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RESEARCH REPORT NO. 185

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LEXINGTON, KENTUCKY 40506

United States Department of the Interior
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Water Resources Research Institute
University of Kentucky
Lexington, KY

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August, 1992

DISCLAIMER

ABSTRACT

Acid mine drainage (AMD) from an underground coal mine in the Jones Branch watershed in McCreary County, KY, substantially reduced water quality in Jones Branch. Downstream from the mine seeps, the pH was routinely below 4.5 and concentrations of most heavy metals, especially iron, were elevated. A cattail wetland (1,022 m^2) was constructed on Jones Branch in 1989 to obviate the effects of the AMD. Monthly chemical monitoring was performed on the water from above, from below, and from the 26 cells within the wetland. Based on chemical monitoring, the wetland initially improved water quality, increasing the pH and removing substantial amounts of heavy metals. Beginning in the spring of 1991, water quality at the wetland outfall began to decline, and has not improved to date. To augment the chemical monitoring, a biomonitoring study was initiated in the spring of 1990. Acute 48-hr static tests were conducted with newly hatched fathead minnows (<u>Pimephales promelas</u>). Water samples were obtained from the seep inlet, four cells within the wetland, and from Jones Branch above and below the wetland site. Median lethal concentration (LC_{50}) values determined monthly reflect the decline in water quality at the outfall over time. However, within the wetland there was gradual improvement in survivability from inlet to outlet, providing evidence that the wetland was responsible for a modest improvement in water quality.

Descriptors:

Wetlands, Acid Mine Drainage, Bioassay

ACKNOWLEDGMENTS

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INTRODUCTION

OBJECTIVES

Acid mine drainage is a persistent problem in the watershed of White Oak Creek in McCreary County, Kentucky. Seeps from collapsed mine portals of an abandoned underground coal mine are polluting the tributaries of White Oak Creek, with two isolated seeps on Jones Branch reducing the pH of the stream to approximately 4.5 or less. Little or no life was found in Jones Branch below the entry of these seeps into the stream. This coal mine site is abandoned and the clean up is the responsibility of state and federal agencies.

Traditional approaches to the treatment of acid mine drainage include neutralization by addition of a base, oxidation by aeration, and precipitation in a settling basin or pond. These approaches are expensive, and cost the coal mining industry approximately $1 million per day. A more economical way of treating acid mine drainage is needed, especially on abandoned lands.

Limited studies have shown that constructed wetlands have the ability to remove many toxic metals and substantially improve water quality (1-3). The U.S. Forest Service's Northeastern Forest Experiment Station at Berea, Kentucky, constructed a wetland on Jones Branch in the spring of 1989. Chemical monitoring was performed on water from the wetland in an attempt to identify the component(s) which contributed to the overall effectiveness of the structure as a biofilter, and to estimate the functional longevity of the system. The current study was undertaken to augment the water chemical analyses with data on the ability of the wetland to support life by conducting a series of biomonitoring tests. The biological monitoring portion of this study was based on accepted techniques for monitoring effluents from both point- and nonpoint-sources (4-6). The technique used was the 48-hr acute bioassay. This test was selected because of its demonstrated ability to estimate the acute toxicity of a variety of aquatic pollutants, especially heavy metals. Acute toxicity tests were conducted on water obtained from various sites within the wetland and on water from above and below the seeps. The original objectives of the project were fulfilled, with the exception of estimating the chronic toxicity of the water by conducting 8-day embryo-larval toxicity tests with fathead minnows. The extreme acute toxicity of the water precluded the necessity of establishing chronic toxicity.

BACKGROUND

The Surface Mining Control and Reclamation Act of 1977, with its amendments, mandates that mine drainage meet minimum water quality standards for several parameters, including pH, iron, manganese, and total dissolved solids (7). Traditional technologies to improve water quality have proven to be expensive and complex. Therefore, new approaches to improving the quality of mine drainage waters are needed. Wetlands, both natural and artificial, have been shown to treat effectively or supplement the treatment of urban stormwater runoff and municipal wastewaters by removing selected pollutants (8-13). Few studies have examined the use of constructed wetlands to obviate the effects of acid mine drainage. The effectiveness of most wetlands has been studies in the laboratory, with little work done in the field (14-17). The field studies that have been performed have been limited in their scope, and not a great deal is understood concerning the mechanisms of removal of metals by a wetland. However, it is becoming clear that not only the plants in a constructed wetland are important, but also the bacterial populations play a significant role in removing heavy metals from water (18-23).

RESEARCH PROCEDURES

The protocol followed in this study involved two approaches. A brief description of each of these strategies is given below, followed by more detailed procedures.

1. The first question to be addressed by the proposed study was where within the wetland would the water quality be improved enough to support aquatic life. This objective was approached by conducting toxicity tests on water collected from various sites within the wetland.
2. The second objective was to evaluate the length of time the wetland would be functional in obviating the effects of acid mine drainage on aquatic life. This was accomplished by conducting monthly toxicity tests over a period of two years, and by evaluating the effectiveness of the wetland over time.

STUDY SITE

Jones Branch, a tributary of White Oak Creek, is located in McCreary County, Kentucky. The stream is impacted by acid mine drainage (AMD) from two collapsed mine portals (Seeps 1 and 2) located approximately 1.4 stream miles above the confluence of Jones Branch with White Oak Creek. The U.S. Forest Service's Northeastern Forest Experiment Station at Berea, Kentucky, supervised the construction of a wetland and an access road to the site. Construction was completed during the summer of 1989 and the flow of acid mine water through the wetland was initiated in August of 1989.

WETLAND DESIGN

The wetland designed at the Jones Branch site consisted of a total area of 16,200 sq. ft. comprised of two fields (Field No. 1 ≈9,600 sq. ft. and Field No.

2 ≈6,600 sq. ft.). A schematic representation of the constructed wetland is presented in Figure 1. Field No. 1 consisted of 16 cells, approximately 600 sq. ft. per cell, with cell 0 containing no vegetation. The remaining cells were planted with cattails (Typha sp.). AMD from the two mine portals was flumed into Cell 0. Water flowed progressively through the remaining 15 cells of Field No. 1 and was then flumed into Field No. 2 at Cell 16. After flowing through the 10 cells of Field No. 2, the water was allowed to flow into Jones Branch. The design provided 200 to 600 sq. ft. of surface area per flowing gallon per minute. The flow rate ranged from 23 to 75 gpm. The length of the flow path through Fields 1 and 2 was approximately 580 to 600 linear ft., providing a contact time of approximately 120 min for the water as it passed through the wetland.

Each cell of the wetland was constructed with a 6 in. limestone base overlaid with 18 in. of compost or humus material. Cattails initially were planted and other plants have subsequently invaded the area.

CHEMICAL MONITORING

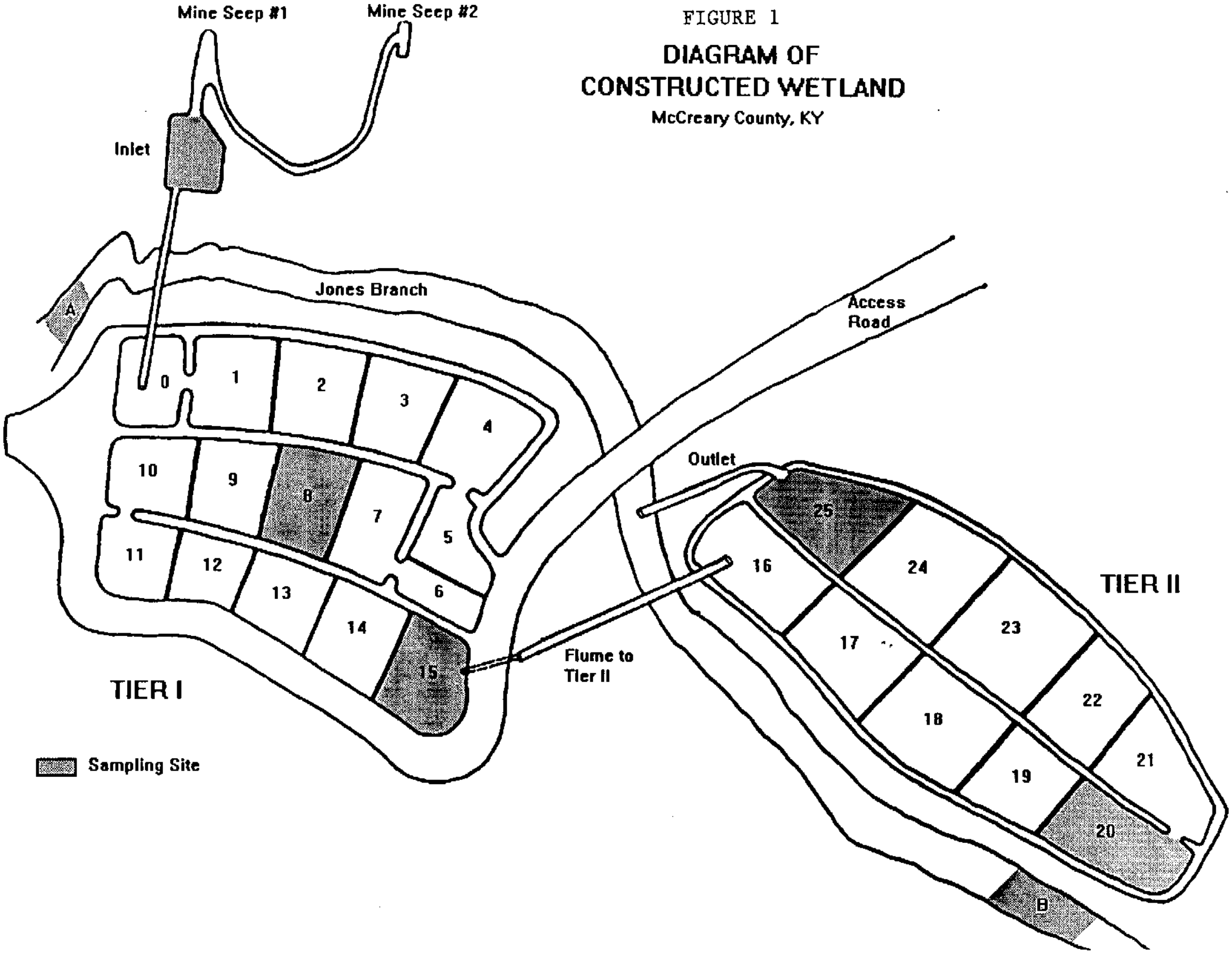
The U.S. Forest Service's Experiment Station at Berea, Kentucky, conducted a chemical monitoring program of the wetland with three major objectives. The first was to determine if wetland treatment would restore stream water quality to acceptable levels. The second objective was to evaluate the cells of the wetland to identify the portion and constituents of the wetland which were most important in removing specific components of the AMD. Finally, the long-term effectiveness of the wetland was to be determined by monitoring at regular intervals over a three year period.

