

**Review and Remedial Repairs of Carbon Run Abandoned  
Mine Drainage Treatment Project**

**A Report to the Shamokin Creek Restoration Alliance and  
the Northumberland County Conservation District**

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## **Executive Summary**

Since the construction of the mine drainage treatment system at Scarlift Site 42 in Northumberland County, numerous problems have occurred, which could potentially reduce the effectiveness of the treatment system. While Site 42 showed promising signs upon completion, the dissolved oxygen levels in the Pond 1 (vertical flow wetland) standpipes increased enough to cause concern. Work in October 2006 attempted to address existing concerns with the vertical flow wetland in the first pond of the treatment system. Increased concentrations of dissolved oxygen, decreased alkalinity, and the presence of iron solids in the water flowing out of the standpipes of the vertical flow wetland were highly indicative of less-than-ideal conditions existing within the limestone layer at the base of the wetland. Remedial actions were taken, including the addition of new compost and the reopening of the steel slag. Comparing current and past data, an analysis of the effectiveness of these corrections has been made, and, as much as can be determined in the short time that has passed since these actions, the situation seems to be improving. Dissolved oxygen in two of the three standpipes is below detection level (0.3 mg/L), but standpipe flow rates have not yet shown an increase. Further monitoring is recommended.

## Introduction

Scarlift Site 42 is located in Shamokin, Northumberland County on land owned by the Northumberland County Commissioners (Figure 1). It is part of the Shamokin watershed, which collects runoff and groundwater from a total area of about 23 km<sup>2</sup>. The watershed is mainly forested with a few wetlands and contains a large number of mine spoils.

The elevation of the Site 42 discharge was lowered in 1999 to permit drainage of a coal mine pool in order to allow deeper mining (the mine is no longer in operation). This water flows directly into Carbon Run, a tributary of Shamokin Creek. This drainage poses an environmental risk because of high iron loading. This has adverse effects on stream ecology and renders the stream water unfit to drink without costly treatment.

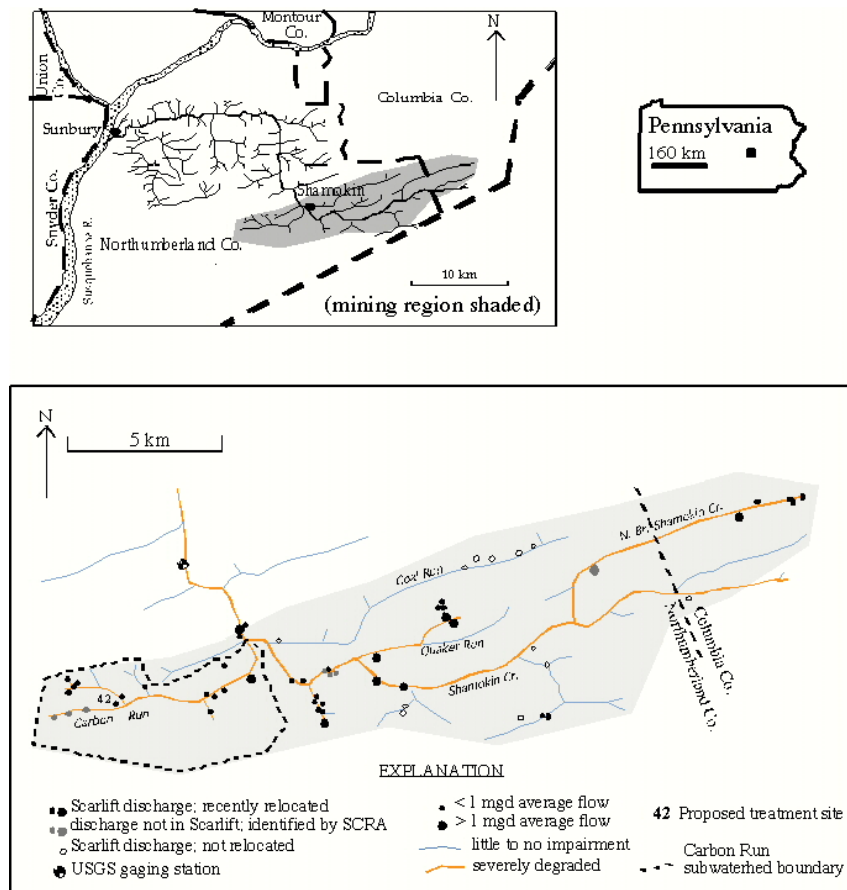


Figure 1. Location of predominant mining region in Northumberland and Columbia Counties. Site 42 is located on the western end of the region within the Carbon Run stream network.

