PASSIVE TREATMENT OF ACID MINE DRAINAGE

<u>VERTICAL FLOW SYSTEM</u>

JENNINGS WATER QUALITY IMPROVEMENT COALITION

Jennings Environmental Education Center
Pennsylvania Department of Conservation and Natural Resources
Brady Township, Butler County, PA
1999

JENNINGS WATER QUALITY IMPROVEMENT COALITION
c/o STREAM RESTORATION INCORPORATED
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July 30, 1999

Pennsylvania Department of Environmental Protection
Bureau of Watershed Conservation
P.O. Box 8555
Harrisburg, PA 17105-8555

Attn: Jane Earle, Water Pollution Biologist
Division of Watershed Support

Re: Final Report for Project 18
US EPA FY96 Section 319
Passive Treatment of Acid Mine Drainage
Demonstration Project
Jennings Environmental Education Center
Brady Twp., Butler Co., PA
A:\101401\final report

Dear Ms. Earle:

Enclosed is the final report, "Passive Treatment of Acid Mine Drainage, Vertical Flow System" submitted by the Jennings Water Quality Improvement Coalition.

This report represents only a small portion of the contributions made by the public-private partnership to the effort supported by this grant. We hope that this report will meaningfully acknowledge the importance of the project and the funding received through your office.

Please review and comment. The submission of a good-quality work product is very important to all of us.

Your patience and assistance has been very much appreciated. If there are any questions or comments, please do not hesitate to contact any of the participants.

Very truly yours,
Stream Restoration Incorporated

By Margaret H. Dunn, PG

express mail EJ882826636US

copy: Dave Johnson, Center Manager, Jennings Environmental Education Center, PADCNR
John Oliver, Secretary and Josh First, Director of Environmental Education, PADCNR
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Javid Mirza, District Mining Manager, PADEP, Knox District Mining Office
Charles D. Cooper, PE, PLS, CDS Associates, Inc.
Darcy and Kitty Peart, Keystone Tall Tree Girl Scout Council
Robert Kleinman, PhD, and George Watzlaf, Mining Engineer, US Department of Energy
Robert Dolence, Deputy Secretary, PADEP
Bernie Sarnoski, Mine Drainage Prog. Coordinator, US Environmental Protection Agency

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Funded by
Pennsylvania Department of Environmental Protection
Bureau of Watershed Conservation
United States Environmental Protection Agency Fiscal Year 1996 Section 319 Grant

cover photo: Underdrain installation (11/18/96) for Vertical Flow System by Grove City College students Chris Shattuck and Peter Sharpe; Slippery Rock University student Jeanette Hilty; Jennings Environmental Education Center maintenance staff Gary Jenkins; working with design engineer, Charles D Cooper, PE, PLS, C D S Associates, Inc.

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PASSIVE TREATMENT OF ACID MINE DRAINAGE

VERTICAL FLOW SYSTEM

JENNINGS WATER QUALITY IMPROVEMENT COALITION

EXECUTIVE SUMMARY

The Jennings Water Quality Improvement Coalition received a grant from the Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation, through U. S. Environmental Protection Agency FY96 Section 319 funding. The project goals as stated in the proposal were (1) to improve the mine discharge at the Jennings Environmental Education Center (Bureau of State Parks, Pennsylvania Department of Conservation and Natural Resources) to meet the state in-stream water quality standards, (2) to mitigate the dissolved aluminum problem, (3) to provide measurable results relating to the recovery of the ecosystem, (4) to demonstrate a successful multi-component design, where site conditions are limiting, that is readily accessible for maintenance, cleaning, and revisions, and (5) to provide a unique educational opportunity available to the public and school groups. Due to the unwavering efforts of a public-private partnership among state agencies, mining, excavation, and environmental companies, college and home school students, Girl Scouts, and volunteers, these objectives have not only been achieved but exceeded.

Selected Highlights

Treated Discharge Quality

comparison of raw and treated sample analyses indicates that the Vertical Flow System (a.k.a. Vertical Flow Pond), operational for about two years,

- removes the dissolved aluminum from the mine drainage;
- neutralizes the acidity in the discharge and generates additional alkalinity (more than predicted);
- provides for the abatement of an untreated discharge (used in the environmental education program to compare and contrast the physical and chemical characteristics of treated and untreated drainage);
- generates sufficient excess alkalinity, that even with the addition of road drainage and ground water flows, the final drainage is net alkaline and meets in-stream standards, except for manganese;
- removes heavy metals from the drainage (the first known documentation in Pennsylvania);

Receiving Stream Characteristics

comparison of flow, water quality, and aquatic life data, characterizing the receiving stream above and below the confluence with the discharge indicates that

- Big Run is impacted upstream of JEEC by abandoned mine drainage (but has improved in the last 20 years);
- Big Run ranges in flow from 420 to 2800 gpm and the JEEC discharge comprises about 1 to 7% of the flow;
- the passively treated drainage increases the pH and alkalinity only slightly in Big Run, due to the much larger flow of the receiving stream;
- the density and diversity of macroinvertebrates in riffles and pools both upstream and downstream were very low with only a slight improvement in density and diversity in riffles and pools, respectively, after installation of the Vertical Flow System;

- nickel and zinc concentrations in the streambed sediments are lower below the confluence with the treated discharge;
- periphyton algal densities are similar in Big Run to that of an unimpacted stream; however, the diversity is lower;
- higher concentrations of aluminum and zinc are observed in tissue of caddisflies collected from Big Run compared to caddisflies from nearby unimpacted streams;

Vertical Flow System Design
the design was original and included many firsts (unique features) including

- Flow Splitter Box - to divide the inflow (raw water) into separate streams;
- Overdrain - to distribute the flow at the surface of the treatment media;
- Outlet Control Box - to vary the head in the system and to flush the system;
- Effluent Aerator - to encourage oxidation of metals in the treated water;
- Amended Compost Treatment Media(spent mushroom compost amended with limestone aggregate) - to increase treatment longevity;

Education and Outreach
the installation of the system by the public-private partnership allowed for the following

- successful implementation of a "hands-on", learn-work program where Girl Scouts and home school and college students worked with environmental professionals in the actual installation of and "As-Built" plans for the full-scale system;
- expansion of the widely-acclaimed education program by the Jennings Environmental Education Center staff to include the Vertical Flow System and other components;
- well-received oral and poster presentations by the Girl Scouts and home school and college students to their peers, interested citizenry, and individuals from academia, the mining industry, state and federal agencies, and environmental professionals at the annual Slippery Rock Watershed Coalition Symposium (1999 attendance over 200) regarding their role in the project;
- field tours have been conducted as part of regional and local conferences and workshops;
- articles in magazines, newsletters, and local and regional newspapers (See attached selected articles.);
- articles in the Slippery Rock Watershed Coalition monthly newsletter, "The Catalyst", with current distribution of over 350 copies per month;

Unexpected Outcomes

Scientific Discoveries
During the monitoring and evaluation of the Vertical Flow System, there were the following unexpected observations:

- Data regarding the removal of zinc, nickel, and cobalt were generated for the Vertical Flow Pond. To our knowledge, these are the first data of their type reported for passive systems in Pennsylvania. The Vertical Flow Pond consistently decreased concentrations of these metals, which ranged from 300 to1400 ug/L in the raw water to 20 to 70 ug/L in the treated effluent of the Vertical Flow Pond.
- The concentrations of aluminum and zinc in tissue of caddisflies were higher in the abandoned mine drainage-impacted receiving stream than in unimpacted streams.

- The overdrain system distributes the influent and helps to eliminate the effects of short-circuiting in the Vertical Flow System.

"Outgrowth" Projects

Due to the public-private partnership with continued enthusiasm regarding passive treatment technology, additional demonstration projects have been generated. The following are selected examples (See section on related projects.):

- Dye Tests - to visually document the distribution of the influent across the Vertical Flow Pond;
- Channel Wetland - to evaluate the efficacy of a planting medium fabricated using a mixture of pond fines from a nearby sand and gravel operation and composted biosolids from a municipal sewage treatment plant;
- Pilot-Scale Systems - to evaluate different treatment media for use in Vertical Flow Systems;
- Warm Season Grass Plot - to evaluate the effectiveness of revegetation of minespoil using warm season grasses;

Awards & Acknowledgments

The efforts involved in the installation of the Vertical Flow System have resulted in unexpected public recognition. The following are selected examples (See news articles and photographic log.)

- 1998 Three Rivers Environmental Award - Jennings Environmental Education Center, Bureau of State Parks, PA Dept. of Conservation and Natural Resources, for environmental education programs;
- 1998 Three Rivers Environmental Award - C D S Associates, Inc. for design innovations and volunteer effort at Jennings and in the Slippery Rock Watershed Coaltion;
- PA Department of Conservation and Natural Resources Certificate of Appreciation - Girl Scouts Darcy Peart and Mary Jo Clark for involvement in the construction of the Vertical Flow Pond and pilot-scale systems;
- PA Department of Conservation and Natural Resources Certificate of Appreciation - Jennings Water Quality Improvement Coalition for contributions to passive treatment technology at Jennings Environmental Education Center;
- Keystone Tall Tree Girl Scout Council Certificate of Appreciation - Charles D. Cooper, PE, PLS, Jennings Water Quality Improvement Coalition for developing implementing the "learn-work" program relating to passive treatment technology;
- Senate Proclamation from State Senator Mary Jo White - Margaret H. Dunn, PG, Jennings Water Quality Improvement Coalition for contributions to passive treatment technology and volunteer effort.

The work of the public-private partnership known as the Jennings Water Quality Improvement Coalition is expanding. With every project, there are new questions and innovative solutions to be discovered. The grant provided by the PA Department of Environmental Protection, Bureau of Watershed Conservation, under US EPA Section 319 funding has been an indispensable part of the effort.

