7 - Two-Stage Channel

Method and Purpose. A two-stage, or compound, channel consists of a deeper central channel that conveys a smaller discharge, such as the 1.5-year or bankfull discharge, and one or two side channels that convey overbank flows up to a design discharge, effectively creating a new floodplain (Myers, 1990). The compound channel is created by cutting the banks of the main channel and lowering the adjacent floodplains. By creating new overbank area, more out-of-bank flooding will occur onto the newly formed floodplain. Although this option is similar to bank cutting (see Option 6), a compound channel creates a new floodplain and lowers the banks, as opposed to cutting the banks back.

Design Approach. Since it is desirable to have more frequent flooding only on the left bank to protect the fort, an asymmetrical channel should be designed with a flood-stage channel cut out of only the left bank. According to Higginson, et al. (1990), constructed floodplains in compound channels are usually one to two times the width of the main channel. For Great Meadow Run, assuming a bankfull channel of 10 feet wide by one foot deep, an approximation

of the channel dimension can be made using Eq. 1 with $n = 0.045$ (some vegetation will be removed initially, but will re-establish in time). Based on the discharges given in Table 3 at the fort, the configuration in Figure 7, and a flood-stage channel width of 20 feet (twice the bankfull channel width), Table 4 gives the flow depth in the flood-stage channel. Following construction, the banks should be compacted and revegetated with native grasses and shrubs. The new stream corridor should be monitored for a period of years to assure channel stability and vegetative regrowth.

Table 4. Flow depths in a flood-stage channel for a two-stage channel design.

Return Period (years)	Flow Depth (y) (feet)
5	0.9
10	1.4
25	1.8
50	2.1
100	2.3

Disadvantages. The design and construction of a two-stage channel at Fort Necessity may result in an undesirable change in the aesthetics of the landscape in the vicinity of the fort. Although wetlands would be encouraged on the left bank, the remainder of the meadow would not receive any benefits due to the depth of entrenchment of the main channel. The asymmetrical design could result in the loss of soil moisture from the right bank, shifting vegetation further toward non-native species.

Similar to the other options that require significant construction, the alder trees and grasses that line the banks down to the water's edge will have to be removed on the left bank, possibly resulting in reduction of bank stability, and shade, cover, and food for the aquatic habitat. In addition, a major part of the stream that is viewed by visitors will be excavated and altered, temporarily disturbing the aesthetics of the battlefield.

Estimated Cost of Construction: \$28,000 for excavation of 3490 cubic yards plus vegetation costs.

CONCLUSIONS

Great Meadow Run is a first-order stream in the Appalachian Plateau of south-western Pennsylvania. It runs through a natural wetland meadow that is the site of an historic battle in 1754. Since the time of this battle, changes to the meadow and stream channel have resulted in a straighter, deeply entrenched stream which can no longer flood the meadow with a frequency needed to maintain the wetlands. Native vegetation has been replaced with exotics. It was the purpose of this project to examine alternatives for restoring or partially restoring the stream to

the time of Washington's battle so that the native vegetation can once again survive in at least a portion of the meadow.

The hydrology of the watershed has changed little since the 1700's. Slight changes in discharge are due to the highway (US Route 40) and other drainage from the visitor's center and other paved surfaces. Despite the many changes to the stream and meadow, such as the addition of several feet of fill, placement of drain tiles, and straightening of the channel, Great Meadow Run is relatively stable even though it is deeply entrenched. The dense vegetation at the banks and the nature of the bank material helps to maintain slow channel adjustments over a range of flows.

Seven options were developed as possibilities for restoring, at a minimum, the function of Great Meadow Run. Four of the options were classified as passive in that they require relatively little earth movement and adjustments to the stream channel would be fairly slow. Three options were classified as aggressive in that significant construction and excavation would be required. Although the use of a reference channel was explored, suitable reference channels were not found and because of the modifications within the Great Meadow Run channel and meadow, it is unlikely that the use of a reference channel will produce the desired results in terms of maintaining the wetland meadow.

Recommendations

It is the opinion of these authors that aggressive methods should be avoided for this project. Aggressive methods will result in a very abrupt disruption to the current ecosystem and channel stability. It is preferable to encourage a gradual response to a minimal change that, in time, yields the desired results for the ecosystem as well as the form and function of the stream. In addition, all aggressive methods will require post-construction monitoring and maintenance over a period of years to assure that the channel is stable while waiting for vegetation to mature. The stream channel could become unstable due to the disturbance of soils during construction.

