PASSIVE TREATMENT DEMONSTRATION PROJECT

Jennings Water Quality Improvement Coalition

Jennings Environmental Education Center
Pennsylvania Department of Conservation and Natural Resources
Slippery Rock Watershed, Brady Township, Butler County, PA

2001

Stream Restoration Incorporated
A PA Non-Profit Organization 501(c)(3)
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Date: February 22, 2002

To: PA Department of Environmental Protection
Bureau of Watershed Management
Rachel Carson State Office Building
P.O. Box 8555
Harrisburg, PA 17105-8555

Attn: Jane Earle, Project Officer
Russell L. Wagner, Chief, Nonpoint Source Management Section

Re: Final Report
ME #358078 - Passive Treatment Demonstration Project
Jennings Environmental Education Center, Bureau of State Parks, PADCNR
Slippery Rock Creek headwaters
Brady Township, Butler County, PA
200304/final rept/transmittal

Enclosed is the Final Report for the Passive Treatment Demonstration Project. Project work and Operation and Maintenance at the demonstration site are on-going with award-winning environmental education and public outreach programs developed through the Jennings Environmental Education Center.

Notably, “hands-on” educational opportunities and further understanding of passive technology have been through efforts of students from Grove City College, Slippery Rock University, and Westminister College. As part of public outreach, their findings have been and will continue to be presented at the annual Slippery Rock Watershed Coalition Symposium and PA Academy of Science. These presentations are often reported in the Slippery Rock Watershed Coalition monthly newsletter. Papers and posters have been and will be later this year presented at national conferences.

In-kind contributions have increased throughout the life of the grant and the overall effort has been extensive.

Pilot-scale systems included in this grant are: a “test bed” compost wetland and a tank containing a mixture of limestone and spent mushroom compost duplicating the full-scale system constructed with and monitored by Grove City College students; and, four tanks containing limestone aggregate mixed with either sawdust or aquatic macrophytic compost constructed with and monitored by Westminster College students. Their reports are included.

If you have any questions or comments, please contact our office.

From: Stream Restoration Incorporated

By: Margaret H. Dunn, PG, President

Sent: Express Mail

JENNINGS WATER QUALITY IMPROVEMENT COALITION

FINAL REPORT: PASSIVE TREATMENT DEMONSTRATION PROJECT

Jennings Environmental Education Center
Bureau of State Parks, Pennsylvania Department of Conservation and Natural Resources
Slippery Rock Creek Watershed, Brady Township, Butler County, PA

submitted to

Pennsylvania Department of Environmental Protection
Bureau of Watershed Management

Brief Description of Project Work Conducted through Grant

Three pilot-scale systems were listed in the proposal and four pilot-scale systems were constructed and monitored as part of this grant. (1) A "test bed" compost-only wetland and (2) a tank containing a mixture of spent mushroom compost and limestone (same mixture as full-scale demonstration Vertical Flow Pond) were constructed with and monitored by Grove City College students. (3) A tank (plus a replicate tank) containing a limestone and sawdust mixture and (4) a tank (plus a replicate tank) containing a limestone and aquatic macrophytic compost mixture that were constructed with and monitored by Westminster students. Findings for this and other pilot-scale work have been presented at the 1998, 1999, 2000, and 2001 annual Slippery Rock Watershed Coalition Symposium as proposed in the grant. Numerous additional papers and oral presentations have been delivered at local, state, and national conferences.

Contract Number & Amount: **ME#358078; $14,000**

Grant Program: **FY98 US EPA Section 319 NPS**

Administered by: **Stream Restoration Inc.**[Non-Profit (501(c)(3)]

In-Kind Contributors:
Jennings Environmental Education Center
PA DEP, Knox District Mining Office
Grove City College
Westminster College
Quality Aggregates Inc.
Slippery Rock Watershed Volunteers
BioMost, Inc.
Stream Restoration Incorporated

December 2001

cover photos: (upper left) Charlene Wick, Grove City College student, inspects tank with mixture of compost and limestone; (upper right) test-bed wetland built by Grove City College students (ca. 1999); (lower left) Westminster College students install four demonstration tanks, containing mixtures of limestone with either sawdust or aquatic macrophyte compost (3/2001)

PUBLIC-PRIVATE PARTNERSHIP EFFORT

Vertical Flow System Monitoring
PA Dept. of Env. Protection, District Mining Ops., PO Box 669, Knox, PA 16232
CARLIN, Sherry, Watershed Mgr.; GILLEN, Timothy, PG; BOWMAN, Roger, Engineer; PLESAKOV, James, MCI; VanDYKE, Timothy, Insp. Supervisor; ODENTHAL, Lorraine, Permit Chief; MIRZA, Javed, Dist. Mining Mgr. (814) 797-1191

Environmental Education, Public Outreach, Construction Assistance
Jennings Env. Ed. Ctr., PADCNR, 2915 Prospect Rd., Slippery Rock, PA 16057
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Pilot-Scale Demonstration Systems
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BRENNER, Frederick, PhD, Biology; Students: BUSLER, Shaun; KOSICK, Kim; GARDNER, Corrie; McENTIRE, Matt; ABRAMSON, Nate; KAISER, Aaron; DOOLEY, Kristine; TIPPIE, Carol; WICK, Charlene (724) 458-2113

Westminster College, Market Street, New Wilmington, PA
WOOSTER, Timothy, PhD, Chemistry; BALCZON, Joseph, PhD, Biology; Students: BEHAM, Jessica; BENNETT, Jennifer; BORDEN, Katherine; HALL, Christopher; MARTIN, Joshua; RICE, Seth; ZAHNISER, Christina (724) 946-7171

Pilot-Scale System Design and Construction Services
C D S Associates, Inc., 1000 Hiland Ave., Coraopolis, PA 15108
COOPER, Charles D., PE, PLS (412) 264-4090

Limestone Aggregate
Quality Aggregates Inc., 200 Neville Rd., Neville Island, PA 15225
ALOE, Joseph, President; ANKROM, Jeff, Vice President (412) 777-6717

Pilot-Scale System Construction Assistance for Westminster College
BioMost, Inc., 3016 Unionville Rd., Cranberry Twp., PA 16066
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Grant Administration and Volunteer Effort
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Jennings Water Quality Improvement Coalition
Final Report: Passive Treatment Demonstration Project

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Project Summary

Background

A severely degraded acid mine discharge emanates from an abandoned deep mine at Jennings Environmental Education Center (Jennings), Pennsylvania Department of Environmental Protection, Bureau of State Parks. Numerous reclamation efforts have been initiated within the last thirty years to abate this pollution. In 1973, mine seals were installed by the Pennsylvania Department of Environmental Protection. These seals failed in 1985 causing a large fish kill in the receiving tributary, Big Run. In 1989 the PA DEP, Bureau of Abandoned Mine Reclamation, constructed a series of ponds and wetlands, which partially treated the mine drainage. To address the remaining water quality issues and abandoned mine lands located at the site, the Jennings Water Quality Improvement Coalition was formed in 1992. Since this time, the restoration efforts have also focused on providing public outreach and environmental education opportunities with numerous participants, including government agencies, private industry, grassroots organizations, volunteers, and local colleges and universities. With assistance from the PA DEP Knox District Mining Office, US Bureau of Mines, and private industry, an Anoxic Limestone Drain was constructed in 1992 and failed shortly thereafter due to plugging by aluminum hydroxide particulates. In 1997, a Vertical Flow Pond was constructed to replace the Anoxic Limestone Drain through the Section 319 Program. This passive system continues to effectively treat the mine discharge today.

Below is a partial list of participants.

US Bureau of Mines
CDS Associates, Inc.
Girl Scouts
Jesteadt Excavating
Slippery Rock University
Quality Aggregates Inc.
Stream Restoration Inc.
BioMost, Inc.
Westminster College
Allegheny Minerals Corp.
Jennings Environmental Ed. Center
Grove City College
Homeschool Students
PA Bureau of District Mining Ops.(Knox)
Shaliston Trucking
Amerikohl Mining, Inc.
U. S. Department of Energy
Urban Wetland Institute
Amerikohl Mining, Inc.
Hedin Environmental

Demonstration Project

The Jennings Water Quality Improvement Coalition received a grant from the PA DEP, Bureau of Watershed Conservation, through U.S. Environmental Protection Agency Section 319 funding. Though this grant, the following projects have been completed:

- A “test bed” compost-only wetland and a demonstration tank containing a mixture of spent mushroom compost and limestone (same mixture as full-scale demonstration Vertical Flow Pond) were constructed with and monitored by Grove City College students.

- A demonstration tank (plus a replicate tank) containing a limestone and sawdust mixture and a demonstration tank (plus a replicate tank) containing a limestone and aquatic macrophytic compost mixture that were constructed with and monitored by Westminster College students.

- Water sampling of the full-scale system to compare the results of the demonstration tanks.

For over a decade, Jennings Environmental Education Center has been a pioneer in demonstrating passive technologies to treat abandoned mine drainage. Jennings was established with the purpose of providing educational opportunities to the public and has developed a strong program that directly addresses environmental problems caused by abandoned mine drainage and environmentally-friendly solutions developed to solve these problems. Each year Jennings serves the community by providing educational opportunities to over 167,000 visitors, 280 schools, 11 colleges and universities, and a number of civic organizations.

Grove City College

Under the direction of Dr. Fred Brenner, Grove City College students have been actively involved in the Coalition conducting research at Jennings. With the assistance of CDS Associates and BioMost, Inc. students dissected and replaced the treatment media of a pilot-scale tank. This tank contained a media of compost fortified with limestone, similar to the full-scale Vertical Flow Pond. The media was again replaced with a similar mixture of compost and limestone; however, bentonite was placed along the sides of the tank to prevent piping. In addition, a test bed wetland was built in succession with the tank to simulate the full scale system. Water samples were conducted weekly for two years.

Selected Findings and Comparison with Full-Scale Vertical Flow Pond

- The total iron content of the drainage is comparably retained in both the VFP and the test tank and test-bed wetland, from 40 to 50 mg/l in the raw water to 9 mg/l in the effluent.

- Neither the full-scale nor the pilot-scale systems significantly removed manganese.

- The amount of alkalinity generated within the pilot-scale system was significantly lower than the full-scale model, 56 mg/L and 183 mg/L, respectively

- The pilot-scale system was not as effective in treating the drainage during the winter, possibly due to the tank and wetland freezing, which would not have affected the full-scale system as drastically.

<u>Westminster College</u>

As part of the Environmental Science Capstone class, a research proposal was submitted by Westminster College students to the Slippery Rock Watershed Coalition and Jennings Water Quality Improvement Coalition to conduct a study to evaluate the effectiveness of two different media in the treatment of abandoned mine drainage at the Jennings Environmental Education Center. With the assistance of CDS Associates and BioMost, Inc., students installed four tanks with flows adjusted in proportion with the full-scale system. For one tank, students utilized sawdust and limestone as their treatment media, while the other tank contained macrophytic compost and limestone. Replicant tanks were built for each mixture. Water samples were conducted hourly for 25 hours and tri-weekly for a period of two weeks. A total of 320 samples were collected and analyzed in the automated laboratory at Westminster College with a statistical evaluation of the results.

Selected Findings and Comparison with Full Scale Vertical Flow Pond

- The iron concentration in the raw water varied in a cyclical pattern diurnally by about 11 mg/l from 56 to 67 mg/l. The pronounced cyclical 12-hour trend in the average dissolved iron concentration indicated that the highest concentrations were at 7AM and 7PM and the lowest at 11AM and 11PM.

- No pronounced cyclical trend was noticed for aluminum or nickel concentrations.

- Nickel was not removed by either media; however, nickel was removed in the full-scale system.

- Aluminum was almost 100% retained in all systems, pilot-scale and full-scale.

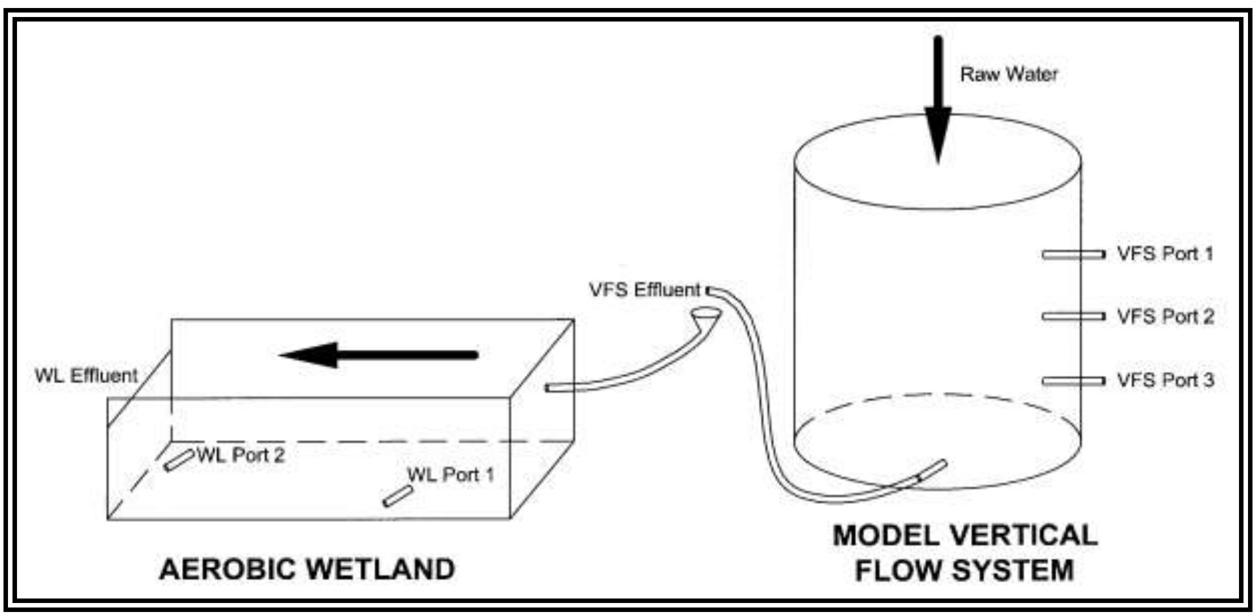
- The sawdust/limestone mixture retained more metals than the macrophytic/limestone mixture.

Grove City College: Pilot Scale Vertical Flow System and Test Bed Wetland

Description

In the spring of 1998, Grove City College students constructed a pilot-scale Vertical Flow Pond designed in proportion to the full-scale demonstration system already in place at Jennings Environmental Education Center. This system was designed to treat 0.55 gpm of the 20 gpm discharge located at the site. The Vertical Flow Pond tank consisted of a 3 1/4' by 5' fiberglass septic tank using a substrate of approximately 1 ½' of mushroom compost and #6 limestone. To equally distribute the water, an under and over drain was constructed with 1" PVC pipes. Three sampling ports were installed at depths of 1, 1 ½, and 3 feet.

Grove City College students also assisted in the construction of a test bed wetland built in sequence with the model Vertical Flow System. This wetland was originally designed to be portable so it could be transported to an abandoned mine site and placed to intercept a portion of the drainage. The 8 x 4 x 1 foot wetland was constructed with ½" plywood and coated with epoxy. Again the water distribution system was constructed with 1" PVC pipes and two sampling ports were installed at 2 and 6 foot increments. The media consisted of 1' of spent mushroom compost and #6 limestone. The wetland was planted with cattails (*Typha latifolia*) harvested from the demonstration area. Below is a schematic of the two systems.



Samples were collected and analyzed weekly from the influent, effluent, and each sampling port (total of 8 samples) for a period of two years. In addition, a bacteriological analysis was completed culturing aerobically and anaerobically on iron, manganese, and sulfate medium.

Findings:
The average influent and effluent analyses are shown below.

Point	Flow (gpm)	pH	alkalinity (mg/l)	acidity (mg/l)	T. Fe (mg/l)	T. Mn (mg/l)	SO_4 (mg/l)
tank influent	0.55	3.6	0	*243	38	19	938
WL effluent	0.55 (Assumed)	6.7	56	55	9	16	960

* Acidity listed based on the reported results of others.

Overall, the test tank and test-bed wetland were effective in removing 29 mg/L of iron from the mine discharge and only 3 mg/L of manganese. Sulfates were actually generated possibly from the gypsum in the spent mushroom compost.

The efficiency of the systems varied seasonally and yearly [See Brenner, et al. (2002) at the end of this section.]. Below are a seasonal and yearly comparison of iron and manganese (mg/L) in the VFP tank influent and the wetland effluent.

Iron

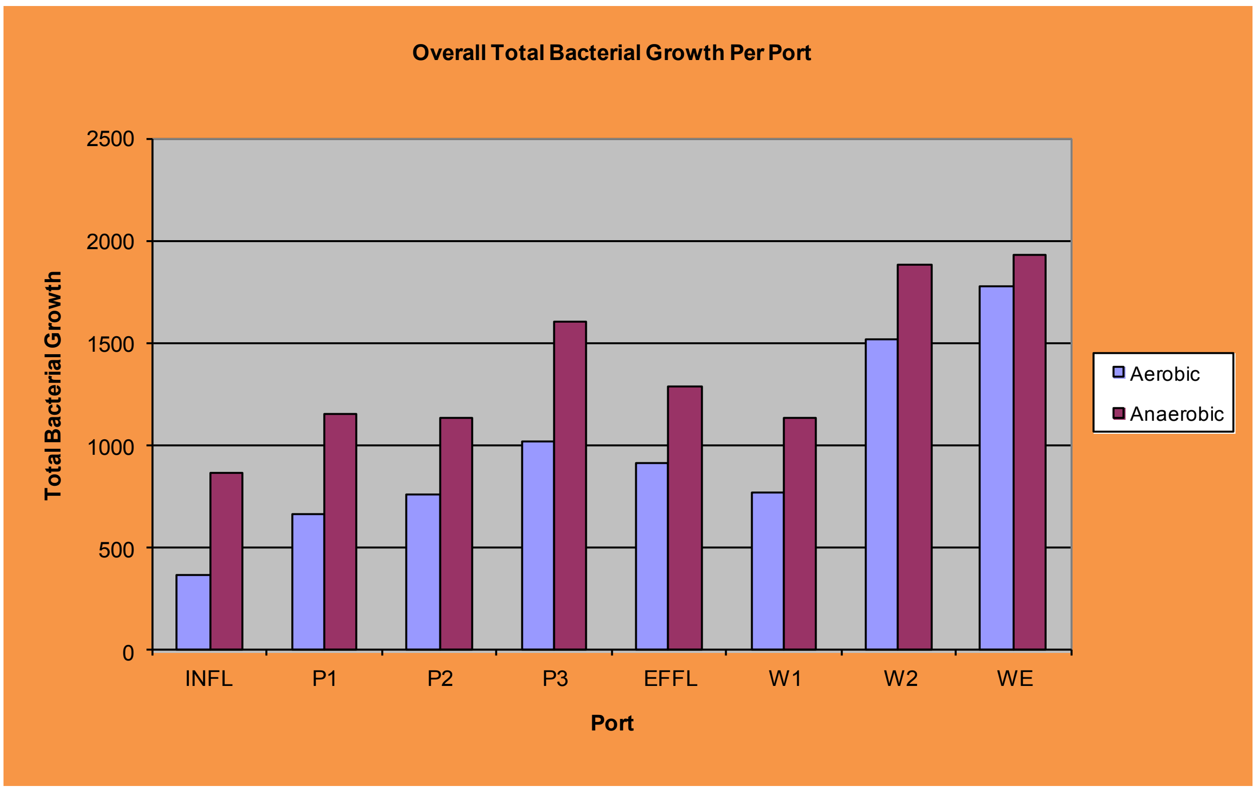
Point	Fall	Winter	Spring	1998	1999
tank influent	36	57	26	41	37
WL effluent	3	33	7	5	11

Manganese

Point	Fall	Winter	Spring	1998	1999
tank influent	18	20	20	19	19
WL effluent	15	19	18	14	18

The model system was most effective during the first year of operation and during the fall, removing 92% and 88% of iron, respectively. The amount of iron removed decreased to 70% during the second year of operation. In addition, the model was least effective during the winter, possibly due to the tank and wetland freezing. The pilot-scale system did not remove manganese as effectively, having the best results in the first year of operation with a 26% decrease.