Passive Treatment of Acid Mine Drainage
<u>Vertical Flow System</u>

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List of Tables & Figures

Tables follow figures at end of section

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Photographic Log

page **Caption**

1. .... **AERIAL PHOTO** (winter 1992) showing installation of anoxic limestone drain and established wetlands (upper right corner); (photo provided by PA DEP, Knox District Mining Office)

2. .... **BEFORE CONSTRUCTION** (6/11/92) showing sparce vegetation; coal refuse from an underground mine which ceased operations in mid-1940's

3. .... **DAVID MACURAK OF JESTEADT EXCAVATING** installs an underdrain, part of the vertical flow system constructed at the Jennings Environmental Education Center (**PA DCNR**). (11/96)

4. .... **OVERDRAIN ASSEMBLY** (5/97) by Slippery Rock University student Jody Cerminara

5. .... **CROSS SECTIONAL VIEW** of the full scale vertical flow system at Jennings Environmental Education Center. Slippery Rock University students finalizing the installation of the overdrain by leveling the 3/4" laterals which are used to evenly distribute the discharge over the entire area of the spent mushroom compost and limestone treatment media. (c. 5/97)

6. .... **OUTLET CONTROL BOX PLACEMENT** (7/24/97) Charles Cooper, PE (CDS Assoc., Inc.) with Jennings maintenance staff.

7. .... **OUTLET MANIFOLD** Part of the unique design of the full-scale vertical flow system at Jennings which allows for continued evaluation and control of the system (c.8/97)

8. .... **MANUAL PLACEMENT OF FLOW SPLITTER BOX MANHOLE** used to house a specially designed flow control device which delivers the flow to the overdrain system evenly distributing the aluminum and iron-laden discharge over the spent mushroom compost and limestone treatment media. (c. 8/97)

9. .... **SAMPLING PORT INSTALLATION** Two sets of sampling ports placed at varying depths within the treatment media of the full-scale vertical flow system at Jennings Environmental Education Center. Samples can be obtained to investigate the changes in water quality as it passes through the ~2' of treatment media. (c. 7/97)

10. .... **FULL SCALE VERTICAL FLOW SYSTEM AT JENNINGS ENVIRONMENTAL EDUCATION CENTER (PA DCNR)** A mixture of spent mushroom compost and limestone is used to treat an aluminum and iron-laden discharge. (4/14/99)

page **Caption**

11. .... **VOLUNTEER KITTY PEART** participating in a dye test to study the effectiveness of the water distribution system at the Jennings Environmental Education Center. Home school students and volunteers have conducted these tests to study the innovative techniques used for the passive treatment of abandoned mine drainage at Jennings.

.... **CONTINUED EVALUATION OF PASSIVE TREATMENT SYSTEM DESIGN** is being conducted by design engineer Charles Cooper, PE and Darcy and Kitty Peart on a volunteer basis to monitor the success of innovative water distribution systems at Jennings Environmental Education Center.

12. .... **BEFORE PLANT ESTABLISHMENT** A mixture of Composted Biosolids and Pond Cleanings (silt) are saturated with acid mine drainage shortly after the collection channel wetland was seeded with a mixture of 24 different wetland plant species. Jennings Environmental Education Center, Butler County, PA (8/97)

.... **SECOND GROWING SEASON** The channel wetland constructed at Jennings Environmental Education Center using a mixture of Composted Biosolids and Pond Cleanings (Silt) to demonstrate the effectiveness of using fabricated substrate for the establishment of wetland vegetation. (6/9/99)

13. .... **U.S. DEPARTMENT OF ENERGY LABORATORY RESEARCH AT FEDERAL ENERGY TECHNOLOGY CENTER (PITTSBURGH)** (5/96) lab-scale limestone-only, down flow system; essentially all aluminum (white), iron (orange), and manganese (black)
precipitates within column; operational for year; effluent storage in carboy in forefront; water collected at Jennings (research conducted by George Watzlaf, proj. Eng.)

14. .... **LABORATORY COLUMNS** (8/97) evaluating chemical processes and effectiveness of various treatment media. Dr. Michael Stapleton, Department of Environmental Geosciences, Slippery Rock University. Untreated water is collected at Jennings Environmental Education Center by SRU students and taken to the lab providing education opportunities and essential data for developing passive technology.

15. .... **DEMONSTRATION TANKS** used to evaluate treatment media on a pilot scale; Timothy VanDyke, Supervisor, and James Plesakov, MCI, PA DEP, Knox DMO, monitoring systems. Continued efforts in passive treatment technology are spurred by the success of the full-scale vertical flow passive treatment system at Jennings Environmental Education Center. (7/3/96)

.... **QUONSET HUT, TEST BED WETLANDS AND PILOT SCALE TANKS** are part of the on-going educational and scientific efforts at the Jenings Environmental Education Center. The quonset hut allows for demonstration systems to be evaluated year-round.

16. .... **"LEARN-WORK" YOUTH PROGRAM** relating to the hands-on passive treatment systems discussed by Girl Scouts and home-school students at dedication event (10/9/98). Jennings Water Quality Improvement Coalition, Jennings Environmental Education Center, PA Department of Conservation and Natural Resources.

page **Caption**

.... **DARCY PEART, LISA AND DANIELLE DUNCAN** learning field surveying techniques with the help of **CHARLES COOPER, C D S ASSOC., INC.,** at Jennings Environmental Education Center.

17. .... **WORKSHOP** for master's candidates in Sustainable Systems at Slippery Rock University. Innovative programs at Jennings Environmental Education Center incorporate the passive treatment technology utilized for the design of the installed full scale system. (11/96)

.... **HIGH SCHOOL STUDENTS** participate in a stream study that demonstrates the impact of acid mine drainage on Big Run. Students identify the source of the discharge and perform hands-on field tests to evaluate the effectiveness of the full-scale vertical flow system at Jennings. (3/26/98)

18. .... **4TH ANNUAL WATERSHED COALITION SYMPOSIUM BEING HELD AT JENNINGS.** Part of a joint effort between the Jennings Water Quality Improvement Coalition and the Slippery Rock Watershed Coalition where high school, college and graduate students present the work being done at Jennings and throughout the watershed. (4/16/99)

19. .... **INCREASING PUBLIC AWARENESS** using continually updated posters which explain the numerous and varied efforts based at the Jennings Environmental Education Center. Posters like this one are used at local, regional and national conferences and symposia, community events, learn-work programs, volunteer days and site tours to explain the extensive work being done by the Jennings Water Quality Improvement Coalition. (4/16/99)

20. .... **MARY JO CLARK** shakes hands with **PA DCNR** Secretary **JOHN OLIVER** as she accepts a Certificate of Appreciation during the site dedication for the full-scale vertical flow system at Jennings Environmental Education Center. (10/9/98)

.... **JENNINGS ENVIRONMENTAL EDUCATION STAFF AND C D S ASSOCIATES, INC.,** (JENNINGS WATER QUALITY IMPROVEMENT COALITION) pose with both of their Three Rivers Environmental Awards for the work being done at Jennings related to abandoned mine drainage abatement and education, (5/26/98)

PROJECT BACKGROUND

HEDIN, Robert, PhD, Ecologist, Hedin Environmental
with contributions by DUNN, Margaret H., PG, BioMost, Inc.

Introduction

The Jennings Environmental Education Center(JEEC), Bureau of State Parks, Pennsylvania Department of Environmental Protection, is deleteriously affected by acid mine drainage(AMD) that flows from an abandoned drift mine on the Middle Kittanning coalbed(Allegheny Gp.; Kittanning Fm.). The Brydon Mine was operational between 1935 and 1944. Degraded drainage of the same quality issued from each of the two entries located at the JEEC. This drainage flowed through JEEC about 1000 feet prior to entering Big Run, a tributary of Slippery Rock Creek. Elimination or abatement of the pollution has been attempted four times during the last 30 years. In the 1960s, the Commonwealth's Operation Scarlift Program funded an investigation of AMD problems in the Slippery Rock Creek Watershed (Gwin, 1970). As a result of recommendations from this study, mine seals were installed that eliminated flow from the Brydon mine. In 1984, however, the seals failed and the flow of AMD into Big Run was renewed.

Reclamation History

In 1989, the Bureau of Abandoned Mine Reclamation (BAMR) constructed a series of ponds and wetlands that intercepted the mine water. The passive system consists of a sedimentation pond followed by a series of two wetlands and a pond. This system will be referred to as the *lower wetland system*. The final discharge of the lower wetland system flows down a steep slope to Big Run. BAMR monitored the lower wetland system between 1989 and 1991. The data, published in a paper by Dietz et al. (1994), indicated that the system improved the water chemistry, but did not produce the desired circum-neutral pH discharge with low concentrations of metals. Table 1 shows summary data.

Table 1. Average influent flow and water chemistry for the lower wetland system, April 1989 – February 1991. (data from Dietz et al., 1994)

	flow	pH	acidity	Fe	Al	Mn	SO_4
influent	34	2.90	258	22	19	6	519
effluent	na	3.33	154	15	14	6	303

flow in gpm; acidity in mg/L $CaCO_3$; Fe, Al, Mn and SO_4 in mg/L.

In 1992, the Jennings Water Quality Improvement Coalition was formed. With financial assistance provided by the Knox District Mining Office (Knox DMO), the US Bureau of Mines, and others, an anoxic limestone drain was constructed below the Brydon mine east of State Route 8 and upgradient of the lower wetland system. The anoxic limestone drain (ALD) contained 400 tons of limestone aggregate arranged in long narrow cells that were generally 3 feet deep, 3 feet wide, and buried under 2-3 feet of spoil and clay. Six cells with a total length of 575 feet were constructed. The discharge from the ALD flowed into a collection ditch which conveyed the drainage to the original watercourse. The flow in the watercourse mixed with road drainage and both were conveyed by culvert beneath State Route 8. The drainage returns to the watercourse and then enters the lower wetland system. The ALD discharged alkaline water with the average chemical characteristics shown in Table 2. Flow through the lower wetland precipitated the iron so that the final effluent had neutral pH and low concentrations of Fe and Al.

