Watershed Scale Approaches to AMD Remediation: Martin Creek and Sandy Creek WV 342

Final Report

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Executive Summary

The goal of the Clean Water Act (CWA) is to restore and protect the Nation's waters. West Virginia's Special Reclamation Fund (SRF), administered by the Department of Environmental Protection's Office of Special Reclamation, supports the goals of the CWA by treating acid mine drainage (AMD) discharges from post-1977 coal mines that have transferred their surety bonds and water treatment liabilities to the State. Known as bond forfeiture sites, the cost of treating their AMD discharges to CWA standards is high and, unfortunately, the treated water is commonly discharged to streams that are severely impaired due to AMD from pre-1977 abandoned mines. Thus the expense of treating bond forfeiture sites is rarely reflected in-stream restoration benefits. This project explored a strategy for using SRF funds for permit compliance while restoring AMD impaired watersheds. It shifts the treatment from individual discharges to the receiving stream while achieving compliance at a point downstream in the watershed rather than at the point where discharge leaves the bond forfeited property.

This reduces the number of treatment locations and allows treatment at stream locations with pre-existing road access and the potential to restore the maximum number of stream miles. Most significantly, for less cost, it treats all of the acidity in the stream rather than the small fraction that originates at bond forfeiture sites.

This study compared the costs and benefits of in-stream vs. at-source AMD treatment in two watersheds in northern West Virginia: Martin and Sandy Creeks, both in Preston County. Both streams are severely impaired by AMD and both contain a mix of abandoned mines and bond forfeitures and both discharge to major recreational water bodies: the Cheat River and Tygart Lake. The results (Table 1) indicate that in-stream dosing alone would not achieve adequate stream benefits but, when paired with ongoing or planned restoration projects, would restore 3.4 and 10.8 miles of Muddy Creek and Sandy Creek respectively. Costs for the in-stream options were less than the costs of current at-source treatment projects which restore zero stream miles.

Table 1 Summary of costs for in-stream vs. at-source dosing. Projected stream mile recovery anticipates completion of AMD projects either underway or planned.

Martin Creek	At-source treatment	In-stream treatment
O&M cost projection (years)	20	20
Annual O&M	$ 218,084	$ 145,533
Total Capital Cost	$ 4,825,824	$ 1,200,000
Total O&M	$ 4,361,684	$ 2,910,664
Total cost	$ 9,187,508	$ 4,110,664
Projected stream mile recovery*	**0**	**3.4**
Sandy Creek		
O&M cost projection (years)	20	20
Annual O&M	$ 189,568	$ 223,708
Total Capital Cost	$ 2,609,587	$ 1,444,032
Total O&M	$ 3,791,369	$ 4,474,166
Total cost	$ 6,400,955	$ 5,918,198
Projected stream mile recovery**	**0**	**10.8**

* With completion of the T&T AMD project
** With addition of a passive treatment unit at Barlow Portal

Projected 20-year costs for the two options indicate that in-stream dosing on Martin Creek would save $5,076,844 or a 55% cost reduction while in-stream dosing on Sandy Creek would save $482,757 or a cost reduction of 8%. The difference in cost savings is largely due to the smaller number of bond forfeiture sites in the Sandy Creek watershed.

Introduction

Acid mine drainage (AMD) is the most important source of stream impairment in West Virginia. Most of it comes from pre-law, abandoned coal mines. Post-1977 bond forfeiture coal mines are also an important but secondary source of AMD. Previous studies have demonstrated significant cost savings and projected increased environmental benefit by applying in-stream lime dosers at strategic locations within the stream system rather than using lime dosers to treat individual sources (Ziemkiewicz 2006). In the fall of 2015 the West Virginia Department of Environmental Protection (WVDEP) Office of Special Reclamation (OSR) commissioned the West Virginia University Water Research Institute (WVWRI) to determine the advantages of in-stream vs. at-source AMD treatment in two watersheds in northern West Virginia: Martin Creek and Sandy Creek. Martin Creek is the most important source of AMD entering the Cheat River upstream of the Cheat Canyon, an important white water tourism location while Sandy Creek discharges to Tygart Reservoir, also an important recreational water body.

The performance of the watershed-scale approach to AMD remediation via in-stream dosing was evaluated dosing the streams over a one year period, monitoring water quality in response to treatment and comparing results to restoration targets.

Sampling locations for restoration targets were at Martin Upstream Fickey (MUF) for the Martin subwatershed study and at both the Left Fork Little Sandy Mouth (LFLSM) and Maple Run Mouth (MRM) for the Sandy Creek subwatershed. Results from weekly sampling indicate in-stream treatment was successful in achieving restoration targets in the Martin Creek subwatershed. Despite fluctuations in doser operations, continuous monitoring of pH at the compliance point at MUF indicated that pH was maintained within the restoration target with the exception of a pH spike above 9.0 that lasted for 30 minutes, this event coincided with lime doser charging at an upstream site. In the Sandy Creek subwatershed, LFLSM restoration targets were within range for pH and dissolved aluminum (Al) during the study period, while total iron (Fe) exceeded the restoration target of 14 mg/L for 9 out of the 37 samples. At compliance point MRM, weekly sampling results for pH, dissolved Al and dissolved Fe were within restoration target range during the entire study period.

Background

Martin Creek:

Approximately 3.4 stream miles in the Muddy Creek drainage are impaired by acid mine drainage (AMD). The majority of the acid load comes from the Martin Creek sub watershed, including Fickey Run and Glade Run. According to the Lower Cheat River Watershed Based Plan (WBP), Fickey Run is impaired by two abandoned mine land (AML) and two bond forfeiture sites (BFS), while Glade Run is impaired by five AML and five BFS. Both Fickey Run and Glade Run flow into Martin Creek, which receives AMD from two AML sites before it joins Muddy Creek 3.2 miles above its confluence with the Cheat River. Approximately 0.7 miles above Martin Creek, Muddy Creek receives AMD from several AML sources originating from the Dream Mountain Ranch. Muddy Creek supports a quality cold water fishery upstream of its junction with Martin Creek.

Sandy Creek:

Sandy Creek is a subwatershed in the lower section of the Tygart Valley River basin. The Sandy Creek subwatershed drains over 90.3 square miles and flows into Tygart Lake (WVDEP 2003a). As per the 1982

Tygart Valley River Subbasin Abandoned Mine Drainage Assessment, Sandy Creek was identified as contributing 49.5% of the total acid load to the Tygart between Philippi, WV and the mouth at Fairmont, WV. Water quality data collected during the assessment found 9,325 lbs/day of acid being discharged into Tygart Reservoir from Sandy Creek (WVDEP 1987).

West Virginia Department of Environmental Protection (WVDEP) identified multiple AML sites that discharge AMD into Left Fork Little Sandy Creek, Left Fork Sandy Creek, and Maple Run. Additionally, several BFS within the watershed fall under WVDEP's Office of Special Reclamation (OSR).

The 2002 303(d) list identified impairment by iron, aluminum (total) and manganese (WVDEP 2003b) in the Sandy Creek watershed. Total maximum daily loads (TMDL) limits were developed in 2001. In 2003, the state water quality standard for aluminum changed from total to dissolved aluminum. In its 2004 list, WVDEP only maintained aluminum listings if dissolved aluminum data were available and those data indicated impairment (WVDEP 2004). Five of the six streams previously listed for total aluminum were delisted and the 2004 list only included Little Sandy Creek as impaired by dissolved aluminum.

Project Design

The project was organized around three tasks for both Martin and Sandy Creeks:

Task 1: Dosing Trials

- Site Access – granted through WVDEP.
- Site Preparation and Doser Installation – completed through sub-awards with contractors.
- Doser Operation and Maintenance – Visual assessments performed weekly during sampling events by WVWRI personnel. Martin Creek dosers were checked daily by Aquafix; Sandy Creek dosers were checked daily by WVDEP and Save the Tygart Watershed Association (Aquafix was notified when maintenance was needed).
- Lime – Contracted through Aquafix.

Task 2: Water Quality Sampling

- Grab samples were collected at eleven sites weekly since 27 October 2015 through 20 December 2016 in the Martin Creek watershed with the exception of two weeks in April (12^{th} and 19^{th}).
- Grab samples were collected at eleven sites weekly between 17 February and 6 April 2016 and 7 June through 21 December 2016 in the Sandy Creek watershed.
- Field parameters included: temperature (°C), dissolved oxygen (ppm), specific conductance (µS/cm), and total dissolved solids (mg/L) and turbidity via transparency tube.
- Grab sample were analyzed to determine: pH, alkalinity, acidity, conductivity, sulfates, and total suspended solids along with total and dissolved metals (iron, magnesium, aluminum, calcium, and manganese).
- Flow measurements were determined in-stream when conditions permitted and were calculated when in-stream measurements were not possible.

Task 3: Sludge Monitoring

- Visual assessments via transparency tube, photographs, and lab measured total suspended solids (TSS) estimated turbidity in the receiving streams.

Monthly reports were provided to WVDEP during the course of the study.

Project Goal

The goal of this project was to evaluate, with minimal infrastructural cost, the performance of in-stream dosing. This involved moving temporary dosers to key locations in the test watersheds and providing temporary power arrangements. It was recognized that power and lime feed interruptions would occur but still permit evaluation of the treatment strategy. Outcomes included not only evaluation of the in-stream treatment strategy but also identification of optimal doser locations. Given positive results, permanent dosers using line power and slurry feed would be installed at the identified locations.