We believe that Option 2 (Engineered Debris Jams), a relatively passive option, will provide the gradual change that is desirable, will have minimal impact on the aesthetics of the park during construction, will cause minimal disruption to the current physical system, and will produce the desired results with the majority of the work being performed by the stream itself. It should be kept in mind that the results will not be immediate, but rather will be produced over a period of time. The plates attached at the end of this report illustrate the progression of the channel and vegetative adjustments over time.

Our recommendations are based on the results of our study of the river mechanics and geomorphology associated with Great Meadow Run, although we also made every attempt to consider the aesthetics of the park. Other factors that may be considered in the selection of a preferred alternative by the National Park Service include economics, politics, priorities, and other physical factors associated with the park.

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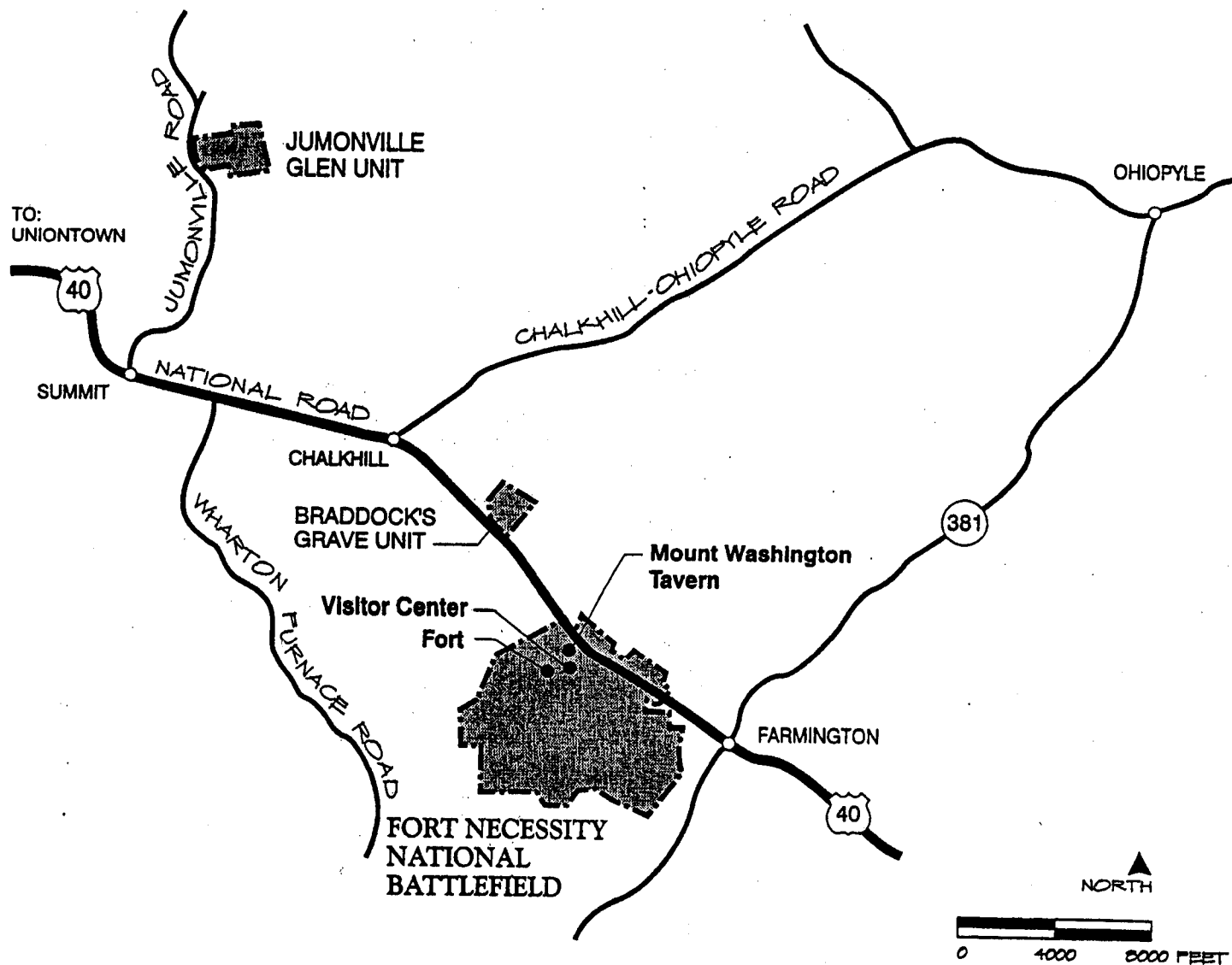