The bacteriological activity within the test tank and test bed wetland were inversely correlated with the decrease in iron and manganese; however, this amount also varied seasonally and yearly. (See Tippie at the end of this section.) This finding is substantial evidence that bacteria do play a role in the removal of metals in Vertical Flow Ponds and wetlands. Below is a chart summarizing the total bacterial growth at each port.



Flow Rate (L/second)

Jennings Environmental Center Acid Mine Drainage Project

Date	Influent	Port 1	Port 2	Port 3	Effluent	Cattail Port 1	Cattail Port 2	Cattail Effluent
9/24/1998	0.0435	0.1786	0.036	0.1852	0.0163	drip	0.0485	0.0114
10/3/1998	0.0568	0.0962	0.0340	0.0676	0.0251	drip	0.0459	0.0196
10/13/1998	0.0481	0.06061	0.0347	0.0813	0.0199	0.0046	0.0495	0.0204
10/21/1998	0.0373	0.0847	0.0334	0.0543	0.0143	0.0025	0.0474	0.0124
10/28/1998	0.0124	0.0532	0.0315	0.1000	0.0087	0.0058	0.0500	0.0103
11/4/1998	0.0298	0.2174	0.0335	0.1220	0.0122	0.0061	0.0500	0.0016
11/11/1998	0.0324	0.0645	0.0331	0.1250	0.0169	0.0055	0.0523	0.0118
11/19/1998	0.0568	0.2541	0.0320	0.1370	0.0195	0.0030	0.0521	dry
12/2/1998	0.0518	0.2183	0.0324	0.1562	0.0212	dry	dry	dry
1/29/1999	0.0466	0.2834	0.0320	0.1391	0.0154	dry	dry	dry
2/8/1999	0.0478	0.2326	0.0290	0.1299	0.0115	0.0092	0.0092	0.0073
2/17/1999	0.0459	0.2439	0.0304	0.1136	0.0079	0.0071	0.0645	0.0093
2/23/1999	0.0495	0.2381	0.0302	0.1316	0.0174	frozen	frozen	frozen
3/5/1999	0.0505	0.2381	0.0272	0.1234	0.0096	frozen	0.0585	frozen
3/12/1999	0.0454	0.1111	0.0303	0.1111	0.0172	0.0056	0.0550	frozen
3/18/1999	0.0485	0.2128	0.0248	0.1075	0.0060	0.0030	0.0658	0.0059
4/16/1999	0.0422	0.2500	0.0234	0.1018	0.0165			
4/23/1999	0.0391	0.2326	0.0246	0.0926	0.0126	0.0048	0.068	0.0036
4/30/1999	0.0413	0.1961	0.0253	0.0893	0.0133	0.0059	0.0719	0.0028
9/15/1999	0.0254	0.1449	0.0415	0.1087	0.0216		0.0833	0.0347
9/22/1999	0.0266	0.1266	0.0446	0.1250	0.0192		0.0885	0.0184
9/29/1999	0.0201	0.1369	0.0326	0.0962	0.0168		0.0952	0.0143
10/6/1999	0.0166	0.1282	0.0292	0.0847	0.0117		0.0885	0.0162
10/13/1999	0.0161	0.1369	0.0313	0.1163	0.0127		0.0971	0.0158
10/20/1999	0.0141	0.1299	0.0304	0.1064	0.0111		0.0833	0.0084
10/27/1999	0.0083	0.1316	0.0300	0.1190	0.009		0.0943	0.0122
11/3/1999	0.0108	0.1449	0.0309	0.1050	0.0075		0.0917	0.0095
11/10/1999	0.0129	0.1515	0.0303	0.1176	0.0097		0.0917	0.0065
12/1/1999	frozen	0.1282	0.0228	0.1316	0.0120		0.0862	0.0064
12/8/1999	0.0173	0.1389	0.0284	0.0990	0.0114		0.0893	0.0096
2/24/2000	0.05	0.1	0.0294	0.125	0.0061			
3/10/2000								
3/16/2000		0.0833	0.0269	0.1	0.0046			
Averages	**0.0348**	**0.1609**	**0.0308**	**0.1126**	**0.0136**	**0.0053**	**0.0684**	**0.0117**
Average I	0.043	0.182	0.030	0.114	0.015	0.005	0.053	0.010
Average II	0.020	0.129	0.031	0.110	0.012		0.090	0.014

pH

Jennings Environmental Center Acid Mine Drainage Project

Date	Influent	Port 1	Port 2	Port 3	Effluent	Cattail Port 1	Cattail Port 2	Cattail Effluent	
9/24/1998	3.655	3.317	3.316	6.256	6.292	no sample	6.738	6.558	
10/3/1998	3.284	3.183	3.244	5.604	5.908	6.786	6.861	6.457	
10/13/1998	3.26	3.08	3.25	5.84	6.28	6.43	6.63	6.31	
10/21/1998	3.503	3.334	3.402	6.436	6.553	6.686	6.891	6.755	
10/28/1998	3.802	3.359	3.575	6.238	6.384	6.485	6.842	6.741	
11/4/1998	3.543	3.249	3.363	6.308	6.401	6.746	6.685	7.145	
11/11/1998	3.644	3.35	3.298	5.989	6.011	6.523	6.620	6.623	
11/19/1998	3.686	3.48	3.469	6.315	6.482	6.827	6.779	6.810	
12/2/1998	3.300	3.232	3.281	5.898	5.876	dry	dry	dry	
1/29/1999	3.492	2.398	3.546	6.342	6.045	6.674	6.678	6.573	
2/8/1999	3.685	3.585	3.643	6.570	6.206	6.748	6.640	6.542	
2/17/1999	3.663	3.468	3.455	5.979	5.907	6.398	6.763	6.505	
2/23/1999	3.684	3.605	3.571	6.292	6.176	frozen	frozen	frozen	
3/5/1999	3.808	3.697	3.649	6.323	6.391	frozen	6.734	frozen	
3/12/1999	3.608	3.540	3.468	6.083	6.128	5.949	6.796	frozen	
3/18/1999	3.557	3.541	3.544	6.331	6.438	6.579	6.714	6.790	
9/22/1999	4.129	3.891	4.539	6.146	6.2.8		6.707	6.533	
9/29/1999	3.929	3.65	4.448	6.048	6.2520		6.788	6.553	
10/6/1999	4.025	3.656	4.659	5.912	6.180		6.489	6.520	
10/13/1999	4.028	3.642	4.473	6.017	6.222		6.560	6.550	
10/20/1999	4.556	3.773	4.687	6.111	6.271		6.471	6.439	
10/27/1999	3.972	3.819	5.013	6.203	6.190		6.637	6.630	
11/3/1999	3.787	3.59	4.785	6.079	6.242		6.546	6.546	
11/10/1999	3.718	3.51	4.693	6.049	6.092	6.566	6.525	6.530	
12/1/1999	frozen	3.815	4.458	5.689	5.826	6.200	6.328	6.244	
12/8/1999	3.812	3.678	3.925	5.456	6.008	6.460	6.494	6.328	
2/24/2000	3.733	3.472	3.355	3.83	3.745				
3/10/2000	3.595	3.5	4.434	5.539	5.486				
3/16/2000	3.86	3.58	3.511	5.449	5.501				
Averages	**3.726**	**3.483**	**3.864**	**5.977**	**6.053**	**6.537**	**6.663**	**6.576**	
Percent Change	**3.725**	**3.479**	**3.864**	**5.977**	**6.053**	**6.537**	**6.663**	**6.576**	
Average 1	3.573	3.339	3.442	6.175	6.217	6.569	6.741	6.651	
Average 2	3.929	3.660	4.383	5.733	5.835	6.409	6.555	6.487	
# of Samples	28	29	29	29	28	15	24	22	204

Sulfate (ppm)
Jennings Environmental Center Acid Mine Drainage Project

Date	Influent	Port 1	Port 2	Port 3	Effluent	Cattail Port 1	Cattail Port 2	Cattail Effluent	
9/24/1998	1200	1100	800	800	900	N/A	1000	800	
10/3/1998	1200	1200	1100	1000	1100	N/A	1200	1000	
10/13/1998	800	800	700	700	800	2000	1000	800	
10/21/1998	800	800	800	700	750	2000	1600	1450	
10/28/1998	900	900	800	1000	1000	2000	1200	1000	
11/4/1998	900	900	1000	950	950	1400	1200	1100	
11/11/1998	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
11/19/1998	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
12/2/1998	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
1/29/1999	1000	900	800	900	850	N/A	N/A	N/A	
2/8/1999	900	900	800	1000	950	900	900	1000	
2/17/1999	1000	800	900	1000	950	900	1100	900	
2/23/1999	700	800	700	800	700	N/A	N/A	N/A	
3/5/1999	900	900	800	850	800	N/A	1000	N/A	
3/12/1999	900	850	900	750	800	850	1000	N/A	
3/18/1999	900	800	800	950	900	1000	1000	1000	
4/16/1999	1100	900	900	800	850				
4/23/1999	800	750	800	700	700	700	900	800	
4/30/1999	950	800	800	900	900	1000	950	900	
9/15/1999	850	800	800	850	800		1900	1000	
9/22/1999	800	900	850	800	900		1800	900	
9/29/1999	800	850	900	850	850		2000	900	
10/6/1999	1000	900	700	750	750		850	800	
10/13/1999	900	900	850	850	900		950	900	
10/20/1999	900	800	800	850	900		900	1100	
11/3/1999	1100	1100	1000	1000	800		950	900	
11/10/1999	900	900	1000	900	850	900	900	1000	
12/1/1999	1200	1000	900	850	850	900	900	1000	
12/8/1999									
								900	
3/10/2000	1000	900	900	900	850				
3/16/2000									
Average	**938**	**890**	**850**	**862**	**860**	**1213**	**1145**	**960**	
Average I	934.4	881.3	837.5	862.5	868.8	1275.0	1080.8	977.3	
Average II	945.0	905.0	870.0	860.0	845.0	900.0	1238.9	940.0	
# of Samples	26	26	26	26	26	12	22	21	185

Manganese (mg/L)

Jennings Environmental Center Acid Mine Drainage Project

Date	Influent	Port 1	Port 2	Port 3	Effluent	Cattail Port 1	Cattail Port 2	Cattail Effluent	
9/24/1998	22.50	27.00	18.50			12.25	3.40	18.50	
10/3/1998	15.00	22.00	18.50	15.50	21.00	33.00	1.25	24.00	
10/13/1998	20.00	20.00	21.00	19.00	17.50	22.50	3.25	17.00	
10/21/1998	19.00	21.00	18.00	17.50	16.50	12.50	5.50	8.00	
10/28/1998	18.00	20.00	19.00	20.50	22.00	17.50	3.38	7.50	
11/4/1998	17.50	24.00	20.00	19.50	20.50	16.50	28.00	8.00	
11/11/1998	20.00	21.00	18.00	17.00	19.00	0.20	3.38	16.00	
11/19/1998	22.00	19.00	18.00	24.00	21.00	13.50	37.00	11.00	
12/2/1998	21.00	20.00	19.00	17.50	12.00	N/A	N/A	N/A	
1/29/1999	17.80	18.00	21.50	19.75	21.25	N/A	N/A	N/A	
2/8/1999	20.50	18.50	18.50	19.00	18.00	17.00	20.00	17.00	
2/17/1999	17.50	19.00	16.00	18.50	17.50	20.00	14.50	19.50	
2/23/1999	20.00	19.50	19.00	19.50	18.00	N/A	N/A	N/A	
3/5/1999	20.50	21.50	19.50	21.00	20.50	N/A	18.50	N/A	
3/12/1999	19.50	19.50	20.00	18.00	20.00	17.50	17.00		
3/18/1999	19.50	21.00	19.50	21.50	22.00	20.00	17.50	19.00	
4/16/1999	20.50	22.00	21.00	22.00	17.50				
4/23/1999	20.00	19.00	22.00	21.00	19.50	17.00	17.50	18.50	
4/30/1999	19.00	19.50	21.50	18.00	19.00	15.50	14.00	17.50	
9/15/1999	24.50	22.50	21.50	20.00	24.00		3.50	24.50	
9/22/1999	15.50	15.50	17.50	16.00	18.00		6.50	16.50	
9/29/1999	16.00	19.00	15.00	17.50	15.00		4.00	14.50	
10/6/1999	15.50	15.00	17.50	14.50	17.50		4.50	13.50	
10/13/1999	16.00	15.00	16.00	13.50	15.50		8.00	13.50	
10/20/1999	21.00	14.50	15.50	15.00	16.50		10.00	14.50	
10/27/1999	15.00	15.50	19.50	15.00	17.00		13.50	14.50	
11/3/1999	16.00	15.00	17.00	15.00	17.00		18.00	20.00	
11/10/1999	14.00	15.00	17.50	18.00	15.50	11.00	15.00	19.50	
12/1/1999		19.00	18.00	18.00	19.50	9.00	14.50	17.50	
12/8/1999	22.50	21.50	19.00	20.00	22.00	11.00	18.50	22.00	
3/10/2000	25.00	15.00	18.75	21.25	25.00				
Average	**19.03**	**19.16**	**18.75**	**18.32**	**18.63**	**15.64**	**12.31**	**16.33**	
Average I	19.46	20.61	19.39	19.38	19.04	16.78	13.61	15.50	
Average II	18.27	16.88	17.73	16.98	18.54	10.33	10.55	17.32	
# of Samples	30	31	31	30	30	17	26	24	219

Iron (mg/L)

Jennings Environmental Center Acid Mine Drainage

Date	Influent	Port 1	Port 2	Port 3	Effluent	Cattail Port 1	Cattail Port 2	Cattail Effluent	
9/24/1998	37.00	30.00	16.20	20.25	8.75	<20.0	2.50	3.80	
10/3/1998	50.00	46.25	25.50	31.25	8.00	1.50	1.65	0.90	
10/13/1998	36.25	33.75	36.25	1.90	13.00	90.00	1.45	25.50	
10/21/1998	41.25	35.00	14.50	0.70	1.75	2.00	0.75	0.50	
10/28/1998	37.50	41.25	20.00	1.80	10.00	4.00	0.90	0.25	
11/4/1998	42.50	49.00	24.00	25.63	8.75	0.50	1.25	4.00	
11/11/1998	40.00	40.00	18.75	3.00	4.20	4.00	1.40	0.50	
11/19/1998	38.75	43.75	26.25	2.25	0.25	41.00	0.55	0.60	
12/2/1998	41.50	40.50	33.75	8.50	9.00	N/A	N/A	N/A	
1/29/1999	65.50	72.50	41.50	69.00	79.50	N/A	N/A	N/A	
2/8/1999	67.50	80.50	26.00	42.00	43.00	8.00	4.00	27.50	
2/17/1999	43.50	38.50	17.00	14.50	13.00	12.50	1.50	9.00	
2/23/1999	30.50	29.50	18.00	1.00	11.50	N/A	N/A	N/A	
3/5/1999	19.50	33.50	11.00	13.50	2.50	N/A	1.50	N/A	
3/12/1999	29.50	33.50	14.50	1.50	1.50	4.50	2.00	N/A	
3/18/1999	27.5	28.5	15.5	3	17.5	1.5	2.25	1	
4/16/1999	18	16	12.7	1	1.25				
4/23/1999	20.5	21.5	23.5	0.5	1.25	4.25	6	1.5	
4/30/1999	38	31	13	26	33.75	10.5	9.5	19.5	
9/15/1999	24	23	20	6	21.5		1.5	1.5	
9/22/1999	29	36	16.5	55	33.5		2	1.5	
9/29/1999	29.5	19	22.5	2.5	0.5		0.5	3	
10/6/1999	29.5	28	17	3.5	1.75		0.75	0.25	
10/20/1999	4.5	24.5	9.5	2.5	9		0.5	2.75	
10/27/1999	29.5	30.25	3	0.75	2.25		2	0.5	
11/3/1999	72.5	61.5	77.5	9	4		4.5	4	
11/10/1999	35	35	15.8	0.75	1.5	9.5	0.75	1.5	
12/1/1999		76	67.5	70	70	3.5	4	56	
12/8/1999	92.5	91	90	85	52	5	2	38	
3/10/2000	30	37	24	31	34.5				
Averages	**37.96**	**40.19**	**25.71**	**17.78**	**16.63**	**12.64**	**2.23**	**8.85**	
Average I	38.14	39.18	21.47	14.07	14.13	14.17	2.48	7.27	
Average II	37.60	41.93	33.03	24.18	20.95	6.00	1.85	10.90	
# of Samples	29	30	30	30	30	16	25	23	213

Alkalinity (mg/L)

Jennings Environmental Center Acid Mine Drainage Project

Date	Influent	Port 1	Port 2	Port 3	Effluent	Cattail Port 1	Cattail Port 2	Cattail Effluent	
9/24/1998	0.00	0.00	0.00						
10/3/1998	0.00	0.00	0.00	10.0	39.6	118.0	181.0	34.8	
10/13/1998	0.00	0.00	0.00	60.8	77.6	86.3	159.4	58.6	
10/21/1998	0.00	0.00	0.00	73.2	80.2	169	105	70.6	
10/28/1998	0.00	0.00	0.00	76.6	90	78	129.4	67	
11/4/1998	0.00	0.00	0.00	55.6	58.2	78.4	121.4	90	
11/11/1998	0.00	0.00	0.00	65.6	58.4	79.6	114	49.4	
11/19/1998	0.00	0.00	0.00	39.6	66.2	77.8	99.4	62	
12/2/1998	0.00	0.00	0.00	24	24.4	N/A	N/A	N/A	
1/29/1999	0.00	0.00	0.00	12	8.8	N/A	N/A	N/A	
2/8/1999	0.00	0.00	0.00	49.9	55.6	61	62.2	47	
2/17/1999	0.00	0.00	0.00	29	27.4	62.6	83.4	33.6	
2/23/1999	0.00	0.00	0.00	39	36	N/A	N/A	N/A	
3/5/1999	0.00	0.00	0.00	51	114.8	N/A	60.6	N/A	
3/12/1999	0.00	0.00	0.00	33.2	20.8	47.6	62	N/A	
3/18/1999	0.00	0.00	0.00	60.4	65.6	46.6	73.6	55.2	
4/16/1999	0.00	0.00	0.00						
4/23/1999	0.00	0.00	0.00						
4/30/1999	0.00	0.00	0.00	35	60.2	58.2	123.4	53.4	
9/15/1999	0.00	0.00	14.40	50.6	49.8		89.6	33.6	
9/22/1999	0.00	0.00	2.20	47.4	52		128.4	38.4	
9/29/1999	0.00	0.00	4.00	39	54.4		109.4	41	
10/6/1999	0.00	0.00	6.20	40.6	47.4		75.6	40.2	
10/13/1999	0.00	0.00	1.00	32.4	48.4		65.2	39.8	
10/20/1999	0.00	0.00	1.00	33	51.6		53.4	36.4	
10/27/1999	0.00	0.00	1.00	34	35.6		52.4	43.8	
11/3/1999	0.00	0.00	2.00	41	49.4		58.2	41	
11/10/1999	0.00	0.00	8.00	48	42		62.4	39.4	
12/1/1999	0.00	0.00	4.00	19	30.4		54	26.2	
12/8/1999	0.00	0.00	0.00	13.2	34.4	49.2	58	25	
2/24/2000	0.00	0.00	0.00	0	0				
3/10/2000	0.00	0.00	0.00	3.4	15				
3/16/2000	0.00	0.00	0.00	13.4	19.8				
Averages	**0.00**	**0.00**	**0.00**	**37.66**	**47.13**	**77.87**	**90.89**	**46.65**	
Average I	0.00	0.00	0.00	44.68	55.24	80.26	105.75	56.51	
Average II	0.00	0.00	3.13	29.64	37.87	49.20	73.33	36.80	
# of Samples	33	33	33	30	30	13	24	22	218.00

Total Dissolved Solids (mg/L)