Results

Martin Creek

Task 1: Doser operations: Martin Creek

AML discharges in the upstream end of Fickey Run were responsible for the majority of iron loading to Martin Creek. Dosing trials in November 2015 through January 2016 caused dissolved iron to precipitate resulting in significant iron hydroxide moving through Martin Creek and into Muddy Creek, particularly during high flow conditions. As a result it was decided to terminate dosing at the upper Fickey Run location and move the compliance point from the mouth of Martin Creek to the point immediately upstream if its junction with Fickey Run. Restoration targets remained pH 3.2 to 9.0; dissolved Al 15 mg/L; and total iron 10 mg/L. The Fickey (F1) doser was taken off line on 29 December 2015 and was moved to the Left Fork Little Sandy site on 12 Feb 16 for project WV 347. However, water quality monitoring on Fickey Run continued.

Solar power supply was inadequate to maintain reliable doser operation during winter months. As a result, batteries were manually recharged by the site contractor, Aquafix Inc. In addition, the in-stream pH probe and feedback to lime feed control was not reliable. As a result lime feed was reset to manual control. Generators were installed to recharge batteries at the G1 and M1 dosers. A permanent power supply was installed via WVDEP at G1 to alleviate power interruption.

A two-stage auger system was installed at doser G1 on 19 May 16. On 27 July 16, the G1 doser was switched to the permanent power supply. In an effort to assess Martin Creek chemistry with one doser, M1 was turned off on 10 August until 24 August 16 and then permanently beginning 26 August 16. Doser and sampling locations are shown in Figure 1.

M1 was taken offline on 10 Aug 16 to 24 Aug 16 then again on 26 Aug 16 for the remainder of the project period, leaving G1 as the sole doser on the Martin Creek watershed.

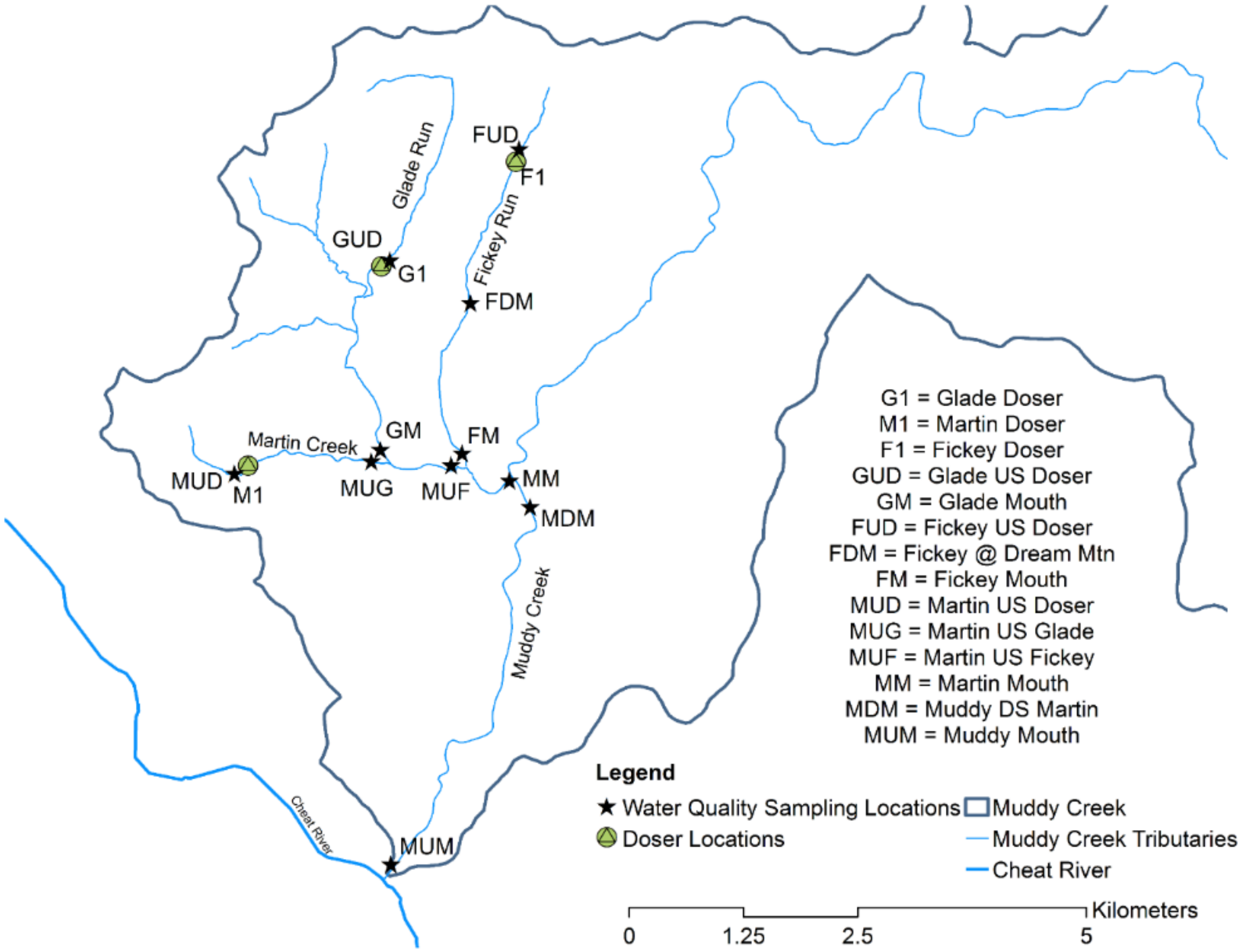

Figure 1. Martin Creek doser and water quality sampling stations.

Task 2: Water Quality Monitoring

Acid and Metal Loading under Varying Conditions

Martin Creek was sampled weekly at eleven sites between 27 October 2015 through 20 December 2016 with the exception of two weeks in April (12th and 19th). Stream flows varied widely in these headwater streams both seasonally and in response to storms. At various times both, one, or zero dosers were engaged as part of the test and in response to power and feed interruptions

Restoration Target Performance

The following discussion addresses system performance with regard to the three restoration targets: pH (3.2 to 9.0), dissolved aluminum (15 mg/L) and total iron (10 mg/L) as determined at Martin Creek upstream of Fickey Run (MUF).

Despite periodic inconsistencies in doser operations, the pH, Al dissolved and Fe total targets have been met at MUF since initiation of dosing in early November 2015. It is important to note that at-source dosers in upper Martin Creek were turned off on 11 Feb and turned back on in March (shaded area in Figure 2).

Also, M1 was taken offline on 10 Aug 16 to 24 Aug 16 then again on 26 Aug 16 for the remainder of the project period, leaving G1 as the solitary doser on the Martin Creek watershed. During this time, restoration targets were met for pH, Al d and Fe t (Figure 2).

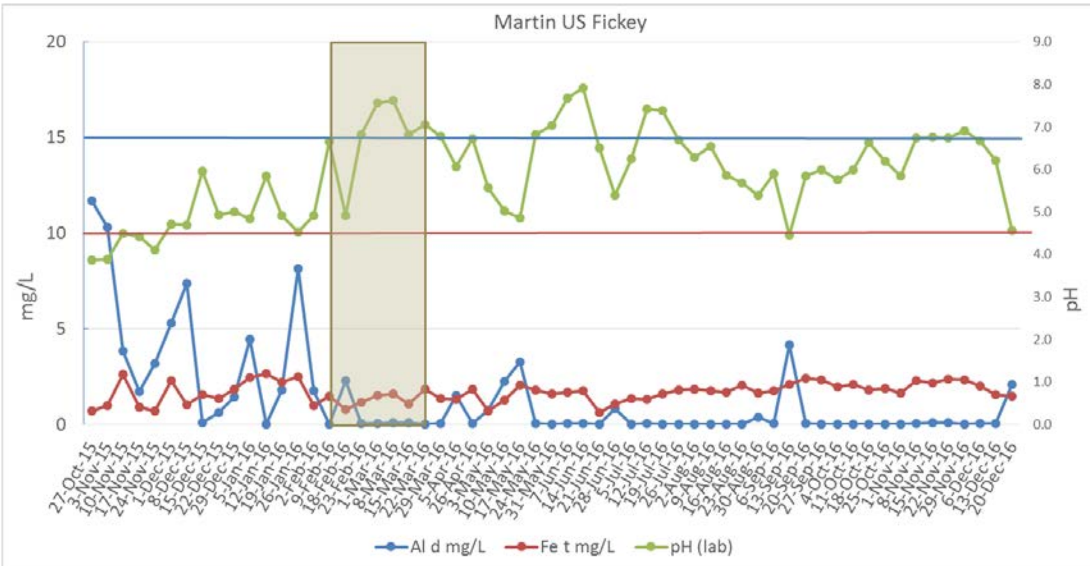

Figure 2. Restoration target performance measured at the compliance point (MUF). The blue horizontal line represents the dissolved aluminum (Al d) restoration target and the red horizontal line represents the total iron (Fe t) restoration target. The shaded area indicates the dates when the Martin Creek at-source dosers were turned off.

