Alternatives for Restoring Headwater Streams via Sediment Pond Removal in the Appalachian Coal Belt Region

Project No. GR506211

Final Report

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Table of Contents

List of Figures

List of Tables

1.0 Introduction

In the Appalachian Coal Belt Region, sediment ponds are often located in close proximity to headwater streams. Research indicates that between 60 to 80% of the cumulative channel length in mountainous areas is comprised of headwater (first and second-order) streams (Schumm, 1956; Shreve, 1969). Many researchers view headwater streams as vital ecosystems as these channels 1) supply downstream reaches with nutrients, organic matter and sediment, 2) support large populations of macroinvertebrates, which are key to downstream ecosystems, and 3) increase biodiversity by providing habitat for rare and endangered species. Because of the importance of headwater streams, cost-efficient methods need to be developed for replacing sediment ponds, following their useful life, with restored headwater streams.

1.1 Objectives

- Document currently employed method for sediment pond removal.
- Develop and/or modify design techniques for restoring the function of headwater streams and floodplains following sediment pond removal.
- Employ these design techniques by removing a typical sediment pond
- Re-establish riparian vegetation to provide shading, organic matter, habitat, and streambank stability as part of the restoration design.
- Document the economic factors associated with these new and/or modified techniques for the removal of a sediment pond and creation of a headwater stream.

1.2 Planned Monitoring

- Prior to construction, bi-weekly grab samples at four sites analyzed for pH, EC, sediment (turbidity, settleable solids and suspended sediment concentrations), as well as various nutrients and metals.
    - Approximately 50 m upstream of the sediment pond
    - Immediately upstream of the sediment pond
    - Immediately downstream of the sediment pond
    - Approximately 50 m downstream of the sediment pond
- During construction, an ISCO 3700 sampler will be used to collect samples at 30-minute intervals, both upstream and downstream of the construction area.

- Permanent cross-sections upstream and downstream of the project reach will be surveyed before, during and following construction.
- Bed material sampling upstream and downstream of the project reach will occur before, during and following construction.
- Permanent photo-stations upstream, downstream and within the project reach will be established.

1.3 Planned Outreach

- Development of a case study that can be downloaded from http://www.bae.uky.edu/UKReclamation. Key stakeholders will be notified of the availability of the case study.
- Field day to 1) describe the specific methodology of removing sediment ponds and establishing naturally designed headwater streams, 2) relay design and construction experiences, and 3) discuss monitoring results.
- Final report to the Environmental and Public Protection Cabinet, Department of Natural Resources, Division of Mine Reclamation and Enforcement.
- Conference proceedings and refereed journal article detailing the project.

2.0 Documentation of Sediment Pond Removal Techniques

2.1 Identification and Assessment of Current Practices

Current methods for sediment pond removal where investigated through site visits as well as personal consultations with coal mine operators and engineering consulting firms located in Ohio, West Virginia, Kentucky, Virginia and Alabama.

2.1.1 Types of Sediment Ponds

Several types of sediment ponds were indentified through consultation and field investigation efforts. These types included:

- Bench ponds with a single spillway outlet.
- Bench ponds were not further considered for this project since the establishment of natural streams in contour diversions does not lend itself to natural stream design (NCD) techniques

that incorporated geomorphic landscape configurations of ephemeral streams with a reforested watershed.

- Ponds located near the toe of valley fills (VFs) with a single spillway.
- Ponds located near the toe of VFs with both an emergency spillway and a drop inlet located approximately 1 to 2 ft below the invert of the emergency spillway.
- Ponds located near the toe of VFs with an emergency spillway and perforated riser for passive dewatering.
- Ponds located at a distance substantially down-gradient of VFs such that a portion of the runoff was generated from forested areas – single emergency spillway.
- Ponds located at a distance substantially down-gradient of VFs such that a portion of the runoff was generated from forested areas – an emergency spillway and drop inlet.
- Ponds located at a distance substantially down-gradient of VFs such that a portion of the runoff was generated from forested areas – an emergency spillway and perforated riser.
- Ponds located down-gradient of disturbed areas with an emergency spillway, straight pipe, and fixed siphon with passive dewatering or with a valve that either restricted flow and/or required manual opening of the valve to initiate dewatering (often used for release of stored water after treatment for manganese).

2.1.2 Baseflow

Another distinction that affects sediment pond replacement strategies is the presence or temporary absence of runoff entering the pond. Those ponds that were located down-gradient of traditionally constructed VFs, either in close proximity or further down-gradient, predominantly had base flow throughout the year (i.e. a perennial stream). This was the case even for ponds initially located in intermittent streams and to a somewhat lesser extent for ponds initially located in ephemeral streams.

Ponds located in areas that received runoff from disturbed or reclaimed areas predominately had relatively short duration intermittent flows. Ponds that where located down-gradient of areas reclaimed using the Forest Reclamation Approach (FRA) received substantially lower peak flows than traditionally reclamation areas and flows where much longer in durations. Ponds below FRA areas had periods of no flow during a portion of the summer months and early fall.