Table 2. Average flow and chemistry for the Jennings ALD, April 1993 – December 1993 (from Watzlaf et al., 1994)

	Flow	pH	alkalinity	Fe	Al	Mn	SO_4
influent	na	3.3	0	73	21	9	691
effluent	24	6.3	177	62	<1	9	680

flow in gpm; alkalinity in mg/L $CaCO_3$; Fe, Al, Mn and SO_4 in mg/L.

After six months of operation, the ALD developed permeability problems and a seep developed at the end of the 2nd cell that discharged partially treated mine water. Over three months, the flow of the seep increased from 5% to 95% of the ALD flow. The seep developed upgradient of the zone of maximum Al removal (cells 3 and 4). Partial excavation of the ALD at the end of the 3rd cell revealed that the limestone aggregate contained copious amounts of Al hydroxide sludge. (See attached "As-Built" plans.)

Findings were published (Watzlaf, 1994) and the site was included in a field tour of the 1994 International Land Reclamation and Mine Drainage Conference in Pittsburgh, PA.

A pilot-scale system (See Related Projects Section - Project #2) to evaluate the effectiveness of a "SAPS" utilizing spent mushroom compost as the treatment media was installed and evaluated by the Jennings Water Quality Improvement Coalition. After 13 months, the discharge from the system became acidic. A pilot-scale Vertical Flow System utilizing spent mushroom compost amended with limestone aggregate was then placed on-line. The flows were accelerated and the data gathered provided a basis for the full-scale demonstration system which is discussed in the following section.

VERTICAL FLOW SYSTEM

HEDIN, Robert, PhD, Ecologist, Hedin Environmental
with contributions by DUNN, Margaret H., PG, BioMost, Inc.

In 1995, the Jennings Water Quality Improvement Coalition proposed to construct a Vertical Flow System **(a.k.a. Vertical Flow Pond)** below the Brydon mine and upgradient of the lower wetland system. The vertical flow technology is believed to be less prone to plugging with aluminum solids. The proposal was funded by the Bureau of Watershed Conservation (Section 319 Program) in 1996 and the system was constructed in the summer of 1997. The performance of the system was monitored from September 1997 to June 1999.

VFP Construction

Construction diagrams for the VFP are attached. The system consists of a 1-foot thick layer of river gravel, overlain by a 2 ½-foot thick organic substrate(spent mushroom compost amended with limestone aggregate). Based on the elevation of the emergency spillway and the adjustable discharge pipe in the Outlet Control Box, the water level in the pond can be varied, with the maximum height of the standing water approximately 3 feet above the surface of the organic substrate.

Water flows into the system through an optional overdrain, down through the substrate, and into an underdrain placed in the river gravel (AASHTO #57). Both the overdrain and underdrain are constructed using 2- inch PVC headers that contain perforated ¾-inch laterals that extend 15 to 20 feet and are spaced every 6 feet. The overdrain can be disconnected, allowing the mine water to flow directly into the southeastern corner of the pond. The underdrain is connected to a 4-inch flexible plastic pipe whose elevation is controlled in the outlet control box. The height of the effluent pipe in the outlet control box, combined with head losses related to the substrate permeability and flow rate, determine the water level in the VFP. Girl Scouts, Homeschool and Grove City College and Slippery Rock University students constructed the overdrain and underdrain assembly as well as construction of the Outlet Control Box and appurtenances.

The organic substrate consists of 300 tons of spent mushroom compost (from Creekside Mushrooms Ltd., Kittanning, PA) amended with 380 tons of limestone aggregate. The mushroom compost was purchased in the autumn of 1996 and placed in the system in August of 1997. Thus, the material was aged, not fresh. The limestone aggregate came from the Boyers Quarry(operated by Quality Aggregates Inc.) in the Slippery Rock Creek Watershed. Vanport limestone (Allegheny Gp.; Clarion Fm.), is a high-calcium(90%+), marine limestone. The size of aggregate used was AASHTO #9 Special, a washed product with Top Size: 3/8" x 16 mesh. The limestone and mushroom compost were mixed and placed with an hydraulic excavator and by labor of Grove City College and Slippery Rock University students.

Data Collection

The performance of the Jennings VFP was evaluated by measuring flow rates, chemical and physical characteristics of water samples, and hydrologic aspects of the system (principally water elevations). The data were collected independently by several participants in the Coalition. Originally, the primary party responsible for monitoring activities was the Environmental Technology Group, headed by Dr. Robert Kleinman, in the former U.S. Bureau of Mines, now in the U.S. Department of Energy. George

Watzlaf, Mining Engineer, (DOE) assisted with the collection and analysis of 16 water samples. Due to the departmental changes, however, Slippery Rock University and the PADEP, Knox District Mining Office assumed much of the analytical commitment. Robert Hedin and Charles Cooper also performed regular measurements of the flow rates and of the field parameters. Table 3 identifies the sampling participants, while Table 4 shows the respective sampling events. In all,198 measurements and/or sampling events occurred between September 1997 and June 1999. An EXCEL spreadsheet containing all data is attached to this report.

Table 3. Coalition participants contributing flow and water chemistry data to the Jennings VFS project.

	contact	**sampling and analysis**
Slippery Rock University (SRU)	DENICOLA, Dean STAPLETON, Michael	samples collected as part of Environmental Science Program; analyses performed by students using SRU equipment
Knox District Mining Office (DMO)	PLESAKOV, James VANDYKE, Timothy	samples collected using standard inspection protocols and analyzed by the PA State Laboratory(a.k.a. PADEP lab)
U.S. Department of Energy (DOE)	WATZLAF, George	samples analyzed by former Bureau of Mines mine drainage laboratory
Hedin Environmental (HE)	HEDIN, Robert	field measurements of flow, VFP water elevation, pH, temperature, and alkalinity
CDS Associates (CDS)	COOPER, Charles	field measurements of flow and VFP water elevation

Table 4. Sampling and flow measurement events by Coalition participants (acronyms shown in Table 3)

	VFP in	VFP out	lower weir	lower final	other	TOTAL
DMO	32	17	13	5	0	67
SRU	17	20	14	0	16	67
DOE	7	8	0	0	1	16
CDS	0	27	0	0	0	27
HE	0	21	0	0	0	21
TOTAL	**56**	**93**	**27**	**5**	**17**	**198**

Most mine water samples were collected from four locations: the VFP influent (raw water), the VFP effluent, the weir located upstream of the lower wetland system, and the final discharge of the lower wetland system. When comparing data between these stations, it is important to appreciate extraneous inflows of water that may occur between the sampling points. Between the VFP influent and effluent, the only extraneous inflows of water are from precipitation and ground water. Neither is considered significant when compared to the mine water flow. Flow at the lower wetland weir is a combination of the VFP effluent, untreated AMD that bypasses the VFP for educational purposes, and drainage intercepted in road ditches along State Route 8. As will be discussed below, the flow of untreated mine water is significant during high flow periods. Also, during storms the flow from Route 8 facilities can be substantial. The final discharge of the lower wetland is a combination of influent from the weir, direct precipitation, and an unknown inflow of ground water.

Average flow and chemical results are shown in Table 5. Median values were within 5% of the average values. Because the quality of water in the lower wetland depended upon alkalinity generation by the vertical flow pond, most sampling efforts focused on the VFP. Throughout the monitoring period, the VFP always discharged alkaline, circumneutral pH water. Specific analyses of the VFP's affect on Mn, Fe, acidity and alkalinity follow.

Table 5. Average flow and chemical conditions for the Jennings passive treatment system, September 1997 – June 1999.

	VFP in	VFP out	Lower Weir	Lower Final
flow, gpm	na	22	23	47
# of flow measurements	0	72	8	5
# of chemical measurements	54	51	14	5
pH	3.3	6.6	6.8	6.5
alkalinity, mg/L	0	196	172	56
acidity, mg/L	284	-184	-145	-38
Fe, mg/L	56	8	1	<1
Al, mg/L	19	<1	<1	<1
Mn, mg/L	15	14	12	8
Ca, mg/L	99	278	244	na
Mg, mg/L	55	58	na	na
Na, mg/L	<3	<6	<6	<10
Sulfate, mg/L	665	747	712	678

Effect of the VFP on Manganese

Influent and effluent concentrations of Mn are shown in Figure 1. While the VFP only removed an average of 1 mg/L, its effect on Mn differed over the monitoring period. Mn was removed during the first five months of the VFP operation. Effluent concentrations during this period were 20-40% lower than influent concentrations. During the last 18 months of monitoring, influent and effluent concentrations were similar. Two sets of samples suggested moderate Mn release.

The temporary removal of Mn from mine water is commonly observed for passive systems with organic substrates. The current explanation is that ion-exchange and chelation processes, both related to the organic substrate, remove Mn. The capacities of both processes are limited and eventually exhausted. The release of Mn from passive systems is thought be related to changes in pH or redox conditions.

Effect of the VFP on Aluminum

Complete removal of Al was predicted and observed (Figure B). All VFP effluent samples contained less than 1 mg/L Al. The removal of Al occurs when flow through alkaline substrate increases the pH to above 6, causing the formation of aluminum hydroxide solids. There is no indication in the current data set that Al removal is decreasing with time.