A pH probe (sonde) was placed in-stream at MUF on 8 January 2016. It recorded pH at 15 minute intervals. With the exception of two recordings of 9.41 pH and 9.55 pH on 16 June 2016 (caused by upstream activity of filling M1 doser), values stayed within the restoration target of 3.2 to 9 pH (shaded area in Figure 3). Fluctuations in pH at MUF were responsive to in-stream dosing operations.

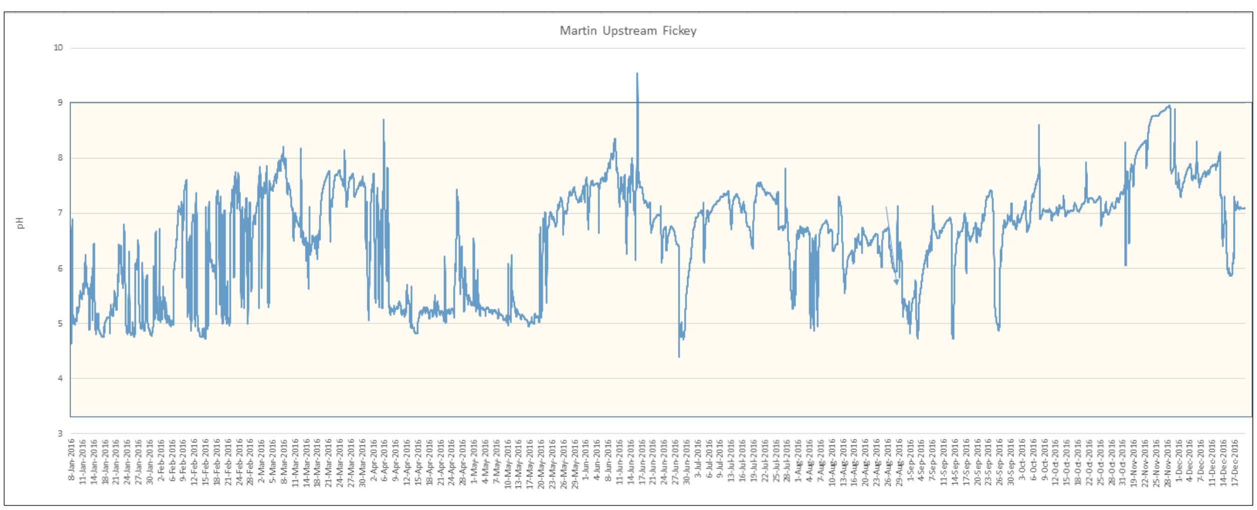

Figure 3. pH values at MUF site from in-stream sonde between 8 January 2016 and 20 December 2017; yellow shading shows restoration target range of 3.2 to 9 pH.

An example of consistent steady pH near neutral is seen during 28 September to 16 November in Figure 4.

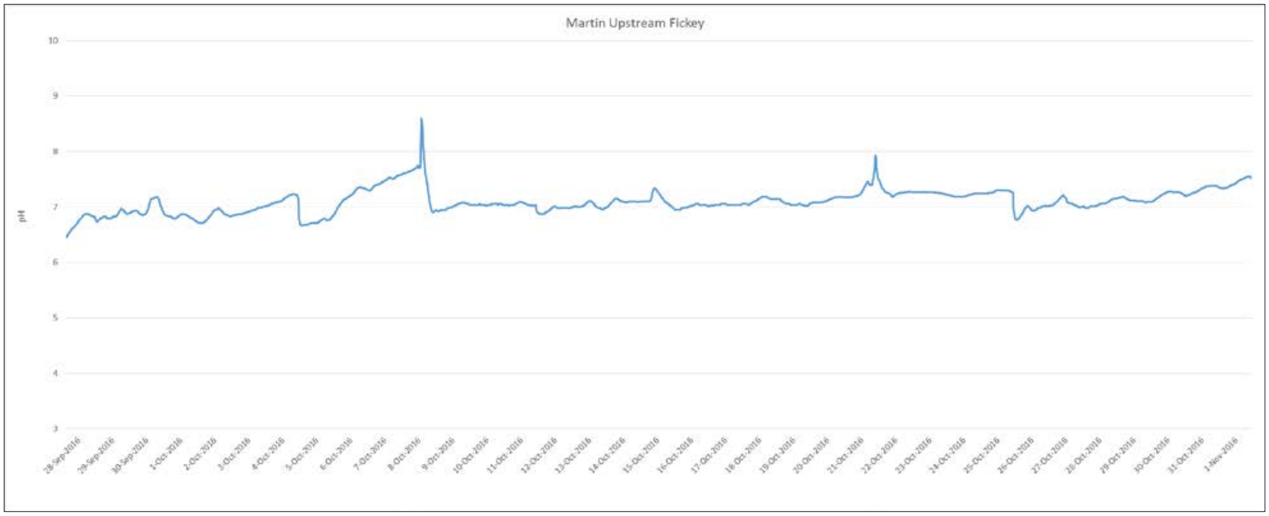

Figure 4. pH values at MUF site from in-stream sonde between 28 September 2016 to 16 November 2016. Note only G1 was operational during this time period.

Task 3: Sludge Monitoring

Field measured turbidity (via a transparency tube) and laboratory measured TSS provided a measurement of suspended metal flocs at the sampling stations. Photos were taken at sites to show aesthetic changes to the Martin Creek watershed in response to dosing.

No correlation was found between TSS and flow (Q) at the MUF sampling site (Figure 5). While field observations suggested that higher TSS was associated with increased flow, the results suggests that precipitated metal flocs comprising the TSS were likely mobilized by sudden changes in flow rather than absolute flow volumes. Thus, the effect would be a pulse rather than sustained, elevated TSS after rainfall or runoff events.

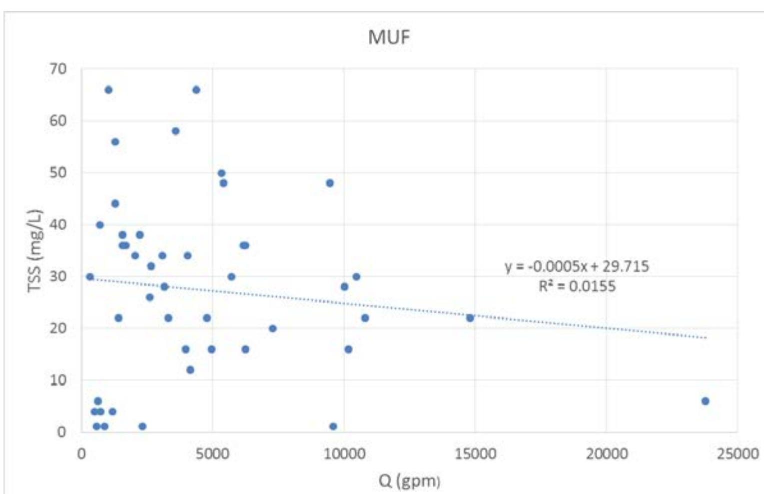

Figure 5. Total suspended solids (TSS) and flow (Q) at the compliance point (MUF).

Martin Creek upstream Fickey Run (MUF)

Figure 6 and Figure 7 depict average and high flow conditions at MUF compliance point while doser was operational.

Figure 6. MUF site during average flow conditions on 15 November 16. Only G1 doser operational.

Figure 7. MUF site during high flow conditions on 2 February 16. Both G1 and M1 dosers operational.

Sandy Creek

Task 1: Doser operations: Sandy Creek

Lime dosing was initiated on the Left Fork Little Sandy on 10 Feb 16; Maple Run dosing was initiated on 17 Feb 16. The solar panels attached to the dosers were unable to supply their power requirements with sufficient reliability. To supplement the solar power supply, generators were purchased by WVDEP and installed at both doser sites. WVDEP provided training and oversight for Save the Tygart Watershed Association to assist in running the generators on a daily basis to provide power to the dosers if needed (note: solar was not installed at the Maple site until March). Overall issues with the dosers in July included generator failure and lime feed interruptions. Sampling and doser locations are shown in Figure 8. Sandy Creek water sampling locations, stars indicate doser sites (yellow = Maple; blue = LFLS).

