Assessment of the Markle Passive Treatment System

Technical report provided by Hedin Environmental through the Trout Unlimited Technical Assistance Program TUTAG-27

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Background

In 2002 the PADEP Bureau of Abandoned Mine Reclamation (BAMR) designed and constructed a passive treatment system in the Mill Creek watershed near Strattanville, PA. BAMR refers to the system as the "Kotchey Site." The Mill Creek Coalition (MCC) refers to the site and system as "Markle." The system treats an artesian flow of Fe-contaminated water. These discharges are common in this region and have been successfully treated with anoxic limestone drains followed by settling ponds and constructed wetlands. The success of these passive systems depends on the ability of the ALD to generate enough alkalinity to fully neutralize the acidic water and the proper design and sizing of the ALD, settling ponds and wetlands. Reliable design criteria for this type of passive system have been available since 1994 (Hedin et al., 1994).

Construction plans and as-built plans were obtained from BAMR. The system includes a rectangular ALD that is 101 ft wide by 268 ft long by 4 ft deep. Assuming a density of AASHTO #3 limestone of 1.35 ton/CY, then the ALD contains about 5,400 tons of limestone. The ALD discharges to a single settling pond whose size and shape were constrained by site conditions. A stream runs along the site and a 50 ft setback was maintained. The installed settling pond has a surface area of 41,300 ft^2 and is 4 ft deep. Map 1 shows the existing conditions.

The construction process included collection of the artesian discharge and its plumbing into the ALD. The discharge was from an abandoned gas well with existing casing. During construction the casing broke and an uncontrolled discharge developed that made construction difficult. The discharge was collected in an aggregate-filled pit that had a pipe that carried flow to the ALD influent manifold. The pit was sealed with clay. Both the ALD and the settling ponds were constructed with a synthetic liner. A drain was placed beneath the ALD liner to collect flow not captured in the gas well collection system. This flow was thought to be acidic water containing aluminum and unsuitable for ALD treatment. The flow was discharged directly into the settling pond.

Water discharges into and out of the settling pond through pipes. This method of flow control can allow short circuiting, so five floating curtains were placed in the pond to promote a serpentine flow path. The settling pond effluent is through a 12 inch pipe that discharges to a rock-lined channel to the receiving stream. A rectangular weir was installed in the channel for flow measurements. An emergency discharge channel was installed in the settling pond breast about 150 ft from the primary discharge pipe. The emergency channel discharges to the same stream.

The receiving stream is an unnamed tributary to Little Mill Creek that enters Little Mill 150 ft below the treatment system inflow. Little Mill Creek in this area has been seriously polluted for many decades by AMD from abandoned surface mines. Remediation activities by the Mill Creek Coalition have improved the quality of Little Mill. The Markle system is an important component of the restoration of Little Mill Creek and Mill Creek.

System Inspections (March, May, and June 2007)

The system was inspected several times in 2007. Several problems were apparent. The intended discharge pipe was clogged with iron and debris, causing water to rise in the pond and discharge though the emergency spillway. Because of the location of the spillway, flow through it made about 15% of the settling pond non-functional. This was especially apparent in March when the site was inspected during cold weather. The pond between the ALD discharge and the emergency spillway was mainly open water (Photo A). The pond south of the spillway was frozen (Photo B).

The raised water elevation in the pond (caused by the plugged effluent pipe) negatively impacted the purpose of the floating curtains. The curtains were installed to assure a serpentine flow path and provide maximum retention. The curtains are intended to be secured in a water-tight fashion to one side of the pond and extend toward the other side, stopping short of the opposite bank by 10-20 feet. The curtains may operate as intended when the effluent pipe is operational. However, when the pipe is clogged and water elevations in the pond are 6-9 inches higher, a gap develops between the curtain and the pond liner on the secured end (Photo C). The gaps allow water to leak by the curtain and bypass a substantial portion of the treatment system. In March and May 2007, all of the curtains were observed to be leaking in this manner. This problem, combined with the effluent through the emergency spillway provided a flow path that avoided 75% of the pond.

