FIELD TRIALS IN AMD TREATMENT

By

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ABSTRACT: Interviews of leading reclamationists revealed general observations on past research and perceptions of success of field practices in the prediction, prevention, and treatment of acid mine drainage. Of significance is the lack of continuity in past AMD research and past failure of industry to document the success of ameliorative or preventative practices. Suggestions for new and continued research are offered, and the efforts of the WV Division of Energy's Abandoned Mine Land & Reclamation Section toward remediation of problem forfeiture sites by the use of constructed wetlands are summarized.

It has been my pleasure to attend this symposium for several years in various capacities. First as a regulator, then as an industry representative, as a consultant, and finally as a researcher and presenter. During this time I have also had the opportunity to see considerable effort expended in predicting, preventing, and treating acid mine drainage. I am sure I share a measure of frustration with most of you present here today at the seeming Lack of progress in the first two facets of this endeavor, and have been forced, Like most who are regulated, to focus my efforts on the third facet.

As an inspector with the WV Department of Natural Resources in the Late 1970's and early 1980's, I began to realize the economic and environmental impact of acid mine drainage to the mining industry and the area it is manifested. I reviewed the work of many of you present here today to explain the phenomena of AMD formation and began to spend a great deal of time thinking about the mechanics and hydrology of AMD formation in mines and refuse areas. I got a good taste of dealing with AMD firsthand while with industry, and my wondering continued with new vigor, since it became my responsibility to predict, prevent, and often treat AMD. As my role changed to consultant, I began to look at more diverse problems, including the long-term economics of the problem, and as a researcher through the University, I have tried to keep these perspectives and present my observations in simple terms (the only terms I understand), remembering that knowledge without communication or implementation is folly.

I appreciate the opportunity to stand among those who have contributed so much to the understanding of acid mine drainage at this distinguished forum, but am directing most of my remarks (and criticisms) toward the most important group present - coat operators.

I empathize with today's operator who cannot make a good decision about the feasibility of mining a reserve of coat that may have the potential of producing AMD. The rules keep changing (for the worst) so that it is impossible to estimate the amount of compliance (and expense) that wilt be required at the end of the mining process. Surviving operators realize that operating in any coat regime, historically acid-producing or not, has certain economic risks which must be included when evaluating the feasibility of mining the seam. if the costs (including potential preventive or treatment costs) are too high, the reserve is not merchantable.

Operators and regulators have Looked to the academic community for means of predicting, preventing and treating AMD. Most of you here are somewhat familiar with research begun at the turn of the century on this subject. If most operators and honest environmentalists were to chart the curve of knowledge on the subject over this period, both would express dissatisfaction with our progress. The growth of knowledge has been painfully stow, given the amount of time and money spent on research over the years. Yes, the problem is quite complicated, and is compounded by variable mining methods, geology, hydrology, and a host of other factors, but I feet there are two big hindrances to making progress in dealing with AMD. One is a Lack of continuity in research. The other is the failure of industry to document experimental mining and reclamation practices where they affect water quality.

When I was first introduced to the problem, I thought most difficulties arose from a lack of diligence toward following the prescribed plans for predicting, preventing or property treating AMD. As I gained experience, I saw the problem was much more complex, and that concrete answers to prediction, prevention, or treatment were not so clear. The opportunity to talk at length with leading reclamationists in the National Mine Land Reclamation Center's (NMLRC) WV-10 project confirmed my perception that many educated people are dissatisfied with the collective progress of AMD research. As I talked to operators, consultants, regulators, and researchers who had years of experience in dealing with AMD, I realized I was getting nebulous, or worse, conflicting answers to fundamental questions about AMD formation, prevention, and treatment technology. Jeff Skousen and I selected 150 individuals to discuss the topics and techniques presented in Exhibit 1. I interviewed just over 20 of them when I became convinced that the information gleaned from even our older research efforts is not reaching those who need it.

I found that nearly all reclamationists were frustrated by the lack of growth of knowledge about AMD. Some indicated that despite the research, study, and field implementation, very Little progress has been made. I would ask you a related question today;

What of our research in the past 80 years has actually reached the operator or regulator and helped him predict, prevent, or effectively ameliorate acid mine drainage?

As I consider the papers presented at this symposium and other information transfer efforts, I have gleaned more from the documentation of field trials than from laboratory research, yet the number of documented field trials in prevention and treatment is small compared to the Laboratory efforts. I realize limitations in time and economics often mandate that trials be moved indoors, where variables can be defined, minimized, or eliminated, but I also realize the inability to recreate the hydrology of a mine, weathering influences, and other conditions that are field specific.

If we are to make progress in solving AMD problems, we must concentrate on relevant laboratory efforts and then follow through with field trials. We must demonstrate the efficacy of some of the practices and procedures that we have advocated as "Best Available Technologies" in our handbooks. How can we make progress in solving the problem when our track record of strictly following (and then documenting the results) some of these procedures is so poor? Basic preventative and ameliorative practices such as pit liming, alkaline trench installation, high and dry placement of toxic materials, wetlands, and other strategies need laboratory research to determine the mechanism of success, but documentation of success or failure in the field is what should spark the interest of the regulator, operator, land owner, and environmentalist. I am dismayed at the paucity of documentation of field trials, and what is the most frustrating is the knowledge that something was tried somewhere, but was not property supervised or followed up adequately to determine its success. Operators have had to keep their attention focused on production, researchers have had to concentrate on the direction provided by grant makers, and regulators have tried to make the best decision based on limited available knowledge and funds. All are frustrated.

