MID-ATLANTIC REGION

RESEARCH/RESOURCES MANAGEMENT REPORT

EVALUATION AND INSTALLATION OF A WETLAND FOR TREATMENT OF ACID MINE DRAINAGE AT FRIENDSHIP HILL NATIONAL HISTORIC SITE

U.S. DEPARTMENT OF THE INTERIOR

NATIONAL PARK SERVICE

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EVALUATION AND INSTALLATION OF A WETLAND FOR TREATMENT OF ACID MINE DRAINAGE AT FRIENDSHIP HILL NATIONAL HISTORIC SITE

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INTRODUCTION

The following is a brief chronology of the Bureau's research efforts to design a constructed wetland system to treat acid mine drainage (AMD) at the Friendship Hill National Historic Site.

March 1985: An Interagency Agreement was established between the Bureau of Mines and the National Park Service to evaluate alternative methods to mitigate AMD that flows in Ice Pond Run.

June 1985: A report "Alternative Methods to Reduce AMD Pollution in a Stream at Friendship Hill National Historic Site" was prepared that analyzed the AMD problem and presented several alternatives available to treat the AMD. These alternatives included mine sealing, infiltration control, daylighting, oxidation inhibitors, conventional water treatment, and wetlands.

August 1985: An Interagency Agreement was established between the Bureau of Mines and the National Park Service to perform research at Friendship Hill National Historic Site and evaluate the feasibility of using a constructed wetland to treat AMD from Ice Pond Run.

August 1985 - January 1986: Preliminary experiments treating Ice Pond Run AMD using an on-site wetland simulator (Portabog) were performed to test the feasibility of a wetland treatment process. Baseline flows of Ice Pond Run and its variations in water quality were established.

March-June 1986: The designs for the first pilot-scale wetland were developed, reviewed, and prepared for execution.

June 1986: A Project Status Report was prepared that described the general soil conditions of the proposed site for the pilot-scale wetland, the tolerance of various wetland vegetation to AMD, the results of the Portabog experiments, and the proposed design for the first pilot-scale wetland.

Summer 1986: The first pilot-scale wetland was constructed and planted with cattails and other assorted wetland plants tolerant of AMD.

September 1986: Water began to flow through the pilot-scale wetland.

November 1986: Forty thousand lbs. of live Sphagnum moss was planted in the upper portion of the wetland.

June 1987: The first pilot-scale wetland design ceased to be effective in the treatment of AMD.

May 1988: A Project Status Report was prepared that described the performance of the first pilot-scale wetland in considerable detail. Also prepared was a proposal for the second pilot-scale wetland based on the results of the first one, as a summary of what the Bureau had learned concerning the AMD mitigation mechanisms from its research at other wetlands constructed to treat AMD. The design of the second pilot-scale wetland incorporated a novel feature to promote bacterial sulfate reduction using induced subsurface flow.

August 1987: Operation of the first pilot-scale wetland was terminated.

May - July 1988: Designs for the second pilot-scale wetland were developed, reviewed, and prepared for execution.

July-October 1988: The second pilot-scale wetland was constructed on the site of the first one. Planting was completed in early October.

November 1988: The second pilot-scale wetland was put into full operation during the first week of November. The full operation included the use of the novel subsurface flow capability.

February 1989: A Status Report was prepared that described the construction and start-up of the second pilot-scale wetland with preliminary observations on its performance.

August 1989: Cattail growth was well-established in the pilot-scale wetland. Engineering revisions were made to overcome operation and maintenance problems with the original subsurface flow system. This system caused significant differences in wetland performance relative to convention wetland designs. A Project Status Report was prepared that detailed the performance of the second pilot-scale wetland and presented the results of intensive monitoring efforts.

THE FIRST PILOT-SCALE WETLAND EXPERIMENT

Overview

The wetland construction design selected for Friendship Hill was intended to minimize construction costs yet result in sufficient vegetative growth to treat Ice Pond Run AMD. Organic substrate material in the form of readily available hay bales was used for the two Sphagnum plots. Fertilizer pellets were intended to support vegetation in the remainder of the wetland system. Sphagnum was chosen for use in the wetland because, at the time, it was the plant considered most effective for treatment of heavily-contaminated AMD. Recent data and field observations at Friendship Hill and other wetland sites have shown that Sphagnum has a limited treatment capacity for moderate to strong AMD. The limited duration performance of the Sphagnum sections at Friendship Hill bears this out. Typha was chosen for the same reasons as Sphagnum and is still considered a viable plant type to be planted in wetlands that receive various strengths of AMD. Several constructed Typha wetlands currently exist that successfully treat AMD similar to that of Ice Pond Run, at least in the short-term. However, a significant difference between these sites and the pilot-scale wetland is that the Typha was planted in a rich organic substrate that had alkaline materials incorporated in it. The role of alkaline substrates in Typha wetlands is not well understood. In fact, the numerous processes that constitute the wetland AMD treatment system have only recently begun to be researched in detail.

The first pilot-scale wetland at Friendship Hill removed iron and sulfate for about a five month period before it ceased to perform effectively. During that time, the Sphagnum sections generally removed the majority of the sulfate entering the wetland and the Typha sections removed the majority of the iron. We believe that in addition to the stressful conditions under which the Sphagnum was established, the AMD treatment capacity of the Sphagnum was consumed faster than the Sphagnum was able to regenerate additional capacity through growth. The Typha were not able to become firmly established due to the strength of the AMD and the absence of a suitable rooting substrate.

Construction of First Pilot-Scale Wetland

Construction diagrams of the pilot-scale wetland are shown in Figures 1-3. Figure 1 is a plan view, Figure 2 is a longitudinal cross-section of the pilot-scale wetland, and Figure 3 is the plan view with the planting scheme overlain on it. The wetland was constructed in mid-summer of 1986 by Bureau of Mines and National Park Service personnel. An excavation was made 316 ft long by 40 to 70 ft wide, encompassing a total of about 15,000 square feet. The flow through the wetland was 20 gal/min, although the area of the wetland could, based on accepted wetland construction practice at that time, treat about 30 gal/min. The initial depth of the wetland was set between 0.7 and 1.0 ft. The base of the excavation, on natural clay, provided an average 1% grade from inflow to outflow. Seven sets of boards were placed across the width of the wetland to separate it into seven plots and regulate water depth. Water flowed between plots by running over the boards.

Above the wetland, a dam was built across Ice Pond Run to provide a pool from which water could be diverted into the wetland. Flow ran through an adjustable sluice gate, into 320 ft of buried 10-inch plastic pipe, and emptied into plot 1. A 24-inch pipe was placed down-gradient from the last set of boards, to channel the outflow from the system for sampling and flow measurement. The dam performed well until Spring 1987. During severe rainstorms in early April, 1987, serious erosion occurred around and under the dam. Flow into the wetland was not lost, but concerns about the effects of further erosion prompted repair efforts. In August, 1987, the pool was deepened and the dam increased in size. At the same time, a concrete gauging flume was built below the wetland. Outflow water (from plot 7) flowed through this flume.

Locally collected Typha were planted in late August, 1986, in plots 1, 4, 5, 6, and 7. Plants were collected from a freshwater seepage area and from a stand of volunteer Typha growing in a local coal yard. Individual plants consisted of roots and emergent leaves, and were planted on 3 ft centers directly in the clay base of the wetland.

In September 1986, a small section of plot 3 was planted with a variety of emergent aquatic plants obtained from a nursery in Wisconsin. These included softstem and hardstem bullrushes, three species of Carex, wild iris, and bluestem jointgrass (figure 3).

On November 13, 1986, plots 2 and 3 were planted with 40,000 lb. of live Sphagnum purchased from a Wisconsin peat moss quarry. The moss was purported to be dominantly S. recurvum. Plot 2 and half of plot 3 had been previously filled with bales of hay and the moss was set directly on top of the inundated bales. In areas with no hay bales, the moss itself was used to build up the substrate for its optimal growth above the water surface.

The only amendments made to the wetland vegetation were slow-release fertilizer tablets buried in the clay around each cattail in April, 1987.

Operation and Maintenance

The pilot-scale wetland became operational in September, 1986, when water was diverted into the system. Maintenance activity consisted mainly of water flow and depth regulation. Water depths in the cattail sections were initially too high for good cattail growth and treatment performance. Consequently, 6-inch pipes were placed at each end of board D (see Figure 1) during October, 1986. The water was reduced to a level 0.3 to 0.5 ft deep. A weir was installed in the outflow pipe in December 1986, to allow periodic flow measurement prior to the installation of an outflow flume and water level recorder. Notches were made in the plot-separation boards to lower water levels in the wetland, since the pipes had caused channelized flow in the plots. A weir was installed in the inflow pipe in August, 1987, after it was determined that the sluice gate design did not permit the use of standard equations for flow calculation.

Performance

AMD flow was determined weekly after December 1986, by reading a pipe weir at the wetland outflow and weekly after July 1987, by reading a pipe weir at the inflow. During late August and September 1987, inflow and outflow rates were approximately equal. Thus, it is reasonable to assume that inflow rates were approximately equal to measured outflows for earlier months.

Flow through the wetland was quite variable, ranging from about 600 to over 200,000 gallons per day (gpd), or 0.4 to over 139 gal/min. The average flow over the October 1986 to September 1987 period was 36,000 gpd (25 gal/min). The wetland was designed to treat about 43,000 gpd of flow. Extremely high flows resulted when Ice Pond Run flowed over the sluice gate after rain storms before the reconstruction of the Ice Pond Run diversion and the height of the sluice gate was increased.

Water samples were collected weekly at the inflow pipe (WS01), at board C separating the Sphagnum and Typha plots (WS02), and at the outflow pipe (WS03). Water pH, which averaged 2.8 at the inflow, was affected minimally by the wetland. Significant differences between the inflow and outflow chemical data were observed for iron, sulfate, aluminum and manganese concentrations. Because the largest decreases were in iron concentrations, and the patterns of removal generally paralleled those of manganese and aluminum, only iron removal will be discussed in detail in this report.

Five sets of water samples were collected in summer of 1986, before the Sphagnum was planted. During this period, plots 2 and 3 contained hay bales, and plots 4-7 had been planted with Typha. Minor, but significant changes in water chemistry were apparent on these five weeks. Outflow iron concentrations averaged 20 mg/L less than inflow. Most of this decrease occurred in the Typha plots.

