WATERSHED PROJECT

STREAM RESTORATION THROUGH COAL MINE DRAINAGE ABATEMENT

Cherry, Marion, Venango, Washington Townships, Butler County, PA

SLIPPERY ROCK WATERSHED COALITION

1999

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FINAL REPORT: WATERSHED PROJECT

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Cherry, Marion, Venango, Washington Townships, Butler County, PA

submitted to

Pennsylvania Department of Environmental Protection
Bureau of Watershed Conservation

Brief Description of Project Work Conducted through Grant

Designed and installed 900-ton anoxic limestone drain, settling pond, and 1/4-acre wetlands at SR101A site. Prepared SR96 site for future passive treatment system installation. Monitored streams and abandoned mine discharges in 27-sq. mi. Slippery Rock Creek headwaters area. Compiled analyses and presented data during site tours and at annual Slippery Rock Watershed Coalition Symposia and other conferences regionally, nationally, and internationally since 1996.

Contract Amount: **$86,742**

Grant Program: **FY96 US EPA Section 319 NPS**

Administered by: **Slippery Rock University**
Dr. Dean M. DeNicola, Biologist

In-Kind Contributors:
Slippery Rock University
PA DEP, Knox District Mining Office
PA DEP Bureau of Abandoned Mine Reclamation
Grove City College
PA Game Commission
Amerikohl Mining, Inc.
Quality Aggregates Inc.
Volunteers
C D S Associates, Inc.
Stream Restoration Incorporated

December 1999

PUBLIC-PRIVATE PARTNERSHIP

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EXECUTIVE SUMMARY

Participants in the Slippery Rock Watershed Coalition received a grant from the Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation, through U.S. Environmental Protection Agency FY96 Section 319 funding. The project goals as stated in the proposal were (1) to abate mine discharges SR 101A and SR 96, (2) to combine efforts with others to restore a two-mile section of Slippery Rock Creek to a viable fishery, (3) to significantly improve an additional two-mile section of Slippery Rock Creek downstream of the target restoration area, (4) to document, singly and in combination, the contribution and the degree of success of different restoration techniques relating to the watershed recovery, (5) to provide educational/research opportunities for students from local schools.

Due to the expanded effort necessary at the SR 101A site caused by unstable site conditions and a more than doubling of the discharge flow in comparison to that of the background monitoring, only site preparation was possible at the SR 96 site.

Nonetheless, with the unwavering commitment of the participants and their generous donations which included (1)construction of the site access and staging area by the PA Bureau of Abandoned Mine Reclamation and PA Game Commission, (2)installation of monitoring wells by Amerikohl Mining, Inc., and (3)reduction in the limestone aggregate price by Quality Aggregates Inc., the positive impact of this project has greatly exceeded expectations.

The Anoxic Limestone Drain is generating a net gain of about 2500 lbs. per month of alkalinity and the Settling Pond and Wetlands are retaining about 900 lbs. per month of iron. The total iron content in the discharge is being decreased by about 90%, from 84 mg/L to 6 mg/L (medians).

Due to the combined positive effects of this and other restoration efforts (such as the passive systems installed by the Knox District Mining Office), fish have been observed, on occasion, in a four-mile section of Slippery Rock Creek, probably for the first time in about a century. Slippery Rock University, however, has identified that some metals continue to exceed water quality standards for biota at many of the Slippery Rock Creek monitoring stations, especially manganese, iron, aluminum, and zinc. In addition, little improvement in the streambed sediment metal concentrations has been identified. These conditions may help to explain the lack of substantial recovery in macroinvertebrates and algae at this time, even though a notable trend in the improvement of the water quality of Slippery Rock Creek as been shown, based on the continued monitoring by the Knox District Mining Office.

The "hands on" participation in the wetlands planting and watershed monitoring by over 60 students and volunteers has contributed to the strong growth experienced by the Slippery Rock

Watershed Coalition. The difficulties incurred during construction and the generosity of the participants also demonstrates what can be accomplished by a successful public-private partnership effort.

SELECTED HIGHLIGHTS

SR101A Passive Treatment System

- Early attempts to collect the abandoned mine drainage were unsuccessful due to the presence of disturbed, unstable site material. In order to determine the elevation at which to construct the Anoxic Collection System, Anoxic Limestone Drain, and other components, monitoring wells were installed and water levels measured.

- As the probable water table associated with the degraded drainage would be permanently lowered by the Anoxic Limestone Drain causing an increase in the drainage flow rate, the size of all system components were enlarged.

- Due to the three-foot layer of saturated iron precipitates, construction of the Anoxic Limestone Drain was delayed. A temporary ditch was installed and the construction area was allowed to drain.

- Based on the monitoring data to date, the long-term alkalinity in the effluent from the Anoxic Limestone Drain is expected to be between 200 and 220 mg/L.

- With a 70 to 100 mg/L dissolved iron content in the untreated discharge, the alkalinity in the Anoxic Limestone Drain effluent is more than sufficient to maintain a net alkaline effluent from the final wetland through the 25-year design life of the system.

- Over 90% of the iron in the degraded drainage is being removed by this passive treatment system. The current median iron content in the raw water is 84 mg/L and in the final effluent is 6 mg/L, probably in the form of solids.

- With the neutralization of the acidity in the abandoned mine drainage and the production of excess alkalinity, the Anoxic Limestone Drain generates 1 1/4 tons of alkalinity per month.

Public Outreach/Educational Opportunities

- A Pittsburgh newspaper published the need for volunteers to plant the Wetland 2. About 40 volunteers of all ages from at least four counties participated in the very successful planting.

- About 20 Slippery Rock University students in a class on Aquatic Plants, volunteered and planted cattails in Wetland 1.

- The 1999 Slippery Rock Watershed Coalition Symposium attended by about 200 people highlighted the SR101A passive treatment system. Other tours have used the SR101A site to demonstrate the successful implementation of an Anoxic Limestone Drain.

- Over 20 Slippery Rock University students have completed degree requirements while gaining “hands-on” experience participating in a large-scale watershed restoration project and learning valuable sample collection and analysis techniques.

Impact on Slippery Rock Creek
(water monitoring by the PADEP, Knox District Mining Office)

- Based on a preliminary interpretation of water quality monitoring conducted by the PADEP, Knox District Mining Office, the combined impact of the implementation of passive treatment systems has resulted in a significant downward trend in acidity and a significant upward trend in alkalinity in Slippery Rock Creek headwaters.
- The combined impact of the various passive treatment systems has resulted in the observation of fish in a four-mile section of Slippery Rock Creek, probably for the first time in a century.

Stream Ecosystem
(aquatic life, streambed sediment, and water monitoring by Slippery Rock University)

Water Quality

- Acidity was higher at all sites impacted by mine drainage based on a comparison of monitoring data from the seven, acid mine drainage-impacted stream sites with the two control sites.

- Dissolved oxygen was near saturation at all sites most of the year; therefore, no negative impacts to biota would be attributed to low dissolved oxygen content.

- Upstream of site #44, there are no passive systems. The lowest average stream pH on the main branch of Slippery Rock Creek was observed at this monitoring station.

- Below installed passive treatment systems, dissolved iron appears to have decreased in a two-mile section of Slippery Rock Creek. (There was only one background sampling event prior to installation of the systems, the interpretation of the decrease is, therefore, tenuous.)

- The metals with the highest soluble and total aqueous concentrations were iron, manganese, and aluminum.

Streambed Sediments

- The mean concentrations of all elements measured in the clay fraction of the sediment were distinctly higher in Seaton Creek, the most heavily-impacted, major tributary in the Slippery Rock Creek headwaters.

- Sandstone cobbles coated with metal precipitates, lost aluminum, iron, and manganese, and gained zinc, after being placed in the unimpacted, control stream.

- Limestone cobbles coated with metal precipitates, lost aluminum, iron, and zinc, and gained manganese, after being placed in the unimpacted, control stream.

- “Clean” sandstone and limestone rocks gained manganese and lost zinc in the control stream, indicating that abundant iron on the AMD-coated rocks may have affected the adsorption of manganese and zinc.

Aquatic Community

- Mean macroinvertebrate densities in riffles were 1 to 2 orders of magnitude higher at the two control sites than at the most heavily-impacted sites on most dates.

- Macroinvertebrates initially increased after installation of passive systems but later decreased. The cause is uncertain. (At site 60, the downstream monitoring point for SR101A, the construction of a beaver dam flooded the riffle area, potentially masking any improvement in the macroinvertebrate community.)

- Much of the substrate at the impacted sites is dominated by clay, a very poor substrate for macroinvertebrates.

- Lower algal densities at some AMD sites is most likely due to the presence of clays and metal precipitates burying the rocks, rather than a purely chemical effect. (Algal species composition is generally affected by AMD but not algal densities.)

- Serious impact on benthic algal diversity does not begin to appear until below pH 4.5.

- Algae in the closest monitoring point (#60) downstream of SR101A became more similar to that of unimpacted streams after installation of the SR101A passive treatment system, a positive indication that there has been some improvement at site 60.

- Macroinvertebrate taxa at abandoned mine drainage-impacted sites were mostly Diptera and hydropsychid caddisflies.

- Mayflies continue to be almost entirely absent, indicating that the Slippery Rock Creek headwaters are still highly impacted by abandoned mine drainage.

- Burial by sediment, compromised data which could have been collected from leaf pack decomposition.

- Tissue concentrations in hydropsychid caddisflies collected at both an AMD-impacted site and a control site were below detection limits for nickel, lead, copper, cobalt, and chromium.

<u>Summary</u>

- Based only on the average pH and alkalinities, the Slippery Rock Creek headwaters should be able to support a larger and more diverse invertebrate fauna.

- Pools do not support many invertebrates; therefore, future monitoring of pool areas in Slippery Rock Creek is not recommended.

- Some of the chemical data indicated that concentrations of manganese, iron, aluminum, and zinc are near or at the toxic threshold for stream fauna, which may be having the greatest affect on invertebrates.

- The great variability in water quality over time and the overall low invertebrate densities probably result from impacts during periods of high abandoned mine drainage input.

- The disturbance in the watershed by the abandoned mines greatly increases soil erosion, which can have as large or larger detrimental affect on invertebrates as water chemistry.

- It is probably the combination of burial by fine sediments and toxic levels of metals at certain times during the year that are still affecting the flora and fauna of Slippery Rock Creek.

PROJECT TIMELINE

(Partial list; See water monitoring compilation for DMO events.)

1995/06/08	grant application submitted	CDS
1995/08/31	revisions to application, as requested	CDS
1995/11/27	revisions to application, as requested	CDS
1996/05/13	site insp: BAMR(to build access), DMO, HE, CDS	
1996/05/22	initial watershed monitoring under grant	SRU
1996/06/12	raw water flow & field alkalinity	HE
1996/07/01	start date, as per contract	DEP
1996/07/11	QA Plan submitted	HE/SRU/CDS
1996/08/05	SRU MOU	SRU/DEP
1996/08/08	Bill Slusser, PA Game Commission regarding access	CDS
1996/08/12	field topographic survey	CDS
1996/08/14	access and staging area construction	BAMR
1996/08/15	Env. Assessment w/ PNDI Search	HE/CDS
1996/08/15	field topographic survey	CDS
1996/08/15	drainage ditch installed	JE/HE/CDS
1996/08/15	Quarterly Report	HE/SRU
1996/08/16	PA One Call notified	CDS
1996/08/19	field topographic survey	CDS
1996/	SR 4012 state road bond ($10000)	HE
1996/	Washington Twp. waived road bond	CDS
1996/	Stream Encroachment Waiver WL1096604	DEP
1996/08/11	E&S Control Plan for site preparation	CDS
1996/08/31	Env. Assessment Appr. EA10-006NW - pub. PA Bull.	DEP
1996/09/04	conceptual work drawing	CDS
1996/09/05	Venango Twp. road bond ($4000 - CDS CK5418)	CDS/HE
1996/09/10	topographic plan	CDS
1996/09/12	raw water - field measurements	HE
1996/09/20	raw water - field measurements	HE
1996/10/02	raw water - field measurements	HE
1996/11/02	Env. Assessment Appr. EA10-006NW - pub. PA Bull.	DEP
1996/11/06	Quarterly Report	HE
1996/12/19	watershed monitoring	SRU
1997/02/07	location of drainage ditch, etc.	CDS
1997/02/15	Quarterly Report	SRU
1997/05/09	raw water flow measurement	HE
1997/05/28	monitoring wells (3) installed	AMI/CDS
1997/09/17	raw water flow measurement	HE
1997/11/	Quarterly Report	SRU/BMI
1998/05/05	monitoring wells- WL measurements	BMI
1998/06/17	river gravel delivered	SEI
1998/06/17	collection system installation	JE/BMI
1998/06/17	monitoring wells - WL measurements	BMI
1998/06/18	pipe, etc., delivered	BMI/HE
1998/07	E&S Control Plan	BMI
1998/07/15	water monitoring	BMI

1998/07/22	**Venango Twp. road bond ($4000 - CDS CK5418)**	**CDS/HE**
1998/07/22	**site prep incl. silt fence installation**	**JE/BMI**
1998/07/23	**site prep - working bench for ALD**	**JE**
1998/07/24	**ALD excavation pit**	**JE**
1998/07/24	**monitoring wells - WL measurements**	**BMI**
1998/07/27	**ALD install plastic liner**	**JE/BMI**
1998/07/27	**monitoring wells - WL measurements**	**BMI**
1998/07/27	**est. completion: ALD-80% incl. collection system**	**JE/BMI/HE**
1998/07/28	**limestone aggregate delivery - 895.66 tons**	**SEI**
1998/07/29	**ALD install inlet and outlet manifolds**	**JE/BMI**
1998/07/29	**field located ALD**	**BMI**
1998/08/03	**raw water sampling port installation**	**BMI**
1998/08/03	**monitoring wells - WL (1 hr. after hydr. barrier installed)**	**BMI**
1998/08/03	**est. complete: ALD-100%,SP-85%,Wtld1-75%,Wtld2-10%**	**JE/BMI/HE**
1998/08/04	**rip-rap delivered for spillways**	**SEI**
1998/08/05	**monitoring wells - WL measurements**	**BMI**
1998/08/05	**ALD discharge - field measurements**	**HE**
1998/08/07	**monitoring wells - WL measurements**	**JE**
1998/08/10	**Wetland 2 discharging (final effluent)**	**BMI**
1998/08/10	**monitoring wells - WL measurements (after system on-line)**	**BMI**
1998/08/20	**ALD & final discharge - field measurements**	**HE**
1998/08/23	**ALD & final discharge - field measurements**	**HE**
1998/08/28	**ALD & final discharge - field measurements**	**HE**
1998/08/31	**site revegetation**	**BMI/Bliss**
1998/08/21	**Wetland 2 planted**	**Volunteers**
1998/08/21	**monitoring wells - WL measurements**	**BMI**
1998/09/03	**ALD discharge - field measurements**	**HE**
1998/09/23	**watershed monitoring**	**SRU**
1998/09/23	**ALD & final discharge - field measurements**	**HE**
1998/10/01	**ALD & final discharge - field measurements**	**HE**
1998/10/12	**Wetland 1 planted**	**SRU volunteers**
1998/10/14	**US EPA and PA DEP field tour**	**HE/BMI/JE**
1998/11/06	**ALD & final discharge - field measurements**	**HE**
1998/11/09	**field survey for “As-Builts”**	**ETI/BMI**
1998/11/10	**final field survey for “As-Built” plan**	**ETI/BMI**
1998/11/10	**monitoring wells - WL measurements**	**BMI**
1998/11/15	**Quarterly Report**	**HE/SRU**
1998/12/21	**ALD flow measurement**	**HE**
1999/01/18	**As-Built Plan (draft)**	**BMI**
1999/01/19	**ALD & final discharge - field measurements**	**HE**
1999/04/16	**SRWC symposium site tour**	**HE/BMI/JE**
1999/05/05	**monitoring wells - WL measurements**	**BMI/HE/JE**
1999/06/09	**water monitoring**	**BMI**
1999/09/21	**watershed monitoring**	**SRU**
1999/11/12	**Quarterly Report**	**SRU**

Abbreviations:

Hedin Environmental(HE); Jesteadt Excavating(JE); Slippery Rock University(SRU); Bliss Reclamation Co.(Bliss); Shaliston Enterprises, Inc.(SEI); CDS Associates, Inc. (CDS); Knox District Mining Office(DMO); BioMost, Inc.(BMI); Amerikohl Mining, Inc. (AMI); Bureau of Abandoned Mine Reclamation(BAMR); Department of Environmental Protection(DEP)

Slippery Rock Watershed Coalition
Final Report: Watershed Project

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VI **CHEMICAL AND BIOLOGICAL MONITORING OF SLIPPERY ROCK CREEK**

-DeNICOLA, Dean, PhD, Biologist; Slippery Rock University
-STAPLETON, Michael, PhD, Geochemist; Slippery Rock University

VI. **NEWS ARTICLES**

PASSIVE TREATMENT SYSTEM

SR 101A SITE

PA GAMELANDS NO. 95
WASHINGTON TOWNSHIP, BUTLER COUNTY, HIGGINS CORNER, PA

Abstract

A passive treatment system was installed to treat a 35-gpm, net acidic, abandoned mine discharge containing about 84 mg/L of dissolved ferrous iron. At the point of issue, the pH of the drainage was >5. The aluminum and dissolved ferric iron contents were insignificant. The total manganese content was 3 mg/L or less which is at or near standard surface coal mine permit effluent limits. The passive system consists of the following components constructed in series: an anoxic collection system with raw water sampling port, an anoxic limestone drain (containing 900 tons of aggregate), a settling pond (4700 SF at design water level), and two aerobic wetland cells (7100 SF and 5400 SF at design water level for Wetland #1 and #2, respectively). Due to the presence of disturbed, unstable material, initial attempts to install a collection system were unsuccessful. To prepare the site for installation of the collection system, a drainage ditch was installed to encounter the water at about the same elevation as the proposed collection system. The flow of the raw water was about 2.4 times more than the background monitoring indicated, due to a slight lowering of the water table. This increase in flow necessitated a significant increase in materials and size of the components. In order to complete the project within the grant amount approved by the PA Bureau of Watershed Conservation under the US EPA Section 319 program, the following were donated by participants in the Slippery Rock Watershed Coalition: construction of the access and staging area by PA Bureau of Abandoned Mine Reclamation and PA Game Commission; monitoring well installations by Amerikohl Mining, Inc. and C D S Associates, Inc.; price reduction in limestone by Quality Aggregates Inc. Since successfully placed on-line in August 1998, the effluent from the final constructed wetland has been consistently net alkaline (pH $\geq$ 6.3) contributing an excess of about 60 to 100 mg/L of alkalinity with little or no dissolved iron. The Anoxic Limestone Drain is generating a net gain of about 2500 lbs. per month of alkalinity (as calcium carbonate) which includes the neutralization of about 1200 lbs. of acidity and an additional generation of about 1200 lbs. of alkalinity). Over 900 lbs. per month of iron are being retained in the Settling Pond and Constructed Wetlands. Iron solids do, at times, occur in the effluent in excess of 7 mg/L. Upon further establishment of vegetation in the two wetland cells, the solids in the effluent are expected to decrease. The design life of the system is 25 years. Monitoring upstream and downstream by the PA Department of Environmental Protection, Knox District Mining Office, of this and other passive systems, indicates that the water quality of Slippery Rock Creek is improving.

INTRODUCTION

In order to restore the watershed in relation to the degradation caused by abandoned minelands, the Slippery Rock Watershed Coalition has been focusing on the most heavily-impacted area --- the headwaters. The PA Department of Environmental Protection has inventoried the abandoned minelands in the headwaters and have assessed the drainage quality and stream impacts. (Ref.: PA DEP, Knox District Mining Office, 9/1998, Slippery Rock Creek Watershed Comprehensive Mine Reclamation Strategy, Reclamation/ Remediation Plan, 192pp.) Utilizing this work, participants in the Coalition have been implementing passive treatment systems and land reclamation techniques to restore specific sites and discharges. The Anoxic Limestone Drain (ALD) installed to abate the discharge known as SR101A is the fourth ALD to be constructed in the headwaters.

Site Location

The SR101A passive treatment system is located within PA Game Lands No. 95 near the community of Higgins Corner in Washington Township, Butler County, PA. The site lies south of township road T-518 (Higgins Corner Road) and north of the main branch of Slippery Rock Creek in the headwaters area. The site is located on the 7 ½' USGS Hilliards topographic map (PI1977) at 41^{o} 05' 56" latitude and 79^{o} 50' 30" longitude.

Brief Site History - Mining and Reclamation

The source of the discharge appears to be the Mizner Mine which was operated from 1895 to 1903, according to a compilation of mine mapping entitled “Extent of Mining, Butler County, Washington and Venango Townships, Brookville Seam” (author and date unknown). This would have been a drift mine on the Brookville coalbed. Abandoned coal refuse piles and a railroad grade are located below the coal crop. Under the Commonwealth’s Operation Scarlift, mine seals were installed ca.12/1/1976 for a mine opening about 1/4-mile east of the SR101A site in an attempt to abate the drainage from this and/or a related mine. [Ref: Gwin, Dobson & Foreman, Plan of Deep Mine Seals 32 to 36, Lake Erie Mine Area, Slippery Rock Creek Mine Drainage Project (Contract no. SL 110-4-101.1), Rev. 12/1/76 - As Built Seals: PA Department of Environmental Resources, Office of Resources Management] Operation Scarlift designated one of the discharges as SR101. This discharge is approximately the same as SR101A. (See Table 1.)

Pre-Construction Site Description

Just prior to construction, the site was wooded between the public road and the discharge area. The seep zone for SR101A occurred along the upgradient embankment of the abandoned railroad grade. Iron precipitates (about 2 to 3 feet in thickness) filled the cut excavated for the railroad. Between the railroad grade and Slippery Rock Creek, there was about a one-acre “dead area” which was covered with iron precipitates. (A small portion of the “dead area” was not reclaimed in order to visibly depict “before and after” conditions.) During site preparation, the raw mine water was observed to flow from a carbonaceous shale located stratigraphically below the Brookville coalbed. This is consistent with other discharges in the area that emanate below the Brookville coalbed. (See photo log, p. 1, 2, 6.)

Discharge Characteristics

Table 1 depicts the flow and chemical characteristics of the untreated discharge. Under Operation Scarlift, SR101 was monitored monthly for the year 1969. During monitoring prior to placing the mine seals, this discharge was observed to be ephemeral. (The old weir was found during the most recent site preparation.) The Knox DMO collected data for the discharge between December 1994 and August 1996, for the same seep area. Samples were collected and flows were measured at a new weir placed downgradient of the large seepage zone. Because of iron oxidation/hydrolysis that occurred between the seeps and the weirs used by both Operation Scarlift and the DMO, the reported pH and alkalinity values are likely lower than would have been the case if samples had been collected directly at the points of issue. Note, however, that the flows and iron content of the drainage appear to have increased and the acidity decreased after installation of the mine seals under Operation Scarlift. Prior to commencement of construction at the site, sampling at the points of issue was difficult due to a "treacherous quagmire" of iron sludge.

Funding Sources for Current Restoration Effort

Hedin Environmental, BioMost and Jesteadt Excavating constructed the system under contracts with Slippery Rock University. The University's funding is provided by a grant from the PA DEP Bureau of Watershed Conservation Nonpoint Source Program. The PA Game Commissison and PA DEP Bureau of Abandoned Mine Reclamation constructed the access road to the site. Amerikohl Mining, Inc. installed the monitoring wells at no cost. Limestone was provided by Quality Aggregates Inc., at a discount worth more than $2,000. The Knox DMO provided sampling, technical and field assistance valued at $5,000+.