A central clearinghouse for reclamation and acid mine drainage or mine water quality research does not exist, as I understand, so papers are not easily located for a literature review. An attempt to establish such a Library was initiated by The National Coat Association, resulting in a bibliography of research from 1910 to 1976, and its contents read Like this year's program. [1] The USEPA and OSMRE has spent sums of money on AMD research for many years, but the results of this research is far from accessible to the coal operator for whose benefit it was intended. it is difficult for researchers to determine what has been examined previously, resulting in this shallow slope in the curve of knowledge about AMD.

One fairly recent occurrence that provides a measure of hope for the end of this frustration is the creation of the NMLRC. This organization provides a means of directing research in acid mine drainage. A meaningful workshop here in Morgantown in December, 1989 helped define the pool of collective knowledge about the fundamentals of AMD, hydrology, water treatment and control. The guidelines for new research promulgated by those in attendance provide meaningful direction for research. [2]

I have been privileged to participate in the evaluation of reclamation technologies and in another project to evaluate the ameliorative mechanisms of wetlands which expands the Laboratory work to the field. The objective of the former project is the creation of handbooks that document proven procedures for successful reclamation and preservation of water quality.

One of the most compelling areas of interest has been the treating of mine waters with anhydrous ammonia. We take too much for granted when we assume operators have all the expertise necessary to efficiently treat AMD to protect the environment. The WV Mining and Reclamation Association has responded to the pleas of responsible operators for information and assistance on this technology to prepare a handbook providing this assistance. The 28 page handbook was prepared with the help of leading reclamationists and environmental chemists involved with acid mine drainage in West Virginia, and I was pleased to help prepare it through the WV-10 project. I invite you to contact the WVMRA for a copy. [3]

Another promising development is the commitment of the WV Division of Energy (WVDOE) towards water quality restoration at its bond forfeiture sites. This avenue toward gathering information seems unlikely, but I feet represents a viable means of long-term study of ameliorative techniques.

I have been assisting the WVDOE in evaluating, diagnosing, and remedying some of its worst bond forfeitures in a special project dealing with water quality for over three years. We have Looked at over 40 sites with a range of water quality problems, and have evaluated the impact on the watershed and designed appropriate mitigative strategies, including soil amendments, alkaline trenches, and constructed wetland systems, which I should Like to discuss very briefly today. The project recently expanded to include all bond forfeitures in WV since SMCRA - 400 permits in 29 counties involving over 10,000 acres. Of course, only a small portion of these manifest poor water quality, and the WVDOE is interested in not only land reclamation, but water reclamation, with emphasis on passive (rather than active) amelioration.

The sites are representative mine sites, with various degrees of water quality degradation. Continuity and documentation is assured since the mitigative work must be done by the state through detailed plans and competitive bidding. The state has demonstrated its commitment to water quality at bond forfeiture sites by the exemplary management of the Alton (DLM) Project and by its construction and monitoring of four wetland systems at bond forfeiture sites paid for by the operators through The Special Reclamation Fund and forfeiture of securities.

The WVDOE has constructed wetlands at four surface mine sites with acid mine drainage in an attempt to mitigate the adverse effects of these drainages. These are natural abatement systems with no synthetic chemicals. Included in the project is a program to manage, maintain, and monitor these systems so that their design and application may be refined for future sites. The monitoring program Lasts one year at a minimum, and the oldest site is nearing its anniversary date.

All four wetland systems have been constructed on schedule and within tolerance of the specifications approved by the WVDOE. Each system has provided a measure of water quality improvement to date. Past performance of wetland systems constructed outside this project has indicated several months are usually necessary for the stabilization of the systems and for the biological mechanisms to establish themselves. White success to date amongst the sites has been variable, so is the influent water quality and quantity, design criteria, and the time of year of construction and transplant effort of the systems. Judgment and conclusions are not offered at this time, but it is apparent the construction effort has made an improvement on the previous water quality existent at each site. The anniversary date of the completion of each site will provide a full year of data to tend information to evaluate the efficacy of the project.

Construction of wetlands for amelioration of acid mine drainage is a fledgling science, and the chemical and biological mechanisms for acid neutralization and metal reduction are not fully understood. Considerable variation in design exists among wetland builders, with the primary difference involving substrate and humic strata composition and flow patterns. Each of the four designs varied these constituents in hopes that the monitoring program would shed information about the merits of each strategy.

Considerable disagreement exists about the sizing criteria of wetlands used for this purpose. Sizing recommendations by the U.S. Bureau of Mines have also undergone refinement since the early 1980's. [4]

The construction costs, cost per square foot of wetland, type of barrier, substrate, average flow and iron concentrations, as well as iron toad per day and # square feet provided per pound of iron is summarized for each of the four systems in Table 1.

Substantial costs were involved in each construction project specific to the site such as diversions, (de)mobilization, revegetation, sediment control, and clearing and grubbing. While each of these activities is necessary to perform the work, they are either structured on the total bid amount or depend on the specifics of the site. These costs were deducted from the estimates in Table 1. They are included in the estimates in Table 2, where they are presented with the Low bid, bidder, functional area of wetland, and cost per square foot. Table 3 summarizes the builder, manager, and initiation of the implementation of the system.

The basic design of all four systems is quite similar. Excavated "sediment channel" impoundments were designed and constructed, utilizing available moderately sloped land. Channels range in width from 25 to 50 feet, and from 100 to 200 feet tong. Depth from improved bottom to crest of the embankments is less than 5 feet. Weirs are used for water level manipulation. included in the plans were provisions for periodic "feeding" of the system with limestone and fertilizer. This effort has not been implemented at any of the systems since it is a modified form of chemical treatment and compromises the goal of the project (Low or no maintenance amelioration).