Jennings Environmental Center Acid Mine Drainage Project

Date	Influent	Port 1	Port 2	Port 3	Effluent	Cattail Port 1	Cattail Part 2	Cattail Effluent	
9/24/1998	0.70	0.77	0.76	0.78	0.78	N/A	1.10	0.81	
10/3/1998	0.75	0.71	0.80	0.64	0.68	1.29	1.13	0.80	
10/13/1998	0.77	0.82	0.83	0.74	0.78	1.12	1.06	0.84	
10/21/1998	0.63	0.77	0.70	0.76	0.74	1.25	0.98	0.84	
10/28/1998	0.72	0.70	0.75	0.79	0.83	1.12	1.01	0.88	
11/4/1998	0.74	0.78	0.79	0.78	0.81	0.99	0.96	0.93	
11/11/1998	0.70	0.72	0.71	0.81	0.80	0.93	0.93	0.84	
11/19/1998	0.60	0.66	0.74	0.75	0.78	0.91	0.89	0.85	
12/2/1998	0.78	0.78	0.75	0.74	0.73	N/A	N/A	N/A	
1/29/1999	0.67	0.74	0.75	0.76	0.76	N/A	N/A	N/A	
2/8/1999	0.68	0.69	0.72	0.72	0.75	0.74	0.78	0.76	
2/17/1999	0.69	0.69	0.67	0.69	0.65	0.75	0.72	0.60	
2/23/1999	0.69	0.65	0.59	0.63	0.58	N/A	N/A	N/A	
3/5/1999	0.59	0.57	0.62	0.63	0.67	N/A	0.67	N/A	
3/12/1999	0.71	0.69	0.59	0.63	0.64	0.68	0.66	N/A	
3/18/1999	0.67	0.69	0.63	0.76	0.68	0.71	0.74	0.68	
4/23/1999									
4/30/1999	0.60	0.65	0.67	0.58	0.53	0.69	0.67	0.67	
9/15/1999	0.69	0.74	0.64	0.69	0.68		1.30	0.74	
9/22/1999	0.75	0.76	0.67	0.74	0.76		1.18	0.68	
9/29/1999	0.66	0.68	0.54	0.60	0.65		0.83	0.58	
10/6/1999	0.56	0.65	0.59	0.63	0.65		0.72	0.72	
10/13/1999	0.54	0.67	0.57	0.64	0.62		0.69	0.61	
10/20/1999	0.60	0.73	0.60	0.67	0.69		0.70	0.70	
10/27/1999	0.72	0.72	0.65	0.66	0.73		0.75	0.67	
11/3/1999	0.71	0.69	0.65	0.69	0.73		0.73	0.73	
11/10/1999	0.76	0.77	0.70	0.76	0.77		0.74	0.74	
12/1/1999		0.72	0.63	0.69	0.69	0.73	0.75	0.71	
12/8/1999	0.76	0.73	0.71	0.69	0.69	0.70	0.73	0.67	
2/24/2000	0.76	0.74	0.73	0.69	0.64				
3/10/2000	0.65	0.68	0.67	0.65	0.62				
3/16/2000	0.66	0.69	0.69	0.59	0.60				
Average	**0.68**	**0.71**	**0.68**	**0.70**	**0.70**	**0.90**	**0.86**	**0.74**	
Average 1st	0.69	0.71	0.71	0.72	0.72	0.93	0.88	0.79	
Average 2nd	0.68	0.71	0.65	0.67	0.68	0.72	0.83	0.69	
# of Samples	30	31	31	31	31	14	25	23	216

Conductivity (mOhms)

Jenning's Environmental Center Acid Mine Drainage Project

Date	Influent	Port 1	Port 2	Port 3	Effluent	Cattail Port 1	Cattail Port 2	Cattail Effluent	
9/24/1998	1100	900	1100	1150	1200	no sample	1700	1200	
10/3/1998	1250	1260	1320	1240	1260	2150	1840	1275	
10/13/1998	820	800	800	900	800	535	610	800	
10/21/1998	870	900	880	820	820	510	660	830	
10/28/1998	860	810	800	760	725	520	630	730	
11/4/1998	820	870	880	840	830	590	700	740	
11/11/1998	880	890	900	875	850	700	750	860	
11/19/1998	1210	1210	1200	1400	1250	1700	1590	1490	
12/2/1998	1300	1400	1400	1300	1250	N/A	N/A	N/A	
1/29/1999	1000	1100	1000	1100	1100	N/A	N/A	N/A	
2/8/1999	1000	1100	1000	1200	1200	900	900	1100	
2/17/1999	1000	900	900	1000	1100	1100	1200	1100	
2/23/1999	900	900	900	1000	950	N/A	N/A	N/A	
3/5/1999	875	900	950	1000	1000	N/A	850	N/A	
3/12/1999	1000	1050	1100	1000	1000	1100	1050	N/A	
3/18/1999	1000	1000	950	1100	1050	900	950	900	
4/23/1999	1000	1000	1100	1100	1150	1150	1200	1000	
4/30/1999	1100	1100	1150	1250	1100	1100	1400	1150	
9/15/1999	2000	2150	1950	2000	1850		3550	1900	
9/22/1999	2200	2150	1900	2000	2000		3200	1800	
9/29/1999	3600	3400	2800	2700	2700		3300	2700	
10/6/1999	1200	1200	1150	1200	1250		1350	1250	
10/13/1999	1250	1300	1200	1250	1250		1400	1250	
10/20/1999	1100	1150	1100	1150	1200		1200	1200	
10/27/1999	1150	1200	1050	1200	1200		1150	1200	
11/3/1999	1050	1050	1000	1100	1100		1100	1000	
11/10/1999	1200	1250	1150	1250	1250	1300	1250	1250	
12/1/1999		1000	900	950	1000	1000	1000	950	
12/8/1999	1100	1150	1100	1050	1100	1050	1150	1000	
2/24/2000	1100	1100	1100	1250	1200				
3/10/2000	1000	1000	1250	1150	1100				
3/16/2000	1100	1200	1200	1000	1200				
Average	**1195**	**1200**	**1162**	**1196**	**1189**	**1019**	**1372**	**1195**	
Average I	999	1005	1018	1058	1035	997	1069	1013	
Average II	1465	1450	1346	1375	1386	1117	1786	1409	
# of Samples	31	32	32	32	32	16	26	24	225

Bactierological Analysis of Water Samples from Pilot-Scale PTS

Note: Results below are the level of bacterial growth determined on a scale of 1 to 100. For an explanation of the results, please review Brenner, et al. 2002 and Tippie, et al. 1999.

Abbreviations: A - Aerobic, AN - Anaerboic, INFL - Influent (Raw Water), P1 - Port 1, P2 - Port 2, P3 - Port 3, EFFL - VFS Effluent, W1 - Wetland Port 1, W2 - Wetland Port 2, WE - Wetland Effluent

FE A	INFL	P1	P2	P3	EFFL	W1	W2	WE	Totals
9/24/1998	50	65	40	55	45	40	55	50	400
10/13/1998	1	15	10	45	45	48	40	35	239
10/28/1998	20	25	20	30	35	35	40	50	255
11/11/1998	25	35	20	40	30	25	45	50	270
12/2/1998	1	15	25	10	35	25	30	25	166
2/23/1999	15	15	10	15	10	60	60	55	240
3/9/1999	5	15	10	10	1	0	0	0	41
3/24/1999	0	5	15	15	20	25	30	0	110
4/12/1999	15	15	20	25	20	0	0	0	95
9/15/1999	15	15	15	20	20	0	25	30	140
9/22/1999	0	2	10	5	1	0	75	50	143
9/30/1999	0	1	2	1	1	0	30	70	105
10/7/1999	1	3	3	15	2	0	20	60	104
10/11/1999	0	30	80	50	5	0	15	15	195
10/20/1999	0	20	15	40	50	0	30	20	175
10/27/1999	0	2	2	20	10	0	20	20	74
11/4/1999	2	5	50	40	15	15	20	30	177
11/11/1999	0	1	10	20	30	15	20	50	146
	150	284	357	456	375	288	555	610	

FE AN									
9/24/1998	55	50	45	60	60	65	50	70	455
10/13/1998	0	20	1	5	20	30	15	30	121
10/28/1998	65	60	20	30	50	65	55	60	405
11/11/1998	55	50	15	20	65	50	40	25	320
12/2/1998	25	1	50	50	45	65	45	40	321
2/23/1999	5	5	15	5	20	25	35	20	130
3/9/1999	10	55	35	35	0	0	0	0	135
3/24/1999	28	5	5	20	15	55	50	0	178
4/12/1999	20	25	45	55	25	0	0	0	170
9/15/1999	35	45	25	25	0	0	25	55	210
9/22/1999	10	5	20	20	10	0	50	30	145
9/30/1999	0	1	20	5	30	0	60	75	181
10/7/1999	0	10	25	20	5	0	40	20	120
10/11/1999	1	5	20	30	15	0	30	15	106
10/20/1999	10	20	20	40	20	0	15	10	135
10/27/1999	0	10	5	5	10	0	10	15	55
11/4/1999	20	10	10	20	0	20	40	50	170
11/11/1999	1	1	10	10	10	20	30	50	142
	340	378	386	445	390	395	590	565	3499

FE	INFL	P1	P2	P3	EFFL	W1	W2	WE	
Aer	150	284	357	456	375	288	555	610	
Anaer	340	378	386	445	390	395	590	610	

MN A	INFL	P1	P2	P3	EFFL	W1	W2	WE	Totals
9/24/1998	0	0	0	25	25	2	5	20	77
10/13/1998	0	0	0	0	0	5	10	15	30
10/28/1998	1	5	25	0	40	35	25	50	181
11/11/1998	0	0	0	6	0	2	5	0	13
12/2/1998	0	1	1	20	25	15	45	55	162
2/23/1999	5	1	5	1	10	15	35	20	92
3/9/1999	5	15	30	15	10	0	0	0	75
3/24/1999	0	25	65	15	10	25	40	0	180
4/12/1999	25	10	20	25	20	0	0	0	100
9/15/1999	15	25	20	20	20	0	30	30	160
9/22/1999	0	1	8	3	1	0	60	60	133
9/30/1999	0	0	0	0	0	0	50	70	120
10/7/1999	3	1	5	25	2	0	20	50	106
10/11/1999	1	0	0	10	0	0	1	30	42
10/20/1999	0	0	0	0	1	0	5	15	21
10/27/1999	0	0	0	0	0	0	20	30	50
11/4/1999	2	1	5	20	5	30	30	50	143
11/11/1999	0	2	2	3	10	30	20	40	107
	57	87	186	188	169	159	401	535	

MN AN									
9/24/1998	0	2	2	55	48	40	45	65	257
10/13/1998	1	30	35	30	25	25	75	50	271
10/28/1998	5	5	5	0	20	25	50	45	155
11/11/1998	15	20	5	45	1	20	50	10	166
12/2/1998	0	5	1	55	20	60	55	50	246
2/23/1999	5	5	25	25	15	20	20	20	135
3/9/1999	20	55	3	20	35	0	0	0	133
3/24/1999	1	50	40	5	25	45	50	0	216
4/12/1999	5	55	20	45	30	0	0	0	155
9/15/1999	20	25	45	25	0	0	35	50	200
9/22/1999	5	0	60	40	0	0	10	30	145
9/30/1999	0	0	0	10	0	0	65	80	155
10/7/1999	70	15	15	50	50	0	40	50	290
10/11/1999	1	1	0	1	0	0	20	20	43
10/20/1999	0	0	0	0	0	0	2	5	7
10/27/1999	0	0	0	0	0	0	20	40	60
11/4/1999	5	5	10	5	5	30	30	40	130
11/11/1999	0	0	10	5	2	50	20	70	157
	153	273	276	411	276	315	587	625	

MN	INFL	P1	P2	P3	EFFL	W1	W2	WE
Aerobic	57	87	186	188	169	159	401	535
Anaerobic	153	273	276	411	276	315	587	625

SO4 A	INFL	P1	P2	P3	EFFL	W1	W2	WE	Totals
9/24/1998	40	55	0	40	30	40	60	45	310
10/13/1998	2	20	30	40	35	35	20	25	207
10/28/1998	25	45	15	20	50	55	60	45	315
11/11/1998	25	20	20	20	50	25	25	20	205
12/2/1998	25	20	20	35	25	40	40	45	250
2/23/1999	15	50	15	20	15	55	65	55	290
3/9/1999	2	15	15	10	5	0	0	0	47
3/24/1999	1	15	10	15	10	15	30	0	101
4/12/1999	1	15	15	20	25	0	0	0	76
9/15/1999	10	5	25	25	10	0	20	30	125
9/22/1999	2	1	10	15	1	0	55	75	159
9/30/1999	1	2	5	5	1	0	40	50	104
10/7/1999	1	1	3	5	1	0	5	30	41
10/11/1999	1	5	10	10	10	0	20	20	76
10/20/1999	1	10	8	40	60	0	40	40	199
10/27/1999	2	3	5	20	10	0	25	30	95
11/4/1999	5	10	10	30	10	40	40	50	195
11/11/1999	2	3	5	10	10	20	20	70	140
	161	295	221	380	358	325	565	630	

SO4 AN									
9/24/1998	35	50	0	40	30	40	20	45	260
10/13/1998	5	20	25	45	45	50	35	75	300
10/28/1998	45	40	45	50	65	60	70	60	435
11/11/1998	25	30	50	55	45	50	50	45	350
12/2/1998	0	0	0	45	40	40	50	55	230
2/23/1999	10	15	15	10	5	15	40	35	145
3/9/1999	50	55	45	75	70	0	0	0	295
3/24/1999	50	55	45	60	15	60	55	0	340
4/12/1999	45	40	40	50	45	0	0	0	220
9/15/1999	35	55	25	60	25	0	50	25	275
9/22/1999	40	20	80	80	30	0	70	80	400
9/30/1999	20	50	60	30	40	0	65	70	325
10/7/1999	3	3	5	10	5	0	30	50	106
10/11/1999	0	50	3	20	70	0	50	50	243
10/20/1999	2	15	10	60	70	0	30	15	202
10/27/1999	1	1	10	10	5	0	20	10	57
11/4/1999	1	1	10	10	5	0	20	10	57
11/11/1999	1	1	5	10	2	60	30	60	169
	368	501	473	710	612	375	685	625	

SO4	INFL	P1	P2	P3	EFFL	W1	W2	WE
Aerobic	161	295	221	380	358	325	565	630
Anaerobic	368	501	473	710	612	375	685	625

	INFL		P1		P2		P3		EFFL
9/24/1998	180	9/24/1998	222	9/24/1998	174	9/24/1998	275	9/24/1998	238
10/13/1998	9	########	105	########	101	########	165	########	170
10/28/1998	161	########	180	########	130	########	130	########	260
11/11/1998	145	########	155	########	110	########	186	########	191
12/2/1998	51	12/2/1998	42	12/2/1998	97	12/2/1998	215	12/2/1998	190
2/23/1999	55	2/23/1999	91	2/23/1999	85	2/23/1999	76	2/23/1999	75
3/9/1999	92	3/9/1999	210	3/9/1999	138	3/9/1999	165	3/9/1999	121
3/24/1999	80	3/24/1999	155	3/24/1999	180	3/24/1999	130	3/24/1999	100
4/12/1999	111	4/12/1999	160	4/12/1999	160	4/12/1999	220	4/12/1999	165
9/15/1999	130	9/15/1999	170	9/15/1999	155	9/15/1999	175	9/15/1999	75
9/22/1999	57	9/22/1999	29	9/22/1999	188	9/22/1999	163	9/22/1999	43
9/30/1999	21	9/30/1999	54	9/30/1999	87	9/30/1999	51	9/30/1999	72
10/7/1999	78	10/7/1999	33	10/7/1999	56	10/7/1999	115	10/7/1999	65
10/11/1999	4	########	91	########	113	########	121	########	100
10/20/1999	13	########	65	########	53	########	180	########	201
10/27/1999	3	########	16	########	22	########	55	########	35
11/4/1999	39	11/4/1999	36	11/4/1999	95	11/4/1999	135	11/4/1999	45
11/11/1999	4	########	8	########	42	########	58	########	64

	W1		W2		WE
9/24/1998	227	9/24/1998	235	9/24/1998	295
10/13/1998	193	########	195	########	230
10/28/1998	275	########	300	########	310
11/11/1998	172	########	215	########	150
12/2/1998	245	12/2/1998	265	12/2/1998	270
2/23/1999	190	2/23/1999	255	2/23/1999	205
3/9/1999	0	3/9/1999	0	3/9/1999	0
3/24/1999	225	3/24/1999	255	3/24/1999	0
4/12/1999	0	4/12/1999	0	4/12/1999	0
9/15/1999	0	9/15/1999	185	9/15/1999	220
9/22/1999	0	9/22/1999	320	9/22/1999	325
9/30/1999	0	9/30/1999	310	9/30/1999	415
10/7/1999	0	10/7/1999	155	10/7/1999	260
10/11/1999	0	########	136	########	150
10/20/1999	0	########	122	########	105
10/27/1999	0	########	115	########	145
11/4/1999	185	11/4/1999	200	11/4/1999	290
11/11/1999	195	########	140	########	340

Above: Charlene Wick, Grove City College student, takes a water sample from a port of the test tank containing compost and limestone mixture (ca. 1999).

Above: Test-bed wetland constructed by Grove City College students (ca. 1999).

PAPERS AND PRESENTATIONS

Grove City College: Pilot-Scale Systems

Professional Papers

BRENNER, Fred J., KOSICK, Kimberly D., BUSLER, Shaun L., GARDNER, Corrie A., TIPPIE, Carol (accepted 2002) Efficiency of a Scale Model Vertical Flow and Aerobic Wetland System in Treating Acid Mine Drainage: *in* 2002 Proceedings of Annual National Meeting American Society of Mining and Reclamation.

BRENNER, Fred J. (in press) Slippery Rock Creek an Integrated Approach to Watershed Restoration: *in* Water Resources Education, Training and Practice: Opportunities for the Next Century. John J. Warwick (ed.), American Water Resources Association and the Universities Council of Water Resources. pp. 891-896.

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Oral Presentations

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BRENNER, Fred J. (04/1999) Overview of Seaton Creek Monitoring and Research at Jennings: *at* 1999 Slippery Rock Watershed Coalition Symposium.

BRENNER, Fred J. (10/1998) Pilot-Scale Systems and Student Participation: *at* Field Tour for USEPA and PADEP of EPA Section 319 projects.

BRENNER, Fred J. (10/1998) Student Research with Pilot-Scale Demonstration Systems: *at* “Celebrating Environmental Partnerships” Jennings Water Quality Improvement Coalition Dedication of Full-Scale Vertical Flow System.

KOSICK, Kimberley D., GARDNER, Corrie A., BUSLER, Shaun L. (5/2000) Treatment of Acid Mine Drainage with a Test Tank Vertical Flow Pond and Test Bed Wetland: *at* 2000 Beta Beta Beta Competition at Gannon University. [awarded 2nd place]

KOSICK, Kimberley D. (4/2000) Selected Pilot Scale Systems at Jennings: *at* 2000 Slippery Rock Watershed Coalition Symposium.

TIPPIE, Carol (4/2000) Bacterial Colonization in Selected Pilot Scale Systems at Jennings: *at* 2000 Slippery Rock Watershed Coalition Symposium.

TIPPIE, Carol (4/1999) Bacteriological Activity in the Vertical Flow Wetland at Jennings: *at* 1999 Slippery Rock Watershed Coalition Symposium.

News Items

“The Catalyst”, Slippery Rock Watershed Coalition monthly newsletter

(09/2000) “Kim Kosick Received Award in TriBeta Competition”
(12/1998) “US EPA & PA DEP Tour Recently Completed Section 319 Projects”
(11/1998) “Celebrating Environmental Partnerships”
(10/1998) “Grove City College Continues AMD Research and Watershed Study”
(06/1998) “Grove City College Research Activities at Jennings Continue”
(06/1998) “Grove City College Presentations [SRWC Symposium]”
(02/1998) “Grove City College Students to Participate in AMD Research at Jennings”

EFFICIENCY OF A SCALE MODEL VERTICAL FLOW AND AEROBIC WETLAND SYSTEM IN TREATING ACID MINE DRAINAGE[1].

Fred J. Brenner[2], Kimberly D. Kosick, Shaun Busler, Corrie A. Gardner, and Carol Tippie.