TABLE 1: CHARACTERISTICS OF UNTREATED SR101A DISCHARGE

BEFORE RECLAMATION										
Date	Sampler	Flow (gpm)	pH	Alk (mg/L)	Acidity (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	SO4 (mg/L)	Comments
01/07/69	OSL	17	2.8	0	448	32	NR	NR	528	pre- mine seal
02/10/69	OSL	22	3.0	0	150	20	NR	NR	250	
03/11/69	OSL	1	3.4	0	256	17	NR	NR	365	
04/08/69	OSL	6	2.7	0	290	18	NR	NR	432	
05/06/69	OSL	2	2.8	0	160	18	NR	NR	230	
06/03/69	OSL	2	2.9	0	126	17	NR	NR	192	
07/09/69	OSL	4	2.7	0	360	31	NR	NR	413	
08/05/69	OSL	1	2.5	0	464	58	NR	NR	739	
09/09/69	OSL	0								
10/07/69	OSL	0								
11/04/69	OSL	0								
12/09/69	OSL	0								
12/22/94	DMO	18	5.7	26	194	106	3	<0.5	630	post- mine seal
03/01/95	DMO	9	3.7	0	160	73	2	<0.5	596	
03/23/95	DMO	11	3.8	0	162	83	2	<0.5	533	
04/11/95	DMO	9	3.4	0	160	59	2	<0.5	536	
05/25/95	DMO	26	3.8	0	150	78	2	<0.5	512	
07/27/95	DMO	40	3.5	0	180	75	2	<0.5	500	
09/21/95	DMO	6	3.6	0	154	80	3	<0.5	558	
10/18/95	DMO	6	3.5	0	204	80	2	<0.5	632	
11/02/95	DMO	12	3.2	0	162	51	2	<0.5	419	
12/13/95	DMO	NR	6.0	54	180	106	2	<0.5	750	
01/25/96	DMO	10	3.6	0	146	56	2	<0.5	522	
02/22/96	DMO	12	3.7	0	162	104	2	<0.5	423	
03/19/96	DMO	12	3.6	0	224	83	2	<0.5	563	
04/16/96	DMO	NR	3.7	0	178	70	2	<0.5	494	
05/16/96	DMO	16	5.7	28	178	86	2	<0.5	519	
06/12/96	HE	13	NR	20	NR	NR	NR	NR	NR	
06/26/96	DMO	12	4.9	10	134	97	2	<0.5	591	
07/24/96	DMO	12	5.7	17	162	90	2	<0.5	681	
08/13/96	DMO	11	5.0	9	172	87	2	<0.5	645	
09/12/96	HE	34	5.5	36	192	NR	NR	NR	NR	post- site drain
09/18/96	DMO	60	5.7	38	170	83	2	<0.5	657	
09/20/96	HE	30	NR	54	147	103	2	<0.5	NR	
10/02/96	HE	36	5.8	NR	NR	NR	NR	NR	NR	
10/23/96	DMO	30	5.9	40	158	84	2	<0.5	592	
12/11/96	DMO	28	6.0	44	150	79	2	<0.5	644	
02/19/97	DMO	NR	5.9	44	146	70	2	<0.5	495	
03/19/97	DMO	36	5.9	42	122	67	2	<0.5	618	
04/16/97	DMO	58	6.0	42	128	70	2	<0.5	484	
05/09/97	HE	32	NR	NR	NR	NR	NR	NR	NR	
05/21/97	DMO	26	6.0	40	134	63	2	<0.5	509	monit. wells set
06/25/97	DMO	26	5.9	40	122	68	2	<0.5	494	
07/15/97	DMO	24	5.9	42	126	68	2	<0.5	523	
08/20/97	DMO	32	5.9	38	160	78	23	<0.5	523	
09/17/97	HE	21	NR	NR	NR	NR	NR	NR	NR	
10/08/97	DMO	24	5.8	40	180	81	2	<0.5	569	
12/11/97	DMO	45	5.9	44	144	79	2	<0.5	523	
01/21/98	DMO	24	6.0	42	140	83	2	<0.5	570	
03/25/98	DMO	36	6.0	42	148	85	2	<0.5	518	
04/29/98	DMO	40	5.8	34	142	73	2	<0.5	521	
05/22/98	DMO	40	3.2	0	104	70	2	<0.5	105	
07/15/98	BMI	43	5.6	42	116	81	2	<0.5	NR	

Notes: Operation Scarlift(OSL); PADEP Knox District Mining Office(DMO); Hedin Environmental(HE) BioMost, Inc.(BMI); 0=dry; NR=Not Reported; HE field measurements--all others lab(total concentrations)

SITE PREPARATION

Access Road and Staging Area

On August 14, 1996, the PA Game Commission assisted in the layout of the access road. On the same and following days, the PA Bureau of Abandoned Mine Reclamation cleared the area and constructed the access from the public road to the staging area. The staging area was then leveled and stabilized in order to provide a place for temporary storage of equipment and materials and future parking. (See photo log, p. 3.)

Drainage Ditch

On August 15, 1996, the seepage area was excavated in order to intercept and to combine the seeps that comprise the SR101A drainage. A ditch was dug along the slope above the discharge area. The excavation revealed several feet of disturbed soil/subsoil overlying several feet of gray clay. Directly underlying the clay material was a friable, black shale. The soil and clay were dry, while the black shale transmitted a considerable amount of water. This original ditch caved during excavation which made collection of the seepage difficult. To stabilize the area, a ditch was constructed perpendicular to the slope to drain the construction area. This ditched flow (originally, 100 gpm) was directed into a flexible, plastic pipe with an outlet on the east side of the site. The discharge of the pipe was used for subsequent sampling and flow measurement purposes. (See photo log, p.15.) During the following month, flow from the pipe decreased to 35 gpm, with flows from the original seepage area decreasing to <1 gpm. The Knox DMO and Hedin Environmental used this pipe to measure flows and sample the mine drainage. The discharge was sampled 17 times between September 1996 and December 1997. Because the sampled water was not aerated, the pH, alkalinity, and Fe values measured more accurately reflected the raw water quality. (Note in Table 1 the consistent alkalinity measurements of about 40 mg/L and pH values >5.) The average flow rate of the collected water in 1996 and 1997 was 34 gpm, 2.4 times higher than the average flow of the original SR101A seep (14 gpm). With the Knox DMO's input, a decision was made to design a system for a 35-gpm flow and to avoid, as much as possible, the collection of additional water during construction.

During construction of the treatment system, the water was “re-collected" and sampled again. The analytical results were similar to previous ones (See 7/15/98 in Table 1.).

Monitoring Well Installation

Due to the disturbed, unstable soils, exploration pits to determine the shallow subsurface water elevation (probable water table associated with the mine drainage) were not feasible. (Sloughing from the sides quickly filled the pits.) As an accurate determination of the target water-bearing zone and associated static water table elevations are important for successful placement of the collection system and subsequent passive treatment components, Amerikohl Mining, Inc. and C D S Associates, Inc. donated the time, materials, labor, expertise, and equipment for the installation of three monitoring wells. 6-inch air-rotary holes were drilled and 2-inch, Schedule 40, PVC pipe was used for the riser. The bottom two feet of the riser was hand-slotted to act as a screen. The annulus was backfilled with pea gravel to one foot above the screen. The remainder was backfilled with drill chips. No bentonite was used to isolate a specific water-bearing zone. Water levels were measured and changes noted before, during, and after installation of the passive treatment system. (See drill logs, As-Builts, photos, and brief narrative.)

SR101A PASSIVE TREATMENT SYSTEM AND LAND RESTORATION

The system consists of an anoxic mine water collection system, an Anoxic Limestone Drain, a shallow retention pond, and two constructed wetlands. The final discharge flows into a natural cattail wetland that has developed along the riparian area of Slippery Rock Creek. The components of the treatment system are described below. Details are shown on the attached As-Built plans.

Anoxic Collection System

As previously noted, preliminary exploration with a backhoe revealed that the contaminated water flowed from friable, black, carbonaceous shale located beneath gray clay that was 1-3 feet below the ground surface in the seepage area. An interception ditch was excavated through the clay and into the shale. A collection system consisting of perforated, 4-inch, SDR35 PVC pipe, bedded in PennDOT 2B river gravel, wrapped in geotextile fabric, was placed in the interceptor ditch and buried. (See photo log, p. 7 & 8.) Additional gravel was placed around the drainage system in the eastern end of the ditch where a majority of the water was encountered. During construction, the collection system discharged to a drainage ditch dug perpendicular to the slope on the east side of the site. With completion of the treatment facilities, the collection system was redirected into the ALD. The temporary discharge channel was sealed with native clay material to assure that the preferred flow path for the degraded drainage was into the collection system and into the ALD. (See As-Builts.)

Using a short section of an SDR35 PVC pipe as a protective casing, ½-inch PE tubing with standard hose fittings was placed into the collection system to allow for sampling of raw water prior to entering the ALD. (A drill pump is necessary to extract a sample.) (See As-Builts and photo log, p. 13.)

Anoxic Limestone Drain

The ALD was installed in the area of the old railroad grade. 2 to 3 feet of iron precipitates, railroad ties, and about 1½ feet of slag were excavated from the railroad grade and buried on site. The base of the ALD is constructed in the clay material which was directly beneath the slag. Consisting of 900 tons of PennDOT 3B limestone aggregate, the limestone drain is 120 feet long by 50 feet wide by 3 feet deep. An hydraulic barrier was created downgradient of the ALD by filling and compacting on-site clay material in a trench below the drain. The source of the aggregate used is the marine Vanport limestone (Allegheny Gp; Clarion Fm.) which is quarried in Boyers, PA by Quality Aggregates Inc. about two miles west of the site. (Quality Aggregates Inc. discounted the price of the aggregate in order to assist in the completion of the project.) This unit is high in calcium carbonate (92%). Plastic sheeting was used to line and to wrap the drain in order to discourage leakage of water and generated gas. The drain was then buried under 2+ feet of soil and subsoil. Water enters the ALD through a manifold consisting of 20 feet of perforated 4-inch, SDR 35, PVC pipe bedded in 2B river gravel installed across the width of the limestone drain at its eastern end. After flowing through the aggregate, an "L-shaped" manifold collects the treated water at the southwestern corner of the drain. The effluent pipe is solid 4-inch, Schedule 40, PVC which was plumbed directly onto the manifold. A 22.5^{o} elbow was inserted in the outlet pipe in order to prevent premature exposure to oxygen. (See photo log, p. 9 thru 12, 14 and As-Builts.)

Settling Pond and Wetlands

Water flows from the ALD through a shallow pond and into two, serially-connected, wetlands. The pond (150 feet in length and 30 feet in width) currently has a water depth of approximately 2 feet. The pond has a surface area of 4,700 ft^2 at design water level and a capacity of approximately 60,000 gallons. The pond discharges into a wetland that is 210 feet long by 40 feet wide. Water depths in the first wetland are 1-2 feet. The second wetland is 180 feet long by 30 feet wide and also has 1-2 feet water depths. The wetlands have a total water surface area of 12,500 ft^2 at design water level and a total capacity of ~155,000 gallons.

The substrate in both wetlands consists of ~3 inches of spent mushroom compost mixed with ~3 inches of original soil. The substrate was intended to enhance the establishment and growth of emergent wetland plants. Wetland #2 was planted by 35 volunteers on August 21, 1998. Plants (cattails) were spaced at 2-3 foot intervals. The planting was successful, resulting in a good stand by October 1998. Several(about one "pick-up truck" load) other wetland plant species were acquired elsewhere on the gamelands and transplanted to both wetlands during the August planting. Wetland #1 was planted on October 10,1998 with cattails spaced at 5-10 foot intervals by Slippery Rock University students. It is anticipated that the first cell will develop into a wetland as these plants propagate and others colonize the site. The wetlands were planted primarily with *Typha latifolia* harvested from nearby wetlands impacted with mine drainage.

At the design flow rate of 35 gpm, the theoretical retention for the pond and wetlands (215,000 gallons) is over 100 hours.

A permanent upland diversion ditch was constructed in order to convey surface and shallow subsurface water away from the passive system.

Revegetation

The embankments, regraded area overlying the ALD, and land reclamation area were revegetated on 8/31/98 with the following mixture, which was approved by the PA Game Commission:

	Rate	
Birdsfoot trefoil	10	lbs/ac.
White dutch clover	4	lbs/ac.
Kentucky bluegrass	10	lbs/ac.
Perennial ryegrass	6	lbs/ac.
Fertilizer (10-20-20)	300	lbs/ac.
Aglime	4	tons/ac.
Hay mulch	2½	tons/ac.

Natural Wetlands

The second wetland discharges to a large, natural, cattail wetland, which discharges to Slippery Rock Creek. Several acres of wetland exist between the final system discharge and Slippery Rock Creek. The natural wetland was not disturbed during construction.

OBSERVATIONS AND SYSTEM PERFORMANCE

Water Level Fluctuations in Monitoring Wells

The monitoring wells were installed about 9 months after installation of the temporary ditch used to drain the construction area. The water levels measured in the monitoring wells shortly after installation and about 1 year later were the same or similar. These water levels were used to determine the elevation of the "riser" in the anoxic collection system and the base elevation of the ALD and settling pond.

Prior to construction of the ALD, a portion of the anoxic collection system was installed and the intercepted drainage was piped away from the construction area. In response to this activity, the water level dropped about 4 ½ to 5 feet in the wells with the discharge flows increasing dramatically.

Upon excavation of the pit for the ALD, the water level was lowered an additional foot in Monitoring Well 1; however, the water levels in Monitoring Wells 2 and 3 exhibited a recovery of 2 to 2 ½ feet in comparison with the previous measurement. MW1, 2, and 3 are about 55, 50, and 15 feet, respectively, from the ALD excavation area. An explanation for the greatest fluctuation in the furthest well may be to MW2 and 3 being completed at an elevation about 6 feet below MW1. The moderate recovery noted in MW2 and 3 is probably due to the influence of water associated with the sandstone intercepted by these wells. (During drilling, the disturbed nature of the material encountered in MW2 and 3 made the determination of the target depth difficult. Pilot holes were not drilled.)

About 1 hour after the clay plug was installed at the southern end of the collection system to divert the water into the ALD, the closest wells (MW2 & 3) exhibited additional recovery.

After construction of the hydraulic barrier below the ALD and the inundation of the ALD, an additional moderate recovery was noted in all wells with a concomitant decrease in discharge flow.

About ½-year after installation of the system, the wells recovered to within 2 to 2 ½ feet of the pre-installation water levels. As expected, effluent flows have also decreased. (Please note that seasonal fluctuations were not considered and the unusually dry conditions may be a significant factor both in the discharge flow rate and in the water levels in the wells.)

Based on the above observations, lowering the water table 2 to 2 ½ feet is the probable explanation for the increased flows (Darcy's Law) in comparison to pre-installation monitoring.

(See Table 2, photo log, As-Builts, and drill hole logs.)

TABLE 2: FLUCTUATIONS WITHIN MONITORING WELLS FROM 1997/05/28 TO 1999/05/05

Monitoring Well Data

(wells drilled: 1997/05/27)

		Monitoring Well #1 Stick Up (ft) = 1.7; Total Depth (ft) = 15.0; Surf. Elev. (ft) = 1246.5					Monitoring Well #2 Stick Up (ft) = 0.9; Total Depth (ft) = 21.0; Surf. Elev. (ft) = 1246.8					Monitoring Well #3 Stick Up (ft) = 0.9; Total Depth (ft) = 15.0; Surf. Elev. (ft) = 1240.3				
Activity	Date	Stick Up Elevation (ft)	Total Depth (ft)	Depth to Water (ft)	Static Water Elevation (ft)	Fluct-uation (ft)	Stick Up Elevation (ft)	Total Depth (ft)	Depth to Water (ft)	Static Water Elevation (ft)	Fluct-uation (ft)	Stick Up Elevation (ft)	Total Depth (ft)	Depth to Water (ft)	Static Water Elevation (ft)	Fluct-uation (ft)
~1 hr. after drilling	1997/05/28	1248.2	16.7	10.2	1238.0	~~~	1247.7	21.9	10.0	1237.7	~~~	1241.2	15.0	6.5	1234.7	~~~
	1998/05/05	1248.2		10.2	1238.0	0	1247.7		9.9	1237.8	0.1	1241.2		6.5	1234.7	0
collection system installed	1998/06/17	1248.2		15.0	1233.2	-4.8	1247.7		14.7	1233.0	-4.7	1241.2		11.1	1230.1	-4.6
ALD pit excavated	1998/07/24	1248.2	16.6	15.9	1232.3	-5.7	1247.7	22.3	16.2	1235.2	-2.5	1241.2	15.2	13.5	1232.7	-2.0
	1998/07/27	1248.2	16.6	16.5	1231.7	-6.3	1247.7	22.3	16.8	1230.9	-6.8	1241.2	15.2	12.8	1228.4	-6.3
1 hr. after clay plug	1998/08/03	1248.2	16.6	16.5	1231.7	-6.3	1247.7	22.3	16.0	1231.7	-6.0	1241.2	15.2	11.7	1229.5	-5.2
ALD discharging	1998/08/05											1241.2		7.0	1234.2	-0.5
	1998/08/07											1241.2		6.2	1235.0	0.3
system on-line	1998/08/10	1248.2	16.6	13.5	1234.7	-3.3	1247.7	22.3	13.2	1234.5	-3.2	1241.2	15.2	8.9	1232.3	-2.4
	1998/08/21	1248.2	16.5	13.5	1234.7	-3.3	1247.7	22.3	13.3	1234.4	-3.3	1241.2	15.2	8.9	1232.3	-2.4
	1998/11/10	1248.2	16.5	13.6	1234.6	-3.4	1247.7	22.3	13.4	1234.3	-3.4	1241.2	15.1	9.0	1232.2	-2.5
	1999/05/05	1248.2	16.5	12.6	1235.6	-2.4	1247.7	22.3	12.5	1235.2	-2.5	1241.2	15.1	8.5	1232.7	-2.0

Passive Treatment System Performance

The performance of the system was monitored between August 1998 and January 1999 by Hedin Environmental (HE) and the Knox DMO (Table 3). HE's efforts included field measurements of flow rate, pH, alkalinity, and Fe concentrations at the final discharge. The DMO measured flows and collected samples of the effluent from the ALD and final wetland for analysis by the PA DEP laboratory. The observation period was characterized by very dry conditions in western PA. Many shallow groundwater discharges and headwater streams in the region became dry during the autumn of 1998. Over the observation period, the SR101A discharge flow rate decreased, but only from 35 gpm to 25 gpm. During the height of the drought (December 1998), the SR101A discharge was an important source of water to the headwaters of Slippery Rock Creek. Its treatment was likely especially important to stream biota during this period.

Samples of the untreated mine water, collected before the system was constructed, averaged 5.9 pH, 42 mg/L alkalinity, 149 mg/L acidity, 76 mg/L Fe, 2 mg/L Mn, and <1 mg/L Al (Table 1). The passive system was designed to generate alkalinity through the dissolution of limestone in the ALD, and decrease Fe concentrations through the precipitation of iron oxide solids in the pond and wetlands. During the time of observation, the ALD discharged an average of 219 mg/L alkalinity (Table 3). This average is affected by higher alkalinity values that result during the first month of an operation, and the lower alkalinity values that result when the parameter is measured in the laboratory (as opposed to the field). The long-term average for the ALD is predicted to be 200-220 mg/L of alkalinity. This concentration is more than sufficient to assure a net alkaline discharge. A discharge containing 200 mg/L alkalinity can buffer the acidity contained in 110 mg/L Fe. The highest recorded concentration of Fe at the site was 106 mg/L (12/13/1995), while the highest Fe concentration measured in the ALD discharge to date is 92 mg/L (12/9/1998).

The pond and wetlands have decreased iron concentrations from an average 84 mg/L to 9 mg/L. At the mean measured flow rate of 31gpm, the system is calculated to be removing iron at an average rate of about 8 g Fe per m^2 per day. This compares to rates of 6-20 g per m^2 per day for other passive treatment systems that receive mine drainage with chemistry. We anticipate that the system's performance will improve as the wetlands mature. The system's Fe removal performance may, however, always be low (relative to other passive systems) because the settling pond is shallower than ponds at other sites. (The depth of the SR101A pond was limited by a concern to stay above the water-bearing shale.)

Slippery Rock Creek likely receives a discharge from the SR101A system that has lower Fe concentrations than are indicated by the final discharge data in Table 1. The natural wetland that lies between the system effluent and Slippery Rock Creek acts as a huge sink for residual iron that is not captured by the SR101A system.

TABLE 3: CHEMICAL COMPOSITION OF EFFLUENT--- ANOXIC LIMESTONE DRAIN & FINAL WETL

AFTER RECLAMATION											
ALD Effluent							Final Effluent				
Date	Sampler	Flow (gpm)	pH	Alk (mg/L)	Fe (mg/L)	SO4 (mg/L)	pH	Alk (mg/L)	Fe (mg/L)	SO4 (mg/L)	Comments
08/05/98	HE	17	7.0	255							ALD completed 08/03/98
08/20/98	HE	36	6.9	230				103			Wtld2 discharges 08/10/98
08/23/98	HE		6.9	240			6.7	114	8		Wtld2 planted 08/21/98
08/28/98	HE	35	6.8	241			6.9	108	7		
09/03/98	HE	34		234							
09/11/98	DMO	44	6.4	184	83	634	6.7	104	7	660	
09/23/98	HE	32	6.7	228			6.8	112			
10/01/98	HE	33	6.6				7.0				
10/14/98	DMO	29	6.6	184	77	660	6.8	104	5	547	Wtld1 planted 10/12/98
11/06/98	HE	27		211				81			
11/13/98	DMO	26	6.4	190	82	633	6.5	80	11	629	
12/09/98	DMO	25	6.5	212	92	680	6.5	92	18	663	
12/21/98	HE	27									
01/19/99	HE	25		219				100			
01/26/99	DMO	28	6.6	164	88	776	6.5	78	27	688	
02/16/99	HE	35		214				91			
02/24/99	DMO	30	6.5	198	92	660	6.5	90	28	702	
03/31/99	DMO	30	6.7	208	89	590	6.8	60	6	489	
04/16/99	HE	40	6.2	199			6.4	54			
04/27/99	DMO	30	6.5	154	104	656	6.6	56	7	631	
04/28/99	HE	40		202				54			
05/05/99	HE	43	6.7	202			6.5	60			
05/25/99	DMO	40	6.5	186	81	557	6.5	66	6	497	
06/16/99	DMO	30	6.5	174	84	586	6.6	60	2	570	
07/21/99	HE	31		203				58			
07/23/99	DMO	32	6.5	146	77	646	6.4	66	0	634	
08/11/99	DMO	32	6.5	176	82	579	6.6	64	1	596	1 yr. after PTS installed
09/03/99	HE	28		206				59			
09/14/99	DMO	24	6.4	176	80	594	6.4	76	1	605	
09/23/99	HE	26	6.7	202	48		6.7	54	6		
10/19/99	HE	27		205							
10/27/99	DMO	24	6.6	206	96	771	6.5	56	6	776	
11/23/99	DMO	24	6.5	204	91	817	6.3	58	9	818	
AVERAGE		31		202	84	656		77	9	634	

Notes: PADEP Knox District Mining Office(DMO); Hedin Environmental(HE); HE field analyses - DMO lab analyses total concentrations reported for lab analyses

A bar chart depicts the change through time of the recorded flows, acidity, alkalinity, and total iron concentrations relative to various activities at the site. (See Figure 1.) Note that the reported water quality can vary substantially depending on various factors, including the presence of solids caused by disturbing the substrate, the length of time and type of preservation between sampling and analysis, the aeration of the drainage prior to sample collection, the laboratory techniques used, etc. Nonetheless, the comparison of the data does provide an indication that the acidity decreased and the alkalinity, flows, and iron concentration increased after installation of the deep mine seals. In addition, a more confident comparative relationship is the depiction of the increased flows during the recent restoration effort and the improvement of the final discharge which has no or insignificant acidity, excess alkalinity, and a low total iron concentration. An area chart with 3D visual effect (Figure 2) provides a dramatic comparison of alkalinity and acidity associated with the restoration activities at the site. Other graphs with polynomial trend lines shown are attached at the end of this section. (See Figures 3 thru 8.) Note the direct relationship between iron and sulfate concentrations. This is an indication that the source of the iron is pyrite.