During the four months following the planting of Sphagnum in the fall of 1986, iron concentrations at the outflow averaged 79 mg/L less than the inflow. This represented a 52% decrease in total iron. The Sphagnum plots removed, on average, 32 mg/L. In April and May, 1987, total removal of iron by the wetland averaged about 31 mg/L, a 17% decrease in total iron. This was partly due to very high flow rates in early April, but even during moderate flow periods, removal was less than earlier in the year. Of the 31 mg/L removed, 19 mg/L was removed by the *Sphagnum* plots.

After June 5, 1987, concentrations of iron and all other metals were not decreased by the wetland. On one day, August 14, iron concentrations in the outflow were 130 mg/L higher than the inflow indicating remobilization of iron previously deposited in the wetland.

Changes in the oxidation state of dissolved iron occurred through the wetland. Ninety-seven percent of the iron in the inflow was in the ferric form (Fe^{3+}), while the average of the outflow was 70% ferric iron. Virtually all of the iron reduction occurred in the *Sphagnum* plots, presumably in the submerged hay bales where anaerobic conditions may have been present. When flow rates were low, much of the reduced iron was reoxidized in plots 4-7. When flows were high, less oxidation of iron was observed in these plots. Removal of total iron in the *Typha* plots was correlated strongly with the amount of reduced iron entering the plots (correlation coefficient $r=0.86$). This suggests that the primary mode of iron removal in these sparsely vegetated plots was oxidation and sedimentation of reduced iron, probably aided by iron-oxidizing bacteria such as *Thiobacillus*.

During the short period of effective wetland performance, more than half of the sulfate removal observed occurred in the *Sphagnum* plots. The most likely mechanism for this removal was bacterial sulfate reduction. The environmental conditions produced by the slow flow of sulfate-rich water through hay bales are ideal for dissimilatory sulfate reduction by bacteria such as *Desulfovibrio*. During this process, sulfate is converted to hydrogen sulfide, which either reacts with dissolved metals and precipitates, or bubbles out of the wetland. H_2S odors were detected occasionally in the *Sphagnum* sections, and submerged hay bales were covered with black residues identified as iron sulfide compounds.

During the winter and spring of 1986/87, the *Sphagnum* plots were green. However, in May 1987, the green color began to fade, and by mid-July the *Sphagnum* was brown. During this decline, live plants were often covered with white crystals that, upon analysis, proved to be gypsum ($CaSO_4 \cdot 2H_2O$). In late July, samples of the brown moss were collected and transplanted to fresh water in a laboratory. After a month, no development of green color had occurred, indicating that the moss was dead. Samples of the dead moss were extracted with a sodium pyrophosphate solution and were found to contain 18,000 ppm of organically-bound iron, in contrast to an original content of 1500 ppm. This amount of accumulated iron is similar to those reported by Wieder and Lang (1982) for peat from a natural wetland that had received low level AMD for about 20 years. Therefore, 18,000 ppm may represent a saturation level for iron accumulation by *Sphagnum*.

Over 90% of the *Typha* planted sent up shoots in spring of 1987. However, they began to decline in late spring, and by August, only 20% of the plants remained alive. It was hoped that the plants would completely fill the plots by mid-summer, as had occurred at many other sites. However, very few of the plants sent up new shoots, and little filling-in of the area around living plants occurred. Survival of *Typha* was highest in plot 4 and lowest in plots 6 and 7. Plant mortality may have been related to water depth, which was greater than 0.7 ft. in plots 6 and 7, and generally less than 0.5 ft. in plot 4. The lack of a sufficient rooting substrate and the strength of the AMD probably further stressed the transplanted Typha.

Results of the pilot-scale experiment indicate that construction of a wetland with Sphagnum moss and Typha planted in an infertile, clay substrate will not result in a viable ecological community or provide satisfactory long-term water treatment given the strength of AMD at Friendship Hill. The addition of Sphagnum moss to the wetland did result in the significant removal of metals and sulfate from the AMD for several months. Unfortunately, the moss eventually accumulated toxic levels of iron, died, and water improvement ceased. Planted Typha also experienced very high mortality and nowhere did it become as dense as expected or desired.

Summary

The Bureau's attempt to treat Ice Pond Run AMD using a low-cost and simply-designed wetland was successful only in the short term. Many physical problems occurred which plagued the experiment in 1986/87, such as flow control and measurement problems, washout of the dam, and water depth control in some plots. While these problems were corrected, the basic design was flawed in that it did not provide sufficient organic substrate for the growth of wetland vegetation, which finally was overwhelmed by the high AMD loading.

These results showed that long-term water quality improvement could not be achieved at Friendship Hill by simply creating a shallow water system and planting it with <u>Sphagnum</u> and <u>Typha</u>. Had this experiment worked, a very inexpensive and simple solution to the Friendship Hill water problem may have been feasible.

THE SECOND PILOT-SCALE WETLAND EXPERIMENT

Introduction

In separate research activities, constructed wetlands were observed that successfully treated acid mine drainage that is chemically similar to that found in Ice Pond Run (Table 1). Both sites 1 and 2 are dense Typha wetlands constructed with a limestone bed covered with 12-18 inches of spent mushroom compost. At Site 2, cattails were growing quite well and reproducing clonally at the inflow, where the pH was 2.7. This indicates that cattails can grow in extremely acid water if they are provided a suitable rooting substrate. In the first pilot-scale wetland at Friendship Hill, the Bureau attempted to grow Typha in a compacted clay substrate. In a fertile organic substrate, Typha establishment and growth appeared to be readily established.

A very important feature of sites 1 and 2 was the presence of alkaline materials that raised the pH and appeared to stimulate biological activity, especially at the water-substrate interface. At Site 1, the alkalinity was supplemented by surface applications of lime. At Site 2, higher pH values were found in stagnant areas where black sediment and white precipitates were observed. At both sites, increased pH was associated with black sulfur-rich suspended sediments and bubbles of CO_2 and H_2S rising to the surface. These conditions are indicative of anaerobic conditions and high rates of microbial activity. Anaerobic bacterial sulfate reduction can result in the formation of metal sulfides, and generate hydrogen sulfide gas and alkalinity.

In light of these observations, the Bureau proposed to modify the previous pilot-scale wetland design to test the effectiveness of a _Typha_/mushroom compost system. The research was intended to answer the following questions:

1) Could the exposure of AMD to the anaerobic subsurface layers (below the surface water/compost interface) improve the wetland's treatment efficiency?

2) Does a layer of limestone placed below the organic compost in the wetland improve water quality, or would a layer of river gravel (containing only 10% calcareous rock) be equally efficient?

The original goal of the proposed wetland system was to develop a system that required only annual maintenance (fertilizer and/or alkaline additions) and would yield a water discharge with a pH of 6-8, iron concentrations less than 3 mg/L, and manganese concentrations less than 2 mg/L. Because of the severity of the Ice Pond Run AMD and the general lack of data on long-term wetland performance, the more realistic goals of this second pilot-scale wetland were to establish a viable vegetative wetland community, lower the iron concentrations in the AMD to about 50 to 75 mg/L, and raise pH to about 4.

As a result, a novel research-grade constructed wetland was designed by the Bureau that incorporated biological mechanisms believed to be important for a constructed wetland system to treat AMD. The result of this effort was to be the construction and operation of a flexible test bed that would permit the assessment of the feasibility of a full-scale constructed wetland design for the Friendship Hill National Historic Site.

Construction

The cattail plots in the original Friendship Hill wetland (numbers 4, 5, 6, and 7 shown in Fig. 1) were reconfigured into two cells, separated from the sphagnum moss plots and from each other by earthen berms.

The reconstructed portion of the wetland consists of two main cells (cells 2 and 3; Fig. 4). Cell 2 allows the AMD to flow over the surface of a layer of mushroom compost as in a conventional constructed wetland. Cell 3 allows the investigation of water quality improvement obtained by forcing the flow of AMD through the anaerobic zone of the compost. Subsurface infusion pipes were installed in cell 3 to accomplish this purpose.

Within cells 2 and 3, three independent lanes have been created by placing fiberglass sheeting parallel to the direction of water flow. Water flows between cells (but within lanes) by way of PVC plumbing installed in the earthen berm separating the cells. In each lane, two 60-ft long perforated PVC pipes are buried in the gravel and are connected to the outflow pipe from the preceding cell. By turning a valve, water can be directed into either the underflow system or the cell surface. Two of the three treatment lanes (B and C of Fig. 4) in each cell have a 6-inch layer of limestone covered by an 18-inch layer of compost. The remaining lane (A of Fig. 4) has a layer of gravel which contains only 10% calcareous rock. This design feature was incorporated to study the importance of using limestone gravel in the treatment of AMD.

The pilot-scale wetland was put into operation in late October 1988. The next few months were used to troubleshoot the physical operation of the relatively complex wetland design, as well as collect data describing the establishment of a wetland ecosystem. The spring of 1989 represented the first growing season for the pilot-scale wetland and the beginning of an intense monitoring and sampling program by the Bureau of Mines. Also working at the site, under contract to the Bureau, is Professor W. J. Vail, a microbiologist at Frostburg State University in Maryland.

Monitoring and Performance

The results of ten months of monitoring demonstrated that increasing the contact of the AMD with the subsurface layers of compost and gravel markedly improved water quality. The treatment lane containing limestone gravel showed a greater improvement of water quality compared to the non-limestone lane when the subsurface infusion pipes were turned on for the first time only. Subsequently, the limestone gravel appeared to have little additional effect on water quality. When AMD flowed over the surface of the compost, as opposed to subsurface flow, the water quality did not improve significantly.

Surface water samples were collected biweekly from the inflow and outflow pipes of each of the six treatment subcells (Fig. 4). The water quality parameters determined included pH, alkalinity, acidity, ferrous iron, total iron, calcium, magnesium, aluminum, sodium, sulfate, and manganese concentrations.

Water samples were collected from ten locations within the wetland. Data from three of these locations are presented in Figures 5 to 8. The complete data set is given in the Appendix. WS02 is the station for the collection of water samples that represent the AMD flow into the reconstructed wetland. WSB3 and WSA3 are the stations for outflow from the subsurface infusion subcells containing limestone and non-calcareous gravel, respectively.

A comparison of the water quality parameters at station WS02 (where the water flows into the reconstructed portion of the wetland) to those at station WSB2 (where the water flows out of a surface-flow-only subcell) indicated that there was little improvement in water quality for the first six months. At first, merely causing AMD to flow over the surface of the compost did not improve the water quality. Beginning in May, some decrease in iron concentration was observed as the AMD flowed through cell 2. Samples taken from station WSA2, where the gravel layer consists of only 10% calcareous rock, showed exactly the same chemical composition as WSB2, suggesting that the limestone gravel layer in subcell B2 did not aid in AMD treatment. The chemical composition of water from station WSC2 was identical to that at WSB2.