The pipe was unblocked during the first week of June and a discharge through the intended channel was reestablished.

<u>Flow Measurements</u> Flow measurements have been made at a 24 inch wide rectangular weir located in the channel between the final pond effluent pipe and the stream. The weir, as observed in June 2007, does not provide an accurate flow measurement for two reasons. First, a rectangular weir is not appropriate for the flow range occurring at the site. When using weirs, it is desirable to use a structure where the error of the water depth measurement does not substantially influence the estimated flow rate. The range in flow at the Markle site is likely 100-400 gpm.

The formula for a rectangular weir with end contractions is shown below (Equation A).

$$\text{Flow (gpm)} = 1492*(L - 0.2H) * H^{1.5} \qquad \text{(A)}$$

where L is the width of the weir and H is the head on the weir, both measured in feet.

Table 1 shows the head (water height above weir in stilling area) for various flow rates.

Table 1. Head levels for various flows for a 24 inch rectangular and 90^o V notch weir.

Flow	Head, inches	
gpm	**24" rectangular**	**90^o V notch**
100	1.3	4.5
200	2.0	6.0
300	2.6	7.1
400	3.2	8.0

In order to have confidence in the flow estimates, the head measurements for the existing 24" rectangular weir must be made to the nearest tenth of an inch. This is not a reasonable expectation, especially when the weir is usually found to be partially blocked by leaves, sticks, or iron sludge. The preferred situation is one where flow measurement errors of ½ inch do not substantially change the flow rate. Table 1 also shows the head measurements for a 90^o triangular weir (V notch). The range in head is twice as large, making accurate measurement of flow rate much easier. Flow measurements at the site would be greatly improved with the installation of a V-notch weir.

The second reason that the rectangular weir does not provide accurate flow measurements stems from the nature of its installation. The accurate measurement of flow with a weir requires a stilling area behind the weir. Water falls over the weir at a rate that can be predicted based on known constants (gravity, friction, etc.). If a stilling area does not exist, then the true velocity over the weir may be affected by other factors and flow estimates made using the weir charts will be inaccurate.

Photo D shows the weir. There is not a stilling area. Water flows down a sloped channel to the weir and discharges over the weir with more velocity than the calculations assume. The weir is underestimating flow rate.

Table 2 shows flow rates measured in June 2007. A flow could not be measured on June 8 when all other flows were measured because a large stick was found to be blocking the weir and backing water in the channel. The stick was removed and the flow was measured on June 11 after conditions had equilibrated. Flows were measured at the ALD and underdrain discharges by making a timed collection of a known volume in a bucket (Photos E and F). The ALD discharge required the use of a 16 gallon tub. The timed-volume flows are accurate to within 10% or less.

Table 2. Flow rate measurements (gpm) made for the weir using equation A and at the pipe discharges using the timed-volume method.

Date	Weir flow (inches)	ALD pipe	Underdrain pipe
June 8	na	309	6
June 11	200 (2.0")	na	na
June 21	164 (1.75")	300	na

Measurement made at the effluent weir using standard weir charts significantly underestimate flow rate. On June 21 when the influent flows were about 306 gpm (assuming the underdrain flow was the same as June 8), the weir flow estimate was 47% low. It is unknown whether there was ever a stilling area behind the weir that would have resulted in more accurate flow measurements in the past.

Performance of the Markle Passive System

Table 3 shows data collected for the system and Little Mill Creek by Hedin Environmental through this study. Table 4 shows the average results of samples collected by BAMR from the passive treatment system between January 2003 and May 2007. The ALD and pond have been sampled 40 times. The underdrain has been sampled 20 times. Table 1 also shows selected data collected by Hedin Environmental in June 2007 to simplify comparisons. Figure 1 shows iron concentrations at the ALD effluent and pond effluent between January 2003 and June 2007.