The importance of having periods of no flow with respect to sediment pond removal and establishment of natural streams is simply that the need to temporarily dam and/or bypass base flow may not exist. Hence, there is a likely cost savings and a high probability of reducing discharge of sediment during sediment pond removal and natural stream establishment construction activities. Also without inflow, there was an expectation that construction activities would be more efficiently (cost-effectively) executed both with respect to sediment removal and sediment blending with embankment materials. In many situations, the terrain did not enable establishment of a bypass diversion around the sediment pond. In these cases: 1) temporarily stored runoff was pumped through pipes to bypass the sediment pond, 2) temporary diversions where established directing flow through the sediment pond towards a spillway or dam breached area, or 3) no provisions were made for inflow diversion and base flow simply entered the sediment pond during sediment removal and/or breaching of the embankment.

2.1.3 Smaller Sediment Ponds due to Fill Placement Optimization Process (FPOP)

Throughout the Appalachian Coal Mining Region, sediment ponds are the prevalent method for controlling storm water and sediment generated from disturbed areas. In Kentucky and West Virginia, sediment ponds were predominantly built down-gradient of VFs. Approximately 7,000 such sediment ponds are estimated to have been constructed in the last few decades. From 1975 through approximately 2009, many sediment ponds were located further down-gradient in a watershed due to the larger size of VFs that were prevalent during that timeframe. Hence, sediment ponds were oftentimes located in perennial and intermittent streams. Since approximately 2009, with the advent of the Fill Placement and Optimization Process (FPOP) issued by the Kentucky Department of Natural Resources as Reclamation Advisory Memorandum (RAM) # 145, the area extent of VFs has decreased resulting in smaller fills placed higher in watershed. Thus, RAM #145 facilitated the placement of sediment ponds higher in watersheds in either intermittent and/or ephemeral streams. In Ohio and Virginia, much of the mining is conducted as re-mining and there is no need for VFs for most of these areas.

2.1.4 Sediment Pond Removal Techniques

Sediment pond removal techniques varied widely among mine operations. Common decisions and methods, based on informal discussions, encompass the following items:

- Timing and baseflow
    - When baseflow occurred, year-round mining operations either conducted sediment and embankment removal whenever it was convenient or somewhat considered the drier-part of the seasons.
    - When there where long periods without baseflow, the mine operator would often target sediment and embankment removal.
- Bypass baseflow
    - Most mining operations do not temporarily dam and bypass baseflow and storm flow during pond removal and stream reconstruction.
    - Frequently, baseflow is routed through a portion of the deposited sediment via a temporary channel cut into the sediment pond while attempting to avoid active sediment removal operations. Thus, the temporary in-pond diversion is relocated during sediment removal operations.
- Dewatering provisions during sediment pond removal
    - Most sediment ponds are designed and constructed without dewatering provisions.
    - For single spillway sediment ponds, water is either discharged through the emergency spillway through pumping (decanting) standing water and baseflow and/or by incrementally breaching the spillway to enable surface waters to be decanted. A sump is often constructed adjacent to the spillway prior to pumping. In some instances, a trench or number of trenches will be excavated to assist in reducing the pore water pressure of deposited sediment to further assist in dewatering.
    - For sediment ponds that have both an emergency spillway and a drop inlet, principal spillway dewatering is either accomplished as described above or water is pumped (sometimes siphoned) into the principal spillway. A sump is often constructed adjacent to the principal spillway with or without trenches.
    - Sediment ponds with perforated risers passively dewater between storm events and continually pass baseflow. Hence, dewatering for pond removal is easier. Sumps, trenches and a pump or siphon are sometimes used to expedite dewatering of sediment pore water.
    - Ponds outfitted with a floating siphon also dewater between storm events. The size of storm that is passively dewatered depends on the floating siphon configuration.

- Sediment removal and sediment blending
    - Sediment removal proved to be difficult due to the remote location of sediment ponds and that removal occurred after Phase II bond release when often earthwork equipment was relocated to other mine areas and/or other mine sites. Additionally, except when enhanced dewatering provisions were designed into the original construction of the sediment pond, deposited sediment was saturated and despite dewatering efforts there was fundamentally a sediment-soup mixture. Thus, sediment removal was inefficient during excavation and also during transport to other locations. If sediment removal was to be accomplished without entry into the pond, a long-arm backhoe or excavator was used. Besides these being specialized pieces of equipment, their rate of sediment removal is slow compared to other processes.
    - Since sediment removal was time consuming and costly, the predominant method utilized was, after partial dewatering of the deposited sediment, soils from the embankment were mixed with deposited sediments and moved via dozers to areas adjacent to and within the sediment pond and nearby the embankment. This was a very cost effective solution compared to the alternative of sediment removal and haulage.
- Sediment load and water quality
    - Since the collaborator was not able to acquire a permit to proceed with the sediment pond removal and with the stream restoration design, we do not have sediment load or water quality data. It is certainly reasonable that construction that would proceed without baseflow or bypassing baseflow would be expected to generate less sediment. Also, conducting sediment and pond removal operations when there is a lower probability of convective storms and when planning around frontal storms would also decrease sediment impacts.
- Sediment controls down-gradient of the embankment
    - Normally, there was no attempt to control sediment during embankment removal except for the utilization of best management practices such as rock check dams and/or straw bales.