Once a month, Forest Service personnel obtained water samples from 1) the AMD entering the wetland, 2) even numbered cells within the wetland, beginning with Cell 0, and 3) the water entering Jones Branch from the wetland. In addition, water from Jones Branch above and below the wetland site was routinely sampled. Since Jones Branch is a first-order, intermittent stream, there were several months of no-flow, when virtually all of the stream water below the wetland originated from the wetland outfall.

FIGURE 1

DIAGRAM OF CONSTRUCTED WETLAND

McCreary County, KY



Each water sample consisted of four 8-oz bottles of water. One bottle contained filtered water, one acidified with nitric acid, and the remaining two bottles were raw, untreated water. Water samples were transported to the Forest Service Laboratory and either analyzed immediately or stored at 4°C until analyzed. The water was analyzed for a wide range of water quality characteristics and for the presence of several metals. Table 1 lists the analyses performed on each sample of water.

BIOMONITORING

Biomonitoring of the water from various cells within the wetland supplemented the chemical monitoring data to aid in evaluating the effectiveness of the wetland in obviating the effects of AMD. Toxicity tests were performed following procedures recommended by the U.S. Environmental Protection Agency (4, 5). Initially, water samples were obtained from the combined effluents of Seeps 1 and 2, from each even numbered cell in the wetland, and from the outflow to Jones Branch. These samples were collected at the same time that Forest Service personnel collect samples for chemical analyses. After preliminary toxicity tests indicated that there was little difference in response between successive cells along the continuum, it was decided to test water from the wetland inlet, cells 8, 15, 20, 25 (outlet), and from Jones Branch above and below the wetland (Figure 1). These sample sites provided data from the beginning, middle, and end of each of the two fields. Monthly samples were collected as grab samples in clean 1 gal "milk" jugs, placed on ice, and returned to the laboratory at Eastern Kentucky University. Samples were used immediately or refrigerated at 4°C for no more than 72 hr. For all sites, toxicity tests were conducted using the sampled water at full strength (100%) and at four dilutions. All wetland sites were tested at dilutions of 12.5%, 6.25%, 3.1%, and 1.5% of the sample. Water samples from Jones Branch above the wetland were diluted to 50%, 25%, 12.5% and 3.1%, while water from below the site was diluted to 25%, 12.5%, 6.25%, and 3.1%.

Acute toxicity tests were conducted with newly hatched (1-3 day old) fathead minnows (*Pimephales promelas*). This particular test was selected after

TABLE 1. Water sample analyses for the wetland study.[1]

Variable	Sample Type[2]	Units	Method[3]
Sediment	Raw	ppm	Filtration
Turbidity	Raw	JTU	Colorimetric
Conductivity	Raw	μmho	Potentiometric
pH	Raw		Potentiometric
Carbonate	F	mg/L as $CaCO_3$	Titration
Acidity	Raw	mg/L as $CaCO_3$	Titration
SO_4	F	ppm	IC
NO_3	F	mg/L N	IC
Ni	FA	ppm	APS
K	FA	ppm	APS
Cr	FA	ppm	APS
B	FA	ppm	APS
Si	FA	ppm	APS
Zn	FA	ppm	APS
P	FA	ppm	APS
Fe	FA	ppm	APS
Cu	FA	ppm	APS
Mn	FA	ppm	APS
Mg	FA	ppm	APS
Na	FA	ppm	APS
Co	FA	ppm	APS
Al	FA	ppm	APS
Ca	FA	ppm	APS
Pb	FA	ppm	APS

[1] Analyses performed by the Forest Research Station Laboratory, Berea, KY.

[2] Sample type refers to a raw sample, a filtered (F) sample, and a filtered, acidified (FA) sample.

[3] Method refers to ion chromatography (IC) and argon plasma spectroscopy (APS).

consultation with Q.H. Pickering of the Aquatic Biology Section, U.S. Environmental Protection Agency (EPA), Newtown, Ohio (personal communication). Fathead minnow larvae were obtained from the U.S. EPA in Newtown, Ohio. Ten larvae were placed in 1 L Pyrex beakers containing 0.75 L of test solution. Tests were conducted for 48 hr in replicate at 22 ± 2°C with no renewal. Initially, water in Jones Branch upstream of the mine seeps was evaluated for its ability to serve as a source of control and dilution water. It proved to be unsuitable, both in quality and supply, and a synthetic fresh water of moderate hardness (4) served as the dilution water for all toxicity tests. Test and control water were evaluated for standard water quality parameters at the beginning and end of the test. Temperature, dissolved oxygen, conductivity, and pH were determined using a Fisher LCD thermometer, YSI oxygen meter (model 54), a Markson conductivity meter (model 10), and a Fisher pH meter (model 735), respectively. Test organisms were monitored daily and dead specimens were removed. At the beginning of selected tests, the chemical stability of the water samples, having been stored for up to 3 days, was evaluated. Full-strength samples of each test water were preserved and sent to the Forest Service Laboratory for analysis of the full range of metals. The complete analysis is reported in the Appendix (Table A-1).

TEST RESPONSES AND ANALYSIS OF DATA

The test response in the 48 hr static acute test was mortality, which was determined by the failure of the larva to move when prodded. Median lethal concentrations (LC_{50}) were calculated using the Trimmed Spearman-Karber method (24).

DATA AND RESULTS

WATER QUALITY IN JONES BRANCH

Water quality in Jones Branch was monitored in 1988 and 1989 to establish a database, allowing comparison of characteristics before and after construction of the artificial wetland. Several water quality characteristics were monitored (Table 1), and quantitative results for selected characteristics over the 3 years of the study are presented in Figures 2-5. The flow of acid mine water through the wetland was initiated in August of 1989.

Conductivity, pH, and heavy metal concentrations in Jones Branch above the mine seeps were within acceptable levels for an intermittent stream (Figs. 2A - 5A). The impact of the acid mine drainage was pronounced, with pH dropping to 2.7-2.8 and conductivity increasing to 4100 μmhos prior to wetland construction (Figs. 2B, 3B). Aluminum and iron concentrations were high, at 22.2 and 812 mg/L, respectively (Figs 4B, 5B).

The constructed wetland on Jones Branch began operation in August of 1989. The wetland substantially reduced the specific conductivity in Jones Branch below the mine seeps by approximately 90% over the first 11 months of operation. Since the summer of 1990, improvements have been much more variable, with some seasonal trends noted (Figs 2-5). The initial reductions in heavy metal concentrations (e.g., aluminum and iron, Figs. 4 and 5, respectively) were also dramatic, with initial reductions of approximately 98%. The pH in Jones Branch was raised from 2.7 - 3.0 to 6.12 immediately after wetland treatment began. For the next eight months, pH gradually declined, reaching a level of 3.4 in March of 1990. Since that date, pH has fluctuated somewhat, but has never exceeded 5.0. The mean pH between March, 1990, and May, 1992 was 3.55. This was still below the average of 4.38 observed in Jones Branch above the outfall of acid mine water (Fig 2A).

WATER QUALITY THROUGHOUT THE WETLAND

One major objective of the study was to evaluate the effectiveness of the wetland to improve the water quality of the acid mine drainage. As can be seen in Figure 6, water from the mine seeps (inlet) had an average pH of 3.17 for the 3 years of the study. As the water moved through the wetland, pH did not improve substantially until the water reached the second field of cells. At the outfall (cell 25), the pH of the water was initially improved, but after 6 months, the pH dropped to 2.58 and was not substantially improved after that date (Fig. 6). In fact, the pH at the outfall was usually below that of the inlet.

A similar pattern was observed for conductivity. The initial flow through the wetland improved conductivity from an inlet value of 5560 μmhos to an outfall level of 2450 μmhos (Fig. 7). However, over the next 6-8 months, the conductivity gradually increased, never reaching levels observed in water above the wetland (Fig 3A).

Heavy metal concentrations throughout the wetland varied greatly. This observation was partly due to the fact that heavy metal concentrations (e.g. aluminum, iron) in the AMD water (inlet) fluctuated with the seasons. Overall concentrations of aluminum initially were reduced from the inlet to outfall, but after about 6 months of operation, the concentrations in the outfall water increased (Fig. 8). The concentrations of iron were reduced dramatically during the first 4 months of wetland treatment, declining from an input level of 1305 mg/L to am outfall concentration of 0.46 mg/L (Fig. 9). After that time, iron exceeded the concentration found in Jones Branch above the wetland (Fig 5A).

TOXICOLOGICAL MONITORING

The quality of water directly affects the survival of aquatic organisms. Prior to the construction of the wetland, no animal life was observed in Jones Branch. Therefore, one of the goals of this remediation project was to evaluate the success of the treatment by determining if sensitive life stages of fish could survive. This component of the study was initiated approximately 10 months after initiation of AMD through the wetland. As noted in the previous section, water quality throughout the wetland had begun to degrade by the spring of 1990, and therefore, interpretation of results from the toxicity tests should be made in light of the failure of the wetland to clean up the AMD.

Newly hatched larvae of the fathead minnow were selected as a test organism for the toxicity tests. Acute 48-hour static tests were conducted monthly from July of 1990, to May, 1992. At no time did any larvae survive in the full strength water taken from any of the wetland cells or from Jones Branch above and below the wetland. Full-strength water from the wetland cells produced mortality of all test animals, usually within the first 2-4 hours of exposure. Substantial dilution of the test water was always required to allow survival of the larvae. Dose-response data for the test conducted in the month of June, 1991, are given in Table 2, and these responses are typical of those obtained throughout the 2-year study. A 50% dilution of water from above the wetland resulted in complete survival, while water below the wetland was diluted to 12.5% of sample before complete survival was attained. Water from the inlet and cells throughout the wetland required dilution to 1.6% of sample to achieve survival, with one exception. At a dilution of 3.1%, water from the outfall (cell 25) allowed partial survival of the test population.