The system has not functioned as well as anticipated. The ALD has not generated enough alkalinity to completely neutralize the AMD. The effluent of the ALD is still net acidic. The settling pond has only removed 30% of the iron (comparison of ALD effluent and Pond Pipe stations).

BAMR suspected that the rate of iron removal in the settling pond was limited by oxygen transfer into the water. To test this idea, the influent was aerated with a Turbo Jet for several days in August 2004. The effects of the aeration on the systems performance are shown in Table 5. The aeration lowered the effluent Fe concentration from ~66 mg/L to an average 38 mg/L. Fe removal was doubled. BAMR personnel report that these results were disappointing as complete removal of Fe was expected with the aeration.

<u>Fe Removal</u> Passive systems where iron oxidation and hydrolysis occurs under buffered conditions (pH 6-7) usually remove iron at an area-adjusted rate of ~20 grams of Fe per square meter per day (gFe $m^{-2}d^{-1}$). This rate is thought to be a consequence of oxygen transfer limitations and also oxidation kinetics that are affected by the pH. Aeration can increase Fe removal because it increases oxygen transfer and also increases pH through carbon dioxide degassing.

Table 3. Measurements made at the Markle site in 2007 By Hedin Environmental.

Sample	Date	Flow*	pH	Alk	Acid	Fe	Mn	Al	SO4
Treatment System Sampling									
ALD Effluent	June 1		6.4	158	37	123	18	0.2	846
Pond Out, Pipe	June 1	~5%	6.2	114	32	62	17	0.1	791
Pond Out, spillway	June 1	~95%	5.9	102	31	82	18	0.1	791
ALD Effluent	June 8	309	6.5	170	33	126	18	0.1	662
Underdrain	June 8	6	5.6	6	135	45	14	0.8	509
Pond Out, Pipe	June 8		6.4	105	37	72	18	0.2	621
Pond Out, spillway	June 8	0							
Pond Out, weir	June 11	200							
Pond Out, weir	June 21	164							
ALD Effluent	June 21	300							
Little Mill Creek Sampling									
LM Upsteam	June 1		5.2	10	24	1.2	11.8	0.5	435
LM Downstream	June 1		5.9	2	25	9.7	12.2	1.1	414
LM Upsteam	June 8	1,985	5.9	2	31	0.8	10.2	0.3	330
LM Downstream	June 8	2,509	6.3	22	33	8.4	11.2	0.9	472

Flows are gpm; pH is standard units; all other parameters are mg/L; Alkalinity and Acidity as $CaCO_3$
** flow rates at weir estimated from depth of water and equation A; all other flows by timed-volume method*

Table 4. Performance of the Markle Passive System

Point	When	Flow	pH	Alk	Acid	Fe	Al	Mn	SO4
ALD eff	2003-07	na	6.3	128	58	101	<0.5	18	970
Underdrain	2003-07	na	5.2	21	117	48	0.6	13	567
Pond pipe	2003-07	162*	6.3	81	75	70	<0.5	18	923
ALD eff	6/1/07	na	6.4	158	37	123	0.2	18	846
Pond spill	6/1/07	na	5.9		31	82	0.1	18	791
ALD eff	6/8/07	309**	6.5	170	33	125	0.1	18	662
Underdrain	6/8/07	6**	5.6	6	135	45	0.8	14	509
Pond pipe	6/8/07	na	6.1	110	37	72	0.2	18	621

*Flows are gpm; pH is standard units; all other parameters are mg/L; Alkalinity and Acidity as $CaCO_3$; 2003-07 data are BAMR data; values are the average of 20-38 samples; pond effluent samples during the aeration experiment are not included in the averages; June 2007 data collected by Hedin Environmental and analyzed by G&C Labs; * measured at the weir by BAMR; ** measured by the timed-volume method*