The Pierce site is located near Ellamore, east of Buckhannon in Upshur county. It was the first to be designed and the Last to be constructed. Its design employs a "classic" approach to wetland construction - surface flow over a limestone enriched substrate and humic strata. Elevations were critical since the total relief from the major AMD seep to the county road was only a few feet. This contour surface mine is the site of considerable research activity by the US Bureau of Mines Pittsburgh Research Center, which maintains at Least one current project there. This wetland provides a relatively high surface area to iron load ratio (Table 1).

The S. Kelly site is Located southeast of Morgantown in Monongalia county. It varies from the earlier design in efforts to encourage subsurface flow under and through the humic strata. This zone has been shown to exhibit reduction reactions which are advantageous over the oxidation reactions known to occur in surface flows. Oxidation reactions produce unstable, gelatinous ferric hydroxides, iron oxyhydroxides, and more acidity, white the aerobic zone within the humic strata has been demonstrated to reduce sulfates and form pyrite, more concentrated, stable products. These subsurface anaerobic processes also produce alkalinity which will further ameliorate the acidic drainage. [5]

The physical means of encouraging this subsurface flow was the use of "tiger drain", a geotextile fabric which was placed under and on the upstream side of the hay bate barriers. This wetland system provided limited surface area for the amount of iron load (Table 1) because the available area was quite limited, and the flows and iron concentrations were high.

The Z & F site is Located near Smithtown, northwest of Fairmont in Marion county. Its construction employed substrate and humic strata similar to the previous designs, but encouraged subsurface flow by means of 61, plastic pipes under earthen barriers. This wetland system provided the least (Table 1) surface area per pound of iron in the drainage, (Less than 1/10 the Pierce site) due to areal constraints, moderately high flows and very high iron concentrations. It was the first to be constructed, commencing in the inclement winter weather months.

The Keister site is located near Audra State Park in Barbour county. It employed an innovative design aimed at reducing costs and implementing construction ease. Instead of a mixed humic strata overlying crushed limestone, hay bales were used over an improved cell bottom. This design innovation was in response to recent research that indicated the limestone was not critical in the desired biological and chemical processes in wetland systems. [6]

The modification resulted in only a Limited amount of Limestone being used, and increased organic content in the system. Wooden boards tined with plastic (braddice cloth or mine curtain) provided the barriers necessary to direct water flow, and provisions were made to encourage subsurface flow. This site provided considerable suitable area for wetland construction, so a relatively high (Table 1) area-to-Load ratio was established.

The WVDOE is serious about protecting water quality, and the provisions of P.L. 95-87 allow the use of monies collected from operators to ameliorate water quality problems at abandoned mine land sites as well as at sites where the bond is inadequate. In addition to the implementation of wetland technology, the WVDOE is implementing alkaline trenches, soil amendments, and other technologies, and documenting their success.

In closing, I appeal to operators to search for new methods to prevent and ameliorate AMD, to diligently implement what has been prescribed as best available technology, and to document their success so that we may Learn by doing, and then by sharing this information at forums such as this symposium. I commend the researchers that have brought us to this point in our knowledge about the prediction, prevention, and treatment of AMD, and advocate a more coordinated emphasis on applied research in the form of well-documented field trials.

EXHIBIT 1

WV-10 (2)

6-90

Topics or Reclamation Techniques to be Evaluated Under
NMLRC Project WV-10

I. Acid Mine Drainage

A. Ammonia
B. Antimicrobial Ameliorants

1. Application in existing/active refuse
2. Application in surface mine reclamation
3. other bactericide applications

C. Limestone

1. alkaline trenches
2. surface applications
3. pit floor lining
4. chemical neutralization of drainage

D. Disposal of Treatment Pond Sludge
E. Segregation and Special Placement of Acid-Producing Materials during Mining & Reclamation

1. effects on water quality
2. effectiveness of clay caps to reduce infiltration

F. Blending of Inert or Alkaline Material with Acid-Producing Materials During Mining & Reclamation
G. Hydrologic Influences on Acid Production

1. flushing cycles of backfills
2. change in water movement through backfills

H. Chemical Injection of Material

1. lime injection into refuse or deep mines
2. sodium compound injection
3. phosphate injection
4. fly-ash injection into backfills

I. Phosphate Application to Toxic Material
J. Acid Mine Drainage prediction Models

1. Acid-Base accounting
2. leaching techniques
3. mathematical or statistical models

K. Acid-Base Accounting for Overburden Analysis
L. Wetlands

II. Revegetation

   A. Refuse Areas

      1. direct seeding
      2. tree planting

   B. Wildlife Habitat Plans
   C. Fly Ash
   D. Kiln or Flue Dust
   E. Sewage Sludge or Other Waste Materials

III. Environmental Effects of Mining

   A. Steep Slope Surface Mining
   B. Deep Mine Subsidence
   C. Deep Mine Sealing and Inundation

TABLE 1

site	area	$/sq.ft.*	construction	substrate	flow gpm	iron ppm	load lb./day	sq.ft./lb.
Pierce	8750	$ 7.16	earthen dike, open channel	crushed lime	11	27	4	2483
S. Kelly	15263	$ 5.87	hay bale w/ fabric	crushed lime	15	264	47	326
Z & F	9287	$ 6.66	earthen dike, pipes	#4 limestone	10	351	40	230
Keister	14397	$ 4.99	wooden dikes w/ windows	#4 limestone	13	16	3	5494

* cost is total estimate less diversions, mobilization, revegetation, sediment control, and clearing and grubbing.