In order to compare the toxicological data obtained from the various sites, median lethal concentrations (LC_{50}) were determined. Table 3 give the LC_{50}'s, expressed as percent of sample, for each of the 21 tests. Jones Branch above the wetland was intermittent and water samples could not be collected in late summer or early fall of 1990 and 1991. Due to technical difficulties, there were not enough larvae to conduct a complete suite of tests in September or November, 1990. Therefore, LC_{50} values were available only for the outfall and Jones Branch below the wetland. Other missing data were due to problems collecting enough water to run the test.

As can be seen in both Table 3 and Figure 10, toxicity of water in Jones Branch below the wetland decreased in the summer and improved substantially during the winter. In most tests, the Jones Branch water below the wetland also was substantially less toxic than the water coming out of the wetland (cell 25).

TABLE 2. Toxicity of water from a constructed wetland system treating acid mine drainage, as determined in a 48-hour static test with fathead minnow larvae (June, 1991).

PERCENT SURVIVAL							
Percent Sample	**Stream Above**	**Wetland Inlet**	**Cell 8**	**Cell 15**	**Cell 20**	**Cell 25 (Outlet)**	**Stream Below**
100.0	0	0	0	0	0	0	0
50.0	100	-	-	-	-	-	-
25.0	100	-	-	-	-	-	0
12.5	100	0	0	0	0	0	100
6.25	-	0	0	0	0	0	100
3.1	100	0	0	0	0	40	100
1.6	-	95	95	100	95	100	-
0 (Control)	100	100	100	100	100	100	100

Table 3. LC50 values for acid mine drainage treated by a constructed wetland determined with fathead minnow larvae in a 48-hour static test.

LC_{50} Values (Percent Sample)

DATE	STREAM ABOVE	WETLAND INLET	CELL 8	CELL 15	CELL 20	CELL 25 (OUTLET)	STREAM BELOW
7/90	-	2.25	3.16	3.16	2.59	3.16	7.63
8/90	-	2.11	2.52	2.83	3.87	4.32	3.74
9/90	-	-	-	-	-	5.45	32.7
10/90	70.7	2.21	3.59	3.85	4.12	3.35	17.7
11/90	-	-	-	-	-	5.08	50.0
1/91	70.7	4.90	4.42	4.27	4.42	4.42	50.0
2/91	70.7	2.21	2.45	4.42	4.27	6.93	48.0
3/91	70.7	1.50	4.27	4.90	4.42	5.26	47.5
4/91	68.2	2.21	2.21	2.45	3.84	4.42	46.1
5/91	70.7	4.12	1.59	4.42	2.92	2.54	50.0
6/91	70.7	1.52	1.52	2.21	1.52	2.92	17.7
7/91	-	1.52	1.78	4.27	2.74	4.42	8.84
8/91	-	2.21	4.42	-	4.27	-	7.43
9/91	-	1.44	2.21	2.21	3.02	-	8.84
10/91	-	2.21	2.21	2.29	4.27	6.47	5.44
11/91	-	2.15	2.07	2.15	2.15	2.15	0.01
1/92	70.7	2.21	2.21	4.12	4.12	-	-
2/92	70.7	1.44	1.44	2.21	2.21	2.21	50.0
3/92	33.9	0.93	2.21	2.84	0.40	2.18	47.5
4/92	68.3	2.21	1.44	2.21	2.21	1.44	8.54
5/92	70.7	2.21	2.29	-	2.21	-	50.0

These improved LC_{50} values for water below the wetland probably was due to dilution by upstream water.

An examination of the survival responses throughout the wetland indicated that no significant improvement was achieved between inlet and outfall (Table 3, Figure 10). However, this result must be evaluated in light of the fact that the toxicity tests were conducted during the period in which water quality was declining throughout the wetland. Both LC_{50} values and water quality characteristics of the wetland acid mine drainage water were examined to determine whether any correlations existed (Figures 11-14). Analysis of the data yielded little positive correlation. Rain events and flow rates through the wetland may also have contributed to the water quality characteristics, and these data will be evaluated for their influence on toxicity responses.

CONCLUSIONS

The use of constructed wetlands to obviate the effects of acid mine drainage has potential for success, but careful evaluation of the site, the design, and especially the size of the wetland must be done. The constructed wetland site on Jones Branch in McCreary County, Kentucky, initially improved the water quality in the stream. However, the long-term operation of the wetland did not achieve the desired results. Within 6 months of the initial operation, water quality in Jones Branch declined to a level slightly above that observed prior to wetland construction. Without any maintenance of the wetland, quality remained poor through the end of the study. The minimal improvement observed probably was achieved by the sequestering of heavy metals in the wetland and the dilution of the wetland acid mine water with uncontaminated flow from upstream. Although biomonitoring results could not be correlated with a specific water quality characteristic, the overall poor water quality was confirmed by the extreme toxic response of the fathead minnow larvae.

The ultimate finding of this study is that the size of this wetland was not adequate to clean up the severe acid mine drainage problem at Jones Branch. Continued lack of maintenance of the wetland in the current state could mean that the wetland itself may pose a threat to the health of Jones Branch. Therefore, it is recommended that steps be taken to improve the pH of the acid mine drainage since enlargement of the wetland would be difficult. This step would provide an environmental for the precipitation of heavy metals, as well as more suitable conditions for metal-metabolizing bacteria. In addition, it would be worthwhile to assess the microbial population of the wetland to ascertain if the appropriate bacteria are present. By providing some routine maintenance to this site, the construct wetland could be effective in improving the water quality in Jones Branch.

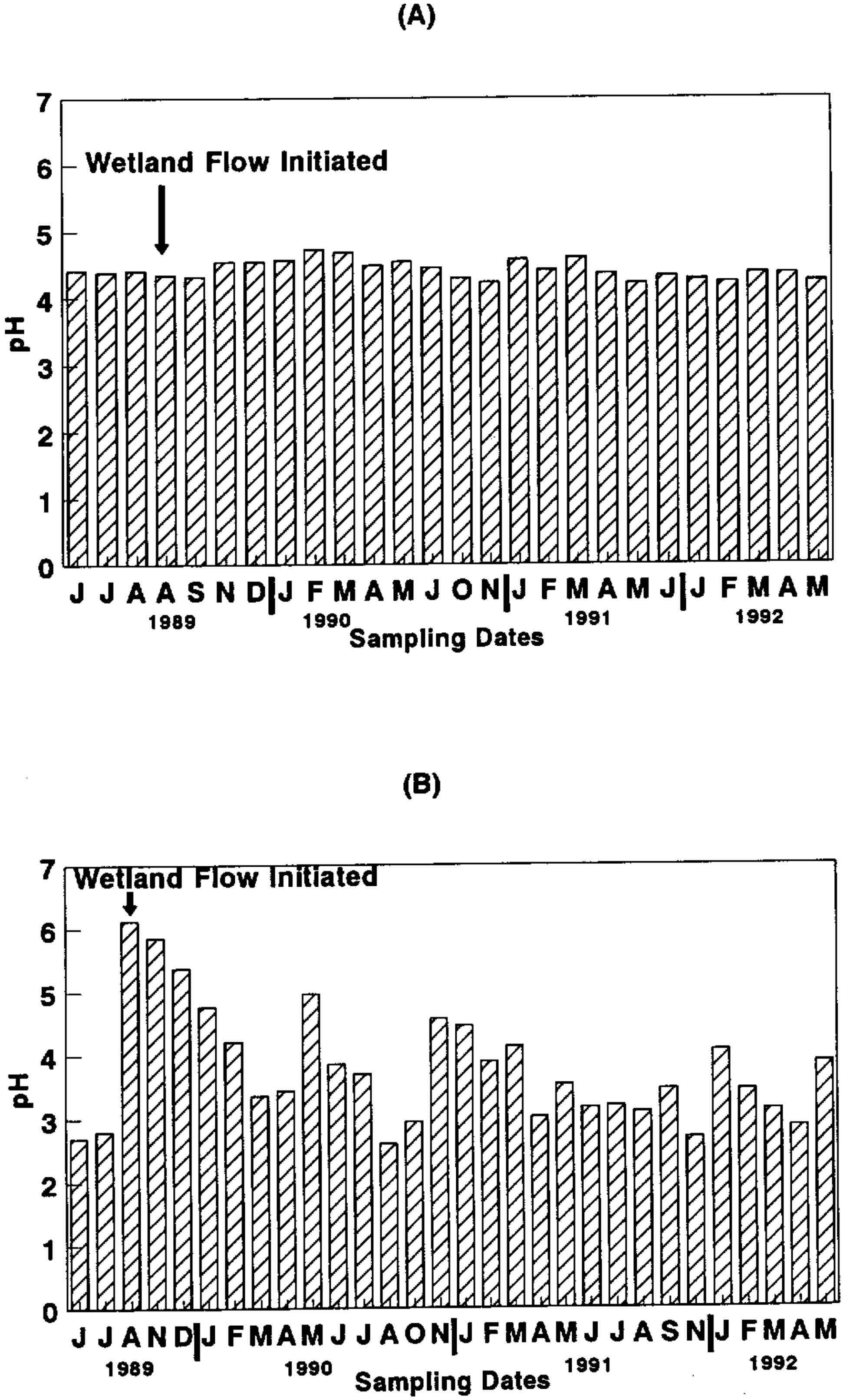


Fig. 2. Comparison of pH levels in Jones Branch above (A) and below (B) the outfall of the constructed wetland treating acid mine drainage.