Comparison of Flow, Acidity , Alkalinity, and Total Iron Concentration
(Mean Values)

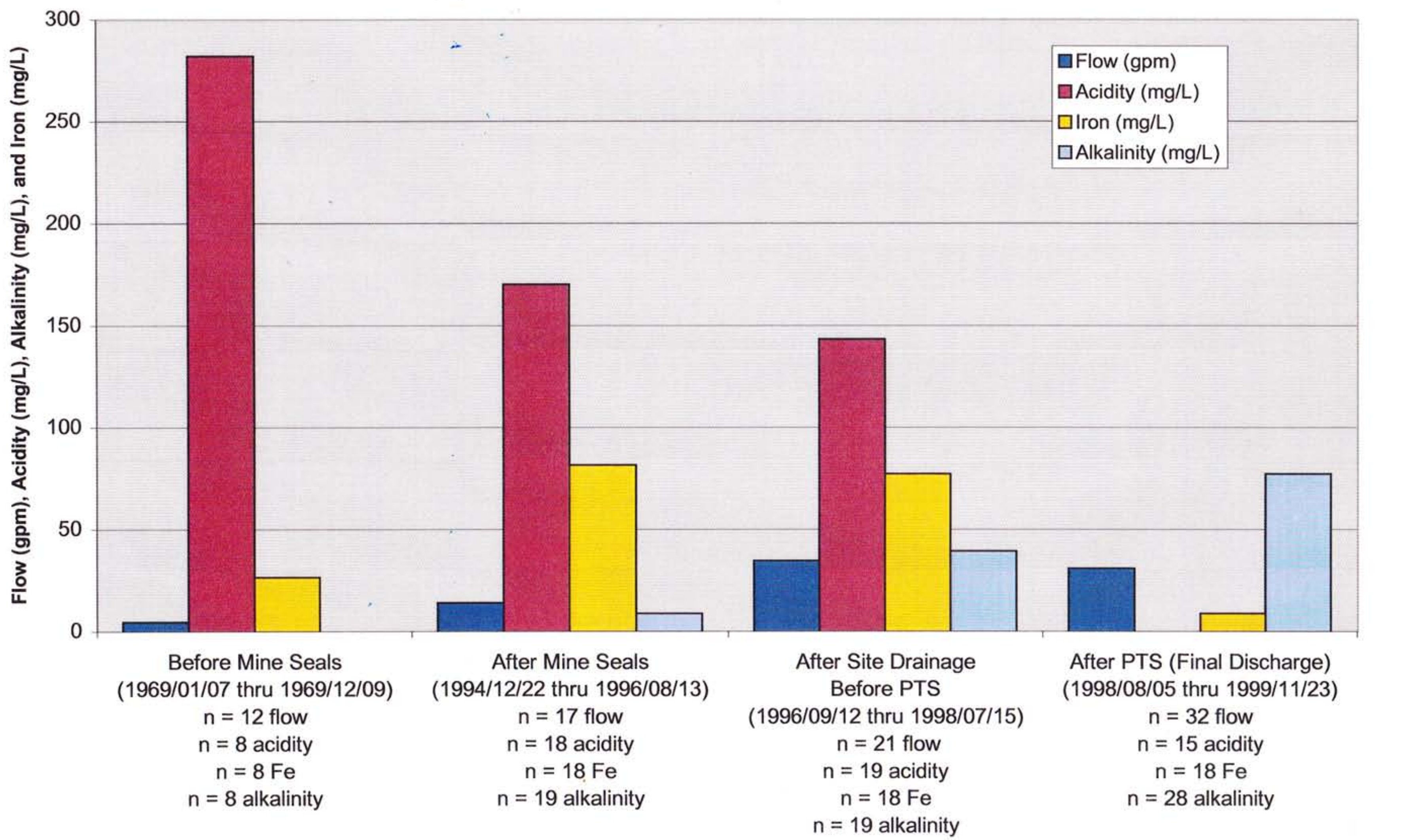


Figure 1

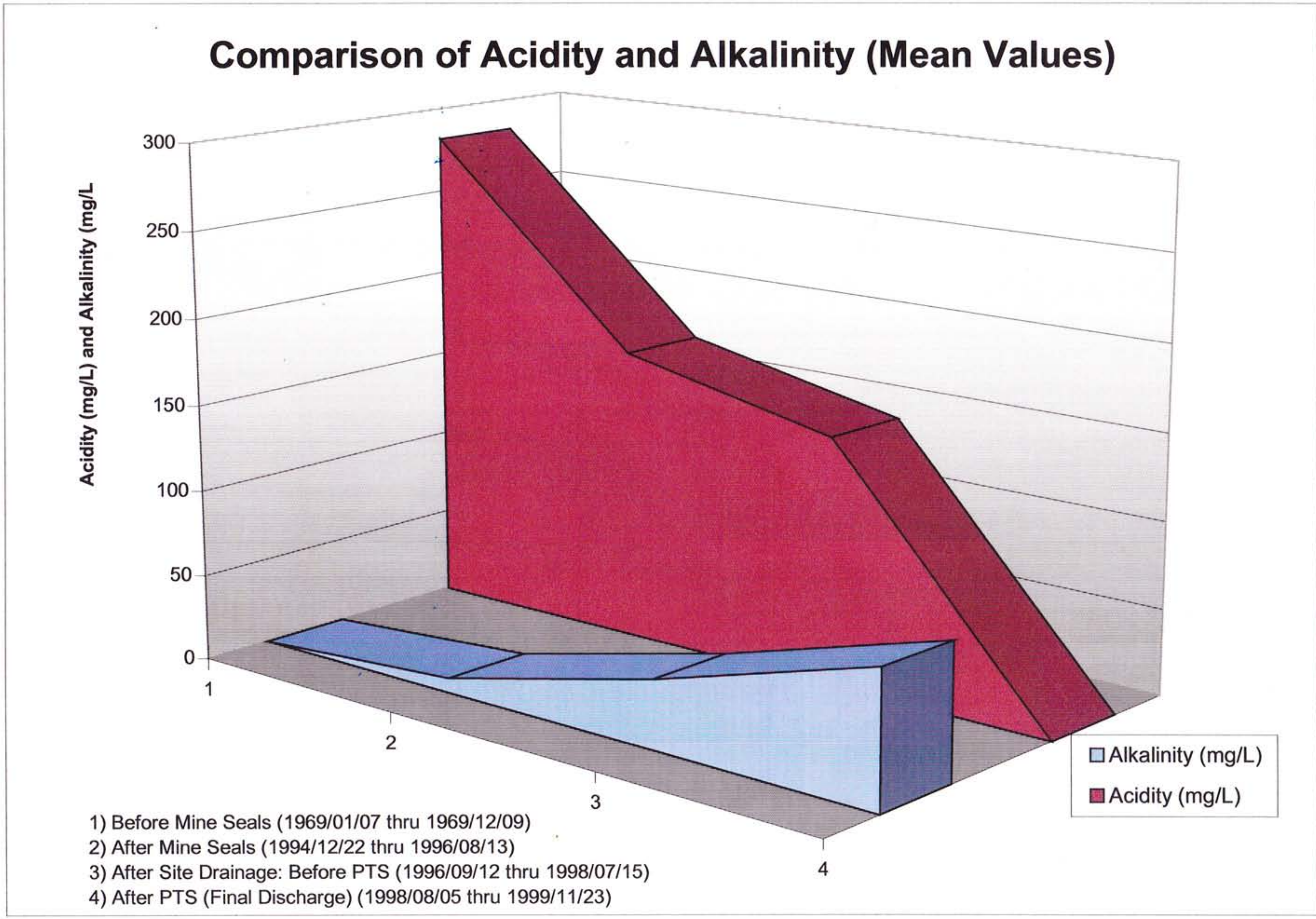

Comparison of Acidity and Alkalinity (Mean Values)
Acidity (mg/L) and Alkalinity (mg/L
300
250
200
150
100
50
0
1
2
3
4
Alkalinity (mg/L)
Acidity (mg/L)
1) Before Mine Seals (1969/01/07 thru 1969/12/09)
2) After Mine Seals (1994/12/22 thru 1996/08/13)
3) After Site Drainage: Before PTS (1996/09/12 thru 1998/07/15)
4) After PTS (Final Discharge) (1998/08/05 thru 1999/11/23)

Figure 2

Long-term Operation and Maintenance

The SR101A passive system should not require substantial O&M for ten years. Post-construction inspections of the site indicated that the disturbed areas are well vegetated and surface water diversions are operating as intended. Berms that surround the settling pond and wetlands are all at least 1.5 feet above current water levels. There is no reason to suspect that the pond or wetlands will overtop their berms in the next decade. Substantial blockage of the ALD discharge pipe or the spillways of the ponds and wetlands could compromise the hydrolgic integrity of the system. In the short-term, this would only occur because of beaver activity or vandalism. The site should be periodically inspected to assess these potential problems.

In the long-term (beyond 10 years), losses of limestone in the ALD and accumulation of iron sludge in the pond and wetlands will effect the performance of the system. Assuming that water continues to flow to the ALD, its performance should not decline for more than 25 years. If the ALD adds 170 mg/L alkalinity (40 mg/L influent and 210 mg/L effluent) to an average flow of 35 gpm, then it will dissolve 14 tons of limestone per year (90% $CaCO_3$). After 25 years the ALD should contain ~550 tons of limestone. This quantity of limestone is sufficient to provide a 46-gpm flow with 12 hours of retention time. (Research indicates that attainment of the maximum alkalinity from an ALD requires 10-15 hours of retention.) Assuming that the ALD does not subside in a manner that compromises retention of water within the limestone bed, the system should continue to discharge water with 200 - 220 mg/L alkalinity for approximately 30 years. After 30 years, the quantity of alkalinity generated will gradually decrease.

Before the ALD fails, the iron-removal capability of the system will be compromised by the accumulation of iron sludge and a concurrent decrease in retention time. Studies of passively precipitated iron sludge indicate a settled density of ~0.15 g Fe/cc. If the system removes 65 mg/L Fe from a 35-gpm average flow, then it will accumulate approximately 8,000 gallons of sludge per year. At current water depths, the system has a capacity of 155,000 gallons. Iron sludge accumulations will reduce ~6% of the storage capacity each year. Raising the height of the spillways can increase sludge storage capacity. The wetlands contain 2 - 3 feet of freeboard, so there is substantial capacity for additional sludge storage. However, sludge will accumulate more quickly in the settling pond, where less freeboard and the ALD discharge pipe elevation limit depth manipulations. It is likely that iron oxide accumulation in the pond will begin to degrade performance within 5-10 years. It will then be beneficial to remove the sludge, probably with a sludge pump. If iron oxide recovery proposals currently under consideration prove cost-effective, the sludge will likely be collected and removed. Alternatively, the nonhazardous sludge could be buried nearby. Evaluation of the O&M requirements for the system would be enhanced by periodic measurement of Fe concentrations at the effluents of the pond and two wetlands, as well as measurement of water and sludge depths in the cells.

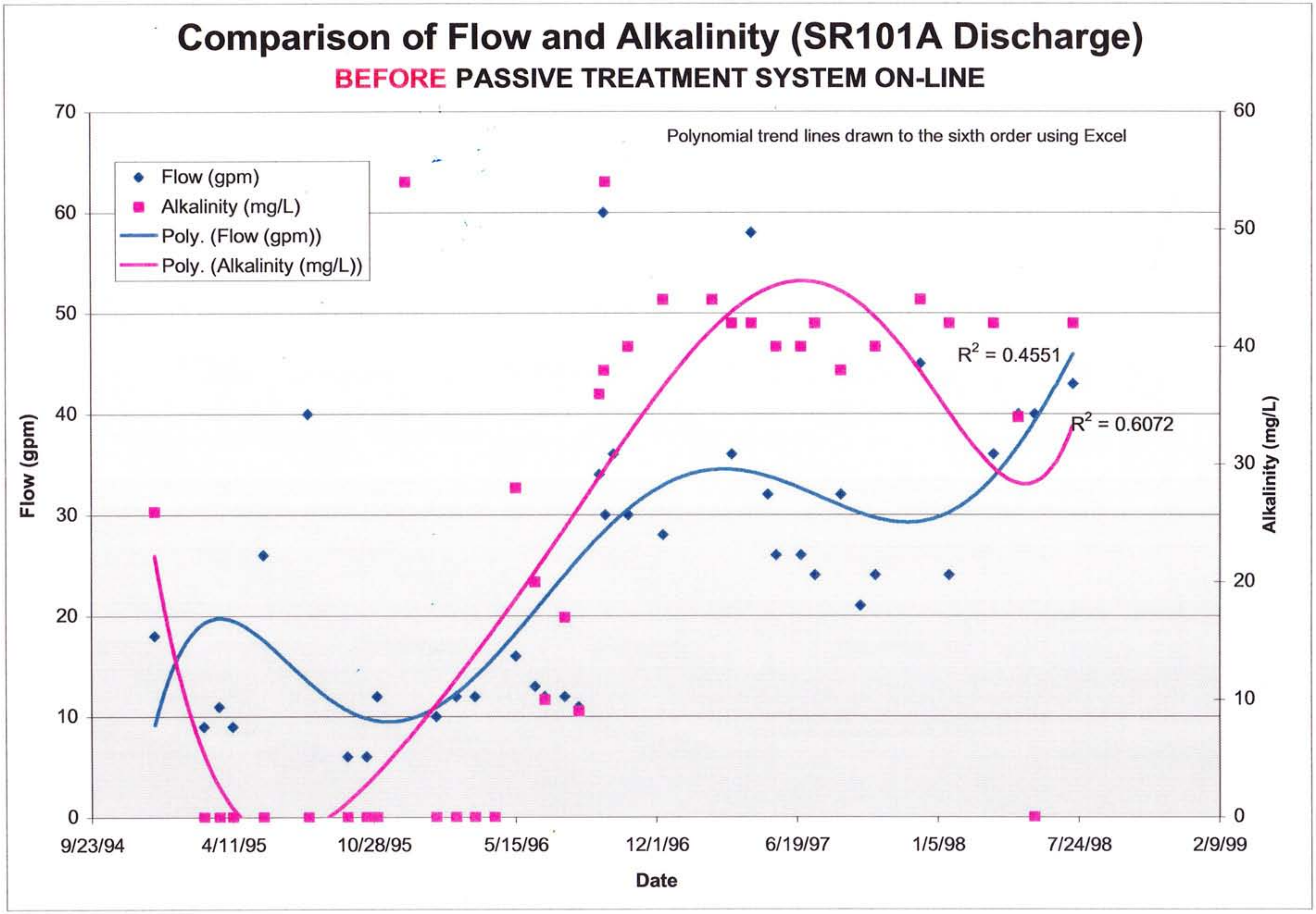

Comparison of Flow and Alkalinity (SR101A Discharge)
BEFORE PASSIVE TREATMENT SYSTEM ON-LINE
Polynomial trend lines drawn to the sixth order using Excel
Flow (gpm)
Alkalinity (mg/L)
Poly. (Flow (gpm))
Poly. (Alkalinity (mg/L))
R² = 0.4551
R² = 0.6072
70
60
50
40
30
20
10
0
Flow (gpm)
60
50
40
30
20
10
0
Alkalinity (mg/L)
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
1/5/98
7/24/98
2/9/99
Date

Figure 3

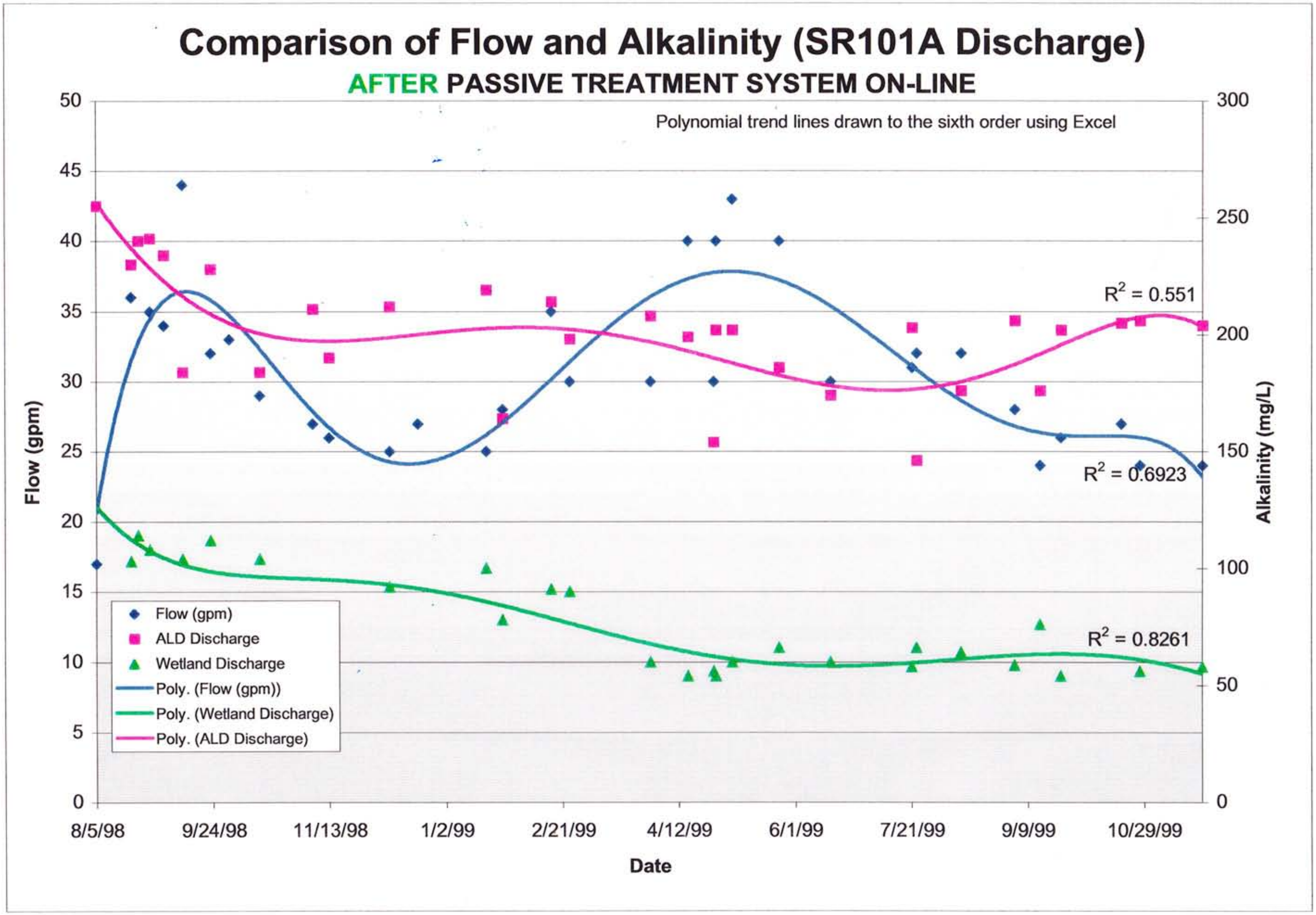

Comparison of Flow and Alkalinity (SR101A Discharge)
AFTER PASSIVE TREATMENT SYSTEM ON-LINE
Polynomial trend lines drawn to the sixth order using Excel
Flow (gpm)
Alkalinity (mg/L)
Date
50
45
40
35
30
25
20
15
10
5
0
300
250
200
150
100
50
0
8/5/98
9/24/98
11/13/98
1/2/99
2/21/99
4/12/99
6/1/99
7/21/99
9/9/99
10/29/99
R^2 = 0.551
R^2 = 0.6923
R^2 = 0.8261
Flow (gpm)
ALD Discharge
Wetland Discharge
Poly. (Flow (gpm))
Poly. (Wetland Discharge)
Poly. (ALD Discharge)

Figure 4

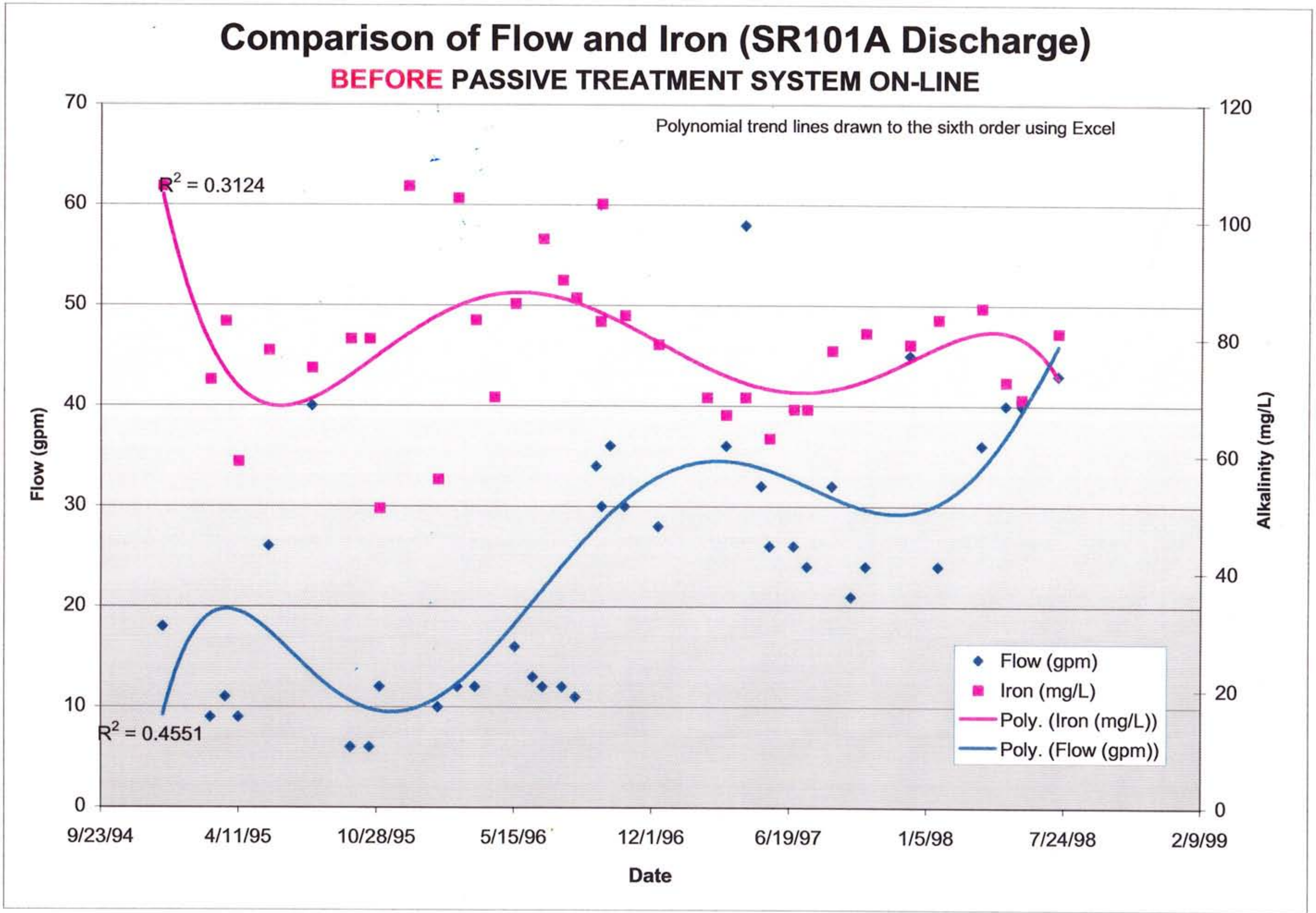

Comparison of Flow and Iron (SR101A Discharge)
BEFORE PASSIVE TREATMENT SYSTEM ON-LINE
Polynomial trend lines drawn to the sixth order using Excel
R^2 = 0.3124
R^2 = 0.4551
Flow (gpm)
Alkalinity (mg/L)
Date
70
60
50
40
30
20
10
0
120
100
80
60
40
20
0
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
1/5/98
7/24/98
2/9/99
Flow (gpm)
Iron (mg/L)
Poly. (Iron (mg/L))
Poly. (Flow (gpm))

Figure 5

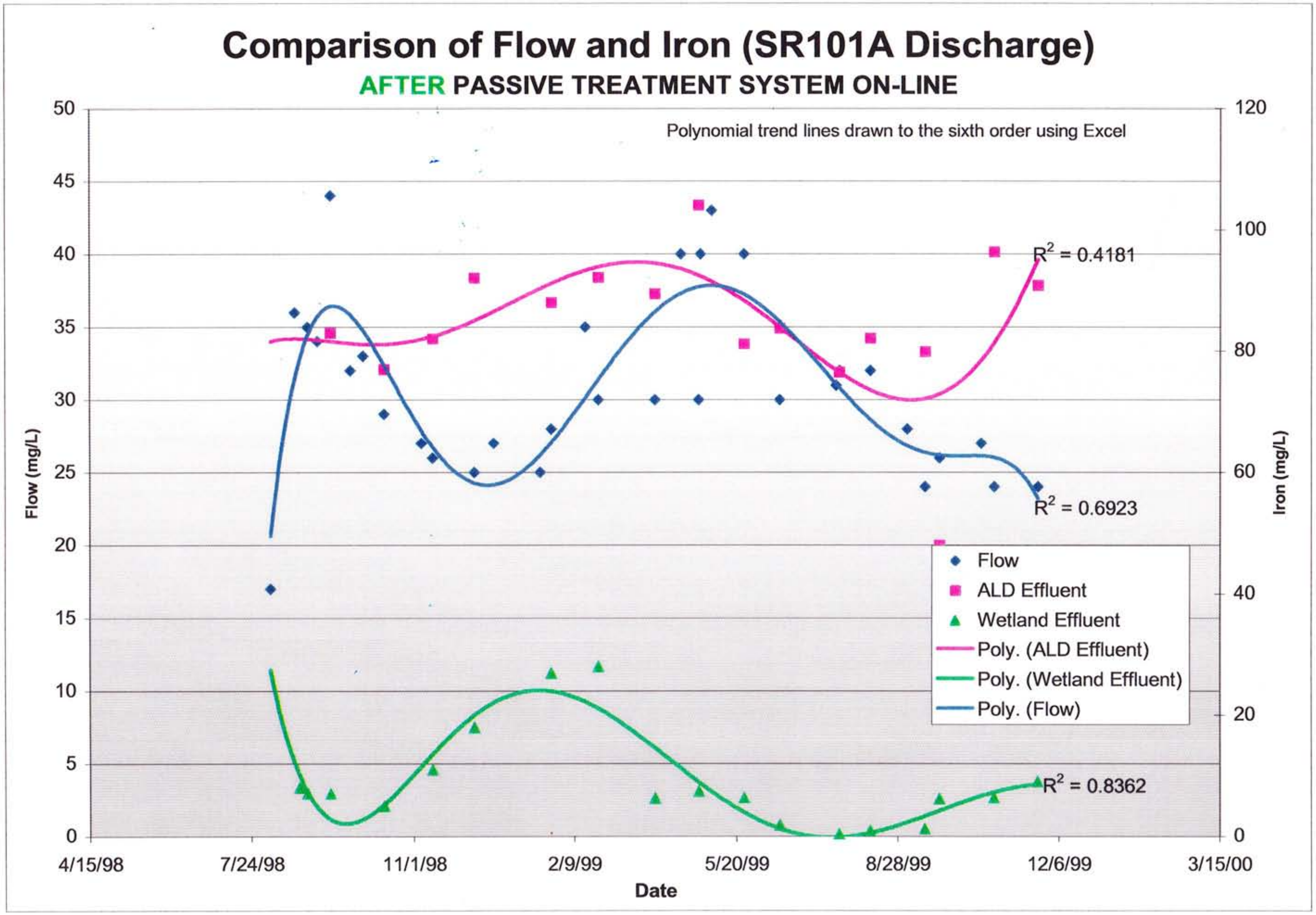

Comparison of Flow and Iron (SR101A Discharge)
AFTER PASSIVE TREATMENT SYSTEM ON-LINE
Polynomial trend lines drawn to the sixth order using Excel
Flow (mg/L)
Iron (mg/L)
Date
50
45
40
35
30
25
20
15
10
5
0
120
100
80
60
40
20
0
4/15/98
7/24/98
11/1/98
2/9/99
5/20/99
8/28/99
12/6/99
3/15/00
R^2 = 0.4181
R^2 = 0.6923
R^2 = 0.8362
Flow
ALD Effluent
Wetland Effluent
Poly. (ALD Effluent)
Poly. (Wetland Effluent)
Poly. (Flow)