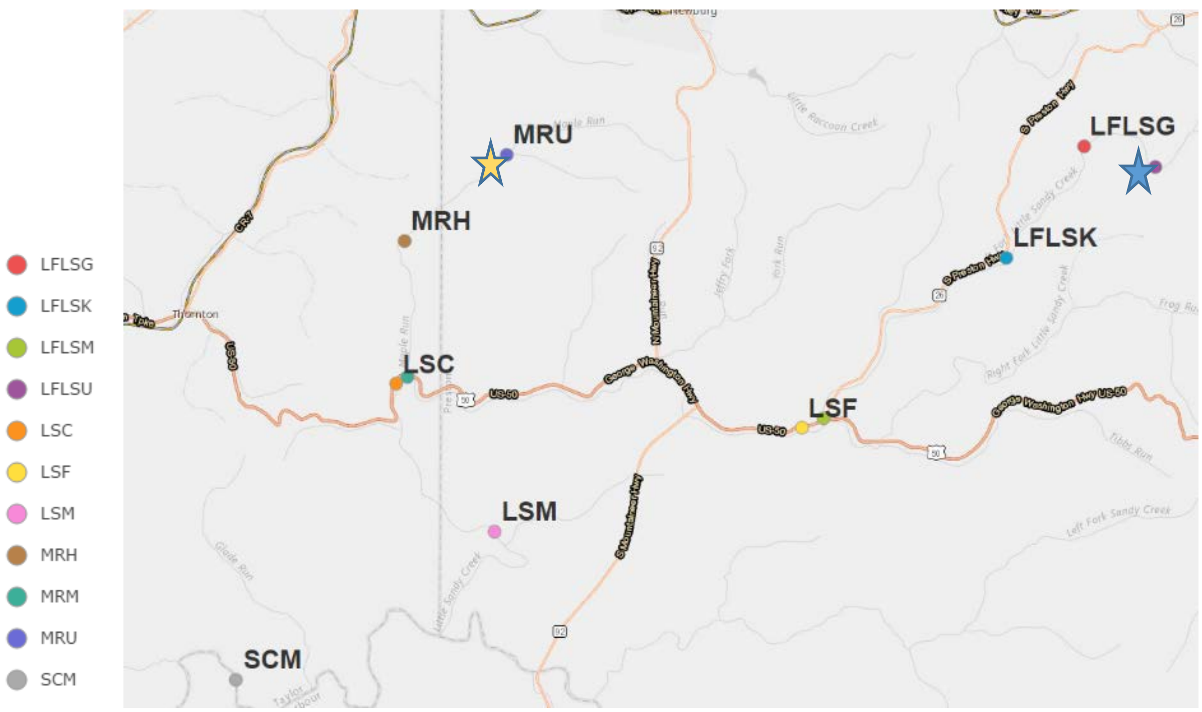

Figure 8. Sandy Creek water sampling locations, stars indicate doser sites (yellow = Maple; blue = LFLS).

Task 2: Water Quality Sampling

Acid and Metal Loading in Varying Conditions

Sandy Creek sites were sampled weekly between 17 February and 21 December 2016. Variations in-stream flow were noted to better gauge its effect on treatment efficiency. Factors such as low, average, or high flow events and varying doser activity during these flow events at both LFLS doser and Maple doser were represented over the one year sampling interval. Restoration targets were based on pH and iron and aluminum concentrations.

Restoration Target

There were two restoration target compliance standards in the Little Sandy watershed: pH (3.3 to 9.0), dissolved aluminum (12 mg/L) and total iron (2 mg/L) as determined at Maple Run mouth (MRM) and pH

(2.5 – 9.0), dissolved aluminum (33 mg/L) and total iron (14 mg/L) at the Left Fork Little Sandy Mouth (LFLSM).

At LFLSM restoration targets were met for pH and dissolved aluminum. Total iron, however, exceeded the limits 24% of the time (Figure 9). These exceedances occurred even when the dosers were operational indicating an overload of iron in the system from several headwater sources. It is likely that additional at-source treatment will be needed to eliminate sufficient iron to achieve compliance.

Concentrations of dissolved Al, total Fe, TSS and pH are shown in Figure 9. Note data prior to 17 February 2016 for total Fe and pH was provided by OSR, no data was available for dissolved Al.

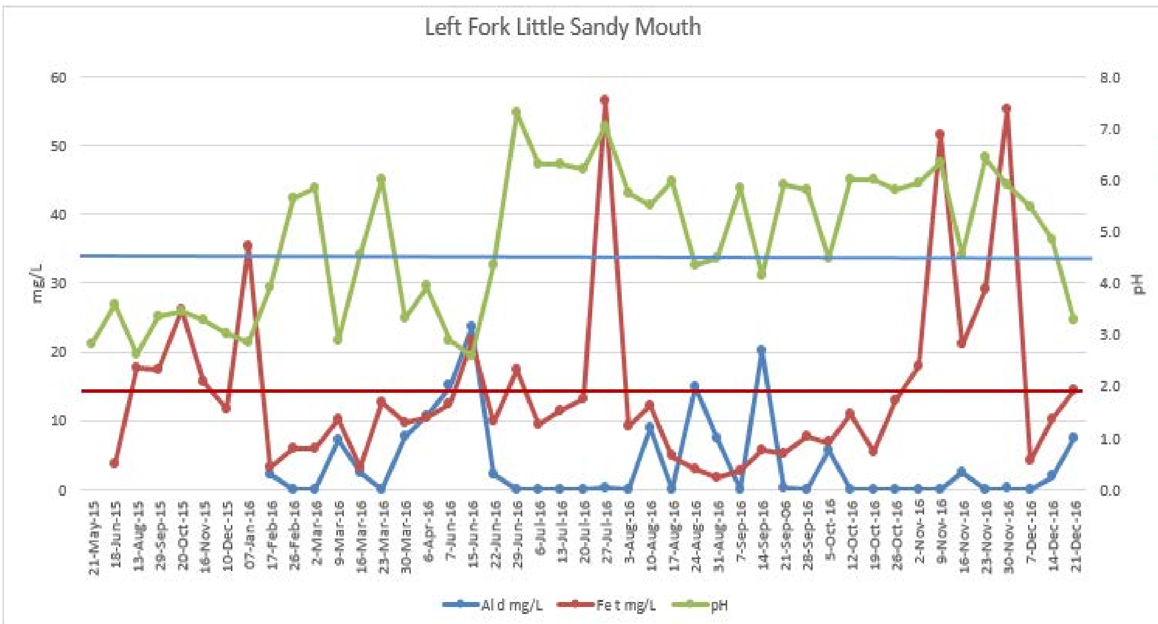

Figure 9. Left: dissolved Al and total Fe at LFLSM; right: total suspended solids (TSS) and pH.

On Maple Run, on the other hand, restoration targets were met when the dosers were operational (Figure 10).

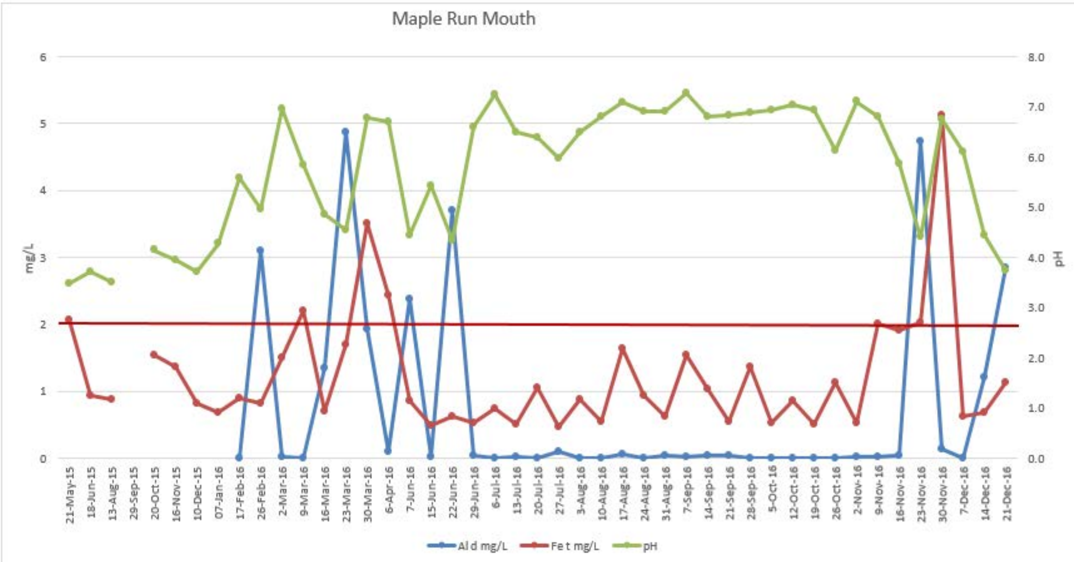

Figure 10. Left: dissolved Al and total Fe at MRM; right pH.

Task 3: Sludge Monitoring: Sandy Creek

Field measured turbidity (via a transparency tube) and laboratory measured total suspended solids (TSS) provided a measurement of suspended metal flocs at sampling stations. Photos were taken at sites to show aesthetic changes to the Sandy Creek watershed in response to dosing during varying flows and seasonal conditions.

No correlations were found between TSS and flow (Q) at either LFLSM or MRM sites (Figure 11 and Figure 12).

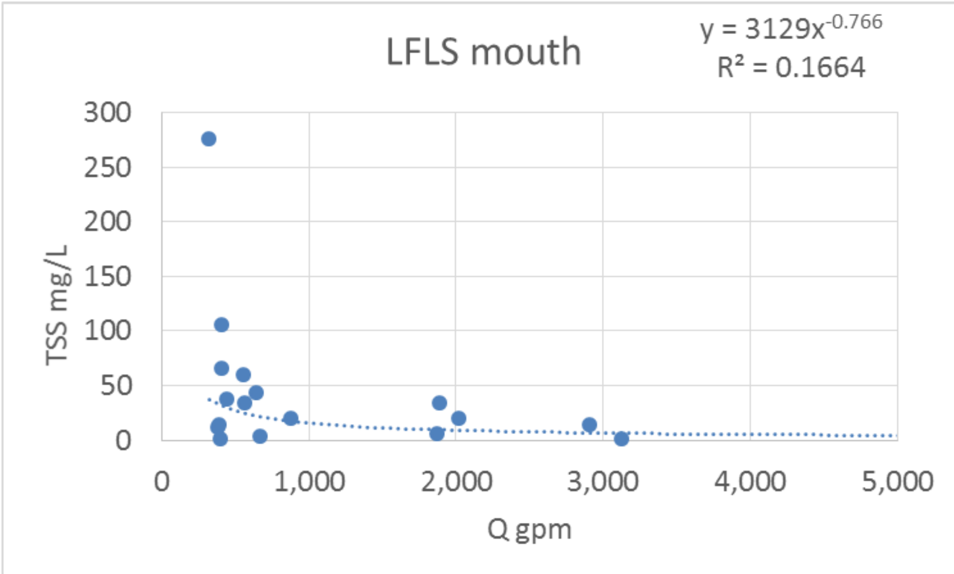

Figure 11. TSS and Q at LFLSM compliance point.