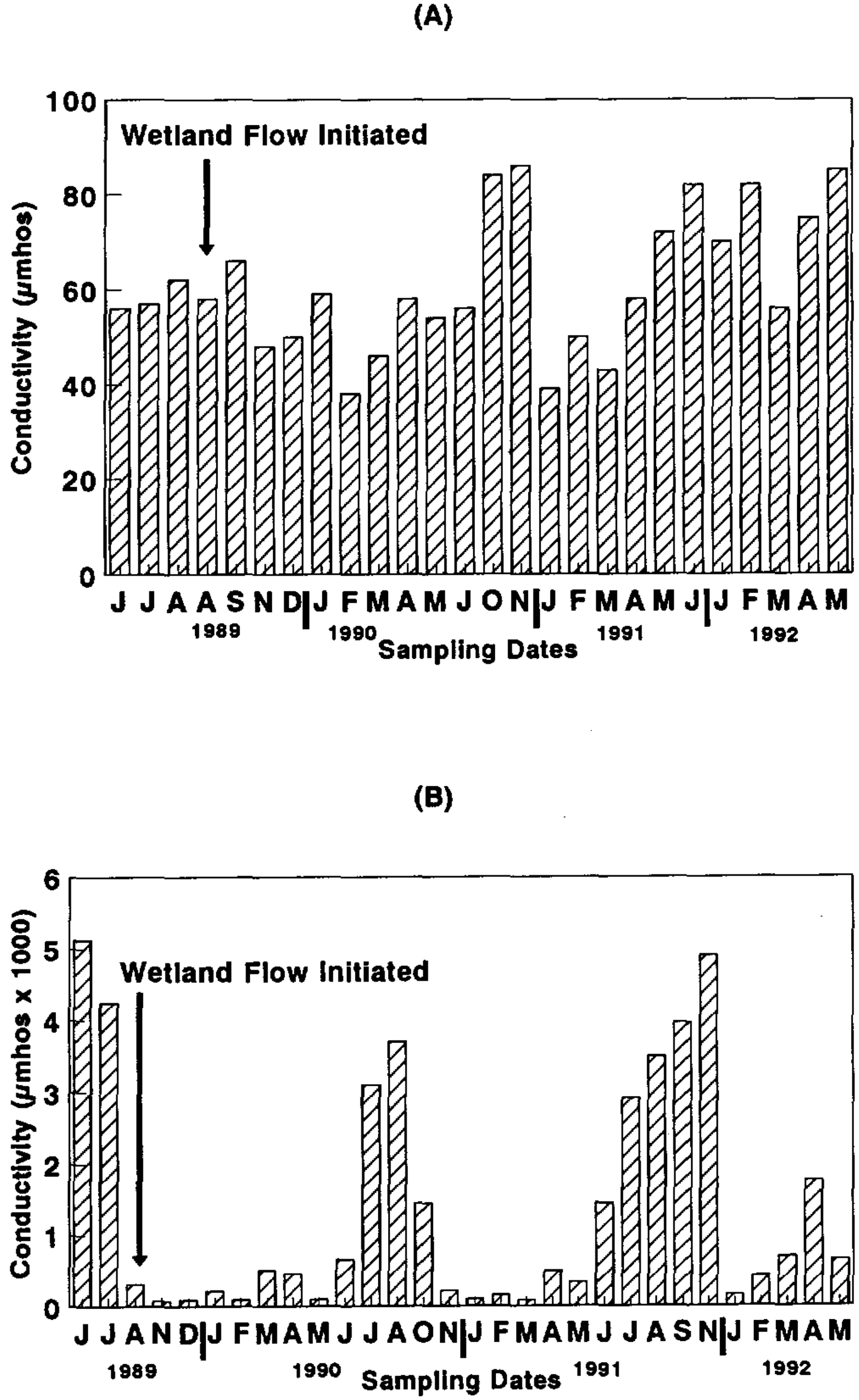


Fig. 3. Comparison of conductivity levels in Jones Branch above (A) and below (B) the outfall of the constructed wetland treating acid mine drainage. Note the difference in conductivity scale between (A) and (B).

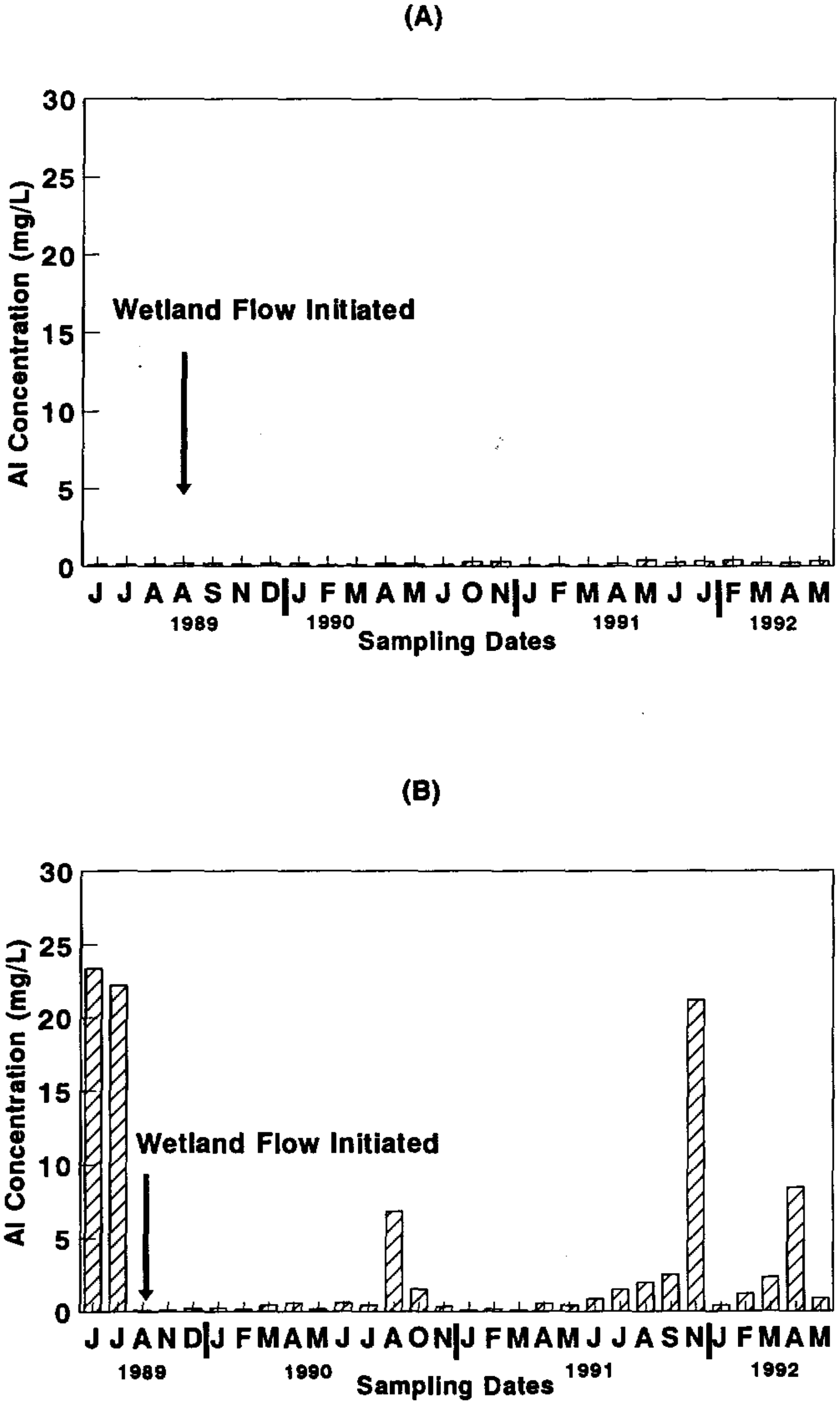


Fig. 4. Comparison of aluminum concentrations in Jones Branch above (A) and below (B) the outfall of the constructed wetland treating acid mine drainage.

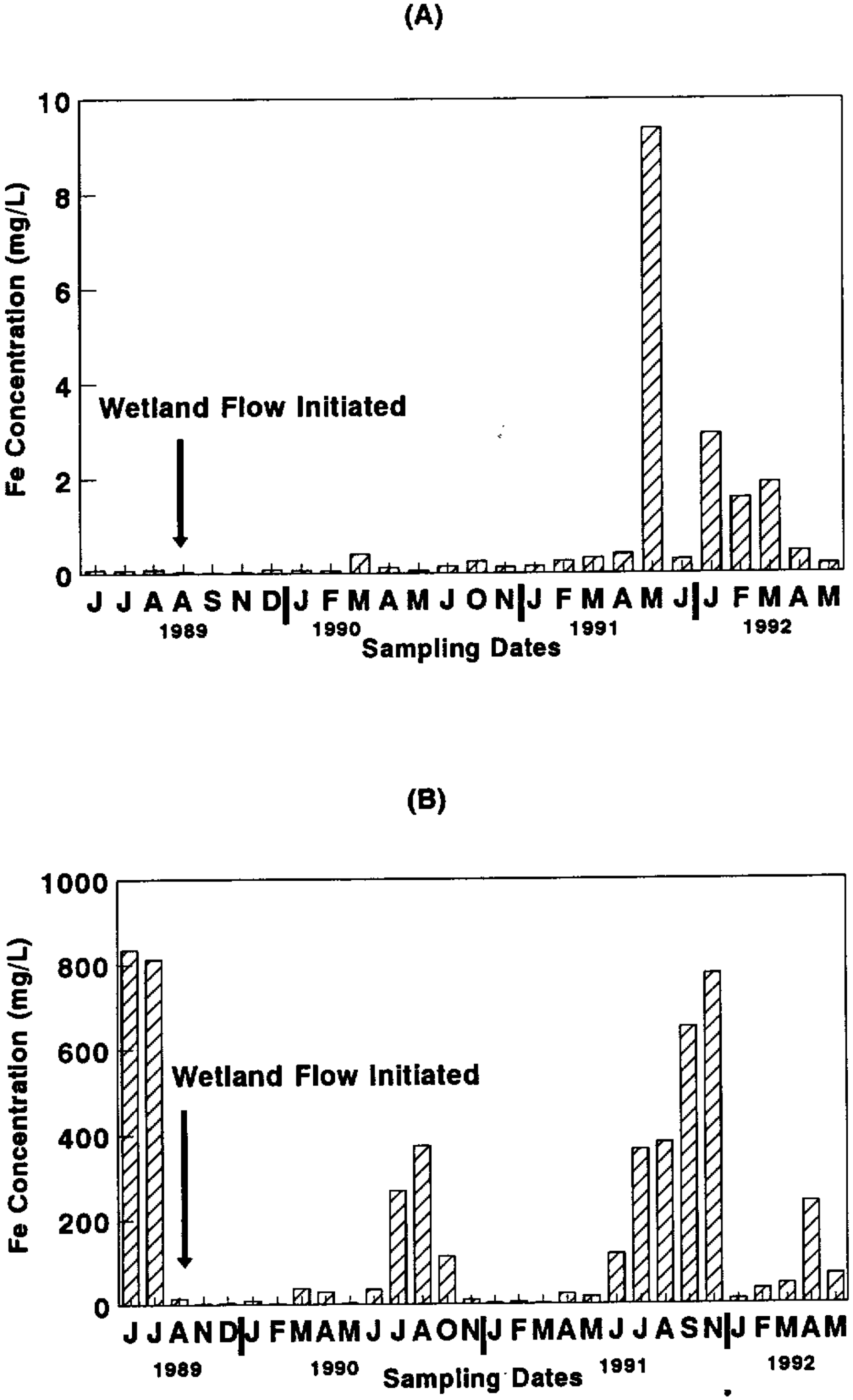


Fig. 5. Comparison of iron concentrations in Jones Branch above (A) and below (B) the outfall of the constructed wetland treating acid mine drainage. Note difference in iron concentration scale between (A) and (B).