- Complete or partial embankment removal
    - Often, only the floodplain portion +/- 20 to 30 ft of the embankment was removed and the remainder portion of the embankment somewhat regraded into surrounding areas.
- Vegetation
    - Grasses and legumes were the predominate plants of choice.
    - Few trees were planted along the future riparian zone of the constructed stream or in the immediate contributing watershed that was formed from blended soils.
- Stream reconstruction
    - Stream reconstruction methods appeared to be rather basic. The construction of "streams" that had a vague resemblance to nearby un-impacted streams was the norm. Often, rock riprap was highly incorporated into the re-constructed streams by professionals untrained in natural channel design techniques. Replacement of rock armoring was not evident. There was no account taken of establishment of the riparian zone to enhance stream function with respect to incorporation of woody debris for organic material and a carbon source, no nitrogen source from riparian trees, and no appreciable shading for temperature control. Pool-riffle sequencing was somewhat hap-hazard. The use of reference reaches was not always evident. It should be noted that most of these observations were drawn in the first year of this project.

2.2 Development of Alternative Methods

2.2.1 Consultations

In addition to consultations with coal mine operators and engineering consulting firms in Ohio, West Virginia, Kentucky, Virginia and Alabama, informal discussions were held with individuals from various federal and state agencies and stream restoration specialists. Discussions with Appalachian engineering consultants and the coal mining industry were extensively expanded to gain insights from residential and commercial construction activities and from large international consulting firms and the international mining industry. The focus of these expanded discussions, especially with large international firms and industry, was on sites that had steep terrain and rainfall that was similar or greater than Appalachia. Sites in Chile, Peru, New Caledonia, Borneo and the

Philippines were especially beneficial. No costs associated with these site assessments were charged to the grant.

2.2.2 Reduction of Baseflow

The elimination of baseflow for a portion of the year decreases the erosion and transport of sediment during sediment and embankment removal, and establishment and stabilization of a natural stream reach. Since many sediment ponds are constructed below the toe of VFs and traditional VFs predominantly generate year-round baseflow, it is beneficial to re-visit VF construction techniques. It the last two years, VFs have been constructed with the objective to reduce conductivity emanating from fills and to mimic the seasonal hydrologic cycle of streams in Appalachian forested areas. Both objectives have been realized. Sediment ponds located down-gradient of VFs that did not have a rock underdrain connection to the crown of the fill and that where constructed with particular attention paid to fill compaction and enhanced surface water management techniques had periods of time without base flow emanating from the fill. Base flow ceased between approximately mid-May through early to late November. The added advantage of such VF construction is that baseflow not only mimicked forested land hydrology but that the removal of sediment ponds could be scheduled during a four to five month period without concern for erosion and transport of sediment during sediment removal and stream establishment. Of course, planning around frontal storms and convective storms is still necessary.

2.2.3 Sediment Pond Designs for Efficient Sediment Removal and Stream Establishment

Sediment ponds can be designed that incorporate features that expedite sediment and embankment removal and re-establishment of natural streams. Such designs have been successfully incorporated into projects located throughout many areas of the world. Sediment pond designs need to incorporate dewatering provisions, multi-chamber provisions, and a partial rock base to expedite sediment removal using standard construction equipment.

The sediment pond dewatering system identified during site assessments consisted almost exclusively of a perforated riser. One mine operator retrofitted approximately two dozen sediment ponds with a valved fixed siphon that was located within a straight-pipe; the principal spillway. Dewatering systems consisting of a floating siphon or trenches with either an internal sand filter or external sand filter were not found except for the experimental sediment pond constructed by the University of Kentucky in 1996 as part of the initial loose-dumped spoil forest reclamation technique project. This experiment, conducted by Kentucky Department of Natural Resources (Paul Rothman and Carl Campbell) and University of Kentucky researchers, was the precursor to the Kentucky Reclamation Advisory Memorandum #124 (Forest Reclamation Approach).