Figure 6

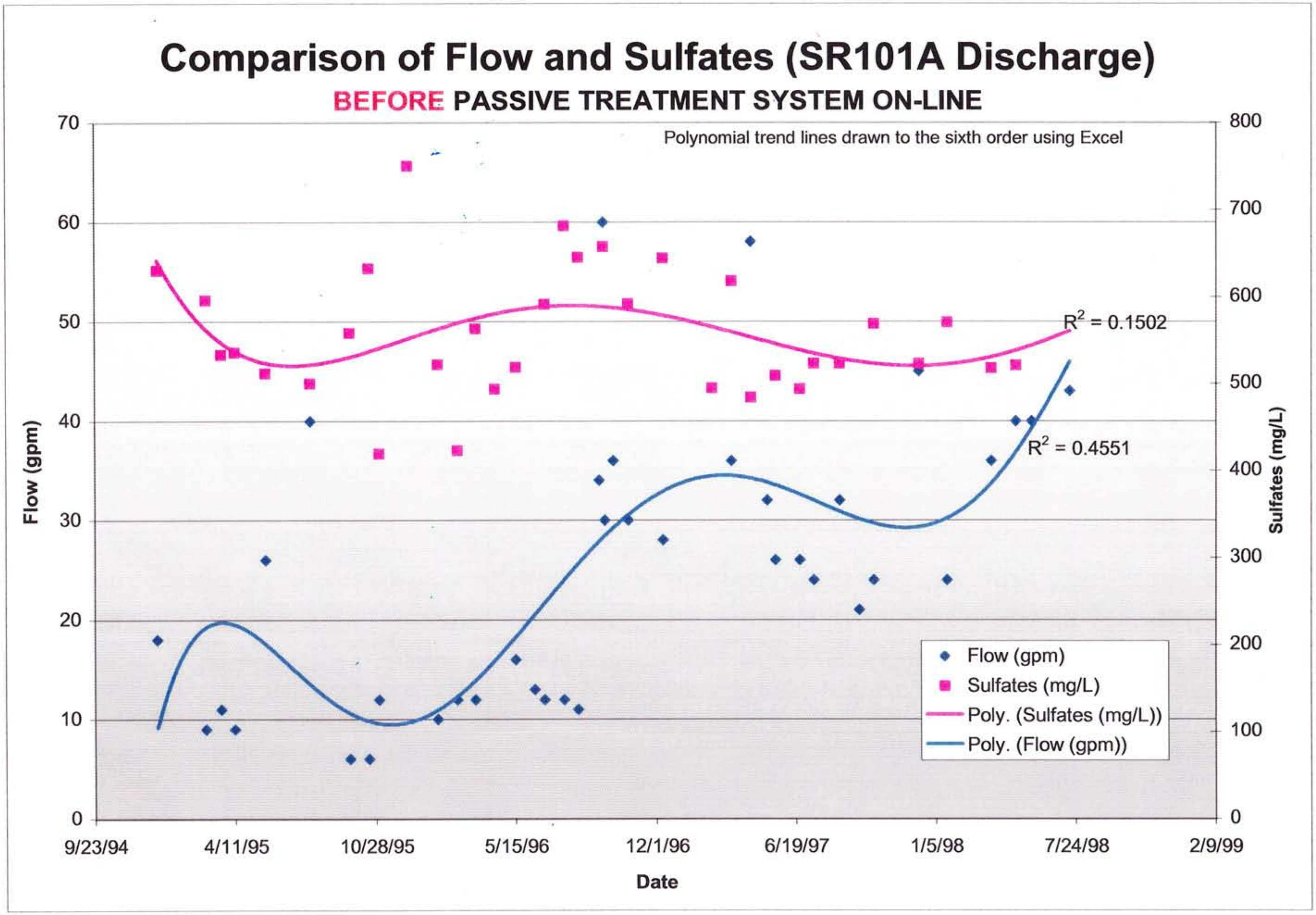

Comparison of Flow and Sulfates (SR101A Discharge)
BEFORE PASSIVE TREATMENT SYSTEM ON-LINE
Polynomial trend lines drawn to the sixth order using Excel
R^2 = 0.1502
R^2 = 0.4551
Flow (gpm)
Sulfates (mg/L)
Poly. (Sulfates (mg/L))
Poly. (Flow (gpm))
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800
Sulfates (mg/L)
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
1/5/98
7/24/98
2/9/99
Date

Figure 7

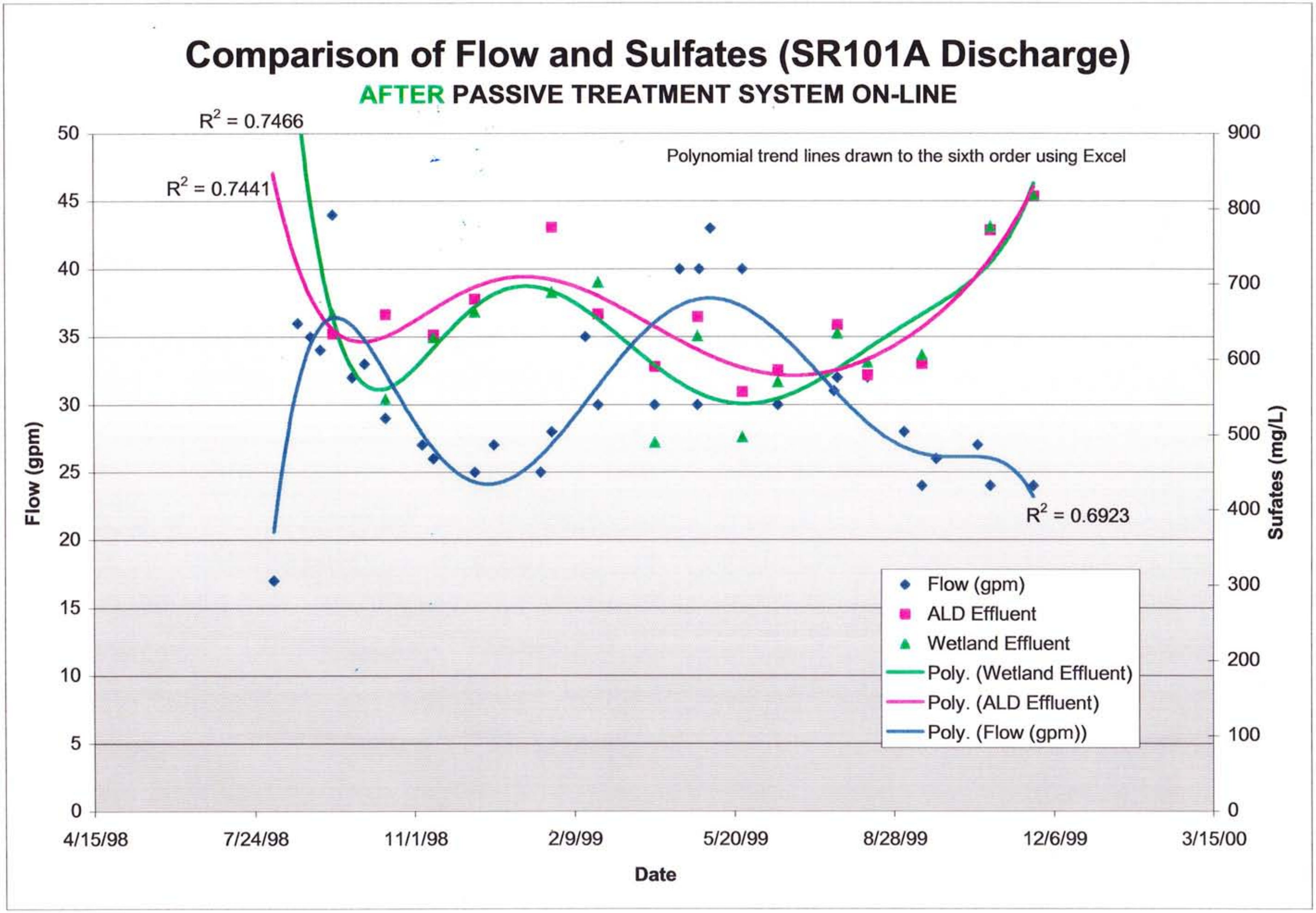

Comparison of Flow and Sulfates (SR101A Discharge)
AFTER PASSIVE TREATMENT SYSTEM ON-LINE
Polynomial trend lines drawn to the sixth order using Excel
R² = 0.7466
R² = 0.7441
R² = 0.6923
Flow (gpm)
Sufates (mg/L)
Date
50
45
40
35
30
25
20
15
10
5
0
900
800
700
600
500
400
300
200
100
0
4/15/98
7/24/98
11/1/98
2/9/99
5/20/99
8/28/99
12/6/99
3/15/00
Flow (gpm)
ALD Effluent
Wetland Effluent
Poly. (Wetland Effluent)
Poly. (ALD Effluent)
Poly. (Flow (gpm))

Figure 8

APPENDIX

DRILL LOGS - MONITORING WELLS # 1, 2, 3

GEOLOGIC LOG DRILL HOLES/OVERBURDEN ANALYSIS DATA

Hole No.:	MW1
SURFACE ELEVATION	1246.5
BOTTOM OF COAL ELEVATIONS:	1245.0
	(end @ 1231.5)
Groundwater Elevations and Date Measured:	(See MW Data Chart)
Surveyed by:	hand-level and rod (BioMost) from points with known
Survey Method:	elevations (CDS)
Remarks:	**Stick up- 1.7'; TD-15'**

Operation Name:	Higgins PTS Project
Method of Drilling:	Air-Rotary
Date Drilled:	05/27/97
Drilled By:	McKay&Gould Drilling Co., Darlington, PA
Logged By:	M. Dunn, R.P.G.
Township:	Washington
County:	Butler
Quadrangle:	7 1/2' Eau Claire (PR1979)
Laboratory:	G & C Coal Analysis Lab., Inc.
UTM's Zone:	17 Northing_______ Easting_______
LATITUDE	41° 08' 21" LONGITUDE 79° 48' 34"

Depth	Thick-ness	Scale	Graphic Log	Lithologic Description and Water Conditions	OBS Sample No.	Log Interval	% Total Sulfur	Fizz Rating	Neutralization Potential (ppt)
1	1		\\\\\\\\\\\\\\\\	subsoil; clayey; dry					
1.5	0.5		[solid black]	coal					
4	2.5		~ ~ ~ ~ ~	claystone; org some shale; dry					
6	2	5	-.-.-.-.-.-.-.-	siltstone; OD and dk-org					
11	5	10	~ ~ ~ ~ ~	claystone; dry; org lt-gy md-gy dr-gy					
15	4	15 20	- - - - - - - ________	shale; dk-gy shale;carbonaceous; some "bony"					

GEOLOGIC LOG DRILL HOLES/OVERBURDEN ANALYSIS DATA

Hole No.:	MW2	Operation Name:	Higgins PTS Project
SURFACE ELEVATION	1246.8	Method of Drilling:	Air-Rotary
BOTTOM OF COAL ELEVATIONS:		Date Drilled:	05/27/97
		Drilled By:	McKay&Gould Drilling Co., Darlington, PA
	(end @ 1225.8)	Logged By:	M. Dunn, R.P.G.
Groundwater Elevations		Township:	Washington
and Date Measured:	(See MW Data Chart)	County:	Butler
		Quadrangle:	7 1/2' Eau Claire (PR1979)
Surveyed by:	hand-level and rod (BioMost) from points with known	Laboratory:	G & C Coal Analysis Lab., Inc.
Survey Method:	elevations (CDS)	UTM's Zone:	17 Northing_______ Easting_______
Remarks:	**Stick up- 0.9'; TD-21'**	LATITUDE	41° 08' 21" LONGITUDE 79° 48' 32"

Depth	Thick-ness	Scale	Graphic Log	Lithologic Description and Water Conditions	OBS Sample No.	Log Interval	% Total Sulfur	Fizz Rating	Neutralization Potential (ppt)
4	4		\\\\\\\\	disturbed material; predomin. sands clay; dk-brn, md-org, dk-org zones					
11	7	5, 10	~ ~ ~ ~ ~	clay material;md-gy & org. zones siltstone; dk-gy (thin)					
13	2		- - - - -	shale; dk-gy					
17	4	15		shale; carb; with bony (@15" hit water- 10 gpm)					
18	1		- - - - -	shale; md-gy					
21	3	20	:::::::::	(@19' hit water) sandstone; md-gy; md-gn					

GEOLOGIC LOG DRILL HOLES/OVERBURDEN ANALYSIS DATA

Hole No.: MW3
SURFACE ELEVATION 1240.3
BOTTOM OF COAL ELEVATIONS: (end @ 1225.3)
Groundwater Elevations and Date Measured: (See MW Data Chart)
Surveyed by: hand-level and rod (BioMost) from points with known
Survey Method: elevations (CDS)
Remarks: **Stick up- 0.9'; TD-15'**

Operation Name: Higgins PTS Project
Method of Drilling: Air-Rotary
Date Drilled: 05/27/97
Drilled By: McKay&Gould Drilling Co., Darlington, PA
Logged By: M. Dunn, R.P.G.
Township: Washington
County: Butler
Quadrangle: 7 1/2' Eau Claire (PR1979)
Laboratory: G & C Coal Analysis Lab., Inc.
UTM's Zone: 17 Northing_______ Easting_______
LATITUDE 41^{o} 08' 28" LONGITUDE 79^{o} 48' 25"

Depth	Thick-ness	Scale	Graphic Log	Lithologic Description and Water Conditions		Log Interval	% Total Sulfur	Fizz Rating	Neutralization Potential (ppt)
7	7	5		disturbed material; sandy; clay with SS frags subsoil; clayey					
12	5	10		claystone;md-gy dk-bn (1')					
13	1			shale; carb					
15	2	15		shale; md-gy					
		20		sandstone; md-gy; md-gn					

Slippery Rock Watershed Coalition
Final Report: Watershed Project

Photographic Log

BEFORE RECLAMATION

(SR101-A 8/12/96)

Panoramic view looking south across "dead zone" toward Slippery Rock Creek. Note red-orange iron precipitates.

TOPOGRAPHIC SURVEY

(SR101-A 8/12/96)

"Dead area" - topographic survey by CDS (Looking south)

(SR101-A 8/12/96)

"Dead area" - topographic survey (Looking north)

BUREAU OF ABANDONED MINE RECLAMATION

(SR101-A 8/14/96)

(SR101-A 8/15/96)

(SR101-A 8/14/96)

PA Department of Environmental Protection, BAMR contribute to the effort by clearing and constructing access and staging area.

MONITORING WELL INSTALLATION

(SR101-A 5/28/97)

Monitoring Well 1 - drilling by McKay&Gould for Amerikohl Mining

(SR101-A 5/28/97)

Monitoring Well 1 - installation Amerikohl Mining & Tim Danehy (BMI)

DRAINING SITE

(SR101-A 5/28/97)

Temporary drainage ditch installed (8/15/96) to dewater construction area near future collection system.

AFTER DRAINING SITE

(SR101-A 5/5/98)

"Dead area" characterized by accumulation of red-orange iron precipitates (note footprint in center foreground). (Looking north)

(SR101-A 5/5/98)

"Dead area" - dewatered prior to construction. (Note dry pipe.) (Looking north)

ANOXIC COLLECTION SYSTEM

(SR101-A 6/17/98)

Anoxic Collection System: Jesteadt Excavating & BioMost (Looking north)

ANOXIC COLLECTION SYSTEM

(SR101-A 6/17/98)

Anoxic Collection System "wrapped" in geotextile (Looking NE)

ALD CONSTRUCTION

(SR101-A 7/27/98)

Anoxic Limestone Drain construction in old railroad bed by Jesteadt Excavating. (Looking west to future outlet)

ALD CONSTRUCTION

(SR101-A 7/27/98)

ALD construction by Jesteadt Excavating (Looking southeast)

(SR101-A 7/27/98)

ALD construction: placement of 6-mil plastic liner by BMI (Looking SW)

LIMESTONE PLACEMENT

(SR101-A 7/29/98)

ALD: 900 tons of AASHTO#3 limestone from Boyers Quarry (Quality Aggregates); trucking-Shaliston Enterprises construction by Jesteadt Excavating (Looking west)

MANIFOLD SYSTEM

(SR101-A 7/29/98)

ALD inlet manifold bedded in river gravel prior to receiving mine drainage (Looking SE)

(SR101-A 7/29/98)

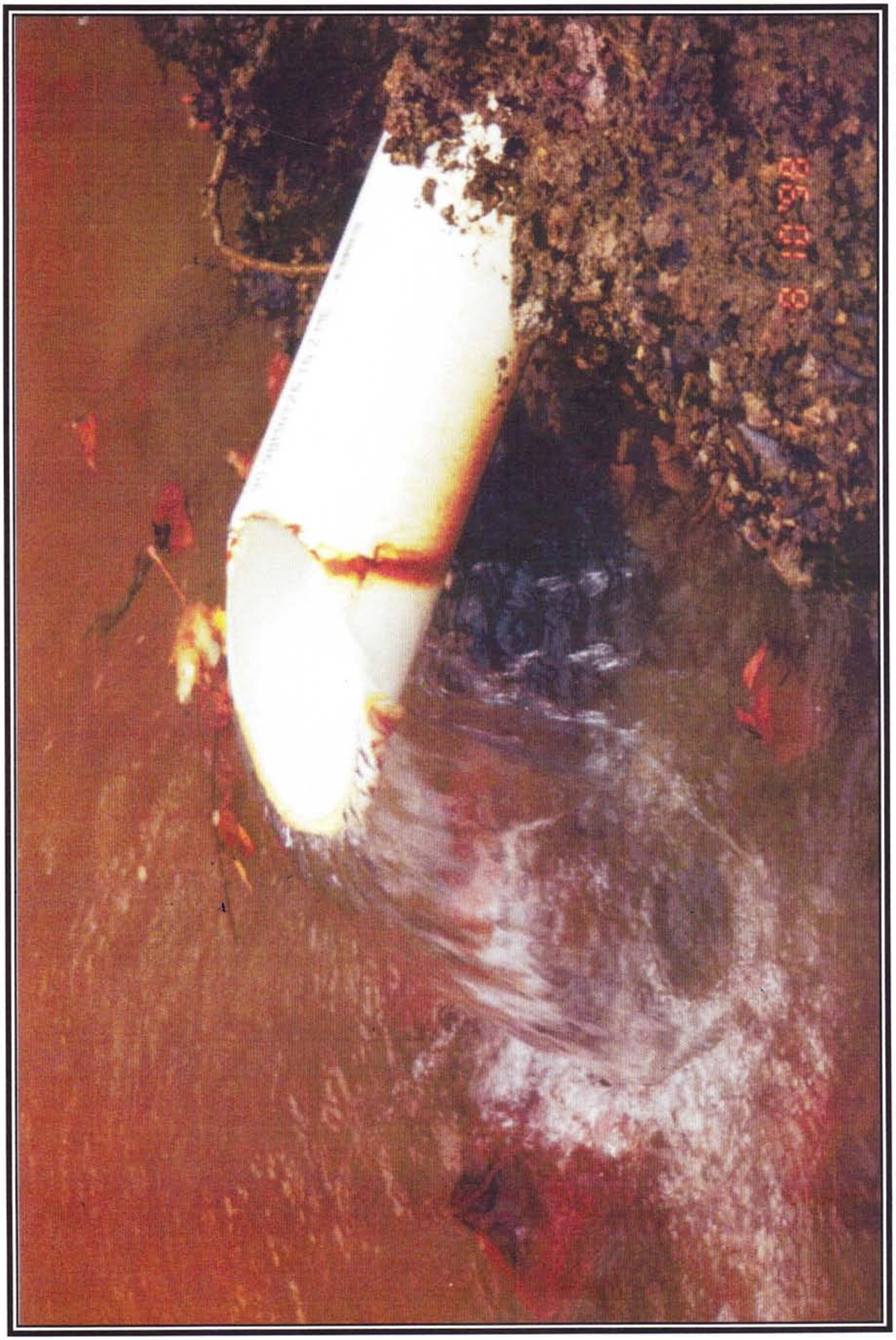
ALD outlet manifold; Jerry Jesteadt & Dave Macurak, Jesteadt Excavating (Looking SE)

RAW WATER SAMPLING PORT

(SR101-A 8/3/98)

Raw Water Sampling Port: ½" PE tubing placed near bottom of anoxic collection system (note 4" SDR 35 casing on right) (Looking north)

ALD EFFLUENT



(SR101-A 8/10/98)

ALD effluent (about 40 gpm) Day 7 after placing on-line

FINAL GRADING

(SR101-A 8/10/98)

Final grading: Day 7 after SR101-A system on-line (Looking SW)

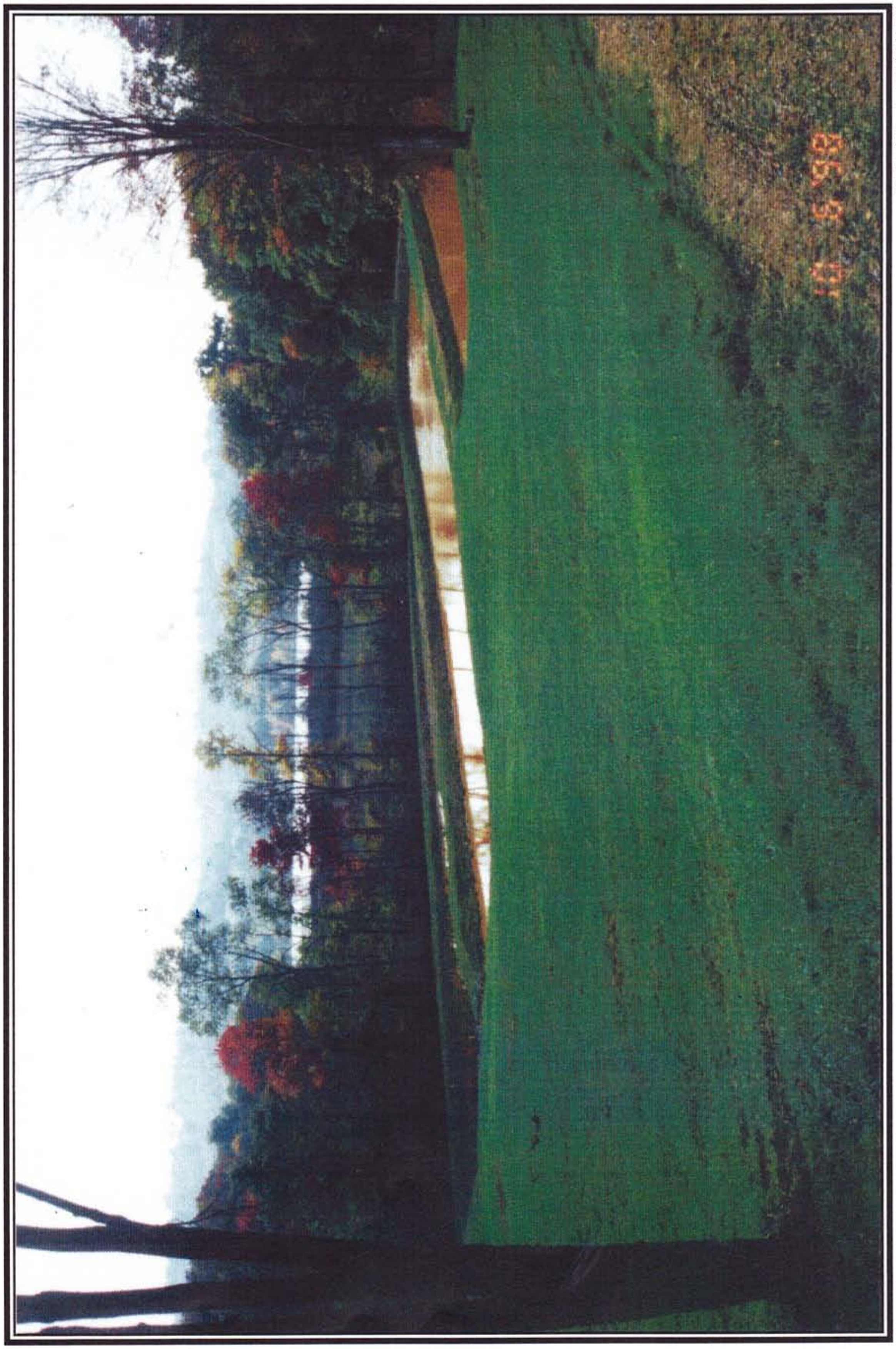
VOLUNTEER EFFORT

(SR101-A 8/21/98)

Volunteers plant Wetland #2 with cattails harvested nearby.