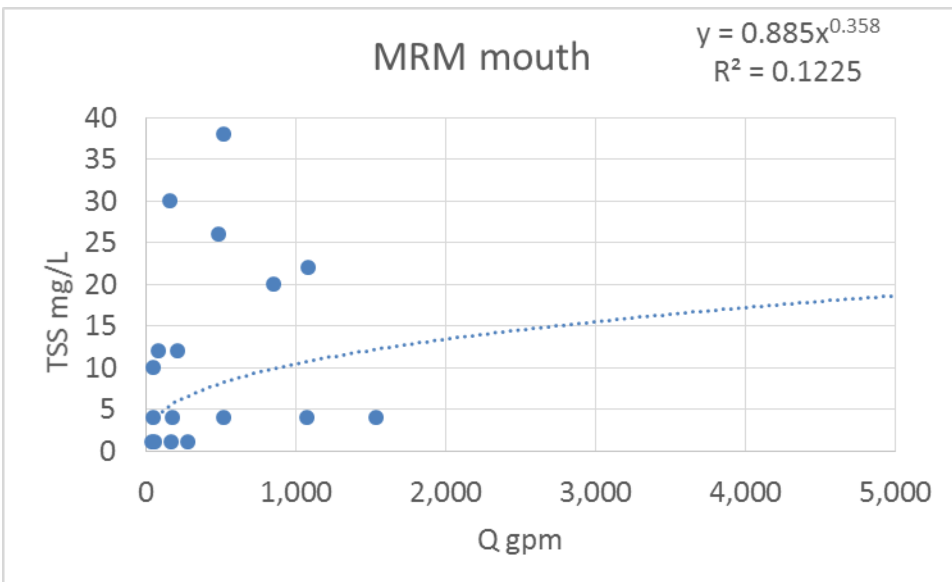

Figure 12. TSS and Q at MRM compliance point.

Left Fork of Little Sandy Mouth (LFLSM)

Figure 13 and Figure 14 depict low and high flow conditions at LFLSM compliance point while doser was operational.

Figure 13. LFLSM site during low flow conditions on 19 October 16. Doser operational.

Figure 14. LFLSM site during high flow conditions on 26 February 16. Doser operational.

Maple Run Mouth (MRM)

Figure 15 and Figure 16 depict low and high flow conditions at MRM compliance point while doser was operational.

Figure 15. MRM site during low flow conditions on 7 Sept 16. Doser operational.

Figure 16. MRM site during high flow conditions on 2 March 16. Doser operational.

Conclusion/Recommendations

In-stream dosing success relies on consistent dosing. Variabilities caused by solar power were resolved with permanent power supply at G1 and LFLS.

Martin Creek

For the Martin Creek study, G1 was sufficient in maintaining compliance at MUF during fall 2016 after M1 was turned off, restoration targets were within range even during high flow conditions on 20 December 2016 sampling event (12,620 gpm at MUF).

Sandy Creek

While MRM restoration target was maintained through the study, LFLS exceeded target levels about 27% of the time. Several untreated AML discharges contributed much of the iron to LFLS downstream of the in-stream doser. Installation of a passive treatment at the largest of these (the Barlow Portal) would improve the probability of success of in-stream dosing on the LFLS.

Cost Evaluation (At-Source vs. In-Stream)

This study compared the costs and benefits of in-stream vs. at-source AMD treatment in two watersheds in northern West Virginia: Martin and Sandy Creeks, both in Preston County. Both streams are severely impaired by AMD and both contain a mix of abandoned mines and bond forfeitures and both discharge to major recreational water bodies: the Cheat River and Tygart Lake. The results are summarized in (Table 2). They indicate that in-stream dosing alone would not achieve adequate stream benefits but, when paired with ongoing or planned restoration projects, would restore 3.4 and 10.8 miles of Muddy Creek and Sandy Creek respectively. Costs for the in-stream options were less than the costs of current at-source treatment projects which restore zero stream miles. Detailed cost evaluation is provided in Table 3 and Table 4.

Projected 20-year costs for the two options indicate that in-stream dosing on Martin Creek would save $5,076,844 or a 55% cost reduction while in-stream dosing on Sandy Creek would save $482,757 or a cost reduction of 8%. The difference in cost savings is largely due to the smaller number of bond forfeiture sites in the Sandy Creek watershed.

Table 2. Summary of costs and benefits associated with the two alternative AMD treatment strategies evaluated during this study.

Martin Creek	At-source treatment	In-stream treatment
O&M cost projection (years)	20	20
Annual O&M	$ 218,084	$ 145,533
Total Capital Cost	$ 4,825,824	$ 1,200,000
Total O&M	$ 4,361,684	$ 2,910,664
Total cost	$ 9,187,508	$ 4,110,664
Projected stream mile recovery*	**0**	**3.4**
Sandy Creek		
O&M cost projection (years)	20	20
Annual O&M	$ 189,568	$ 223,708
Total Capital Cost	$ 2,609,587	$ 1,444,032
Total O&M	$ 3,791,369	$ 4,474,166
Total cost	$ 6,400,955	$ 5,918,198
Projected stream mile recovery**	**0**	**10.8**

* With completion of the T&T AMD project

** With addition of a passive treatment unit at Barlow Portal

Table 3. Evaluation of costs associated with at-source vs. in-stream (watershed scale) AMD treatment.

Martin Creek	**At-Source AMD Treatment**					
Permit Name	Permit No.	construction completed	no. of trt sites	current O&M	estimated O&M*	Capital cost**
Rockville Mining	65-78	4-Apr-06	3	$ 49,755		$ 1,268,508
Rockville Mining	S-65-82	1-Dec-05	3	$ 51,162		$ 1,792,032
T&T Fuels	U-125-83	20-Oct-03	1	$ 17,286		$ 197,205
Lobo Capital	UO-204	NA	1		$ 47,631	$ 448,895
Rockville Mining	S-91-85	NA	1		$ 48,309	$ 909,935
Crane Coal	S-27-83	13-May-05	1	$ 3,941		$ 209,250
			10	$ 122,144	$ 95,940	$ 4,825,824

O&M cost projection (years)	20
Annual O&M	$ 218,084
Total Capital Cost	$ 4,825,824
Total O&M	$ 4,361,684
Total cost	**$ 9,187,508**

Martin Creek	**Watershed scale AMD Treatment**				
Permit Name	Permit No.	construction completed	no. of trt sites	estimated O&M*	Capital cost**
Glade Run	NA		1	$ 93,594	$ 850,000
Martin Creek	NA		1	$ 51,939	$ 350,000
			2	$ 145,533	$ 1,200,000

O&M cost projection (years)	20
Annual O&M	$ 145,533
Total Capital Cost	$ 1,200,000
Total O&M	$ 2,910,664
Total cost	**$ 4,110,664**

* O&M includes	Lime	** Capital	Doser
	Manpower		Installation
	Sludge handling		Sludge handling system
	Sludge disposal		
	Maintenance		

Table 4. Evaluation of costs associated with at-source vs. in-stream (watershed scale) AMD treatment.

At-Source AMD Treatment

Sandy Creek

Permit Name	Permit No.	construction completed	no. of trt sites	current O&M	estimated O&M*	Capital cost**
Maurice Jennings	61-83	NA	1		$ 10,671	$ 339,993
Maurice Jennings	53-78	NA			$ 37,295	$ 812,288
Mangus Coal	S-1036-91	NA	1		$ 54,102	$ 754,750
Amanda Nicole	S-1018-88		1	$ 87,500		$ 702,557
			3	$ 87,500	$ 102,068	$ 2,609,587

O&M cost projection (years)	20
Annual O&M	$ 189,568
Total Capital Cost	$ 2,609,587
Total O&M	$ 3,791,369
Total cost	**$ 6,400,955**

Watershed scale AMD Treatment

Sandy Creek

Permit Name	Permit No.	construction completed	no. of trt sites	estimated O&M*	Capital cost**
Left Fk. Little Sandy	NA		1	$ 145,254	$ 850,000
Maple Run	NA		1	$ 62,555	$ 350,000
Barlow passive				$ 15,900	$ 244,032
			2	$ 223,708	$ 1,444,032

O&M cost projection (years)	20
Annual O&M	$ 223,708
Total Capital Cost	$ 1,444,032
Total O&M	$ 4,474,166
Total cost	**$ 5,918,198**

* O&M includes	Lime	** Capital cost includes	Doser
	Manpower		Installation
	Maintenance		
	Power		

References

West Virginia Department of Environmental Protection (WVDEP). 1987. Abandoned mine lands inventory update form. Problem area WV_3549: Sandy Creek Watershed. Department of the Interior, Office of Surface Mining. Prepared by L Bennett.