In 2000, a treatment system was designed and constructed through the cooperation of Bucknell University, the Northumberland County Conservation District (NCCD), the Shamokin Creek Restoration Alliance (SCRA), and both state and federal government agencies. The full name of the project is the Carbon Run Sub-watershed Abandoned Mine Drainage Treatment Project. It is a passive treatment system that consists of a vertical flow wetland and two oxidation/settling ponds (Figure 2). These ponds effectively neutralize the pH, raise dissolved oxygen (DO) concentration, and allow precipitation of iron hydroxides before the water joins Carbon Run.



Figure 2. Overview photograph of the entire treatment system looking east from Pond 1, the vertical flow wetland (labeled SAPS here).

The site has been monitored yearly by Bucknell Introduction to Geochemistry students for flow rates and water chemistry at the inflow, outflow, and at each pond in order to evaluate its effectiveness. This report discusses some of the current problems encountered in maintaining appropriate pH and concentrations of DO, and the work employed to correct them. Additionally, analysis of current water chemistry is compared with previous data, and recommendations for system improvements are given.

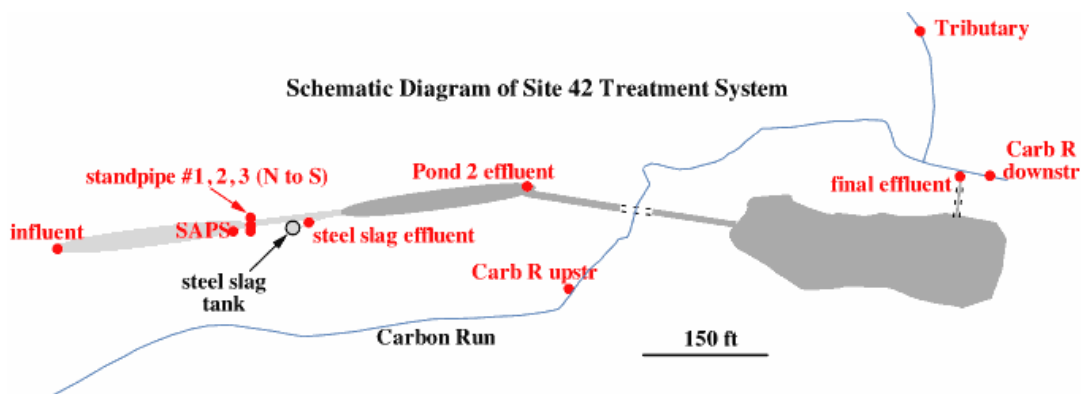
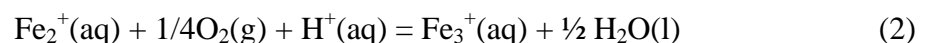
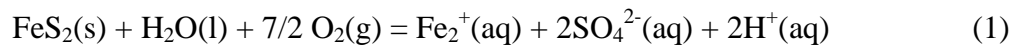
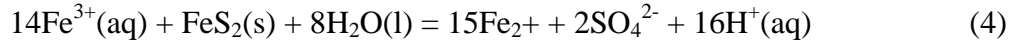
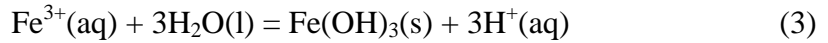


Figure 3. Map view of treatment system and sample sites.

## Background

When a deep mine is constructed it inevitably intersects the water table, and to avoid flooding this water must flow out by gravity or be pumped out. After a mine has been abandoned it fills with water, which remains in contact with the mine walls for a sufficient amount of time to dissolve minerals from the wall. Once this water is exposed to the air a series of chemical reactions occur involving dissolved solids, namely iron sulfide (pyrite), that lower the pH, decrease DO, and precipitate iron oxides. The most important reactions are given below:





The mineral pyrite,  $\text{FeS}_2(\text{s})$  reacts on contact with water and oxygen. This releases  $\text{H}^+$  ions, which decreases the pH, and also produces Fe(II) ions and sulfate. In Equation (2), Fe(II) reacts with oxygen and hydrogen ions to form Fe(III) and water. Once in solution, Fe(III) reacts with water and precipitates iron oxide  $\text{Fe}(\text{OH})_3(\text{s})$  and also increases pH (Equation (3)). Fe(III) also reacts with pyrite and water to produce Fe(II) and sulfuric acid (Equation (4)).