Figure 1. Location of Fort Necessity National Battlefield, Pennsylvania

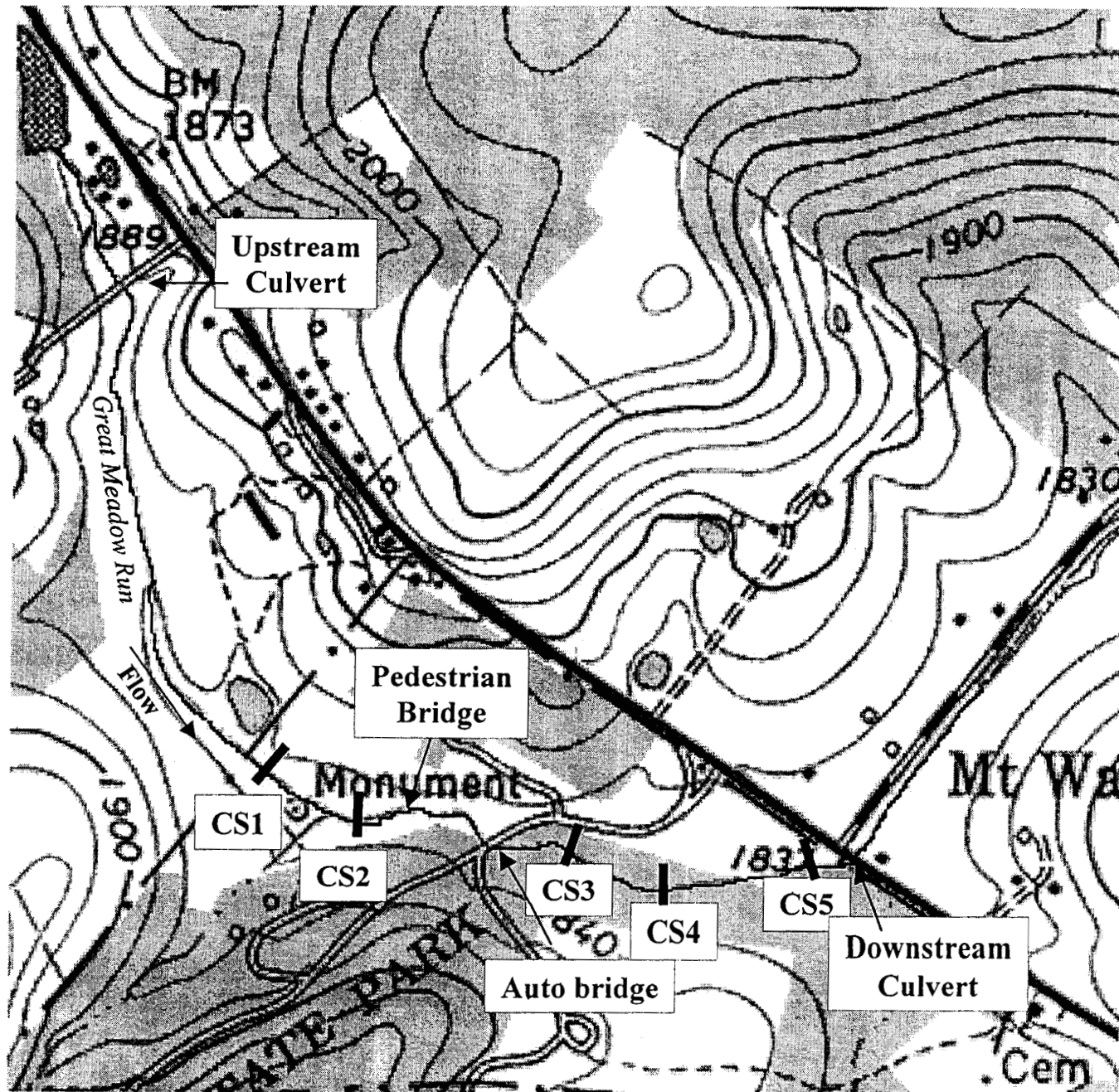


Figure 2. Great Meadow Run with locations of cross sections (CS) and structures.