WVDEP. 2003a. An ecological assessment of the Tygart Valley River Watershed. Report number: 05020001. Division of Water and Waste Management, Watershed Assessment Section.

WVDEP. 2003b. 303(d) list complete with listing rationale. Department of Water and Waste Management.

WVDEP. 2004. 2004 Integrated water quality monitoring and assessment report. Department of Water and Waste Management.

Ziemkiewicz, P.F. 2006. Watershed-based versus at-source AMD treatment: costs and benefits. West Virginia Mine Drainage Task Force Symposium, Morgantown, WV.

Appendix A, Martin Creek

Other Monitoring Points

Figure 17 to Figure 19 summarize dissolved aluminum, total iron, pH and TSS results for the remaining sampling stations.

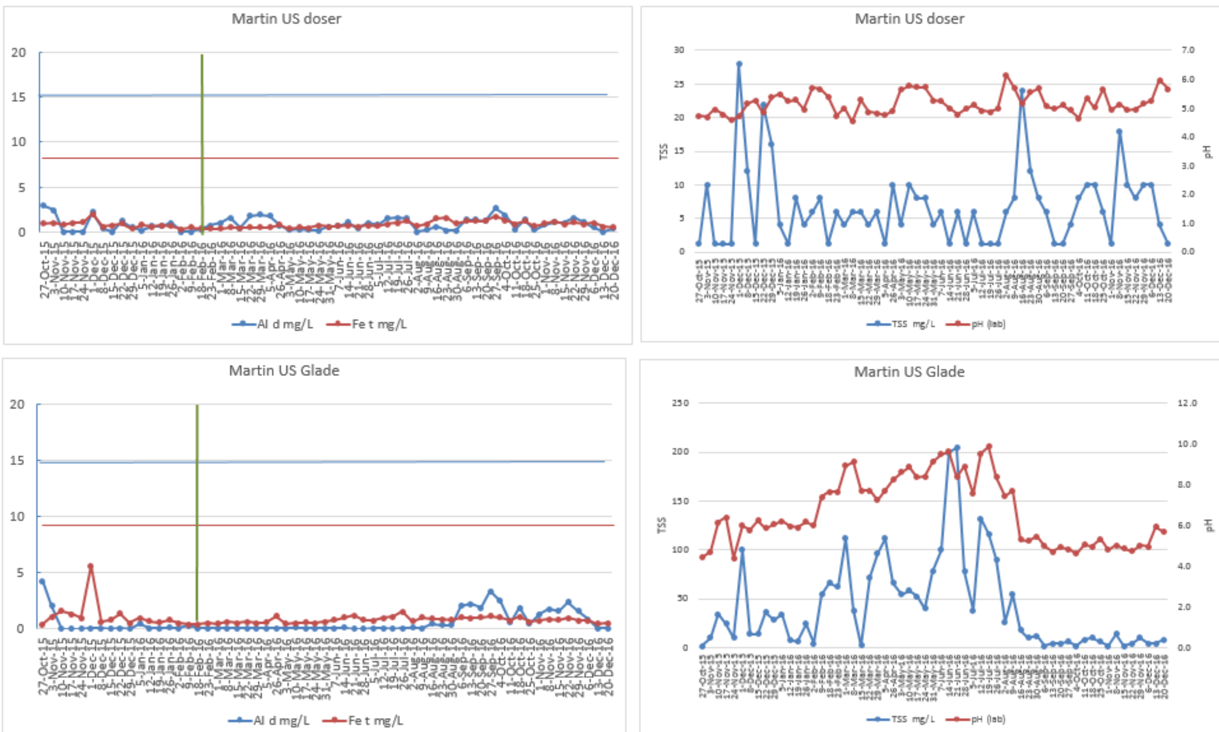

Figure 17. Left, restoration target performance measured at the Martin Creek sampling points. The blue horizontal line represents the dissolved aluminum restoration target and the red horizontal line represents the total iron restoration target. The vertical, green line indicates the date when the Martin Creek at-source dosers were turned off. Right, pH and flow measurements.

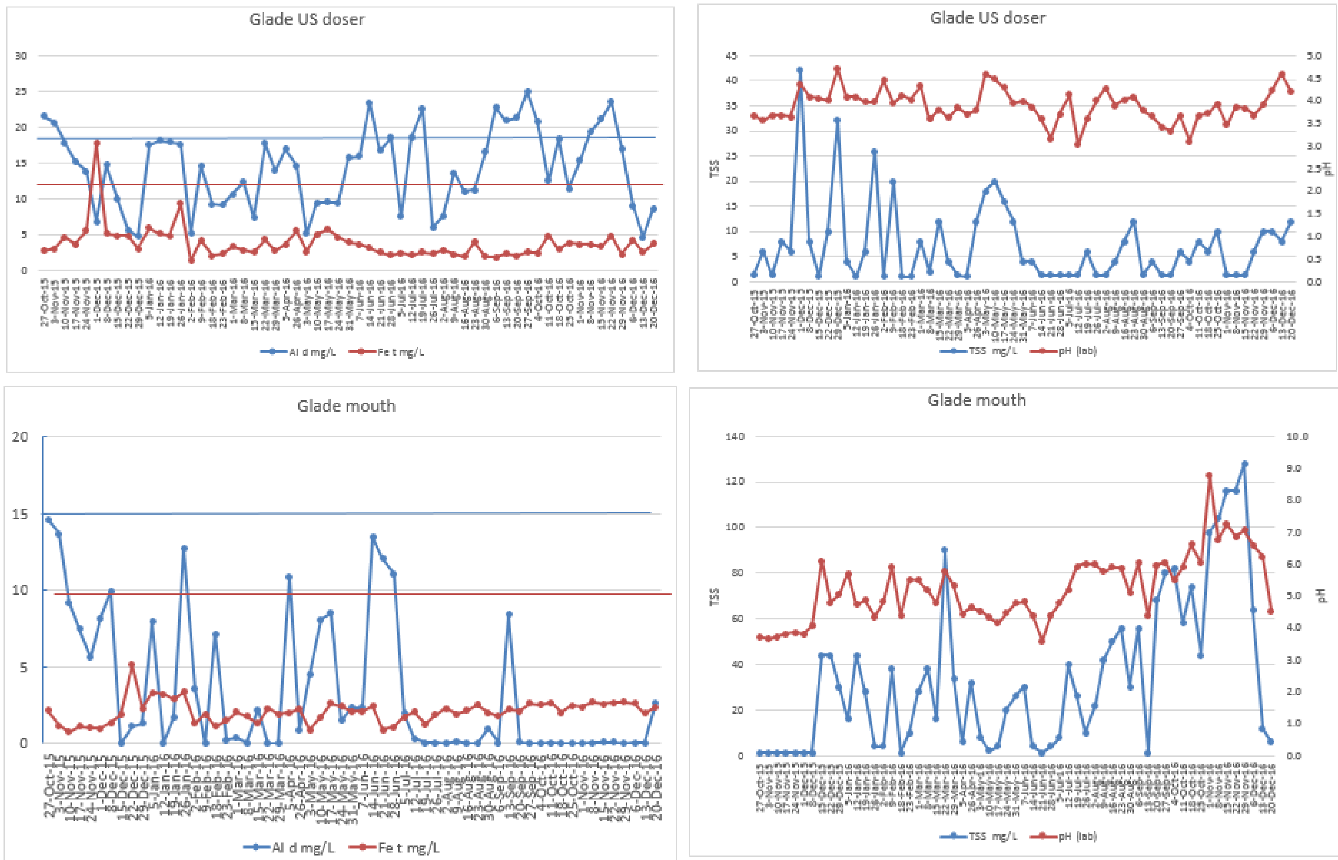

Figure 18. Left, restoration target performance measured at the Glade Run sampling points. The blue horizontal line represents the dissolved aluminum restoration target and the red horizontal line represents the total iron restoration target. Right, pH and flow measurements.