The effects of acid mine drainage can be reduced by passing the water through a series of ponds to increase alkalinity, restore dissolved oxygen, and permit settling of precipitates (Figure 3). The first pond, a vertical flow wetland, is filled with layers of limestone aggregate and compost. The limestone adds alkalinity as water flows through and reacts to form bicarbonate and release calcium ions:



The compost contributes  $\text{CO}_2$  as it decomposes:



These reactions contribute to the complete reaction:

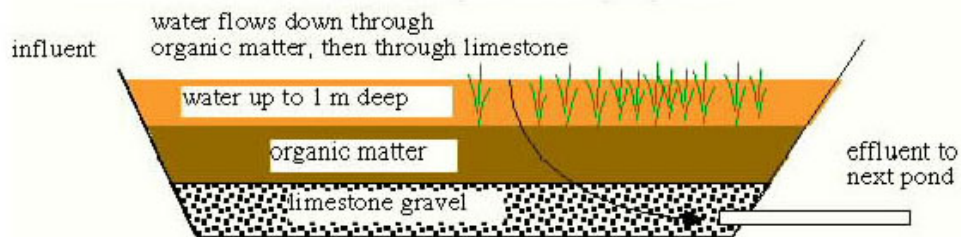
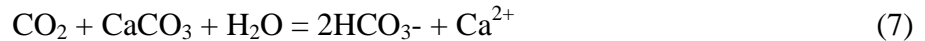


Figure 4. Cross section of vertical flow wetland.

Within the vertical flow wetland, low concentrations of dissolved oxygen are ideal to prevent precipitation of oxides that could potentially coat the surface of the limestone gravel and impede reactions. This is achieved by decomposition of the compost. After neutralization the water is passed through two settling ponds, where water is both aerated and allowed to stand in order to precipitate metal compounds, especially iron hydroxide. Once the treated water has an acceptable pH and ion load, it can safely rejoin a natural stream, where DO levels will naturally increase as the water flows turbulently and mixes with healthy stream water.

## History of Site 42

Before construction began at Site 42, deep mine drainage from the North Mountain Tunnel emerged from a 15-inch diameter corrugated plastic culvert (Figure 4). An orange precipitate existed within the culvert while “soft reddish-orange sediment” persisted throughout the outflow ditch (Eidem and Moffe, 1998).



Figure 5. Site before treatment.

Table 1. Pretreatment data for Site 42 discharge 1998.

Date	pH	Alkalinity		Hot Acidity as CaCO <sub>3</sub>	Dissolved Fe
		DO	as CaCO <sub>3</sub>		
mg/L					
5/29/1998	5.7	5.8	29	13.2	15.6
7/2/1998	5.8	4.7	31	15.8	18.4

Prior to the construction of the acid mine treatment system in the fall of 2000, Site 42 was the second main source of dissolved iron for the Carbon Run subwatershed. Samples were taken directly from the point of discharge before construction began. The sample from 5/29/1998 as well as the sample taken on 7/2/98 had dissolved iron concentrations of 15.6 mg/L and 18.4 mg/L respectively (Table 1).

Dissolved oxygen measured 5.8 mg/L and 4.7 mg/L for the successive samples taken directly from the source of discharge (Table 1). This low DO was expected because the source is underground. Exposure to the air will cause the DO to increase even further, but it is the goal of the vertical flow wetland to create the reducing conditions to prevent iron hydroxide precipitation. Low dissolved oxygen content in the standpipes from Pond 1 would be a good indicator that these conditions have been reached. The addition of alkalinity is also an essential contribution of the vertical flow wetland.

After construction of the system was completed, initial success was observed in 2000 and 2001 measurements. The hot acidity of Site 42 effluent measured below 1 mg/L while the alkalinity had increased dramatically from a measured 28.9 mg/L from the discharge on 5/29/98 to 88 mg/L in the effluent on 12/13/2000.