During the first eight months of wetland operation, attempts were made to use the subsurface infusion pipes in subcells A3, B3, and C3. At first, the pipes worked well and the results were encouraging. When the pipes were turned on for the first time on November 7, 1988, the pH and alkalinity increased, and iron, manganese, and aluminum concentrations decreased (Table 2). Calcium concentrations in effluent water were increased by the subsurface infusion treatment, probably because of the partial dissolution of limestone gravel and minerals present in the compost. Sulfate concentrations also increased slightly as the AMD flowed through the wetland, probably due to the dissolution of gypsum.

The second time that the infusion pipes were turned on (February 14, 1989), similar water quality results were observed. By the third time the pipes were turned on (March 27, 1989), improvements in the water quality were much less apparent. The pipes had become partially clogged with sediments and iron oxyhydroxide floc, reducing the amount of AMD that contacted the anaerobic compost layer. Although the pipes were not deliberately turned off, this clogging eventually eliminated all subsurface flow by April 18, 1989.

When the infusion pipes were turned on for the first time, the water coming from the limestone gravel lane improved water quality compared to the lane containing only 10% calcareous rock. During the second and third periods that the pipes were turned on, no significant differences between AMD treatment by two gravel types could be detected. This suggests that the type of rock material present in the gravel layer may not affect the ability of the wetland to treat AMD in the long term. This hypothesis will be studied further.

A modified subsurface infusion system was installed in subcells B3 and A3 on June 27 and August 29, 1989, respectively. The new system consists of a single sheet of Plexiglas pushed into the compost at a right angle to the direction of water flow 6.5 m from the flow into the subcells, so that the bottom edge of the sheet sits just on top of the gravel surface. The

Plexiglas sheet dams the surface water and forces it to flow down into the basal gravel layer. The water then diffuses up through the compost before it reaches the outflow pipe. For the first few weeks after construction, this modification significantly affected the AMD. The pH of the surface water upstream of the Plexiglas dam in subcell B3 was 2.7, but directly below the dam, the pH of the surface water increased to 6.3. The final pH of the outflow from subcell B3 was also 6.3. The most recent data on these trial dams has indicated that their ability to treat AMD has decreased with time.

For the first few months following the wetland reconstruction, mineral dissolution and cation exchange reactions were probably important treatment mechanisms, but it is likely that microbial processes will be more important over a longer period of time. Bacterial sulfate reduction, which occurs in the anaerobic subsurface layers, can result in increased pH and alkalinity, as well as in decreased sulfate and metal concentrations. As the Friendship Hill wetland aged, the subsurface layers became anaerobic. Platinum electrode potential profiles showed that the redox potentials decreased from approximately +650 mV in the aerobic surface water down to approximately -100 mV in the subsurface compost layer. Thus, conditions ideal for high rates of sulfate reduction appear to have developed in the compost. Sulfate reduction rates measured in the wetland compost layer indicate that high rates were occurring and that products of this microbial process are accumulating with time.

During this same sampling period, Dr. W. J. Vail of Frostburg State University has been collecting water and substrate samples for microbial enumeration. Regular counts of total heterotrophic bacteria present in water samples collected at the influent (WS01) and effluent (WS03) stations have indicated an increase in bacterial cells in the water as it flows through the wetland. Counts of sulfate-reducing bacteria have been done periodically on compost samples since March 1989. Population sizes have shown a gradual increase through summer months. Preliminary comparisons of sulfate reducing bacteria population sizes and pore water chemistry indicate a positive correlation between population estimates and pore water alkalinity.

Summary

The results of the first ten months of operation of the second Friendship Hill constructed wetland show that:

1) exposure of the AMD to the subsurface layers in the wetland can substantially improve the AMD water quality;

2) iron concentrations were decreased by the traditional surface flow treatment system;

3) the inclusion of a limestone gravel layer in the wetland design does not appear to be necessary to treat AMD; however, further research should be done to fully assess this possibility;

4) microbial processes expected to become established in the wetland are present and may be expected to contribute positively to AMD treatment.

Future research will address the question of the long-term treatment efficiency of the wetland and will focus on the relative effects of mineral dissolution and microbial processes on AMD treatment.

THE NEXT STEPS

The Bureau will continue to monitor the performance of the pilot-scale wetland during 1990. During this time period, separate research activities on the treatment of AMD by constructed wetlands will continue. By the end of 1990, the results of these research activities should put the Bureau in a position to provide recommendations to the NPS concerning the design parameters and expected performance characteristics of a constructed wetland system to treat Ice Pond Run. These recommendations will be based on the performance of the pilot-scale wetland as well as observations of the performance of several other wetlands the Bureau is monitoring. The end of 1990 will mark a decision point where the benefits of continued monitoring of the pilot-scale wetland to yield longer term performance data will be weighed against the risks of building a full-scale wetland design for Friendship Hill National Historic Site based on the data collected to date.

REFERENCE

Wieder, R. K. and G. E. Lang. 1982. Modification of acid mine drainage in a freshwater wetland. In: Proceedings of the symposium on wetlands of the unglaciated Appalachian region, B. R. McDonald (ed.), West Virginia University, Morgantown, WV.

TABLE 1. - Chemical composition of surface water in three constructed wetlands that receive AMD.

SITE	pH in	pH out	Acidity ($mg\ L^{-1}$) in	Acidity ($mg\ L^{-1}$) out	Total Fe ($mg\ L^{-1}$) in	Total Fe ($mg\ L^{-1}$) out	Manganese ($mg\ L^{-1}$) in	Manganese ($mg\ L^{-1}$) out	Sulfate ($mg\ L^{-1}$) in	Sulfate ($mg\ L^{-1}$) out
Site 1	2.8	6.2	318	<10	84	4	38.4	17.4	1300	640
Site 2	2.7	5.1	930	45	177	15	43.3	33.0	2225	1675
Ice Pond Run	2.7		1284		218		11.7		2350	

TABLE 2. - Chemical composition of inflow and outflow water from the subsurface infusion pipe system in the second pilot-scale wetland on November 10, 1988.

	Inflow to infusion pipe system	Outflow from infusion pipe system
pH	2.9	6.4
Alkalinity (mg L^{-1})	<0	230
Total Iron (mg L^{-1})	243	37
Aluminum (mg L^{-1})	48	12
Manganese (mg L^{-1})	13	8

FIGURE LEGENDS

Figure 1. - Plan view of first pilot-scale wetland.

Figure 2. - Typical longitudinal cross-section of first pilot-scale wetland.

Figure 3. - Planting scheme of the first pilot-scale wetland.

Figure 4. - As-built plans for the second pilot-scale wetland.

Figure 5. - Total iron concentrations in water in the Friendship Hill wetland system during the study period. Symbols indicate: untreated water flowing into the wetland (open squares); water leaving surface flow only subcell in wetland (open triangles); water leaving subsurface flow wetland subcell containing noncalcareous gravel (open circles); water leaving subsurface flow wetland subcell containing limestone gravel (plus signs). Arrows mark times when the subsurface system was turned on and off. Symbols "1" and "2" denote when underflow dams were installed in the calcareous and noncalcareous gravel lanes, respectively.

Figure 6. - Sulfate concentrations in water in the Friendship Hill constructed wetland during the study period. Symbols are the same as described for Figure 5.

Figure 7. - Alkalinity (as ppm $CaCO_3$) of water in the Friendship Hill wetland system during the study period. Symbols are the same as described for Figure 5.

Figure 8. - The pH of water in the Friendship Hill constructed wetland system during the study period. Symbols are the same as described for Figure 5.

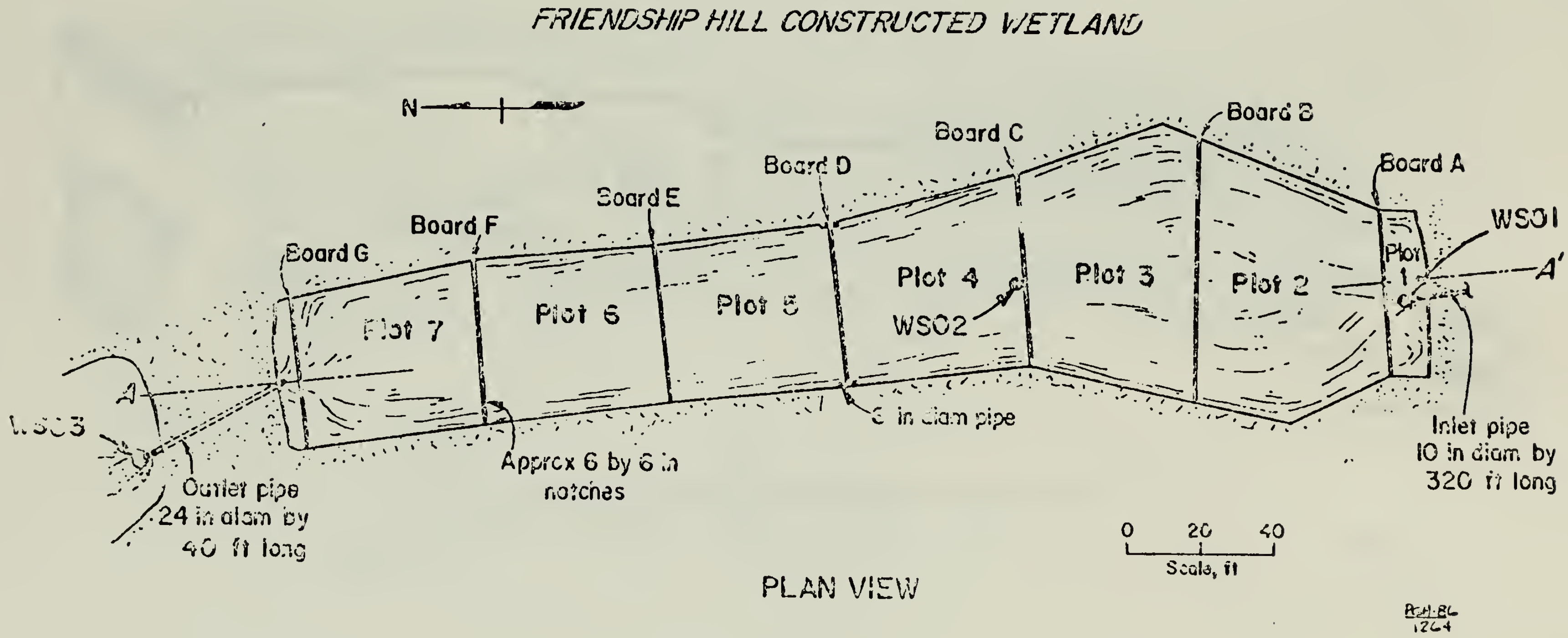

FIGURE 1. - Plan view of first pilot-scale wetland.