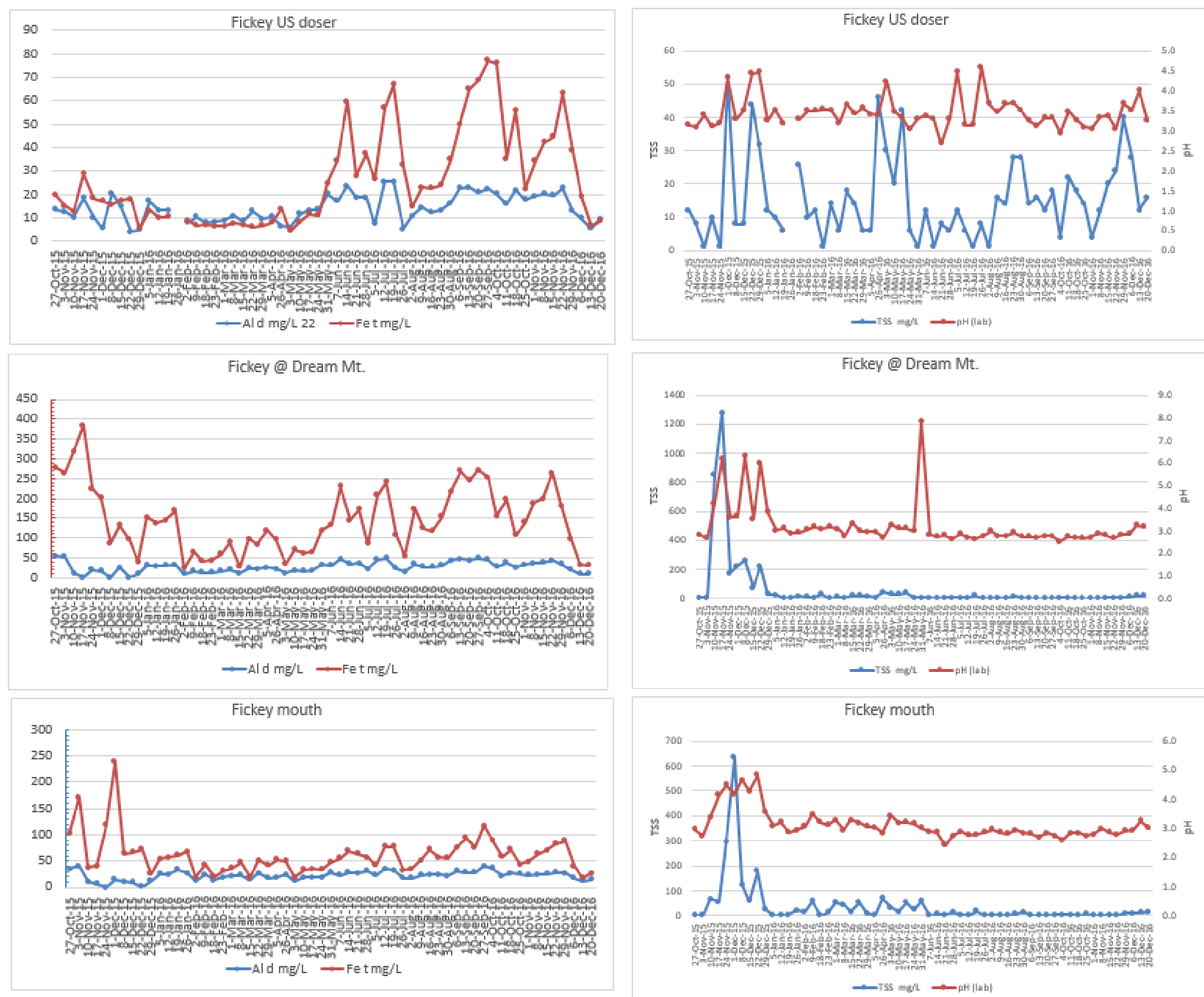

Figure 19. Left, restoration target performance measured at the Fickey Run sampling points. The blue horizontal line represents the dissolved aluminum restoration target and the red horizontal line represents the total iron restoration target. Right, pH and flow measurements.

Appendix B, Sandy Creek

Sandy Creek, other monitoring sites

The following discussion addresses system performance with regard to the three restoration targets: pH (3.3 to 9.0), dissolved aluminum (12 mg/L) and total iron (2 mg/L) as determined at Maple Run mouth (MRM) and pH (2.5 – 9.0), dissolved aluminum (33 mg/L) and total iron (14 mg/L) at the Left Fork Little Sandy Mouth (LFLSM). Concentrations of dissolved Al, total Fe, TSS and pH are shown in to Figure 20 to Figure 24 for all sites monitored.

Compliance Points (LFLS and MRM)

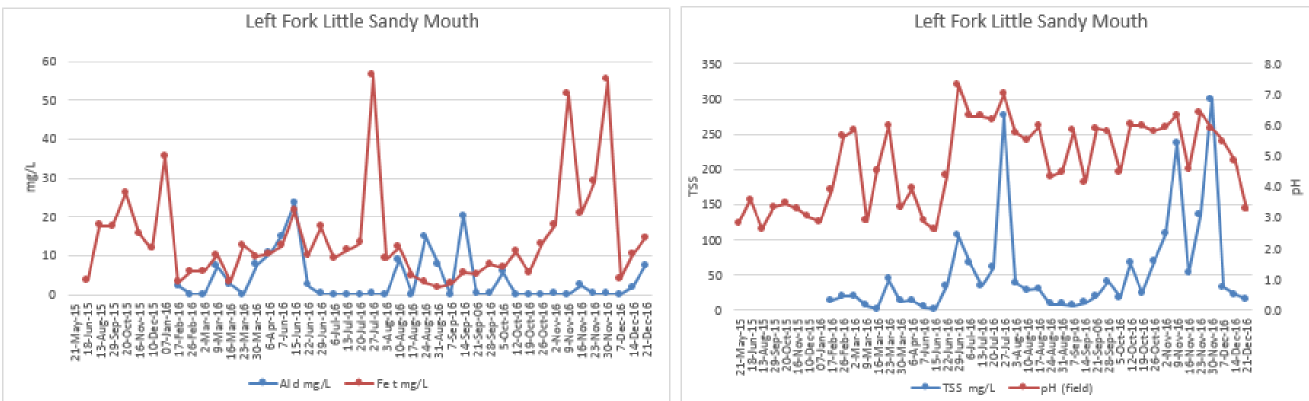

Figure 20. Left: dissolved Al and total Fe at LFLSM; right: total suspended solids (TSS) and pH.

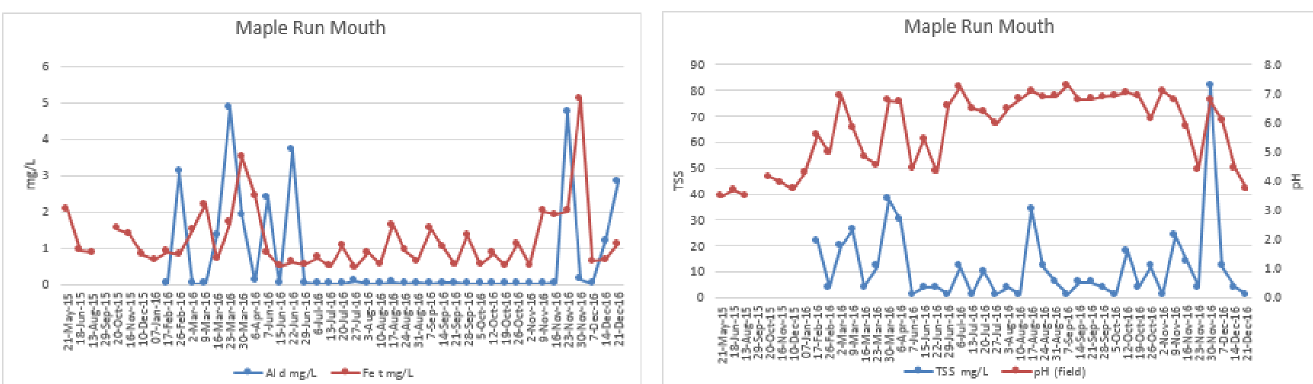

Figure 21. Left: dissolved Al and total Fe at MRM; right: TSS and pH.

