Existing Passive AMD Treatment Systems Evaluation and Recommendations
Carbon Run Site 42 AMD Discharge Passive Treatment System
Carbon Run Watershed, Northumberland County

Technical Report Prepared by Skelly and Loy, Inc. through the Trout Unlimited AMD Technical Assistance Program

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Background

Shamokin Creek Restoration Alliance (SCRA) requested technical assistance through the Trout Unlimited AMD Technical Assistance Program to evaluate and provide recommendations for an existing AMD passive treatment system within the Carbon Run watershed. On June 4, 2013, Skelly and Loy, Inc. and SCRA personnel visited the Carbon Run Site 42 AMD passive treatment system to conduct water sampling, flow measurements where possible, field water quality measurements, and dye tracer tests in the vertical flow wetland (VFW) at the site. This report provides a summary of historic data and data collected during the site visit as well as recommendations for improving the existing treatment system effectiveness that in turn may provide improved restoration efforts for Carbon Run.

Existing Data

Pennsylvania Department of Environmental Protection (PA DEP), Bucknell University students under the direction of Dr. Carl Kirby, and SCRA have collected flow and water chemistry data for the raw Site 42 AMD discharge, different locations within the system including the final outfall, and upstream (CR2) and downstream (CR3) stations on Carbon Run from 1997 to 2011 relative to the existing passive treatment system. The Site 42 AMD discharge was identified in the Operation Scarlift Project No. SL-113 report by Gannett Fleming Corddry and Carpenter, Inc. (1972) and results from the North Mountain Tunnel that drains the abandoned Bear Valley deep mine workings. The Site 42 AMD discharge is characterized as the highest contributor of iron, manganese, and acidity loading to the Carbon Run watershed upstream of the Site 49 Henry Clay Stirling Mine Pump Slope AMD discharge located approximately four miles downstream on Carbon Run. The passive treatment system was constructed in 1999-2000 and placed into operation in March-April 2000. The quality of the water chemistry data appears to be reasonable including the fact that a majority of the historic metal concentrations were reported as dissolved concentrations. Dissolved metals concentrations are more useful in correlating reported hot acidity concentrations and understanding the treatment effectiveness for adding alkalinity and precipitating the dissolved metals. Dissolved metals concentrations are also necessary to conduct geochemical modeling to predict treatment capabilities of the most common treatment materials including limestone and lime. Total recoverable metal concentrations provide a worst-case scenario for predicting treatment needs since one must assume that the entire concentration is dissolved, depending on the pH, and contributes to the acidity that requires alkaline treatment. Additionally, flow measurements were intermittently performed during water sample collection for chemical analysis by Bucknell University students/personnel. Simultaneous flow and water sampling are highly recommended to correlate concentration with flow, determine loading estimates, and evaluate trends in treatment based on flow conditions.

Since the water quality sampling events for the treatment system outfalls typically did include flow measurement, it is reasonable to develop a correlation between variability in water quality of the treatment system based on flow. Prior to the system construction, including stations along Carbon Run, flow and water chemistry data were collected from 1997 to 2000 for the Site 42 AMD discharge by PA DEP and Bucknell University. The flow and water chemistry data were then used to develop a passive treatment approach for intercepting and remediating the AMD from the tunnel discharge at Site 42. This information revealed the following historic averages information (Table 1) for the Site 42 AMD discharge.