Abstract: The efficiency of a scale model vertical flow wetland (VFW) and aerobic wetland system in treating acid mine drainage was monitored over a two year period. The vertical flow system was constructed using a mixture of mushroom compost and limestone and the aerobic wetland was a cattail (*Typha latifolia*) dominated system constructed with mushroom compost as the planting medium. Water samples were collected weekly and analyzed for pH, acidity, alkalinity, iron, manganese, iron and manganese oxidizing bacteria. There was nearly a three unit increase in pH (3.73-6.65) along with a 83% reduction in acidity from an average of 300 mg/L to 50mg/L (83%) and corresponding net alkaline discharge of between 40-9 mg/l. The average iron concentrations were reduced from 32 to 4 mg/l (88%), but only an average of 2 mg/L (11%) of manganese was removed with all manganese reductions occurring in the aerobic wetland. The efficiency of the system varied seasonally, as well as between years, and the reductions in iron and manganese concentrations were correlated with bacterial activity within the systems. The majority of reduction in acidity in the VFW occurred within the upper 45 cm of the substrate, whereas alkaline addition and metal removal occurred between 45 and 90 cm of substrate depth. The efficiency of the systems decreased in the second year of operation. The efficiency of the scale model was similar to systems currently treating acid mine drainage in northwestern Pennsylvania.

Key Words: passive treatment, bacteria, iron and manganese reduction

Introduction

Constructed aerobic wetlands have been used for over four decades for the treatment of acid mine drainage (Kleinmann *et al.*, 1983; Burris *et al.*, 1984; Gerber *et al.*, 1985). Many of these early systems were based on observations of natural *Sphagnum* wetlands receiving mine drainage,

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but almost all of these constructed *Sphagnum* based wetlands ceased to be effective in improving water quality after several months. As a result of early work, almost all acid mine drainage treatment wetlands are currently being planted with cattails (*Typha latifolia*) since they have been shown to be tolerant of a wide range of water conditions (Sencidiver and Bhumbla 1988, Samuel *et al.*1988, Brenner *et al.* 1993, 1995). Although numerous wetlands were constructed during the last three decades, little research has been undertaken to understand the mechanisms operating within these constructed wetland systems.

The most accepted theory for the removal of metals by constructed wetlands involves oxidation and hydrolysis resulting in the precipitation of metals (Hedin 1989). Wieder and Lang (1986) reported that 93 and 27 percent of iron and manganese accumulation, respectively, was in oxidized forms. In drainages with a pH less than 6, the abiotic oxidation rates are slower and oxidizing bacteria become an important component of these treatment wetlands (Kleinmann and Crerar, 1979, Brenner *et al.* 1995). These chemoautotrophic and chemoheterotropic bacteria have been reported to increase the oxidation of ferrous iron, thereby enhancing the formation of iron precipitates (Brenner *et al.* 1993, 1995). Brenner *et al.* (1995) reported that a greater amount of iron oxidizing bacteria occurred in association with cattail rhizomes than elsewhere in the substrate, suggesting increased iron oxidization in the rhizosphere. But this increase in oxidation associated with the rhizosphere may be due to a combination of plant induced oxygenation and iron bacteria (Sencindiver and Bhumbia,1988, Brenner *et al.* 1995). In addition to iron oxidizing bacteria, manganese oxidizing bacteria and fungi have been shown to be the primary source of manganese removal from AMD in constructed wetlands (Brenner *et al.* 1995, Robbins *et al.* 1999).

During the last decade, vertical flow wetlands (VFWs) have been used to treat AMD, but the mechanisms operating within these systems are not completely understood. Based on the initial design of these systems proposed by Kepler and McCleary (1994), VFWs provide net alkalinity through the dissolution of limestone and sulfate reduction, resulting in the precipitation of iron and aluminum in the substrate. Brenner (2001a,b) reported that VFWs are effective in removing over 90% of the iron and aluminum, but they are not as effective in manganese removal. Demchak (1998) indicated that the efficiency of some of these systems began to decline after 18-24 months due to a reduction in limestone and iron accumulation in the substrate with similar results occurring in scale models of these systems (Brenner, 2001a,b). When these scale models were dissected, iron precipitates had accumulated in the upper third of the substrate and the efficiency of the systems in both alkaline addition and metal removal had declined in the second year of operation (Brenner, 2001a,b). Demchak (1998) also reported that overall effectiveness varied seasonally, especially as the systems aged. In theory, these systems function anaerobically. However, in a recent study, Brenner (2001a,b) reported that iron, manganese and sulfate bacteria were isolated from these systems under both anaerobic and aerobic conditions, suggesting the occurrence of both oxidative and reduction processes operating in VFWs.

The object of the current study was to evaluate the efficiency and the role of bacteria in the treatment of AMD in a scale model VFW and aerobic wetland system over a two year period. The model systems were based on the design of a VFW and aerobic wetland system operating at the Jennings Environmental Center in Butler County, PA.

Methods

In the spring of 1998, a scale model VFW and aerobic wetland was constructed at the Jennings Environmental Education Center, Butler County, Pennsylvania (Fig. 1). The system was designed proportionally to a system treating an acidic discharge on the property. The scale model was designed for an average flow of 2.1 L/min. with an average acidity of 300 mg/l and average iron and manganese concentrations of 32 mg/L and 18 mg/L, respectively. The VFW was constructed using a 1 m tall x 1.5 m diameter fiberglass septic tank using substrate consisting of a mixture of 45 cm of mushroom compost and # 9 (0.94 cm) limestone at a ratio of 1 compost:1.4 limestone by weight.. The water distribution system consisted of over and underdrains constructed of 2.5 cm PVC pipes. Sampling ports were installed at depths of 30, 45 and 90 cm. A 2.42 x 1.21 x 0.3 m deep aerobic wetland was constructed, using treated 1.5 cm thick plywood. The substrate consisted of clean river gravel overlain by a mixture of 30 cm of mushroom compost and # 9 limestone (0.94 cm) at a 1 compost:1.4 limestone by weight. The water distribution system was installed in the river gravel using 2.5 cm PVC pipe and sampling ports were installed at the influent, 1.2 m and at the effluent. Samples were collected weekly from the influent, effluent and each sampling port. Samples were analyzed for acidity, alkalinity, iron, and manganese according to the procedures described in the 18th edition of Standard Methods for Analysis of Water and Waste Water (Greensburg *et al.* 1992). Samples were analyzed for total iron and manganese by atomic absorption and by spectrophotometric procedures. Samples for bacteriological analysis were collected in 150 ml polypropylene bottles and cultured aerobically and anaerobically on iron and manganese medium. One ml of each sample was cultured aerobically and anaerobically on iron isolation medium and manganese agar at 20 C for 5 to 7 days as described in the 18^{th} edition of Standard Methods for Analysis of Water and Waste Water (Greensburg *et al.* 1992).

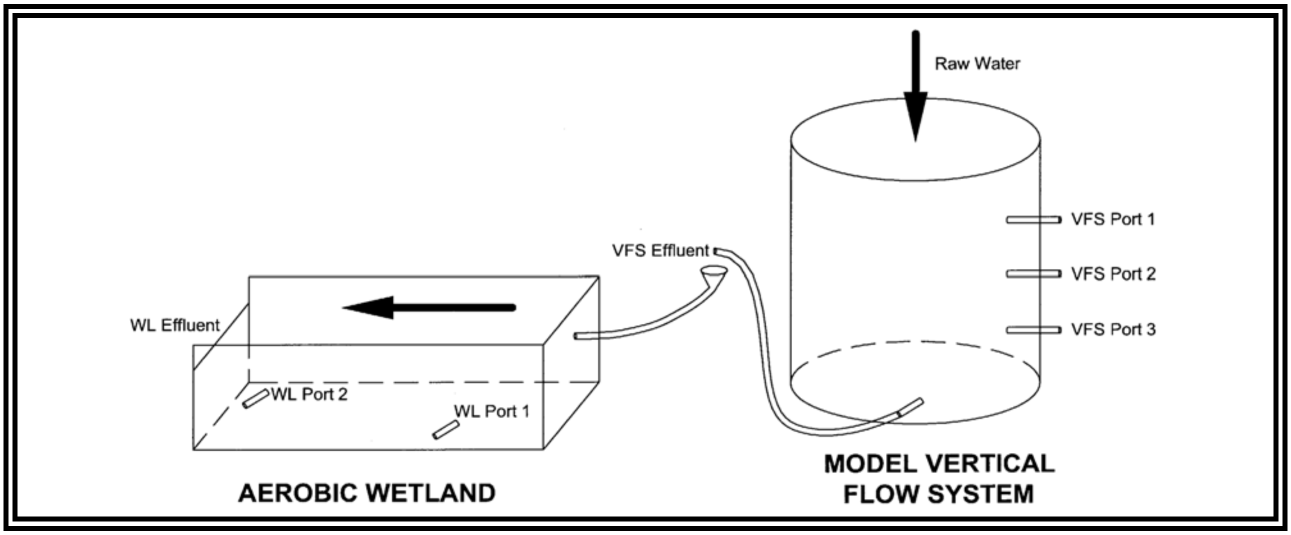

Figure 1. Schematic drawing of the vertical flow and aerobic wetland system at the Jennings Environmental Education Center.

Results and Discussion

The combination of the VFW and the aerobic wetland was effective in removing acidity and reducing metal concentrations in the final discharges, but there was a reduction in the efficiency of the system during the second year of operation. Overall, there was a three unit increase in pH from 3.72 to 6.65 with over 74% of this increase occurring in the VFW. The majority of the increase in pH occurred between the middle 45 cm (sampling port 2) and 90 cm (port 3) substrate depth. Likewise, acidity was reduced from an average of 300 mg/l in the influent to less than 50 mg/l in the final discharge (83%) with over 50% of this reduction occurring in VFW between port 2 (45 cm substrate depth) and port 3 (90 cm substrate depth. The net alkalinity of the final discharge varied between 40 and 90 mg/L with the majority of alkaline addition occurring in the lower 90 cm of substrate in the VFW and in the aerobic wetland. During the second year of operation, there was a 30 and 35% in alkalinity which was probably due, a least in part, to dissolution of limestone in the substrate.

Overall, the combination of the VFW and aerobic wetland was effective in reducing iron concentrations from an average of 32 to 4 mg/L (88.8%) in the final discharge, but the system only removed an average of 2mg/L of manganese (Fig. 2). The efficiency of metal removal

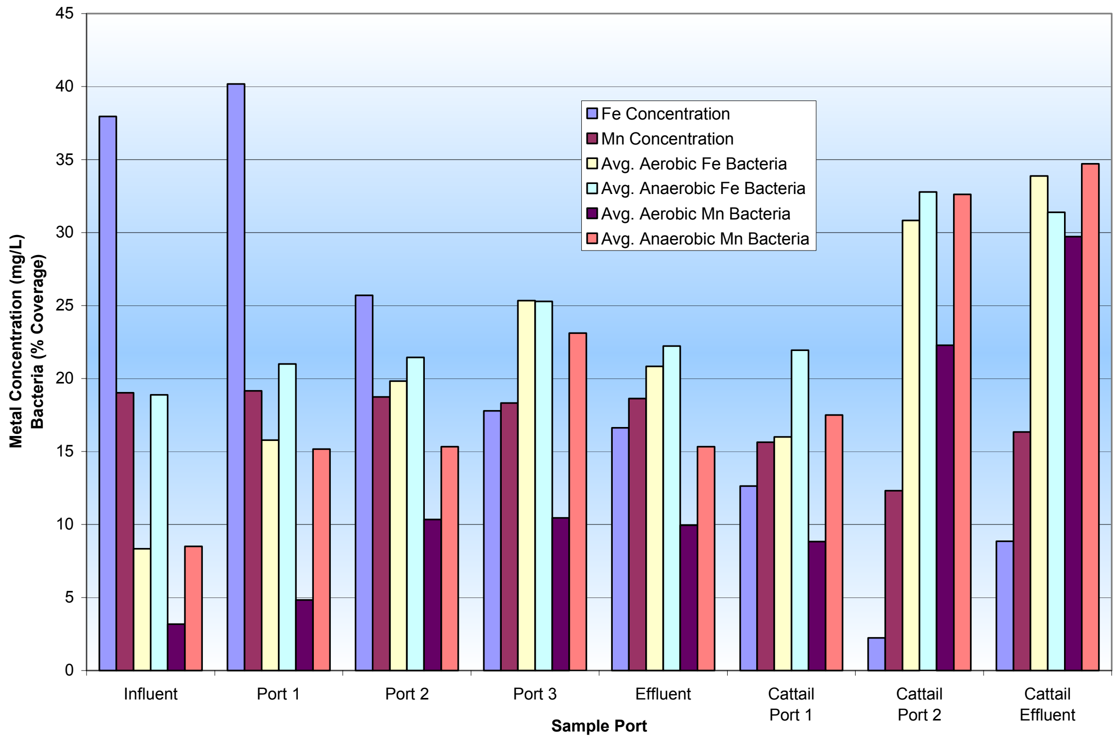

Figure 2. Average metal and bacteria concentrations through vertical flow system and aerobic wetland from 1998 to 2000.

varied seasonally (Fig. 3) and between the two years of operation (Fig. 3). Although, iron concentrations in the influent varied seasonally from an average of 57 mg/L during the winter months (December, January, February) to 26 mg/l in the spring (March April, May), the amount of iron removed was less during the spring than in the other months of the year. During the summer and autumn months, iron concentrations were reduced from 36 to 3 mg/l (92%) compared to 24 mg/L (57-33) (42%) being removed during the winter months. Although lower iron concentrations (26 mg/L) occurred during the spring, the systems also removed less iron (19 mg/L) during this period (which translates into a 73% efficiency of iron removal during these months). The efficiency of iron removal by the VFW decreased during the second year of operation. In the first year, the VFWS removed 34 mg (41-7 mg/L) of iron/L (87%) which decreased to 17 mg/L (46%) during the second year of operation and, in both years, less than 5% of the reduction occurred in the upper 45 cm of the substrate (Fig. 3). Earlier studies (Brenner *et al.* 1993, 1995) report seasonal variations in iron removed and elevated iron concentrations in the effluent from the aerobic wetlands during the winter and early spring. These elevated iron

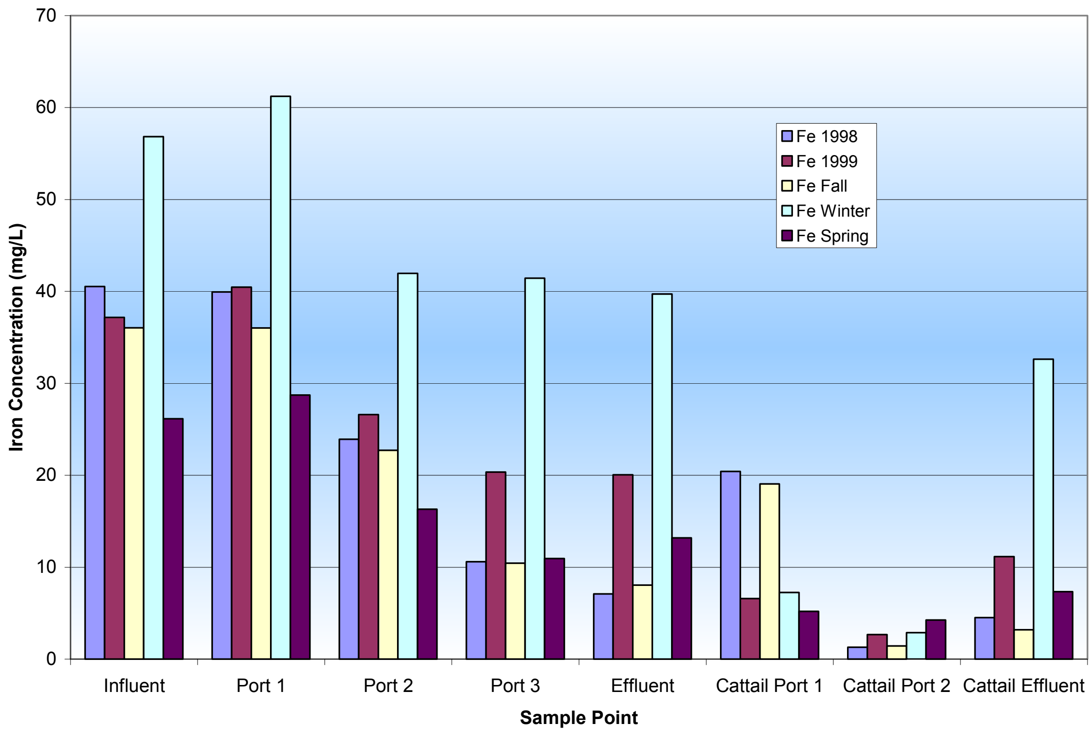

Figure 3. Yearly and seasonal comparison of iron concentrations.

concentrations in the effluent from aerobic wetlands may be due to several factors including the re-dissolving and re-precipitating of iron or the accumulation of iron precipitates and flushing of iron in the discharge.

In contrast to iron, manganese concentrations remained relatively constant throughout the year (18-20 mg/L) (Fig. 4), but manganese removal only occurred at warmer temperatures. During the spring and summer months manganese concentrations were reduced from 20 to 18 mg/l (10%) and from 18 to 15 mg/L (17%), respectively, with only 1 mg/L (5%) being removed during the winter months (Fig. 4). Although there was an initial reduction of iron and manganese in the aerobic wetland, concentrations of both metals increased between the second sampling point and the final discharge with the largest increase occurring during the winter months. These increases in iron and manganese may be due, at least in part, to the re-dissolving and re-precipitation iron and/or the accumulation and flushing of iron in the discharge, the desorbing and resorbing of manganese in the substrate (Brenner *et al.* 1993, 1995).

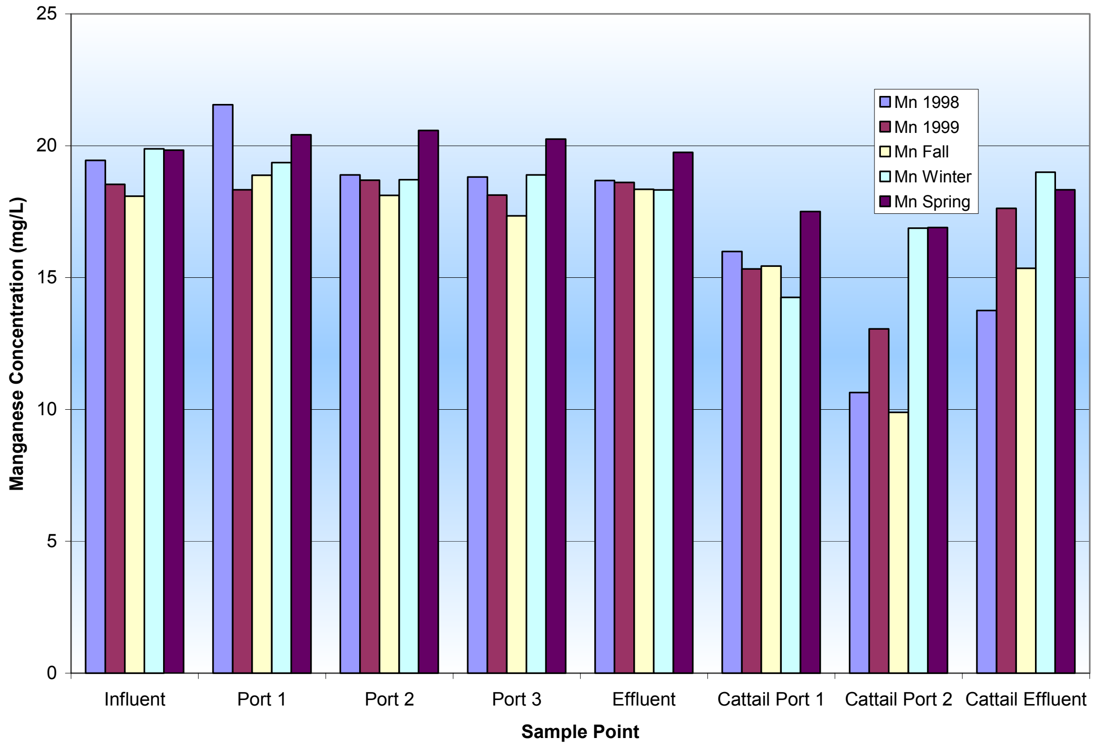

Figure 4. Yearly and seasonal comparison of manganese concentrations.