Success was indicated by a reduction of effluent iron, a low dissolved oxygen content measured from the first standpipe, as well as an increase in alkalinity. The dissolved iron concentration was immeasurable by April of 2000 because it was below the detection limit although 1.5 mg/L were observed in the discharge in December. Dissolved oxygen concentrations from the standpipes in Pond 1 measured 0.3 mg/L. This indicated that the system was working ideally. However, 2.5 mg/L DO was measured on 12/13/00

## Current Compost Problems

While the Carbon Run Site 42 abandoned mine drainage treatment system did display significant success in the year following its construction, and has continued to do so in the time since, a number of slowly developing factors have been combining, suggesting the presence of rather important problems, which need to be assessed. One of the factors requiring attention was the progressively rising concentration of dissolved oxygen in the water flowing out of the standpipes between the first and second ponds (Table 3a-c). As mentioned in the introductory section of this paper, low levels of dissolved oxygen are critical for the system to function at its

greatest potential, and a rise such as that displayed in Table 3a-c, from below the detection limit to 4.8 mg/L would greatly hinder the systems ability to increase alkalinity and therefore neutralize the drainage. If DO were to remain high in this part of the system, oxidized iron solids could potentially precipitate covering the calcite and hindering its reaction with the water. Also serving as an indicator of the less than ideal conditions of the environment at the base of the vertical flow wetlands was the behavior of iron in the water flowing out of the standpipes. Ideally, the conditions in the limestone layer of the vertical flow wetland would be so reducing that no oxidation of iron would be occurring during the interaction of the water and the calcite. The presence of the orange solid iron hydroxide in and around the mouths of the standpipes between Pond 1 and 2 indicate that these ideal conditions are not, in fact, being met. Differences between the concentrations of dissolved iron in the water in the different standpipes for 2005 also raised questions about the conditions at the base of the pond (Table 2). Similar variability between standpipes was also found in the alkalinity (as CaCO<sub>3</sub>) of the water leaving Pond 1, which has been significant since first compared in 2003 (Table 3a-c). Such differences could be representative of variability between the flow paths the water follows flowing into the standpipes. Our data, unfortunately, is not detailed enough to make such an analysis at this time. The pH levels remained relatively consistent from year to year, except for a drop from the typical level of 6.5 to closer to 5.8 in 2003. While this drop may be significant, it is difficult to definitely determine without more frequent monitoring of these levels. Another significant problem is the overflow of water from the first pond flowing directly into the second pond over the embankment. It is highly unlikely that this water was exposed to the compost and calcite long enough to be treated.

An attempt to correct these problems was made in 2003 or 2004, when a new shipment of compost was added to the vertical flow wetland in an effort to better the reducing conditions within the limestone (Kirby, pers. comm.). Due to an unfortunate series of events, however, the compost was not distributed evenly throughout the pond, but rather deposited on one side. To correct this, Shamokin Creek Restoration Alliance volunteers needed to stand and walk on the surface of the drained pond and distribute the compost with shovels. This was not only likely to result in an uneven distribution of the compost, but also compact the compost in selected areas, increasing the likelihood of the formation of channels of preferential flow. Such channels decrease the amount of time the water is in contact with the compost, thus making it difficult to remove the necessary concentrations of dissolved oxygen. These events resulted in the need for more compost to be added to the pond in 2006.

Table 2. Laboratory results 2005: Site 42 (11/1/05 sampling; GEOL 205 class, Bucknell University)

Sites	Total Fe, mg/L	Dissolved metal, mg/L						
		Fe	Mn	Al	Na	K	Mg	Ca
VFW Stndp N	5.2	1.1	1.1	N/A	2.9	0.9	1.4	3.0
VFW Stndp mid	6.5	7.9	2.6	N/A	2.3	0.9	17.8	47.6
VFW Stndp S	3.8	12.4	2.6	N/A	2.3	1.0	16.0	63.9
Pond2 Eff	2.7	0.5	1.9	N/A	1.9	0.9	21.0	59.0
42 Eff	0.6	0.3	1.3	N/A	1.9	1.0	13.7	42.0

Table 3a. Laboratory results: Site 42, Standpipe 1 (2000-2006 sampling, GEOL 205 class, Bucknell University)

