A watershed-based NPDES approach to AMD treatment in Muddy Creek, Cheat River, West Virginia, USA

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Abstract

For decades, the Lower Muddy Creek drainage was impaired by Acid Mine Drainage (AMD) emanating from Surface Mine Control Reclamation Act (SMCRA) pre- (Title 4) and post- (Title 5) law mine discharges. Muddy Creek contributed one half of the acid load to the Cheat River Watershed. In 2016 after legislative revisions to the State's water quality standards (West Virginia Legislative rule 47CSR2), WV Department of Environmental Protection (WVDEP) received approval from the United States Environmental Protection Agency (EPA) for a Watershed-Based NPDES approach in June 2017. The first ever in-stream NPDES permit in the United States was issued to WVDEP Office of Special Reclamation (OSR) at the mouth of Martin Creek. The project has resulted in the treatment of all AMD discharges in the Muddy Creek Watershed. In 2018, the OSR completed construction of a High-Density Lime Slurry System capable for treating 4,200 gal/min (16 m^3/min) of AMD. The Muddy Creek AMD Plant utilizes lime slurry solution to neutralize AMD. The plant includes a 100-t lime silo, two 80-ft (24-m) clarifiers, polymer injection, sludge disposal all controlled by a state-of-the-art computer control system. The plant treats all discharges from the T & T Mine as well as two pre-law and five post-law AMD treatment sources. Those upstream sources are conveyed through a pipeline to the Muddy Creek plant. There is also a similar High-Density Lime Slurry System in Glade Run and a Pelletized Lime Dosing unit near the headwaters of Martin Creek. Both dispense lime slurry or pelletized lime directly into the stream. The Muddy Creek AMD Plant and the two in-stream dosers have restored the 3.4 mi (5.47 km) of Lower Muddy Creek and removed one half of the acid load to the Cheat River Watershed. Before treatment, in 2015, results from an electro-shock fish survey near the mouth of Muddy Creek showed no fish. In 2019, after treatment had begun, a survey detected 143 fish of nine different species. Median pH values increased from 4.3 to 7.3 following treatment. Since June 2018, Muddy Creek has been net alkaline. Median aluminum and iron concentrations decreased from 10 and 9 mg/L, respectively, to 1 mg/L. The median discharge of acidity into the Cheat River decreased from 11,800 lb (5,352 kg) to 1,100 lb/d (498 kg/d) calcium carbonate equivalent. This methodology could be applied to other AMD streams, thereby restoring miles of impaired streams and improving multiple watersheds throughout the United States.

Background

The Surface Mine Control and Reclamation Act (SMCRA) was passed in 1977. SMCRA set legal standards for mine reclamation requiring U.S. States to establish a mine permit process and inspection standards for mining operations. Mine permits issued under SMCRA must include a reclamation plan for the mining activity. The mine operator is also required under SMCRA to attain a National Pollution Discharge Elimination (NPDES) permit. NPDES permits set water quality standards for discharges attributed to the mining activity into the waters of the State. Mining activities conducted after the passage of SMCRA are known as Title 5 mines (active). Mining activity prior to the passage of SMCRA are known as Title 4 mines (abandoned). Title 5 mines must attain a mining permit issued by the State. In the case of a mine permittee who forfeits their permit and does not reclaim the site, the State revokes the mining permit. When this occurs in West Virginia, the West Virginia Department of

Environmental Protection (WVDEP) Office of Special Reclamation (OSR) is responsible for all reclamation including the treatment of AMD from the forfeited permit.

Conditions of Muddy Creek

Muddy Creek contributed 50% of the total acid load to the Cheat River Watershed (Fig. 1) (Ziemkiewicz 2023). For decades, Lower Muddy Creek drainage was impaired by a combination of Title 4 and Title 5 AMD discharges (Fig 2). In 2016, nearly all Title 5 AMD discharges were being treated at their source. All Muddy Creek AMD discharges amounted to an average acid load of 5,395 kg/d. Treating the Title 5 discharges only addressed 878 kg/d leaving 4,517 kg/d untreated in the watershed. In addition, the Title 5 discharges accounted for 4 kg/d of the total iron load in Lower Muddy Creek, accounting for only 10% of the total iron load of 398 kg/d (Fig. 3) (Ziemkiewicz 2023). Not treating the Title 4 discharges does not achieve the goals of the Lower Muddy Creek Restoration Project or the Clean Water Act which states in 101(a) "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (USEPA 2023).