Overall, the bacteriological activity within the VFW, and aerobic wetland was inversely correlated with the iron (aerobic, $r = -0.795$, $P<0.01$; anaerobic, $r = -0.796$, $P<0.01$) and manganese concentrations (aerobic, $r = -0.657$, $P<0.05$; $r = -0.730$, $P<0.01$) (Fig. 5), but seasonal variations occurred in bacteriological activity in both systems, as well as between the two years (Table 1). Except for the spring months (March, April, May) when anaerobic bacteria were positively correlated with iron concentrations, both aerobic and anaerobic bacteria were inversely correlated with iron concentrations during the remainder of the year. Likewise, manganese concentrations were positively correlated with aerobic and anaerobic bacteria during the spring and, except for anaerobic bacteria during the winter months, manganese concentrations were inversely correlated with bacteriological activity during the other months of the year. During, the first year of operation, iron concentrations were inversely correlated with aerobic bacteria (r = -0.839, P<0.01), but there was not a significant correlation between anaerobic bacteriological

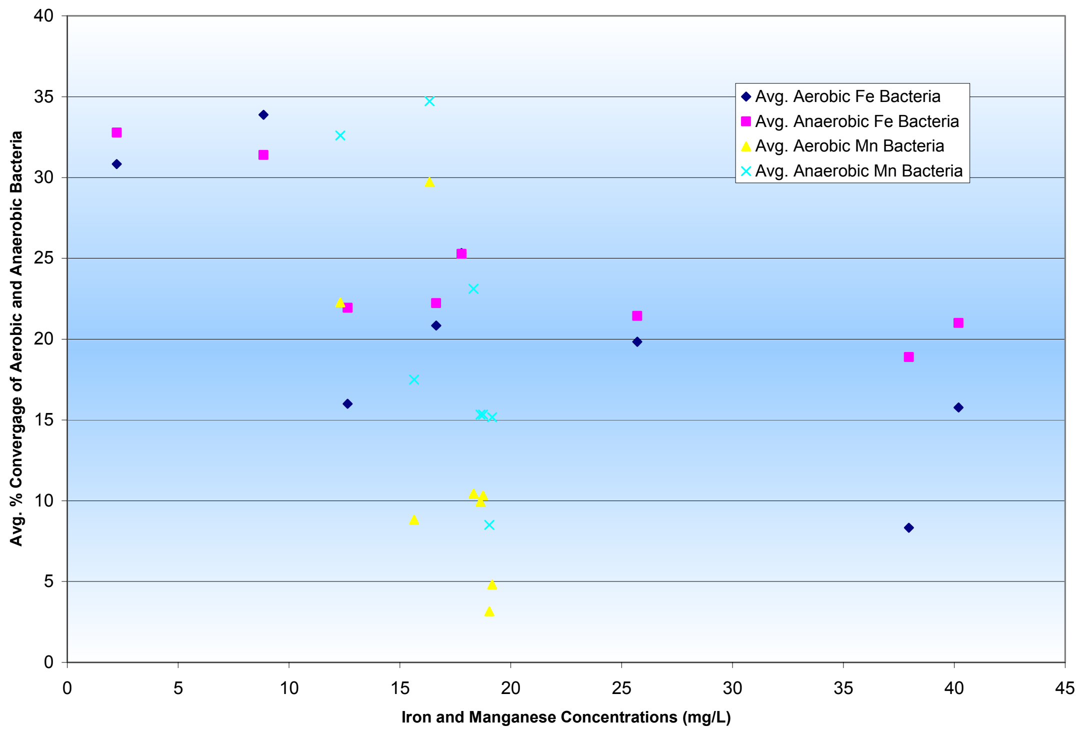

Figure 5. Comparison between average metal concentrations and bacteria levels.

activity and iron concentrations (r = -0.258, P> 0.1). Whereas during the second year, iron concentrations were inversely correlated with both aerobic (r = -0.602, P<0.05) and anaerobic (r = -0.456, P<0.05) bacteria. Manganese concentrations during the first year were inversely correlated with both aerobic (r = -0.734, P< 0.01) and anaerobic (r = -0.861, P<0.01) bacteriological activity, but in the second year, manganese concentrations were only inversely correlated with aerobic bacteria (r = -0.443, P<0.05).

Table 1. Seasonal Yearly Comparisons of Correlation Coefficients Between Bacteriological Activity and Metal Concentrations in a Vertical Flow and Aerobic Wetland System.

	Season			Year		
	Summer-Fall	Winter	Spring	1	2	Overall
Iron						
Aerobic	-0.840**	-0.892**	0.155	-0.839**	-0.602*	-0.901**
Anaerobic	-0.700**	-0.889**	0.371	-0.258	-0.466*	-0.813**
Manganese						
Aerobic	-0.618*	-0.314	0.562*	-0.734*	-0.443*	-0.579*
Anaerobic	-0.730	-0.141	0.487*	-0.443*	-0.272	-0.661

*P<0.05, **P<0.01, ***P<0.001

The season and yearly variations in iron and manganese bacteriological activity appears to be related to the efficiency of iron and manganese reductions of both VFWS and aerobic wetlands. Although the precipitation of iron and manganese oxides continues to be an important aspect of metal reductions in passive treatment systems, bacteriological activity appears to be a major factor in the efficiency of these systems in the removal of iron and manganese from acidic discharges.

<u>Conclusions and Recommendations</u>

There was a three unit increase in pH and removal of 250 mg/L of acidity in the upper 45 cm of the VFW with the majority of the alkaline addition occurring between 45 and 90 cm of the VFW substrate. Although the efficiency of the VFW and aerobic wetland system varied seasonally, as well as between years, overall the system was effective in the removal of iron, but not manganese. The concentrations of both metals, however, were inversely correlated with aerobic and anaerobic bacteria. The results of this study, as well as those of Brenner *et al.* (1993, 1995), suggest chemoauthotrophic and chemoheterotrophic bacteria are important components of both VFW and aerobic wetlands. Although in theory VFWs are designed to function anaerobically, the isolation of both iron and manganese bacteria from these systems suggest that the systems are not completely anaerobic or that these bacteria are functioning facultatively. Previously authors (Brenner *et al.*, 1993, 1995; Hedin *et al.* 1994) have suggested that the removal of manganese in aerobic wetlands is sequential and occurs only after the removal of iron. Brenner and Pruent (1999) reported that manganese concentrations were reduced from 11.3 mg/L to 4.8 mg/L (58%) in a limestone drain, settling pond and aerobic wetland systems with the majority of the iron being removed by the limestone drain/settling pond and manganese removal occurred in the aerobic wetland. These along with the current study suggest that increasing the pH and alkalinity via either VFWs or limestone drains will improve the efficiency of aerobic wetlands to removal manganese from AMD.

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Erie, PA 16541-0001 and USDA, APHIS, PPQ, Harrisburg, PA. *An Eradication Program for Giant Hogweed in Northwestern Pennsylvania.* – Giant hogweed (*Heracleum mantegazzianum*) is an invasive, non-native, herbaceous weed commonly reaching heights of three meters or more. Giant hogweed is a designated Federal noxious weed due to the fact that varied glycosides within its sap can lead to severe chemical burns on human skin. In 1995 it was noted that Erie County and environs had hogweed in approximately ten locations. A survey program coupled with intensive media promotions led to the identification of over seventy confirmed sites in Northwestern Pennsylvania. We have systematically tracked down hogweed sites and treated stands of hogweed in two stages: first, flowers were removed mechanically before seed set, and second, a chemical mixture was applied to vegetative foliage. We believe that after numerous rechecks and reapplications, all ninety-two of the known hogweed sites have been brought under control. Stands will continue to be checked and retreated early in spring of 1999 for germination of seeds already in the soil. **(95)**

Brenner, Elaine K.[1]*, **Fred J. Brenner**[2], **James J. Mondok**[3] and **Robert J. McDonald**[3]. [1]Department of Chemical Engineering, Chemistry and Environmental Science, New Jersey Institute of Technology, Newark, New Jersey, [2]Department of Biology, Grove City College, Grove City, Pennsylvania, [3]Mercer County Conservation District, Mercer, Pennsylvania. *Comparison of Water Quality Management Methods on Two Subwatersheds on Coolspring Creek, Mercer County, Pennsylvania.* – Despite the use of best-management practices, the water quality within many agricultural watersheds has failed to improve. As a result, new methods of watershed management are now being explored. At Lake Latonka, approximately 1000 ha watershed, four sediment control structures were installed between 1986-1988 in an attempt to reduce sediment, as well as, nutrients and bacteria loading entering the lake. In the Munnel Run watershed a water quality improvement program was initiated in the early 1990's, which included restoring riparian buffers and wetlands, and fencing cattle out of the streams. The current study evaluates the effectiveness of these programs on nonpoint source pollution abatement. In general, both programs achieved improvement in the water quality in the watersheds. However, there were significant variations among the water quality parameters, suggesting that both programs were successful, but other practices may be necessary to achieve water quality goals watersheds. **(12)**

Brenner, Fred J.*, **Kimberly D. Kosick**, **Shaun L. Busler** and **Corrie A. Gardner**, Department of Biology, Grove City College, Grove City, PA 16127. *Effectiveness of a Model Combined Vertical Flow and Test Bed Wetlands in Treating Acid Mine Drainage.* – A model of a combined vertical flow and test bed wetlands were monitored weekly over 10 months to determine their effectiveness in the treating acid mine discharges. Samples were obtained from 8 locations within the system and the results to date, indicate that these wetlands were effective in removing acidity and increasing pH. The pH increase from less than 3.0 to between 6.5 and 7.2 and acidity decreased from over 300 mg/l to < 2 mg/l at the point of final discharge with a corresponding increase in alkalinity. These wetlands were effective in removing aluminum and iron, but were ineffective in the removal of manganese and sulfate increased in the final discharge possibly due to bacteriological activity in the final discharge. These studies will continue to determine how long these systems will be effective in the treatment of the acid mine discharges. **(155)**

Bres, Mimi[1]* and **Kenneth W. Thomulka**[2], [1]Department of Biology, Prince Georges Community College, Largo, MD 20774, [2]University of the Sciences, Philadelphia, PA 19104. *Enzyme Walk.* – Enzyme activity and how various combinations of enzyme, substrate or inhibitor impact on the rate of an enzyme reaction are very difficult concepts to teach. Students are usually unable to visualize these activities. An exercise to demonstrate these effects will be presented. It has no cost, requires no equipment and little advance preparation. Students are anonymously assigned roles as enzyme, substrate or inhibitor based on some numbering system. For example, if the last digit of your phone number is a 1, you are an enzyme and are given the pass-word "how are you today?". Everyone else is a substrate and should say "fine, thank you". Students are instructed to walk around randomly and shake hands with everyone they encounter. If they recognize each other as an enzyme and substrate by completing the phrase, they have formed a product. The product is escorted to the side of the room and the enzyme returns for another substrate. Some students are data recorders. The "reaction" can be stopped at intervals to determine the amount of product produced. This data, when plotted, resembles data obtained from a "real" enzymatic reaction. The exercise requires a large room. It might be done in a hall, auditorium or gym. For schools with small calsses, perhaps sections could be combined. **(88)**

Briggs, Michelle A.,* Department of Biology, Lycoming College, Box 152, Williamsport, PA 17701. *The Allelopathic Potential of Solidago Altissima (Goldenrod).* – Allelopathic interactions arise because plants release chemicals into the environment. These chemicals can then affect germination, growth and/or microbial interactions of other plants. In Pennsylvania, *Solidago altissima* (tall goldenrod) commonly grows in large clonal clumps, often with no other plants growing within the clone. This pattern may be due to more than simple competition, since related species are allelopathic.

finding the slope of the linear regression. Fungal biomass was quantified by HPLC following ergosterol extractions by the reflux method. HPLC equipment read, displayed, and measured peak areas of ergosterol absorbing at 282.0nm. The fungal community's contribution to total decomposition was derived graphically from plotting peak area against the volume injected and comparing them to a standard curve derived from an ergosterol solution of known concentration. These values were expressed as ergosterol concentrations, which are directly proportional to the fungal colonization present, and were used to compare fungal contributions in an acidic creek versus a non-acidic creek. Insect communities were also analyzed using EPA and RBA methods. Various water chemistry parameters were monitored at the start and end of the leaf pack incubation period to ensure that water pH was the only significant impairment factor between the three sites. **(148)**

Klinger, Ellen G.* and **Mel Zimmerman,** Lycoming College, Williamsport, PA. *Carrying Capacity of White-Tailed Deer (Odocoileus virginianus) at Rider Park, Williamsport, PA.* – Deer density studies are of specific importance in protected nature preserves, which often harbor overabundance of organisms. This is the first year in a long-term study of deer damage in Rider Park, outside of Williamsport, PA. Population estimates of deer in Rider Park over the last three years range from 50-80 per square mile. This study quantified damage to woody and herbaceous components of the park's ecosystem and used these amounts to determine environment dependant Capacity numbers. A 950 square meter exclosure was erected on the property and inventories of herbaceous plants inside and outside the exclosure were taken and used to determine similarity of the two environments. Deer browse of woody vegetation was studied in November and February and used to determine amount of available biomass and to calculate carrying capacity numbers for twelve different sites in the park. This carrying capacity calculations were compared with deer drive and scat population survey numbers to determine the severity of deer overpopulation within the park boundary. **(91)**

Klotz, Larry*[1] and **Timothy Falkenstein**[2], [1]Shippensburg University, Shippensburg, PA 17257 and [2]Rettew Associates, Lancaster, PA 17603. *Vascular Plant Communities of the Southern Part of the Mount Cydonia Ponds Natural Area, Michaux State Forest, Franklin County, Pennsylvania.* -- Vegetation and topography were described for a group of 17 natural ponds and the surrounding upland forest. Each pond comprises a peripheral zone of broadleaved deciduous swamp forest and a non-forested central zone. The central zone area ranges from 250 to 1200 m^2. Its maximum depth relative to the upland forest ecotone ranges from 0.4 to 1.9 m. The upland forest is dominated by mixed oaks (*Quercus montana, Q. alba, Q. velutina*) in the canopy and *Pinus strobus* in the subcanopy. *Acer rubrum* and *Nyssa sylvatica* dominate both of these strata in the swamp forest. Five of the ponds lack vegetation in the central zone. In the remainder, the central zone contains one to three of the following vegetation types: (1) dense or sparse shrub swamp dominated by buttonbush (*Cephalanthus occidentalis*), (2) tall or low marsh of mixed graminoids and forbs, (3) rooted, floating-leaved species. **(116)**

Kory, William B., University of Pittsburgh at Johnstown, Johnstown, PA. *Pennsylvania's Counties on the Eve of the 21st Century: A Demographic Delineation.* – Pennsylvania, along with a number of other northeastern states, is projected to have only a slight increase in population in the year 2000. This demographic trend is due to the continuous out migration of population from the region, especially from the city of Philadelphia and the city of Pittsburgh. This presentation will focus on the sixty-seven counties in Pennsylvania to see if there is a spatial pattern ,of population losses within the Commonwealth. The data from the 1990 Census will be compared with the 1998 population estimates and the results plotted and analyzed. Nearly 30% of the counties in Pennsylvania are projected to have population losses. This will result in the realignment of political representation within the state, revenue losses, declining employment and the proportional growth in the elderly population as the younger populace migrates out. **(13)**

Kosick, Kimberly D.*, Corrie A. Gardner, Shaun L. Busler and **Fred J. Brenner,** Biology Department, Grove City College Grove City, PA 16127. *Effectiveness of Constructed Wetlands in Ameliorating Acid Mine Drainage.* – In the spring of 1998, a two-cell wetland was constructed at the Jennings Environmental Education Center located south of Slippery Rock, Butler County, PA. Mine discharge enters a vertical flow wetland systems (VFS) containing a 50:50 mixture of spent mushroom compost and limestone. Samples were collected from eight locations in the systems and analyzed for pH, acidity, alkalinity, iron, manganese, aluminum and sulfate over 18 months. Based on the results to date, the systems remain effective in increasing pH and Alkalinity while reducing acidity, iron and manganese concentrations in the effluents. The pH increased from an average of 3.73 to 6.58 in the influent to an average of 6.58 in the effluent, for an overall 76% increase with a corresponding 78% reduction in acidity. Iron and manganese were reduced to 84% and 20%, respectively. There was not an overall trend to the effectiveness of the system in reducing aluminum and sulfate concentrations.

Although metal reductions were similar to other constructed wetlands, the concentrations in the effluents did not meet Pennsylvania Clean Water Quality Standards. **(25)**

Kosick, Kimberly D.*, **Corrie A. Gardner**, **Shaun L. Busler** and **Fred J. Brenner**, Biology Department, Grove City College, Grove City, PA 16127. *Seasonal Variation in Efficiency of Acid Mine Treatment Wetlands.* – Seasonal variation in the efficiency of a two-cell wetland system in treating acid mine drainage was analyzed over two years. These wetlands were constructed during the spring of 1998 at the Jennings Environmental Education Center located south of Slippery Rock, Butler County Pennsylvania. For the purpose of this study, the seasons were defined as follows: spring-March-May, fall-September-November, winter-December-February. There was not a significant seasonal variation in the efficiency of treatment of pH, acidity, and manganese. Based on an analysis of variation (ANOVA), there was a significant seasonal variation in the treatment of iron (F_{obs} = 6.37, $P<0.05$), with the highest and lowest efficiency occurring during the spring and winter months, respectively. There was also a seasonal variation in ine addition (F_{obs}= 7.26, $P<0.05$) with alkalinity of the effluents being highest in the spring and lowest during the winter months. **(150)**

Kratzer, Jud* and **Mel Zimmerman**, Department of Biology, Lycoming College, Williamsport, PA 17701. *The Effects of Trout Habitat Restoration and the Cessation of Stocking on the Chemistry, Benthic Macroinvertebrate Community, and Fish Community on Big Bear Creek, Lycoming County, PA.* - The brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) fishery of Big Bear Creek, a tributary of the Loyalsock Creek in Lycoming County Pennsylvania, has been declining over the past several decades. The construction of 70 wood and rock "Rosgen" structures, was completed in October 1999 in order to narrow and deepen the stream, providing more trout habitat. Stocking of hatchery-raised trout was ended in 1999 in hopes that wild trout would provide a sufficient fishery within a few years. The only major changes seen in the stream's chemistry were increases in alkalinity and pH due to the limestone structures that were built. After 6 months of study, the habitat construction and cessation of stocking have had no major effect on benthic macroinvertebrate or fish communities. Over the next few years, the brook ut population is expected to boom because electro- ning has revealed a large number of streambred ages 0 and 1 brook trout, with much fewer streambred ages 0 and 1 brown trout. **(147)**

Kunkle, Justin M.* and **Timothy W. Sipe**, Department of Biology, Franklin and Marshall College, Lancaster, PA. 17604-3003. *Forest Composition and Juvenile Tree Performance in Response to Bedrock Variation in Lancaster County, PA.* – We are investigating the effects of five bedrock types (limestone, sandstone, schist, shale, quartzite) on forest composition and tree seedling growth and photosynthesis. Permanent plots were established in 15 sites, three per bedrock type. All trees >1 m tall were recorded in each site. Sixteen intact soil cores (7.5 cm x 25 cm) were extracted by hand auger from each site and transferred to PVC tubes. Field-germinated seedlings of *Liriodendron tulipifera, Acer rubrum, Acer saccharum,* and *Fagus grandifolia* were transplanted into the tubes and grown for four months in a glasshouse. Preliminary results show that overstory composition differs substantially in response to bedrock, with limestone and shale exhibiting the greatest distinction. The species differed significantly in photosynthetic response to both low and high irradiances, but there was no significant bedrock effect. *A. rubrum* and *L. tulipifera* showed the greatest growth overall, with variable bedrock effects within and among species. **(186)**

Kwasny, Jessica A.* and **Kenneth M. Klemow**, Department of Biology, Wilkes University, Wilkes-Barre, PA 18766. *Developing an Online Taxonomic Key to the Plants of the Kirby Park Natural Area.* – Individuals who lack expertise in plant identification often use field guides to identify unknown specimens. Though popular, such guides have several disadvantages including use of complex terminology and a focus on a single group of plants (wildflowers, trees, ferns). Another approach would be to develop a new, user-friendly tool for plant identification using a hypertext-based system that combines words and images on electronic pages that can be linked. Such a hypertext-based taxonomic key is being created for the plants from Kirby Park Natural Area in Wilkes-Barre, PA. An initial version of that key, created in 1998, is being revised. Individual pages, created in HTML, provide either choices based on text and figures, or an identification of species typically found in the park. The pages are embedded with links to other choices or to an identification page. The updated version of the key is set up using frames to facilitate navigation. The pages are uploaded to the Wilkes University mainframe and made available through the Internet. The usefulness of the key will be assessed through tests conducted by local ninth grade students. **(1)**

Lauver, Jeremy M.* and **Allan F. Wolfe**, Department of Biology, Lebanon Valley College, Annville, PA 17003. *A Study of the Cuticular Setae on the Second Antennae of Artemia franciscana.* – The second antennae of the brine

EFFECTIVENESS OF A VERTICAL FLOW SYSTEM AND CONSTRUCTED WETLAND IN AMELIORATING THE IMPACTS OF ACID MINE DRAINAGE

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Abstract: In the spring of 1998, a two-celled wetland was constructed at Jenning's Environmental Education Center in Slippery Rock, PA. The mine runoff first entered a vertical flow system (VFS) containing a mixture of mushroom compost and limestone. Th effluent then flowed into a test bed wetland for further treatment, which contained mushroom compost and *Thyphus latifolia*. Water samples from eight locations in the system were collected weekly and analyzed for nine water quality parameters. Conductivity, total dissolved solids, and pH were measured using field meters. Alkalinity and acidity were determined by titrating with H_2SO_4 and $CaCO_3$, respectively. Iron, manganese, and aluminum were analyzed using a Hach colorimeter, and within the last three months, atomic absorption spectroscopy. The average pH of the influent was 3.73, and the average effluent pH was 6.58, for an overall 76% increase. The acidity of the effluent leaving the wetland was reduced approximately 78% with a corresponding alkaline addition of between 40-90 mg/L H_2SO_4. Iron, manganese, and aluminum concentrations were reduced by 77%, 20%, and 95%, respectively.