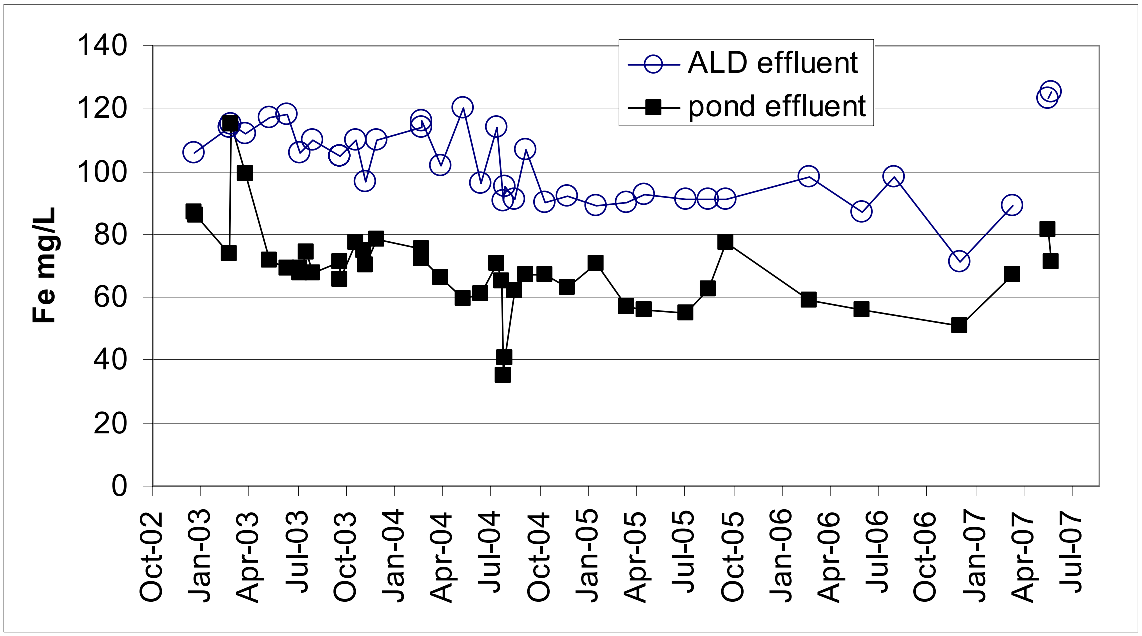

Figure 1. Fe concentrations at the Markle Passive Treatment System. The decrease in effluent Fe concentrations in August 2004 is due to the TurbeJet experiment. All data collected by BAMR except June 2007 data which were collected by this project

Table 5. Effect of aeration on Fe removal by the Markle system. (BAMR data)

Point	**When**	**what**	**Flow**	**pH**	**Alk**	**Acid**	**Fe**	**Mn**
ALD effluent	Jul 29	passive		6.0	89	54	114	19
ALD effluent	Aug 11	Turbo		6.4	155	58	90	16
ALD effluent	Aug 13	Turbo		6.3	125	74	95	18
ALD effluent	Aug 31	passive		6.1	99	65	91	16
Pond effluent	Jul 29	passive	171	6.0	68	49	71	18
Pond effluent	Aug 9	passive		6.4	122	53	65	18
Pond effluent	Aug 11	Turbo		6.2	59	48	35	16
Pond effluent	Aug 13	Turbo		6.2	60	71	41	17
Pond effluent	Aug 31	passive	171	6.0	74	65	62	15
Pond effluent	average	passive		6.1	56	88	66	17
Pond effluent	average	Turbo		6.2	60	60	38	17

Flows are gpm; pH is standard units; all other parameters are mg/L; Alkalinity and Acidity as $CaCO_3$;

Table 6 shows Fe removal rates for the system measured in June by this investigation. The calculation was done using data collected: 1) on June 1 before the discharge pipe was unclogged and water was discharging through the emergency spillway, and 2) on June 8 after the pipe was unclogged and all water was discharging from the pipe. The flow rate for the June 1 sampling was assumed as the same as June 8. The pond surface area, 41,300 ft^2, was measured from the BAMR as-built drawings. The underdrain was ignored because June 8 measurements indicate that its iron loading was less than 1% of the ALD's (3 lb/day vs. 463 lb/day).