TABLE 2

Total estimates and costs:

site	construction $	management $	total $	low bid $	bidder	area sq.ft.	$/sq.ft. $
Pierce	94,446	13,792	108,238	103,444	HJC Corporation	8750	11.82
S. Kelly	131,142	13,792	148,934	148,200	Battle Ridge	15263	9.71
Z & F	78,974	13,792	92,766	109,998	A. L. King	9287	11.84
Keister	164,082	17,344	181,426	225,000	Green Mountain	14397	15.63

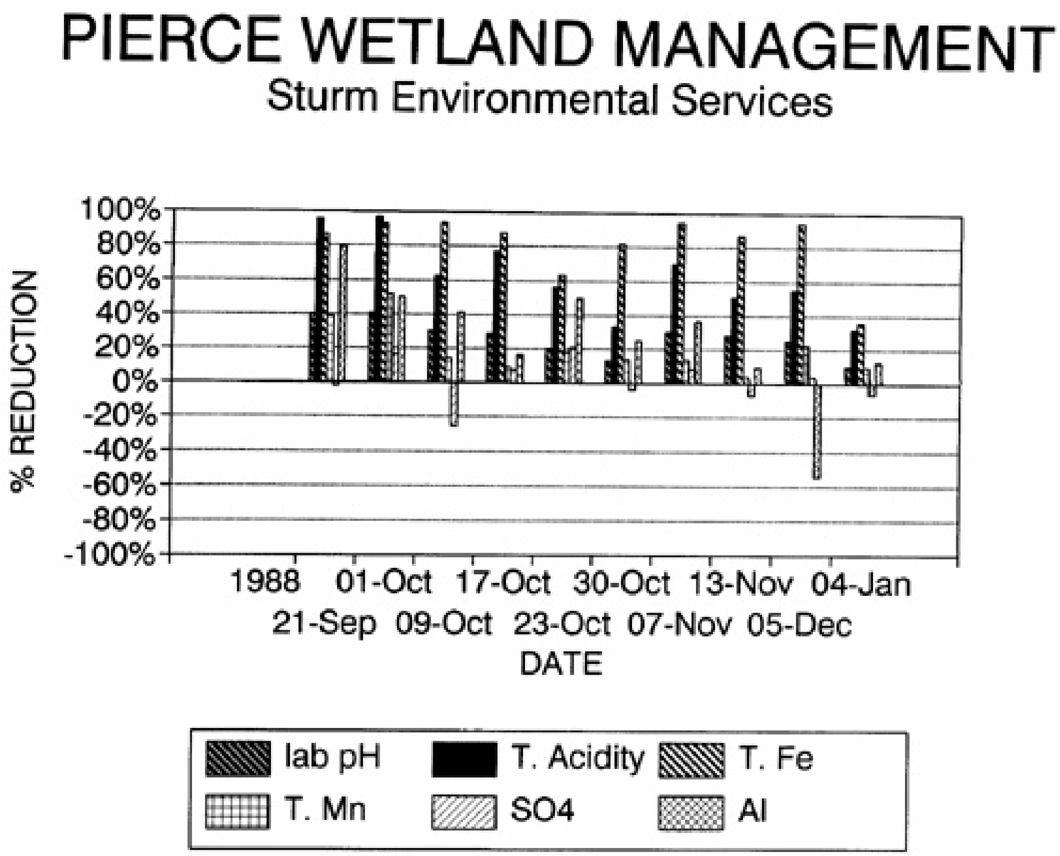
TABLE 3

site	contractor	maintenance (sub)contractor	date of initiation of system
Pierce	HJC Corporation	Sturm Environmental Services	September 1, 1990
S. Kelly	Battle Ridge	CTL Engineering	August 29, 1990
Z & F	A. L. King	Terradon Corporation	March 16, 1990
Keister	Green Mountain	Sturm Environmental Services	July 26, 1990

ACKNOWLEDGEMENTS

1. Gleason, Virginia, and Henry H. Russell. (Bituminous Coal Research, Inc.) Coat and the Environment Abstract Series: Mine Drainage Bibliography 1910-1976. September 30, 1976.
2. National Mine Land Reclamation Center, West Virginia University. Acid Mine Drainage Workshop December 12-13, 1989 "Follow-Up Report".

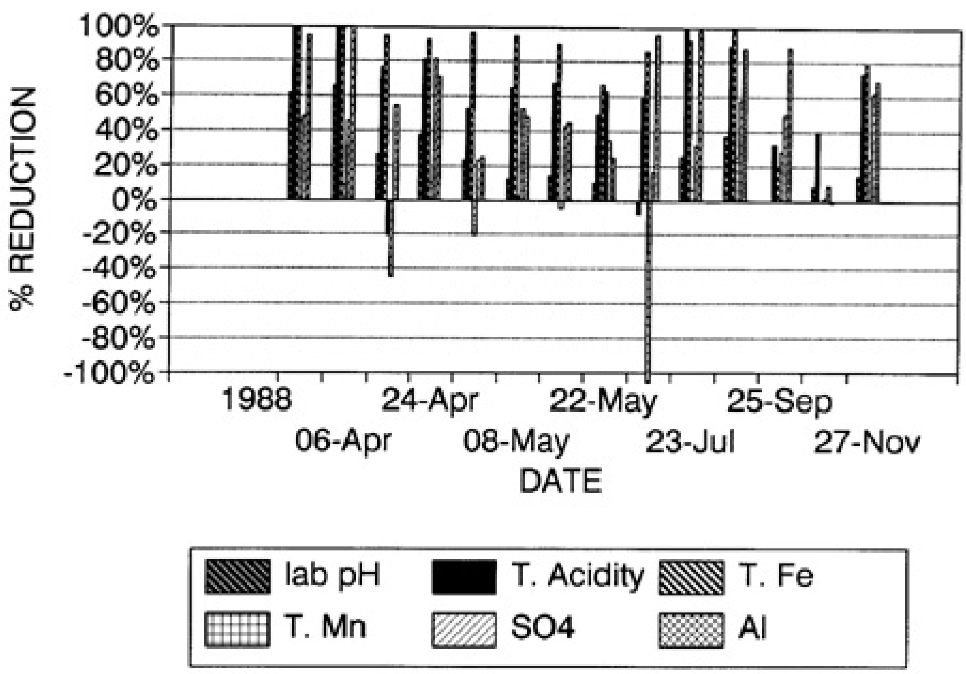
3. Faulkner, Ben B.. Handbook For Use Of Ammonia in Treating Mine Waters. published by West Virginia Mining & Reclamation Association, Charleston, West Virginia in October, 1990.
4. Hedin, Robert S., & Robert W. Nairn. "Sizing and Performance of Constructed Wetlands: Case Studies". in Proceedings of The 1990 Mining and Reclamation Conference and Exhibition. April 23-26, 1990, Charleston, West Virginia.
5. Hedin, Robert S., David M. Hyman, and Richard W. Hammack. "Implications of Sulfate-Reducing and Pyrite Formation Processes for Water Quality in a Constructed Wetland: Preliminary Observations". in Proceedings of the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the US Department of The Interior (Bureau of Mines and office of Surface Mining Reclamation and Enforcement) April 17-22, 1988, Pittsburgh, PA.
6. Hammack, Richard W. and Robert S. Hedin. "Microbial Sulfate Reduction as a Method for Treating Acid Mine Drainage: A Laboratory Study". in Proceedings of the Ninth Annual West Virginia Surface Mine Drainage Task Force Symposium, Ramada Inn, Morgantown, West Virginia. April 25-26, 1989.