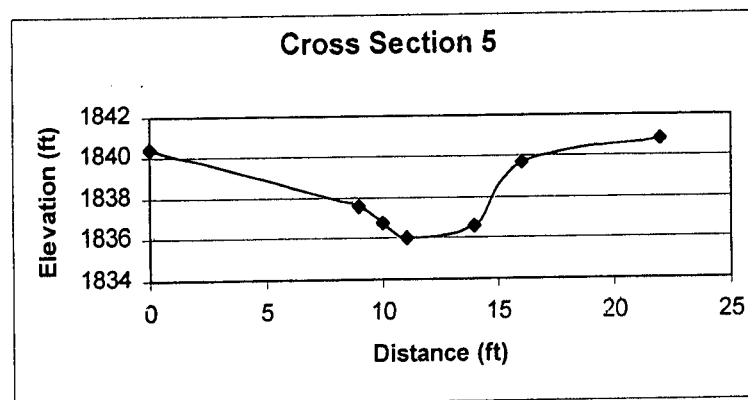
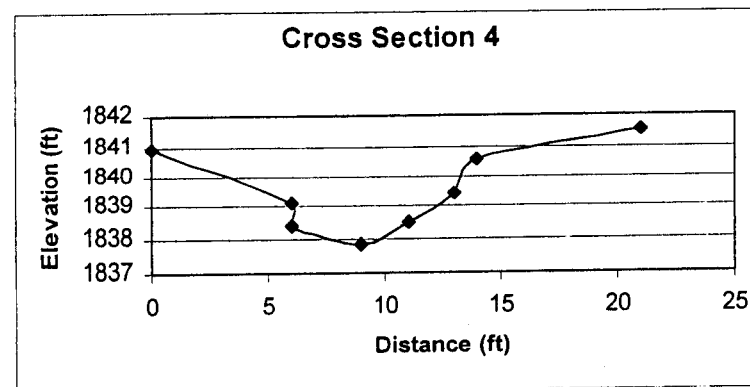
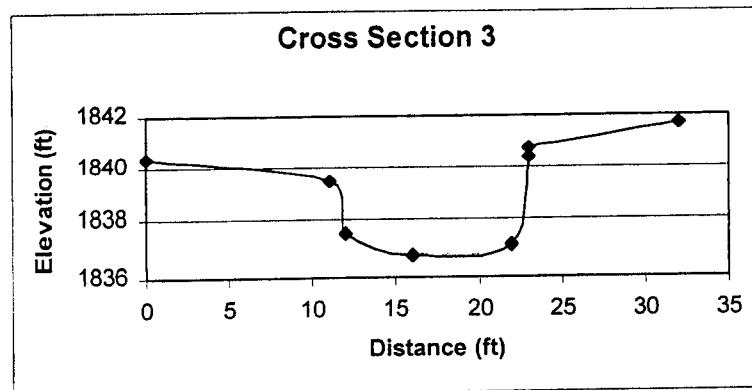
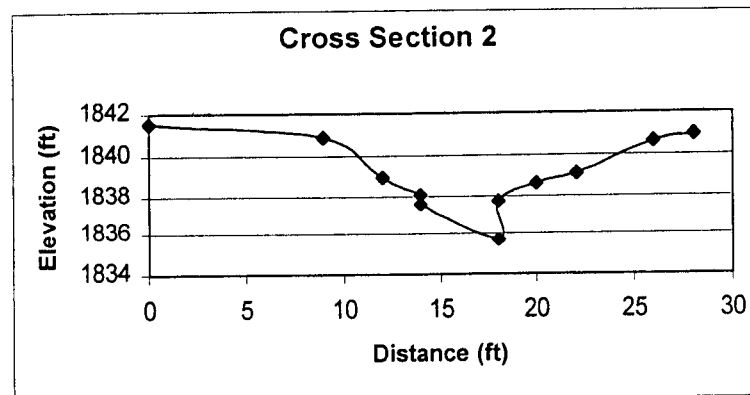
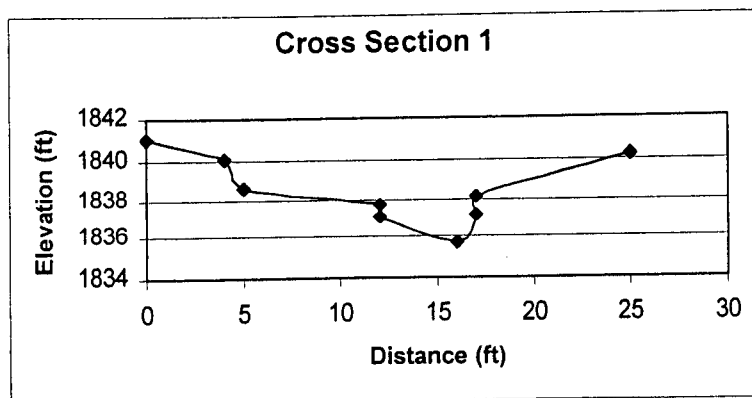