(SR101-A 8/21/98)

REVEGETATION



(SR101-A 10/6/98)

Revegetation 1 ½ months after seeding (Looking SW)

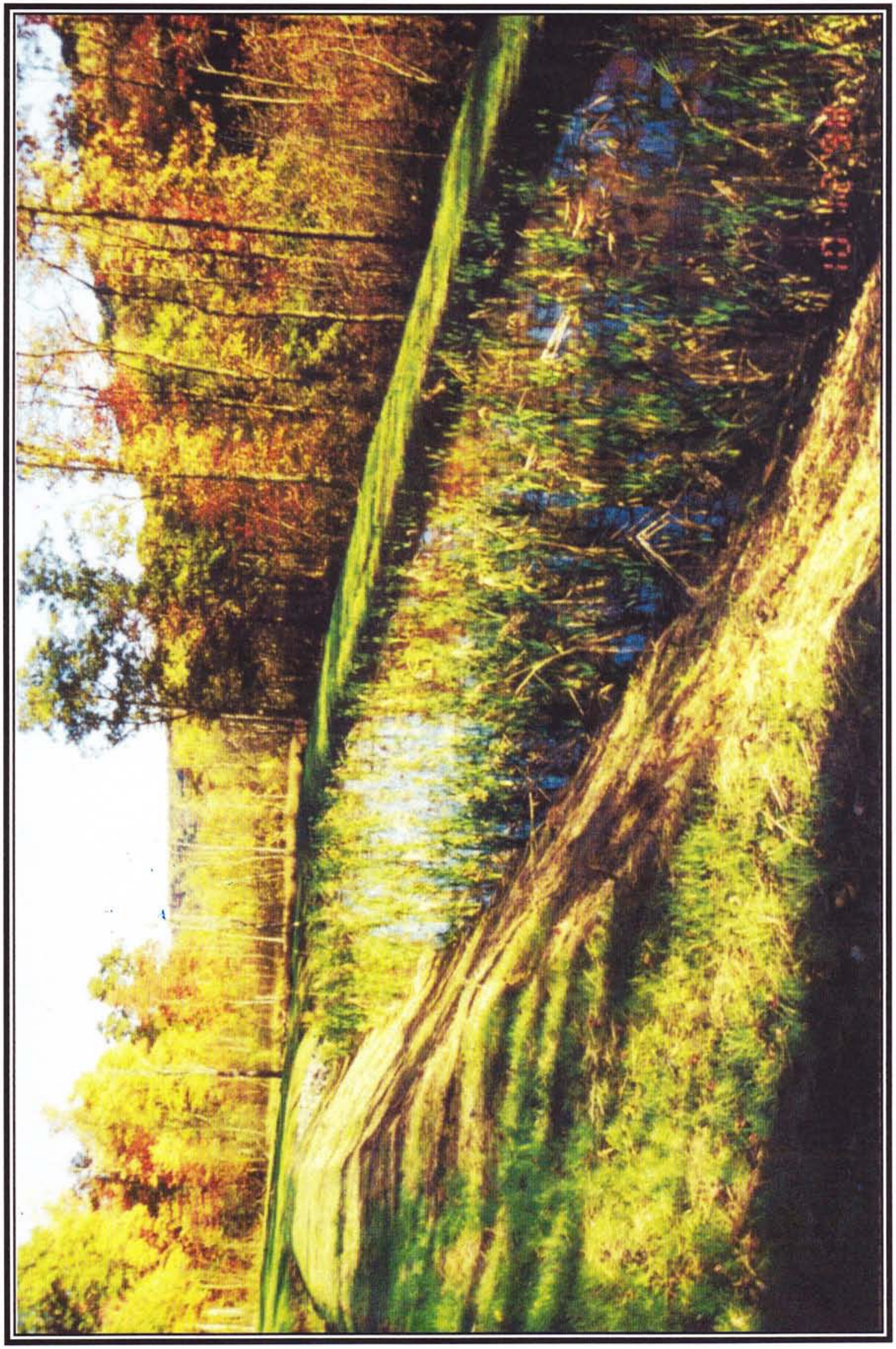
SRU VOLUNTEERS

(SR101-A 10/12/98)

Slippery Rock University volunteers plant Wetland #1 with cattails harvested nearby (Dr. Jerry Chmielewski, Aquatic Plants class)

(SR101-A 10/12/98)

WETLAND #2



(SR101-A 10/12/98)

Wetland #2 about 2 months after planting by Slippery Rock Watershed Coalition volunteers. (Looking east)

BRIEF PRELIMINARY REVIEW OF

SR101A PASSIVE TREATMENT SYSTEM IMPACT ON SLIPPERY ROCK CREEK

Based on information provided by the

Pennsylvania Department of Environmental Protection
Bureau of District Mining Operations
Knox Office

through the

Comprehensive Mine Reclamation Strategy
Slippery Rock Creek Watershed headwaters.

Participants are

BOWMAN, Roger, Engineer
GILLEN, Timothy, PG, Hydrogeologist
VANDYKE, Timothy, Inspector Supervisor
PLESAKOV, James, MCI
ELICKER, Theresa, MCI
EDMISTON, William, MCI
KOWALSKY, Robert, MCI
ALLEN, William, Compliance Specialist
ODENTHAL, Lorraine, Permit Chief
MIRZA, Javid, District Mining Manager.

(The following cursory review is by Margaret H. Dunn, PG, BioMost, Inc. Upon compilation of more long-term data, the Slippery Rock Watershed Coalition intends to provide a more thorough report.)

INTRODUCTION

As part of the Comprehensive Mine Reclamation Strategy (CMRS), implemented in 1994, the Knox District Mining Office (DMO) has identified 74 mine drainage sources in the 27-square mile headwaters area of the Slippery Rock Creek. In this area targeted for restoration, about 4000 acres (25% of the total area) are underlain by abandoned underground mine workings and about 8000 acres (50% of the total area) have been included in surface mine permit applications.

The DMO continues to conduct a comprehensive water quality monitoring program to determine the characteristics of the significant discharges and their individual and combined impacts on the streams. The DMO also monitors the completed passive treatment systems and land restoration projects in the watershed to determine the degree of success/failure of these projects.

As the monitoring continues, a more thorough evaluation of this data will be provided in later watershed reports.

MONITORING STATIONS NOTED IN THIS REPORT

The stream sampling points with on-going water quality monitoring are identified on the attached Project Location Map. The relationship of SR101A to these points is depicted on this map.

Stream stations #46 and #60 are selected for the upstream and downstream monitoring points, respectively, for SR101A. Both the upstream (#46) and the downstream (#60) monitoring points are impacted by other untreated flows and flows from other passive treatment systems. Several acres of volunteer wetland receives the final effluent from the SR101A passive treatment system. This wetland adjoins a lake constructed by the PA Game Commission. A downstream monitoring point above the lake on Slippery Rock Creek that excludes the influence of other discharges was not established.

Stream monitoring station #64 is also included to determine if Slippery Rock Creek is improved further downstream by the combined impact of the SR101A passive system and the seven other passive systems installed to abate discharges on the main branch of Slippery Rock Creek.

(The DMO monitoring of discharge SR101A is included in the section of this report relating to the evaluation of the recently completed passive treatment system.)

REVIEW OF WATER QUALITY MONITORING

Due to time and manpower constraints, etc., stream flows were only occasionally measured at the stream monitoring points #46, 60, and 64. In order to depict the significantly variable flow conditions found within the Slippery Rock Creek watershed, the measured flows for the SR115 discharge have been included. These reported flows are used to represent the differences between high and low flow conditions throughout the year.

The flow for the SR115 discharge is extremely variable, ranging from 0 to 700 gpm. The flow has been observed to directly reflect high flow and low flow conditions in Slippery Rock Creek.

The first Anoxic Limestone Drains(discharges SR114B and 114D) were placed on-line in 9/95. Since that time, a large settling pond for the net alkaline discharge at SR115 has been constructed. The downstream effects of this settling pond and the two anoxic limestone drains are monitored at point #46. A Vertical Flow Pond for discharge SR109 has also been on an unnamed tributary that confluences with the main branch directly below point #46.

Acidity of Slippery Rock Creek

Comparing the acidity at all points (#46, 60, 64) with the reported flows at SR115, demonstrates that the stream's acidity has been decreased since the implementation of recent reclamation activities. Prior to installation of the above noted passive systems, during high flow periods the acidity in the stream was increased. After installation of the systems, however, there is only a slight increase in the stream acidity in relation to increased flows. (See Figures 1 & 2.)

Alkalinity of Slippery Rock Creek

The inverse relationship of high flow conditions with alkalinity is dramatically observed by comparing #46 reported alkalinity with the SR115 flow rate. (See Figure 3.) The polynomial trend lines as seen on Figure 4 provide an indication, however, that since installation of the first system on 9/95 that the alkalinity has an upward trend. Note particularly for stream station #60, where the trend line shows an increase in gradient after installation of the SR101A passive system in 8/98. This may reflect the positive impact of the SR101A treatment system on the Slippery Rock Creek.

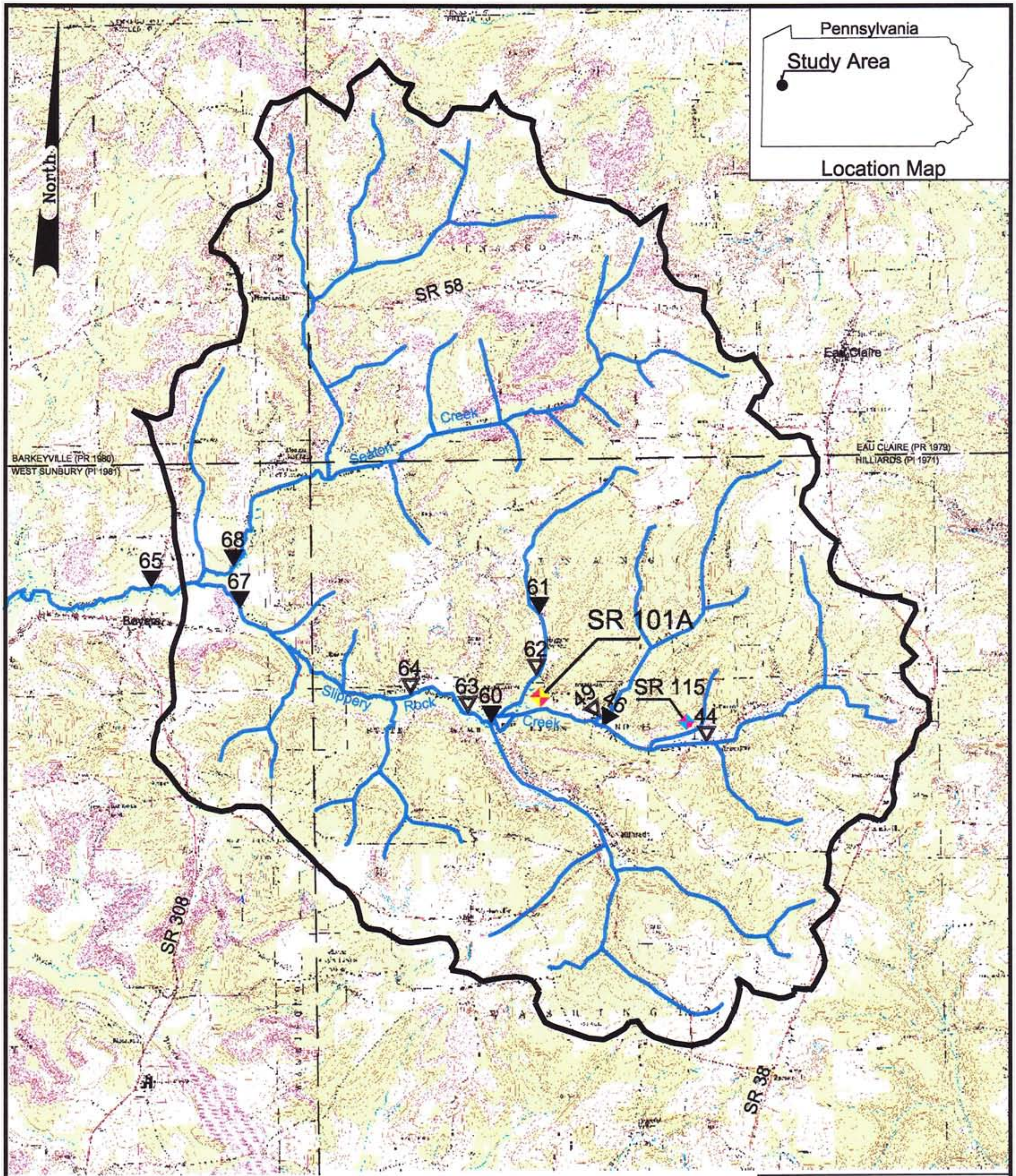
Iron Content of Slippery Rock Creek

As the upper reach of Slippery Rock Creek appears to have alkalinity slightly exceeding the acidity due to the influence of the passive treatment facilities, the iron content measured in that section of the stream above #60 would probably reflect solids either suspended in the stream or due to a disturbance of the streambed. The iron content measured at #64, at times, may be dissolved.

SUMMARY

Based on a cursory review of the monitoring data provided by the PADEP, Knox District Mining Office, the water quality of Slippery Rock Creek appears to be improving. There remains an increase in acidity and a decrease in alkalinity during high flow periods even though the Anoxic Limestone Drains and Vertical Flow Pond continue to generate excess alkalinities persistently throughout the year. (For example, compare effluent quality of SR101A in separate section of report.) The upper reach of Slippery Rock Creek (from the downstream monitoring point for SR101A), however, generally appears to be slightly net alkaline. Even when the stream is net alkaline, the iron concentration at times exceeds the in-stream criterion of 1.5 mg/L. This may be due to particulates.

Additional passive treatment systems and land reclamation are scheduled for the watershed. Continued monitoring and implementation of these restoration projects will more clearly determine the long-term benefit to Slippery Rock Creek.



44 ▽ STREAM MONITORING POINT - Water

46 ▼ STREAM MONITORING POINT - Water, streambed sediments, aquatic life

STREAM

HEADWATERS TARGET AREA

0 0.5 1.0 2.0

GRAPHIC SCALE
(miles)

PROJECT LOCATION MAP

SLIPPERY ROCK CREEK
STUDY AREA

SLIPPERY ROCK WATERSHED COALITION
Butler County, PA
Scale: 1" = 1 mile Date: 12/1999

watershed1

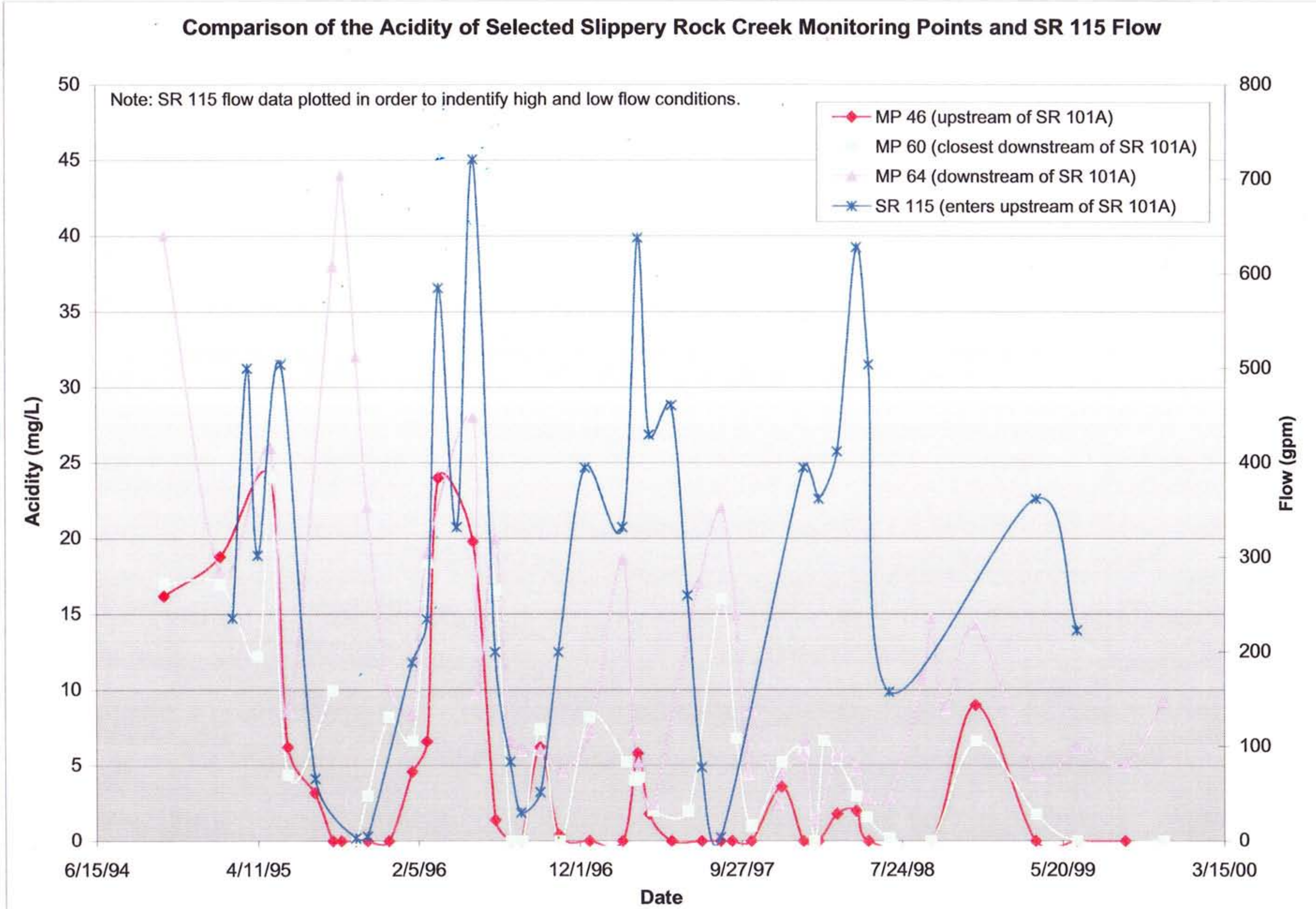

Comparison of the Acidity of Selected Slippery Rock Creek Monitoring Points and SR 115 Flow
Note: SR 115 flow data plotted in order to indentify high and low flow conditions.
MP 46 (upstream of SR 101A)
MP 60 (closest downstream of SR 101A)
MP 64 (downstream of SR 101A)
SR 115 (enters upstream of SR 101A)
Acidity (mg/L)
50
45
40
35
30
25
20
15
10
5
0
Flow (gpm)
800
700
600
500
400
300
200
100
0
6/15/94
4/11/95
2/5/96
12/1/96
9/27/97
7/24/98
5/20/99
3/15/00
Date

Figure 1

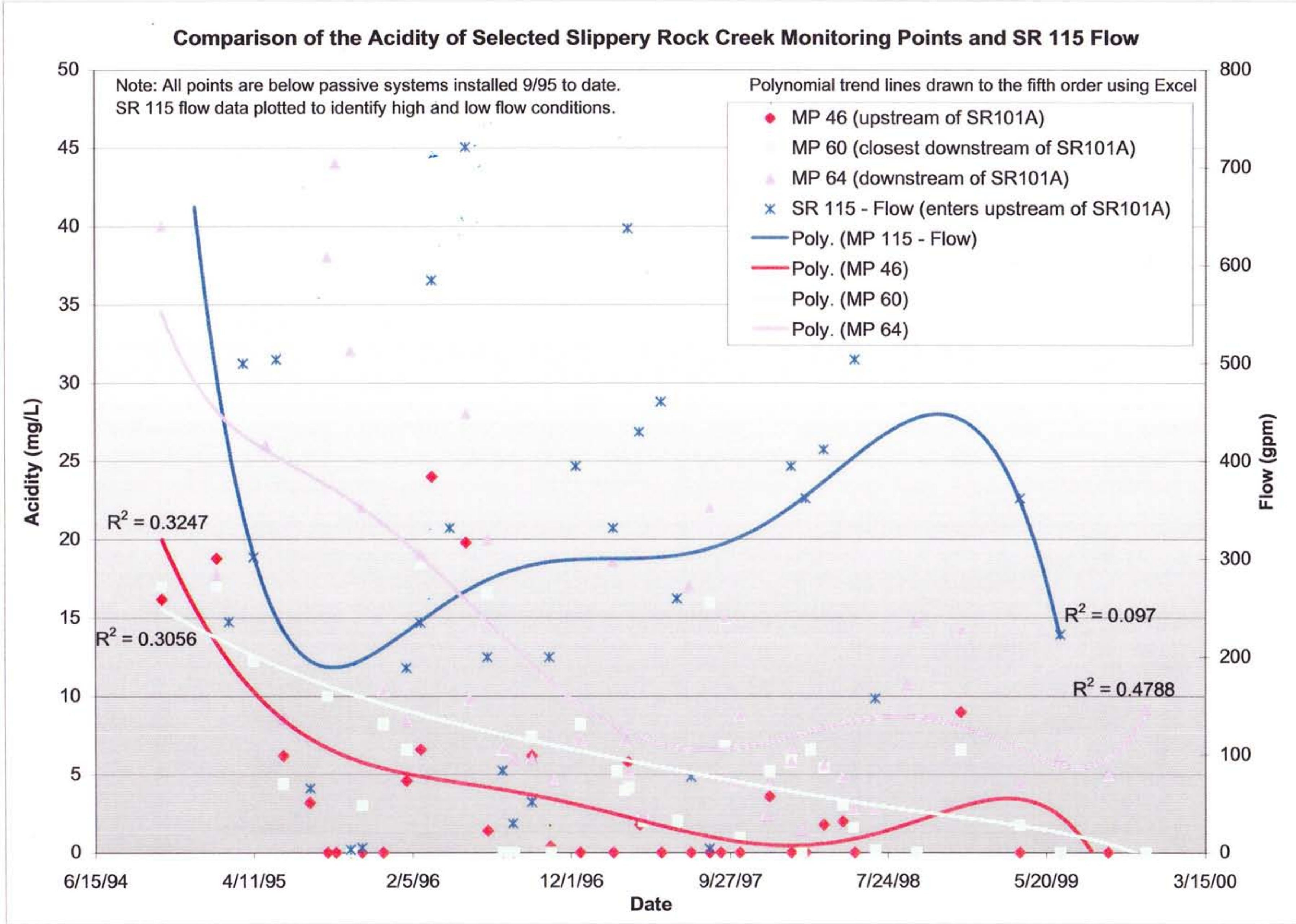

Comparison of the Acidity of Selected Slippery Rock Creek Monitoring Points and SR 115 Flow
Note: All points are below passive systems installed 9/95 to date.
SR 115 flow data plotted to identify high and low flow conditions.
Polynomial trend lines drawn to the fifth order using Excel
MP 46 (upstream of SR101A)
MP 60 (closest downstream of SR101A)
MP 64 (downstream of SR101A)
SR 115 - Flow (enters upstream of SR101A)
Poly. (MP 115 - Flow)
Poly. (MP 46)
Poly. (MP 60)
Poly. (MP 64)
R^2 = 0.3247
R^2 = 0.3056
R^2 = 0.097
R^2 = 0.4788
Acidity (mg/L)
Flow (gpm)
Date
50
45
40
35
30
25
20
15
10
5
0
800
700
600
500
400
300
200
100
0
6/15/94
4/11/95
2/5/96
12/1/96
9/27/97
7/24/98
5/20/99
3/15/00