Pierce Wetland Management

date	pH			T. Hot Acidity			T. Iron			T. Manganese			T. Sulfates			T. Aluminum			Flow	Acid load
	in	out	%	in	out	%	in	out	%	in	out	%	in	out	%	in	out	%		
1988	3.2	3.2	0%	190	190	0%	30	30	0%	11	11	0%	294	294	0%	10	10	0%	9.1	21
21-Sep	3.2	5.3	40%	104	5	95%	9	1	86%	8	5	39%	224	229	-2%	8	2	80%	7.9	10
01-Oct	3.2	5.4	41%	116	4	97%	35	3	93%	8	4	52%	265	222	16%	5	2	50%	16.4	23
09-Oct	3.2	4.6	30%	133	49	63%	14	1	93%	11	9	14%	240	300	-25%	9	5	41%	10.3	16
17-Oct	3.2	4.5	29%	112	25	78%	10	1	88%	8	7	9%	270	251	7%	8	7	16%	10.3	14
23-Oct	3.6	4.5	20%	62	27	56%	5	2	63%	4	3	17%	144	114	21%	7	4	51%	90.8	68
30-Oct	3.3	3.8	13%	111	74	33%	8	1	82%	8	7	14%	228	236	-4%	11	8	25%	14.5	19
07-Nov	3.2	4.6	30%	125	37	70%	11	1	94%	9	8	13%	269	248	8%	10	7	37%	17.3	26
13-Nov	3.1	4.3	28%	136	67	51%	12	2	86%	9	8	4%	248	266	-7%	10	9	10%	11.1	18
05-Dec	3.4	4.5	24%	107	48	55%	30	2	94%	7	6	22%	200	193	4%	4	6	-54%	10.4	13
04-Jan	3.5	3.9	10%	113	77	32%	2	2	36%	8	7	9%	219	233	-6%	12	10	12%	35.2	48