An experimental sediment pond was configured with multiple spillways to test their performance with respect to effluent sediment concentration and overall sediment trap efficiency. Two types of sand filters were installed: internal sand filter and external sand filter. An internal sand filter was installed at the bottom of the pond. It discharged through a pipe to a grass filter down-gradient of the sediment pond. The pipe was valved to control the flow rate and/or was manually operated from close to open positions. Besides the enhanced sediment trap efficiency and reduced effluent sediment concentration another significant advantage of such an internal sand filter is that deposited sediment had low water content thereby expediting sediment and embankment removal. An external sand filter was constructed down-gradient of the sediment pond. Within the sediment pond was installed either a trench filled with rock or a mounted sand-rock filter. Numerous configurations are possible. An external sand filter has the added advantage of re-generating the filtering action of a sand filter through sand surface racking or removal and replacement of the surface layer.

Ponds outfitted with a floating siphon also dewater between storm events. The size of storm that is passively dewatered depends on the floating siphon configuration.

Ponds with a floating decant are capable of dewatering without a siphon since the outlet pipe is near the bottom of the pond. Thus, to dewater prior to sediment pond removal first the inlet pipe is simply lowered to just above the sediment level and then after a sump is constructed the inlet pipe is lower near the base of the sump to further reduce the water level.

Passive dewatering systems such as floating siphons or decant systems and internal trenches and/or internal sand filters and/or external sand filters drain deposited sediment and expedite either sediment removal and transport or blending operations. The advantage of dewatered sediment within the sediment pond was readily realized and will be highly beneficial in sediment and embankment removal.

Such designs as multi-chamber sediment ponds located on a gradient that enables gravity flow from the upper to lower sediment chambers can assist in sediment removal. A number of such ponds were constructed in Borneo for coal mining and in Georgia at a construction site. If sediment removal is a design element, than the embankment that separates the up-gradient chamber from the down-gradient chamber can be constructed to accommodate a track hoe and trucks to efficiently remove sediment from the up-gradient chamber. The dimensions of the up-gradient chamber should be based on the reach of excavation equipment. The embankment that separates the up- and down-gradient chambers can be constructed of rock riprap and smaller rocks to enable passive dewatering via gravity flow between the two chambers. This keeps the up-gradient sediments ‘relatively dry’ and easy to be removed. The up-gradient chamber also predominantly captures sand-size particles and therefore also functions as a passive sand filter for runoff that seeps through deposited sediment as it proceeds to the down-gradient chamber.

To further expedite sediment removal and re-establishment of a natural channel, it is recommended to place rock along a portion of the bottom of the sediment pond that will act as a stabilized ‘road’ for an excavator and truck to enter the pond and load-out deposited sediments. If bed rock is reached during pond construction, it too can act as a road base. The road base should be aligned with the future natural stream pattern in mind. The additional advantage of establishing such a rock base during pond construction is that natural stream bed armoring will exist for natural stream foundation material.

When dewatering systems were designed and installed into sediment ponds, then sediment removal was much more cost-effectively accomplished. It was estimated that sediment removal was approximately four to five times more cost effective when deposited sediment was passively dewatering through either an internal or external sand filter. Dewatering systems and sediment pond provisions that accommodate sediment removal allow for efficient removal and/or blending of deposited sediment with embankment soil. Another benefit is that blended soils had lower water contents and were inherently more stable, quicker to establish grasses and legumes, and enable planting a larger range of seedlings and transplanting of larger trees within the proximity of the newly established riparian zone.

2.2.4 Sediment Controls during Sediment and Embankment Removal

The most efficient and readily constructed best management practice for sediment control during sediment and embankment removal operations is a combination weep berm-natural grass filter. If there is baseflow or storm water, such flows can be easily directed to a weep berm that is either constructed parallel to the embankment or parallel to the down-gradient stream. A weep berm constructed just down-gradient and parallel to the embankment appears to be the most efficient control technique. Soil removed from the embankment during initial construction activities is readily available for use in weep berm construction.

2.2.5 Complete or Partial Embankment Removal

It seems reasonable that complete embankment removal would be accomplished. Partial removal may restrict the natural progression of stream sinuosity over time.

2.2.6 Vegetation

The ability to blend drier deposited sediment with embankment soil should allow for more stable slopes at a steeper angle than the alternative of using wetter soils. Hence, the geomorphic pattern of forested lands should be more feasible. Additionally, the somewhat drier soils should enable transplanting larger trees and establishment of a wider variety of seedlings to more closely match undisturbed natural Appalachian forest. Use of the FRA should be more feasible based on the ability to more readily transport and place blended soils. Establishment of such a forest is critical in the development of natural stream that has both form and function. Steeper channel side slopes can also be established with the blended soils and judicious placement of rock relocated from the emergency spillway.

3.0 Preliminary Design

The preliminary design was completed by David Bidelspach at Stantec Consulting, Inc. and was not funded by this grant.

3.1 Site Description

The John Tate sediment pond is located near Hazard, Kentucky within the Krypton Quadrangle (figs. 1 and 2). The sediment pond was installed on the Pigeon Roost Branch, which flows directly into the North Fork of the Kentucky River. The sediment pond is approximately 0.9 acres in size.