Effect of the VFP on Iron

The VFP was predicted to retain Fe, but the amount of sustained removal was higher than anticipated. Figure C shows influent and effluent Fe concentrations. While the influent water contained 20-85 mg/L Fe, the final VFP effluent consistently contained 5-10 mg/L Fe. The VFP's retention of Fe did not appear to be increasing or decreasing through the monitoring period. Several processes may be responsible for the Fe retention. The influent water is predominantly ferrous iron (U.S. DOE analyses indicate 67 mg/L ferrous iron and 71 mg/L total iron). It is probable that a portion of the iron is oxidized to soluble ferric iron before flowing through the organic substrate. As the acidic water flows down through the alkaline substrate, ferric iron should precipitate as ferric hydroxide. This process is supported by Charles Cooper's observation that the overdrain system and the surface of the organic substrate are both becoming encrusted with iron hydroxides. Any ferrous iron that flows deep into the organic substrate is subjected to alkaline, reducing conditions that promote the precipitation of iron as siderite ($FeCO_3$), mackinawite (FeS), or pyrite (FeS_2). The relative significance of each of these processes in decreasing Fe concentrations in the VFP is not known.

Effect of the VFP on Acidity and Net Alkalinity

The VFP generated more net alkalinity than was predicted. The system was expected to retain all of the Al, 25-50% of the Fe, none of the Mn, and to add 50-75 mg/L of titratable alkalinity to the water. This treatment is approximately equal to the generation of 250 mg/L net alkalinity. The VFP has, in practice, generated an average 468 mg/L net alkalinity (from Table 5, 284 mg/L acidity neutralized with 184 mg/L net alkalinity discharged). The larger net alkalinity generation resulted from the more complete Fe removal and higher concentrations of titratable alkalinity.

Figure D shows the influent acidity and effluent net alkalinity (expressed as negative acidity). Net alkalinity values were calculated for Knox DMO data from concentrations of Fe, Mn and alkalinity. (The DEP does not report net alkalinity.) There may be a gradual decrease in the net alkalinity occurring. Additional monitoring is necessary to assess the significance and rate of this important change.

Effect of the VFP on Sulfate

An important purpose of the VFP's organic substrate is to act as a carbon source for bacterial sulfate reduction. Sulfate reduction has been recognized as an important natural process in the treatment of AMD in natural and constructed wetlands. Sulfate reduction lessens concentrations of sulfate and generates sulfide. The sulfide can degas or precipitate within the wetland as a metal sulfide (primarily FeS or FeS_2) and elemental sulfur. The processes decrease acidity by neutralizing mineral acidity or generating bicarbonate alkalinity.

Unfortunately, the significance of sulfate removal in the Jennings VFP is uncertain because of contradictory results from the US DOE and PA DEP analytical laboratories. Table 6 shows sulfate concentrations on days when samples of both the VFP influent and effluent were sampled. While the PA DEP laboratory always reports higher concentrations at the effluent, the US DOE laboratory always reports lower concentrations at the effluent. We do not have an explanation for the variation in laboratory results.

The substantial differences between sulfate values measured by the DOE and DEP laboratories deserve future investigation. Much of the mining and restoration industry's opinion regarding the occurrence and significance of sulfate reduction in passive systems is based on data collected and analyzed by the US Bureau of Mines and US DOE at a common analytical laboratory. The results obtained from the Jennings system appear consistent with previously reported findings for other substrate-based passive treatment systems. If problems exist with the US DOE sulfate values, then conclusions about sulfate reduction must be reevaluated. With the elimination of the US Bureau of Mines, much of the current analytical expertise at passive systems is being supplied to restoration groups by the PA DEP. If problems exist with the DEP sulfate numbers, the significance of sulfate reduction in passive systems may be underestimated by those analyzing the results of their treatment efforts.

Generation of Titratable Alkalinity by the VFP

Titratable alkalinity is the amount of alkalinity present in a water sample before it is oxidized by natural or chemical means. This measure differs from *net* alkalinity, which is measured after treatment with an oxidant (which oxidizes any ferrous iron and manganese present). Ideally, titratable alkalinity measurements are made in the field to minimize iron hydrolysis that decreases the alkalinity. PA DEP measures titratable alkalinity in the laboratory on cooled samples that, presumably, have undergone little iron hydrolysis.

Generation of titratable alkalinity by the VFP displayed a cyclic pattern that correlated with flow and season. Figure E shows the patterns for flow and alkalinity.

Table 6. Sulfate measurements for the Jennings VFP made by the PA DEP and US DOE analytical laboratories.

Date	Data Source	Sulfate, VFP in	Sulfate, VFP out	Difference
09/25/97	US DOE	694	662	-32
10/07/97	DMO / DEP	707	793	+86
10/15/97	US DOE	745	731	-14
10/29/97	US DOE	767	714	-53
11/05/97	DMO / DEP	805	810	+5
11/20/97	US DOE	804	728	-76
12/08/97	DMO / DEP	638	727	+89
12/19/97	DMO / DEP	633	942	+309
02/23/97	US DOE	764	754	-10
01/23/98	DMO / DEP	678	720	+42
02/04/98	DMO / DEP	662	683	+21
03/31/98	DMO / DEP	515	744	+229
05/04/98	DMO / DEP	431	534	+103
06/02/98	DMO / DEP	553	628	+75
07/30/98	US DOE	769	722	-47
08/04/98	DMO / DEP	786	823	+37
10/07/98	DMO / DEP	810	870	+60
11/13/98	DMO / DEP	770	845	+75
01/27/99	DMO / DEP	598	836	+238
04/21/99	DMO / DEP	508	722	+214
04/29/99	US DOE	691	677	-14
average	**US DOE**	**748**	**713**	**-35**
average	**DMO / DEP**	**650**	**763**	**+113**

all concentrations in mg/L

The highest effluent alkalinity values, 220-250 mg/L alkalinity, were measured in late summer and autumn months when flows were low and water temperatures were still warm. The lowest VFP effluent alkalinity values,150-170 mg/L alkalinity, were measured in winter and spring months when flows were high and water temperatures were low.

Downgradient Affects of the VFP on Water Chemistry
The VFP discharges to a "step-down" channel wetland, a shallow constructed wetland and pond which discharges into the original watercourse (mixing with untreated mine water), through a road culvert beneath State Route 8, returned to the original watercourse, and into the lower wetland system. The channel wetland and upper wetland/pond system very effectively precipitates Fe contained in the discharge from the VFP. The upper pond is regularly covered with duckweed (which does not tolerate elevated concentrations of Fe) and the final pond discharge did not have any Fe staining. Above Route 8 and below the upper pond, treated water mixes with untreated acid mine drainage that bypasses the VFP for educational purposes to compare and contrast the physical and chemical characteristics of the raw and treated drainage. This mixture of treated and untreated mine drainage flows to the lower wetland system and then into Big Run. The targeted quality of the drainage prior to confluencing with Big Run requires: 1) that the treated water contain sufficient excess alkalinity to neutralize the untreated acidic water, and 2) that there is sufficient retention to precipitate the metals from the untreated water. Both of these conditions have been continuously satisfied since construction of the VFP and upper wetland/pond system. All samples from the influent weir to the lower wetland and from the final discharge were alkaline with low Fe and Al concentrations (Table 3). In addition, as part of the Center's education program, Jennings personnel regularly measure pH and Fe concentrations at the discharge of the lower wetland system. Center personnel report that all tests indicated pH ~7 with < 1mg/L Fe.

The adequacy of the VFP to generate sufficient excess alkalinity was assessed in the spring of 1999 by qualitatively comparing alkalinity and acidity loadings of the two flows. A SRU hydrology class installed two weirs on the untreated discharges in February 1999 that facilitated measurement of flows. In the spring of 1999, Hedin made four measurements of flow at all stations. The total flow of untreated water averaged 12 gpm, while the VFP discharge averaged 29 gpm. Assuming that the untreated flow had an acidity of 230 mg/L (the average of two VFP influent samples collected in April 1999), then neutralization by the 29 gpm of treated water required at least 95 mg/L net alkalinity. The VFP discharge averaged 137 mg/L net alkalinity in April 1999.

Removal of Zinc, Nickel, and Cobalt by the VFP
Analyses by the DOE include a suite of heavy metals that can occur in acid mine drainage. The Jennings AMD samples always contained detectable concentrations of Zinc (Zn), nickel (Ni), and cobalt (Co). Detectable concentrations of copper (Cu) were found on one date. In all cases, the VFP substantially decreased concentrations of the heavy metals (Table 7). The mechanism for removal is unknown. It could result from ion exchange, chelation, carbonate formation, or sulfate formation. The data demonstrate the utility of vertical flow technology for treating low concentrations of Zn, Ni, and Co.

Table 7. Effect of the VFP on concentrations of zinc, nickel, cobalt and copper.

	Zn		Ni		Co		Cu	
date	in	out	in	out	in	out	in	out
09/25/97	700	30	530	30	280	30	<20	<20
10/15/97	750	40	570	30	300	50	<20	<20
10/29/97	820	20	920	40	330	50	<20	<20
11/20/97	790	30	510	20	320	60	<20	<20
12/23/97	770	50	590	50	330	70	<20	<20
07/30/98	1390	30	610	20	300	30	490	<10
04/29/99	700	70	530	100	310	70	<20	<20

all concentrations in ug/L

Head Requirements to Operate the VFP

The operation of the Jennings VFP requires head. The head is the difference in elevation at the surface of the ponded water in relation to the discharge pipe. Charles Cooper and Robert Hedin monitored head requirements between February 1998 and June 1999 by measuring the surface water elevation of the VFP, noting the elevation of the effluent pipe, and measuring the VFP effluent flow rate. (The elevation of the effluent pipe was only adjusted three times during the monitoring period.) The head measurements ranged from 0.1 to 3.0 feet and averaged 1.5 feet. Figure F shows head values and flows over the monitoring period. As expected, a significant relationship between the flow rate into the system and head requirement existed (Figure G).