Z & F WETLAND MANAGEMENT
from TERRADON data



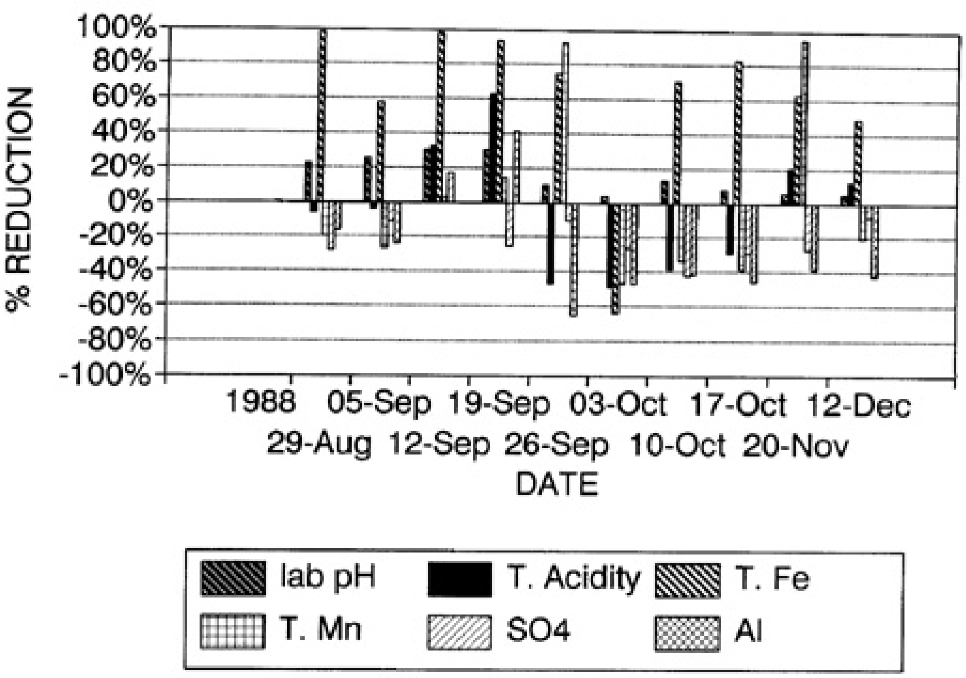
Z & F Wetland Management

date	pH in	pH out	pH %	T. Hot Acidity in	T. Hot Acidity out	T. Hot Acidity %	T. Iron in	T. Iron out	T. Iron %	T. Manganese in	T. Manganese out	T. Manganese %	T. Sulfates in	T. Sulfates out	T. Sulfates %	T. Aluminum in	T. Aluminum out	T. Aluminum %	Flow gpm	Acid load lbs./day
1988	2.6	2.6	0%	2405	2405	0%	351	351	0%	84	84	0%	2711	2711	0%	224	224	0%	9.6	277
30-Mar	2.6	6.7	61%	2644	0	100%	440	2	100%	45	25	45%	2030	1050	48%	149	8	95%		
06-Apr	2.3	6.6	65%	2440	24	99%	471	6	99%	50	46	9%	3376	1844	45%	176	0	100%	8.3	244
17-Apr	2.6	3.5	26%	2600	600	77%	424	23	95%	43	52	-20%	1000	1450	-45%	193	88	54%	10.0	312
24-Apr	2.4	3.8	38%	2100	400	81%	486	35	93%	48	43	10%	818	152	81%	225	65	71%	10.0	252
01-May	2.2	2.9	24%	2300	1100	52%	500	16	97%	49	59	-21%	3250	2500	23%	236	178	24%	6.0	166
08-May	2.8	3.2	13%	3120	1100	65%	533	27	95%	41	41	2%	3800	1800	53%	227	117	48%	3.6	135
15-May	2.4	2.8	14%	2800	900	68%	475	49	90%	43	45	-4%	3400	1950	43%	223	123	45%	5.5	183
22-May	2.6	2.9	10%	2000	1000	50%	403	136	66%	42	16	63%	2900	1900	34%	182	137	25%	10.0	240
26-Jun	2.8	2.6	-8%	2213	911	59%	478	69	86%	46	123	-168%	1960	1636	17%	183	9	95%	4.6	122
23-Jul	2.4	3.2	25%	3123	11	100%	383	29	93%	48	45	6%	1597	1088	32%	206	3	98%	5.0	187
28-Aug	2.4	3.8	37%	2685	297	89%	493	4	99%	55	41	25%	4692	1982	58%	302	36	88%	3.8	122
25-Sep	2.6	2.6	0%	2366	1605	32%	527	424	19%	54	39	28%	3500	1750	50%	299	35	88%	2.6	74
30-Oct	2.4	2.6	8%	2702	1618	40%	307	307	0%	42	42	2%	3382	3100	8%	169	170	-1%	2.6	84
27-Nov	2.5	2.9	14%	2460	665	73%	330	71	79%	44	34	24%	4428	1669	62%	243	75	69%	5.0	148

Note likely sampling or analytical error on 30-Oct due to dissimilar acidity
and identical metals readings.
Manganese reading on 26-Jun is also likely a sample error.