The principal spillway is located on the right-side of the embankment (facing down-gradient) with the secondary spillway located on the left-side. The height of the embankment is approximately 20 ft on the upgradient or pond side and 40 ft on the down gradient side.

Stream restoration will begin upstream of the sediment pond, will progress through the sediment pond, and will continue down gradient of the sediment pond (figs. 3-11). At the most down gradient section of the restoration site, channel enhancement will be performed along sections of the channel exhibiting locale erosion.

3.2 Reference Reaches

Reference reach data were obtained from sections of E6 and C6 channels upstream of the sediment pond, well outside of the zone of influence of the backwater. These reaches exhibited stability, well-defined bankfull benches, wide and flat valleys, as well as low-gradient slopes. Data collected from these sections of channel will be utilized in the design of upgradient of the sediment pond, through the present location of the sediment pond, and for a section of channel down gradient of the sediment pond.

A second set of reference reach data were collected at a B4 channel located on a section the University of Kentucky's Robinson Forest off of HWY 476 near the town of Rowdy, Kentucky. This reference reach is located in a forested watershed, exhibits stability, and a well functioning step-pool system. Data, collected from this section of channel, will be utilized in the design of the step-pool section of channel that will be constructed along a portion of face of the former embankment. These data will also be used to restore a section of channel down gradient of the sediment pond.

3.3 Methodology

3.3.1 Preliminary Design Parameters

Data collected from the various reference reaches was used to develop a morphological table of preliminary design parameters (Table 1). These design parameters were used to develop a preliminary restoration plan (fig. 12). Approximately 1,465 ft of headwater channel will be restored and/or t of headwater channel will be enhanced.

3.3.2 General Construction Sequence

The proposed general construction sequence is as follows:

- Prior to conducting restoration, the sediment pond requires dewatering. Dewatering the sediment pond will consist of a number of steps.
    - First, a sump will be dug near the earthen emergency spillway. Note that the emergency spillway is located on the opposite end of the embankment from the principal spillway.
    - A siphon will be installed in the sump to dewater as much water from pond as possible. Rocks will the placed around the siphon in the sump to allow for stability and a deeper dewatering depth. Water from siphon will be discharged into the vegetated area down gradient of the embankment and up-gradient of the current channel.
    - A series of notches will be cut into the principal spillway throughout the dewatering process. Prior to notching out the principal spillway, large rocks or boulders (approximately 1 to 3 ft in diameter) will be placed upgradient of the principal spillway, similar to a rock check dam, to decrease the potential for sediment to leave the pond. With continued notching of the principal spillway, additional boulders will be added as necessary.
    - A diversion channel will be excavated and temporarily stabilized to direct the water from the upstream channel to the principal spillway. The diversion channel will be located along the right side of the pond looking down valley.
- Following dewatering, the embankment will be excavated. Excavated materials will be blended with embankment soils and placed in the floodplain.
- Next, the designed channel will be constructed. The designed channel will exit the sediment pond along the former emergency spillway location.
- Materials excavated during the construction of the designed channel along with the prior placed materials from the embankment will be graded to develop the floodplain. During the grading process, efforts will be made to minimize compaction of the soil. Efforts will be made to develop features, such as one or more vernal ponds, to enhance habitat.
- Vegetation (to be selected) will be planted in the floodplain.
- Monitoring of the restored channel will occur in accordance with Kentucky Division of Water requirements.

4.0 Preliminary Water Quality Sampling

A total of six grab samples were collected on a monthly basis from four locations within the vicinity of the sediment pond (Tables 2-5). These locations were 1) approximately 25 m upstream of the sediment pond, 2) at sediment pond inlet, 3) at the principle spillway, and 4) approximately 50 m downstream of the sediment pond. The goal of this preliminary sampling regime was to ascertain the background levels of water quality constituents of interest in mining. All samples were taken during base flow.

Samples were analyzed for total suspended solids (TSS), pH, dissolved oxygen (DO), electrical conductivity (EC), temperature, iron (Fe), sulfate (SO_4), nitrate (NO_3), and manganese (Mn). Analysis of pH, DO, EC and temperature were performed in-situ using a YSI 556 Environmental Monitor. Sulfate and nitrate were measured by means of a quantitative ion chromatography procedure on a Dionex Ion Chromatograph. Manganese and iron concentrations were determined using a GBC SDS 270 Atomic Adsorption Spectrophometer.

5.0 Permitting Difficulties

Joshua Howard of R.M. Johnson Engineering (now with Aquatic Resources Management) submitted the permit for removal of the sediment to the Corps of Engineers in March 2007. A site visit of the impacted site was conducted on August 21, 2007; however, the mitigation site (i.e. the sediment pond) was not visited at this time. While at the time, it was anticipated that the 404 permit (COE) and the 401 Water Quality Certification (DOW) would be completed Fall 2007 with construction commencing shortly afterwards, this did not occur. To date, the U.S. Army Corps of Engineers has not issued a 404 permit related to mining. As such, the proposed design could not be implemented, and hence, the monitoring portion of the project could not proceed.