Figure 2

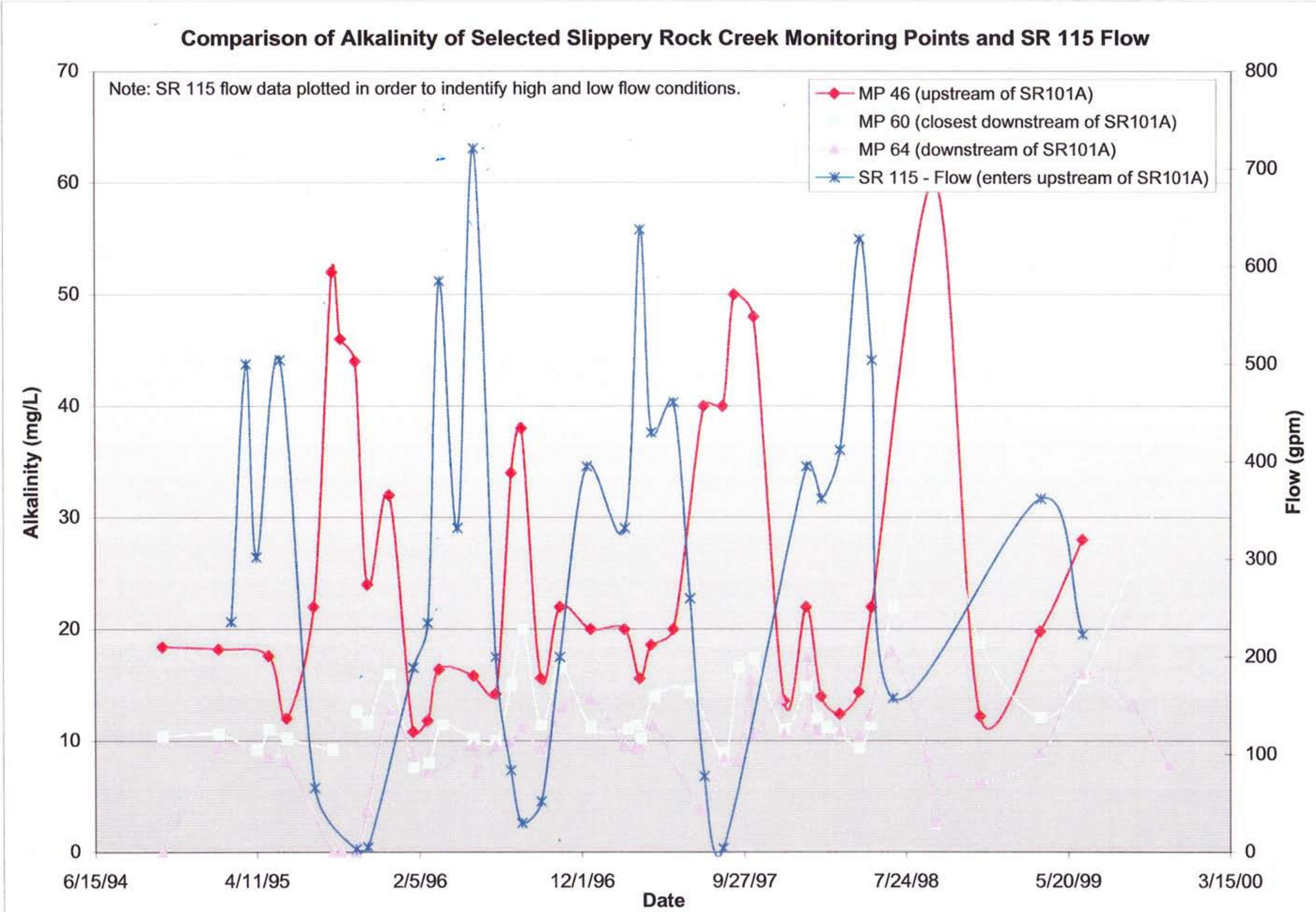

Comparison of Alkalinity of Selected Slippery Rock Creek Monitoring Points and SR 115 Flow
Note: SR 115 flow data plotted in order to indentify high and low flow conditions.
MP 46 (upstream of SR101A)
MP 60 (closest downstream of SR101A)
MP 64 (downstream of SR101A)
SR 115 - Flow (enters upstream of SR101A)
Alkalinity (mg/L)
70
60
50
40
30
20
10
0
Flow (gpm)
800
700
600
500
400
300
200
100
0
6/15/94
4/11/95
2/5/96
12/1/96
9/27/97
7/24/98
5/20/99
3/15/00
Date

Figure 3

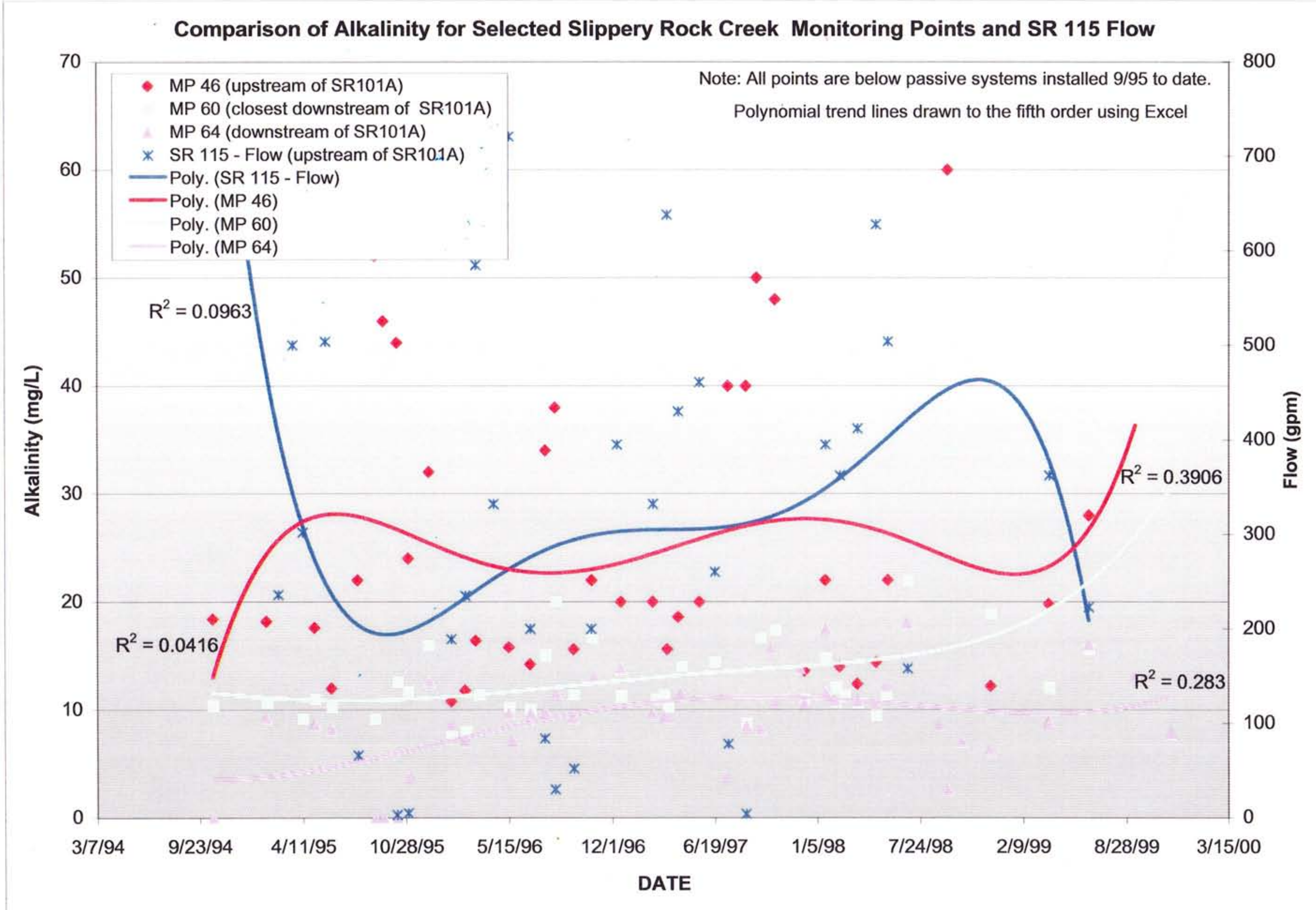

Comparison of Alkalinity for Selected Slippery Rock Creek Monitoring Points and SR 115 Flow
MP 46 (upstream of SR101A)
MP 60 (closest downstream of SR101A)
MP 64 (downstream of SR101A)
SR 115 - Flow (upstream of SR101A)
Poly. (SR 115 - Flow)
Poly. (MP 46)
Poly. (MP 60)
Poly. (MP 64)
Note: All points are below passive systems installed 9/95 to date.
Polynomial trend lines drawn to the fifth order using Excel
$R^2 = 0.0963$
$R^2 = 0.0416$
$R^2 = 0.3906$
$R^2 = 0.283$
Alkalinity (mg/L)
0
10
20
30
40
50
60
70
Flow (gpm)
0
100
200
300
400
500
600
700
800
3/7/94
9/23/94
4/11/95
10/28/95
5/15/96
12/1/96
6/19/97
1/5/98
7/24/98
2/9/99
8/28/99
3/15/00
DATE

Figure 4

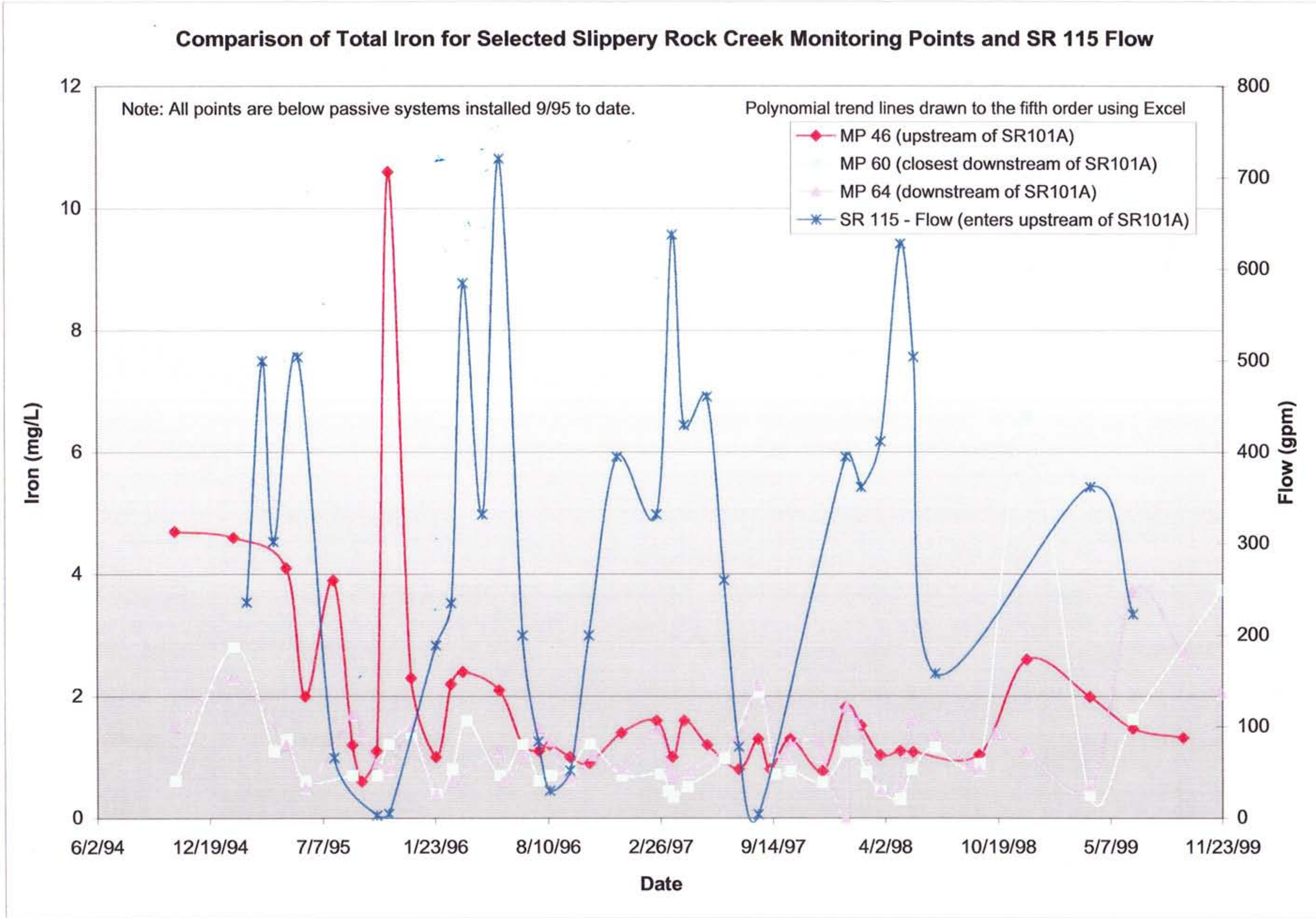

Comparison of Total Iron for Selected Slippery Rock Creek Monitoring Points and SR 115 Flow
Note: All points are below passive systems installed 9/95 to date.
Polynomial trend lines drawn to the fifth order using Excel
MP 46 (upstream of SR101A)
MP 60 (closest downstream of SR101A)
MP 64 (downstream of SR101A)
SR 115 - Flow (enters upstream of SR101A)
Iron (mg/L)
Flow (gpm)
Date
0
2
4
6
8
10
12
100
200
300
400
500
600
700
800
6/2/94
12/19/94
7/7/95
1/23/96
8/10/96
2/26/97
9/14/97
4/2/98
10/19/98
5/7/99
11/23/99

Figure 5

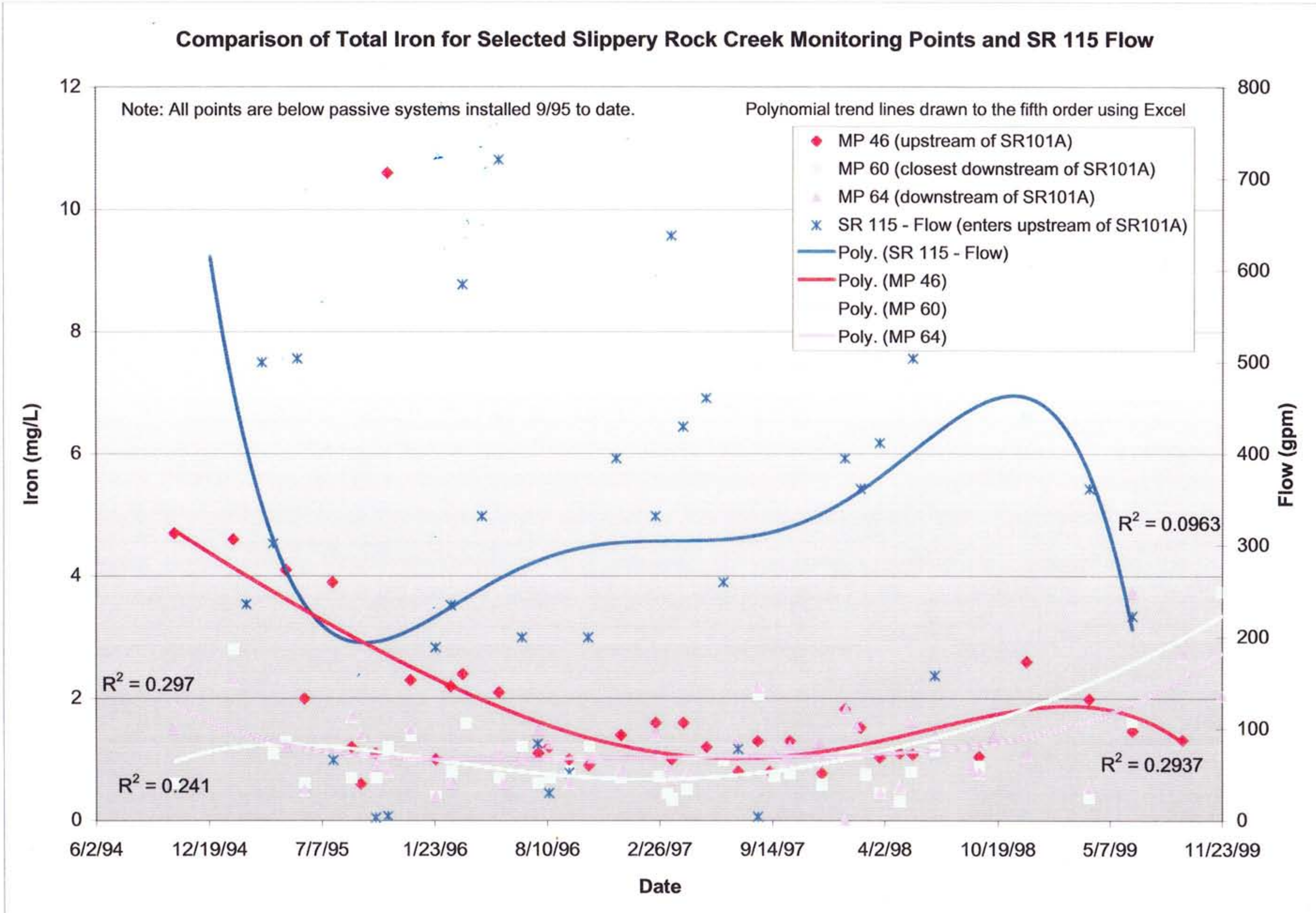

Comparison of Total Iron for Selected Slippery Rock Creek Monitoring Points and SR 115 Flow
Note: All points are below passive systems installed 9/95 to date.
Polynomial trend lines drawn to the fifth order using Excel
MP 46 (upstream of SR101A)
MP 60 (closest downstream of SR101A)
MP 64 (downstream of SR101A)
SR 115 - Flow (enters upstream of SR101A)
Poly. (SR 115 - Flow)
Poly. (MP 46)
Poly. (MP 60)
Poly. (MP 64)
Iron (mg/L)
Flow (gpm)
Date
12
10
8
6
4
2
0
800
700
600
500
400
300
200
100
0
6/2/94
12/19/94
7/7/95
1/23/96
8/10/96
2/26/97
9/14/97
4/2/98
10/19/98
5/7/99
11/23/99
R² = 0.297
R² = 0.241
R² = 0.0963
R² = 0.2937

Figure 6

TABLE 1: CHEMICAL COMPOSITION OF SLIPPERY ROCK CREEK MONITORING POINT 46

Montoring Point ID: 46										
Date	Sampler	flow (gpm)	pH	alk (mg/L)	acid (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	SO4 (mg/L)	Solids (mg/L)
10/19/94	DMO		6.3	18	16	4.7				4
01/31/95	DMO		6.3	18	19	4.6				8
05/04/95	DMO		6.3	18	24	4.1				3
06/06/95	DMO		6.2	12	6	2.0				18
07/26/95	DMO		6.1	22	3	3.9				3
08/29/95	DMO		6.5	52	0	1.2				14
09/14/95	DMO		6.5	46	0	0.6				14
10/11/95	DMO		6.5	44	0	1.1				3
11/02/95	DMO		6.2	24	0	10.6				46
12/12/95	DMO		6.2	32	0	2.3				4
01/25/96	DMO		6.1	11	5	1.0				8
02/21/96	DMO		6.0	12	7	2.2				11
03/13/96	DMO		6.1	16	24	2.4				3
05/16/96	DMO		5.9	16	20	2.1				3
06/26/96	DMO		6.2	14	1	1.2				3
07/25/96	DMO		6.2	34	0	1.1				0
08/13/96	DMO		6.3	38	0	1.2				6
09/18/96	DMO		5.9	16	6	1.0				8
10/23/96	DMO		6.4	22	0	0.9				0
12/19/96	DMO		6.1	20	0	1.4				6
02/19/97	DMO		6.1	20	0	1.6				0
03/19/97	DMO		5.9	16	6	1.0				0
04/09/97	DMO		6.3	19	2	1.6				0
05/20/97	DMO		6.3	20	0	1.2				0
07/15/97	DMO		6.5	40	0	0.8				0
08/19/97	DMO		6.5	40	0	1.3				0
09/09/97	DMO		6.6	50	0	0.8				7.9
10/15/97	DMO		6.7	48	0	1.3				4
12/11/97	DMO		5.9	14	4	0.8				0
01/21/98	DMO		6.2	22	0	1.8				0
02/18/98	DMO		6.1	14	0	1.5				4
03/24/98	DMO		6.2	12	2	1.0				6
04/29/98	DMO		6.0	14	2	1.1				6
05/22/98	DMO		6.3	22	0	1.1				0
09/16/98	DMO		6.5	60	0	1.0				4
12/09/98	DMO		5.5	12	9	2.6				0
03/31/99	DMO		6.2	20	0	2.0				0
06/16/99	DMO		6.5	28	0	1.5				0
09/14/99	DMO		6.6	52	0	1.3				4

TABLE 3: CHEMICAL COMPOSITION OF SLIPPERY ROCK CREEK MONITORING POINT 64

Montoring Point ID: 64										
Date	Sampler	flow (gpm)	pH	alk (mg/L)	acid (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	SO4 (mg/L)	Solids (mg/L)
10/19/94	DMO		3.9	0	40	2				3
01/31/95	DMO		4.9	9.2	17.8	2				4
05/04/95	DMO		5.1	8.6	26	1				22
06/06/95	DMO	24000	5.6	8.2	8.6	1				3
08/29/95	DMO		3.5	0	38	2				3
09/14/95	DMO		3.5	0	44	1				8
10/12/95	DMO		3.9	0	32	1				6
11/02/95	DMO		4.1	3.8	22	1				3
12/12/95	DMO		5.9	12.6	10.4	2				6
01/25/96	DMO		5.4	8.6	8.4	0				4
02/22/96	DMO		5.1	7	19	1				3
05/16/96	DMO		5.5	9.6	28	1				3
05/23/96	DMO		4.9	7.2	9.8	1				3
06/26/96	DMO		5.6	9.6	20	1				3
07/25/96	DMO		5.5	9.8	6.6	1				0
08/15/96	DMO		5.7	11.4	6	1				0
09/18/96	DMO		5.5	9.2	6	1				0
10/29/96	DMO		6.1	13	4.6	1				10
12/19/96	DMO		5.6	13.8	7.2	1				0
02/19/97	DMO		5.4	9.6	18.6	1				0
03/12/97	DMO		5.6	9.4	7.2	1				0
03/20/97	DMO		5.2	9.2	5.2	1				10
04/15/97	DMO		6.0	11.4	2.4	1				0
07/10/97	DMO		4.3	3.8	17	1				0
08/20/97	DMO		5.1	8.4	22	2				0
09/17/97	DMO		5.1	8.2	15	1				12
10/08/97	DMO		5.8	15.6	4.4	1				0
10/15/97	DMO	1470	5.7	10.6	8.8	1				0
12/04/97	DMO		6.0	13.8	2.4	1				0
12/11/97	DMO		5.5	10.6	4.4	1				0
01/21/98	DMO		6	11.6	5.8	0				0
01/23/98	DMO		6.1	17.4	6.6	2				0
02/10/98	DMO		5.8	10.8	1.4	2				80
03/24/98	DMO		5.9	10.8	5.6	0.46				8
04/29/98	DMO		5.7	10.4	4.8	0.549				6
05/19/98	DMO		6.1	12.2	2.8	1.62				8
06/30/98	DMO		6.3	18	2.8	1.37				8
09/01/98	DMO		4.9	8.6	10.8	0.858				0
09/16/98	DMO		4	2.6	14.8	0.777				0
10/14/98	DMO		4.5	7	8.8	1.39				4
12/09/98	DMO		4.3	6.2	14.2	1.08				4
03/31/99	DMO		5.1	8.8	4.4	0.532				0
06/16/99	DMO		6	16	6.2	3.72				0
09/14/99	DMO		5.7	13.2	5	2.69				0
11/23/99	DMO		4.8	7.8	9.2	2.05				0

Chemical and Biological Monitoring of Slippery Rock Creek, PA
Associated with Installation of Passive Treatment Systems to Treat Acid Mine Drainage

Final Report to the PA DEP

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Keywords: Acid mine drainage, passive treatment, anoxic limestone drain, vertical flow wetland, macroinvertebrates, periphtyon, stream restoration

Abstract

A 70 km^2 area in the headwaters of Slippery Rock Creek in Western Pennsylvania is impacted by acid mine drainage (AMD). Twelve stations, two of which are in unimpacted control streams, have been sampled quarterly beginning in 1996 to monitor changes in water and sediment chemistry resulting from installation of 9 passive treatment systems that remove over 40 kg/day of iron and add over 200 kg/day of alkalinity. Seven of the 12 sites were monitored for changes in benthic algae and macroinvertebrates in riffle and pool areas . Values for pH in the headwaters ranged from 4.2 to 6.9 and were lowest overall at Sites 44, 62, 63 and 64. Alkalinity in the headwaters was highest at Sites 46, 65 and 67. Alkalinity and pH at Sites 46, 49, 60 and 64 were usually higher following initiation of treatment upstream, but there was a high degree of temporal variability. The metals with the highest soluble (dissolved) and total aqueous concentrations were iron, manganese and aluminum. Several metals exceeded water quality standards for biota at many of the sites at some point during the study, especially manganese, iron, aluminum and zinc. The mean concentrations of all the elements measured from the clay fraction of the sediment were distinctly higher in Seaton Creek (Site 68) than all other sites. In addition, sediment at sites 49 and 65 were higher in concentrations of zinc, nickel and cobalt. Overall, there has been perhaps a slight improvement in pH and alkalinity at some of the headwater sites downstream of treatment systems, but little improvement in aqueous or sediment metal concentrations. Most chemical parameters in the watershed were quite variable over time within each site and a better understanding of the hydrology of the area is needed in order to explain some of this variability. Given that an estimated 20% of the AMD discharge into the watershed is being treated, a greater improvement in stream water chemistry is expected as more treatment systems are constructed.

At AMD impacted sites, taxonomic composition for both epilithic and epipelic algae was more affected than algal densities. Impacted sites were dominated by taxa characteristic of low pH waters. Algae at Site 60 in the water did become more similar to that of the small reference site as treatment systems were installed. Invertebrate density and diversity were greatly reduced at AMD affected sites in the headwaters compared to references streams, and did not appear to improve during the study. Macroinvertebrate taxa at AMD impacted sites were mostly Diptera and hydropsychid caddisflies. Cobbles coated with AMD/metal precipitate that were placed into the reference stream for 4 weeks, lost aluminum, iron and zinc, but gained manganese, and had a flora and fauna similar to that for control (noncoated) substrates.

Overall, there appears to be little, if any, significant recovery in macroinvertebrates and algae in the 5 years following the initial building of treatment systems in the headwaters area. Toxic concentrations of iron, manganese, aluminum and zinc are probably impacting the macroinvertebrates more than pH or alkalinities, but complex interactions in the hydrology of the mine pools can cause temporarily harmful concentrations of many chemical parameters in the streams. In addition, much of the substrate at the impacted sites is dominated by clay, which is a very poor substrate for macroinvertebrates. Several recommendations are given for future restoration and monitoring, including a better understanding of the hydrology of the watershed, improving the substrate quality in the streams, and the need for experimental work to determine specifically which chemical factors are limiting the recovery of the biota.