Table 6. Fe removal measurements and calculations made for the June 2007 data.

condition	**Flow gpm**	**SA (ft^2)**	**Fe^{in} mg/L**	**Fe^{out} mg/L**	**Fe removal $gFe\ m^{-2}d^{-1}$**
Overflow	309	41,300	123	82	18.0
Discharge pipe	309	41,300	125	72	23.2

Measurements made in June 2007 of flows and chemistry indicate that the system was removing Fe at a rate of 18 $g\ m^{-2}d^{-1}$ on June 1, when the pond's pipe effluent was plugged and all flow was through the overflow. Recall that March cold weather observations indicated that this flow path bypassed about 15% of the system. On June 8, when the water was flowing through the whole pond and discharging through the pipe, the Fe removal rate was 23 $g\ m^{-2}d^{-1}$. These rates are consistent with other passive systems that treat buffered Fe-contaminated water.

A similar calculation of Fe removal performance cannot be confidently done for the BAMR data. As noted, flow rates are unreliable. The iron concentrations are also suspect. Since mid-2004, ferrous iron concentrations have been routinely 10-15% higher than total iron concentrations. The State Laboratory has been alerted about this discrepancy by DEP personnel.

Based on this analysis of the Markle passive system conducted in June 2007, we conclude that the system is passively treating Fe in a manner consistent with other passive systems in PA. The performance problem is due to overloading. In June 2007, the iron loading to the Markle settling pond averaged 54 $g\ m^{-2}d^{-1}$ of Fe. This loading is twice the recommended rate for settling ponds intended to precipitate iron from alkaline waters.

<u>Alkalinity Generation by the ALD</u> The ALD does not generate a net alkaline discharge. The June samples averaged 35 mg/L net acidity. The BAMR data average 58 mg/L net acidity. Repeated field measurements on June 8 indicated that the ALD discharged water with 170 mg/L alkalinity. (Because alkalinity is unstable in mine water samples, the BAMR alkalinity values are errantly low). The ability of the water to generate more alkalinity through contact with more limestone was tested by conducting limestone incubation tests. The test, using Hedin Environmental's ALKast (alkalinity forecasting) devices, incubates about 30 mL of the water with limestone chips in an anoxic environment. After a period of time, the alkalinity content of the water is measured. Testing has shown that the method accurately predicts the alkalinity that will

be generated by a full scale ALD. Because the test uses limestone chips, not larger AASHTO #3 aggregate, the reactions occur more quickly in the ALKasts. Testing has determined that a 30 minute incubation time approximates 2-3 hours of retention in an ALD, and 120 minute incubation approximates 10-12 hours of retention.

The results of the ALKasts are shown below.

- 0 minutes incubation, 170 mg/L alkalinity
- 30 minute incubation, 180 mg/L alkalinity
- 120 minute incubation, 195 mg/L alkalinity

The testing indicates that additional contact with limestone will NOT result in substantially higher alkalinity concentrations. The system's 5,400 tons of limestone (which at 300 gpm provides 18 hours of retention) are functioning as well as can be expected.

The alkalinity generation by the ALD is disappointing, but it is not unexpected. The Howe Bridge ALD, which has a retention of about 20 hours, discharges water with 160 mg/L alkalinity. The Filson ALDs, which provide a similar retention, produce ~250 mg/L alkalinity. This variation in ALD performance is related to AMD chemistry, not a feature of the ALDs that could be manipulated through conventional construction or design practices.

<u>Stream impacts</u> Two sets of samples were collected from Little Mill Creek by this study. Stream flow measurements were made on June 8 with a velocity meter. The primary impact on Little Mill is an increase in Fe. Concentrations downstream were 8-10 times higher than upstream. The stream was visibly more orange downstream (Photos G and H). The system inflow did not depress pH, which was about 6 on both days.