Table 1
Historic Average Flow and Water Quality of Site 42 Raw AMD Discharge (1997-2011)

Flow (gpm)	Field pH	Sulfate (mg/L)	Total Fe (mg/L)	Fe^{2+} (mg/L)	T Mn (mg/L)	T Al (mg/L)	Hot Acidity (mg/L)	Alk. (mg/L)
351	5.48	112.5	18.82	15.15	2.22	0.18	23.9	16.6

Since the construction of the Site 42 passive treatment system, Bucknell University has conducted several assessments of the system effectiveness through the collection of water samples at various locations within the treatment system, the final outfall, and upstream and downstream of the outfall in Carbon Run. Dr. Kirby organized student research projects in 2001, 2005, and 2008 to evaluate the Site 42 passive treatment system and the resulting effects on Carbon Run, which were able to use pre-construction baseline data collected by students of Dr. Kirby's during the pre-treatment assessment of Carbon Run (1998). Table 2 summarizes the historic data for the final outfall from the Site 42 passive AMD treatment system since its construction in 2000. Also note that additional compost was added to the compost layer in the VFW in 2003. However, the additional compost material was compacted and unevenly distributed across the surface of the VFW, which created channelizing and short-circuiting problems. In 2006, more compost material was added to the surface in an evenly distributed layer.

Table 2
Historic Average Flow and Water Quality of Site 42 AMD Treatment System Final Outfall (2000-2011)

Flow (gpm)	Field pH	Sulfate (mg/L)	Total Fe (mg/L)	Fe^{2+} (mg/L)	T Mn (mg/L)	T Al (mg/L)	Hot Acidity (mg/L)	Alk. (mg/L)
277	6.00	82.3	1.80	1.10	1.33	<0.50	-6.4	58.2

Data collected in Carbon Run prior to and following construction of the Site 42 passive treatment system in 2000 confirm the beneficial effects of the treated AMD discharge on the stream water quality by sampling upstream (CR2) and immediately downstream of the AMD (CR3). Carbon Run appears to be slightly net acidic with low iron and manganese concentrations upstream of the Site 42 AMD source (CR2), while the stream appeared to show increased iron, manganese, sulfate, and alkalinity concentrations downstream of the untreated AMD discharge (CR3). Table 3 summarizes the averages of the all of the historic data collected at the upstream and downstream of the Site 42 AMD discharge sampling stations in Carbon Run.

Table 3
Historic Average Flow and Water Quality of Carbon Run Upstream (CR2) and Downstream (CR3) of the Site 42 AMD Discharge (1997-2011)

AMD Discharge	Cond. (µS/cm)	Field pH	Alkalinity (mg/L)	Sulfate (mg/L)	T Fe (mg/L)	T Mn (mg/L)	T Al (mg/L)	Hot Acidity (mg/L)
CR2	145	5.25	9.0	44.6	1.07	0.97	0.51	7.3
CR3[1]	255	6.20	14.6	87.5	10.8	1.92	0.25	6.8
CR3[2]	280	6.51	45.1	51	0.84	0.85	<0.50	-14.9

[1]Water quality measurements collected in 1998 prior to treatment system construction
[2]Water quality measurements collected from 2000 to 2005 following treatment system construction and operation; this location was relocated a few hundred feet downstream in order to be below the system outfall

Based on this information for the AMD discharge and documented stream impacts, the SCRA personnel applied for and were awarded grant funding to design and construct the passive treatment system to intercept and remediate the Site 42 AMD discharge from the North Mountain Drainage Tunnel. The Site 42 AMD discharge (untreated) annually contributes 14.5 tons of iron, 0.14 ton of aluminum, 1.7 tons of manganese, and 18.4 tons of acidity to Carbon Run based on historic data from 1997-2011.

A 2,000-gallon plastic tank partially filled with steel slag material was installed between the VFW and Pond 2 (settling pond) plumbed to accept water from the VFW and discharge into Pond 2. However, the steel slag was only operated intermittently for experimental purposes and demonstrated brief post-treatment positive effects on the small flow of water allowed to contact the steel slag in Pond 2 by imparting additional alkalinity and increased pH levels.