Introduction

Slippery Rock Creek in Western Pennsylvania, USA is a tributary in the upper Ohio River Watershed that drains a 1,100 km^2 area. The Slippery Rock Creek Watershed has been severely impacted by acid mine drainage (AMD) for more than a century, predominantly from coal mining activities in a 70 km^2 area at the headwaters of the stream. Contact of AMD water with stream water of higher pH can precipitate large amounts of iron hydroxides on the substrata, as well as lower the pH of the stream (Boult et al. 1994, Robb and Robinson 1995). These effects usually result in drastic reductions in benthic macroinvertebrate abundance and diversity (e.g., Dills and Rogers 1974, Letterman and Mitsch 1978, Scullion and Edwards 1980), and significant changes in benthic algal communities (Verb and Vis 2000).

Measures to abate AMD discharges have been implemented in the watershed since the 1970's and have improved water quality in the lower Slippery Rock Creek watershed, however, the main stem and tributaries in the headwaters area remain severely impacted by AMD. Three types of passive treatment systems have been installed since 1995 to treat discharges in the headwaters of the watershed; aerobic pond/wetlands, anoxic limestone drains (ALD), and vertical flow wetlands. When correctly designed for the flow rate and chemistry of the discharge, passive treatment systems have been shown to be extremely effective in improving water quality (Hedin et al. 1994, Robb and Robinson 1995). In addition, there has been extensive reclamation of land area polluted by coal refuse in the watershed. A total of 9 abatement projects have been completed in the headwaters area since 1995 to reduce AMD impacts (Fig. 1), with several more planned in the future. Monitoring of chemical and biological parameters began in 1995 (full scale monitoring started in 1996) to evaluate the effectiveness of passive treatment technology in restoring the stream ecosystems of Slippery Rock Creek in the headwaters area. Our objective was to compare chemical and biological parameters in impacted stream sites in the watershed to unimpacted reference streams prior to and during the restoration process.

Study Site

The headwaters area of Slippery Rock Creek has over 59 AMD discharges that represent an average of 30% of the total flow out of the headwaters drainage . The discharges range in pH from 3.0 to 6.1 and in iron concentrations from 0.3 to 225 mg l^{-1}, and load approximately 1289 kg day^{-1} of acidity and 282 kg day^{-1} of iron into the stream (PA DEP 1998). Seven passive treatment systems have been constructed in the watershed since 1995 to abate AMD impacts (Fig. 1). These systems add over 200 kg day^{-1} alkalinity (as $CaCO_3$) and remove over 40 kg day^{-1} of iron in the headwaters area. In addition, 100,000 tons of coal refuse was removed and 175,000 tons of alkaline ash were applied to an 8.5 ha site in the watershed (Fig. 1). Details of the treatment systems and restoration efforts are provided in the first section of this report.

Methods

Detailed methods were provided in the QA/QC work plan written for this study. Below is a brief summary of the methods. Sample dates for which analyses were performed for each parameter are given in Table 1.

Study Design

Twelve sites in the watershed (Fig. 1) were initially sampled for selected chemical parameters in the summer of 1995. Quarterly, full-scale chemical sampling (spring, summer, fall and winter) occurred from summer of 1996-winter 1998, with an additional sample taken in summer 1999 (Table 1). Samples taken in fall 1999 and after have yet to be analyzed. Seven of the sites are in the main stem of Slippery Rock Creek (2-4th order streams) within the headwaters area and impacted by AMD (sites 44, 46, 60, 63, 64, 65 and 67), 3 are AMD impacted tributaries (49, 62, and 68), and 2 sites are in "control" or reference streams that are unimpacted by AMD (Fig. 1). One of the control streams is a 1st order unimpacted tributary within the headwaters (Site 61), the other is Wolf Creek, a 4th order stream that is in the Slippery Rock Creek watershed but not in the headwaters area. Biological samples were taken at a subset of the sites (44, 46, 60, 61, 65, 67 and Wolf Creek) on the dates specified in Table 1.

Water Chemistry

Temperature, dissolved oxygen, pH, alkalinity and acidity were measured in the field following Standard Methods (APHA 1989). Water samples for dissolved element analysis were filtered in the field through a 0.45 micrometer Millipore Filter and fixed with concentrated HNO_3 to a pH < 2.0. Unfiltered water samples for total elemental analysis were fixed with concentrated HNO_3 in the field. In the laboratory, unfiltered samples were digested with HNO_3 following Standard Methods (APHA 1989). Dissolved and total water samples were analyzed for Fe, Mn, Ni, Co, Pb, Al, Cu, Zn, Cd, Cr, Si, Mg and Ca using a Perkin Elmer Plasma 400 inductively coupled plasma spectrophotometer as outlined in APHA 1989. Sampling for total metals in aqueous samples, which was not required for this project, began in 1997 (Table 1)

Discharged was measured at each site on each sample day using a Marsh McBirney flow meter in order to calculate dissolved and total loadings for each element.

Sediment Chemistry

Sediment was sampled from the stream sites using an acid washed shovel. Because sediment particle size can greatly influence metal sorption, metals analysis was done on the clay fraction of the sediment. Clay was separated from other particle sizes by settling. The resulting clay was dried, weighed and digested following EPA Method 3050A. The samples were analyzed for the same 13 elements as for the water samples using a Perkin Elmer Plasma 400 inductively coupled plasma spectrophotometer as outlined in APHA 1989.

Macroinvertebrates and Algae

Macroinvertebrates in riffles were sampled at Sites 44, 46, 60, 61, 65 and Wolf Creek using a Surber sampler, although a Hess sampler was used on some days at Sites 65 and Wolf Creek when the water depth was too high for a Surber. Samples in riffles areas were not taken at Site 67 because shallow riffles were not present in this area of the stream. Three replicate samples were taken at the sites on the sample dates (although high water prevented sampling at deep water sites on a few dates) and the organisms preserved in 70% ethanol. In the laboratory, individuals were sorted and identified to the lowest taxonomic level possible (usually genus). Macroinvertebrates in pool areas were sampled at Sites 44, 46, 61, 67 and Wolf Creek using an Ekman Dredge following the same procedure. A beaver dam at Site 67 greatly impaired sampling with an Ekman, and samples could not be successfully taken on most dates at this site. There were no suitable pool habitats at Site 60, and initial sampling at Site 65 indicated that there were no invertebrates in the fine compacted clay at this site.

Epilithic periphyton algae (algae that grows on rocks) was scraped from 3 rocks in riffle areas at Sites 44, 46, 60, 61, 65, 67, and Wolf Creek, respectively, using an SG-92 sampler following the protocols of the USGS National Water Quality Assessment (NAWQA) monitoring program (Porter et al. 1993). Because of the time consuming nature of counting algal samples, the 3 rock scrapings were combined into a single composite sample for each site on the sample dates. Epipelic periphyton (algae that grow on the sediment surface) was sampled at the same sites following the coring method of NAWQA (Porter et al. 1993). Two cores were combined into 1 composite sample per site per date. Algal samples were preserved with Lugol's Solution. Algal counts for density were done in Palmer Cells with diatoms lumped into one taxonomic category. The sample was then digested in HNO_3, rinsed, dried onto coverslips and mounted in NAPHRAX for diatom identification (DeNicola et al. 1990). All algae were identified to species.

Leaf Packs

Leaf packs containing 5 g of dried sugar maple leaves were placed at Sites 44, 46, 64 and Wolf Creek in the fall of 1997 and 1998. Packs were removed over the next 5 months following placement and the leaves dried and weighed.

Metal Concentration in Invertebrate Tissue

Given the extremely low density of the macroinvertebrates fauna at most sites in Slippery Rock Creek, it was difficult to collect enough of one type of organism to measure concentrations of metal in their tissues. In the summers of 1997 and 1998 1.7-3.1 g wet weight of hydropsychid caddisfly larvae were collected at Wolf Creek and Site 60. The organisms were digested following EPA Method 3050A for sediments. The samples were analyzed for the same 13 elements metals as for sediment samples using a Perkin Elmer Plasma 400 inductively coupled plasma spectrophotometer as outlined in APHA 1989. Weight wets were converted to dry weight based on a previously established regression. In the summer of 1999, caddisflies were collected again at Wolf Creek but have yet to be analyzed. A beaver dam built at Site 60 at the end of 1999 greatly reduced riffle habitat and caddisflies could not be collected.

Substrate Experiment

Restoration of streams impacted by acid mine drainage (AMD) focuses on improving water quality, however precipitates of metals can remain on the substrata and continue to adversely affect the benthos. To examine solely the effects of AMD precipitates, we compared community composition in 30.5 cm^2 trays of clean and AMD metal-coated substrata that were placed in the reference stream with high water quality, Wolf Creek. Sets of trays containing cobble and limestone, respectively, were placed in an AMD contaminated site (44) for 2 weeks to coat the substrata with metal precipitates. These trays were then transplanted to Wolf Creek along with trays of clean cobble and limestone to create 4 treatments of substrate, each with 5 replicates. After 4 weeks, the substrata of the trays were sampled for invertebrates and periphyton following the methods for riffle substrates above. In addition, rock surfaces before and after placement in Wolf Creek were scraped and digested to determine chemical concentrations of metals. Digestion and analysis of metals followed the above method for sediments. Surface area of the rocks was determined by wrapping them in aluminum foil and comparing to weights of foil of known areas.

Results and Discussion

The complete set of values for all water chemistry and sediment parameters on each sample date are given in Appendix I. Discharge and loadings for metals are in Appendix II.

pH, Alkalinity and Acidity

Values for pH in the headwaters ranged from 4.2 to 6.9 and were lowest overall at Sites 44, 62, 63 and 64 (Figs. 2-4). Pennsylvania water quality standards cite pH below 6 has being detrimental to aquatic life, although severe effects usually are found below 5.5. Most impacted sites in the headwaters area are on this threshold for average pH and often go below 5.5 during certain periods of flow. Alkalinity in the headwaters was highest at Sites 46, 65 and 67 (Figs. 5-7). State water quality standards list impacts occurring below an alkalinity of 20 mg/l for most streams, and sites in the headwaters area almost always below this. The low alkalinity at the small reference stream in the headwaters is also below 20 mg/l, suggesting a naturally low buffering capacity of the geology of the area in general. Alkalinity and pH values were substantially higher in the large reference stream, Wolf Creek, primarily because it is in a different geologic group than the headwaters (Potsville vs. Allegheny) with more tributaries intersecting the Vanport Limestone outcrop geology. Acidity was higher at all AMD impacted sites compared to the control streams (Figs. 8-10). Dissolved oxygen values at all sites were usually near saturating most of the year (Appendix I), and should not have a negative effect on the biota.

There are no treatment systems above Site 44 and it had the lowest pH values on average in the main stem (Fig. 2). Alkalinity and pH at Sites 46, 49, 60 and 64 were usually higher immediately following initiation of treatment upstream, but this often was not sustained (Figs. 2-7). This coincides with data from the discharge of the ALD built at discharge101, which showed higher alkalinities in the first month of operation (see above sections of this report). In ALD and vertical flow wetland systems above these sites, the AMD discharged is passed through a buried limestone matrix and then exposed to the atmosphere in a retention pond prior to discharging into the stream. The dissolution of limestone increases the pH and alkalinity, while exposure to the atmosphere results in the precipitation of oxidized iron and other metal species. Initially high alkalinity discharge in a new ALD might result from the dissolution of fine limestone particles immediately after water enters the system. Despite the initially high alkalinities after a treatment system is installed, the main stem in the headwaters does not appear dramatically different from the reference Site 61 in overall pH, alkalinity and acidity. The tributaries, Sites 62 and 68 (Seaton Creek), still show relatively low pH and high acidities indicating their drainage areas are negatively impacting the main stem and perhaps canceling out effects of the treatment systems.

Interpreting the effect of treatment on water chemistry in the headwaters has been difficult because there was only one sample taken prior to installation of the first treatment system. In addition, alkalinity, acidity and pH were quite variable over time within each site and there could have been runoff-dependent pulses of mine water greatly affecting the stream water chemistry on some sample dates. So although there appears to be a slight improvement in pH and alkalinity downstream of a treatment system after it is installed, the trends are not consistent. Dills & Rogers (1974) found high surface runoff during wet periods often increased dilution of AMD inputs, however we found no significant correlation between stream pH and stream discharge ($p > 0.05$). A better understanding of the hydrology of the area is needed in order to explain some of the natural variability in water chemistry. A greater improvement in stream water chemistry is expected as more treatment systems are constructed and a greater percentage of the discharges are treated.

Aqueous Metals

The metals with the highest soluble (dissolved) and total aqueous concentrations were iron, manganese and aluminum. Mean concentrations for dissolved iron rarely exceeded 1.5 mg/l at impacted sites in the headwaters but was higher than at reference sites, which ranged from 0 to 0.4 mg /l (Fig. 11). Mean concentrations for total iron also were higher in the impacted sites than in the two reference sites (Fig. 12), with concentrations about 3-8 times higher at Sites 63, 62 and 68. Pennsylvania water quality standards list maximum iron levels for aquatic life as 1.5 mg/l total and 0.3 mg/l dissolved. These standards are exceeded a certain times of the year at impacted sites in the watershed except Site 60 (Figs. 11-12, and Appendix I). The decrease in dissolved iron downstream of Sites 44 to Site 60 (Appendix I) may be a result of installed treatment systems between those sites. It is difficult to interpret any decreases in dissolved iron at Sites 46 and 60 because there is only one sample date prior to installation of any treatment system. The high iron concentration at Site 63 indicates there is an obvious input of iron from the tributary that enters just below Site 60.

Dissolve manganese also was lowest for the reference streams, but generally less than 1 mg/l for all sites except 65, 49, 62 and 68 (Fig. 13). The latter three sites were relatively high in total Mn in the water (Fig.14). Pennsylvania state standards for total Manganese are 1.0 mg/l and are 0.3 mg/l for dissolved for New York State (PA does not have a dissolved standard). All the impacted sites in headwaters area exceed these standards at some point during the study.

Mean values of dissolved and total aluminum at impacted sites were similar to values for reference sites, except for the higher concentrations at Site 68 (Figs. 15 and16). Pennsylvania aluminum standards depend on the species of organism, the standard for New York is 1.0 mg/l total Al, which is near the average value for most sites except 46 and 68. Nontoxic silicon is associated with aluminum as aluminum silicates in minerals, and had similar trends in concentrations as aluminum in the aqueous samples. Silicon was slightly higher at impacted sites than at references sites, both as dissolved and particulate species (Figs. 17 and 18).

Lead and zinc were the metals with the next highest concentrations in the water. Both soluble and total lead had concentrations at Sites 68 and 65 higher on average than all the other sites (Figs. 19 and 20). There are no biota standards for lead in surface water for PA, and EPA standards depend on the organism. Concentrations of zinc were quite variable at each site. There was not much difference between impacted sites and the reference sites for total zinc, except for the higher values at Site 68 (Fig. 22). Dissolved zinc was generally higher at the impacted sties than the reference sites and the average concentrations close to or exceeded the toxic threshold minimum, 0.1 mg/l, at Sites 63 and 68. Most of the impacted sites also exceed the minimum at some point in the study (Fig. 21).

Soluble and total cobalt, nickel and cadmium rarely exceed 0.04 mg/L at all sites except for Site 68 (Figs. 23-28). EPA water quality standards are 0.005 for dissolved cobalt, which was only exceeded in a few samples. Standards for nickel and cadmium depend on LC50 tests for particular organisms. Aqueous concentrations of copper and chromium were near the detection limits of the ICP for most samples, and most values below the toxic threshold of 0.012 mg/l (Figs. 29-32). The noticeable higher total copper concentrations at Site 44 resulted from an extremely high value on one date that may be an analytical error.

Aqueous concentrations for both calcium and magnesium were lowest at the small reference stream (Site 61). Concentrations in Wolf Creek were similar to impacted sites except for Sites 68 and 65, which were considerably higher (Figs. 34-37). One would expect higher levels of calcium and magnesium as pH decreases from dissolution of their alkaline minerals. Higher calcium levels in the watershed could also result from dissolution of calcium from limestone in ALD's and vertical flow systems. Given the high sulfate levels in the impacted streams (200-700 mg/l), high calcium may result in precipitation of gypsum ($CaSO_4$) in the streams.

There were no clear temporal trends in the aqueous metal concentrations at the sites (Appendix I). There was not a clear decrease in concentrations of dissolved iron, aluminum and manganese at Sites 60 and 64, which should be affected most by the installed treatment systems, even when only dates of similar discharge were examined . In some metal, such as iron, concentrations go down immediately after treatment was begun but then rise again. However, given that there is only one sample date before any treatment systems were installed, it is difficult to assess an overall affect of the treatment systems over time. In addition, the insolubility of these metals at higher pH and oxygen levels causes them to precipitate soon after they leave the mine discharge, complicating their entrance into the stream. Complex interactions in the hydrology of the mine pools can cause large temporal fluctuations in AMD discharge or dissolution of precipitates in the watershed that may mask affects of the passive treatment.

Sediments

The mean concentrations of all the elements measured from the clay fraction of the sediment were distinctly higher in Seaton Creek (Site 68) than all other sites (Figs. 38-50). In addition, sites 49 and 65 were higher in concentrations of zinc, nickel and cobalt. Other than these exceptions, average sediment concentrations for all the elements were similar among the impacted and reference sites. Pennsylvania does not have standards for metal concentrations in stream sediments. We are still searching literature values for sediment standards for metals, but have found values of 410 and 270 mg/kg for zinc and copper, respectively. The copper standard was exceeded only by Site 68 sediments (Fig. 47), and the zinc standard was exceeded by sediments at Sites 49, 68 and the small reference stream, Site 61 (Fig 43).

As with the aqueous samples, there were no consistent temporal changes in the sediment metal concentrations during the study period (Appendix I).

It is uncertain how relevant our metal data for sediments are too the benthic organisms as clay is not a substrate that supports most taxa. However, the benthic habitat at many sites in the study (46, 49, 63, 64, 65, and 68) were dominated by almost pure clay substrata, probably resulting from erosion of the highly disturbed terrestrial watershed. In addition, clay beds are naturally present in the watershed, often underlying the coal seams (PA DEP 1998).

Benthic algal density

Epilithic algal densities generally increased as stream size gets larger downstream (Fig. 51). Densities in the 4th order Wolf Creek are approximately 100 times higher than at the most upstream site, 1st order Site 44. Benthic algal densities in streams are usually limited by light and thus often increase as stream size increases and the canopy becomes more open (Vannote et al. 1979). In addition, densities are generally highest when the water temperature is warm and light is abundant in summer, and in fall (with the loss of leaves on tress). Others have found that differences in periphyton densities are generally controlled more by light or nutrients than from chemical affects of AMD (Verb and Vis 2000). However, comparison of densities at the 1st order reference site (61), to the smaller AMD impacted sites such as 44, 46 and 60, indicated some reduction at the latter sites. The lower densities at these sites is most likely due to the unconsolidated fine sediment (clays and iron oxide precipitates) burying the rocks, rather than a purely chemical affect from AMD.

Epipelic algal densities follow a similar trend as the epilithon (Fig. 52), except for Site 60, which has very high densities on two sample dates in early 1998. Densities are lower for Sites 44 and 46, again probably reflecting the more unstable substrate in these areas. Temporal changes in both epilithon and epipelon densities do not appear to be related to installation of treatment systems for AMD, which is not surprising given that algal species composition is generally affected by AMD but not algal densities (Verb and Vis 2000).

Benthic algal species composition

Relative abundance values for each taxon in each benthic algae samples are given in Appendix III.

Mean species diversity of the sites for the whole study (i.e., dates pooled for each site) indicate that diversity was highest in Wolf Creek compared to other sites for both epilithic and epipelic algae (Tables 2 and 3). The small reference, Site 61, had a slightly more diverse epilithic and epipelic algal community that the other sites in the headwaters, indicating a small affect of AMD impact on algal diversity at these sites.

The diversity of algae in both the epilithon and epipelon was consistently, slightly higher for most dates in Wolf Creek than for the other sites (Figs. 53 and 54). Comparison of the upstream sites to the small reference stream, 61, indicates that diversity values were variable but similar among the sites for most dates. In fact, overall, epipelic diversity was higher at Sites 44 and 46 than Site 61 on most dates (Fig. 54). Serious impact on benthic algal diversity does not begin to appear until below pH 4.5 (DeNicola in press), which rarely occurred at any of the sites. However, many species of diatoms have narrow pH tolerances and are good indicators of pH, thus while there is little change in diversity there was a shift in species composition at the AMD impacted sites.

Comparing the similarities in average species composition for the whole study (dates pooled for each site) among sites indicates that Wolf Creek is most different from all other sites in both epilithic an epipelic species composition (Tables 4 and 5). Dominant taxa in both the epilithon and epipelon in Wolf Creek were the blue-green alga, *Phormidium*, and the diatoms *Navicula gregaria* and *Navicula lanceolata* (Tables 2 and 3). There were also many rare species in this diverse flora that are typical for a clean water, moderately productive, high pH stream. *Phormidium* is a common taxon in streams and was more dominant at the other sites, indicating it was tolerant of their AMD impacts. Several types of cyanobacteria have been found to be tolerant to heavy metals (Genter 1996), but generally not to very acidic conditions. Diatom taxa typical of low pH are species of *Eunotia* and *Anomoeonies*, which are also abundant in severely impacted AMD streams (Verb and Vis 2000, Warner 1971). In addition, *Achnanthes minutissima,* a common taxon in streams that are highly disturbed, has been found to be abundant in streams with intermittent discharges of AMD (Verb and Vis 2000). Sites 60, 65 and 67 were similar in species composition, primarily because of their higher relative abundance of *E. minor* and *E. exigua* in both the epilithic and epipelic assemblages (Tables 2 and 3). These taxa perhaps reflect a greater impact from AMD and their larger stream size than Sites 44 and 46. The latter sites are more similar to the small reference stream, 61, because of the slightly lower relative abundance of this acid tolerant diatoms and a great abundance of *Phormidium*. Site 61 does have several acid tolerant diatoms, which is not surprising given its pH and low alkalinity. Generally these taxa are less abundant and *A. minutissima* more abundant compared to the AMD impacted sites (Tables 2 and 3).

Algal taxa found in severely impacted AMD sites are generally those you would find in any highly acidic environment (pH < 4), and would include acid tolerant *Euglena* species, green algae such as *Klebsormidium* and *Zygogonium*, and several species of diatoms in the genera

Eunotia, *Pinnularia, Frustulia* and *Nitzschia* (DeNicola in press). Many of the above non-diatom taxa are restricted to very low pH's but the above diatoms are often found in pH as high as 6, and the latter were common in the headwater streams in this study. There has not been much work on separating pH from metal affects on benthic algae, which makes finding indicator species just for AMD difficult. Some of the species found in the AMD impacted sites have been shown to be tolerant of additions of heavy metals in mesocosms (*A. minutissma* and *Fragilaria vaucheria*), while several of the common taxa in Wolf Creek have been found to drop out following metal exposure (*Melosira varians, Nitzschia palea*) (Medley and Clements 1998). Interestingly, the toxicity of some metals such as Zn, Cu and Pb appear to become less toxic to algae has pH decreases, because hydrogen ions compete with metal ions for binding sites (Genter 1996) . Relatively high pH values in the headwaters would mean metal loadings from AMD may have a proportionally larger effected than expected on algae.

To examine species changes in species composition at sites over time, ordination (detrended correspondence analysis) was used. Ordination simplifies patterns in species composition in samples by arranging species and samples in a low-dimensional space (e.g., a 2-dimensional graph) such that similar entities are close by and dissimilar entities are far apart. There are 2 results of ordination analysis, a species and a sample ordination. In the species ordination, species are ordered along axes in the graph, with species close together being similar in the distribution (i.e., they occur together frequently in the samples). In the sample ordination, the samples are ordered along axes, with samples that are close together having similar species composition. The two ordinations are related so that the placement of a sample (x,y coordinates) in the sample ordination corresponds to positions of species in the species ordination that are characteristic of that sample.

Examination of the ordination of epilithic samples indicates that samples from Wolf Creek form an isolated cluster, indicating they are quite different in species composition from the other sites(Fig. 55). Wolf Creek is characterized of taxa typical of circumnuetral pH and slightly eutrophic water, such as *Navicula gregarica* and *Melosira varians*. Samples in the upper left corner of Fig. 55, generally contain taxa that have an acidic flora, with characteristic species such as *Eunotia exigua* and *Frustulia rhomboides* (Fig. 56). This group of samples is primarily from Sites 65 and 67, and contains samples from 1996 and 1997 at Site 60. Later samples from Site 60 are closer to those from the reference, Site 61, indicating an improvement of water quality to less acidic conditions at this sight. This trend is corroborated by comparing the similarities of samples from Site 60 to the average flora at Site 61 (Table 6). From 1996 to 1999, the flora at Site 60 becomes more similar to reference Site 61, indicating an reduction in AMD impact, possibly due to construction of the several treatment systems upstream of this site.

Ordination of the epipelic samples and species shows similar results as the epilithon. Wolf Creek is quite different in species composition from the other sites, Sites 65 and 67 tend to be similar, and samples from Site 60 become more like the flora at the small reference stream over time (Figs. 57 and 58).

Macroinvertebrates

Relative abundance values for each taxon in macroinvertebrates samples are given in Appendix IV.