The accumulation of Al and Fe in the vertical flow system is likely to eventually decrease the hydraulic conductivity of the substrate to a point where increased head is required to push water through the VFP. This phenomenon was not apparent during the monitoring

period. In the spring of 1998, flows of 30 gpm required approximately 2.5 feet of head. In the spring of 1999, flows of 30 gpm still required approximately 2.5 feet of head.

Summary Performance of the Jennings Vertical Flow System

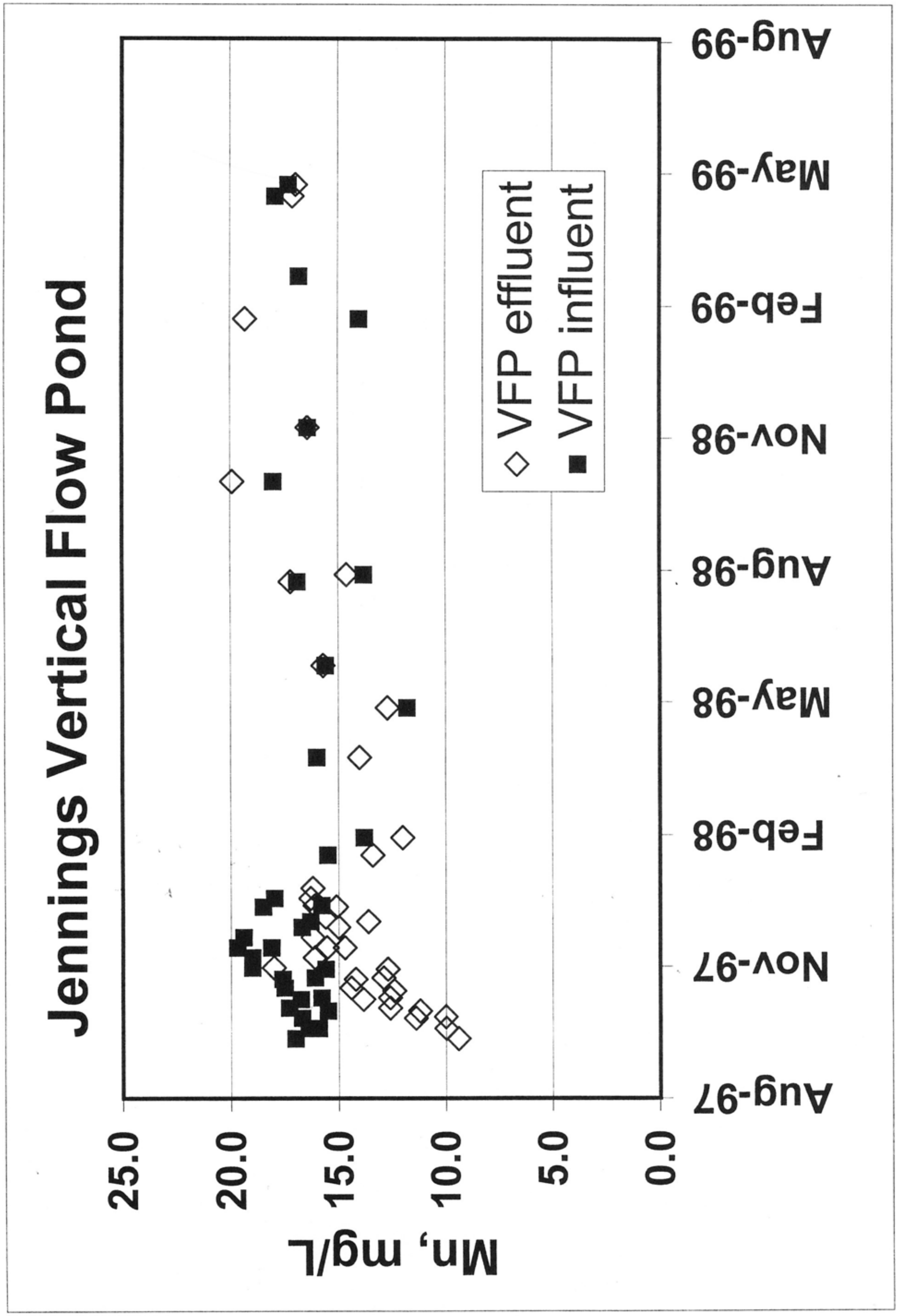
After 20 months of operation, the Jennings vertical flow system continues to discharge alkaline water that contains low concentrations of toxic metals. A flow of untreated AMD, that was intentionally avoided for educational purposes, mixes with the treated discharge and flows to the lower wetland. The alkalinity contained in the treated water has always been sufficient to neutralize the acidic water. As a result of the VFP's performance, water flowing from the lower wetland system into Big Run has been minimally contaminated since the autumn of 1997.

The VFP has required an average 1.5 feet of head to operate since its construction. When the influent flow rate is more than ~ 10 gpm, the head needed to operate the system is notably increased. Further study and evaluation of the changing hydraulic conductivity of the media is to be conducted. The cumulative ability of the system to transmit water may be affected by several factors: the iron oxide coated substrate surface; the organic substrate; the geotextile that separates the substrate from the underdrain; and the limited perforations contained in the underdrain. Over time, it is possible that the continued accumulation of Fe and Al solids will reduce the hydraulic performance of the system. Evidence for such deterioration has not been observed thus far. As noted previously, the VFP is displaying the same head:flow relationship in 1999 that was observed in 1998.

Data regarding the removal of zinc, nickel and cobalt were generated for the VFP. To our knowledge, these are the first data of their type reported for passive systems in Pennsylvania. The VFP consistently decreased concentrations of these metals from 300-1,400 ug/L to 20-70 ug/L. Because Zn is commonly considered an ecologically-important heavy metal, our findings give added value to substrate-based passive systems.

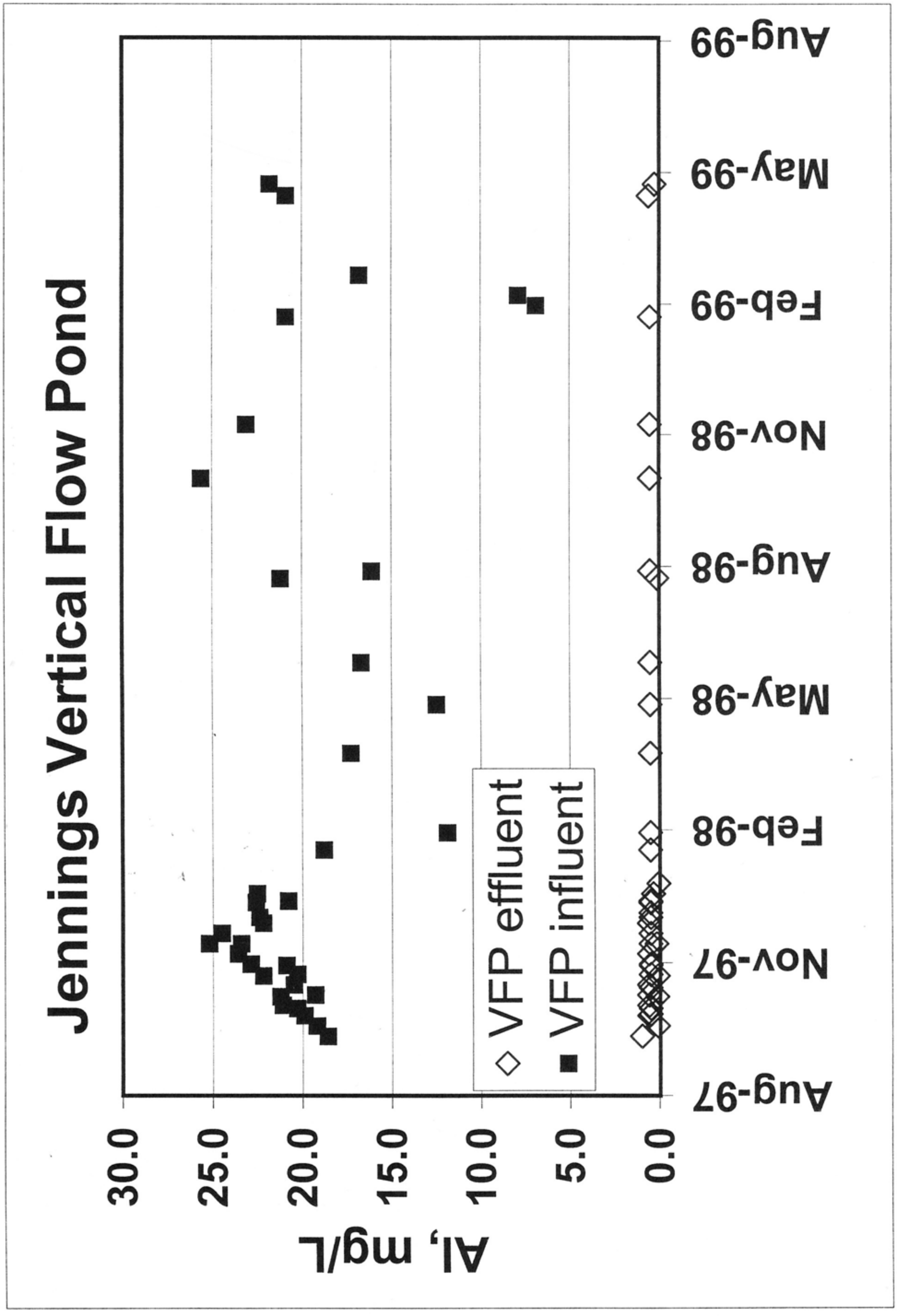
The long-term prognosis for the Jennings vertical flow pond depends on its continued production of alkalinity and its hydrologic integrity. Continued monitoring will determine whether the head : flow ratio degrades. Assessments of the system's ability to generate alkalinity are more quantifiable. Over the first 600 days of the VFP's operation, it generated 37.0 tons of alkalinity as $CaCO_3$. Increased concentrations of calcium suggest that 35.4 tons of the alkalinity are attributable to calcite dissolution. DOE sulfate numbers suggest that only 1.2 tons of alkalinity arise from sulfate removal. Calcite dissolution has removed approximately 38.5 tons of limestone (92% $CaCO_3$ Vanport limestone) or 10% of the original amount incorporated into the substrate. Complete exhaustion theoretically occurs in ~14 years. Under the best hydrologic assumptions, it will probably be necessary to replace the substrate in 7-10 years. The system was designed to facilitate substrate replacement, i.e., associated costs should be reasonable.