Existing System Characterization

The Site 42 AMD passive treatment system that is the subject of this technical assistance project was identified by SCRA as a priority for investigation because of the desire to restore water quality in Carbon Run and the reestablishment of aquatic life upstream of the Site 49 AMD discharge. However, several maintenance events since the system construction in 2000 including the addition of compost material to the VFW have been necessary to maintain the system operation and effectiveness. The Site 42 passive AMD treatment system was the first system to be constructed in the Carbon Run watershed to address the high priority AMD source resulting from the North Mountain Drainage Tunnel from abandoned underground mine workings at the site. Construction of the system was completed in 2000 and the system went into operation in March. A project location map (Figure 1) and LIDAR mapping of the site illustrate the topographic and approximate features of the current passive AMD treatment system as Figure 2, both included in Appendix 3.

The source of the AMD discharge associated with the Site 42 Treatment System is the North Mountain Drainage Tunnel located on the west end of the treatment site. The historic flow and water chemistry data for the Site 42 AMD discharge show a median flow of 369 gallons per minute (gpm) and a range of flows from 90 to 647 gpm (1997-2000). The raw AMD field pH levels ranged between 5.10 and 6.59 with an average of 5.48, and the discharge is moderately net acidic with acidity levels ranging from -5 to 92 mg/L and an average of 24 mg/L. Iron concentrations are moderately high with very low aluminum and low manganese concentrations. The Site 42 AMD discharge is captured in a subsurface piping system that was connected to a drainage pipe from the tunnel to reduce the influence of oxygen with the AMD. This capture piping system directs the water into a constructed VFW in the western portion of the site. The initial thoughts for remediating this discharge that was characterized as mildly acidic and had moderately high ferrous iron levels was to impart additional alkalinity and raise the pH using a VFW followed by aerating the water through passive techniques and open ponds to oxidize and precipitate the iron and provide retention time in the two settling pond components of the system. The benefit of the VFW is to remove the oxygen from the raw AMD and trap carbon dioxide in the lower limestone layer where alkalinity is imparted and the pH is increased while minimizing the oxidation and precipitation of the ferrous iron that would armor and coat the limestone as ferric hydroxides.

Summary data tables and graphs illustrating the metals, acidity, alkalinity, and pH levels for the raw AMD sources and treatment system components sampled during previous sample events by PA DEP, USGS, SCRA, and Bucknell University from 1997 through 2011 are included in Appendix 1. Three PVC standpipes (vertically oriented) connected to an underdrain piping network in the bottom of the VFW provide the means to set the water level in the VFW using an adjustable mechanism for raising and lowering the height of the standpipes and serve as the primary outfall. These three piping networks also serve as the manual flushing mechanism through a connection near the base of the standpipes to gate valve for hand operation to manually flush the iron precipitates from the void spaces in the limestone to the subsequent settling pond. Following alkalinity treatment in the VFW using compost and limestone materials, the water enters an approximately 0.30-acre settling pond containing two baffles placed across the width of the pond to reduce velocities and promote settling and retention of the iron precipitates. Since the steel slag treatment tank located between the VFW and settling does not typically receive water from the VFW, it provides no continuous treatment benefits for the Site 42 system. Water from the settling pond outfalls through three pipes that discharge into a 235-foot-long vegetated channel that conveys the water to an abandoned strip pit converted into a settling pond. The strip pit pond is approximately 0.70 acre in size with varying depths to allow accumulation of iron sludge for many years. Water from the strip pit pond discharges through a pipe on the eastern extent of the pond into a rock-lined channel and into the mainstem of Carbon Run as illustrated on Figure 2 in Appendix 3. All flow from the Site 42 AMD source is accommodated in the system and off-site stormwater runoff does enter the treatment system, specifically from the access road along the southern side of the VFW and settling pond. Emergency spillways serve as the backup outfall structures for all ponds to accommodate flows in excess of the outlet pipe capacities or due to pipe clogging issues.