Figure 3. Cross sections with Distance = 0 at left bank facing downstream.

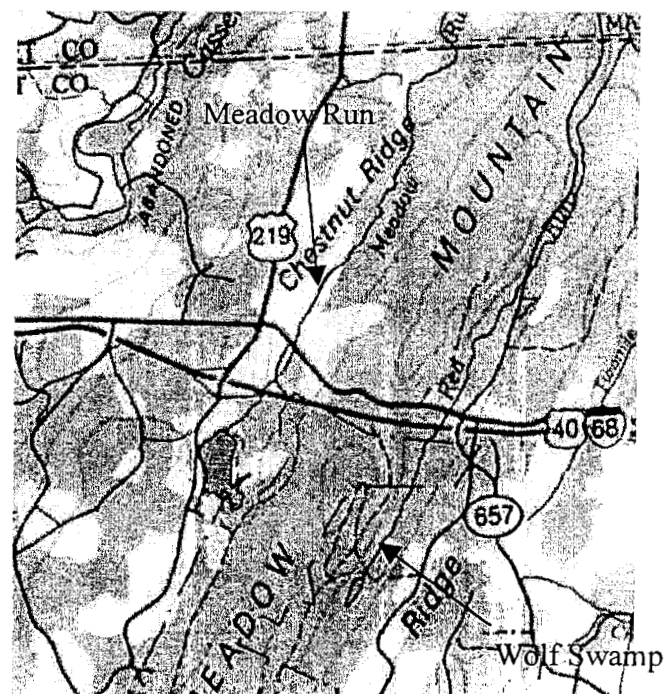
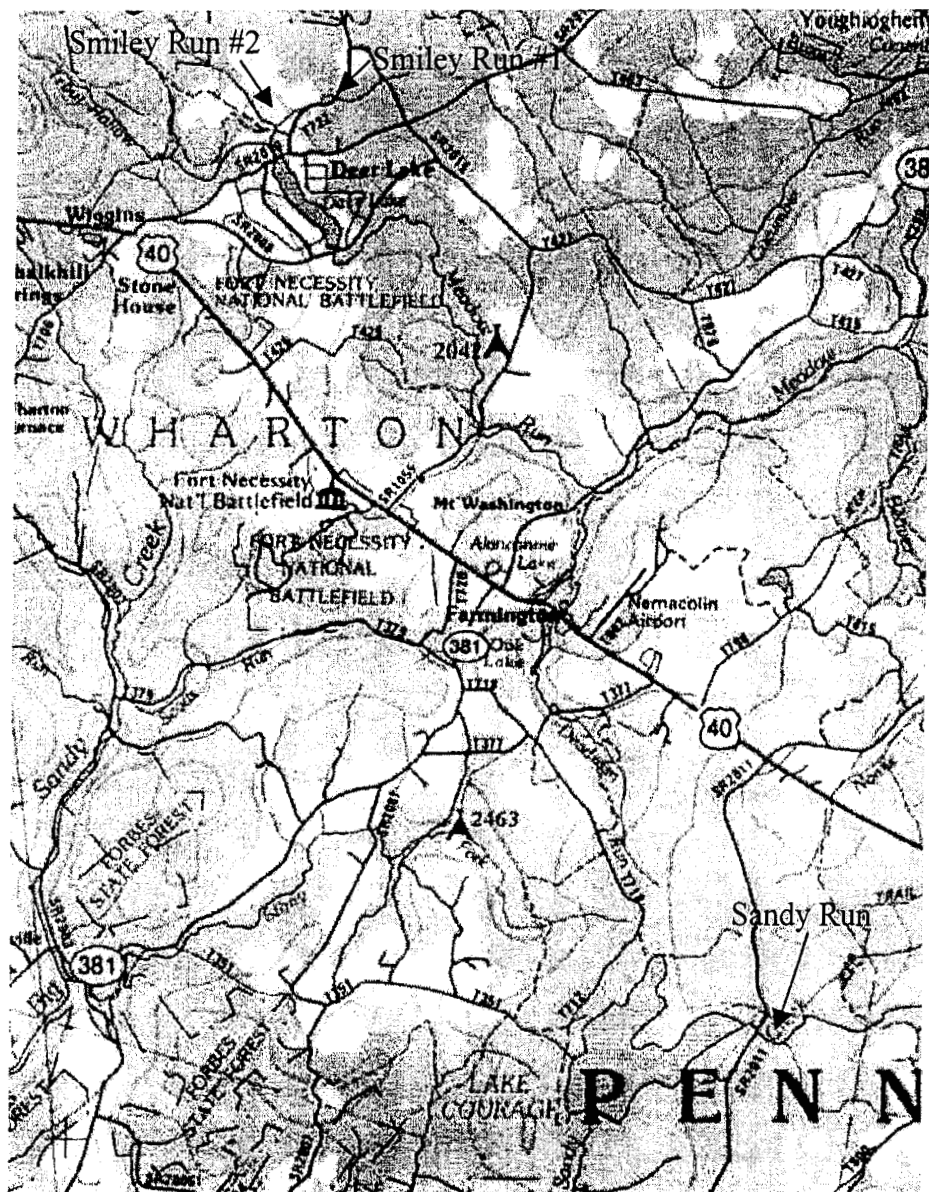