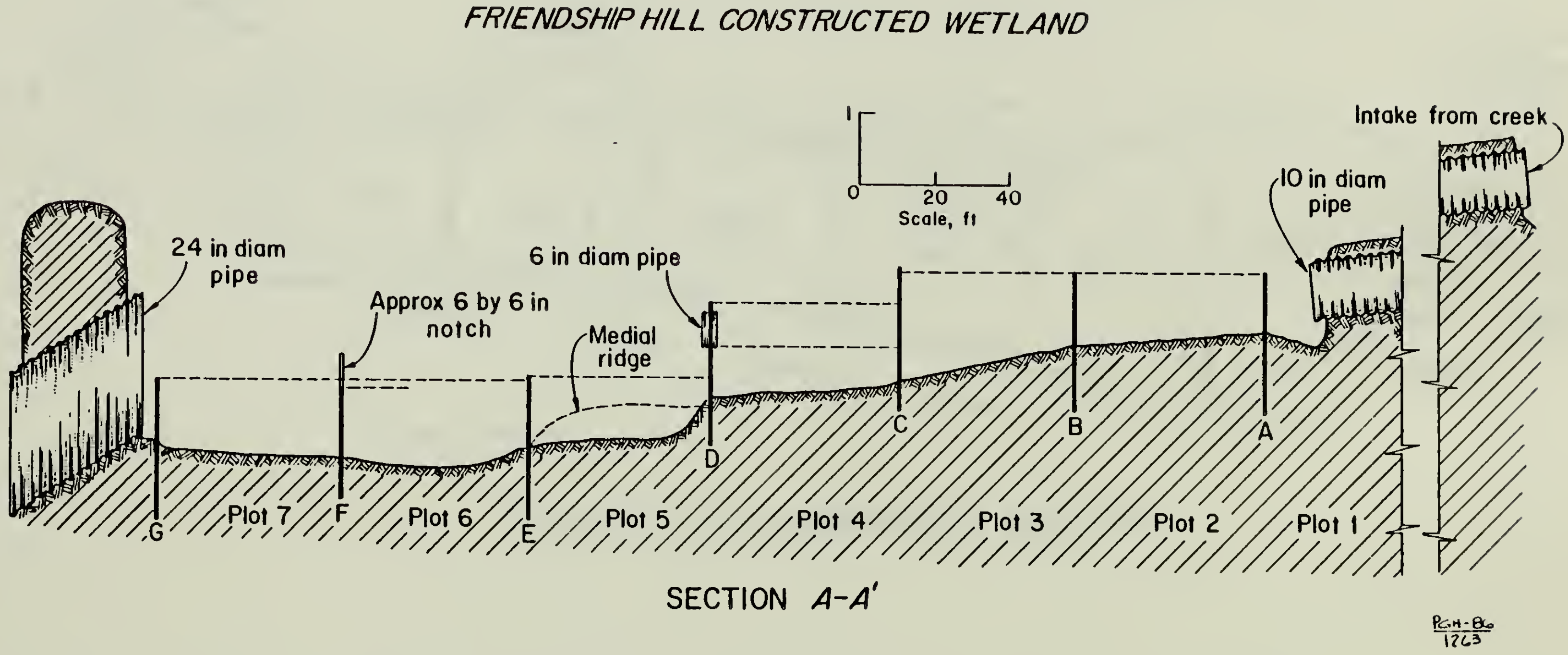

FIGURE 2. - Typical longitudinal cross-section of first pilot-scale wetland.

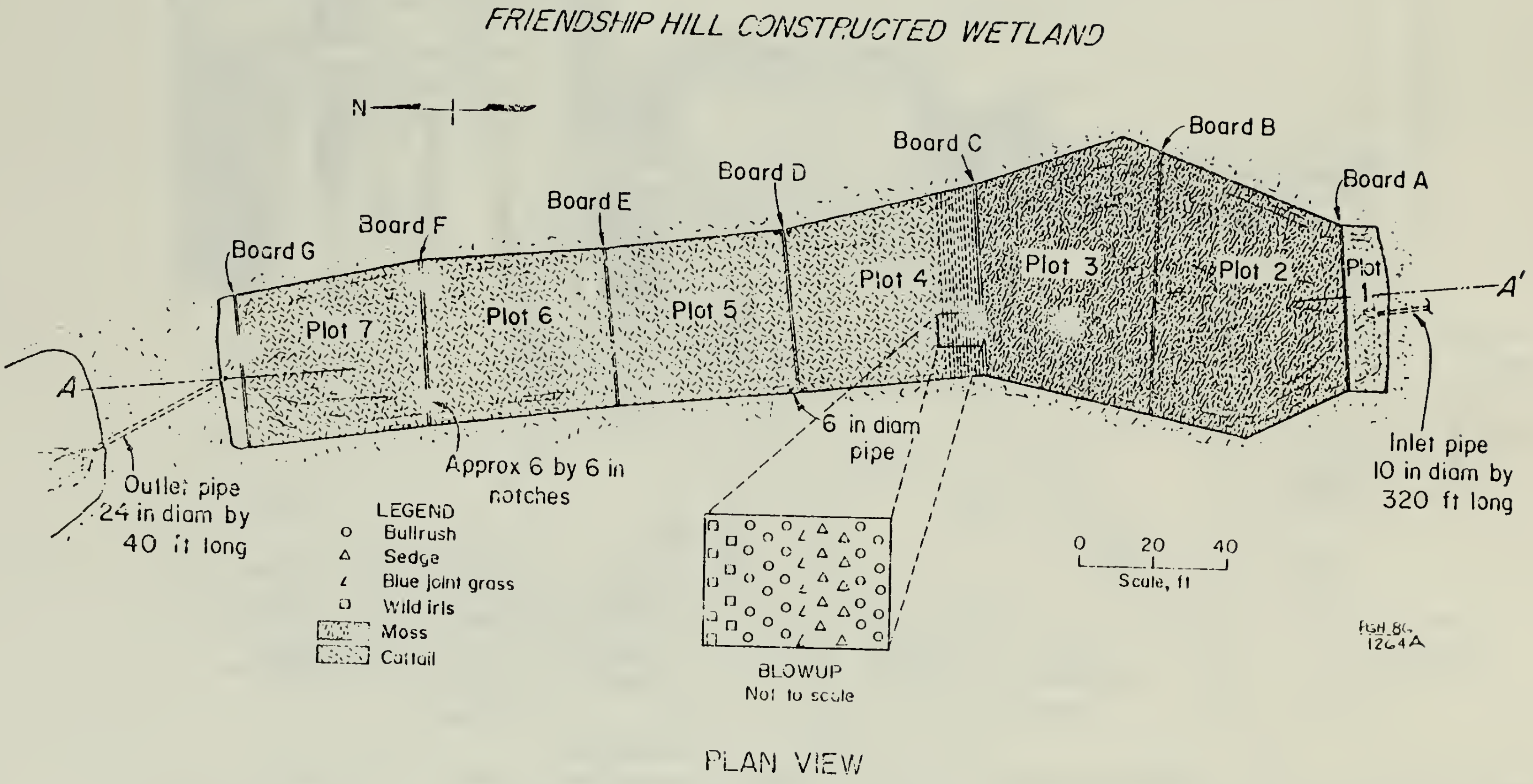

FIGURE [illegible]. - Planting scheme of the first pilot-scale wetland.

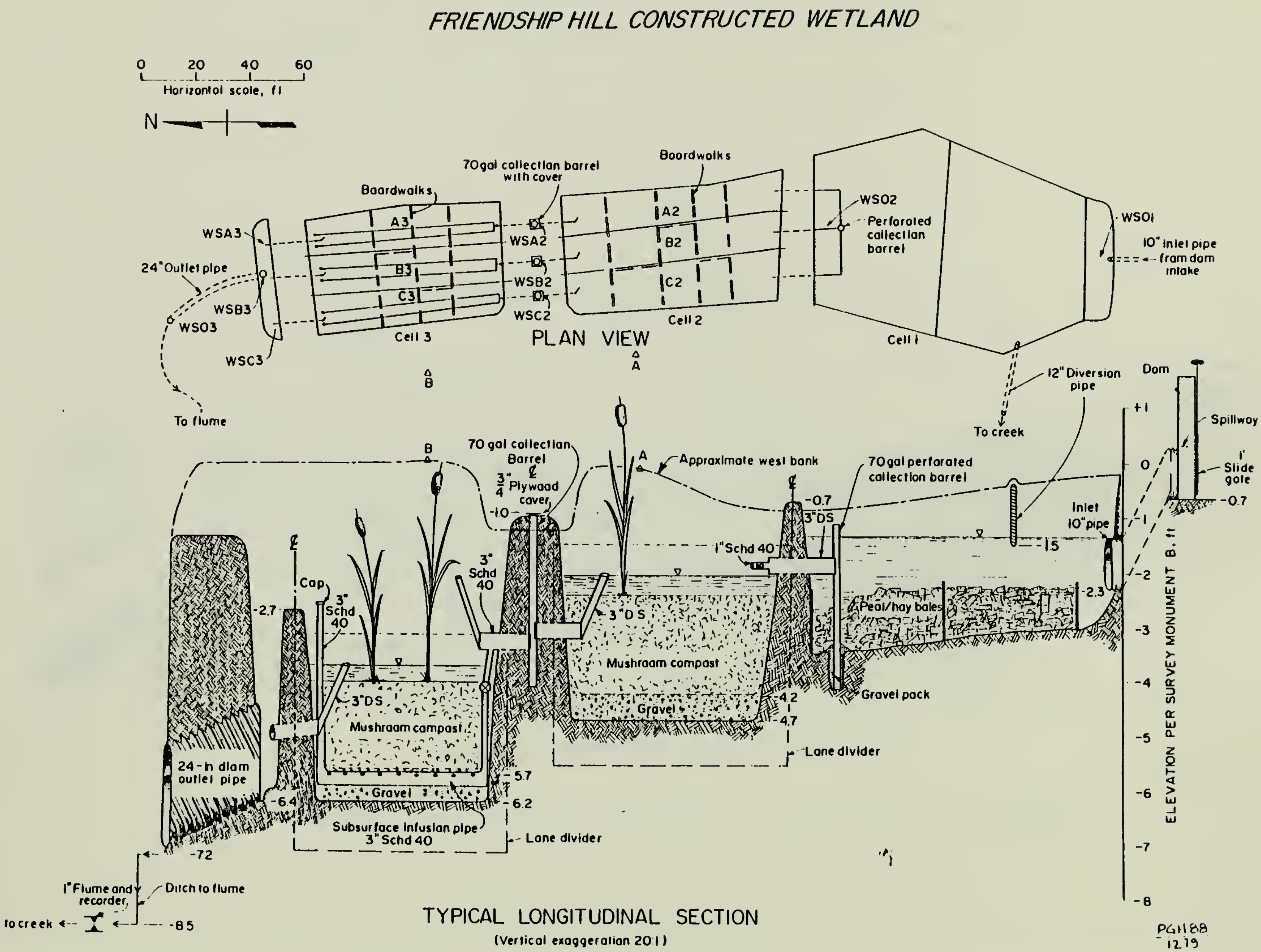

FIGURE 4. - As-built plans for the second pilot-scale wetland.