The passive treatment system was constructed for capturing and treating the identified Site 42 AMD discharge using available land adjacent to Carbon Run and an abandoned strip pit feature downstream for the final settling pond prior to discharge into the stream. During initial characterization of the Site 42 AMD, it was slightly net acidic with moderate levels of dissolved ferrous iron. In order to impart alkalinity to the AMD and keep the ferrous iron from oxidizing and armoring the limestone, a VFW was used to maintain reducing conditions in the limestone treatment layer and helping to trap carbon dioxide to increase the limestone dissolution. The underdrain piping in the VFW discharges into a settling pond for oxidation and precipitation of the ferrous iron upon an increase in the pH levels and the introduction of air. The VFW has an approximate water surface area of 11,500 ft^2 (230 feet long by 50 feet wide approximate dimensions). Considering this surface area, the areal acidity loading rate for the VFW using data from Table 1 is approximately 43 grams per square meter per day (grams/m^2/day), which exceeds the maximum accepted rate for VFW design (35 grams/m^2/day). However, the water quality of the Site 42 raw AMD has appeared to trend toward being net-neutral/net-alkaline based on more recent water quality data. The water level in the VFW is set by three standpipes that are connected to piping networks in the bottom of the VFW, which are capable of flushing the pond through the use of manual gate valves for each of the three piping networks. Following the settling pond, the treated AMD is directed into approximately 235 linear feet of vegetated channel and into the abandoned strip pit for further polishing treatment assuming that the VFW treated water attained enough alkalinity to offset the acidity generated from the hydrolysis of ferric iron. The water from the strip pit pond final discharges into the mainstem of Carbon Run on the east end of the site. All of the VFW and settling ponds use pipes as the principal outlet structure to control the water levels and with emergency spillway features to outlet the water in the event of excess flows or clogging of the pipes. The exact depths of the VFW limestone and compost layers are not known since compost has been added at least twice since the original construction. The system design specified a 3.5-foot layer of limestone overlain by a 0.5-foot layer of compost and 4.0 feet of water over the compost to provide the hydraulic pressure to force water vertically through the treatment materials and out of the underdrain piping system. The water depth in the settling pond is approximately 7.5 feet, and the water depth in the abandoned strip pit is variable with depths exceeding 10 feet.

Previous work conducted by Bucknell University students and staff in 2005 and 2008 to evaluate the Site 42 passive treatment system performance included the function of each treatment system component during the study period. Since additional compost was added to the VFW in 2003 and 2006, the studies were used to assess the impact on the treatment system effectiveness particularly in the VFW and the iron chemistry. Both studies found that the system was in general very effective at converting nearly all of the dissolved ferrous iron into precipitated ferric hydroxide solids, most of which are removed in the two settling ponds. However, the permeability of the VFW was limited based on the quantity of flow measured from the VFW outfall standpipes versus the flow from the emergency spillway. Despite the decrease in permeability of the VFW with only 2% to 50% of the flow going vertically through the treatment materials and out of the underdrain and piping system, the total system effectiveness at removing a majority of the iron and discharging net alkaline water was still attainable.

In the limestone-containing pond at the site (one VFW), the AMD discharge passes through the high calcium carbonate limestone (typically greater than 80% $CaCO_3$) and dissolves the limestone to impart alkalinity and neutralize acidity. With adequate contact time, the resulting net alkaline water is then routed through settling or retention ponds for oxidation and precipitation of the metals, primarily converting ferrous to ferric iron. Gate valves were installed as flow control features to regulate flow from the various underdrain piping networks associated with each standpipe, which were found to be problematic and inoperable shortly after construction. The passive flushing system for the VFW involves the removal of caps on the end of horizontal pipes just downslope of the standpipes that were incorporated into the system to aid in the removal of accumulated iron precipitates from the void spaces in the VFW limestone layer. A schematic plan drawing using LIDAR mapping of the existing Site 42 passive treatment system generated for illustrating the layout of the AMD source and all of the treatment system components as well as sampling locations is included in Appendix 3 (Figure 2).