Figure 4. Locations of reference reaches.

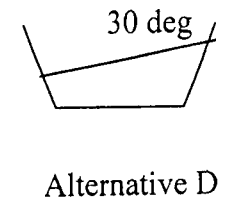
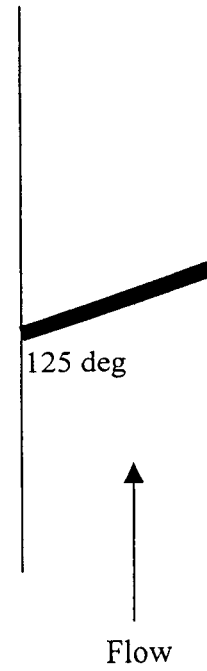
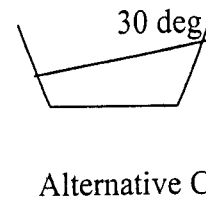
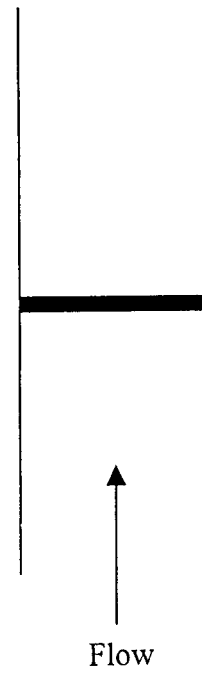
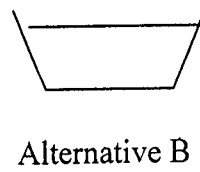
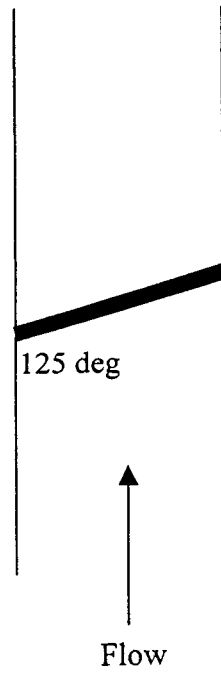
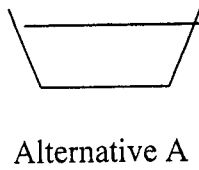
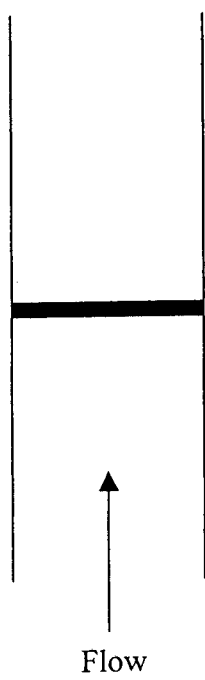


Figure 5. Four alternative alignments for debris jams.