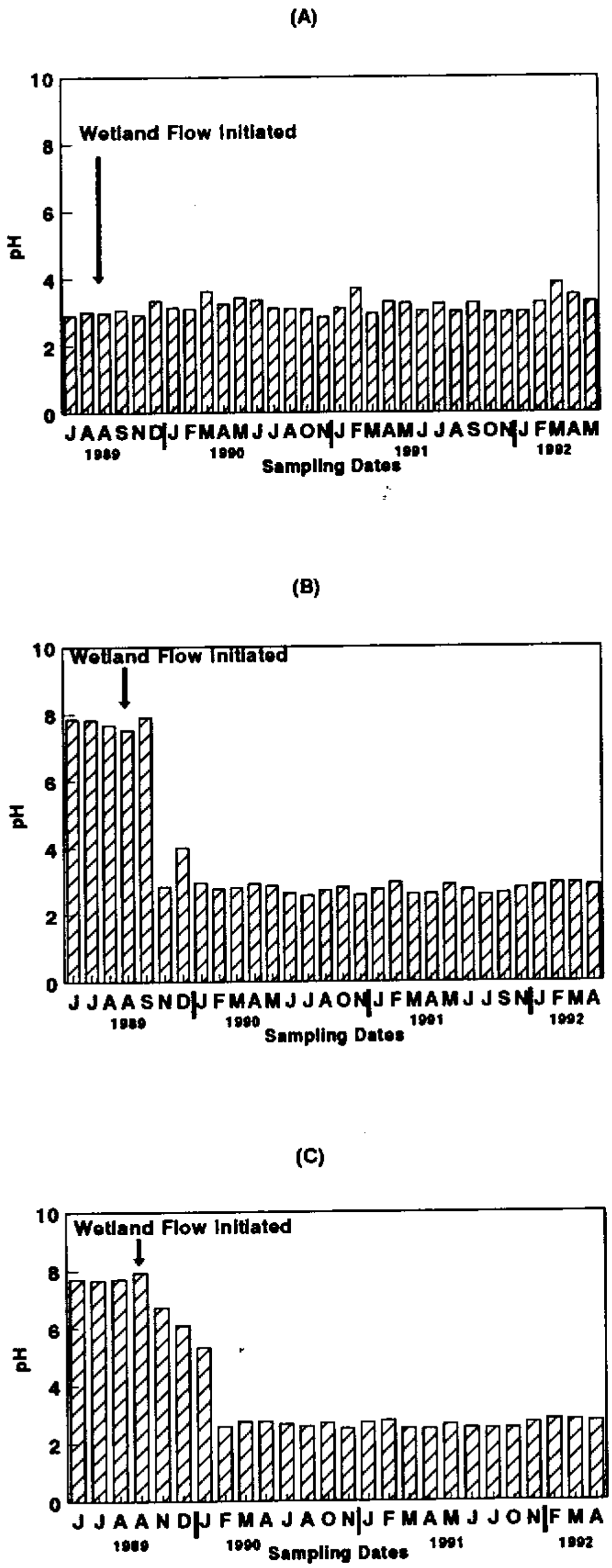


Fig. 6. Comparison of pH in a constructed wetland treating acid mine drainage. Data presented from inlet to wetland from the mine seeps (A), from midway through the wetland (B), and from the outfall (C) to Jones Branch.

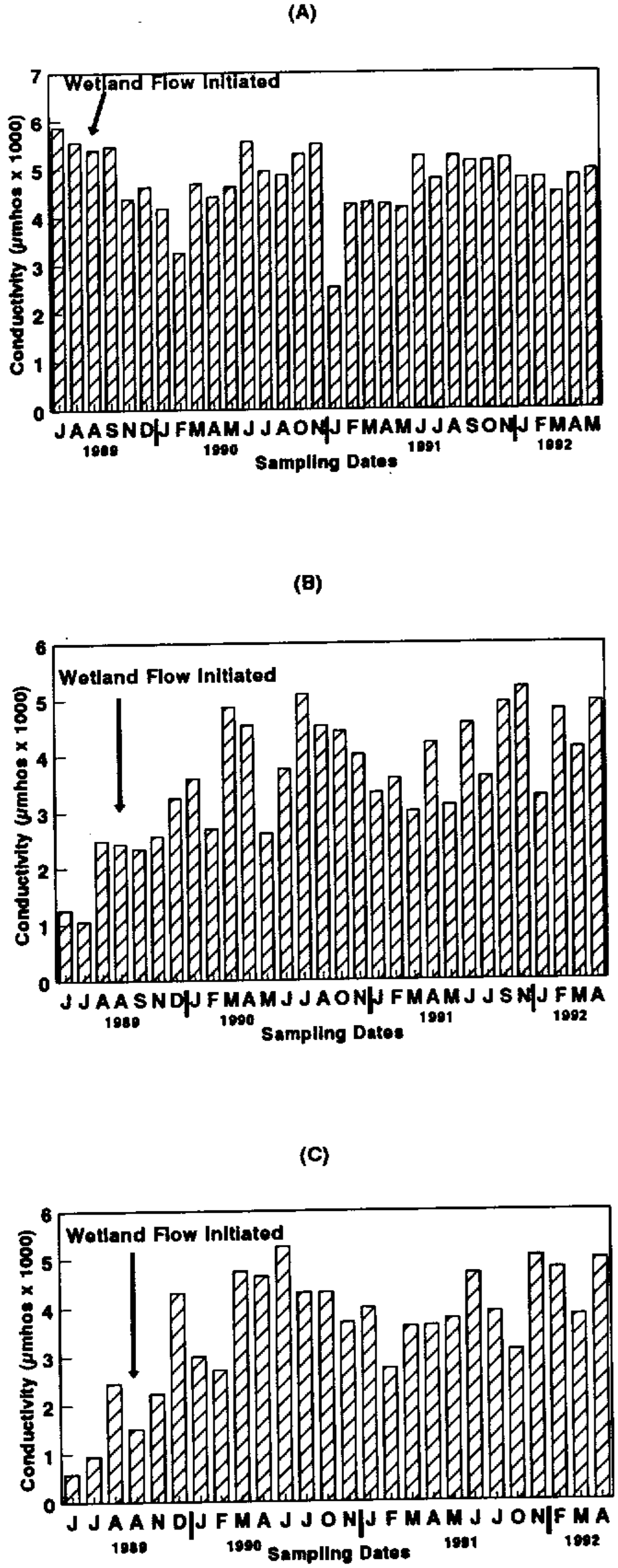


Fig. 7. Comparison of conductivity levels in a constructed wetland treating acid mine drainage. Data presented from inlet to wetland from the mine seeps (A), from midway through the wetland (B), and from the outfall (C) to Jones Branch.

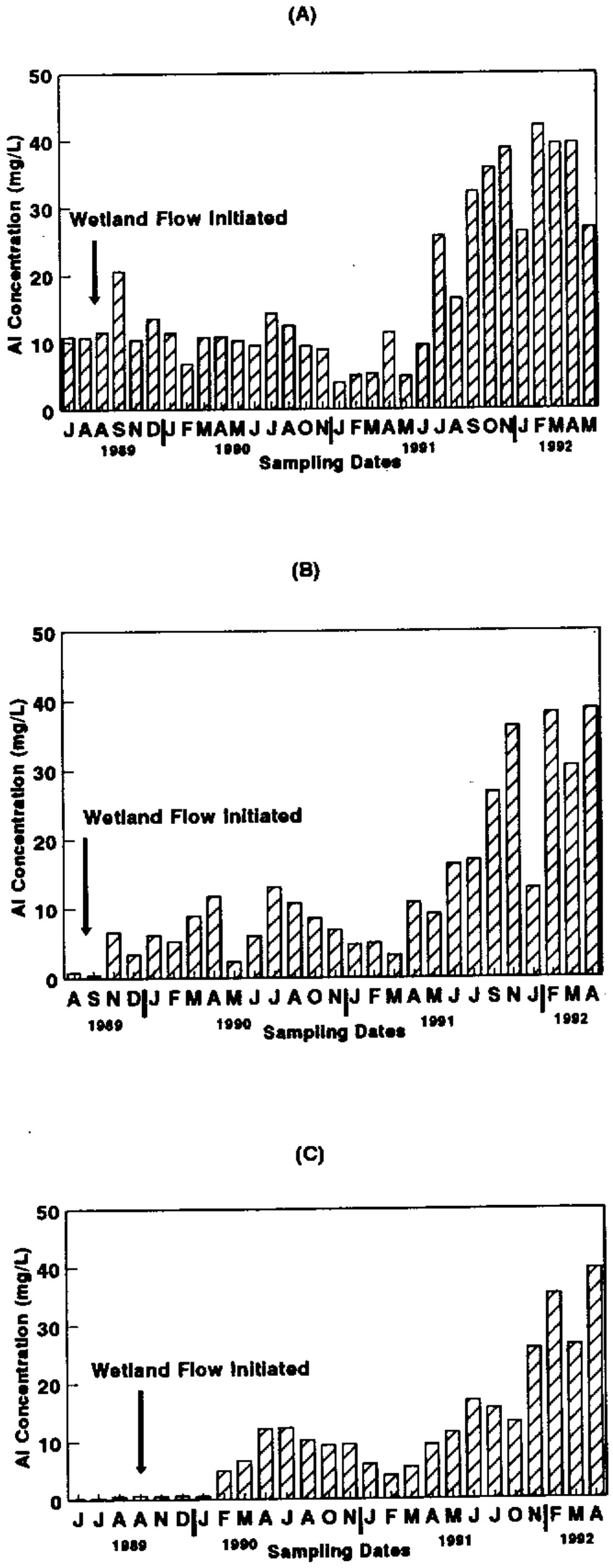


Fig. 8. Comparison of aluminum concentrations in a constructed wetland treating acid mine drainage. Data presented from inlet from the mine seeps (A), from midway through the wetland (B), and from the outfall (C) to Jones Branch.