Some final observations from the site visit on June 4, 2013, include considerable sediment deposition in the first settling pond from runoff that comes off the adjacent access road that runs parallel to the first two treatment ponds and finally as indicated by SCRA personnel is the continued problem with vandalism of the system by ATVs and others who trespass on the site. The ATVs and vandals have caused numerous problems for the treatment system and have damaged berms, channels, pipes, etc. since the system construction, which must be dealt with for future improvements to the system in order to keep it functioning properly and prevent significant damage to system components that may create safety hazards.

Summary of Site Visit Sampling & Investigation

Table 4
Existing Site 42 Treatment System VFW Outfall Snapshot Sampling – June 4, 2013 Data vs. Historic Average Data (2000 - 2008)

Date	Flow (gpm)	pH	Acidity (mg/L)	Alkalinity (mg/L)	Total Fe (mg/L)	Dissolved Fe/Fe^{2+} (mg/L)	Total Mn (mg/L)	Sulfate (mg/L)
2000-2008	175	6.11	<1 to -50*	92.7	8.67	8.50	1.91	90.7
6/4/13	108	6.20	-123	117	10.30	8.10	0.97	74.3

Notes: *Acidity results from 2000-2001 were reported as <1 mg/L and one sample in 2005 was -50 mg/L; Total aluminum levels were always below the detection limit of 0.50 mg/L (2000-2008) and 0.11 (2013).

Table 5
Existing Site 42 Treatment System Final Outfall Snapshot Sampling – June 4, 2013 Data vs. Historic Data (2000 - 2011)

Date	Flow (gpm)	pH	Acidity (mg/L)	Alkalinity (mg/L)	Total Fe (mg/L)	Dissolved Fe/Fe^{2+} (mg/L)	Total Mn (mg/L)	Sulfate (mg/L)
2000-2011	277	6.00	-6.4	58.2	1.80	1.10	1.33	82.3
6/4/13	203	6.12	-27	34	1.30	<0.06	1.10	86.5

Note: Total aluminum levels were always below the detection limit of 0.50 mg/L (2000-2008) and 0.11 (2013).

The treatment system VFW and final outfall data from the June 4, 2013, sampling event as summarized in Tables 4 and 5 indicate that the water quality and effectiveness of the treatment system is performing relatively well based on generating excess alkalinity and typically removing considerable amounts of the dissolved iron since system construction. Because of hydraulic issues with the VFW, the water level was high enough to inundate the influent distribution pipe from the AMD source and force more than 50% of the AMD flow over the emergency spillway, which limits sampling of the raw AMD source (sample collected from the surface of the VFW in the area of the influent pipe). The raw AMD at the site, based on historical and recent data, seems to indicate that the water is approaching net-neutral conditions, which appears to be a result of the system construction and sealing of the drainage tunnel from exposure to the atmosphere. However, this has also impacted the ability to sample the raw influent water because of hydraulic issues in the compost that increase the water surface elevation over the compost layer and inundates the influent pipe, which may impact the results of characterizing the raw AMD water quality. Flow conditions during the sampling event at the final system outfall (203 gpm) appear to be comparable with the historic averages for the Site 42 AMD source (277 gpm). Further evaluation of the different treatment system components was necessary to determine the problem areas that could be improved or modified to enhance the overall treatment system effectiveness under all flow conditions and help to consistently improve Carbon Run. Additional water quality data from the sampling event are included in Appendix 1, and a copy of the laboratory reports for samples collected by Skelly and Loy and SCRA personnel during the site visit are included in Appendix 2.