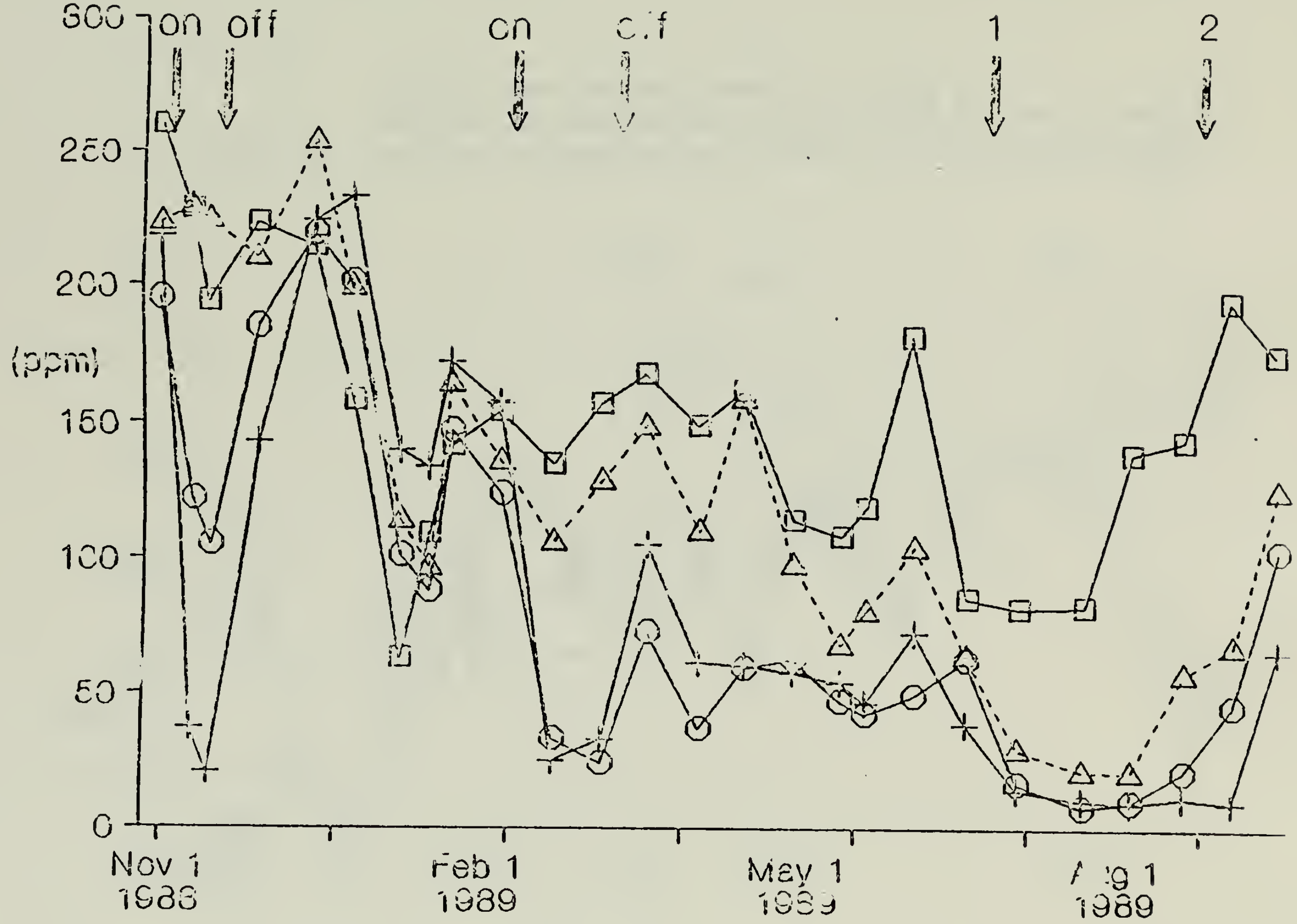

Figure 5. - Total iron concentrations in water in the Friendship Hill wetland system during the study period. Symbols indicate: untreated water flowing into the wetland (open squares); water leaving surface flow only subcell in wetland (open triangles); water leaving subsurface flow wetland subcell containing noncalcareous gravel (open circles); water leaving subsurface flow wetland subcell containing limestone gravel (plus signs). Arrows mark times when the subsurface system was turned on and off. Symbols "1" and "2" denote when underflow dams were installed in the calcareous and noncalcareous gravel lanes, respectively.

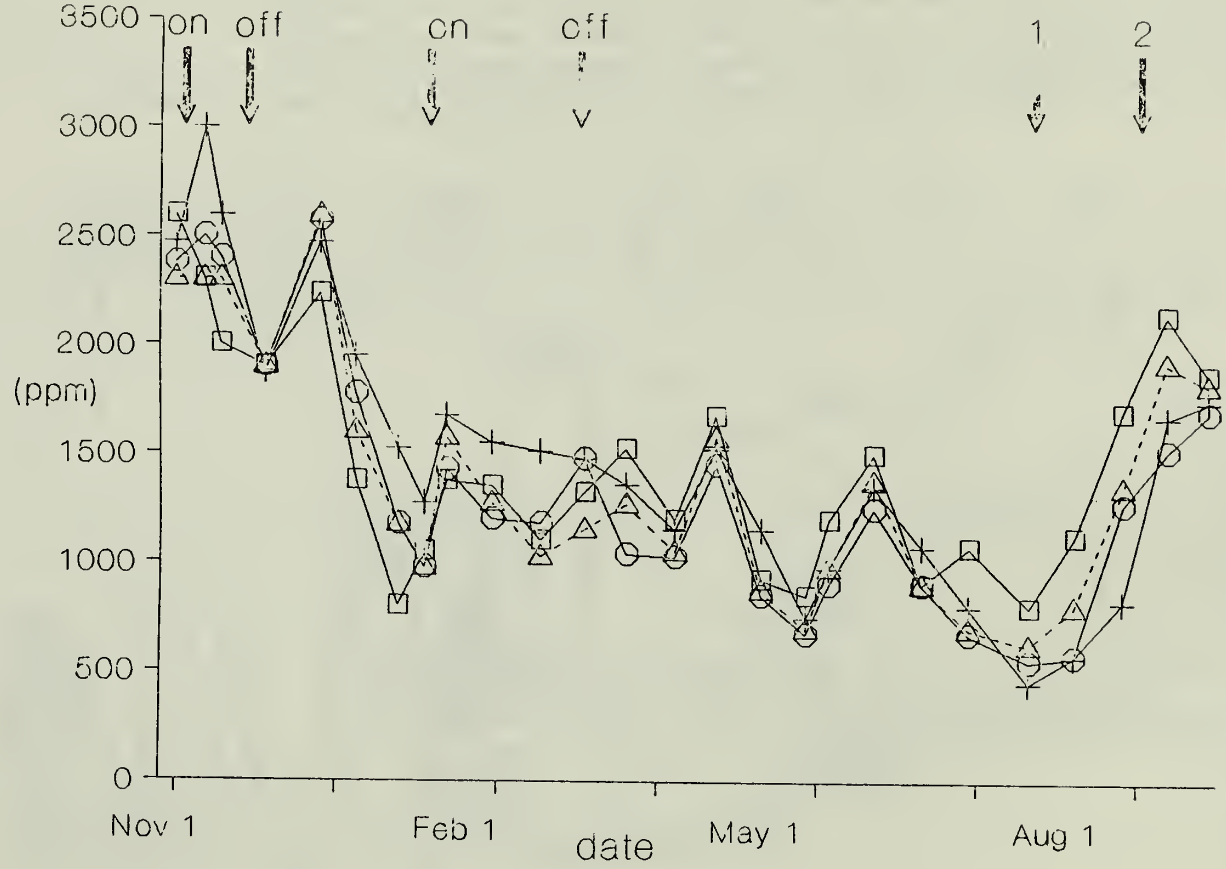

Figure 6. - Sulfate concentrations in water in the Friendship Hill constructed wetland during the study period. Symbols are the same as described for Figure 5.