Introduction

Currently in Pennsylvania, there are 2,500 miles of streams classified as severely impacted by acid mine drainage (AMD) from abandoned coal mines. The "severely impacted" classification describes streams that are either incapable of supporting life or streams with low biodiversity. This widespread impact makes AMD the single leading source of water pollution in the state.

Generally, AMD is characterized by net acidity, low pH, elevated concentrations of heavy metals and sulfates, and other total dissolved solids (Banks et al. 1998). Acid mine drainage is generated when mined areas with high sulfide content are exposed to the weathering conditions of water and air. The mineral most often responsible for the generation of AMD is the oxidization of pyrite, an iron disulfide (FeS_2) by water and air entering abandoned mine shafts (Banks et al. 1998, EPA 1993). The net reaction of the oxidation of pyrite is as follows:

$$4FeS_{2(s)} + 14H_2O + 15O_2 \rightarrow 4\ Fe(OH)_{3(s)} + 8SO_4{}^{2-}{}_{(aq)} + 16H^+{}_{(aq)}$$ (Banks et al. 1998)

Acidity generated in this way results in a very low pH when it exceeds the alkalinity available to the system on an equivalent basis.

When working with AMD, low pH, high acidity, and elevated concentrations of iron, manganese, and aluminum are the areas of greatest concern (Banks et al. 1998, Holtzen and Smith 1998, Powicki 1997). The distribution of aquatic species is directly limited by the range of pH at which the species can survive. Also, the metals can contaminate sediments and concentrate in aquatic food chains, which can be a problem for local wildlife, as well as humans that use the stream as either a food source or for recreation (Powicki 1997).

Passive treatments, such as wetlands, have been used frequently to treat AMD. Passive treatments are desirable because they require little maintenance, they do not require supplementary chemical additions, and treatment is achieved via microbial processes, aquatic plant growth, and neither sludge nor waste is produced (Banks et al. 1998, EPA 1993). Wetlands are among the most productive of natural ecosystems and act as a buffer between terrestrial and aquatic habitats. While offering unique ecological, aesthetic, and practical benefits (Powicki 1997), wetlands treat water in six ways:

1) the filtration of suspended solids and colloidal material
2) uptake of contaminants into the roots and leaves of plants
3) adsorption or exchange of contaminants onto inorganic soil constituents, organic solids, dead plant material, or algal material
4) neutralization and precipitation of contaminants through the generation of HCO_3^-, and NH_3 by the bacterial decay of organic matter
5) destruction or precipitation of contaminants in the aerobic zone catalyzed by the activity of bacteria
6) destruction or precipitation of contaminants in the anaerobic zone catalyzed by the activity of the bacteria (EPA 1993, Majumdar et al. 1998, Majumdar, Miller, and Brenner 1998)

Two distinct zones, an aerobic and an anaerobic zone, exist within wetlands. Paradoxically, the redox reactions that occur in these zones are approximately the reverse of each other. In the aerobic zone at the surface of the wetland, oxidation reactions occur resulting in the production of protons (or acidity) and the oxidation of metals. In this zone, iron is fully oxidized and precipitates out as iron oxyhydroxide, $Fe(OH)_3$. It is these iron oxyhydroxide precipitates that form the characteristic orange-yellow layer on top of rocks, plants, and sediments, called Yellow-boy by miners, which is a visible sign of AMD. In the anaerobic zone within the sediments, reduction reactions occur, consuming protons and precipitating metals. Here, iron is reduced back to iron sulfide compounds and is incorporated into the sediments, where it cannot be reoxidized into the water column (EPA 1993).

By separating the vertical flow system and the wetland, it was hoped that the anaerobic and aerobic processes would be isolated and enhanced. The vertical flow system was expected to be anaerobic, and thus reduce metals. The wetland should enhance the oxidation and provide for some reduction in the sediments. Together, the two-celled system should be effective in neutralizing the pH, lowering the acidity, adding alkalinity, and removing metals from the acid mine runoff.

Methods

In the spring of 1998, construction began on the vertical flow system and wetland box. The vertical flow system (VFS) was proportioned after a full-scale vertical flow pond. The reasoning behind this decision was to determine where in the system various improvements were being made. The VFS was constructed from a fiberglass sewage tank measuring five feet in diameter and approximately three feet in height. One inch PVC pipe was used to construct an over-drain, to evenly distribute water across the surface, and an under-drain to collect the water at the bottom of the system. It was filled to a height of approximately 18" with a mixture of spent mushroom compost and limestone. The mushroom compost essentially consisted of chicken manure, horse manure, gypsum, and hay. It provided a surface for the precipitation of metals and a nutrient source for bacteria. There were five collection ports within the vertical flow system – the influent, effluent, and three ports at varying depths within the sediments. The final effluent from the VFS continued on to the constructed wetland box.

The wetland box was constructed at the same time as the VFS. It was assembled from plywood and measured approximately 8' x 4' x 2'. The middle of the box was braced on three sides with 2" x 4" supports. The box was painted with an outdoor, epoxy paint sealer, and the seams were caulked to prevent leakage. PVC pipe was again used to create a distribution drain and was placed at the bottom of the box to prevent the strict overland flow of the water. This drain was buried in gravel in an attempt to keep it from plugging. The wetland box was then filled to an approximate height of 12" with the mushroom compost. Three ports were used to collect samples, two were at varying levels in the sediments, and the third was the overland flow of wetland effluent.

Water samples were collected from these eight ports on a weekly basis for the academic years of 1998-99 and 1999-00 (Figure 1). These samples were then analyzed for nine water quality indicators. Conductivity, total dissolved solids (TDS), and pH were analyzed using field meters. Alkalinity and acidity were determined by titrating with H_2SO_4 and $CaCO_3$, respectively. Iron, manganese, and aluminum were measured using a HACH colorimeter, and within the past three months, with atomic absorption spectroscopy.

Results and Discussion

To date, thirty-four sample sets were collected and analyzed by the above methods. The influent pH averaged 3.72 over the two years. The system averaged an effluent pH of 6.65 for an increase of 86%. A more in depth analysis demonstrated that 60% of the overall increase in pH occurred between VFS Ports 2 and 3. This was most likely due to the settling of the limestone to the bottom of the system, since the limestone is the major source of alkalinity, and thus, the major force behind the increase in pH. Additionally, 74% of the overall increase in pH occurred in the VFS (Figure 2). There was also little change in average pH between the two academic years of the study.

Alkalinity was not detected in the influent AMD, and there was a net alkaline addition of 46.6 mg/L H_2SO_4. Supporting the conclusion that the limestone has settled to the bottom of the VFS was the fact that the greatest alkaline addition also occurred between VFS Ports 2 and 3. As shown in Figure 3, the alkalinity jumps from 0 to 44.7 mg/L H_2SO_4 at VFS Port 3. Alkaline addition maxed out at Cattail Box Port 2, and then decreased by nearly half at the Cattail Effluent (Figure 3). Strict overland flow of the differences between oxidative and reductive environments may be the reason for this significant change. Alkaline addition decreased 30-35% between the academic years of 1998-99 and 1999-2000 (Figure 4). This was believed to be the result of decreased limestone content throughout the system due to its being dissolved by the runoff. The remaining limestone may have become armored by metal precipitates, thus reducing the availability of limestone to the system.

This system was 78% effective in reducing acidity. Because acidity was so closely linked to pH and alkalinity, the greatest change in acidity also occurred between VFS Ports 2 and 3, as expected (Figure 3). When comparing the percent reductions between the two academic years, there was a large decrease in the reductions. In 1998-99 the cattail box was 82% effective in removing acidity. However in 1999-2000, this efficiency dropped to only 58% even though the total acidity in the system's final discharge was relatively comparable for the two years. This may be explained by the approximate 66% reduction in acidity entering the system during the 1999-00 sampling period (Figure 5). The reduced acidity observed in the 1999-2000 sampling year may be a result of the summer drought conditions, which decreased the flow rate entering the system by half.

Iron was the most concentrated metal in the acid mine runoff. Iron will precipitate out of solution, at an approximate pH of 4-5, as a rust-orange iron oxyhydroxide compound, or ochre. Bacterial oxidation of reduced iron sulfide to ferric sulfate, predominately by *Thiobacillus ferrodoxins*, accelerates the rate of iron removal. Iron concentration in the influent averaged 37.9 mg/L, which was reduced by 77% to 8.85 mg/L in the final discharge. The greatest iron removal occurred between VFS Ports 1 and 2. This was surprising since the pH and alkalinity were not improved until VFS Port 3. Although bacterial growth was analyzed by another researcher, the results were inconclusive. Iron was least concentrated in Cattail Box Port 2. However, the discharge off the Cattail Box increased in iron concentration by 296% (Figure 6). This is may be due to the flushing and re-oxidation of iron from the sediments out of the box.

The removal of manganese was not as effective as that of the other metals, as it only removed 20% of the manganese from the runoff. Influent waters contained an average manganese concentration of 19.0 mg/L. The final discharge off the wetland was 16.33 mg/L. The removal of manganese was consistent throughout the system and no single port showed a great efficiency in removing manganese (Figure 6). Manganese was a difficult metal to remove because it will not precipitate out of solution until a pH of 9.4. Manganese removal was mainly accomplished through the manganese chelating out with iron compounds and through bacteria capable of metabolizing manganese.

The removal of aluminum was very effective (95%) (Figure 6). This could be due to the low concentrations of aluminum in the influent waters (3.7 mg/L), combined with the appropriate pH conditions for aluminum removal. Aluminum will precipitate out of solution at a pH around 6. The greatest percentage of aluminum removal occurred between VFS Ports 2-3 due to the increased pH and alkalinity introduced into the water at this point.

Problems were encountered with the maintenance of the system. These problems were the result of plugging of the PVC pipe drains due to the settling out of the heavy metals. Plugging problems resulted in the need to flush the pipes every few weeks. These maintenance problems may be reduced in the future by using a larger diameter pipe. Also, the wetland box began leaking after two years of being exposed to the elements. This necessitated the disassembly of the box at the end of March 2000 to discover the source of the leakage. The leaks were then corrected and the box replanted.

Layering within the sediments of the wetland box was photographed and measured. The sediments remained approximately 12 inches in depth with cattail roots forming a dense mat throughout the sediments. The top layer of soil contained iron oxyhydroxide compounds, while the bottom sediments were nearly black. The black color may be due to reduced sulfate compounds. High levels of sulfates and sulfate bacteria corresponded to the black sediments located within the wetland.

The influent and effluent of the large vertical flow pond on which the VFS was modeled was monitored by the Jennings Water Quality Improvement Coalition. The vertical flow pond was more effective in introducing alkalinity and removing acidity, but this may be explained by the larger magnitude of the system. The changes in pH and heavy metal reductions were similar to the data presented here.

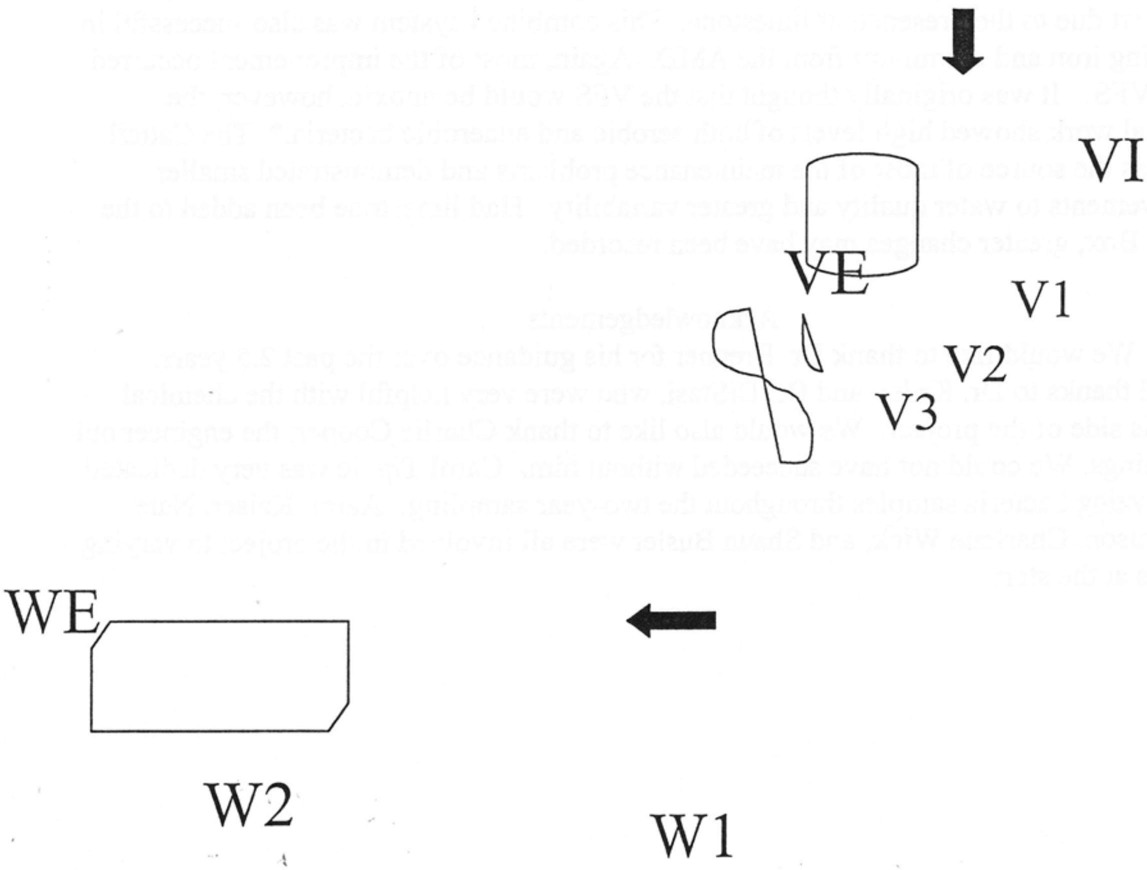
Conclusions

The data supports that our system was successful in increasing the pH, lowering acidity and introducing alkalinity. Most of this improvement occurred in the VFS, in large part due to the presence of limestone. This combined system was also successful in removing iron and aluminum from the AMD. Again, most of the improvement occurred in the VFS. It was originally thought that the VFS would be anoxic, however, the bacterial work showed high levels of both aerobic and anaerobic bacteria.* The Cattail Box was the source of most of the maintenance problems and demonstrated smaller improvements to water quality and greater variability. Had limestone been added to the Cattail Box, greater changes may have been recorded.

Acknowledgements

We would like to thank Dr. Brenner for his guidance over the past 2.5 years. Special thanks to Dr. Kriley and Dr. DiStasi, who were very helpful with the chemical analysis side of the project. We would also like to thank Charlie Cooper, the engineer out at Jennings. We could not have succeeded without him. Carol Tippie was very dedicated to analyzing bacteria samples throughout the two-year sampling. Aaron Kaiser, Nate Abrahmson, Charlene Wick, and Shaun Busler were all involved in the project to varying degrees at the start.

Figure 1. General layout of the combined VFS and Wetland Box at Jennings. This drawing shows the locations of the eight collection ports as well as the direction of water flow. The VFS influent was untreated AMD. Ports 1, 2, and 3 (going down in the VFS) were placed at approximate 4" intervals. The VFS effluent from the bottom sediments was pushed up passively through a 1" diameter tube for easier collection. The VFS effluent then flowed directly into the sediments of the cattail/wetland box. Cattail Port 1 was at an approximate 8" depth within the sediments, and Cattail Port 2 was at an approximate 8" depth. The final Cattail discharge was simply the overland flow.



Introduction

Currently in the state of Pennsylvania, there are 2,500 miles of streams classified as severely impacted by acid mine drainage (AMD) from coal mines, making AMD the single leading source of water pollution in the state.

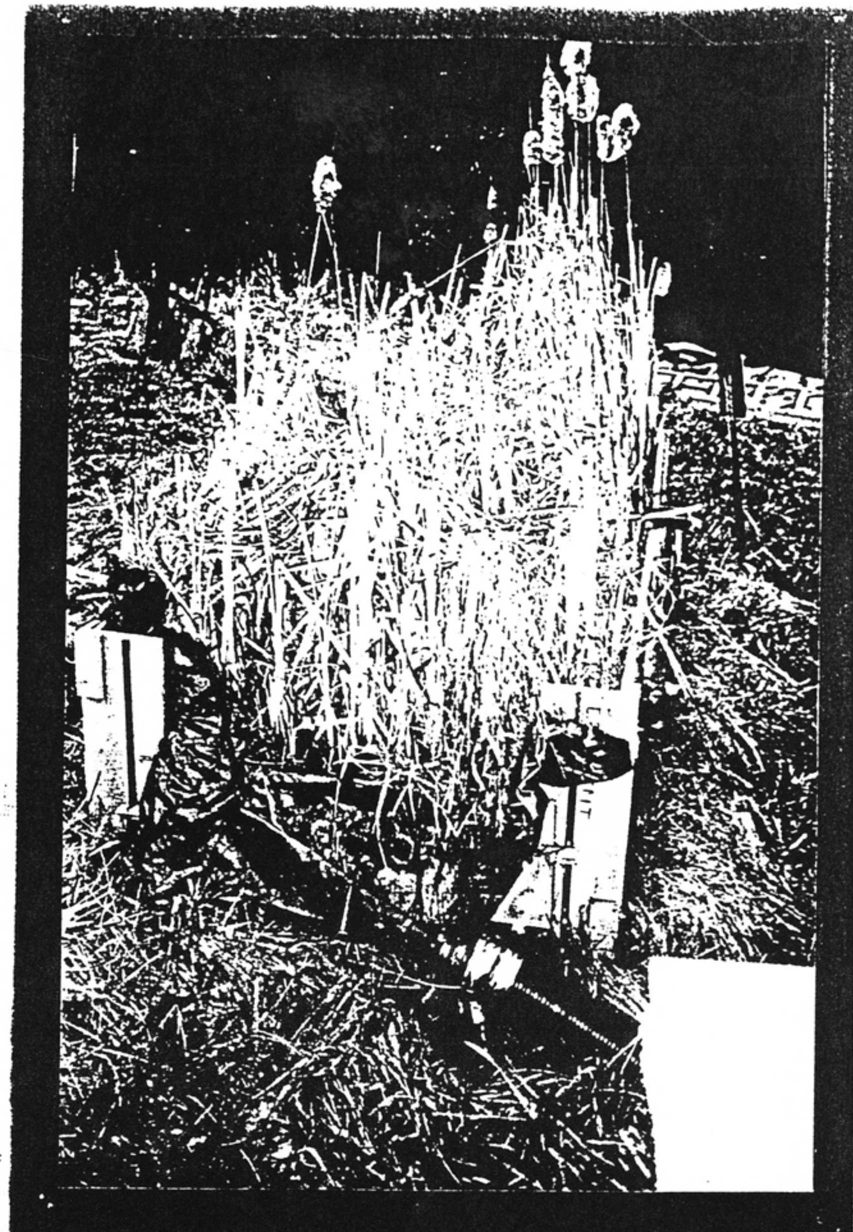
AMD is a term used to describe runoff from mine sites that characteristically has increased acidity, low pH, low alkalinity, and elevated concentrations of heavy metals and sulfates. AMD is generated when mined areas with high sulfide content are exposed to the weathering conditions of water and air.