The investigation of determining what components of the system are not performing properly is necessary to see what can be done to improve the system performance. Water quality data and visual observations during the site visit indicate that the VFW is not working properly based on the amount of AMD flow that bypasses the treatment materials by flowing over the emergency spillway instead of flowing vertically down through the compost and limestone materials. Of the 294 gpm measured flowing from the VFW into the settling pond, 108 gpm were flowing out of two of the three standpipes from the bottom of the limestone layer (the third standpipe was broken off and could not be measured for flow) and 186 gpm were measured flowing over the emergency spillway. Only 37% of the AMD flow was flowing through the VFW treatment materials and out of the underdrain system, while the remaining 63% was receiving minimal treatment flowing across the surface and out of the spillway. The VFW was evaluated using dye tracer tests, but due to limited remaining time on the site and the diluted dispersion of the limited amount of dye, the retention time in the VFW was unable to be determined. No dye was observed in the discharge pipes and the limited migration of dye observed over the surface of the VFW remained near the addition point at the AMD influent. Table 6 summarizes the data collected for the raw AMD (VFW influent, #1), water discharging from the piping network out of the VFW into the settling pond (#2), the emergency spillway outfall from the settling pond (#3), and the final outfall from the strip pit settling pond (#4).

Table 6
Site 42 System VFW Inflow AMD Source, VFW Outfall Pipes, Settling Pond Outfall, & Final Outfall Treatment Snapshot Sampling – June 4, 2013

Parameter	VFW Inflow	VFW Outfall	Settling Pond Outfall	Final Outfall
Flow (gpm)	N.M.	*108	242	203
Field pH	5.40	6.20	5.90	6.12
Field Cond. (µS/cm)	300	393	257	256
D.O. (mg/L)	0.0	0.0	5.6	8.9
Hot Acidity (mg/L)	-23	-122.7	-31.6	-27.1
Alkalinity (mg/L)	26	117	34	34
Dissolved/Total Fe (mg/L)	10.2/14.6	8.1/10.3	<0.06/6.3	<0.06/1.3

Parameter	VFW Inflow	VFW Outfall	Settling Pond Outfall	Final Outfall
Dissolved/Total Al (mg/L)	<0.10/0.11	<0.11/<0.10	<0.11/<0.10	<0.11/<0.1
Dissolved/Total Mn (mg/L)	1.5/1.5	0.97/1.0	1.5/1.5	0.98/1.1
Dissolved Ca (mg/L)	24.0	56.4	N.M.	N.M
Sulfate (mg/L)	83.5	74.3	80.5	86.5
Total Inorganic Carbon (mg/L)	15.7	30.3	N.M.	N.M.

*The flow measured from the two standpipes connected to the VFW underdrain system was 108 gpm. An additional 186 gpm was measured flowing over the emergency spillway from the VFW into the Settling Pond.

Based on the data provided, the effectiveness of the VFW for the AMD that follows the typical vertical flow path through the treatment materials and out of the piping network is reasonable since it does impart considerable alkalinity, provides some iron and manganese removal, and considerably increases the calcium and TIC (dissolved carbon dioxide) levels indicating limestone dissolution. However, the amount of flow exiting the VFW over the emergency spillway as minimally treated water (approximately 63%) offsets the beneficial improvements to the AMD from the VFW treatment materials. Yet the data indicate that while iron concentrations, both dissolved and total, are reduced by 25% to 30% that is being retained in the VFW, the majority of iron is likely precipitated as ferric hydroxide on the top of the compost layer. This is confirmed by the lack of D.O. in the outfall pipes from the VFW underdrains and the high percentage of flow that short circuits the VFW flowing across the surface and discharging over the emergency spillway. Other metals are not of much concern since they are present in very low levels in the raw AMD, considering both aluminum and manganese. The trend in becoming net neutral to net alkaline for the Site 42 AMD source has benefited the treatment system and allowed the performance to remain relatively consistent despite the permeability issues with the VFW keeping the iron removal capacity relatively high (typically >75%).