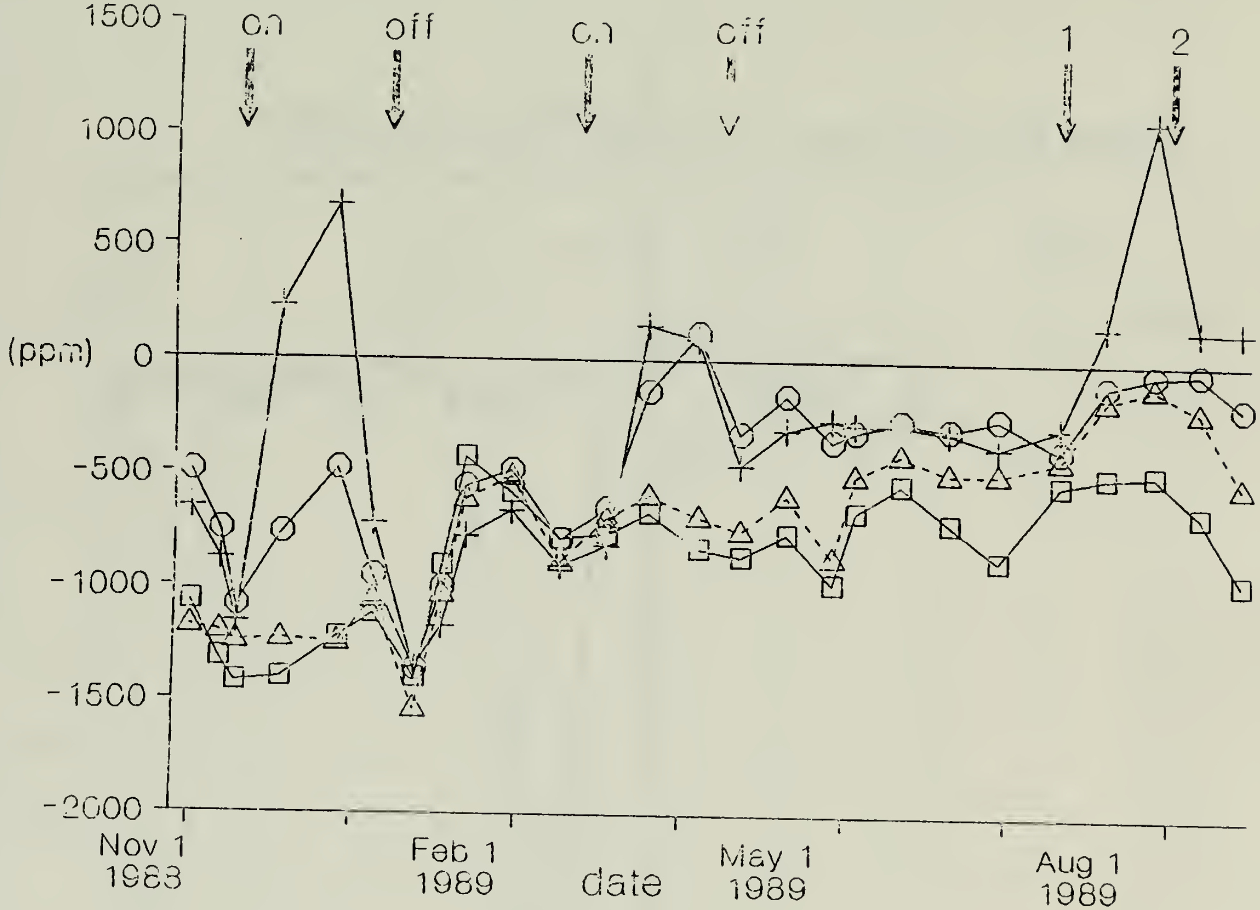

Figure 7. - Alkalinity (as ppm $CaCO_3$) of water in the Friendship Hill wetland system during the study period. Symbols are the same as described for Figure 5.

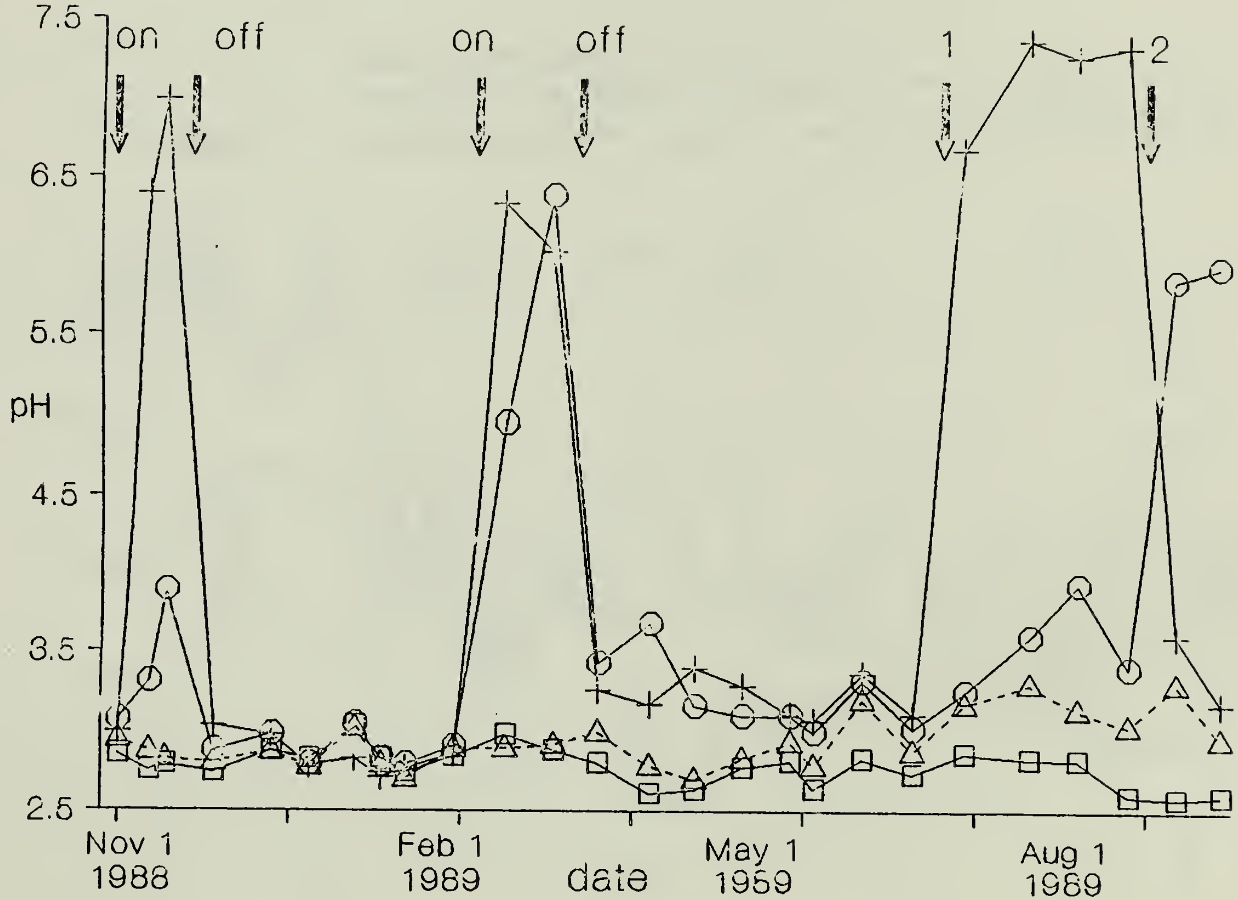

Figure 8. - The pH of water in the Friendship Hill constructed wetland system during the study period. Symbols are the same as described for Figure 5.

APPENDIX -- DATA COLLECTED AT THE FRIENDSHIP HILL SITE DURING 1988 AND 1989

27-Oct-88	seep	2.79	0	1492	233	377	344	139	88.4	6	2850	12.8	0
27-Oct-88	wso1	2.76	0	1390	4.5	269	278	115	94.8	5.6	2475	14.2	0
27-Oct-88	wso2	2.72	0	1319	129	282	263	109	88.4	5.4	2325	13.5	0
27-Oct-88	wso3	3.39	0	622	86.8	118	394	109	49.3	22.1	2125	10	0
01-Nov-88	wsa2	2.94	0	1244	41.4	223	308	113	85.3	9.5	2300	13.5	0
01-Nov-88	wsa3	3.06	0	1087	58.8	195	336	113	76.5	13.9	2375	12.9	0
01-Nov-88	wsb2	2.87	0	1343	45.9	241	282	109	87.4	6.4	2375	13.4	0
01-Nov-88	wsb3	2.99	0	1158	64.5	218	311	113	79.7	11.9	2475	13	0
01-Nov-88	wsc2	2.91	0	1288	50.1	233	301	111	86.4	8.2	2475	13.3	0
01-Nov-88	wsc3	3.03	0	1090	71.4	204	328	112	77.8	12.8	2450	13	0
01-Nov-88	wso1	2.82	0	1490	6.7	261	278	113	92.8	5.2	2550	13.8	0
01-Nov-88	wso2	2.85	0	1422	36.5	260	271	112	91.8	5.3	2600	13.8	0
01-Nov-88	wso3	3.02	0	1106	66.3	210	325	115	79.1	13.2	2450	13.3	0
10-Nov-88	wsa2	2.87	0	1230	36.3	229	287	105	78.6	8.7	2300	13.2	0
10-Nov-88	wsa3	3.3	0	767	53.6	122	418	127	61.4	36.2	2500	13.9	0
10-Nov-88	wsb2	2.88	0	1311	29.3	243	273	105	80.9	6	2300	13.3	0
10-Nov-88	wsb3	6.39	283	54		37	721	168	12.2	116	3000	8.3	0
10-Nov-88	wsc2	2.89	0	1276	51	237	283	104	78.1	7.5	2300	13.2	0
10-Nov-88	wsc3	6.98	777	34		27.9	788	205	4.4	200	3400	4.9	0
10-Nov-88	wso1	2.77	0	1275	7.7	215	239	96.4	81.2	5.1	2200	13.1	0
10-Nov-88	wso2	2.75	0	1404	27.9	228	243	96.8	81.6	5.2	2300	12.9	0
10-Nov-88	wso3	5.23	0	166		71.8	607	159	27.7	90.3	2800	10.9	0
15-Nov-88	wsa2	2.82	0	1246	22	224	278	104	79.7	8.1	2300	13	0
15-Nov-88	wsa3	3.89	0	486		105	444	135	49	45.7	2400	10.6	0
15-Nov-88	wsb2	2.84	0	1255	16.7	226	278	103	80	6.5	2200	13.1	0
15-Nov-88	wsb3	6.99	688	9.5		20.2	762	179	0.5	84	2600	4	0
15-Nov-88	wsc2	2.87	0	1222	22.8	218	273	101	78.7	7.5	2200	12.8	0
15-Nov-88	wsc3	7.02	606	9		18.2	753	166	0.5	63.4	2500	4.4	0
15-Nov-88	wso1	2.78	0	1182	11.6	188	214	83.8	73.4	4.8	1900	12	0
15-Nov-88	wso2	2.79	0	1225	11	194	222	87	76.7	5.2	2000	11.9	0
15-Nov-88	wso3	6.4	192	13		46.2	595	151	19.6	60.1	2400	7.3	0
29-Nov-88	wsa2	2.8	0	1055		210	226	85	66.3	6	1900	11.5	0
29-Nov-88	wsa3	2.87	0	952		185	241	83.5	63	7.4	1900	10.9	0
29-Nov-88	wsb2	2.84	0	945		180	248	86.8	61.2	8.3	1925	11	0
29-Nov-88	wsb3	3.03	0	718		143	306	90.6	51.7	10.7	1875	10.1	0
29-Nov-88	wsc2	2.84	0	963		179	240	83.3	61.6	7.8	1925	10.9	0
29-Nov-88	wsc3	2.9	0	866		167	264	86.8	59	8.4	1875	10.8	0
29-Nov-88	wso1	2.7	0	1033		172	199	78	66.5	5	1800	10.6	0
29-Nov-88	wso2	2.74	0	1119		223	211	83.4	68	4.9	1900	11.4	0
29-Nov-88	wso3	2.89	0	896		175	252	87.6	60.6	8.2	1800	11	0
16-Dec-88	wsa2	2.87	0	1540		254	301	122	97.8	7.2	2600	15.4	0
16-Dec-88	wsa3	2.97	0	1364		219	348	127	88.7	8.7	2575	14.9	0
16-Dec-88	wsb2	2.89	0	1504		243	281	113	91.9	6.1	2475	14.4	0
16-Dec-88	wsb3	2.97	0	1357		224	305	115	87.1	7.8	2475	14.3	0
16-Dec-88	wsc2	2.89	0	1526		247	286	116	94.7	6.4	2600	14.6	0
16-Dec-88	wsc3	2.92	0	1490		240	304	121	94.8	10.7	2575	14.9	0
16-Dec-88	wso1	2.78	0	1534		231	256	105	91.4	5.4	2375	14.5	0
16-Dec-88	wso2	2.87	0	1405		214	246	100	81.9	5.4	2237	12.7	0
16-Dec-88	wso3	2.96	0	1372		226	326	124	91	8.4	2525	15.1	0
27-Dec-88	wsa2	2.77	0	1033	83.1	199	196	74.5	61.7	5.7	1600	10.3	0
27-Dec-88	wsa3	2.79	0	1005	76.7	201	203	79.5	62.9	5.6	1775	10.8	0
27-Dec-88	wsb2	2.76	0	1165	96.4	226	218	84.7	69.5	5.4	1900	11.5	0
27-Dec-88	wsb3	2.78	0	1172	93.9	233	229	88.4	71.7	5.5	1950	12	0