Recommendations

One purpose of the Technical Assistance is to provide options that MCC and BAMR could implement to improve the effectiveness of the Markle system. Five options are considered here:

1. remain passive; lessen flow rate
2. remain passive; modify existing system
3. remain passive; expand existing system
4. remain passive; modify and expand existing system
5. install aeration

The options are described below. A drawing that incorporates Options 2 & 3 & 4 is attached as Map 2.

<u>Option 1, Lessen Flow Rate</u> Before the system was constructed, the AMD discharge flowed from an abandoned gas well. The plan was to connect to that well and pipe the flow into the ALD. During construction the well casing broke and water

discharged from the hole in an uncontrolled manner. A collection system was installed that discharges all water into the ALD.

If the well was repaired and control of the flow was obtained, it might be possible to decrease the flow into the passive system to a rate that can be passively treated to a good condition. Because of the common occurrence of artesian flows from gas and water wells in the area, there are companies with experience in managing these situations. The project would require that the discharge area be opened and a drill rig set up on the hole. The hole would be cleaned out and a pipe installed down to the water-producing zone and grouted in place. The pipe would be valved so that the flow could be controlled. The flow to the system would be set at a rate determined by MCC and BAMR to best protect Little Mill Creek. Based on the measurements made in this study, that flow rate would probably be about 140 gpm.

Because the well currently makes 300 gpm, a substantial portion of the water would not discharge through the system. The fate of this water is debatable. Groups promoting the plugging of AMD-producing wells assume that water that is blocked from flow through these wells is permanently eliminated from the stream system. Others have suggested that the water is diverted to another discharge location. If the well is brought back under control and its discharge through the treatment system is regulated, the MCC should be vigilant for the development of new discharges in the area.

<u>Option 2: Modify Existing System</u> This option modifies the existing system to make it more effective for Fe removal. Last year, a passive treatment system was constructed in the Sewickley Creek watershed (Westmoreland County) that treats alkaline water with 75-90 mg/L Fe. In order to assure non-preferential flow and the slowest water velocities possible, the minewater was distributed into each pond and collected from each pond with 50 ft wide troughs. The troughs very effectively spread out the flow and also aerate. The effectiveness of the ponds is being monitored. To date (8 months) the ponds are removing iron at about 30 g $m^{-2}d^{-1}$, or 50% faster than similar ponds without troughs.

The existing pond could be modified to incorporate the trough concept. At the same time, the pond could be split into two basins, divided by a weir that extends the full width of the pond. In order to provide a foot of drop between the influent trough and each basin, the water elevation in the pond would be raised by one foot. This requires raising the stream-side berm by one foot. The influent to the pond would be distributed the full width with a trough. The pond would be divided at its mid-point by a weir that extends fully across the pond. This weir would redistribute the flow across the full width of the pond and by dropping water 12 inches, provide more aeration. A collection trough could be installed at the end of the final basin that discharges water into the existing channel. The rectangular weir in the channel should be replaced with 90^{o} V notch weir.

We are aware that the presence of the synthetic liner complicates the installation of the cross-pond weir. In order to maintain two distinct pools of water at different elevations, the weir would need to be sealed into the bottom of the pond. The Brinkerton system in the Sewickley Creek watershed demonstrated the effective use of plastic sheet pilings to separate flows. This approach might be used to create the cross weir.

Option 3: Enlarge System The system is functioning at a level consistent with other passive systems, but because it is undersized, the performance is unsatisfactory. The system can be enlarged.

Reconnaissance of the site revealed an area to the north that could be used to construct an additional pond (Photo I). HE personnel met with the landowner on June 8, who expressed concerns about the system being expanded. To allay these concerns, an expansion plan was developed that stayed within the original project boundaries (as delineated on the as-built plans). A 15,000 ft^2 pond can be fit to the north of the existing pond, within the current project boundaries.

If the project boundaries could be extended north to Little Mill Creek, a pond having 25,000 -30,000 ft^2 surface area could be constructed without producing unmanageable excess cuts.

The area to the north of the treatment system contains some wetlands that appear to contain clean water. Mitigation may be required.