Watzlaf (DOE) recently completed a long-term study in which a column of organic substrate and limestone was leached with Jennings AMD. Watzlaf observed a slow progressive decay of the alkalinity-producing capabilities of the organic substrate until, after 1,000 days, it ceased to generate alkalinity. In order to guard against Watzlaf's observations, the organic substrate of the Jennings VFP was amended with limestone. At this time, 600 days after construction, the Jennings VFP is functional, and shows no signs of the degradation documented by Watzlaf. Continued monitoring is necessary to determine the long-term efficacy of the modified substrate used in the Jennings VFP.



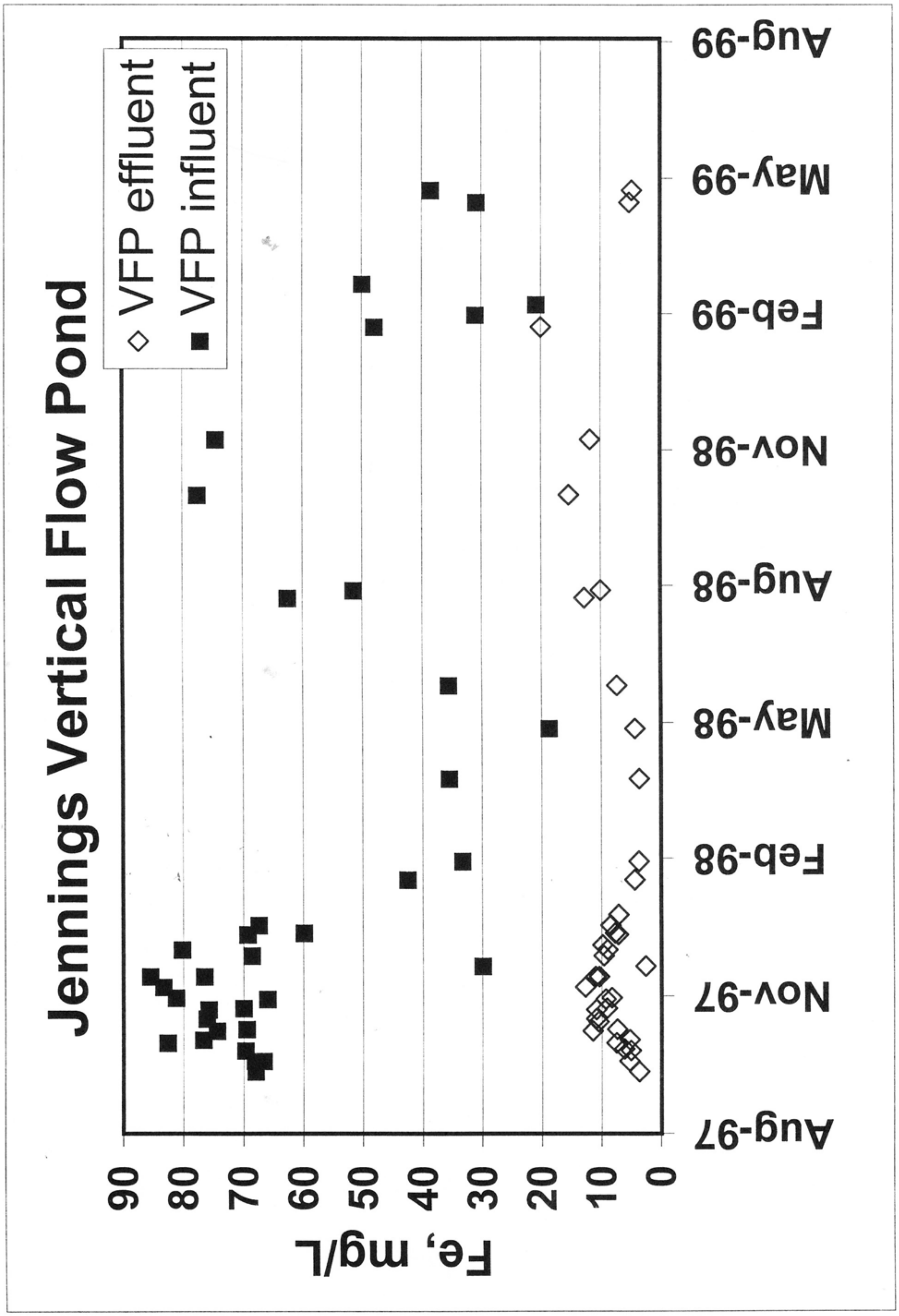
Jennings Vertical Flow Pond
Mn, mg/L
25.0
20.0
15.0
10.0
5.0
0.0
Aug-97
Nov-97
Feb-98
May-98
Aug-98
Nov-98
Feb-99
May-99
Aug-99
VFP effluent
VFP influent

Figure A



Jennings Vertical Flow Pond
Al, mg/L
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Aug-97
Nov-97
Feb-98
May-98
Aug-98
Nov-98
Feb-99
May-99
Aug-99
VFP effluent
VFP influent

Figure B



Jennings Vertical Flow Pond
VFP effluent
VFP influent
Fe, mg/L
90
80
70
60
50
40
30
20
10
0
Aug-97
Nov-97
Feb-98
May-98
Aug-98
Nov-98
Feb-99
May-99
Aug-99

Figure C

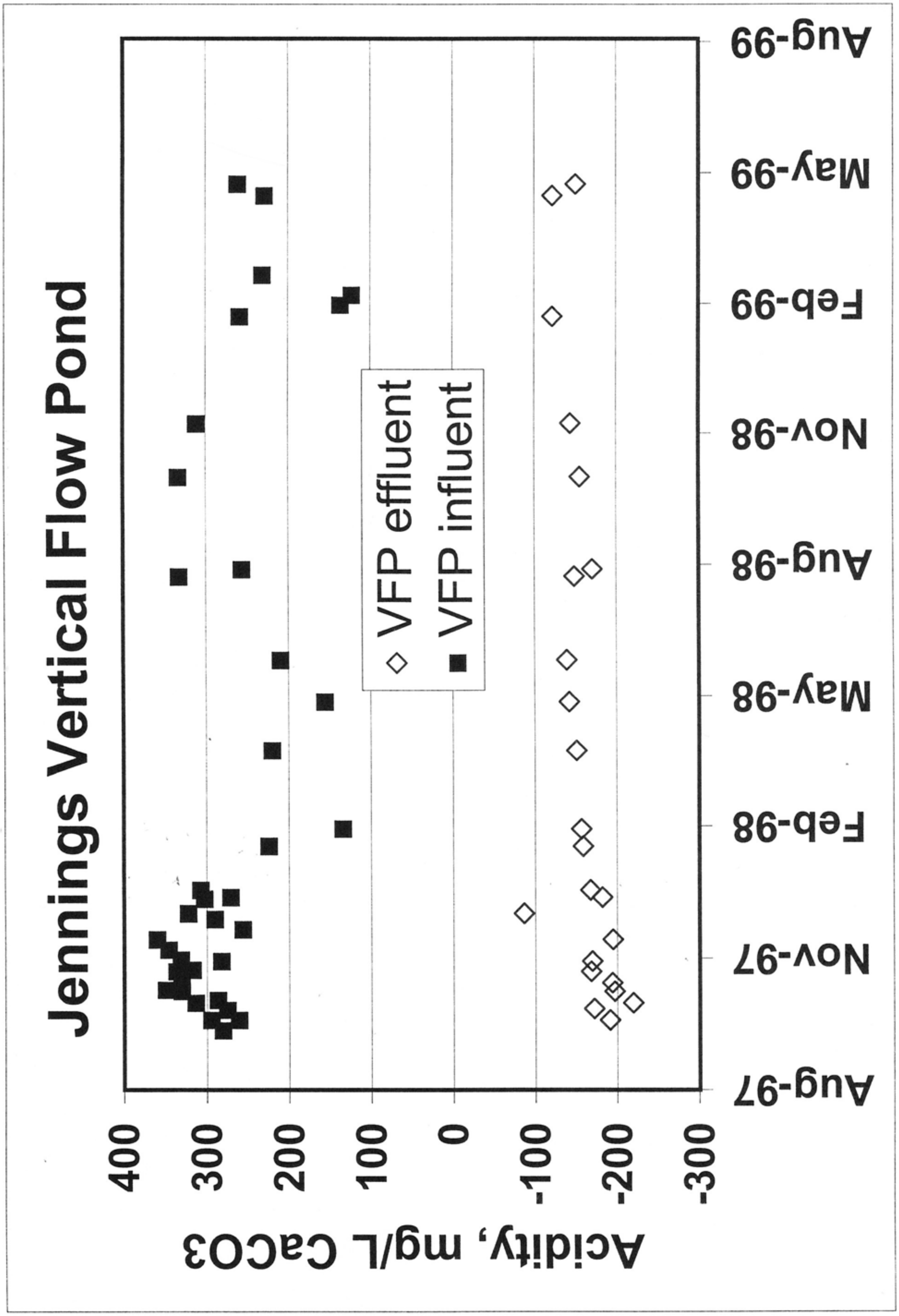
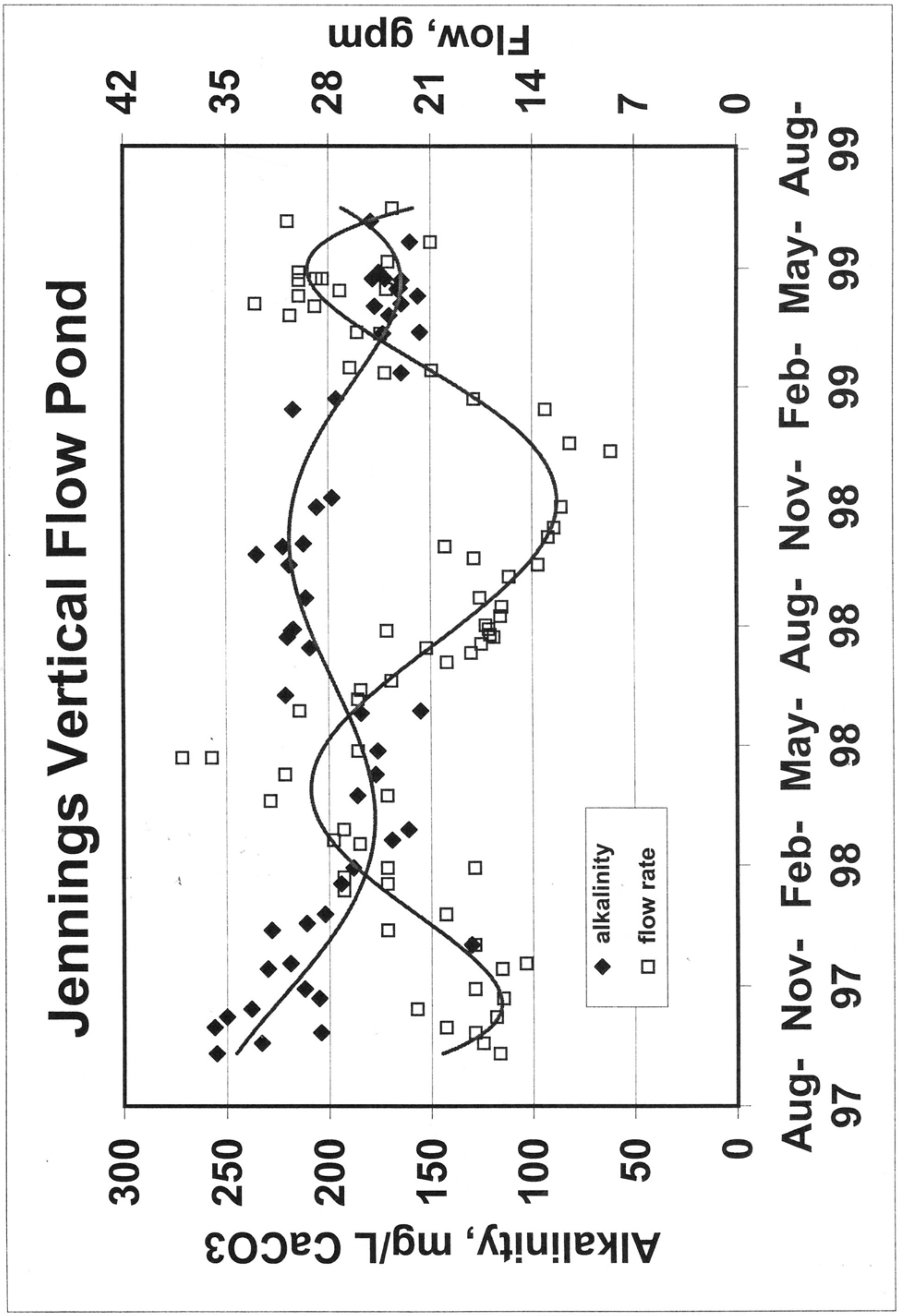