27-Dec-88 wsc2	2.8	0	1013	90.5	210	197	77.5	63.7	5.4	1825	10.6	0
27-Dec-88 wsc3	2.81	0	998	83.6	204	209	80	63	5.5	1850	10.8	0
27-Dec-88 wso1	2.93	0	363	12.8	45.3	72.7	26.3	24.6	2.9	600	4.1	0
27-Dec-88 wso2	2.82	0	906	76.3	158	157	60.5	49.8	4	1375	8.5	0
27-Dec-88 wso3	2.82	0	1039	82.3	210	213	82.1	66.1	5.3	1675	11	0
03-Jan-89 wso2	2.78	0	655	31.4	79.2	97.5	35.5	29.5	5.7	1175	5	0
03-Jan-89 wso3	2.84	0	743	49.3	139	168	63.3	48.4	6.3	1425	8.4	0
09-Jan-89 wsa2	3.01	0	615	23	114	143	54.7	42.3	7.2	1175	7.5	0
09-Jan-89 wsa3	3.04	0	560	21.8	101	146	52.8	39	6.5	1175	7.1	0
09-Jan-89 wsb2	2.78	0	795	37.5	146	175	66.8	50.2	6.7	1500	8.9	0
09-Jan-89 wsb3	2.83	0	778	38.1	140	184	67.5	49.2	6.7	1525	8.9	0
09-Jan-89 wsc2	2.84	0	729	31.4	135	173	64.4	47.5	7.2	1425	8.6	0
09-Jan-89 wsc3	2.87	0	708	30.2	126	178	63.5	46.2	7.2	1425	8.5	0
09-Jan-89 wso1	3.11	0	330	2.8	43.7	69.7	25.3	23.3	6.8	600	4.1	0
09-Jan-89 wso2	3.03	0	431	2.2	63.2	90.8	33.9	29.2	7.1	800	5	0
09-Jan-89 wso3	2.88	0	672	28	117	163	59.5	43.5	6.7	1325	8	0
10-Jan-89 seep	2.88	0	1510	219	343	314	124	82	5.5	2675	11.8	0
17-Jan-89 wsa2	2.79	0	516	32.5	96.8	112	41.4	33.2	7.1	975	5.7	0
17-Jan-89 wsa3	2.82	0	489	28.8	87.9	121	42.4	33.3	7.4	975	5.9	0
17-Jan-89 wsb2	2.82	0	648	45.3	128	137	52.4	40.6	6.8	1200	7.3	0
17-Jan-89 wsb3	2.71	0	664	44.5	134	153	56.4	43.4	7	1275	7.8	0
17-Jan-89 wsc2	2.74	0	620	37.7	124	139	52	38.9	7	975	7.1	0
17-Jan-89 wsc3	2.78	0	619	38.6	117	155	54.7	39.5	7.4	1225	7.4	0
17-Jan-89 wso1	3.05	0	241	9.3	25.3	47.5	16.3	17	7.3	425	2.8	0
17-Jan-89 wso2	2.83	0	588	41.7	109	104	40.3	33.8	5.7	1050	5.4	0
17-Jan-89 wso3	2.79	0	578	36	109	140	50.7	38.3	7.3	1150	6.9	0
24-Jan-89 wsa2	2.7	0	890	18.9	164.6	169.1	66	56.6	6.2	1575	8.6	0
24-Jan-89 wsa3	2.79	0	790	23.2	146.9	160.3	61.3	61	5.4	1425	9.4	0
24-Jan-89 wsb2	2.74	0	961	24.2	187.3	185.3	72.7	61	5.4	1650	9.4	0
24-Jan-89 wsb3	2.76	0	907	27.9	172.5	189.4	71.6	58.2	6.1	1675	9.1	0
24-Jan-89 wsc2	2.72	0	963	27.1	182.2	185.4	72.9	61.4	6.1	1725	9.4	0
24-Jan-89 wsc3	2.76	0	915	28.9	174.5	187.7	71.4	58.4	6.2	1525	9.2	0
24-Jan-89 wso1	2.85	0	487	12	78.8	98.4	36.9	35	8.8	875	5.5	0
24-Jan-89 wso2	2.74	0	787	19.7	141.8	143.6	56.2	50.2	6.4	1375	7.5	0
24-Jan-89 wso3	2.78	0	863	25.6	148.1	156.2	65.7	55.2	6.4	1000	8.5	0
07-Feb-89 wsa2	2.89	0	697	17.6	136	135	53.6	44.4	5.9	1275	6.8	0
07-Feb-89 wsa3	2.9	0	651	17.7	124	136	52.4	42.4	6.3	1200	6.7	0
07-Feb-89 wsb2	2.78	0	817	23.9	166	162	64.8	52.7	5.4	1525	8.1	0
07-Feb-89 wsb3	2.86	0	816	24.2	157	163	63.1	51.9	5.5	1550	7.8	0
07-Feb-89 wsc2	2.84	0	835	21.4	162	158	62.3	52.7	5.5	1525	7.8	0
07-Feb-89 wsc3	2.87	0	772	21.1	149	162	61.5	49.3	5.7	1450	7.6	0
07-Feb-89 wso1	3.04	0	272	12.5	33.7	56.9	20.7	23	9.8	475	3.7	0
07-Feb-89 wso2	2.84	0	765	23.1	154	143	57.4	49.1	5.3	1350	7.3	0
07-Feb-89 wso3	2.88	0	729	19.4	141	153	58.3	47.6	6	1350	7.4	0
22-Feb-89 wsa2	2.89		595	9.9	106	105	38.5	36.7	4.8	1025	5.2	0
22-Feb-89 wsa3	4.94	0	139		33.2	281	54.3	12	9.8	1178	5.3	0.1
22-Feb-89 wsb2	2.88	0	817	16	162	134	51.6	47.9	3.9	1400	6.7	0
22-Feb-89 wsb3	6.33	152			24.8	465	75.9	6.9	10	1510	7.9	0.67
22-Feb-89 wsc2	2.96	0	652	6.2	128	116	43.2	38.8	3.7	1150	5.7	0
22-Feb-89 wsc3	6.64	254			13.4	466	69.4	1	10.6	1300	4.8	0.44
22-Feb-89 wso1	3.78	0	50		0.8	5	1.3	2.2	1.8	50	0.3	0
22-Feb-89 wso2	2.97	0	673	16.9	135	108	42.2	40.5	3.8	1100	5.7	0
22-Feb-89 wso3	6.33	97.7			23.2	370	63.6	8.2	10	1244	6	0.2
08-Mar-89 seep	2.76		1166	1.8	237	221	95.6	67.9	4.4	2175	8.9	0