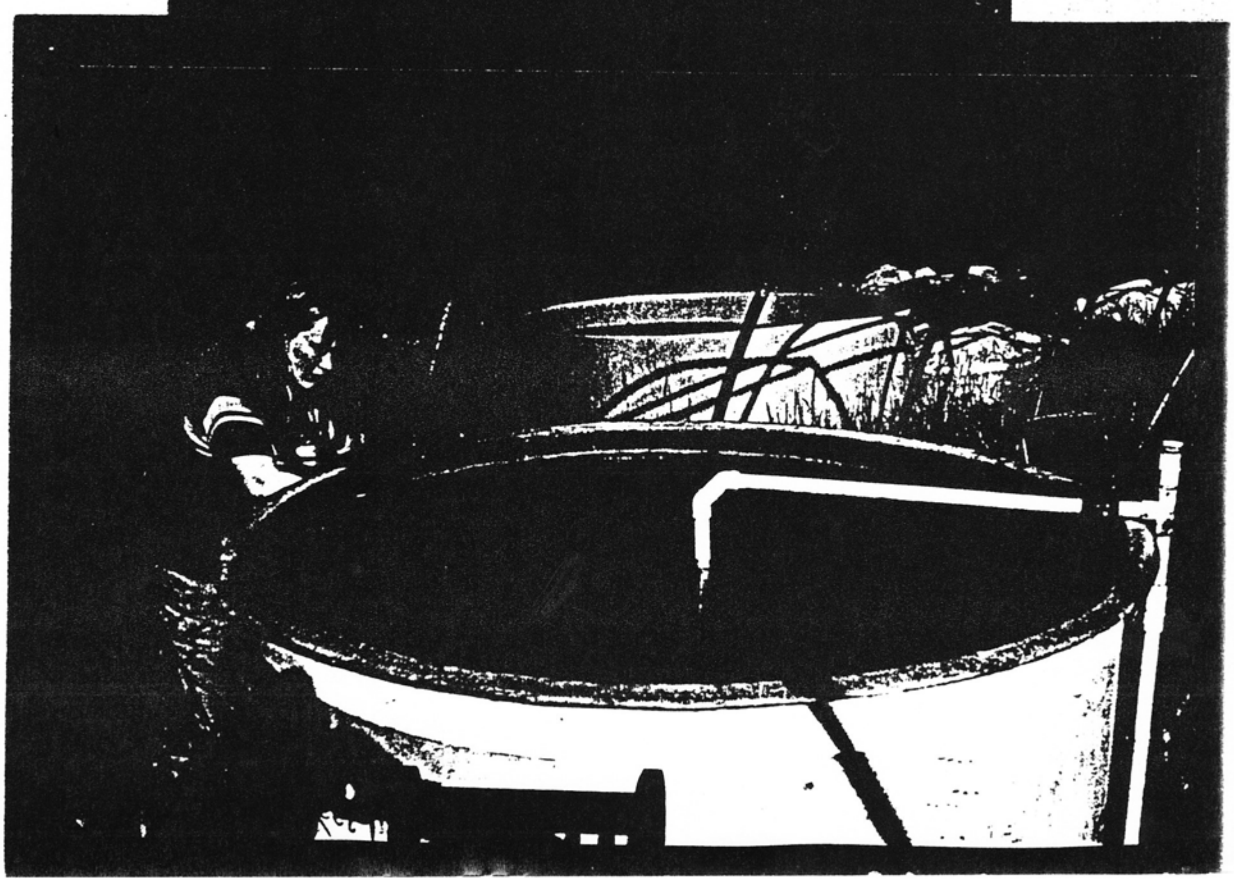
This two-celled system consists of a vertical flow system (VFS) placed in-line with a test-bed wetland. The VFS is designed to isolate and enhance the reductive, anaerobic environment of natural wetlands, which will increase the pH, decrease acidity, introduce alkalinity, and reduce the concentrations of heavy metals associated with AMD. The water then flows into the wetland, where further improvements are expected.

It has been suspected that bacteria play a role in the reduction of heavy metals and sulfates associated with AMD. The goal of this study was to analyze the correlation between bacterial levels and the reduction of heavy metals and sulfates in the passive treatment system.

Methods

- The Vertical Flow System was constructed from a 1.5 m diameter, 1 m tall fiberglass sewage tank. 2.4 cm PVC pipe was used to construct drains to evenly distribute runoff. A mixture of mushroom compost and limestone was added to a depth of 0.45 m.
- The Wetland box was constructed from plywood and measured 2.4 m x 1.2 m x 0.6 m. Mushroom compost was used to fill the wetland box to a height of 0.3 m in order to support the growth of the common cattail, or *Typhys latifolia*.
- 8 samples from various locations throughout the system were collected bi-monthly (1998-99), then weekly (1999-00) during the academic years.
- Each sample was placed on two different plates for each of the three media: Fe specific, Mn specific, and sulfate reducing specific.
- Each plate was incubated for two weeks (1998-99) or one week (1999-00) at room temperature. One plate was incubated aerobically, the other anaerobically in a bell jar using a BBL GasPak© to establish the anaerobic environment.
- The growth levels on the plates were determined on a scale of 1-100 and recorded.

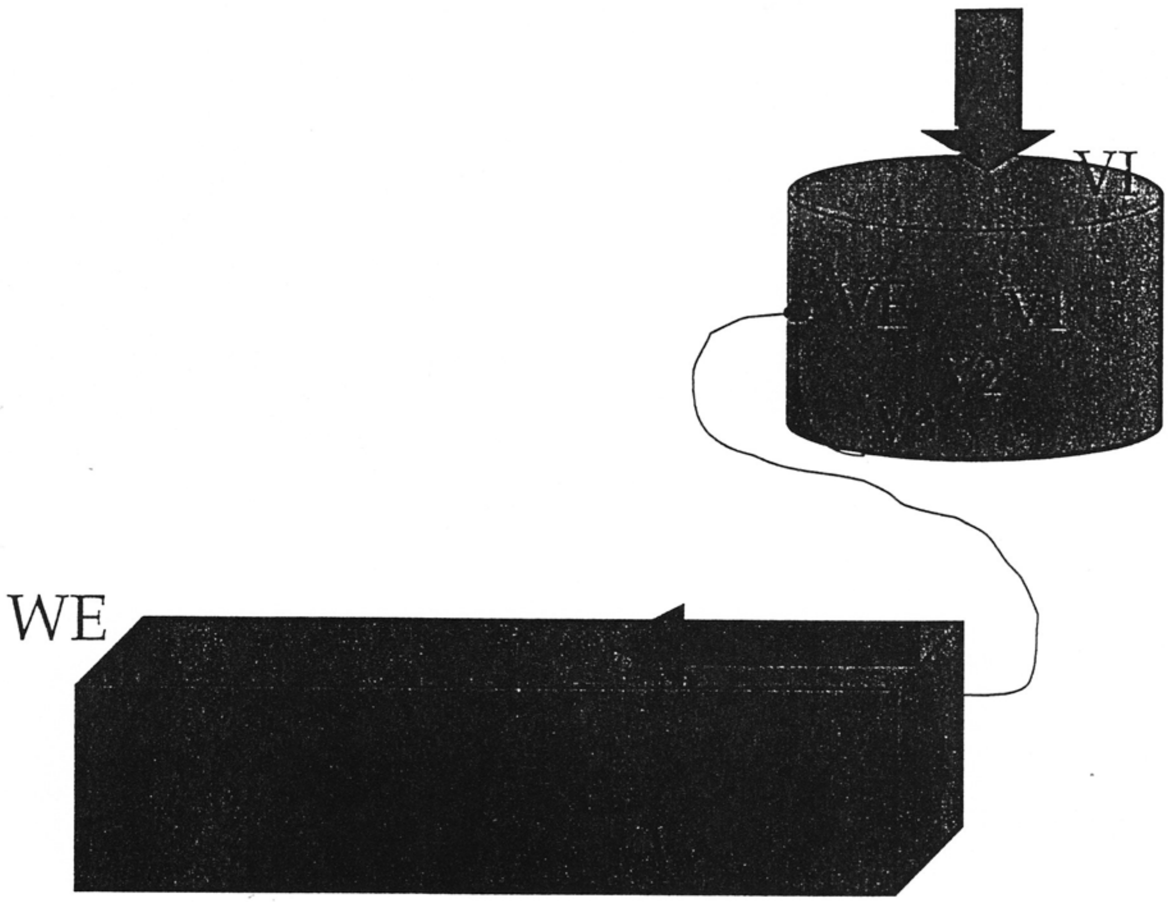


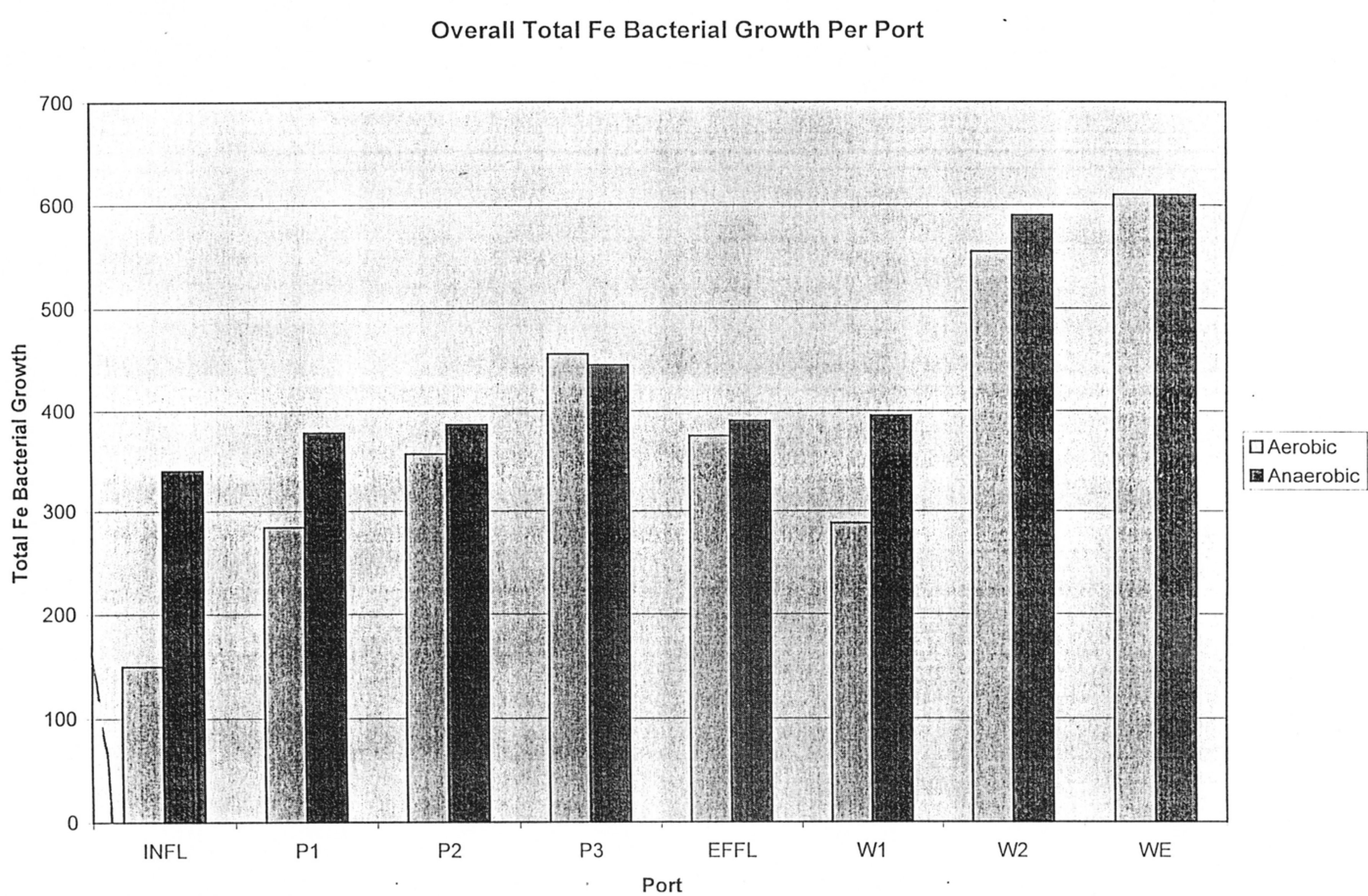


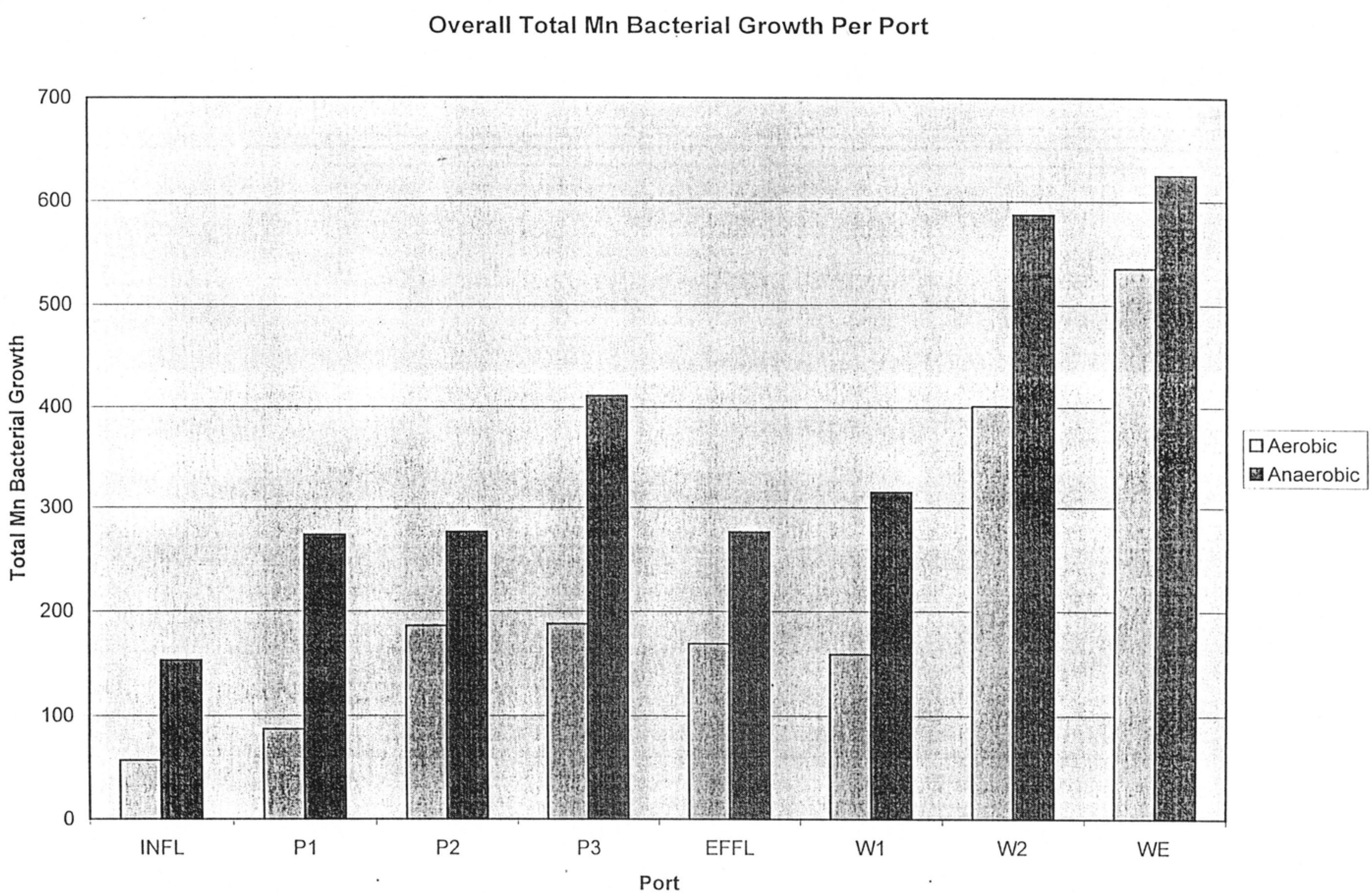
Results

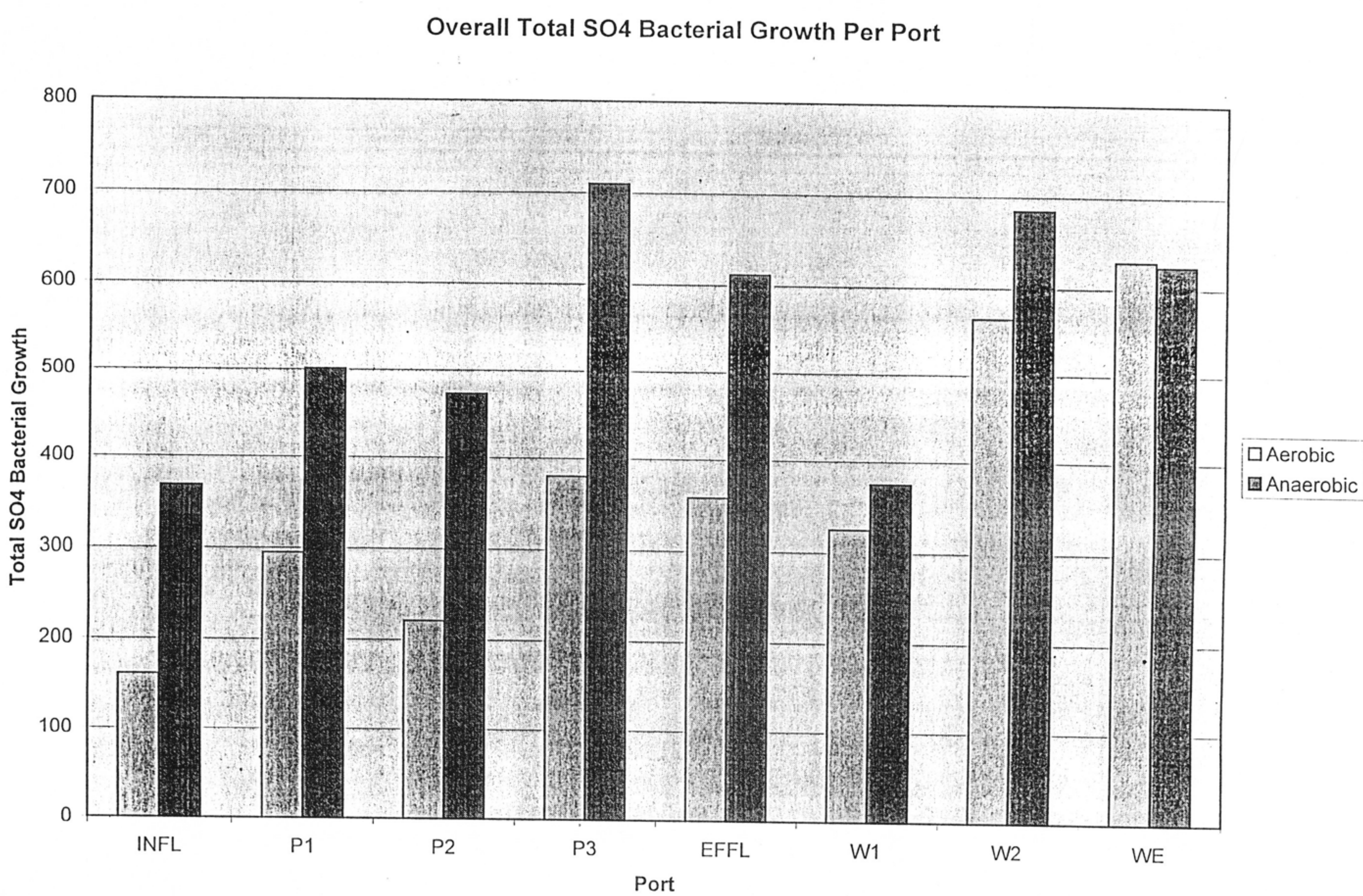
- The bacterial growth levels overall and individually were found to be higher in the Wetland that in the VFS.
- The Fe aerobic growth levels gradually rose in the VFS from 150 to 456, then dropped for VFS Effluent and Wetland Port 1 and then reached peaks around 600 for Wetland Port 2 and Wetland Effluent.
- There was a fairly steady level of anaerobic growth for the Fe bacteria of about 375 throughout the VFS and Wetland Port 1. The growth level then sharply increased to around 600 for both Wetland Port 2 and the Wetland Effluent.
- Aerobic Mn bacterial growth started at around 50 for the VFS Influent and gradually increased throughout the system until were there was a drastic upswing in growth, reaching levels of about 600 for Wetland Port 2 and Wetland Effluent.
- The growth levels for anaerobic Mn bacteria were much higher over all than those for aerobic bacteria. There is an initial low of 153 at the VFS Influent which rises gradually throughout the VFS and then sharply rising to 535 through the Wetland box.
- Aerobic sulfate reducing bacterial growth levels started around 150 and then maintained a fairly even growth level throughout the VFS and Wetland Port 1, then rose sharply to levels around 600 for Wetland Port 2 and Wetland Effluent.
- Anaerobic sulfate reducing bacterial levels maintained a level of about 425 for the beginning of the VFS then rose sharply to over 700. This high remained throughout the rest of the system except for a low of about 475 for Wetland Port 1.