	T. °C	Field pH	Spec. cond. mS/cm	DO, mg/L	SO <sub>4</sub> , mg/L	As mg/L Acidity	CaCO <sub>3</sub> Alk	As mg/L HCO <sub>3</sub> <sup>-</sup> Alk
2000	9.7	5.95	0.618	<0.3	100	<1.0	84	
2001	10.54	6.22	0.420	2.28				
2002	9.25	6.38	0.451	2.1				
2003	9.7	5.6	0.418	1.9		-33.6	76	
2004								
2005	8.96	6.51	0.389	3.93	99	-42.1	62	
2006	10.14	6.4	0.483	0.03			79.8	97.36

Table 3b. Laboratory results: Site 42, Standpipe 2 (2000-2006 sampling, GEOL 205 class, Bucknell University)

	T. °C	Field pH	Spec. cond. mS/cm	DO, mg/L	SO <sub>4</sub> , mg/L	As mg/L Acidity	CaCO <sub>3</sub> Alk	As mg/L HCO <sub>3</sub> <sup>-</sup> Alk
2000								
2001	10.6	6.43	0.437	3.57	34.0	<1.0	83	101
2002	8.83	6.26	0.410	4.5				
2003	9.5	5.8	0.403	2.3		-21.8	53	
2004								
2005	8.76	6.54	0.363	4.77	80	-30.8	46	
2006	9.90	6.58	0.976	-0.06			164	200.08

Table 3c. Laboratory results: Site 42, Standpipe 3 (2000-2006 sampling, GEOL 205 class, Bucknell University)

	T. °C	Field pH	Spec. cond. mS/cm	DO, mg/L	SO <sub>4</sub> , mg/L	As mg/L Acidity	CaCO <sub>3</sub> Alk
2000							
2001	10.7	6.73	0.516	1.17			
2002	9.29	6.45	0.453	2.3			
2003	9.8	5.8	0.482	0.8		-60.8	109
2004							
2005	9.28	6.78	0.433	1.93	80	-76.9	93
2006		6.81		2.26			

## 2006 Remedial Actions

Significant adjustments were made in October 2006 in hopes of increasing the effectiveness of the treatment system. A contractor was hired to add a new layer of compost to the vertical flow wetland. The pond was drained by pumping the water from the base of the pond as well as the inlet directly into the second pond. The compost was evenly distributed using a long-arm excavator to prevent unnecessary compaction. R3 limestone was placed on the compost around the distribution pipe to prevent disturbances of the compost in the area where the flow was particularly strong (Figure 6). The pond was slowly filled by shutting off the pump



at the base of the vertical flow wetlands and allowing the water to back up. Once the pond was filled, the pump at the inflow was also turned off.



Figure 6. Distribution of new compost (left) and placement of rocks to hold compost in place near the distribution pipe (right).

## Methods

The parameters measured in the field on 11/14/2006 included temperature, pH, dissolved oxygen, specific conductance, and flow rate. Field-calibrated YSI multimeters were used for all sample measurements with the exception of measurements of flow rate at Pond 2 standpipes, which were measured using the stopwatch and bucket method. The meters were thoroughly rinsed with deionized water between measurements in order to eliminate any potential contamination. The dissolved metal samples were filtered (0.45 micron) and acidified ( $\text{HNO}_3$ ) in the field; unfiltered alkalinity samples were titrated in the field. A cooler filled with ice kept the samples chilled until they were brought back to the laboratory and refrigerated.

The analytical measurements from the Bucknell University Environmental Science Lab included dissolved metal concentrations for iron, manganese, aluminum, sodium, potassium, and calcium. Using an inductively-coupled plasma atomic emission spectrometer, working curves were derived for each of these elements. Both undiluted and 50x diluted samples were measured for metal concentration. Raw unpreserved samples were sent to Wilson Testing Laboratories for measurement of Fe, Mn,  $\text{SO}_4$  and Hot Acidity.

## Results and Discussion

### *Field parameters and laboratory results*

Measurements were taken at the VFW Standpipe North, VFW Standpipe middle, VFW Standpipe South, Pond 2 Effluent, 42 Effluent, and Carbon Run 5 (CR5). Some parameters were not measured at VFW Standpipe S because there was little flow through the pipe, which may affect some of the data collected. The water temperatures within the treatment site were all approximately  $10^\circ\text{C}$ . Carbon Run 5 was the only site with a significantly different temperature, at  $14^\circ\text{C}$ . This could be due to the fact that measurements were made about 15 minutes after the collection of a sample. Field pH for the different sites measured range from 6.3 to 6.8, again with the exception of CR5 which was 5.7. Specific conductance varied all over the region, but there was a large difference between Standpipe N and Standpipe mid. Standpipe N had a specific conductance of 0.483 mS/cm and Standpipe mid had a specific conductance of 0.976 mS/cm.