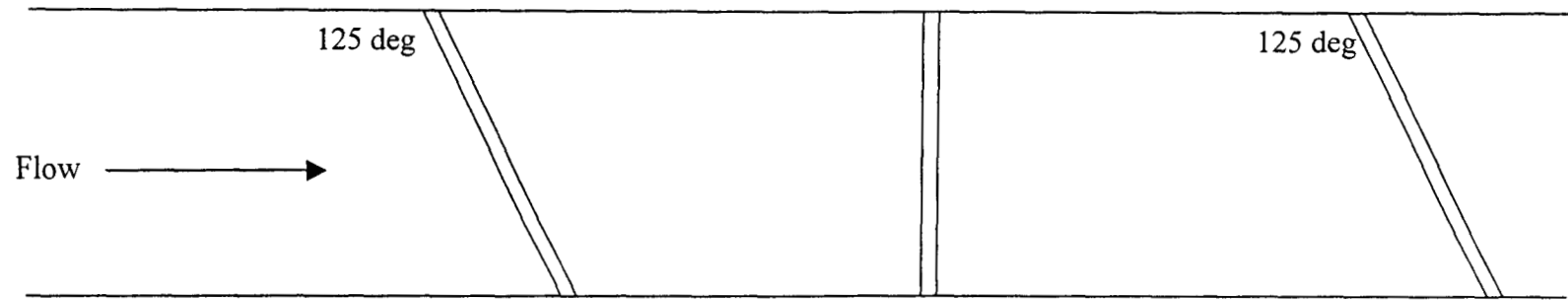


Figure 6. Alternating pattern for debris jams to promote flooding on left bank.

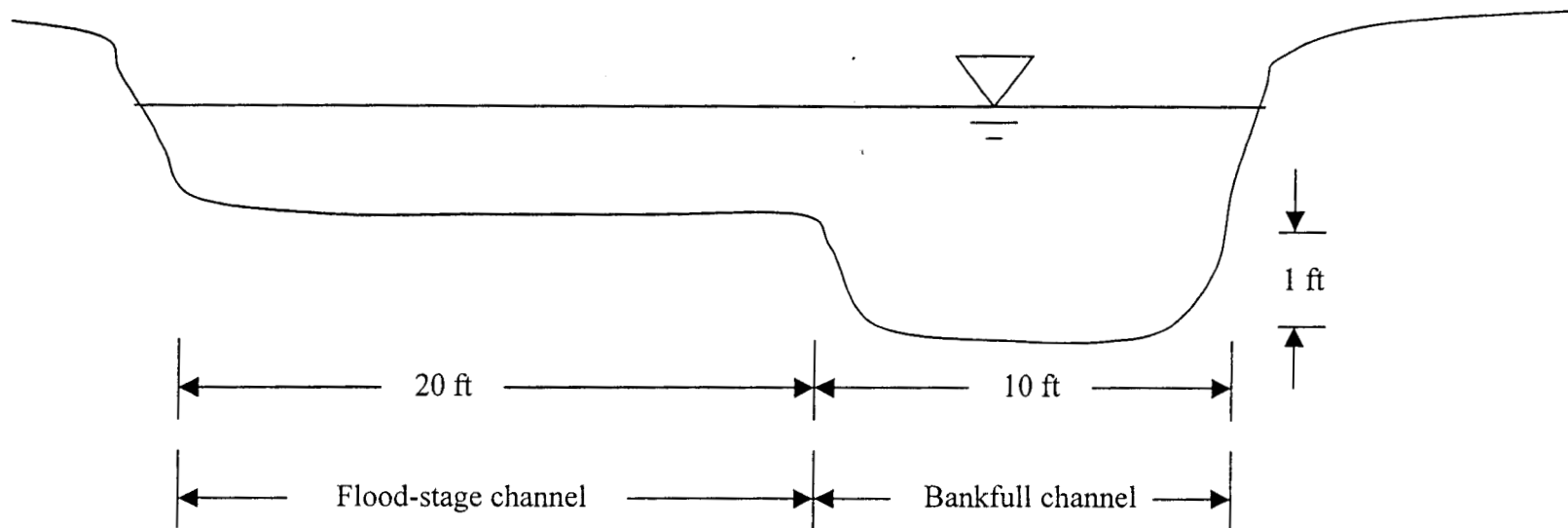


Figure 7. Two-stage channel configuration (Option 7).