Option 4. Modify and Expand Existing System This Option combines Options 3 & 4. As noted in Option 3, the new pond could be made larger if permission was received to extend beyond the current project boundaries. This option provides the maximum passive treatment benefit without complete reconstruction of the existing system

Option 5: Aeration Iron removal can be improved with aeration that raises pH and transfers oxygen into the water. The passive treatment of alkaline Fe-contaminated water followed by passive precipitation in settling ponds has been a popular concept recently. However, bench-scale tests do not always translate into satisfactory field results. It is the author's experience that realized Fe removal in aerated systems is often much less than predicted removal. As noted in this report, BAMR conducted an aeration test at Markle that was deemed a failure because it only doubled iron removal. At the Scrubgrass system in Allegheny County, a Maelstrom Oxidizer was installed to aerate 300-500 gpm of alkaline water containing 80-90 mg/L Fe. The unit doubled the iron removal by the system, but did not achieve a quality effluent. The monthly electricity cost of the aerator (which operates 24/7) is about $150. At the Lions Mining site in Somerset County, the DEP is partially treating 750 gpm of alkaline water with a venturi aerator followed by passive settling. The system lowers Fe from 70 mg/L Fe to 30 mg/L and removes Fe at a rate of about 60 g $m^{-2}d^{-1}$. The system operates off the natural head of the discharge which is about 40 psi. At least 20 psi is necessary to operate the venture effectively. The Markle discharge as currently collected does not retain any head pressure. A compressor would need to be installed to make the venture approach feasible.

WPCAMR, working with Dietz-Gourley Consulting, recently obtained a DEP grant to test a micro-aeration approach on minewater. The Markle site is reportedly being considered for pilot testing. More details can be obtained from the Dietz-Gourley Consulting.

Performance and Surface Area Calculations for the Options

The expected gains of the various improvements in iron removal are shown in Table 7. The calculations consider five flow rates that range around the 3000 gpm rate measured in June 2007. An influent iron concentration of 110 mg/L is assumed. This is the average of the higher BAMR measurements (when ferrous iron was higher than total iron, ferrous iron was used) and the recently collected samples. Settling ponds are generally not effective for lowering iron concentrations to less than 10 mg/L. The goal of the pond is to lower Fe to 10 mg/L. The calculations consider four Fe removal rates: 20 g $m^{-2}d^{-1}$ (the current rate), 30 g $m^{-2}d^{-1}$ (anticipated rate with trough and pond improvements) and 40 and 50 g $m^{-2}d^{-1}$ (possible rates achieved with aeration).

Table 7. Calculated surface area needs for the Markle discharge at varying flow rates and Fe removal rates. The existing pond is 40,300 ft^2.

			Surface area (ft^2) needed at Fe rate below			
flow	**Fe^{in}**	**Fe^{out}**	*20* g $m^{-2}d^{-1}$	*30* g $m^{-2}d^{-1}$	*40* g $m^{-2}d^{-1}$	*50* g $m^{-2}d^{-1}$
200	*110*	*10*	58,602	39,068	29,301	23,441
250	*110*	*10*	73,253	48,835	36,626	29,301
300	*110*	*10*	87,903	58,602	43,952	35,161
350	*110*	*10*	102,554	68,369	51,277	41,022
400	*110*	*10*	117,204	78,136	58,602	46,882

Flows are gpm; Fe concentrations are mg/L; surface areas are ft^2

Option 1 involves lowering the flow rate enough to make the existing system function. At the current Fe removal rate (20 g $m^{-2}d^{-1}$), the required flow rate is 140 gpm.

Option 2 involves modifications to the existing pond that could increase Fe removal rates to 30 g $m^{-2}d^{-1}$. These changes would enable the treatment of 210 gpm.

Option 3 involves the addition of 15,000 ft^2 of new pond. The total combined pond surface area would be 55,300 ft^2. If no other changes were made, the new system would be able to treat 190 gpm.