Economic Factors

The goal of restoring the Cheat River Watershed, even with treatment of AMD, was being attained. The money spent by OSR to treat Title 5 discharges was considered. OSR had been treating AMD discharges from T & T mining permits since 1995. T & T was the largest Title 5 contributor of AMD to Muddy Creek. From 1995 to 2014, OSR spent over 9 million USD on operational costs (Riggleman 2018). Despite these efforts, the treatment plant had to be replaced with new technologies and infrastructure to meet NPDES discharge limits. In addition to the T & T discharges, OSR had nine other treatment sites within the Muddy Creek Watershed, which had cost 3.4 million USD on capital and a total of 11.5 million USD on operation and maintenance from 1995 to 2014 (Sheehan & Ziemkiewicz 2017). OSR also had three other AMD treatment sites within the watershed that had yet to be constructed. This amount of money was that for treating only the Title 5 discharges which accounted for only a small fraction of the acid and iron load in Lower Muddy Creek.

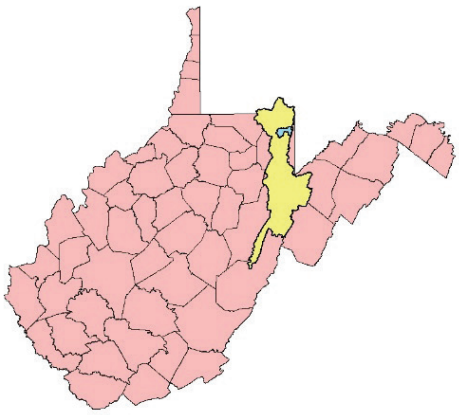

Figure 1 *Cheat River Watershed in yellow with Muddy Creek Watershed in blue (image: Mike Sheehan, OSR)*

OSR and the West Virginia Water Resource Institute (WRI) designed a watershed-based AMD treatment plan that would treat Title 4 and 5 discharges into the Muddy Creek Watershed. The plan would include the new T & T AMD treatment plant and an AMD conveyance line with a lift station piping several Title 4 and 5 discharges to the T & T plant for treatment. In addition, the plan included two in-stream lime slurry dosers at the headwaters of Glade Run and Martin Creek Watersheds. It was determined that the plan would restore 5.63 km of lower Muddy Creek. The West Virginia Abandoned Mine Lands and Reclamation program (AML) had successful results in the nearby Three Forks watershed with in-stream dosing treatment. Its watershed-based approach yielded 1,605 fish representing 21 species where there were none three years prior (Sheehan & Ziemkiewicz 2017). With the plan and the AML results, OSR approached the US Environmental Protection Agency (EPA) for approval for the first in-stream NPDES permit in the United States.

Legislative Requirements

Approval of this approach required the State of West Virginia to alter its own water quality standards, specifically WV Legislative