The dye tracer test performed on the VFW showed that the retention time in the VFW was at least greater than two hours but a specific time could not be determined due to time constraints. The entire VFW outfall was observed discharging from the three standpipes during the site visit and these were the sampling locations for water quality, flow, and dye testing. Secondly, the piping network within the bottom of the VFW was not investigated for flushing velocities and the accumulation of solids in the VFW, but since only a portion of the flow in the VFW was discharging through the normal pathway out of the standpipes (approximately 37% during the sampling event), it can be concluded that the permeability of the compost and limestone materials is compromised, most likely due to ferric iron precipitates on the surface of the compost layer. The data from the sampling event indicate that roughly 70% of the iron entering the VFW, keeping in mind that the raw AMD influent pipe could not be sampled since it was inundated, is dissolved and roughly 80% of the iron discharging from the VFW is dissolved but about 30% of the iron is retained in the VFW or roughly 4.3 mg/L, which will continue to increase the level of plugging/reducing the permeability of the compost layer. The result is that the combined VFW outfall from the three standpipes and water flowing over the emergency spillway primarily untreated is not obtaining as much alkalinity, pH increase, and potential for improved iron oxidation and removal throughout the remainder of the treatment system before discharging to Carbon Run. The first settling pond appears to adequately oxidize nearly all of the dissolved iron, <0.06 mg/L in the outfall on June 4, 2013, and the total iron level is reduced from 6.3 mg/L in the settling pond outfall to 1.3 mg/L in the final settling pond outfall (<0.06 mg/L dissolved iron in the final outfall).

Based on the data provided, the effectiveness of the VFW to provide enough alkalinity to treat the AMD source and oxidize and precipitate the ferrous iron in the settling ponds following the VFW is currently meeting the treatment goals needed to improve Carbon Run. Since the AMD source has trended toward being net alkaline since installation of a subsurface collection and conveyance system from the source to the VFW that reduces the exposure of the AMD to oxygen, this occurrence has helped to improve the system performance and allow for a majority of the iron to be removed prior to entering Carbon Run. In addition to several recommended operational improvements, flushing of the VFW more frequently is necessary to help remove some of the accumulated metals in the treatment materials that accumulate on and within the compost, limestone, and possibly underdrain pipes to maximize the flow through the VFW and minimize flow over the emergency spillway as untreated water.

Carbon Run Upstream & Downstream of the Site 42 System Outfall

Table 7
Carbon Run Historic (Prior to Treatment Systems) Water Quality Data – 1997 to 1999

Parameter	Upstream of Site 42 AMD (CR2)	Site 42 Raw AMD	Downstream of Site 42 AMD (CR3)
pH	5.58	5.55	6.20
Flow (gpm)	259	360	447
Acidity (mg/L)	8.0	44.5	6.8
Alkalinity (mg/L)	6.3	12.6	14.6
Total Fe (mg/L)	0.90	22.33	10.80
Total Al (mg/L)	0.72	0.40	0.25
Total Mn (mg/L)	0.96	2.66	1.92
Sulfate (mg/L)	50.1	134.9	87.5

Note: Data for CR3 was based on only 2 sampling events in 1998, while CR2 and the raw Site 42 AMD were based on at least 13 sampling events from 1997-1999.

Table 8
Carbon Run & Treatment System Outfall Snapshot Water Quality Data – June 4, 2013

Parameter	Carbon Run Upstream (CR2)	Site 42 System Outfall	Carbon Run Downstream (CR3)
Flow (gpm)	29	203	414
Field pH	5.86	6.12	6.36
Field Cond. (μS/cm)	112	256	194
Hot Acidity (mg/L)	-10.8	-27	-20.8

Alkalinity (mg/L)	10	34	31
Dissolved/Total Fe (mg/L)	0.27/0.67	<0.06/1.30	<0.06/0.91
Dissolved/Total Al (mg/L)	<0.10/<0.11	<0.10/<0.11	<0.10/<0.11
Dissolved/Total Mn (mg/L)	0.45/0.50	0.98/1.1	0.57/0.65
Sulfate (mg/L)	37	86.5	60