Option 4 involves both modifications to the existing pond and installation of the new 15,000 ft^2 pond. Assuming that this system treats water at 30 g $m^{-2}d^{-1}$, then it would be able to treat 285 gpm. If the new pond can be expanded to 20,000 ft^2, then the system would passively treat the conditions observed in June 2006 to ~10 mg/L Fe.

Option 5 involves aeration. In order to achieve treatment with the existing pond, an Fe removal rate of about 50 g $m^{-2}d^{-1}$ needs to be achieved. A variety of aeration technologies can likely achieve this rate.

Resource Recovery Opportunities

During the last six years, Iron Oxide Recovery, Inc. has recovered 2,600 tons of pigment-grade iron oxide from mine drainage sludge. The company has only been able to market sludge produced passively. Chemically precipitated sludge is contaminated with non-Fe elements. Sludge produced through aeration of alkaline water has proven to have weak pigmentary characteristics and has not been marketable. IOR is working on this problem and hopes to find non-pigmentary markets for aerator-produced sludges. At this time, however, there is no market.

The sludge passively produced at the Markle site will likely be usable as pigment. IOR has already recovered pigment-grade iron sludge from the Howe Bridge site, where an artesian flow of mine water is treated with an ALD and settling ponds.

Samples were collected of sludge collected from within the ALD discharge pipe and from the overflow channel. The samples of the iron sludge were dried (100^{o}C) and sent to ActLabs for elemental analysis (Table 8). The samples are ashed in a furnace (>1000^{o}C) and the ash is analyzed for elemental composition. The element concentrations are expressed as the oxide minerals that form during the ashing process. These are not the minerals present in the fresh samples. The analysis provides an indication of the purity of the sample.

Natural iron oxide (goethite and ferrihydrite) contain water that is expelled during ashing. This water typically accounts for 15-25% of the weight of original dry sample. It is reported as LOI.

Table 8. Composition of iron sludge samples collected from Markle Site.

	Fe_2O_3	SiO_2	Al_2O_3	LOI
Markle – ALD	80%	4%	<1%	15%
Markle - Pond	80%	4%	<1%	14%

The samples were almost identical in composition. Both samples are very clean iron oxide. A qualitative assessment of color was also positive. The materials can be recovered and processed to a pigmentary product.

The amount of iron oxide sludge present in the settling pond was estimated from the BAMR data, the length of system operation (1,650 days) and an assumed average flow rate of 300 gpm. The system is calculated to contain about 190 tons of Fe as FeOOH. If the system undergoes major renovation, there is enough iron sludge in the pond to make recovery feasible.

IOR recently purchased property in the Strattanville area where it is opening an iron oxide processing center. The center is located only 5 miles from the Markle site. Sludge transportation is a major, and prohibitive, cost of sludge recovery. The Markle site is attractive to IOR for this reason.

IOR has signed a maintenance agreement with Scott Township to maintain the Scrubgrass system in return for ownership of the iron sludge. A similar agreement is being discussed with the Sewickley Creek Watershed Association for the Lowber passive system. If the Markle system is improved but retains its passive treatment elements, MCC may be able to negotiate a long-term maintenance agreement in exchange for the iron sludge.

Photo A. The Markle system in March 2007. The photo is looking south from the NW end of the pond.

Photo B. View from the emergency spillway to the south. The effluent pipe (located at the end of the pond) was plugged, making this portion of the pond ineffective (as indicated by the ice buildup).

Photo C. A gap between the curtain and pond liner that allows short-circuiting. The ALD discharge pipe is in the background.

Photo D. The Markle weir. The absence of a stilling area makes measurements using standard weir charts inaccurate.

Photo E. The ALD discharge to the settling pond. Note the pool made in the aggregate to accommodate a flow measurements with a 16 gallon tub.

Photo F. Measuring flow from the underdrain discharge.

Photo G. Little Mill above the Markle treatment system inflow.

Photo H. Little Mill below the treatment system inflow (view looking downstream from the bridge).

Photo I. Area to the north that could be used for system expansion (the settling pond is visible in the background)