08-Mar-89 wsb2	[illegible]		[illegible]	15.5	162	148	60.1	51.5	4.3	1475	7	0
08-Mar-89 wsb3	6.02	94		21.4	32.7	456	78.1	11.7	8.2	1475	8.6	0.21
08-Mar-89 wsc2	2.88		860	15.7	171	137	55.8	48.9	4.1	1450	6.6	0
08-Mar-89 wsc3	6.52	183		11.2	16.1	467	68.4	1.4	6.1	1325	6.1	0.17
08-Mar-89 wso1	3.39		90	3.2	3.2	18.7	5.2	7.5	4.5	190	0.7	0
08-Mar-89 wso2	2.88		829	23	157	121	49.8	43.4	4.2	1325	6	0
08-Mar-89 wso3	6.37	115		16.1	24.1	420	69.5	6.5	8.3	1400	7	0.1
21-Mar-89 wsa2	2.99		749	11	149	125	51.2	44.6	5.4	1270	5.9	0
21-Mar-89 wsa3	3.42		325	22.1	73	217	49	20.8	6.4	1040	5.5	0
21-Mar-89 wsb2	2.87		916	11.9	189	156	63.6	54	5.9	1580	7.2	0
21-Mar-89 wsb3	3.25		462	24.6	105	266	62.7	30.3	6.2	1360	7	0
21-Mar-89 wsc2	2.82		862	14.1	178	148	59.6	50.7	4.9	1490	6.8	0
21-Mar-89 wsc3	3.23		408	18	93.6	245	55.8	27.7	6.2	1235	6.2	0
21-Mar-89 wso1	2.82		147	6	18.6	29.8	10.3	10.8	5.8	275	1.8	0
21-Mar-89 wso2	2.8		862	19.7	168	131	55.8	48.6	5.1	1525	6.5	0
21-Mar-89 wso3	3.26		366	19.3	79.4	218	52.2	24.9	6	1100	5.8	0
05-Apr-89 wsa2	2.78		595	13.7	110	121	45.5	34.5	6	1050	5	0
05-Apr-89 wsa3	3.67		157	16.7	36.9	254	49.3	13.9	7.9	1025	5.4	0
05-Apr-89 wsb2	2.75		675	14.2	127	119	47.4	37.5	4.4	1100	5.4	0
05-Apr-89 wsb3	3.16		305	13.3	61.5	263	54.1	19.4	7.3	1150	5.3	0
05-Apr-89 wsc2	2.59		689	14.9	129	127	49.6	37.9	4.9	1150	5.6	0
05-Apr-89 wsc3	6.4	115		15.9	26.1	408	61.3	3.8	7.7	1200	6	0
05-Apr-89 wso1	2.93		145	3.5	3.5	17.8	5.4	6.8	8.3	175	1.4	0
05-Apr-89 wso2	2.61		763	28	149	116	49	41.2	3.9	1200	5.6	0
05-Apr-89 wso3	3.99		100	17.1	40.3	298	52.1	12.4	7.6	1075	5.5	0
18-Apr-89 seep	2.65		1323	10.4	266	264	116	79.8	1.1	2425	9.8	0
18-Apr-89 wsa2	2.7		867	11.7	159	161	65.4	53	1.8	1575	7	0
18-Apr-89 wsa3	3.15		355	20.6	59.6	297	68.6	26.7	3.1	1450	8.1	0
18-Apr-89 wsb2	2.69		948	13.8	176	170	69.7	56	0.7	1675	7.5	0
18-Apr-89 wsb3	3.39		260	23.6	60.6	378	76.1	20.5	2.7	1525	7.6	0
18-Apr-89 wsc2	2.71		901	14	163	174	67.7	54.5	1.3	1650	7.3	0
18-Apr-89 wsc3	3.16		419	36.5	88.7	314	74.4	31.2	2.1	1525	8.5	0
18-Apr-89 wso1	2.78		303	6	35.1	47.6	19.1	17.9	3.2	525	2.8	0
18-Apr-89 wso2	2.63		982	18.4	162	146	61.1	52.1	0.7	1675	6.7	0
18-Apr-89 wso3	3.21		343	26.1	71.7	330	70.8	26.8	3	1475	7.8	0
02-May-89 seep	2.72		1010	3.7	192	194	82.2	57.4	4	1825	7.2	0
02-May-89 wsa2	2.83		505	39.1	97.7	97.6	37.4	27.8	4.6	875	4.3	0.4
02-May-89 wsa3	3.09		313	28.4	62.8	155	40.2	17.9	4.7	850	5	0
02-May-89 wsb2	2.8		673	21.3	126	129	50.9	36.4	4.4	1175	5.6	0
02-May-89 wsb3	3.28		281	23.8	57.7	261	56.7	16.1	5.1	1150	5.8	0
02-May-89 wsc2	2.88		471	13.4	77.7	104	36.9	24.7	4.1	875	4	0
02-May-89 wsc3	3.16		322	28.4	61.6	181	46.2	20.8	4.6	1100	5.3	0
02-May-89 wso1	3.07		179	2.2	16.8	27	9.9	8.1	3	250	1.3	0
02-May-89 wso2	2.77		664	32.4	114	99.2	41.3	31.2	4.1	925	4.7	0
02-May-89 wso3	3.1		300	23.7	55.1	176	42.6	17.4	4.7	925	5	0
16-May-89 wsa2	2.93		410	12.4	68.3	84.1	31.6	21.8	4.5	700	3.7	0
16-May-89 wsa3	3.09		264	16.2	47.2	129	33.5	16.1	5.7	675	4.4	0
16-May-89 wsb2	2.84		473	24.6	67.2	86.9	34.4	23.9	3.6	825	4	0
16-May-89 wsb3	3.1		280	24.1	54.3	170	40.3	15.5	4.3	750	4.6	0
16-May-89 wsc2	2.87		317	27.3	40	105	33.7	21.3	5.4	725	3.7	0
16-May-89 wsc3	5.08		56	16.7	17	222	42	4.8	5	775	5	0.3
16-May-89 wso1	2.83		318	4.2	28.6	40	15.1	13.8	4.4	550	2.3	0
16-May-89 wso2	2.81		543	45.7	108	86.9	35.5	26.8	3.2	850	4.2	0
16-May-89 wso3	3.03		259	18.3	44.9	145	34.7	14.9	4.7	750	4.3	0

23-May-89 wsa2	2.78		494	14.7	80.8	116	41.4	28.6	5.2	975	4.6	0
23-May-89 wsa3	2.99		300	4.2	42	164	43.6	20.8	5.7	900	5.3	0
23-May-89 wsb2	2.73		559	3.3	93.9	125	47.3	32.7	4.4	1050	5.1	0
23-May-89 wsb3	3.06		313	5.9	46.6	180	46.5	22.1	4.8	975	5	0
23-May-89 wsc2	2.81		540	5.8	95.1	127	47.7	31.9	4.7	1050	5.1	0
23-May-89 wsc3	2.94		410	5.6	67.5	153	47.8	26.8	5.1	975	5.3	0
23-May-89 wso1	2.72		495	1.8	76.7	86.7	36.3	27.9	3.8	825	4.1	0
23-May-89 wso2	2.64		710	35.3	119	111	46.6	35.1	3.8	1200	5.1	0
23-May-89 wso3	2.93		343	5.5	51.1	170	46.4	23	5	950	5.3	0
06-Jun-89 ws01	2.82		793	173	188	137	58.9	39.2	4	1325	6.3	0
06-Jun-89 ws02	2.83		874	118	182	149	63.7	45.2	3.9	1500	6.7	0
06-Jun-89 ws03	3.33		288	28.8	51.2	292	67.9	18.6	6.6	1300	7.4	0
06-Jun-89 wsa2	3.19		493	68.7	104	247	68.4	29.2	6.4	1375	7.2	0
06-Jun-89 wsa3	3.31		252	20.3	49.2	282	65.4	16.1	7.4	1250	7.4	0
06-Jun-89 wsb2	3.19		607	91.7	130	227	67.3	36.2	4.7	1425	7	0
06-Jun-89 wsb3	3.36		375	52.7	72.5	278	66.6	25.9	5.1	1350	7.3	0
06-Jun-89 wsc2	3.32		419	73.1	101	270	71.7	27	8.2	1400	7.3	0
06-Jun-89 wsc3	3.45		171	12	33	324	71.8	13.3	8	1300	7.4	0
06-Jun-89 seep	2.89		1209	5.8	239	256	112	72.5	5.2	2325	9	0
21-Jun-89 ws01	2.75		462	15.4	52.1	73.5	30	22.6	3.5	750	3.6	
21-Jun-89 ws02	2.73		538	42.6	85.4	94.8	39.6	27.7	3.4	900	4.6	
21-Jun-89 ws03	3.03		312	21.6	41.9	189	48.8	19.3	4.9	950	5.5	
21-Jun-89 wsa2	2.87		428	25	64.2	131	43.1	23.3	4.6	900	4.7	
21-Jun-89 wsa3	3.01		390	38.1	62.7	149	44.6	21.8	4.2	900	5	
21-Jun-89 wsb2	2.94		394	17.7	61.7	178	51	22.1	4.1	1000	5.4	
21-Jun-89 wsb3	3.1		288	18.7	38.5	228	56	18.8	4.4	1075	6.2	
21-Jun-89 wsc2	2.89		380	22.2	55.5	185	51.5	21.2	5.2	975	5.4	
21-Jun-89 wsc3	3.11		260	14.4	31.4	216	55	17.1	5.2	975	5.8	
06-Jul-89 ws01	2.85		471	55.6	72.9	85.2	35.2	26.9	3.3	800	4.1	0
06-Jul-89 ws02	2.86		502	56.7	81.7	89.3	37.1	26.9	3.4	1075	4.3	0.4
06-Jul-89 ws03	5.89		15	9.5	14.7	214	40.4	0.8	7.5	700	3	0
06-Jul-89 wsa2	3.16		168	13.7	28.9	158	38.5	5.7	7.4	700	3.9	0
06-Jul-89 wsa3	3.24		105	5.2	16.4	167	37	1.9	7.7	675	3.7	0
06-Jul-89 wsb2	2.97		349	15.3	51.9	134	41.5	17.8	4.3	800	4.6	0
06-Jul-89 wsb3	6.68		30	9.3	14	314	46.2	0.1	6.5	800	2.5	0
06-Jul-89 wsc2	3.28		147	7	20	180	43.5	6.7	7.2	750	4.1	0
06-Jul-89 wsc3	3.92		7.3	40.6	41.3	176	40.8	0.1	8.6	625	2.9	0
06-Jul-89 seep	2.72		1239	2.5	225	252	110	68	5.3	2075	9.5	0
25-Jul-89 ws01	2.85		460	60.2	76	76.6	31.5	22	3.6	725	3.7	0.17
25-Jul-89 ws02	2.83		488	71.2	82.4	82.5	31.9	22.7	3.6	800	4	1.2
25-Jul-89 ws03	6.65		5	9.5	13.3	173	38.3	0.5	7.2	550	2.8	0
25-Jul-89 wsa2	3.29		106	17.3	21.1	157	37	1.9	9	625	3.5	0.12
25-Jul-89 wsa3	3.59		50	3	7.5	145	34.4	0.4	7.1	550	3.1	0
25-Jul-89 wsb2	3.21		137	21.7	25.2	171	41.1	5.5	6	650	4.2	0
25-Jul-89 wsb3	7.38	109		7.7	10.4	208	40.5	0.1	5.3	450	2	0
25-Jul-89 wsc2	3.12		173	13.4	30	152	40	7.6	6.8	725	4.1	0
25-Jul-89 wsc3	3.59		58	6.2	8.7	165	40.1	0.6	7.2	625	3.8	0
25-Jul-89 seep	2.07		1174	2.8	214	242	107	65.4	5	2000	9.2	-1

			[illegible]	[illegible]	[illegible]	[illegible]	49	14.3	7.9	800	5.3	0
08-Aug-89 wsa3	3.93		38	2.2	9.6	153	38.3	0.3	8.9	575	3	0
08-Aug-89 wsb2	3.39		205	12.4	20.4	189	50.6	19	6.5	875	5.4	0
08-Aug-89 wsb3	7.28	150		6.6	9.2	233	45.3	0.2	6.7	5755	2.8	0
08-Aug-89 wsc2	3.53		190	26.3	32.1	191	52.2	15.2	8.5	850	5.3	0
08-Aug-89 wsc3	3.53		98	1.2	4.6	191	49.5	7.1	7.7	725	5.1	0
08-Aug-89 seep	2.79		1156	8.2	234	264	114	70.2	5.6	2200	9.8	0