The above data for Carbon Run and the treatment system outfall (Table 9) indicate that the stream is relatively unimpacted upstream of the Site 42 AMD treatment system outfall. However, due to the declining performance of the treatment system, Carbon Run shows minor impacts including increased metal concentrations, which may be detrimental to trying to establish aquatic life communities in the stream. Comparing the historic data and recent sampling data for CR3 (Tables 7 and 8), the treatment system has improved the water quality in Carbon Run with slightly higher pH, less acidity and metals (iron, aluminum, and manganese) concentrations, and more alkalinity. Both the changing trend in the raw water quality of the Site 42 AMD source and the passive treatment of the water have proven beneficial to Carbon Run that appears to show improvements downstream to the Site 49 AMD discharge confluence. Summary data tables of the metals, acidity, alkalinity, and pH levels for the sampling stations in Carbon Run from 1997-2011 including data collected during the June 4, 2013, event upstream and downstream of the treatment system and AMD sources by PA DEP, Bucknell University, and SCRA personnel are included in Appendix 1.

Recommendations/Conclusions

The Site 42 passive AMD treatment system was constructed in 1999-2000 and has been in operation with some minor improvements implemented since that time. In general, the treatment system works reasonably well, but based on previous assessments of the system conducted by Bucknell University (2005 and 2008) and the most recent assessment as part of a TU TAG project, the hydraulics of the VFW are compromised and the damages to the system components from ATV use have created issues at the site. As shown on the conceptual layout (Figure 1), eight primary tasks were determined to improve the function and effectiveness of the system and minimize unauthorized access into the two upstream ponds and unwanted vandalism to the system components. The tasks are as follows.

1. Stir compost in VFW to increase permeability and minimize water flow over spillway; remove any accumulated iron sludge from the surface of the compost layer.
2. Inspect and repair VFW underdrain pipes to ensure that they are not clogged and recommend flushing the VFW pipes quarterly, at a minimum, to better maintain permeability.
3. Place up to three limestone check dams in the vegetated channel for additional alkalinity and to enhance iron removal.
4. Install two floating baffles in the strip pit settling pond to increase the iron removal efficiency before final discharge into Carbon Run.
5. Install a valve and bypass pipe on the VFW influent pipe from the mine to allow sampling of the raw AMD and bypass of the water during maintenance tasks.

6. Install chain link fence with gates (4) around the VFW and settling pond to restrict ATV access.
7. Improve access road along VFW and settling pond to promote surface runoff/ drainage to the south and away from the system.
8. Improvements to the existing three emergency spillways including new rip-rap lining.

Table 9
Existing Passive Treatment Systems Recommended Improvements Cost Estimate

Recommended Task	Cost Estimate
Removal of surface debris and stirring of compost in VFW	$10,000
Inspect piping network for clogs and needed repairs	$4,000
Limestone check dams (up to three)	$4,500
Install two floating baffles in strip pit settling pond	$5,000
Install valve and bypass pipe on the VFW influent pipe from AMD source	$6,000
Install chain link fence with gates around VFW and first settling pond	$32,500
Improve access road and promote runoff drainage away from system	$10,000
Improve three existing emergency spillways including new rip-rap	$3,000

The proposed efforts will involve the design, permitting, and construction of the recommended improvements to the existing treatment system using the existing LIDAR mapping used to create the conceptual plan as the basis for the project design and construction activities. In addition to the primary treatment system component recommended improvements, at least quarterly flushing of the VFW in the system is recommended to allow the system to function properly.

The total cost to perform all of the recommended existing treatment system improvements at the Site 42 Passive AMD Treatment System is $75,000 for the eight recommended tasks and an additional $20,000 for contractor mobilization, clearing and grubbing, erosion and sediment controls, and miscellaneous pipe fittings. Any additional limestone including rip-rap and fines to be used for the improvements is recommended to have a minimum calcium carbonate content of 85%. Completion of many if not all of the recommended tasks along with regular periodic maintenance (O&M) will allow the Site 42 treatment system to function properly in order to promote the restoration of this upper section of Carbon Run. Periodic compost stirring and replacement/replenishment will be necessary every few years to maintain permeability and maximize the amount of AMD that flows through the treatment materials in the VFW providing the highest level of treatment efficiency for the system.