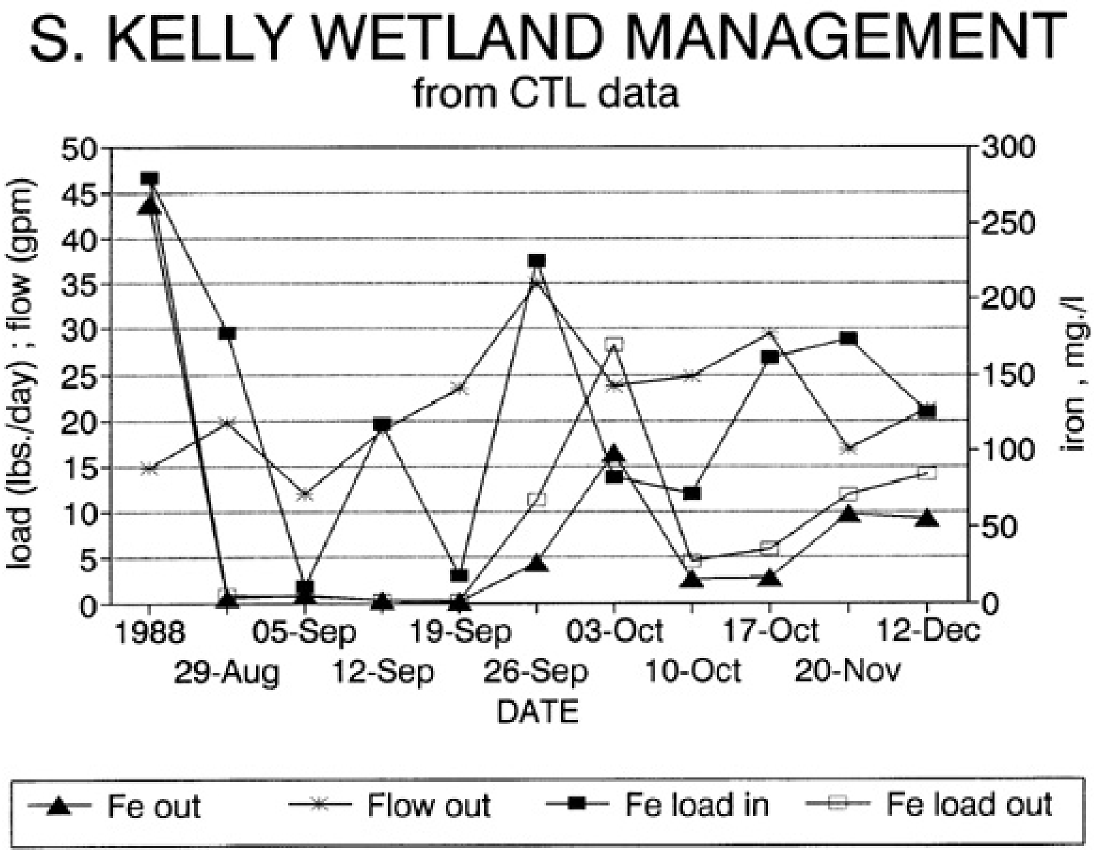
S. KELLY WETLAND MANAGEMENT

from CTL data



S. Kelly Wetland Management

date	pH			T. Hot Acidity			T. Iron			T. Manganese			T. Sulfates			T. Aluminum		
	in	out	%	in	out	%	in	out	%	in	out	%	in	out	%	in	out	%
1988	2.9	2.9	0%	2432	2432	0%	263	263	0%	82	82	0%	4195	4195	0%	270	270	0%
29-Aug	2.8	3.6	23%	1468	1557	-6%	199	4	98%	44	53	-20%	1490	1907	-28%	109	127	-17%
05-Sep	2.6	3.5	26%	1993	2071	-4%	15	6	58%	59	74	-27%	2265	2503	-11%	122	151	-24%
12-Sep	2.4	3.5	30%	1533	1042	32%	105	2	98%	46	44	3%	149	124	17%			
19-Sep	3.2	4.6	30%	133	49	63%	14	1	93%	11	9	14%	240	300	-25%	9	5	41%
26-Sep	2.8	3.1	10%	1320	1952	-48%	107	27	75%	45	3	93%	2995	3294	-10%	102	169	-66%
03-Oct	2.5	2.6	4%	1269	1887	-49%	60	99	-64%	42	61	-47%	2990	3793	-27%	107	158	-48%
10-Oct	2.6	3.0	13%	1357	1877	-38%	54	16	71%	44	58	-34%	3176	4536	-43%	97	138	-42%
17-Oct	2.6	2.8	7%	1467	1905	-30%	100	17	83%	53	73	-38%	2509	3256	-30%	135	197	-46%
20-Nov	2.5	2.6	6%	1473	1170	21%	158	59	63%	43	2	95%	2609	3321	-27%	207	287	-39%
12-Dec	2.6	2.7	6%	1537	1355	12%	109	55	49%	45	54	-21%	3893	4193	-8%	125	178	-42%

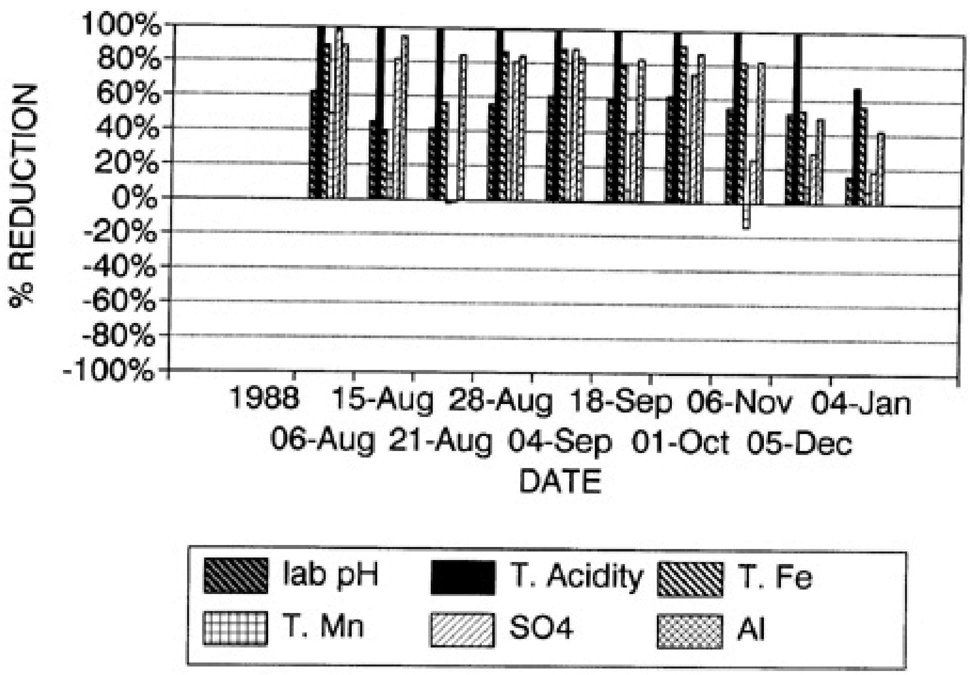


S. Kelly Wetland Management

date	flow	Acid load	flow		Fe load		
	out	out	in	%	in	out	%
1988	14.80	432	14.80	0%	46.7	46.7	0%
29-Aug	19.73	348	12.36	60%	29.5	0.9	-97%
05-Sep	12.00	287	10.50	14%	1.8	0.9	-52%
12-Sep	18.91	348	15.51	22%	19.5	0.4	-98%
19-Sep	23.50	38	18.00	31%	3.0	0.3	-91%
26-Sep	35.00	554	29.20	20%	37.5	11.3	-70%
03-Oct	23.80	362	19.10	25%	13.8	28.2	105%
10-Oct	24.80	404	18.50	34%	11.9	4.7	-61%
17-Oct	29.40	518	22.40	31%	26.8	6.0	-78%
20-Nov	16.80	297	15.20	11%	28.8	11.8	-59%
12-Dec	21.30	393	16.00	33%	20.9	14.1	-32%