Jennings Vertical Flow Pond
Acidity, mg/L CaCO3
400
300
200
100
0
-100
-200
-300
Aug-97
Nov-97
Feb-98
May-98
Aug-98
Nov-98
Feb-99
May-99
Aug-99
VFP effluent
VFP influent

Figure D



Jennings Vertical Flow Pond
Alkalinity, mg/L CaCO3
Flow, gpm
300
250
200
150
100
50
0
42
35
28
21
14
7
0
Aug-97
Nov-97
Feb-98
May-98
Aug-98
Nov-98
Feb-99
May-99
Aug-99
alkalinity
flow rate

Figure E

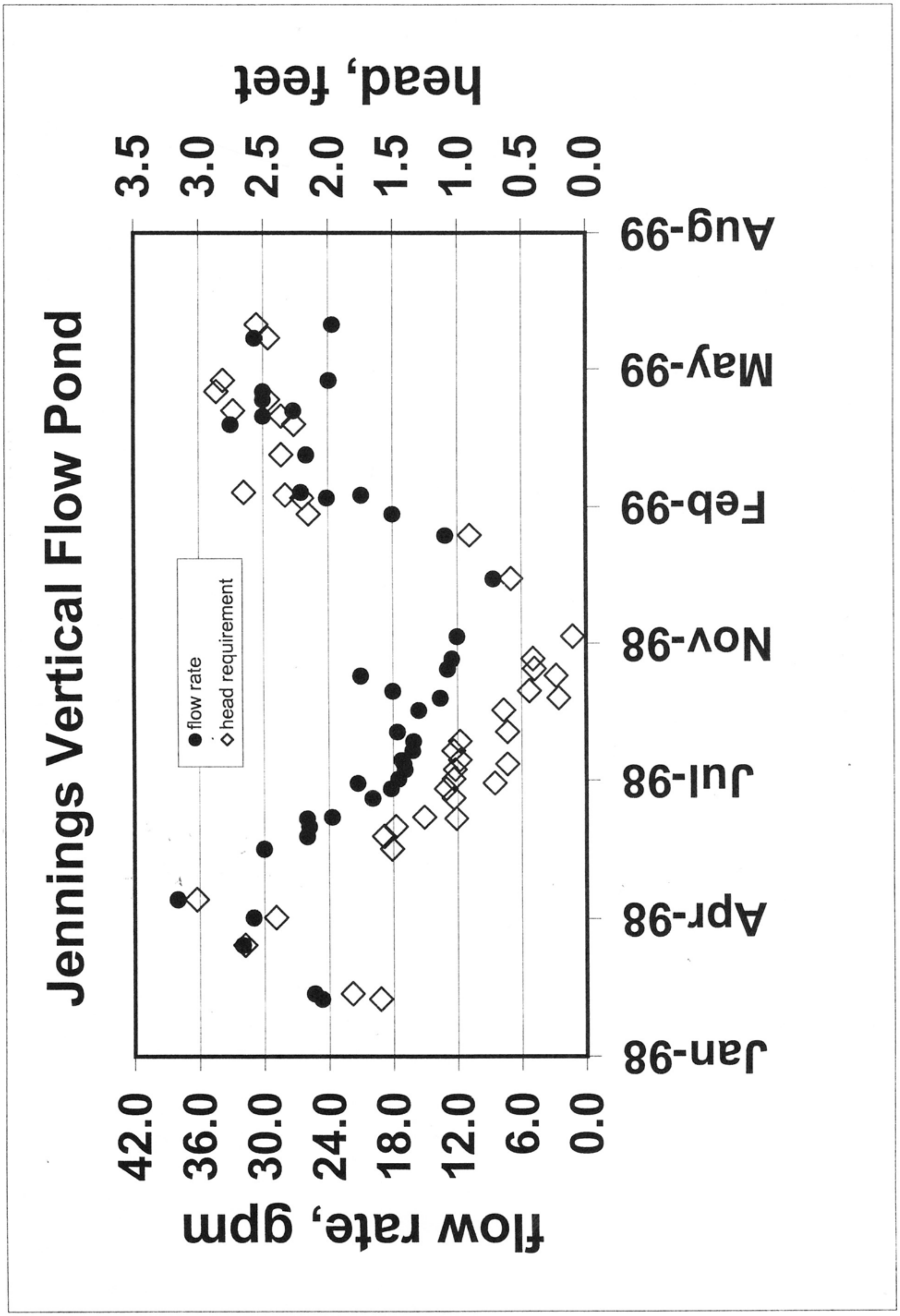

Jennings Vertical Flow Pond
flow rate, gpm
42.0
36.0
30.0
24.0
18.0
12.0
6.0
0.0
head, feet
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Jan-98
Apr-98
Jul-98
Nov-98
Feb-99
May-99
Aug-99
flow rate
head requirement