Other Monitoring Points

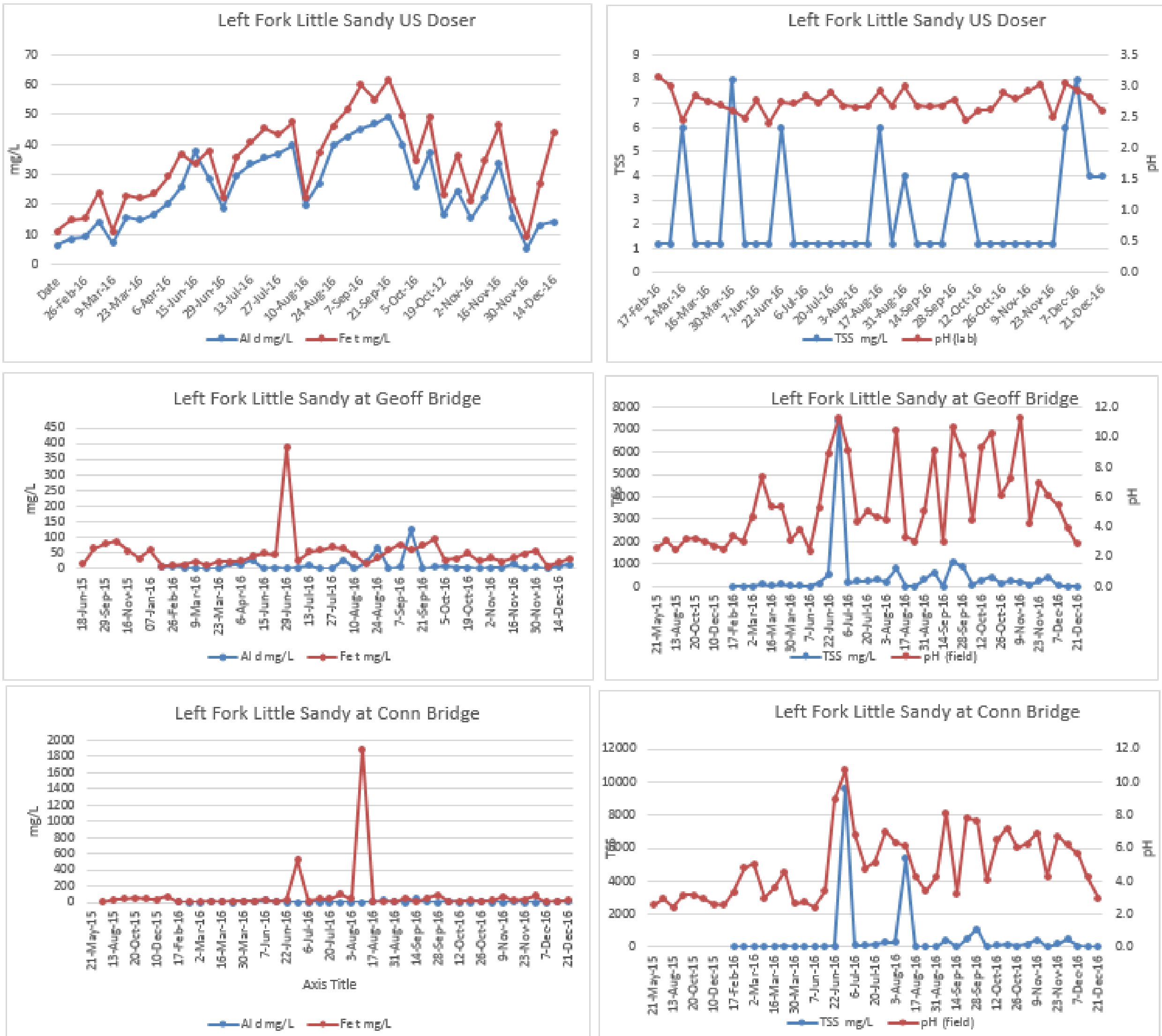

Figure 22. Left, dissolved Al and total Fe at Left Fork Little Sandy sampling points. Right, TSS and pH.

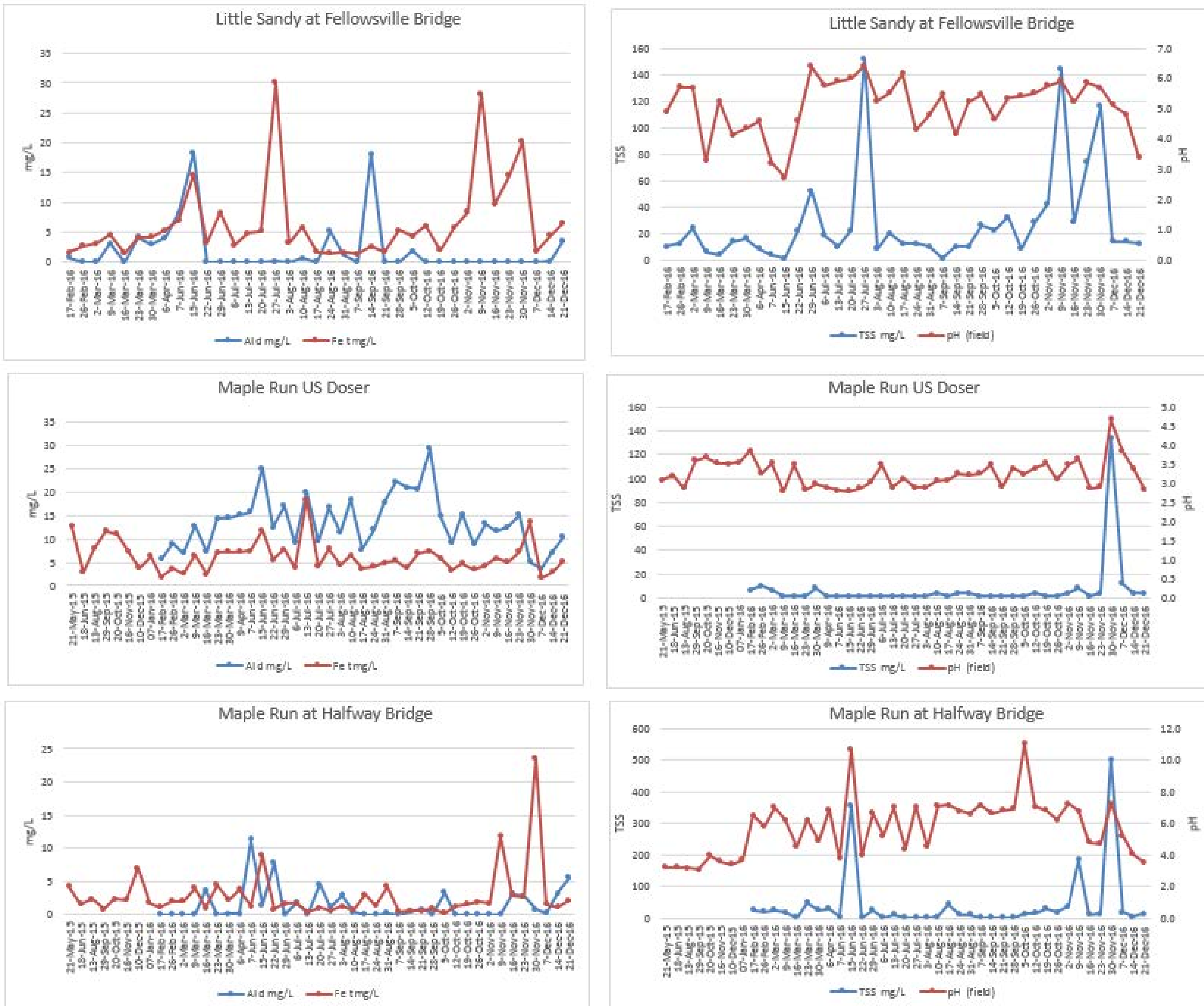

Figure 23. Left, dissolved Al and total Fe at Little Sandy and Maple Run sampling points. Right, TSS and pH..

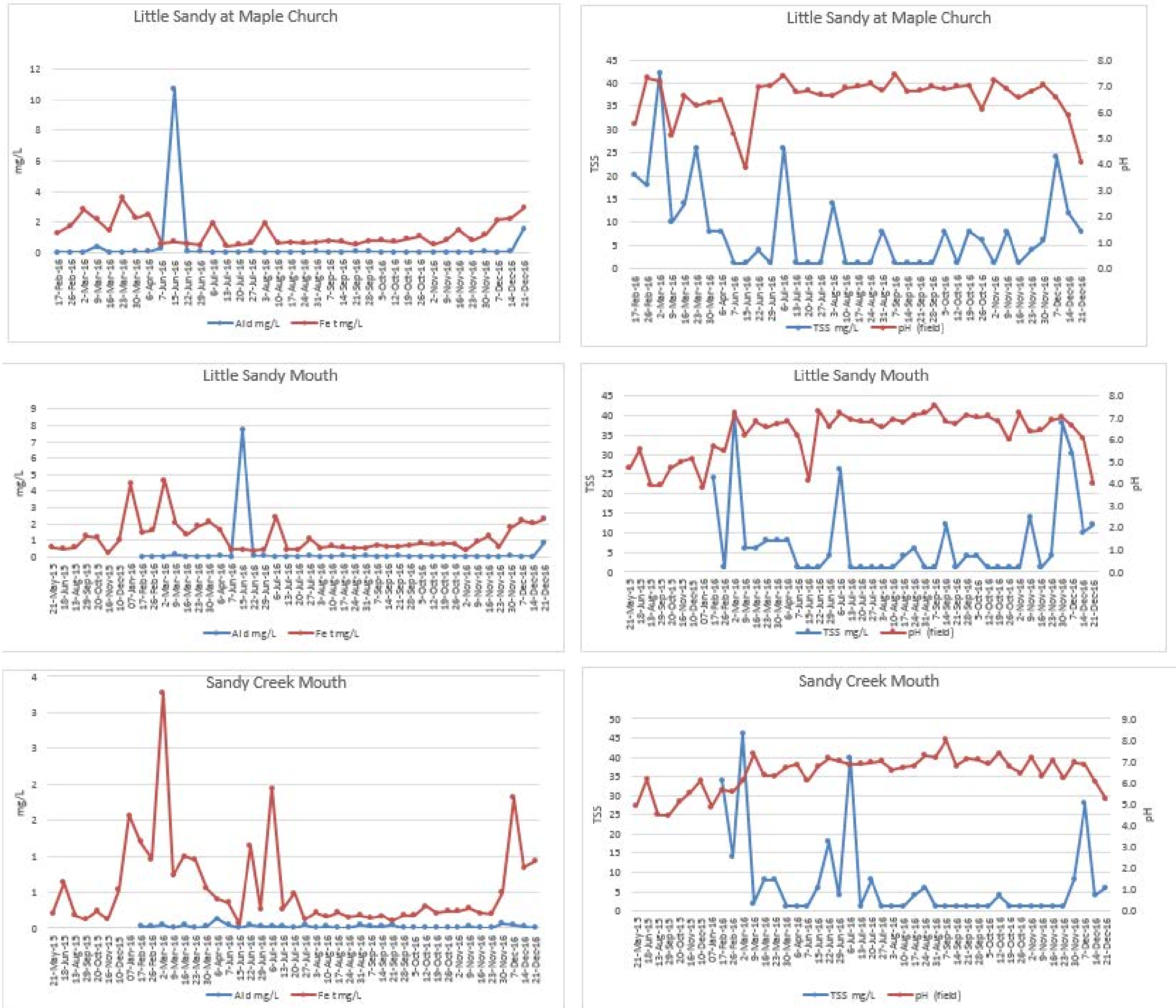

Figure 24. Left, dissolved Al and total Fe at Little Sandy and Sandy Creek mouth sampling points. Right, TSS and pH.