Dissolved oxygen concentrations varied considerably around the treatment site and CR5. Generally downstream from the standpipes dissolved oxygen levels increased as the water flowed towards CR5. The increase is due to the lengthened exposure to atmospheric oxygen. Between the VFW standpipes there was a difference in dissolved oxygen. Standpipe N and standpipe mid both had DO concentrations below the detection limit (0.3 mg/L) for the membrane used and Standpipe S had 2.26 mg/L DO. The difference between Standpipe N and - mid and standpipe S may be due to the fact that Standpipe S had very minimal flow. The standpipes were not measured for sulfate concentration. As the water moved downstream, sulfate concentration decreased. Alkalinity as HCO<sub>3</sub> was also measured in the field. It varied but followed the expected pattern of higher concentrations in the upstream part of the treatment site and decreased concentrations as the water moved away from the limestone. These values were tested for Pond 2 Eff, 42 Eff, and CR5. Hot Acidity increased significantly from the effluent of the treatment site to Carbon Run 5 (Table 5).

*Flow rate*

The flow rates from the discharge of Pond 2 were measured. Standpipe 1 (north) had a flow rate of 76.8 gallons per minute. Standpipe 2 (middle) had a flow rate of 87.6 gallons per minute. Standpipe 3 (south) had a flow rate of 89.4 gallons per minute. Combined, these results give a total flow rate of 253.8 gallons per minute (Table 4).

*Dissolved metals*

Dissolved concentrations of iron, manganese, aluminum, sodium, potassium, and magnesium were measured in the Environmental Science Lab at Bucknell University on November 21, 2006. Samples from most sites were also sent to Wilson Testing Laboratory for iron and manganese analyses. The results for iron, manganese, and aluminum that had been tested in the lab at Bucknell University matched very well with the data received from Wilson Testing Labs. Iron concentrations decreased from the standpipes to Carbon Run 5, indicating that iron hydroxide is precipitating. Manganese concentrations were fairly consistent. Historical concentrations have been approximately 2 mg/L and current concentrations range from 1.6 to 2.3 mg/L. Aluminum was measured to be in concentrations of less than 0.2 mg/L, which was to be expected. The concentration of sodium varied significantly, even between the standpipes, from 3 mg/L to 54 mg/L. Potassium concentrations also varied between the standpipes, ranging from 15 mg/L to 59 mg/L, both probably due to the addition of fresh compost. Concentrations of iron and potassium decreased significantly by the time the water reaches CR5, which is about two miles downstream of Site 42. The consistency of results from Bucknell University and Wilson Labs confirm that those results measured at Bucknell University are valid (Tables 6 and 6a).

Table 4. Discharge at Pond 2 standpipes: Site 42 (11/14/06 sampling; GEOL 205 class, Bucknell University)

Sites	Volume of vessel, (gal)	# of times vessel filled	Total filling time, (sec)	Flow rate, gal/s	Flow rate, gal/min
P2 Stndp 1	5	3	11.73	1.28	76.8
P2 Stndp 2	5	3	10.24	1.46	87.6
P2 Stndp 3	5	3	10.04	1.49	89.4
Total	na	na	na	4.23	253.8

Table 5. Field and laboratory results: Site 42 (11/14/06 sampling; GEOL 205 class, Bucknell University) NA = not analyzed.

Sites	T, °C	field pH	Spec. Cond., mS/cm	DO, mg/L	ORP reading* mV	SO <sub>4</sub> , mg/L	as mg/L CaCO <sub>3</sub>		as mg/L HCO <sub>3</sub> <sup>-</sup>
							Hot Acidity	Alk	Alk
VFW Stndp N	10.14	6.4	0.483	0.03	43.6	NA	NA	79.8	97.36
VFW Stndp	9.90	6.58	0.976	-0.06	-10.6	NA	NA	164	200.08
VFW Stndp		6.81		2.26		NA	NA	NA	NA
Pond2 Eff	9.90	6.27	0.440	7.72	125.2	155	-36	42	51.24
42 Eff	9.82	6.27	0.411	9.4	168.2	125	-32	35.5	43.31
CR5 <sup>2</sup>	13.88	5.69	0.2	12.46	144.4	75	-2	7.4	9.03