Density and species composition in riffles in pools

Mean macroinvertebrates densities in riffles were 1-2 orders of magnitude higher at the 2 control sites (61 and Wolf Creek) than at the most AMD impacted sites on most dates (Figs. 59 and 60). At site 60, macroinvertebrates increased about an order of magnitude approximately 6 months after an ALD was installed 300 meters upstream in 1996, and again in 1998 after installation of a vertical flow system. It is difficult to assess whether the installation of the treatment systems caused the large rise in densities at this site on the 2 dates because densities decreased to previous low levels one sample period after each large increase (Figs. 59 and 60). There was also an order of magnitude increase in invertebrate density at Site 46 immediately following installation of a vertical flow system in 1998 upstream. However, as at Site 60, the densities decreased to previous levels the following quarter. Also there was no increase in density at this site following installation of several ALD's upstream in 1996.

Mean taxa richness (number of different genera present) of macroinvertebrates in riffle areas was less than 6 for all AMD impacted sites on all sample dates, but ranged from 2-45 at the two reference sites (Figs. 61 and 62). Of the impacted sites, Site 44 had the highest overall richness, but was still quite a bit less than for the reference sites. Richness did increase slightly at Site 46 immediately following installation of treatment systems but only by a couple of taxa, and subsequently richness decreased. The large increases in density at Site 60 immediately following installation of the treatment systems was dominated by a few taxa, the caddisfly *Hydropsyche* in 1996 and 2 genera of blackflies in 1998.

Composite samples of the sites (i.e., averaged over dates) indicate there were no extremely dominant taxa at the two reference sites (Table 7). The mayflies, *Isonychia, Stenomena* and *Caenis*, made up over 20% of the taxa in Wolf Creek, and the *Emphemerella* comprised about 5.5% of the Site 61 community (Table 7). Mayflies were almost entirely absent from all other sites, indicating that these sites are still highly impacted by AMD. Mayflies are considered one of the most sensitive orders of aquatic insects to AMD (Warnick and Bell 1969), as well as to isolated effects of low pH and heavy metals (Clements et al. 1988). The dipterans, *Tipula* and *Hexatoma* were abundant at Sites 44 and 46. In general, dipterans are one of the more tolerant groups to AMD (Letterman and Mitsch, 1978, Scullion and Edwards 1980). The filter feeding caddisfly, Hydropsyche, was abundant in riffles at all the sites, including the reference streams (Table 7). This taxon has been found to be tolerant of AMD in several other studies (Warnick and Bell, 1969, Letterman and Mitsch, 1978) and to effects of heavy metals in western US streams (Clements et al. 1988).

Similarity indices and ordination for all samples on every date, indicate that Sites 44 and 46 were most similar in taxonomic composition at most times, and were characterized by the dipterans, *Tipula*, *Hexatoma*, *Chrysopos*, and the midge *Georthocladius* (Table 8 and Figs. 63 and 64). Samples from Wolf Creek were also fairly distinct on all sample dates, because of their abundance of the mayflies, *Stenomena*, *Stenactron*, *Macadnonna*, and *Isochynia*, some stonefly taxa, and the midges, *Chironomus*, *Diamesa*, and *Microtendipes* (Figs. 63 and 64). Other sites varied widely in taxonomic composition on different dates. On several dates, samples from Site 60 were completed dominated by hydropsychid caddisflies and this made them similar to Wolf Creek, which also contained these taxa but in a much more diverse community. Unlike the algal data set, the macroinvertebrates community does not indicate that Site 60 has improved over time. However, a beaver dam was constructed at this site in 1998, completely flooding the riffle area and potentially masking any improvement. The changes in flow, water depth and substrate deposition would have a large impact on the invertebrate community but less of an effect on benthic algal composition.

The low density and taxa richness of the benthic macroinvertebrates in riffles at AMD impacted sites relative to the control sites corresponds to many other studies of AMD effects (Dills and Rodgers 1974, Letterman and Mitsch 1978). Based only on the average pH and alkalinites, the Slippery Rock headwaters should be able to support a larger and more diverse invertebrate fauna (Hoehn and Sizemore 1977). However, some of the chemical data indicated that concentrations of heavy metals are near or at the toxic threshold for stream fauna, and probably are having the greatest affect on invertebrates. There is also great variability in water quality over time, and the overall low invertebrate densities probably result from impacts during periods of high AMD input. In addition, mining disturbance in a watershed greatly increases soil erosion, which alone can have as large or larger a detrimental affect on invertebrates as water chemistry (Hoehn and Sizemore 1977). The watershed in headwaters area of Slippery Rock Creek has been highly disturbed from mining and has a lot of naturally occurring clay. The increased sediment load in the steams together with iron precipitates from AMD bury substrate and reduce invertebrate density and diversity. Sites such as 46 have deep clay and silt deposits that are extremely unstable and poor habitats for invertebrates. It is probably the combination of burial by fine sediments and toxic levels of metals at certain times during the year that are still affecting the macroinvertebrates fauna in the treatment area.

Density and species composition in pools

Density of macroinvertebrates in the fine substrate of pools is highest in Wolf Creek. Of the remaining sites, Site 46 is extremely low in density, probably reflecting the compacted clay substrate the covers most of this site (Fig. 65). All the headwater sites, including the small reference stream, are low order streams where pools are generally not a good habitat for invertebrates, and this is reflected in their low densities.

Species richness in pools of Wolf Creek were not much higher than at other sites (Fig. 66). The high densities in the silt pools of Wolf Creek were due to oligochaete worms (not identified below the class level), which made up 59% of the community, and the chironomid midge, *Chironomus* that made up 22.8% (Table 9). Oligochaetes and *Chironomus* were almost completely absent at the small reference site, but it had a diverse assemblage of other midge taxa and the presence of the burrowing mayfly, *Litobrancha*, also indicates good water quality. There was very little similarity between the macroinvertebrates in pools at any of the sites, indicate they were quite different in community composition (Table 10). Impacted sites were surprisingly diverse in invertebrates, particularly Site 44, which had a fairly diverse chironomid assemblage

(Table 9). However, the substrate in pools at Site 44 is fairly coarse and many of the invertebrates sampled there are more characteristic of riffle areas and might be accidental occurrences. Some chironomid taxa at the AMD impacted sites are generally recognized to be tolerant to AMD (Dills and Rogers 1974, Letterman and Mitsch, 1978, Roback and Richardson 1969, Scullion and Edwards 1980). Although the midge, *Chironomus*, has been found to be one of the most abundant macroinvertebrates in severely impacted AMD sites (Carrithers and Bulow 1973, Nichols and Bulow 1973), it was rarely found at AMD impacted sites in our study. The presence of the megaloptern, *Sialis*, at AMD sites in our study is consistent with previous observations of its tolerance (Nichols and Bulow1973).

Pools are not an abundant habitat in many of these small stream sites, and they generally do not support many invertebrates even in clean, small streams. Given the extremely low densities of invertebrates in the pools at the small stream sites on most dates, and that many of the taxa found were probably accidental occurrences from riffle areas, the samples from pools did not provide much information. We would suggest not sampling invertebrates in pools for future monitoring.

Leaf Pack Decomposition

There was no difference in the rate of leaf pack decomposition among Sites 44, 46, 64 and Wolf Creek in 1997 and 1998 (Fig. 67). Burial of leaf packs in the unstable sediments of Site 44, 46, and 64 created much variability in breakdown rates, and compromised this aspect of the study.

Substrate experiment

The sandstone substrates coated with metal precipitates from AMD, lost aluminum, iron and manganese, and gained zinc, after being in Wolf Creek for 4 weeks (Table 11). Limestone substrate lost aluminum, iron and zinc, but gained manganese (Table 11). The substantial losses of aluminum and iron on both substrates (18-40 %) indicates the potential for loss of these metals on the bottom of the headwater streams if water quality (e.g., pH) is increased. Changes in zinc and manganese are not as clear. "Clean" sandstone and limestone rocks gained manganese and lost zinc in Wolf Creek, indicating the abundant iron on the AMD coated rocks may have affected the adsorption of manganese and zinc.

Given that invertebrate density and richness can be high in other streams with similar pH and alkalinity as Slippery Rock Creek, it may be that iron precipitate on the substrata is having the greatest impact. Scullion and Edwards (1980) found that iron hydroxide precipitates from an alkaline mine discharge had just as great an effect on macroinvertebrates as that of an acid discharge. In addition, Hoehn and Sizemore (1977) working in streams with pH's around 6.0 and affected by AMD, suggested the coating of $Fe(OH)_3$ played a greater role than pH on the fauna. Precipitates of iron onto and in the bodies of invertebrates has been shown to increase mortality (Gerhart 1992). Also, iron precipitates can bury epilithic algal growth and reduce food for macroinvertebrates grazers (McKnight and Fedter 1984).

In our experiment, invertebrate densities on trays of AMD precipitate coated and clean rocks placed in Wolf Creek ranged from 11 to 2959 individuals/m2, and were not significantly different among treatments ($p = 0.51$). Taxonomic composition and diversity of invertebrates were very similar among the treatments with 85-89% of all assemblages being composed of taxa typically found in the ambient fauna of Wolf Creek, *Isonychia, Stenonema* and *Taneopterx.* Periphyton densities ranged from 215,457 to 1,829643/cm^2 and were also not significantly different ($p = 0.40$). Taxonomic diversity and composition were similar among treatments, and similar to what is normally found in the epilithon in Wolf Creek. The diatoms *Nitzschia dissipata* and *Navicula gregarica* dominated in all assemblages. Metal coated substrata in AMD streams did not alone inhibit the colonization of AMD intolerant organisms either for sandstone or limestone cobble. Our results suggest that metals in the water are probably affecting organisms more than benthic metal precipitates. This has been found to be true in similar substrate transfer experiments done in heavy metal contaminated streams in the Western US (W. Clements, pers. com.).

To further examine the roles of water vs. substrate toxicity, a complimentary experiment to examine affect of aqueous metals alone on invertebrates was done in the fall of 1999. Cages of caddisflies from Wolf Creek were placed at Site 65 in the watershed for 96 hours and the rate of metal accumulation will be measured. Survival was nearly 100% but metal concentrations in the tissues not yet been analyzed.

Metal concentrations in caddisfly tissue

Tissue concentrations in hydropsychid caddisflies collected in Wolf Creek and at Site 60 were below detection limits for Nickel, Lead, Copper, Cobalt Chromium, indicating little to no accumulation of those metals. Concentrations of aluminum and manganese were higher in Wolf Creek than at Site 60 on both sample dates. Tissue concentrations for iron and zinc were higher at Site 60 than in Wolf Creek (Table 11). It is interesting to note that values for aluminum and zinc in Wolf Creek and Site 60 were about 3-5 times lower than tissue concentrations we measured in caddisflies from the AMD contaminated stream, Big Run Creek.

The toxicity of metals to aquatic invertebrates is affected by pH conditions, water hardness and the presence of other metals in a complex manner. Some metals, such as cadmium, copper and zinc, are predicted to have a decreased toxicity at low pH's due to competition with H+ at binding sites. Other metals, such as lead, are predicted to have increased toxicity at low pH's do to changes in speciation of the metal. Aluminum appears to be most toxic in the pH range 5.8-6.2 (Mackie 1989, Genter 1996). Assuming accumulation is related to toxicity affects, such interactions may explain why some metals are accumulated more at the higher pH reference site, Wolf Creek. Comparison of values to published standards for invertebrate tissue indicates that aluminum is well below the standard, but is near the zinc standard at Site 60 and one date in Wolf Creek (Table 12). Aquatic invertebrates also have the ability to evolve detoxifying and elimination ability for metals (Klerks and Weis 1987). It is obvious more work is needed to understand the affects of metal toxicity from AMD on biota in Slippery Rock Creek.

Overall Assessment of Water Quality at the Sample Sites in Slippery Rock Creek

The impacts at the uppermost site in the headwaters, 44, are due to untreated AMD entering the stream. The invertebrate fauna density is very low, but relatively diverse compared to some other sites, probably because of the coarse substrate in riffle areas. Unfortunately, most of the pebble to cobble size particles at this are actually coal coated with iron precipitate. Alkalanities and pH are higher at Site 46, which is downstream of Site 44. Site 46 is also downstream of several ALD's and treatment wetlands, which maybe adding alkalinity to the stream. There were substantial jumps in alkalinity at this site immediately after treatment systems were built, which subsequently decreased. The next downstream site is 60, which is in area that has numerous AMD discharges. In addition, the tributaries of Sites 49 and 62 , which have some of the worst water in the watershed, enter the stream above Site 60. The vertical flow system built in August 1998 above Site 49 has improved its pH and alkalinity, however this site was high in aqueous manganese and had high concentrations of zinc in the sediment. Site 62 was low in pH and high in aqueous iron and manganese. Two ALD's have been construct to treat several discharges that use to directly enter Site 60. As at Site 46, there does seem to be an immediate increase in alkalinity following completion of the ALD's, which then subsides. There is also a drop in aqueous iron at this site immediately following the completion of systems, but it is not sustained and the temporal fluctuations are large. The algal composition of this site has become more similar to the small reference stream over time, a positive indication that there has been some improvement at Site 60. In addition, invertebrate density increased by an order of magnitude immediately following the completion of the first treatment system, although it was dominated by a 1 or 2 taxa. The drop in invertebrate densities starting in 1998 may be due to a Beaver Dam flooding the extensive riffle area, rather than effects of water chemistry. A tributary enters the main stem just below Site 60 and seems to degrade water quality at the next downstream site, 63. Site 63 has a lower pH, and high iron and zinc in the water than Site 60, making it one of the poorer sites in terms of water quality. Unfortunately the building of two large vertical flow systems between Sites 63 and 64 does not seem to have affected the water chemistry much at Site 64. There was an increase in alkalinity after completion of the systems, but it has not continued. The large tributary, Seaton Creek (Site 68) has the worst water chemistry in the watershed. It has the highest levels of most aqueous metals, especially iron, manganese, aluminum and zinc. In addition, most metals in the sediment were higher in Seaton Creek compared to other sites. The input from Seaton Creek is probably responsible for the relatively high concentrations of manganese in the water and zinc in the sediments at Site 65. Sites 65 and 67 have substantially greater discharges than the other sites, and are likely receiving a greater percentage of runoff that is not impacted by mining. The dilution of AMD at these sites probably is why alkalinities and pH's are slightly higher on average than other sites further up in the watershed.

Although benthic algal densities in the watershed are not much different from the small reference site, the species composition of algae are indicative of low pH conditions and possibly metal impacts in the main stem. Overall, there appears to be little, if any, significant recovery in macroinvertebrates in the 5 years following the initial building of treatment systems in the headwaters area. Macroinvertebrates density and diversity at the sites remain well below those for the references streams. The average pH values in the watershed should be able to support a more healthy invertebrate community. However there are fairly large fluctuations in pH and there could be short periods of low pH during the year limiting growth. In addition, several metals exceed water quality standards for biota at many of the sites, especially manganese, iron, aluminum and zinc. These metals are probably having the greatest impact on the invertebrate fauna. Concentrations of metals in invertebrate tissue indicate iron and zinc to be the metals that potentially have the most impact. Finally, as stated earlier, the high amount of fine sediments in the watershed and high rates of erosion make for extremely poor substrate for the invertebrates in the most of main stem. On a positive note, the experiment placing AMD coated rocks into Wolf Creek indicated that if water quality in the watershed improves, the precipitates on the substrate do not seem to inhibit colonization of clean water macroinvertebrates or algae. More over there is substantial loss of some metals on the rocks exposed to good water quality.

Given that only about 20% of the acidity and iron loading into the headwaters is currently being treated, more treatment systems and a longer period are probably required for significant recovery to occur. In a Rocky Mountain stream more severely impacted by mining than the streams of this study, Chadwick and Canton (1986) found it took 5-10 years to get a substantial recovery in invertebrates following a dramatic improvement in stream water quality, probably because of an inadequate colonization source and residual metals in the sediments.

An extensive chemical and biological survey of Slippery Rock Creek was done in 1967 by the Academy of Natural Sciences in Philadelphia (1974). This was prior to any restoration efforts in the watershed. Most sites sampled were on the North Branch of Slippery Rock Creek, but one site was roughly between Sites 44 and 46 in this study. In 1967, chemical conditions at this site were much worse than they are presently. Alkalinity was 0 and pH 3.0-3.4. Total iron was between 8 and 12 mg/l, and manganese was around 1.8 mg/l. The substrate was noted to be clay with extensive iron precipitate, although they note some of the iron may have been in reduced form. The biological survey done by the Academy was qualitative, but taxa found can be compared to our results. Algae was less diverse in 1967 and consisted solely of acid tolerant taxa. Many of the acidic diatom taxa found in 1967 still persist in this area today, but in a much more diverse community. The macroinvertebrate fauna was also less diverse and more impacted than today. Most of the taxa found in 1967 were swimming predaceous beetles or hemipterians, both of which were probably feeding on insect drift. We did not collect any of the macroinvertebrate taxa found in 1967 in this area, probably because we did not sample the same variety of habitats (e.g., snags, emergent macrophytes, organisms on the surface). Overall, the stream in this area has improved since 1967, undoubtably from the sealing of some mines and the reclamation of open mine pits that were present at that time. However, our survey indicates that it is still a long way from complete recovery in this headwater area.

Recommendations for future monitoring of AMD recovery

This study has collected a wealth of chemical and biological information on the conditions in the headwaters of Slippery Rock Creek, which has shown little substantial change in the conditions of the stream in the 5 years since installation of the first passive treatment systems. While the study has provided excellent baseline data base for documenting any future changes in the water quality of the stream, there are several aspects of the study design and methods that can be improved to provide the critical information in a less time consuming and more efficient manner. In addition, there are several questions that need to be addressed in more detail in order to have more complete restoration of the watershed. We think the following recommendations could greatly improve the approach taken to restoration, and to monitoring stream recovery following installation of AMD treatment systems.

1) Given the effort to analyze all the chemical and biological parameters, and because treatment efforts in a watershed usually extend over many years, we feel sampling quarterly is not merited for routine monitoring. It is perhaps best to sample quarterly for a year or two prior to treatment in a watershed to get baseline data on seasonal and discharge effects on chemical and biological parameters. Following that, samples taken once or twice a year for monitoring is probably sufficient to detect major changes in the water quality of the stream. For macroinvertebrates the best sampling times appear to be in very early spring and in late summer/early fall.

2) While it is important to analyze as many metals possible in water and sediment samples initially to see if there is a potential toxic problem with a trace metal, routine analysis of metals that have been shown to have extremely low concentrations that are below known standards for biota can be eliminated.

3) While analyzing clay for sediment analysis eliminates substrate size affects, it is difficult to know whether it is representative of what benthic organisms are encountering. It is very difficult to sample metals from sediments accurately and effectively. Other methods of assessing biological effects of metals associated with sediments should be considered.

4) Macroinvertebrates samples from pool areas usually have substantially fewer individuals and lower diversity than riffle samples in small streams. Given the time needed to take and process Ekman samples in pools, they probably can be eliminated for monitoring without much loss of information.

5) In streams heavily impacted by AMD, macroinvertebrates are almost completely lacking while the periphyton flora can be quite abundant and species rich. Therefore, periphyton may provide more specific information on the biological recovery of heavily impacted streams. Macroinvertebrates are import as food items for fish and still need to monitored.

6) Burying of benthic organisms by fine substrate particles can greatly lower their biomass and diversity. An examination of soil erosion in the watershed and the source of fine sediment in the stream, needs to be found. The stream biota will not be completely reclaimed to "normal" conditions unless fine sediments are eliminated at many sites.

7) The lack of correlation between discharge in the streams and parameters for water chemistry is puzzling. The hydrologic connection between mine pools, groundwater discharges, overland flow and the stream appears to be complex. Subsurface flow into the streams that are not discrete discharges may represent a substantial input of AMD. Soliciting a hydrologist to examine these connections would a be great help in planning further restoration.

8) It is obvious that several metals exceed standards for biota in the stream. Water entering and leaving passive treatment systems should be monitored for some of these metals that occur at low but toxic concentrations to see whether they are being removed.

9) More field bioassay and experimental studies are need to understand possible toxic effects of trace metals at very low concentrations in AMD impacted streams. While the water quality may be relatively good in terms of pH and alkalinity in some streams, low amounts of heavy metals in water or sediment can be impacting organisms. More studies like the substrate transfer into Wolf Creek and the use of caged invertebrates to look at metal uptake are needed. In addition, laboratory and field studies using metal dosing into mesocosms would be a good way to pinpoint toxic metal affects. *The restoration plan and design of treatment systems would be much more affective if we can ascertained experimentally exactly what is limiting recovery of the biota.*

References

Academy of Natural Science of Philadelphia, Division of Limnology and Ecology. 1974. Slippery Rock Creek Acid Mine Waste Studies for the Appalachian Regional Commission. Philadelphia, PA. 111 pp.

American Public Health Association., 1989: *Standard Methods for the examination of water and wastewater, 17th Edition.* - Am. Pub. Health Assoc., Washington, D.C.

Boult, S., Collins, D.N., White, K.N. & Curtis, C.D., 1994: Metal transport in a stream polluted by acid mine drainage-the Afon Goch, Anglesey, UK. - *Environ. Pollut.* 84: 279-284.

Cain, D., Luoma, S., Carter, J. & Fend, S., 1992; Aquatic insects as bioindicators of trace element contamination in cobble-bottom rivers and streams. *J. Can. Fish. Aquat. Sci.* 49-2141-2154.

Chadwick, J.W. & Canton, S.P., 1986: Recovery of benthic invertebrate communities in Silver Bow Creek, Montana, following improved metal mine wastewater treatment. - *Water Air and Soil Pollut.* 28: 427-438.

Carrithers, R.B. & F.J. Bulow. 1973. An ecological survey of the west fork of the Obey River, Tennessee with emphasis on the effects of acid mine drainage. J. Tenn. Acad. Sci. 48:65-72.

Clements, W.H., D.S. Cherry, & J. Cairns. 1988. Impact of heaby metals on isect comunities in streams: a comparison of observational and experimental results. Can. J. Fish Aquat. Sci. 45:2017-2025.

DeNicola, D.M. Submitted. A review of diatoms found in highly acidic environments. Hydrobiologia.

DeNicola, D.M., C.D. M^{c}intire, G.A. Lamberti, S.V. Gregory, & L.R. Ashkenas. 1990. Temporal patterns of grazer-periphyton interactions in laboratory streams. *Freshwater Biology* 23:475-489.

Dills, G. & Rogers, D.T., 1974: Macroinvertebrate community structure as an indicator of acid mine pollution. - *Environ. Pollut.* 6: 239-262.

Genter, R.B. 1996. Ecotoxicology of inorganic chemical stress to algae. Pages 404-468, in: R.J. Stevenson, M.L. Bothwell & R.L. Lowe (eds), Algal Ecology, Freshater Benthic Ecosystems. Academic Press, NY.

Gerhardt, A. 1992. Effects of subacute doses of iron (Fe) on *Leptophlebia marginata* (Insecta: Ephemeroptera). Freshwater Biology 27:79-84.

Hoehn, R.C. & D.R. Sizemore. 1977. Acid mine drainage (AMD) and its impact on a small

Virgina stream. Wat. Res. Bullet. 13:153-160.

Horansky, R.H., 1980: The effects of coal mine acid drainage on the aquatic insect communitites of three northwestern Pennsylvania streams. MS Thesis, Dept. of Biology, Slippery Rock University, Slippery Rock, PA. 143 pp.

Klerks, P.L, & J.S. Weis. 1987. Genetic adaptation to heavy metals in aquatic organisms: a review. Env. Pollut. 45:173-205

Letterman, R.D. & Mitsch, W., 1978: Impact of mine drainage on a mountain stream in Pennsylvania. - *Eniviron. Pollut.* 17: 53-73.

Mackie, G.L. 1989. Tolerances of five benthic invertebrates to hydrogen ions and metals (Pb, Cd, Al). Arch. Environ. Contam. Toxicol. 18:215-223.

Medeley, C.N., & W.H. Clements. 1998. Responses of diatom communities to heavy metals in streams: the influence of longitudinal variation. Ecol. Appl. 8:631-644.

Nelson, S.M., & R.A. Roline, 1996: Recovery of stream macoinvertebrate community from mine drainage disturbance. *Hydrobiologia* 339:73-84.

New York State Department of Environmental Conservation. 1986. Water Quality Regulations. NYS Codes, Rules and Regulations, Title 6, Chapter X. Parts 700-705.

Nichols, L.E. & F.J. Bulow. 1973. Effects of acid mine drainage on the stream ecosystem of the east fork of the Obey River, Tennessee. J. Tenn. Acad. Sci. 48:30-39.

Pennsylvania Department of Environmental Protection, Knox Office. 1998. Slippery Rock Creek Watershed. Reclamation/Remediation Plan. 192 pp.

Pennsylvania Department of Environmental Protection. Water Quality Standards. Pennsylvania State Code, Chapter 93.

Porter, S.D., T.C. Cuffney, M.E. Gurtz, & M.R. Meador. 1993. Methods for collecting algal samples as part of the National Water-Quality Assessment Program. U.S.G.S. open-file report 93-409.

Roback, S.S. & J.W. Richardson. 1969. The effects of acid mine drainage on aquatic insects. Proc. Acad. Nat. Sci. Philadelphia 121:81-107.

Robb, G.A. & Robinson, J.D.F., 1995. Acid drainage from mines. - *Geog. J.* 161: 47-54.

Scullion, J. & Edwards, R.W., 1980: The effects of coal industry pollutants on the macroinvertebrate fauna of a small river in the South Wales coalfield. - *F.W. Biology* 10: 141-162.