KEISTER WETLAND MANAGEMENT

SITE 1

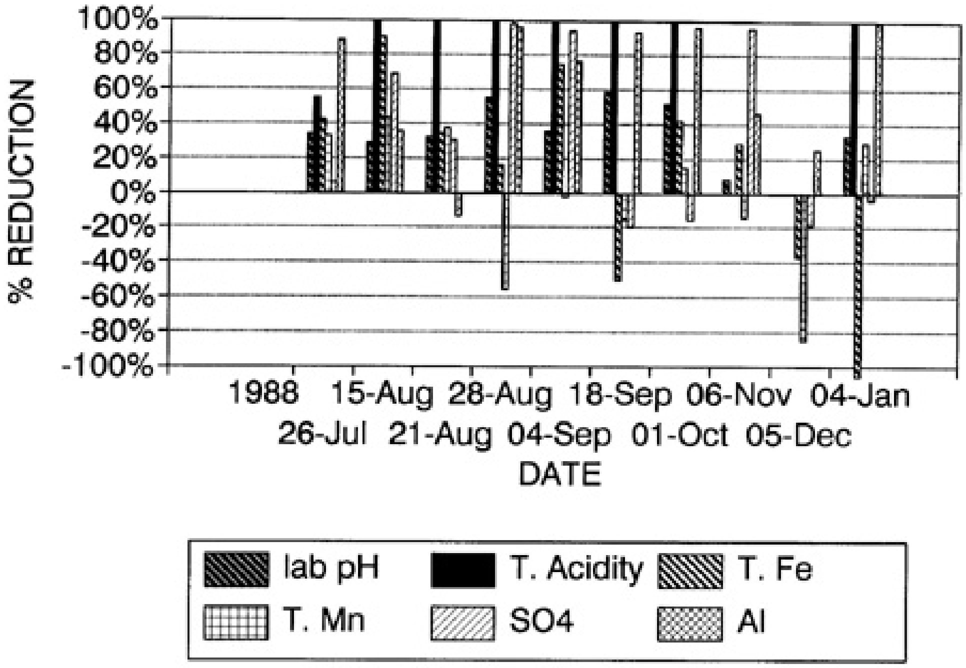


Keister System #1

date	pH in	pH out	pH %	T. Hot Acidity in	T. Hot Acidity out	T. Hot Acidity %	T. Iron in	T. Iron out	T. Iron %	T. Manganese in	T. Manganese out	T. Manganese %	T. Sulfates in	T. Sulfates out	T. Sulfates %	T. Aluminum in	T. Aluminum out	T. Aluminum %	Flow gpm	Acid load lbs./day
1988	3.1	3.1	0%	217	217	0%	6	6	0%	18	18	0%	506	506	0%	14	14	0%	7.00	18
06-Aug	2.7	7.2	63%	323	0	100%	42	5	89%	30	15	49%	768	12	98%	10	1	89%	6.98	27
15-Aug	3.9	7.1	45%	228	0	100%	28	17	40%	30	26	15%	883	160	82%	7	0	95%	1.80	5
21-Aug	4.0	6.8	41%	127	0	100%	11	5	56%	14	15	-1%	450	455	-1%	11	2	84%	11.12	17
28-Aug	3.5	8.0	56%	2276	0	100%	24	3	86%	28	18	35%	965	184	81%	7	1	85%	1.13	31
04-Sep	3.0	7.7	61%	312	0	100%	35	4	89%	27	20	26%	880	102	88%	9	1	83%	1.27	5
18-Sep	3.1	7.6	59%	129	0	100%	15	3	81%	18	17	7%	549	331	40%	6	1	83%	0.78	1
01-Oct	2.9	7.5	61%	207	0	100%	33	3	91%	31	21	32%	771	198	74%	10	1	87%	0.87	2
06-Nov	3.2	7.1	55%	126	0	100%	18	3	82%	19	21	-14%	519	392	24%	7	1	83%	1.59	2
05-Dec	3.2	6.6	52%	152	0	100%	21	10	54%	21	19	10%	520	371	29%	7	3	50%	3.94	7
04-Jan	3.2	3.8	16%	168	54	68%	20	9	56%	21	20	7%	641	529	17%	8	5	42%	10.30	21

KEISTER WETLAND MANAGEMENT

SITE 3



Keister System #3

date	pH in	pH out	pH %	T. Hot Acidity in	T. Hot Acidity out	T. Hot Acidity %	T. Iron in	T. Iron out	T. Iron %	T. Manganese in	T. Manganese out	T. Manganese %	T. Sulfates in	T. Sulfates out	T. Sulfates %	T. Aluminum in	T. Aluminum out	T. Aluminum %	Flow gpm	Acid load lbs./day
1988	3.1	3.1	0%	322	322	0%	28	28	0%	21	21	0%	762	762	0%	26	26	0%	6.30	24
26-Jul	3.3	5.0	34%	359	161	55%	90	52	43%	28	19	33%	643	604	6%	33	4	89%	20.20	87
15-Aug	5.5	7.7	29%	130	0	100%	73	7	91%	28	16	43%	847	262	69%	1	0	36%	0.00	0
21-Aug	4.4	6.5	32%	23	0	100%	28	18	34%	16	10	38%	453	313	31%	1	1	-13%	1.10	0
28-Aug	3.7	8.3	55%	72	0	100%	6	5	16%	12	18	-56%	312	6	98%	6	0	96%	0.10	0
04-Sep	5.0	7.8	36%	71	0	100%	17	4	75%	15	16	-3%	380	22	94%	2	0	77%	0.25	0
18-Sep	3.1	7.5	59%	67	0	100%	3	5	-50%	10	12	-16%	264	317	-20%	6	0	93%	0.99	1
01-Oct	3.5	7.3	52%	40	0	100%	5	3	42%	14	12	15%	301	348	-16%	8	0	96%	0.50	0
06-Nov	6.7	7.3	8%	0	0	0%	7	5	29%	6	7	-14%	407	18	96%	1	1	46%	0.50	0
05-Dec	6.9	6.9	0%	0	0	0%	2	3	-37%	2	4	-85%	188	222	-18%	3	2	25%	0.80	0
04-Jan	4.2	6.3	33%	95	0	100%	1	9	-565%	8	6	29%	225	233	-4%	9	0	99%	0.80	1