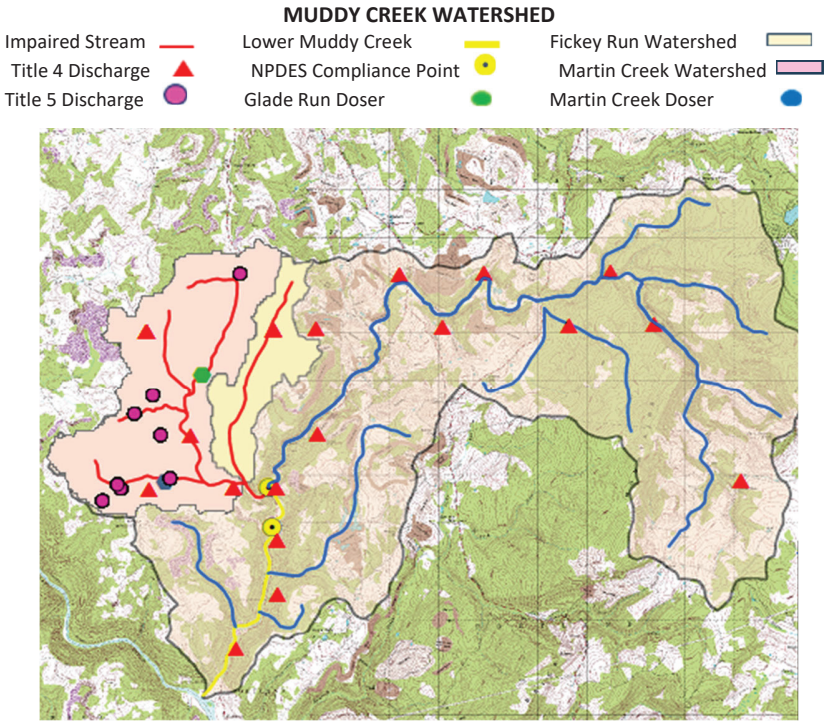

Figure 2 *Muddy Creek Watershed showing Title 5 and 4 discharges, NPDES compliance point locations and locations of OSR's Martin Creek and Glade Run in-stream dosing units (image: Mike Sheehan, OSR)*

Rule 47CSR2 to allow for the variance. The alteration became law in 2016. The specific language in the revised legislation included the following:

7.2.d.8.2. A variance pursuant to 46 CSR 6, Section 5.1, ***based on human-caused conditions which prohibit the full attainment of any designated use and cannot be immediately remedied****, shall apply to WVDEP Division of Land Restoration's* ***Office of Special Reclamation's discharges into Martin Creek*** *of Preston County and its tributaries, including Glade Run, Fickey Run, and their unnamed tributaries. The following existing conditions will serve as* ***instream interim criteria while this variance is in place: pH range of 3.2-9.0, 10 mg/L total iron, and 15 mg/L dissolved aluminum****. Alternative restoration measures, as described in the variance application submitted by WV DEP Division of Land Restoration's Office of Special Reclamation, shall be used to achieve significant improvements to existing conditions in these waters during the variance period. Conditions will be evaluated during each* ***triennial review*** *throughout the variance period. This variance shall remain in effect until action by the Secretary to revise the variance or until July 1, 2025, whichever comes first.*

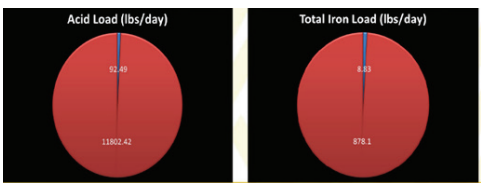

Figure 3 *Acid load and iron load at the mouth of Muddy Creek in 2017. The chart shows the contribution of Title 4 discharges in red vs. Title 5 discharges in blue (Ziemkiewicz, 2023)*

On June 15, 2017, the WVDEP received approval from the EPA for a Watershed-Based NPDES approach. The first in-stream NPDES permit in the United States was issued to OSR at the mouth of Martin Creek.

Water Treatment Infrastructure

As OSR pursued the in-stream variance, OSR was moving forward with the construction of a state-of-the-art AMD treatment plant for T & T AMD mine discharges (Fig. 4). The plant included two 24-meter (80 ft) clarifiers, a lime silo, lime slurry mix tank, polymer injection system, sludge pumping/ disposal system and geotubes with geotube pad for sludge disposal. The AMD treatment plant was designed to treat 17,034 L/min (4,200 gal/min). Average water quality entering the plant had a pH of 2.8, Fe at 1.6 mg/L and Al at 67 mg/L.

A 4 km (2.5 mi) long AMD conveyance pipeline with a lift station was also installed to the north of the treatment plant (Fig. 5). The pipeline collected the major AMD sources along Ficky Run. The AMD in the Martin Creek would be addressed by two in-stream dosing units. The main unit was installed near the headwaters of Glade Run, a tributary of Martin Creek. The dosing unit like the T & T plant would neutralize AMD with lime slurry. A pH probe just downstream from the injection point determined the amount of slurry injected into Glade Run (Fig. 5). The dosing unit at the headwaters of Martin Creek was a pelletized lime unit that served as a backup or during times of extreme flow. These two units ensured comliance with the NPDES variance point at the mouth of Martin Creek (Fig. 2).

Total capital costs for the watershed-based approach are 15.9 million USD compared to a point source approach of 12.5 million USD. The Average operations and maintenance costs for the watershed-based approach is 530,000 USD/a. as opposed to the point source approach of 1 million USD/a. Though initial capital costs were more in the watershed-based approach the capital costs were substantially lower yielding savings over a 10-year period of over 1.2 million USD (Ziemkiewicz, 2023; Table 1). OSR also received 1.2 million USD for initial capital expenses from Southwest Energy (SWE). SWE also contributes 350,000 USD/a for the operations and maintenance costs for the project. SWE had no responsibility for the negative effects originating from Muddy Creek. They voluntarily to contributed to the project as a private industry partner with OSR.