6.0 References

Schumm, S.A. 1956. Evolution of Drainage Systems and Slopes in the Badlands at Perth Amboy, New Jersey. Bulletin of the Geological Society of America 67: 597-646.

Shreve, R.L. 1969. Stream Lengths and Basin Areas in Topographically Random Channel Networks. Journal of Geology 77: 397-414.

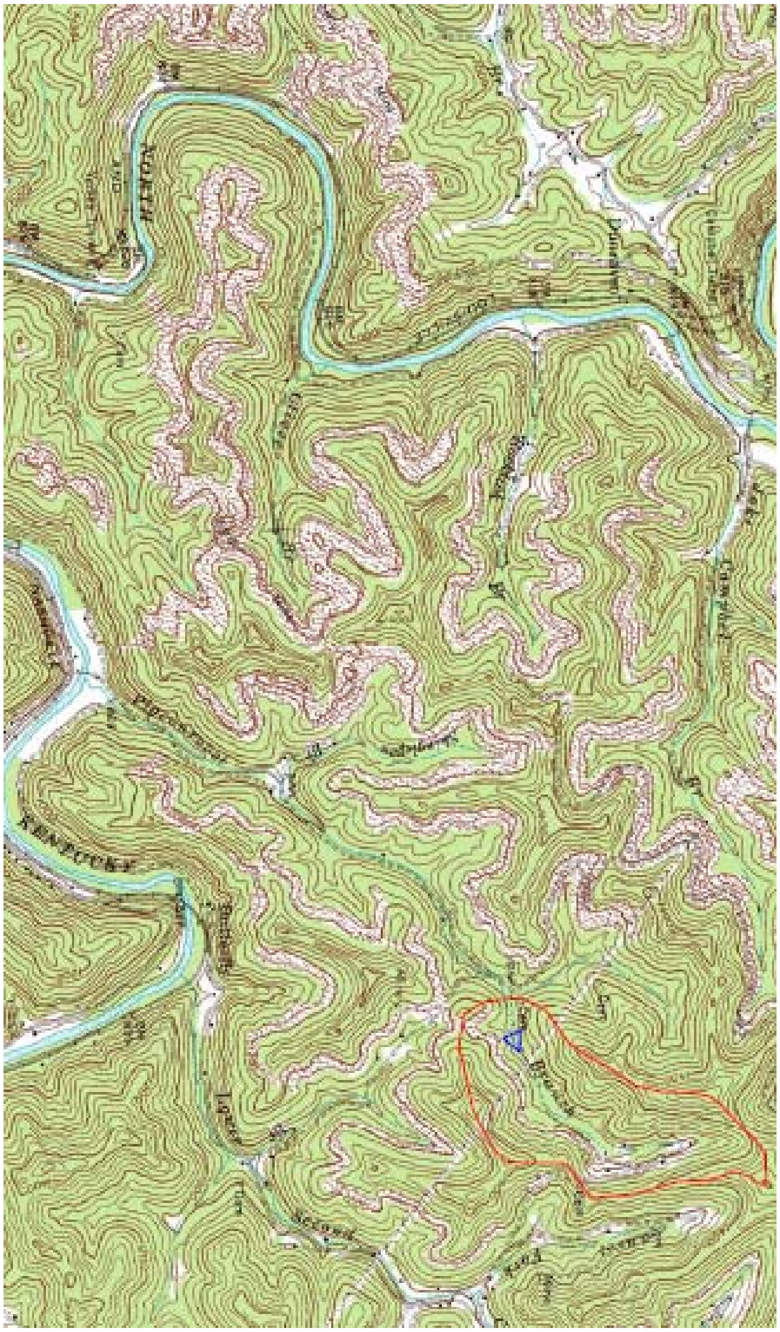

Figure 1: USGS Krypton Quadrangle Map Displaying Restoration Location.

Figure 2: Aerial View of Restoration Site.

Figure 3: Right Side of Valley Facing Down-Gradient.

Figure 4: View of Sediment Pond Looking Up-Gradient.

Figure 5: Principal Spillway.

Figure 6: Boulders Down-Gradient of Principal Spillway.

Figure 7: Left Side of Sediment Pond, Facing Down-Gradient, Near Emergency Spillway.

Figure 8: Up-Gradient End of Sediment Pond

Figure 9: Wetland Area at Up-Gradient End of Sediment Pond.

Figure 10: Wetland Area Down-Gradient of Sediment Pond.

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Figure 11: Headcut in Channel Down-Gradient of Sediment Pond.