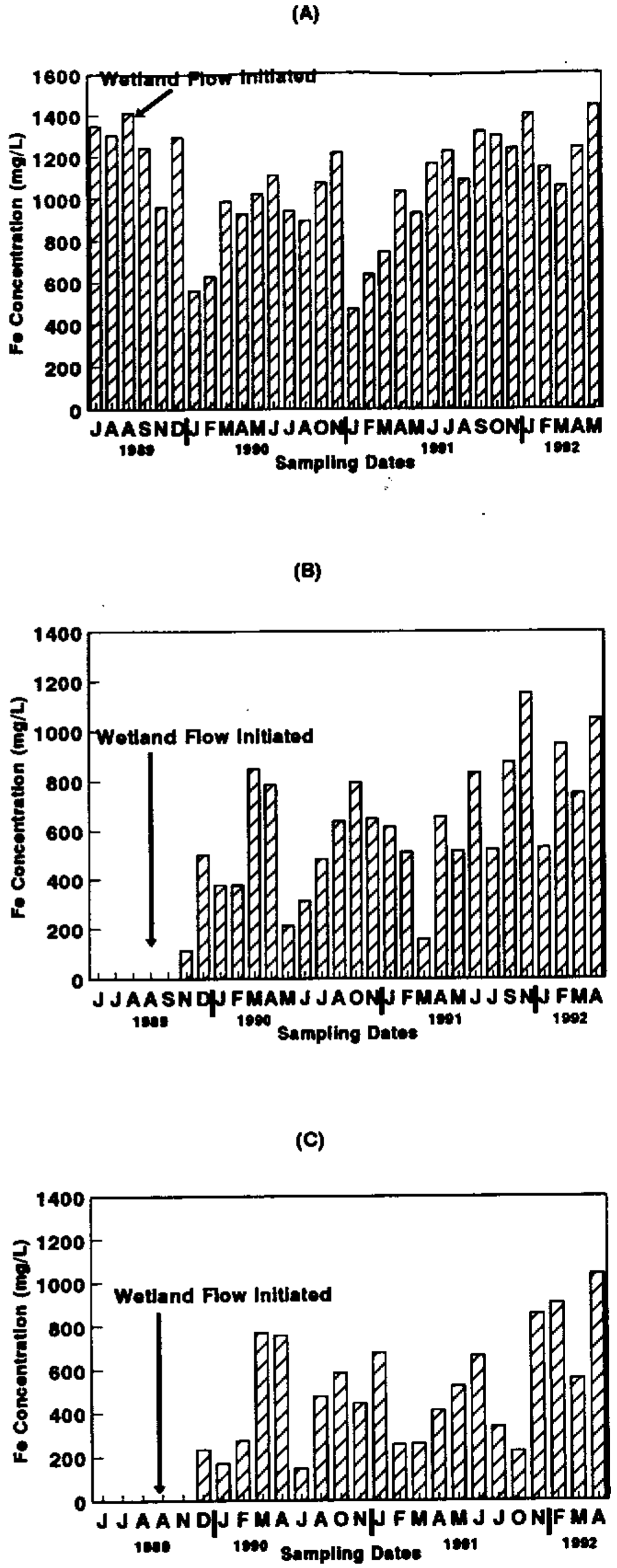


Fig. 9. Comparison of iron concentrations in a constructed wetland treating acid mine drainage. Data presented from inlet to wetland from the mine seeps (A), from midway through the wetland (B), and from the outfall (C) to Jones Branch.

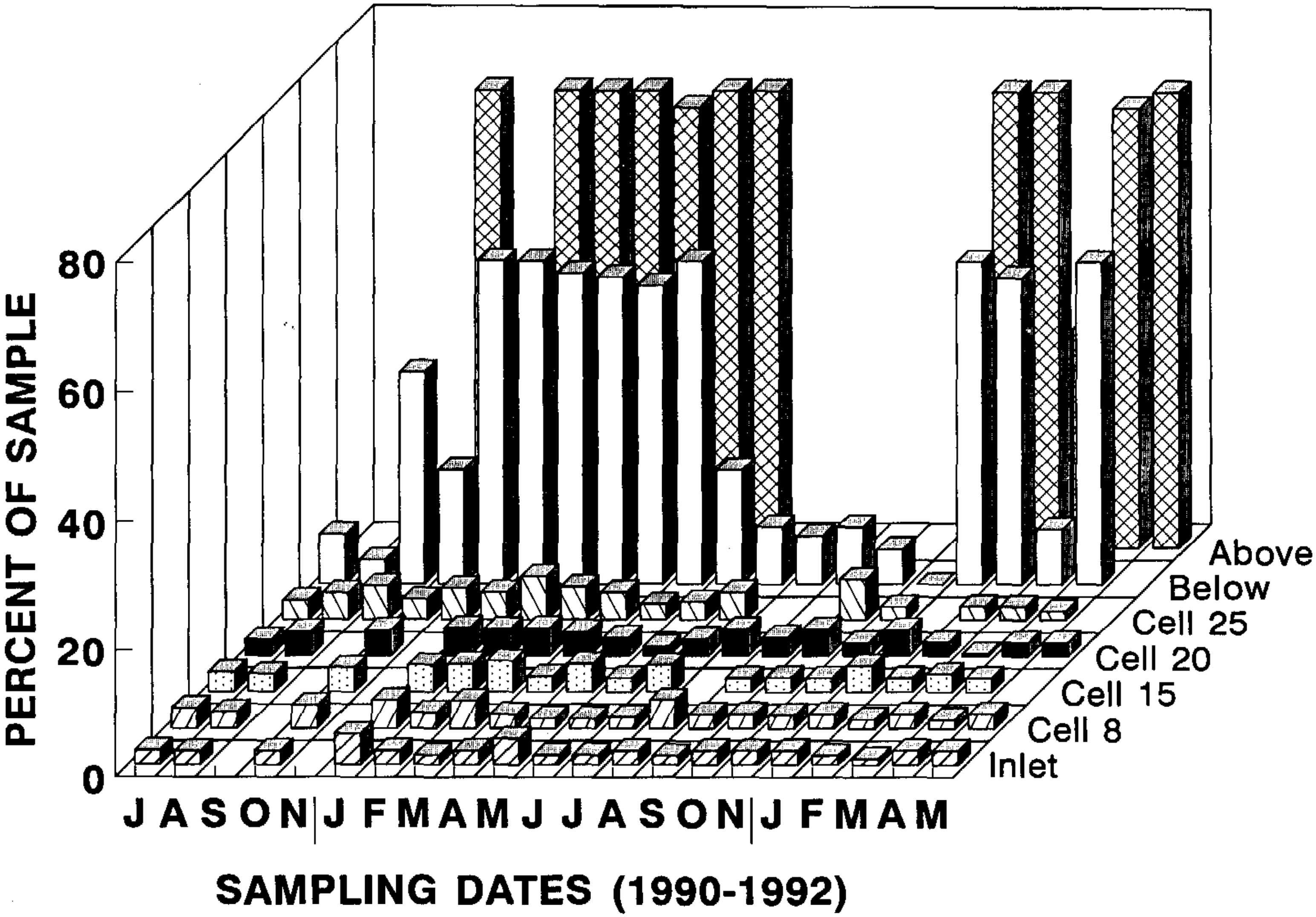


Fig. 10. LC50 values for water from a constructed wetland treating acid mine drainage, determined in a 48-hr static test with 1-3 day fathead minnow larvae.

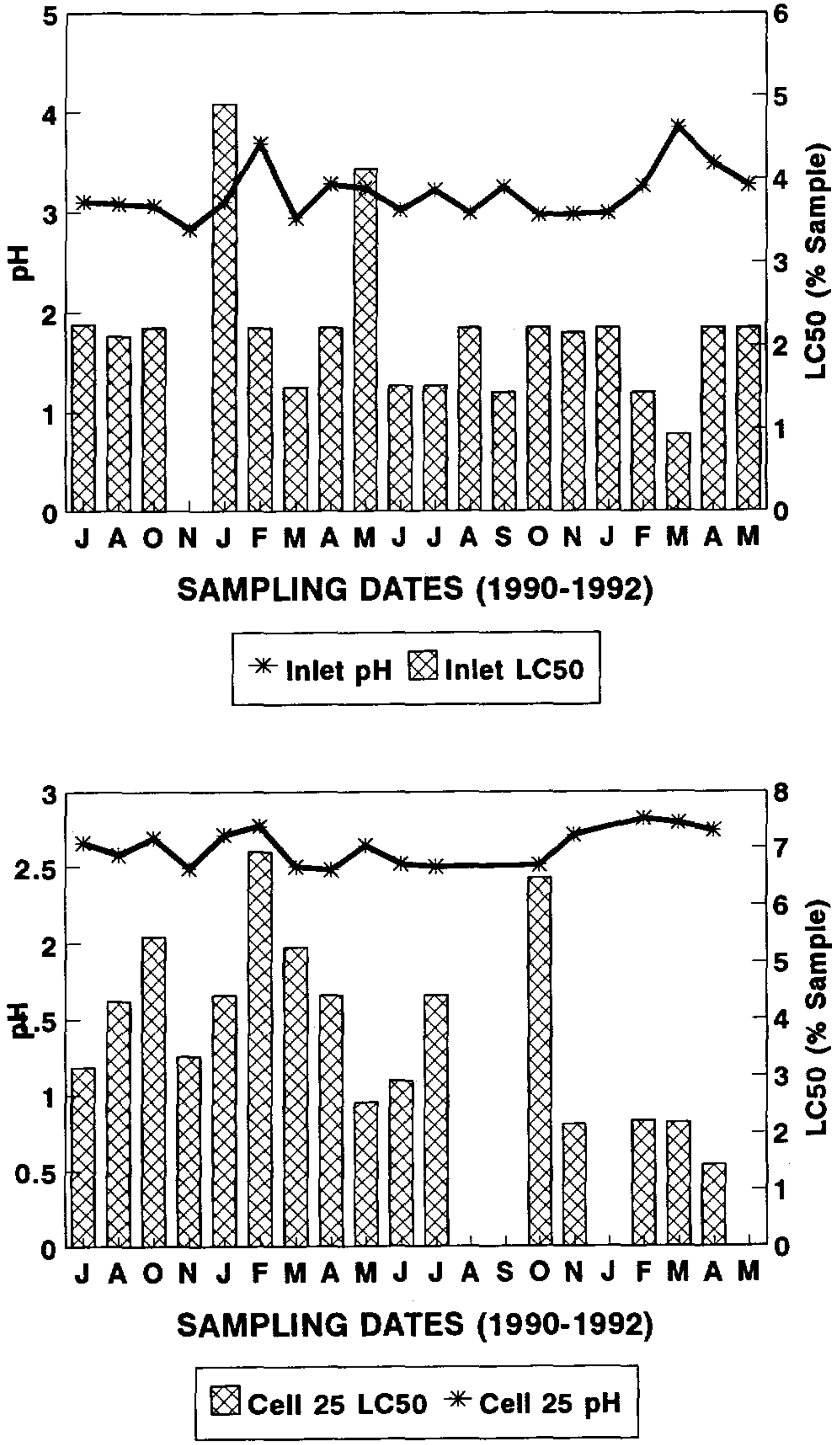


Fig. 11. Comparison of LC50 values with pH levels in inlet and outfall (cell 25) water of a constructed wetland treating acid mine drainage.