Figure 4 *T & T AMD treatment plant (image: Chester Wright, OSR)*

Lower Muddy Creek

Lower Creek was biologically dead and contributing 50% of the acid load to the Cheat River Watershed. Pre and post treatment water quality was evaluated extensively by the WVDEP Watershed Assessment Branch (WAB) at the locations shown in Fig. 7. Treatment of the watershed began in December of 2017. WAB performed water chemistry and fish studies in 2015, 2019, 2021 and 2023.

Before treatment, in 2015, results from an electro-shock fish survey near the mouth of Muddy Creek showed no fish. In 2019, after treatment had begun, a survey detected 143 fish of nine different species (WAB May 2021). Fish species found at the mouth of Muddy Creek

Figure 5 *Glade Run doser with in-stream pH probe in the foreground right (image: Chester Wright, OSR)*

Table 1 *Point source vs. watershed-based approach costs*

Cost	Point Source Approach	Watershed Approach
Capital Expenses	$21,500,000	$15,920,000
Operational and Maintenance/Year	$1,000,000	$530,000
Total Costs Over 10 Years	&22,500,000	$21,220,000
Savings		**$1,280,000**

continued to diversify and population levels maintained were through the 2023 study (Tab. 2).

What has OSR Learned

The chemistry of the AMD presented challenges in the construction, operation and maintenance of treatment system. All materials that came into contact with the impaired water had to be either stainless steel or High Density Polyethlyene (HDPE) or Polyvnil Cloride (PVC) pipe. Ductile iron, steel, and other materials that come in contact with the AMD corrode quickly.

Iron scale from high amounts of ferric iron (Fe^{+3}) accumulated in the conveyance piping (Fig. 8) and lift station wet wells. These challenges were addressed through several methods. A non-calcarious bed was installed at the inlet of the gravity conveyance line. The stone accumulates some of the Fe^{+3} prior to entering into the conveyance line. A maintenance schedule was established that cleaned both gravity and pressurized lines with a high water pressure jet. To prevent the

Table 2 *WVDEP WAB fish community data from 2015–2023 for Muddy Creek watershed. For Specific location see Fig. 7 (Data provided by WAB 2023)*

Muddy Creek Fish Community Comparison Pre-treatment (2015) vs Post-treatment (2019, 2021, 2023)										
Mile Point	MP 0.0 (d.s. treatment facility)				MP 2.1 (d.s. treatment facility)			MP 4.4 (u.s. treatment facility)		
Sample Year	2015	2019	2021	2023	2019	2021	2023	2015	2019	2023
Bluegill			1			2				
Brown Trout								6	1	3
Creek Chub					10	4	15	301	191	133
Green Sunfish		3	12	4	12	11	7			
Greenside Darter				1						
Longnose Dace				3				26	27	3
Mottled Sculpin	No	1	1		3		1	225	653	340
Rainbow Trout	Fish				1	1	1		2	12
River Chub	Observed	111	77	83						
Rock Bass	in 300 Meter	2		4						
Rosyface Shiner	Sample	10	38	19						
Rosyside Dace	Reach	1	1							
Smallmouth Bass		12	9	12						
Spotfin Shiner		1								
Stonecat		2		8						
Tiger Trout			6							
Western Blacknose Dace			4			2		461	485	310
White Sucker								22	82	37
Yellow Bullhead			1							
Total Species	**0**	**9**	**10**	**8**	**4**	**5**	**4**	**6**	**7**	**7**
Total Collected	**0**	**143**	**150**	**134**	**26**	**20**	**24**	**1041**	**1441**	**838**
Fish/meter	**0.00**	**0.48**	**0.50**	**0.45**	**0.09**	**0.07**	**0.08**	**3.47**	**4.80**	**2.79**

Fe^{+3} from entering the lift station from jetting, a sump was installed prior to the lift station. The Fe^{+3} settled into the bottom of the 2 m (6 ft) deep sump. This mitigated accumulation inside the wet well of the lift station.