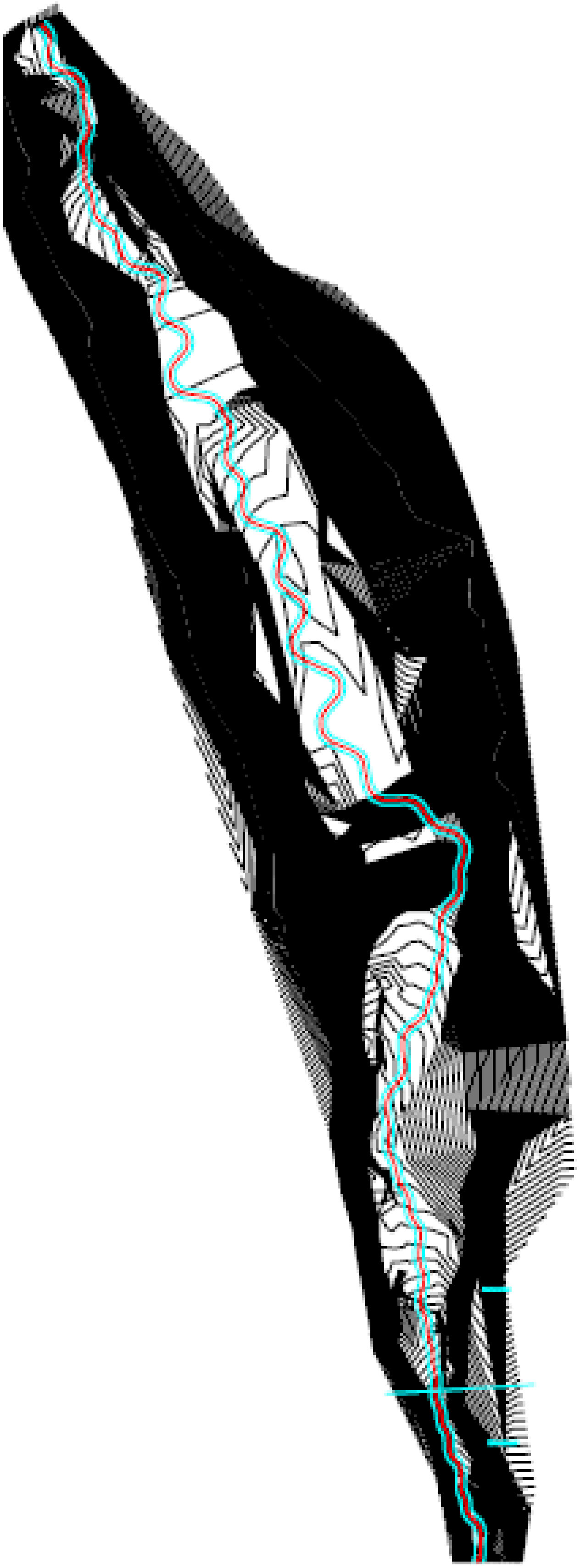

Figure 12: Preliminary Restoration Design Plan View.

Table 1: Preliminary Design Parameters.

Parameter	Design - B4	Design -E4	Design - C4
Reach Name	John Tate - Upper	John Tate -Lower	Mill - E4
Bankfull XSEC Area, Abkf (ft)	6.0	6.5	6.5
Bankfull Width, Wbkf (ft)	11	9	10
Bankfull Mean Depth, Dbkf (ft)	0.5	0.7	0.7
Width to Depth Ratio, W/D (ft/ft)	20.2	12.5	15.4
Entrenchment Ratio, Wfpa/Wbkf (ft/ft)	1.5	8.0	5.0
Bank Height Ratio, Dtob/Dmax (ft/ft)	1.10	1.00	1.00
Min Bkf Max Depth, Dmax (ft)	0.7	1.2	1.0
Max Bkf Max Depth, Dmax (ft)	0.7	1.2	1.0
Min Bkf Max Depth Ratio, Dmax/Dbkf	1.2	1.6	1.5
Max Bkf Max Depth Ratio, Dmax/Dbkf	1.2	1.6	1.5
Min Meander Length, Lm (ft)		45	50
Max Meander Length, Lm (ft)		99	110
Min Meander Len Ratio, Lm/Wbkf		5.0	5.0
Max Meander Len Ratio, Lm/Wbkf		11.0	11.0
Min Radius of Curvature, Rc (ft)		18	25
Max Radius of Curvature, Rc (ft)		32	40
Min Rc Ratio, Rc/Wbkf		2.0	2.5
Max Rc Ratio, Rc/Wbkf		3.5	4.0
Min Belt Width, Wblt (ft)		27	20
Max Belt Width, Wblt (ft)		45	35
Min MW Ratio, Wblt/Wbkf (ft)		3.0	2.0
Max MW Ratio, Wblt/Wbkf (ft)		5.0	3.5
Sinuosity, K	1.10	1.35	1.25
Valley Slope, Sval (ft/ft)	0.0250	0.0100	0.0150
Channel Slope, Schan=Sval/K (ft/ft)	0.0227	0.0074	0.0120
Pool Slope, Spool (ft/ft)	0.0000	0.0000	0.0000
Pool Slope Ratio, Spool/Schan		0.00	0.00
Min Pool Depth, Dpool (ft)	0.9	1.5	1.2
Max Pool Depth, Dpool (ft)	1.0	1.7	1.4
Min Pool Depth Ratio, Dpool/Dbkf	1.7	2.1	1.9
Max Pool Depth Ratio, Dpool/Dbkf	1.9	2.3	2.2
Min Pool Width, Wpool (ft)		10.8	13.0
Max Pool Width, Wpool (ft)		10.8	13.0
Min Pool Wid Ratio, Wpool/Wbkf	1.05	1.20	1.30
Max Pool Wid Ratio, Wpool/Wbkf	1.05	1.20	1.30
Min Length Pool Spacing, Lps (ft)	8	23	20
Max Length Pool Spacing, Lps (ft)	14	50	60
Min Pool Spacing Ratio, Lps/Wbkf	0.75	2.50	2.00
Max Pool Spacing Ratio, Lps/Wbkf	1.25	5.50	6.00