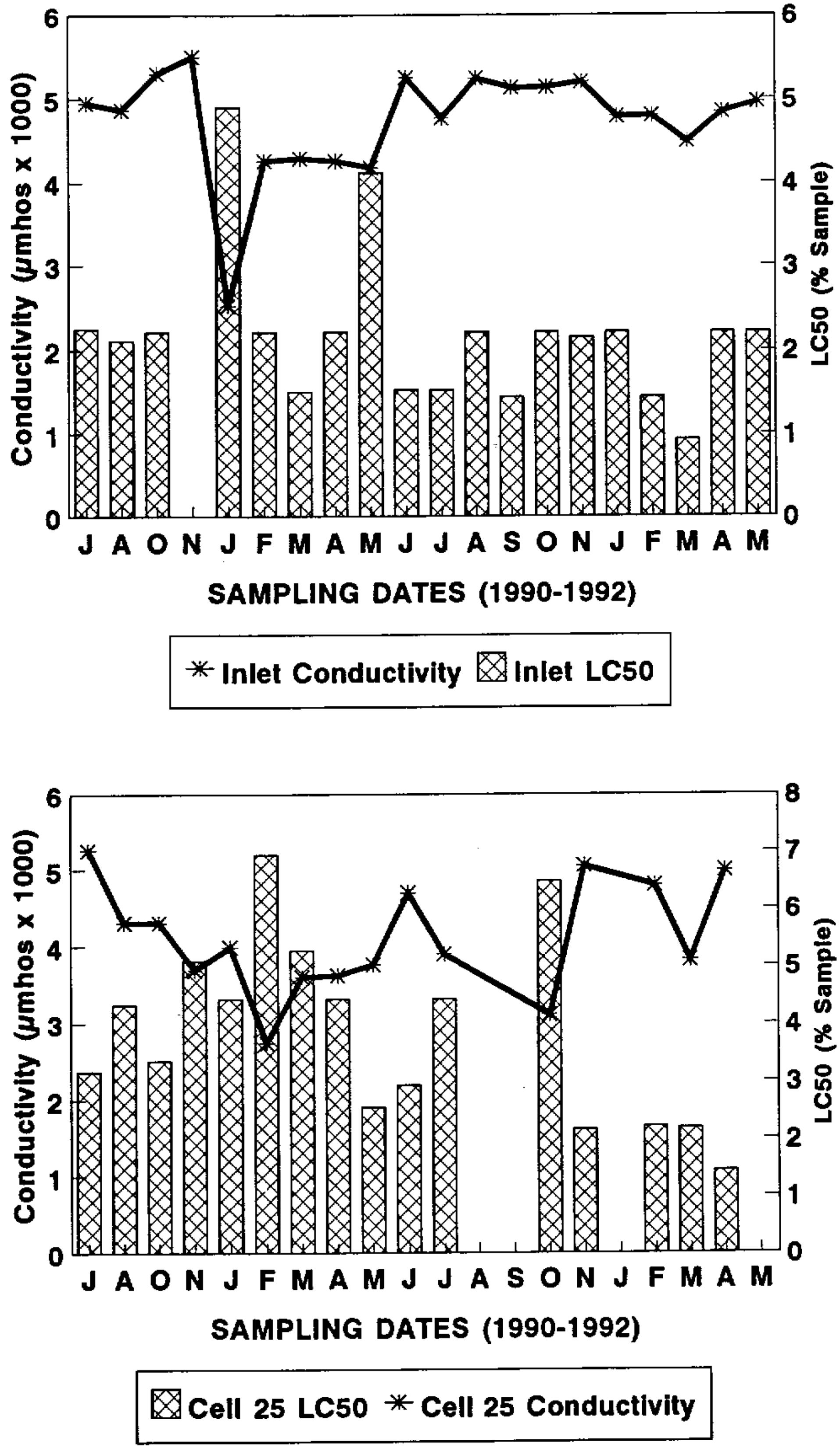


Fig. 12. Comparison of LC50 values with conductivity in inlet and outfall (cell 25) water of a constructed wetland treating acid mine drainage.

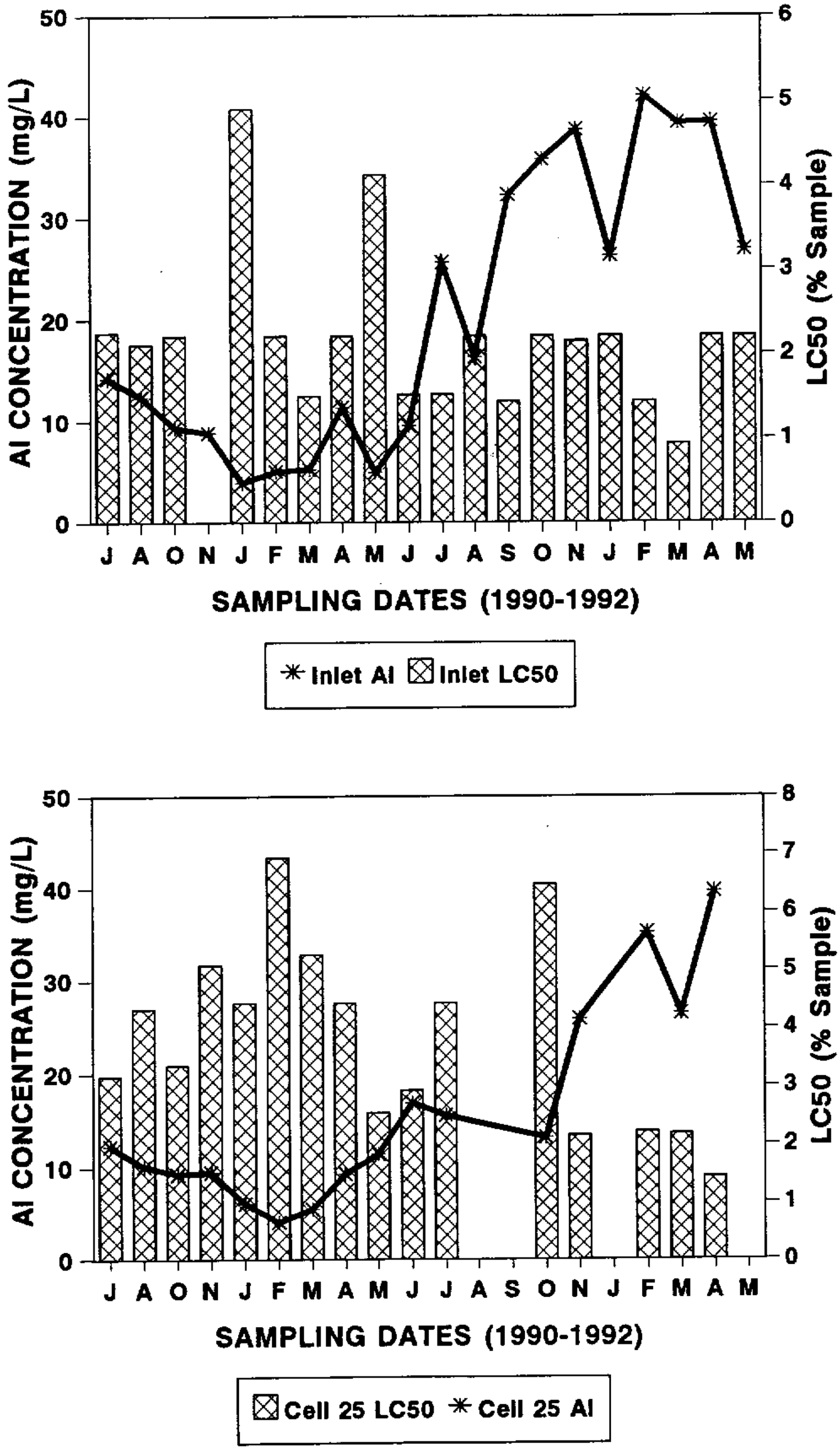


Fig. 13. Comparison of LC50 values with aluminum concentrations in inlet and outfall (cell 25) water of a constructed wetland treating acid mine drainage.