Figure F

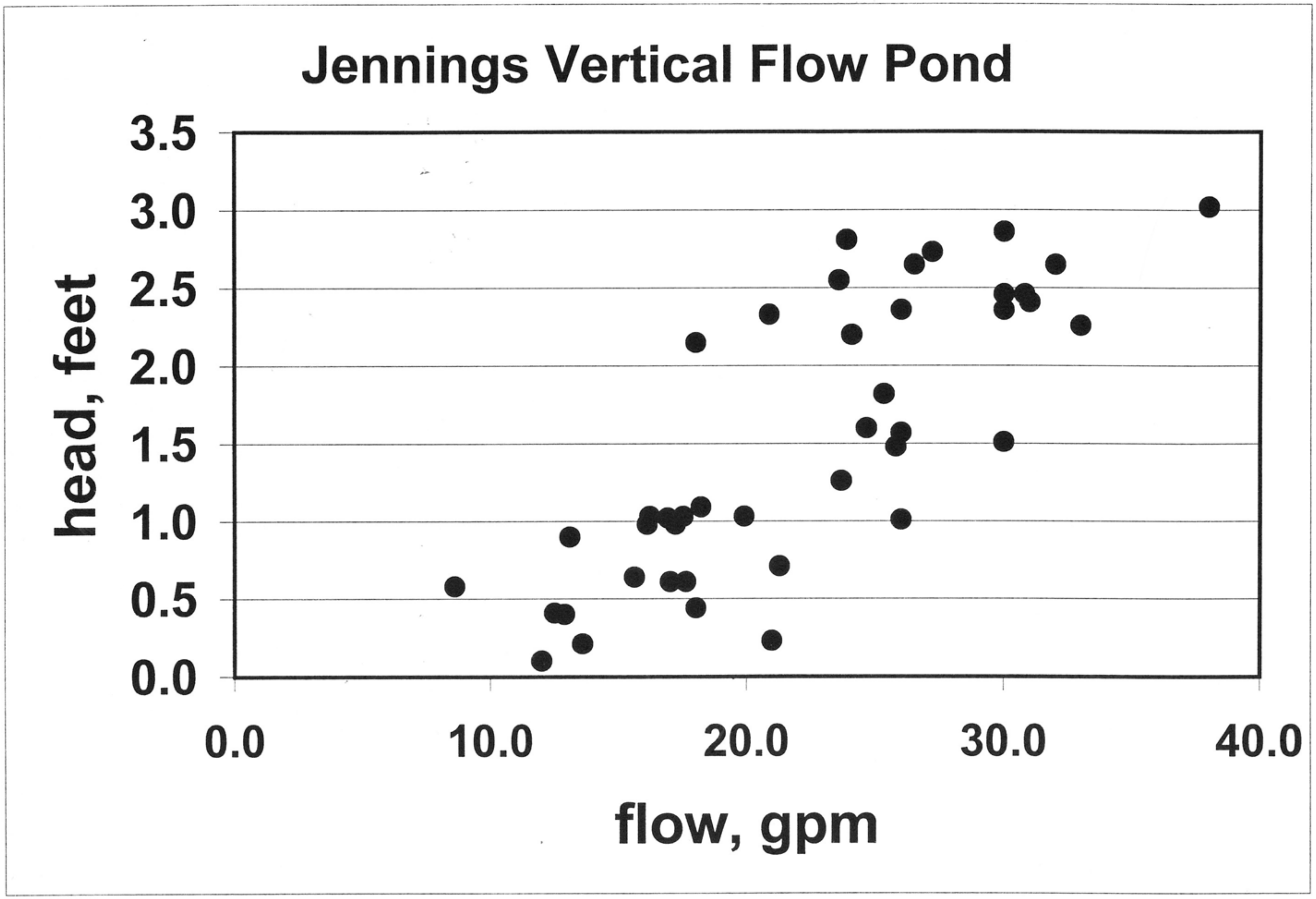

Jennings Vertical Flow Pond
head, feet
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
10.0
20.0
30.0
40.0
flow, gpm

Figure G

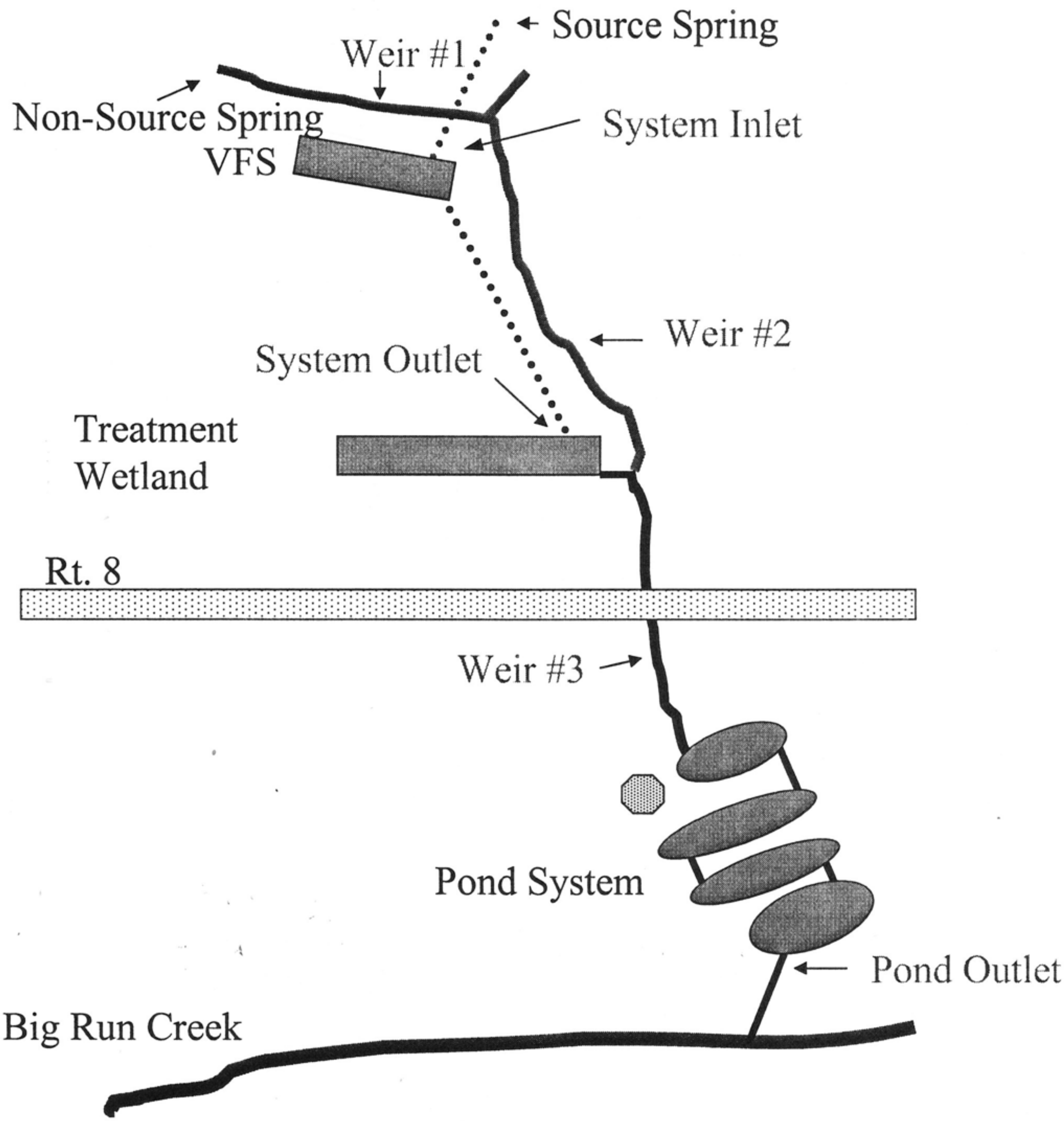

Source Spring
Weir #1
Non-Source Spring
System Inlet
VFS
Weir #2
System Outlet
Treatment Wetland
Rt. 8
Weir #3
Pond System
Pond Outlet
Big Run Creek

Figure H

FINAL REPORT

CHEMICAL AND BIOLOGICAL MONITORING OF BIG RUN, SLIPPERY ROCK CREEK WATERSHED

BEFORE AND AFTER INSTALLATION OF A VERTICAL FLOW SYSTEM TO TREAT ACID MINE DRAINAGE

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

By

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submitted to
Bureau of Watershed Conservation, PA Department of Environmental Protection

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Abstract

Big Run Creek in the Slippery Rock Creek watershed has been monitored quarterly since July 1996 to monitor the effects of a vertical flow passive treatment system installed at Jennings Environmental Education Center in the fall of 1997 to treat acid mine drainage. Chemical and biological parameters were sampled upstream and downstream of the input of the AMD discharge, prior to and following treatment. Values for pH and alkalinity indicate a very slight improvement downstream of the input following treatment, but there was a large degree of temporal variability and pH's downstream still reached below 6 on some dates following the start of treatment. Chemical composition for 13 elements of the clay fraction of sediment indicated no changes following treatment. Density and diversity of macroinvertebrate communities in riffles and pools were severely impacted both upstream and downstream of the input, and showed no effect of the treatment system. High concentrations of Al and Zn in the tissues of hydropsychid caddisflies in Big Run Creek relative to an unimpacted stream, suggest possible toxicity of these metals is responsible for the impact on the macroinvertebrate fauna. The rate of litter decomposition in leaf packs increased after treatment, but more samples are needed to confirm this trend. Diversity of benthic algal communities was low in both riffle and pools and did not improve after treatment was begun.

In general, there has been little to no effect of the passive treatment system on the water quality of Big Run Creek. It is apparent that the stream is impacted above the Jennings discharge. Therefore, while the vertical flow system has greatly improved the water quality of the discharge at Jennings, its effect on the Big Run cannot compensate for the much larger flow of poor water coming from upstream. The presence of several old strip mines and one deep in the watershed above Jennings is a likely source of upstream AMD impact. The lack of extensive iron precipitates on the substrate in Big Run Creek should allow it to recover rapidly if these upstream sources are treated.

Introduction

Big Run Creek is a second order stream in Western Pennsylvania that drains an area of 4.94 km^2 and is a tributary of Slippery Rock Creek the Ohio River Watershed. In 1985 the seal on a 40 year old abandoned deep mine complex burst releasing large amounts of acid mine drainage (AMD) that flowed into Big Run Creek as it runs through the property of the Jennings Environmental Education Center (Fig. 1). The history of passive treatment of that discharge is provided in the description of the treatment system installation at Jennings Environmental Education Center written by Robert Hedin. The chemistry of a particular AMD discharge can vary with local parent material, but in general, exposure of pyrite (FeS_2), and other metal sulfides associated with coal deposits, to oxygen and water results in runoff of extremely low pH and high concentrations of metals, particularly iron. Contact of AMD water with surface stream water of higher pH can precipitate copious amounts of ferric hydroxides