Table 2: Site 1 Constituent Concentrations from Up-gradient Pond Grab Samples (2007).

Date	TSS (mg/L)	pH	DO (mg/L)	EC (µS/cm)	Temperature (°C)	Fe (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Mn (mg/L)
February 12	7	--	--	--	--	--	--	--	--
February 21	NS[*]	--	--	--	--	--	--	--	--
February 23	4	--	--	--	--	0.06	280	1.3	3.7
February 26	1	5.76	10.5	283	5.1	0.01	285	1.8	1.9
March 23	5	6.19	10.9	458	18.5	0.03	260	2.5	1.8
April 13	2	6.03	10.7	320	15.5	0.12	280	0.7	1.8
Mean±SD	4±2	6.0±0.2	10.7±0.2	353.7±92.2	13.0±7.0	0.1±0.0	276.3±11.1	1.6±0.8	2.3±0.9

Site 1 is located approximately 25 m upstream of the sediment pond.

[*]NS indicates no sample was taken as stream was frozen.

Table 3: Site 2 Constituent Concentrations from Pond Inlet Grab Samples (2007).

Date	TSS (mg/L)	pH	DO (mg/L)	EC (µS/cm)	Temperature (°C)	Fe (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Mn (mg/L)
February 12	5	--	--	--	--	--	--	--	--
February 21	10	--	--	--	--	--	--	--	--
February 23	14	--	--	--	--	0.00	120	0.9	3.6
February 26	7	5.4	3.4	62	6.8	0.01	155	1.8	1.5
March 23	--[1]	6.4	4.6	143	16.7	0.01	88	1.5	0.8
April 13	--[1]	6.1	4.4	213	14.7	0.14	40	1.1	1.1
Mean±SD	9±4	6.0±0.5	4.1±0.6	139.3±75.6	12.7±5.2	0.0±0.1	100.8±48.9	1.3±0.4	1.8±1.3

Site 2 is located at the sediment pond inlet.

[1]Sample was suspect

Table 4: Site 3 Constituent Concentrations from Principle Spillway Grab Samples (2007).

Date	TSS (mg/L)	pH	DO (mg/L)	EC (µS/cm)	Temperature (°C)	Fe (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Mn (mg/L)
February 12	3	--	--	--	--	--	--	--	--
February 21	4	--	--	--	--	--	--	--	--
February 23	1	--	--	--	--	0.06	430	1.2	7.4
February 26	1	3.9	12.0	498	7.7	0.32	305	1.1	6.0
March 23	1	4.3	11.0	664	17.2	0.24	350	2.3	5
April 13	1	4.8	10.5	371	14.8	0.06	365	0.9	2.1
Mean±SD	1.8±1.3	4.3±0.5	11.2±0.8	511.0±146.9	13.2±4.9	0.2±0.1	362.5±51.7	1.4±0.6	5.1±2.2

Site 3 is located at the principle spillway.

Table 5: Site 4 Constituent Concentrations from Down-gradient Pond Grab Samples (2007).

Date	TSS (mg/L)	pH	DO (mg/L)	EC (µS/cm)	Temperature (°C)	Fe (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Mn (mg/L)
February 12	3	--	--	--	--	--	--	--	--
February 21	3	--	--	--	--	--	--	--	--
February 23	1	--	--	--	--	0.00	340	1.0	5.1
February 26	3	4.8	12.0	483	7.2	0.75	265	0.9	5.7
March 23	3	4.7	10.3	408	17.2	0.03	325	1.3	2.0
April 13	3	5.4	11.5	247	14.5	0.04	328	0.3	4.2
Mean±SD	3±1	5.0±0.4	11.3±0.9	379.3±120.6	13.0±5.2	0.2±0.4	314.5±33.6	0.9±0.4	4.3±1.6

Site 4 is located approximately 50 m downstream of the sediment pond.