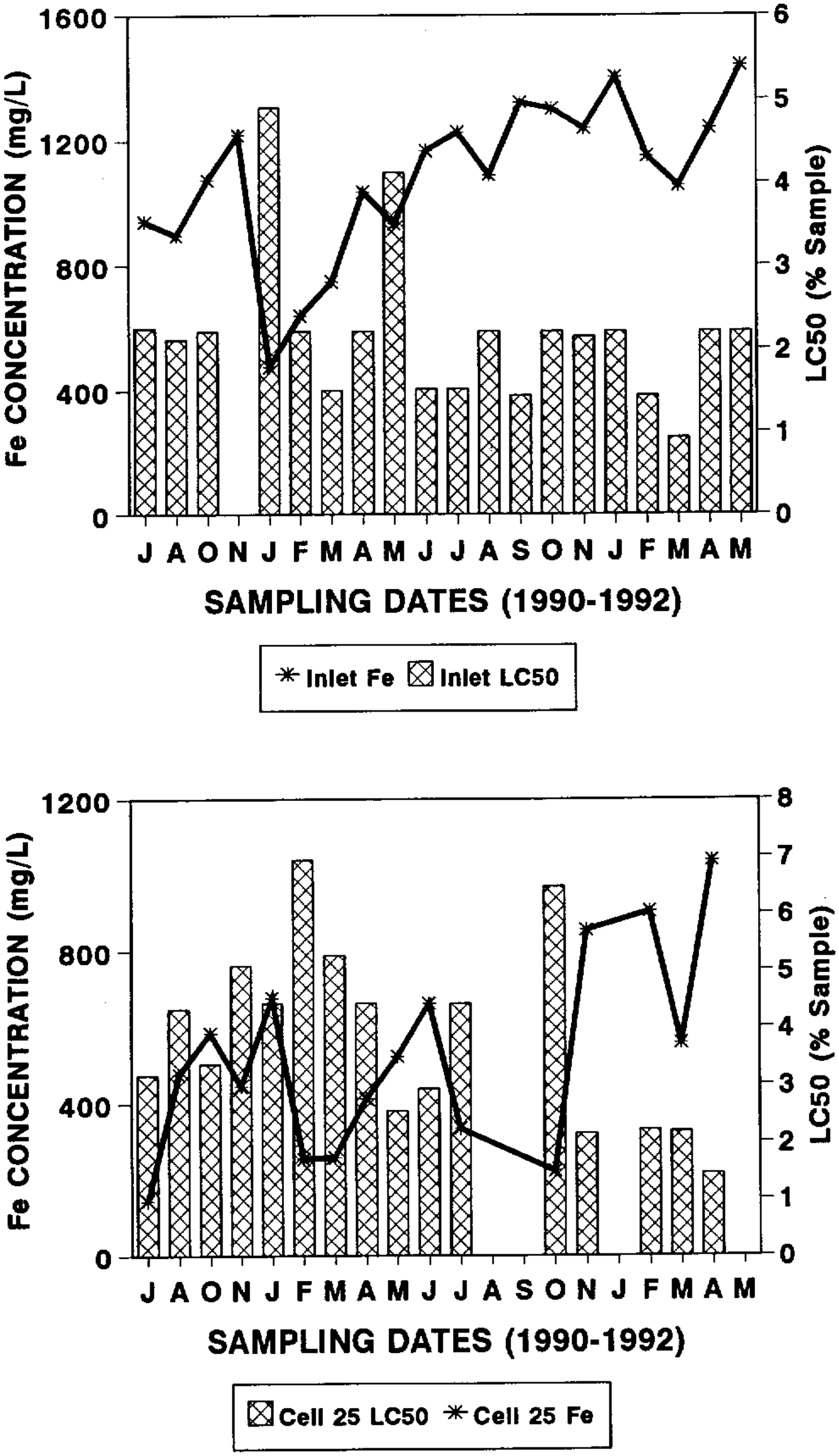


Fig. 14. Comparison of LC50 values with iron concentrations in inlet and outfall (cell 25) water of a constructed wetland treating acid mine drainage.

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APPENDIX

TABLE A-1. **Comparison of water quality characteristics of initial (field) samples of acid mine drainage water from a constructed wetland system with the same samples held for up to 72 hours (lab) at 4°C and used in 48-hour static bioassays with fathead minnow larvae.**

SITE	DATE	WATER SAMP.	pH	COND µmhos	Al mg/L	B mg/L	Co mg/L	Fe mg/L	Mg mg/L	Mn mg/L	Ni mg/L	Pb mg/L	Zn mg/L	SO4 mg/L
Above	2/92	Field	4.22	82	0.39	0.01	0.003	1.57	1.97	0.17	0.01	ND[1]	0.01	26
		Lab	4.10	92	0.32	0.01	0.001	0.10	1.78	0.14	0.01	0.09	0.03	24
	3/92	Field	4.36	56	0.22	0.01	ND	1.91	1.49	0.09	0.003	ND	0.01	29
		Lab	ND	ND	0.18	ND	0.003	0.51	1.44	0.07	ND	ND	0.03	18
	4/92	Field	4.35	75	0.25	0.01	ND	0.45	1.81	0.15	0.01	ND	0.02	21
		Lab	4.42	65	0.23	0.01	0.001	0.06	1.59	0.14	ND	ND	ND	23
	5/92	Field	4.23	85	0.33	0.004	ND	0.18	1.93	0.19	ND	ND	ND	24
		Lab	4.17	85	0.30	0.01	0.001	0.716	2.04	0.20	0.01	0.002	0.04	31
Inlet	2/92	Field	3.26	4800	42.1	1.44	0.64	1150	127	17.5	0.89	2.20	0.76	4200
		Lab	2.68	4860	42.8	1.21	0.44	888	128	17.6	0.89	1.84	0.71	4600
	3/92	Field	3.85	4490	39.4	1.48	0.42	1056	128	17.4	0.87	1.26	0.71	4100
		Lab	ND	ND	39.4	0.81	0.13	1232	126	16.9	0.48	0.50	0.68	4500
	4/92	Field	3.49	4840	39.5	1.54	0.64	1240	129	16.3	0.83	2.22	0.68	4500
		Lab	3.60	4430	42.0	0.72	0.13	1257	127	17.2	0.47	0.32	0.65	4100
	5/92	Field	3.27	4960	26.9	0.78	0.13	1440	148	19.8	0.40	0.51	0.53	4500
		Lab	3.26	4960	25.4	0.78	0.14	1389	145	19.7	0.41	0.40	0.73	4500

TABLE A-1 - continued.

SITE	DATE	WATER SAMP.	pH	COND µmhos	Al mg/L	B mg/L	Co mg/L	Fe mg/L	Mg mg/L	Mn mg/L	Ni mg/L	Pb mg/L	Zn mg/L	SO4 mg/L
Cell 8	2/92	Field	2.89	5000	42.7	1.59	0.74	1001	128	17.5	0.92	2.35	0.84	4400
		Lab	2.56	4420	37.5	1.19	0.43	780	130	17.4	0.81	2.05	0.79	4420
	3/92	Field	3.04	4330	33.7	1.18	0.40	913	114	15.4	0.69	1.27	0.62	3600
		Lab	ND	ND	34.8	0.76	0.11	1060	115	15.5	0.42	0.46	0.72	3900
	4/92	Field	2.94	4980	40.0	1.45	0.60	1048	120	16.5	0.77	2.05	0.67	4200
		Lab	2.93	4480	40.2	0.71	0.14	1172	122	16.7	0.48	0.32	0.66	4100
	5/92	Field	2.69	4720	36.8	0.81	0.13	961	133	17.7	0.47	0.42	0.61	4000
		Lab	2.67	4720	36.4	0.74	0.13	1179	137	17.9	0.46	0.38	0.69	4100
Cell 15	2/92	Field	2.93	4800	38.2	1.45	0.67	947	119	16.3	0.83	2.13	0.74	4300
		Lab	2.61	4280	42.5	1.25	0.45	849	129	17.7	0.92	1.88	0.73	4100
	3/92	Field	2.93	4120	30.5	1.10	0.37	750	104	14.1	0.64	1.19	0.56	3400
		Lab	ND	ND	31.7	0.68	0.10	970	105	14.2	0.39	0.43	0.58	3800
	4/92	Field	2.86	4950	38.7	1.59	0.59	1048	116	16.0	0.85	2.37	0.66	4400
		Lab	3.01	4600	39.4	0.70	0.13	1116	123	16.6	0.47	0.31	0.64	4000
Cell 20	2/92	Field	2.88	4800	38.6	1.52	0.74	891	126	17.1	0.84	2.22	0.79	4300
		Lab	2.70	4080	37.5	1.16	0.42	813	119	16.4	0.84	1.73	0.67	3800
	3/92	Field	2.83	3950	28.0	1.06	0.35	651	99.6	13.4	0.61	1.12	0.52	4600
		Lab	ND	ND	29.3	0.66	0.10	827	102	13.6	0.37	0.65	0.53	3400
	4/92	Field	2.80	4980	40.0	1.55	0.75	1048	118	16.1	0.78	2.32	0.66	4600
		Lab	2.88	4570	37.9	0.69	0.13	1086	122	16.4	0.47	0.30	0.65	4100
	5/92	Field	2.60	4680	35.8	0.81	0.13	803	125	16.8	0.45	0.37	0.63	4000
		Lab	2.56	4680	37.9	0.70	0.12	942	133	17.7	0.47	0.37	1.63	4000

TABLE A-1 - continued.

SITE	DATE	WATER SAMP.	pH	COND µmhos	Al mg/L	B mg/L	Co mg/L	Fe mg/L	Mg mg/L	Mn mg/L	Ni mg/L	Pb mg/L	Zn mg/L	SO4 mg/L
Out-let	2/92	Field	2.82	4800	35.3	1.42	0.49	905	121	17.8	0.79	1.42	0.76	4400
		Lab	2.61	4210	39.4	1.21	0.45	770	127	17.4	0.84	1.91	0.72	3900
	3/92	Field	2.79	3820	26.5	1.10	0.37	558	97.3	13.1	0.60	1.16	0.53	3100
		Lab	ND	ND	28.1	0.60	0.09	732	99.6	13.2	0.36	0.63	0.54	3500
	4/92	Field	2.74	4990	39.7	1.53	0.66	1038	135	16.3	0.79	2.08	0.70	4500
		Lab	2.78	4640	39.3	0.69	0.12	1008	124	16.8	0.46	0.30	0.64	3900
Below	2/92	Field	3.45	420	1.18	0.06	0.05	34.9	6.77	0.93	0.17	0.08	0.01	170
		Lab	3.03	529	1.22	0.04	0.03	40.5	6.54	0.90	0.03	0.06	0.05	190
	3/92	Field	3.14	692	2.28	0.09	0.04	46.4	8.79	1.20	0.05	0.10	0.03	260
		Lab	ND	ND	2.22	0.05	0.01	47.7	9.01	1.14	0.03	0.05	0.04	310
	4/92	Field	2.87	1760	8.45	0.38	0.17	240	29.8	3.96	0.19	0.51	0.18	1000
		Lab	2.93	1530	8.54	0.17	0.03	202	28.1	3.95	0.10	0.05	0.12	826
	5/92	Field	3.88	647	0.99	0.06	0.01	69.3	13.7	2.52	0.02	0.06	0.002	340
		Lab	3.92	647	0.99	0.06	0.02	61.9	13.2	2.52	0.03	0.04	0.04	340

[1] ND = not determined