\*ORP = oxidation/reduction potential; not corrected to Standard Hydrogen Electrode

1. Very little flow through pipe, data collected may not be accurate
2. Measurements made about 15 minutes after collection of sample

Table 6. Laboratory results: Site 42 (11/14/06 sampling; GEOL 205 class, Bucknell University)

Sites	Total Fe, mg/L	Dissolved metal, mg/L						
		Fe	Mn	Al	Na	K	Mg	Ca
VFW Stndp N		9.1	2.0	0.1	3.0	15.0	8.7	
VFW Stndp mid		12.6	2.3	0.2	9.8	59.1	11.9	
VFW Stndp S		3.0	2.3	0.1	54.1	20.8	8.4	
Pond2 Eff		0.9	1.6	0.1	10.0	15.7	9.1	
42 Eff								
CR5		0.1	0.7	0.1		1.8	3.7	

Table 6a. Wilson Testing Laboratory results: Site 42 (11/14/06 sampling; GEOL 205 class, Bucknell University); NA = not analyzed.

Sites	Total Fe, mg/L	Dissolved metal, mg/L						
		Fe	Mn	Al	Na	K	Mg	Ca
VFW Stndp N		8.7	2.1	NA	NA	NA	NA	NA
VFW Stndp mid		12.9	2.2	NA	NA	NA	NA	NA
VFW Stndp S		3.0	1.9	NA	NA	NA	NA	NA
Pond2 Eff		0.71	1.7	NA	NA	NA	NA	NA
42 Eff	2.9	0.2	1.4	NA	NA	NA	NA	NA
CR5		0.13	0.73	< 0.5	NA	NA	NA	NA

Note: Mn concentration from RA 42EFF sample = 1.3 mg/L.

## Discussion

In comparison to data collected in 2005, iron concentrations in the VFW standpipes have not significantly decreased, and this suggests that the addition of compost has yet to affect the system. Despite this fact, the system as a whole is effectively lowering the iron concentrations to

less than 1 mg/L. Since samples were taken the week after the new compost was spread, further sampling within the next few months would be needed to confirm that the remediation worked. Before Pond 1 was drained, there was little flow through the vertical flow standpipes due to the increased amount of iron hydroxides that had precipitated within the pipes. This was still evident after the remediation when minimal flow was observed at the south standpipe. As a result of remediation, dissolved oxygen levels decreased in VFW north and middle standpipes significantly from 2005. Prior to treatment, the high levels of dissolved oxygen in the VFW standpipes suggested that the compost was not providing sufficient reducing conditions. With the addition of compost on October 31, 2006 dissolved oxygen levels decreased within a week to below the detection limit (0.3 mg/L) implying that the compost was working correctly. Dissolved oxygen levels in VFW Standpipe S are not accurate because there was insufficient water flow for measurements, but it appears that DO is still unacceptably high. Compared to data collected in 2005, alkalinity in the vertical flow wetland has increased, indicating that the water is moving through the compost and dissolving limestone more effectively. However, the alkalinity values for Pond 2 effluent, 42 effluent and Carbon Run 5 decreased with respect to 2005 results. This decrease could be due to the small amount of time between the addition of compost and collection of data. With a longer time gap, alkalinity could increase downstream. The flow rate was measured for Pond 2 standpipes, but time did not allow measurement for the vertical flow wetland standpipes. The flow rate at pond 2 standpipes showed considerable increase in flow from 2005. This in addition to the decrease of iron in solution indicates that more water is effectively being treated before entering Carbon Run.

Despite the apparent success in increasing alkalinity and reducing dissolved oxygen, in two of the VFW standpipes, problems are still present. The measured concentrations of potassium and sodium have considerable variation within the three standpipes and the effluents (Table 4). Some of the variation from the south standpipe can be attributed to the relatively low volume of water flowing through the pipe which may have allowed for buildup of various minerals. Because this compost is so fresh, the high concentration of Na and K will most likely decrease over time. Reducing conditions should cause Fe concentrations to initially go up in the standpipes as  $\text{Fe}(\text{OH})_3(s)$  is reduced to Fe(II), then Fe concentrations should go back down, and standpipe flow rates should eventually go up. Close monitoring of the standpipes is recommended to confirm this hypothesis.

## References Cited

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