General Layout of the VFS and Test-bed Wetland

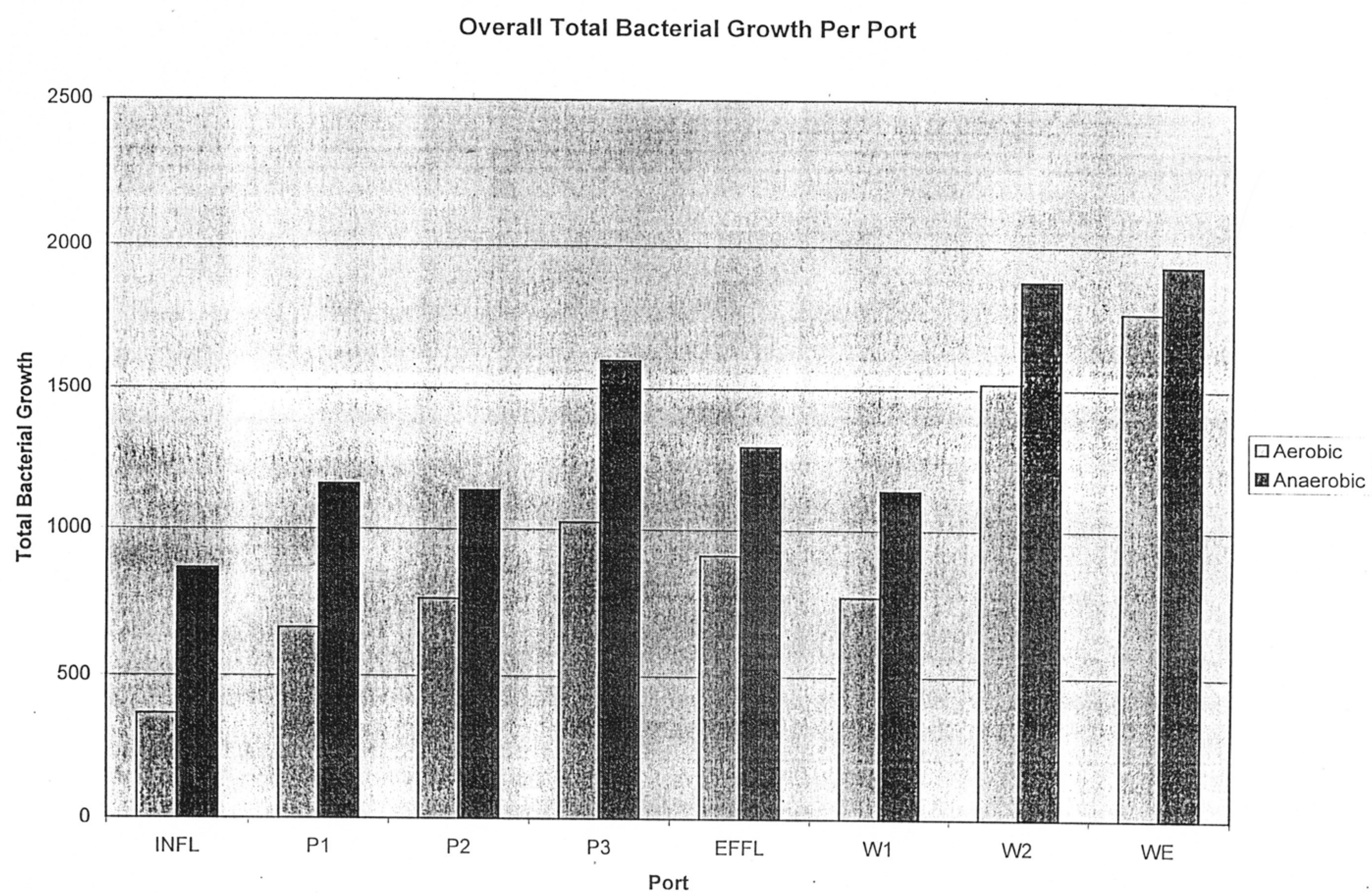



Overall Total Fe Bacterial Growth Per Port
Total Fe Bacterial Growth
700
600
500
400
300
200
100
0
INFL
P1
P2
P3
EFFL
W1
W2
WE
Port
Aerobic
Anaerobic


Overall Total Mn Bacterial Growth Per Port
Total Mn Bacterial Growth
700
600
500
400
300
200
100
0
INFL
P1
P2
P3
EFFL
W1
W2
WE
Port
Aerobic
Anaerobic



Overall Total SO4 Bacterial Growth Per Port
Total SO4 Bacterial Growth
800
700
600
500
400
300
200
100
0
INFL
P1
P2
P3
EFFL
W1
W2
WE
Port
Aerobic
Anaerobic



Overall Total Bacterial Growth Per Port
Total Bacterial Growth
2500
2000
1500
1000
500
0
INFL
P1
P2
P3
EFFL
W1
W2
WE
Port
Aerobic
Anaerobic

Conclusions

- Bacteria are helping to lower the concentrations of heavy metals and sulfates in the passive treatment system being monitored.
- Most of the bacterial effects are being experienced in VFS Port 3, Wetland Port 2 and Wetland Effluent.
- Regular monitoring of the system is crucial for accurate determination of seasonal effects on bacterial growth as well as for overall bacterial effects on the system.

Future Directions

- Plate dilutions of the samples to get growth levels, which are easier to quantitate.
- Continue to monitor the system, including the summer months of May through August.
- Identification of the bacteria present in the system.

Acknowledgements

I would like to thank Dr. Brenner for his advice and support and Charles Cooper, CDS Associates, for his engineering expertise and dedication to cleaning up AMD. Special thanks to Kim Kosick, Corrie Gardner, Aaron Kaiser, Nate Abrahamson, and Charlene Wick, for constructing the system. Most especially I would like to thank Kim Kosick for going out in cold weather and obtaining my samples with me as well as for numerous bits of advice and suggestions.

Abstract

This was a preliminary study on the effects of bacteria on a passive treatment system for acid mine drainage (AMD). In the spring of 1998, a two-celled wetland was constructed at Jennings Environmental Education Center in Slippery Rock, PA. Water samples were collected on a bi-monthly (1998-99) and then weekly (1999-00) basis and analyzed for levels of aerobic and anaerobic bacterial growth. Each sample was plated aerobically and anaerobically on three different types of media, each specific for a particular type of bacterial growth: Fe metabolizing, Mn metabolizing, and sulfate reducing. The plates were incubated at room temperature for one week and then the level of bacterial growth was determined on a scale of 1 to 100. Results indicated that the Fe metabolizing bacteria and the Mn metabolizing bacteria levels (both aerobic and anaerobic) followed a similar pattern. Growth levels peaked at Port 3, Wetland Port 2, and Wetland Effluent. The Sulfate metabolizing bacterial growth levels were less systematic than the Fe and the Mn, but they peaked at the same ports: Port 3 and Wetland Port 2 and Effluent. Seasonal Analysis of the data was inconclusive.

Introduction

Currently in the state of Pennsylvania, there are 2,500 miles of streams classified as severely impacted by acid mine drainage (AMD) from coal mines, making AMD the single leading source of water pollution in the state. AMD is a term used to describe runoff from mine sites that characteristically has increased acidity, low pH, low alkalinity, and elevated concentrations of heavy metals and sulfates. AMD is generated when mined areas with high sulfide content are exposed to the weathering conditions of water and air. This two-celled system consists of a vertical flow system (VFS) placed in-line with a test-bed wetland. The VFS is designed to isolate and enhance the reductive, anaerobic environment of natural wetlands, which will increase the pH, decrease acidity, introduce alkalinity, and reduce the concentrations of heavy metals associated with AMD. The water then flows into the wetland, where further improvements are expected. It has been suspected that bacteria play a role in the reduction of heavy metals and sulfates associated with AMD. The goal of this study was to analyze the correlation between bacterial levels and the reduction of heavy metals and sulfates in the passive treatment system.

Methods and Materials

Samples from each port were collected every other week (1998-1999) and then every week (1999-2000). The plates used were standard disposable plastic Petrie dishes. 1 mL of each sample was plated on 3 different types of specific media (Fe metabolizing, Mn metabolizing and SO4 reducing) in both aerobic and anaerobic conditions. Anaerobic conditions were achieved by sealing the plates inside a bell jar with a BBL© GasPak. The plates were incubated at room temperature for two weeks (1998-1999) or one week (1999-2000). It was found that there was virtually no difference in the growth levels between the plates that were incubated for only one week as opposed to two weeks. The amount of growth was then analyzed and quantitated. This was done by ranking the amount of growth on the plate on a scale of 1 to 100, 1 being one or two pinpoint colonies, 100 being a lawn that is virtually impenetrable to light. The numbers were recorded and then the plates were discarded.

Results

The bacterial growth levels overall and individually were found to be higher in the Wetland System that in the VFS. The Fe aerobic growth levels gradually rose from 150 to 456 in the VFS and then dropped for VFS Effluent and Wetland Port 1 and then reached peaks around 600 for Wetland Port 2 and Wetland Effluent. There was a fairly steady level of anaerobic growth for the Fe bacteria of about 375 throughout the VFS and Wetland Port 1. The growth level then sharply increased to around 600 for both Wetland Port 2 and the Wetland Effluent. Aerobic Mn bacterial growth started at around 50 for the VFS Influent and gradually increased throughout the system until were there was a drastic upswing in growth, reaching levels of about 600 for Wetland Port 2 and Wetland Effluent. The growth levels for anaerobic Mn bacteria were much higher over all than those for aerobic bacteria. There is an initial low of 153 at the VFS

Influent, which rises gradually throughout the VFS and then sharply rising to 535 through the Wetland box. Aerobic sulfate reducing bacterial growth levels started around 150 and then maintained a fairly even growth level throughout the VFS and Wetland Port 1, then rose sharply to levels around 600 for Wetland Port 2 and Wetland Effluent. Anaerobic sulfate reducing bacterial levels maintained a level of about 425 for the beginning of the VFS then rose sharply to over 700. This high remained throughout the rest of the system except for a low of about 475 for Wetland Port 1.

Conclusions

Bacteria are helping to lower the concentrations of heavy metals and sulfates in the passive treatment system being monitored. Most of the bacterial effects are being experienced in VFS Port 3, Wetland Port 2 and Wetland Effluent. Regular monitoring of the system is crucial for accurate determination of seasonal effects on bacterial growth as well as for overall bacterial effects on the system.

Future Directions

In the future it would be beneficial to dilute the samples so that the number of colonies could be counted more easily. The bacteria could also be cultured in liquid media (this would be especially good due to the individual samples liquid state) and then the quantitization could be easily done with a spectrophotometer. This would lead to more accurate data and help to more definitively determine what influence the bacteria have at the different ports. An attempt should also be made to identify the different types of bacteria that are being cultured. This would also help to more definitively determine what role the bacteria are playing in the system.

FE A	INFL	P1	P2	P3	EFFL	W1	W2	WE	Totals
24-Sep-98	50	65	40	55	45	40	55	50	400
13-Oct-98	1	15	10	45	45	48	40	35	239
28-Oct-98	20	25	20	30	35	35	40	50	255
11-Nov-98	25	35	20	40	30	25	45	50	270
2-Dec-98	1	15	25	10	35	25	30	25	166
23-Feb-99	15	15	10	15	10	60	60	55	240
9-Mar-99	5	15	10	10	1	0	0	0	41
24-Mar-99	0	5	15	15	20	25	30	0	110
12-Apr-99	15	15	20	25	20	0	0	0	95
15-Sep-99	15	15	15	20	20	0	25	30	140
22-Sep-99	0	2	10	5	1	0	75	50	143
30-Sep-99	0	1	2	1	1	0	30	70	105
7-Oct-99	1	3	3	15	2	0	20	60	104
11-Oct-99	0	30	80	50	5	0	15	15	195
20-Oct-99	0	20	15	40	50	0	30	20	175
27-Oct-99	0	2	2	20	10	0	20	20	74
4-Nov-99	2	5	50	40	15	15	20	30	177
11-Nov-99	0	1	10	20	30	15	20	50	146
	150	284	357	456	375	288	555	610	

FE AN									
24-Sep-98	55	50	45	60	60	65	50	70	455
13-Oct-98	0	20	1	5	20	30	15	30	121
28-Oct-98	65	60	20	30	50	65	55	60	405
11-Nov-98	55	50	15	20	65	50	40	25	320
2-Dec-98	25	1	50	50	45	65	45	40	321
23-Feb-99	5	5	15	5	20	25	35	20	130
9-Mar-99	10	55	35	35	0	0	0	0	135
24-Mar-99	28	5	5	20	15	55	50	0	178
12-Apr-99	20	25	45	55	25	0	0	0	170
15-Sep-99	35	45	25	25	0	0	25	55	210
22-Sep-99	10	5	20	20	10	0	50	30	145
30-Sep-99	0	1	20	5	30	0	60	75	181
7-Oct-99	0	10	25	20	5	0	40	20	120
11-Oct-99	1	5	20	30	15	0	30	15	106
20-Oct-99	10	20	20	40	20	0	15	10	135
27-Oct-99	0	10	5	5	10	0	10	15	55
4-Nov-99	20	10	10	20	0	20	40	50	170
11-Nov-99	1	1	10	10	10	20	30	50	142
	340	378	386	445	390	395	590	565	3499

FE	INFL	P1	P2	P3	EFFL	W1	W2	WE	
Aer	150	284	357	456	375	288	555	610	
Anaer	340	378	386	445	390	395	590	610	

MN A	INFL	P1	P2	P3	EFFL	W1	W2	WE	Totals
24-Sep-98	0	0	0	25	25	2	5	20	77
13-Oct-98	0	0	0	0	0	5	10	15	30
28-Oct-98	1	5	25	0	40	35	25	50	181
11-Nov-98	0	0	0	6	0	2	5	0	13
2-Dec-98	0	1	1	20	25	15	45	55	162
23-Feb-99	5	1	5	1	10	15	35	20	92
9-Mar-99	5	15	30	15	10	0	0	0	75
24-Mar-99	0	25	65	15	10	25	40	0	180
12-Apr-99	25	10	20	25	20	0	0	0	100
15-Sep-99	15	25	20	20	20	0	30	30	160
22-Sep-99	0	1	8	3	1	0	60	60	133
30-Sep-99	0	0	0	0	0	0	50	70	120
7-Oct-99	3	1	5	25	2	0	20	50	106
11-Oct-99	1	0	0	10	0	0	1	30	42
20-Oct-99	0	0	0	0	1	0	5	15	21
27-Oct-99	0	0	0	0	0	0	20	30	50
4-Nov-99	2	1	5	20	5	30	30	50	143
11-Nov-99	0	2	2	3	10	30	20	40	107
	57	87	186	188	169	159	401	535	

MN AN									
24-Sep-98	0	2	2	55	48	40	45	65	257
13-Oct-98	1	30	35	30	25	25	75	50	271
28-Oct-98	5	5	5	0	20	25	50	45	155
11-Nov-98	15	20	5	45	1	20	50	10	166
2-Dec-98	0	5	1	55	20	60	55	50	246
23-Feb-99	5	5	25	25	15	20	20	20	135
9-Mar-99	20	55	3	20	35	0	0	0	133
24-Mar-99	1	50	40	5	25	45	50	0	216
12-Apr-99	5	55	20	45	30	0	0	0	155
15-Sep-99	20	25	45	25	0	0	35	50	200
22-Sep-99	5	0	60	40	0	0	10	30	145
30-Sep-99	0	0	0	10	0	0	65	80	155
7-Oct-99	70	15	15	50	50	0	40	50	290
11-Oct-99	1	1	0	1	0	0	20	20	43
20-Oct-99	0	0	0	0	0	0	2	5	7
27-Oct-99	0	0	0	0	0	0	20	40	60
4-Nov-99	5	5	10	5	5	30	30	40	130
11-Nov-99	0	0	10	5	2	50	20	70	157
	153	273	276	411	276	315	587	625	

MN	INFL	P1	P2	P3	EFFL	W1	W2	WE
Aerobic	57	87	186	188	169	159	401	535
Anaerobic	153	273	276	411	276	315	587	625

SO4 A	INFL	P1	P2	P3	EFFL	W1	W2	WE	Totals
24-Sep-98	40	55	0	40	30	40	60	45	310
13-Oct-98	2	20	30	40	35	35	20	25	207
28-Oct-98	25	45	15	20	50	55	60	45	315
11-Nov-98	25	20	20	20	50	25	25	20	205
2-Dec-98	25	20	20	35	25	40	40	45	250
23-Feb-99	15	50	15	20	15	55	65	55	290
9-Mar-99	2	15	15	10	5	0	0	0	47
24-Mar-99	1	15	10	15	10	15	30	0	101
12-Apr-99	1	15	15	20	25	0	0	0	76
15-Sep-99	10	5	25	25	10	0	20	30	125
22-Sep-99	2	1	10	15	1	0	55	75	159
30-Sep-99	1	2	5	5	1	0	40	50	104
7-Oct-99	1	1	3	5	1	0	5	30	41
11-Oct-99	1	5	10	10	10	0	20	20	76
20-Oct-99	1	10	8	40	60	0	40	40	199
27-Oct-99	2	3	5	20	10	0	25	30	95
4-Nov-99	5	10	10	30	10	40	40	50	195
11-Nov-99	2	3	5	10	10	20	20	70	140
	161	295	221	380	358	325	565	630	

SO4 AN									
24-Sep-98	35	50	0	40	30	40	20	45	260
13-Oct-98	5	20	25	45	45	50	35	75	300
28-Oct-98	45	40	45	50	65	60	70	60	435
11-Nov-98	25	30	50	55	45	50	50	45	350
2-Dec-98	0	0	0	45	40	40	50	55	230
23-Feb-99	10	15	15	10	5	15	40	35	145
9-Mar-99	50	55	45	75	70	0	0	0	295
24-Mar-99	50	55	45	60	15	60	55	0	340
12-Apr-99	45	40	40	50	45	0	0	0	220
15-Sep-99	35	55	25	60	25	0	50	25	275
22-Sep-99	40	20	80	80	30	0	70	80	400
30-Sep-99	20	50	60	30	40	0	65	70	325
7-Oct-99	3	3	5	10	5	0	30	50	106
11-Oct-99	0	50	3	20	70	0	50	50	243
20-Oct-99	2	15	10	60	70	0	30	15	202
27-Oct-99	1	1	10	10	5	0	20	10	57
4-Nov-99	1	1	10	10	5	0	20	10	57
11-Nov-99	1	1	5	10	2	60	30	60	169
	368	501	473	710	612	375	685	625	

SO4	INFL	P1	P2	P3	EFFL	W1	W2	WE
Aerobic	161	295	221	380	358	325	565	630
Anaerobic	368	501	473	710	612	375	685	625