Another process called pigging was also used. Pigging is where a bullet-shaped piece of high density foam is installed in the line (Fig. 9). Then the line is pressurized pushing the pig through it. The pig then pushes the metals and other debris as it goes throgh the line. Pigging pressurized lines with raw water that is high in Fe has mixed results in cleaning the line. Sites low in Fe pigging is very effective in preventing scale buildup within a conveyance line.

The T & T Mine has had several high flow events dating back to 1994. One such occurence happened in March 2021. The high flow event tested the plant and damaged some of the T & T AMD conveyance lines due to the extreme flows. For several hours, the pH of Lower Muddy Creek went down to pre- treatment levels from the damage to the AMD line. Water flowing into the plant was able to be neutralized but sludge discharged from the plant. The flows were so high that the sludge pumps were not able to keep up with the accumulation of sludge in the clairifiers. There was no fish kill from the event and the T & T plant treated a great deal of the higher flow.

As a result of the 2021 high flow event, OSR revisited the plant's sludge disposal system. OSR currently is finalizing land acquisition for the installation of a new sludge disposal line. The current disposal system injects the sludge from the T & T plant back into the mine. OSR's new location will reduce the head pressure on the sludge pumps by reducing both the distance of the line and the elevation of the injection point. Currently, only one sludge line is being used. OSR is installing two sludge lines to the new locations. More efficient sludge disposal pumps are also being installed. This will increase the efficiency of the sludge disposal system.

Figure 9 *"Pigs" that are used to push through pressurized line to clean the line (image: Greg Phillips)*

Figure 8 *Iron accumulation in AMD pressurized line (image: Greg Phillips)*

Prior to the event the plant computer controlled dosing system began dosing lime slurry at an unusually high rate. In addition, there was a sufficient increase in the conductivity of the discharge water from the T & T deep mine. OSR will use these unusual changes to prepare the plant for the event. Such measures could be removing as much sludge as possible from the clarifiers and increasing the dosing of the Glade Run Doser and Martin Creek.

OSR uses three grades of lime products (Tab. 3). OSR uses pelletized lime in the Martin Creek doser. Pelletized lime easily falls through the silo and dosing unit. When pelletized lime comes in contact with AMD, only the outermost of the particle is nutralized. There is lime within the particle that remains unreacted. In a watershed-based approach, this leaves residual lime in the stream. The particle breaks up as it moves downstream in the creek. During high flows, the residual lime is released as it comes in contact with rocks and debris in the water. This can cause a sudden release of lime, increasing pH to undersirable levels.

Dosing streams with peletized lime needs to be carefully monitored when using in-stream.

Hydrated and enhanced lime is used in the T & T plant and Glade Run Doser to create lime slurry. Treated water is blended with lime in a mix tank to create the slurry. It has been found that enhanced lime is more efficient in the mixing and treatment of AMD. This is believed to be attributed to a smaller particle size aiding in creating lime slurry and a higher CaO percentage to neutralize the AMD. On average, 15 to 20% less of the enhanced lime is needed than hydrated lime. OSR has realized savings when using enhanced lime. Pricing for both products is the same and since less of the enhanced lime is needed to make a given volume of slurry, a savings is realized.

Conclusions

The watershed-based approach required the state of West Virginia to change water quality standards and an approval letter from the USEPA before such an approach could be legally pursued. This is one of the more challenging aspects of a watershed-based approach. Installing AMD conveyance lines, much consideration must be given to water that is high in Fe due to Fe^{+3} scaling issues in both lines and lift stations. The goals of the Muddy Creek project have been realized. The treatment processes have eliminated the contribution of acidity to the Cheat Watershed and Lower Muddy Creek is seeing fish populations return after decades of no biological activity. Ultimately, the point source vs the watershed-based approach comes down to the AMD discharges in the watershed and compairsons of the costs for each approach including both capital and operational costs. The practicality, funds available, and time frames that one approach would take to see results within the given watershed must also be evaluated. Which approach is better comes down to these considerations and would be best implemented on a case by case basis. This is in the interest of effective use of public funds and the environment.

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Table 3 *Grades of lime used by OSR including particle size data and CaO percentage.*

	Grades of Lime Used by OSR		
Parameter	Pelletized Lime	Hydrated Lime	Enhanced Lime
Size	3 mm (1/8") tp 6 mm (1/4")	83% Passing Through 325 mesh	93% Passing Through a 325 mesh
Cao	95%	72%	95%