THE APPLICATION OF THE THETA IMPPS TECHNOLOGY FOR ACID DRAINAGE TREATMENT

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INTRODUCTION

In October, 1987, a complete study was made of several sites in southern West Virginia that had acid mine discharges. This study included an analysis of the geological, hydrological, soil, botanical, zoological and microecological data. The information was integrated., processed and a preliminary systems design prepared. Based on the study. It was determined that the Robin. Hood Refuse Area was the best site for the most efficient. cost-effective application of the Lambda technology.

THE THETA - PROCESS

Before looking at the Robin Hood project, a brief explanation of the Theta Process is necessary. Lambda's Theta Process is a technique for establishing balanced microecosystems in constructed acid mine 'drainage (AMD) treatment systems. The products which produce these microscosystems are called Immobilized Microbial Pollution Purification Systems (IMPPS). The IMPPS consist primarily of metal specific bacteria,, algae and protozoans which' are capable of removing, by various physical, chemical and biological mechanisms, undesired contaminants (i.e. Fe. Mn, Al, SO_4) from the water.

Once the treatment system is designed. each microbe chosen is tested for its efficiency in performing its desired task. This efficiency is greatly enhanced by hybridizing each microbe using a carefully chosen mixture of the same genus and species known to . possess outstanding desirable characteristics. By hybridizing, a "hybrid vigor" is achieved that produces larger, more efficient microbes that reproduce quickly and have exceptional adaptation techniques when environmentally stressed. They must be able to withstand temperature extremes, drought, rapid flow rates, . rapid changes in the chemistries of the water entering the 'ponds and be "reproducible" without the loss of any of the above parameters. Each microbe is frozen, dried. Overheated, overloaded with heavy metals, denied nutrients and must be able to encapsulate quickly when necessary, disencapsulate quickly and never lose their ability to perform their specific ecological function.

The final step before scale-up is to take each pre-tested hybrid and test the multiple combinations that comprise the whole microecosystem. The iron chelators are tested on multiple iron solutions, the sulfur chelators on sulfur forms, etc. The algae groups are to function as a unit to chelate, photosynthesize and provide enough oxygen to oxidize the predicted amounts of metals projected in each pond flow-through system. The deposition, reduction and recombination anaerobes have to bit tested to determine the order of their introduction Into the top fill dirt (based on their ecological function). Finally, the scaled-up microbes are grown in sufficiently large quantities to treat a given-system. The organisms are ' mixed with a thickening agent which forms a gelatinous product <IMPPS.> The IMPPS are then ready for transport and placement into the constructed-treatment system.

All of the above is dependent upon beginning with the correct balance in the microecosystem "planted" in the ponds. It is an exacting, time-consuming task and the key to. the success of the project. Therefore, it is essential to understand the ecological parameters of the site when the coal was formed. An in-depth micro-analysis of the coal "fines" provides data to a trained observer. A microecosystem designed to turn the treatment ponds Into a viable wetlands solves two problems. First, it provides microorganisms that have been hybridized to chelate metals and sulfur, oxidize them into harmless metal and sulfur oxides, and deposit them in a specially prepared bed of soil that will emulate the wetlands of millions of years ago. The oxidized metals and sulfur will turn back into mineable ores for the future while decomposed and compacted plant material will begin the reformation of fossil fuel for future generations.

ROBIN HOOD SITE

The treatment site is located in Boone County near Twilight and is part of Robin Hood Complex which consists of two mines, a preparation plant and refuse disposal area. Both mines are mining In the Dorothy Seam and the combined refuse exhibits a 0.17 percent pyritic sulfur and 0.36 percent total sulfur value, The mines In this area have been active for at least 80 years. Seepage from the refuse area averages 55 gallons per minute and has been collected and treated with sodium or potassium hydroxide for ten years. A typical analysis of this water is shown in Table 1.

Many combinations and ratios of site-indigenous microorganisms were tried on the Robin Hood Refuse water before the most effective combination was found. The Robin Hood site required the use of 53 different bacteria, 47 different algae, 15 different protozoans and their symbiotic fungal -groups (primarily Phycomycates).

It is impossible to pre-determine the speed with which any newly developed system will function to attain compliance. It is possible, however, to determine the scale-up ratios based on what is projected to be the goals set for the attainment of certain levels of effectiveness. Since the Robin Hood site was going into a winter environment where the ponds would layer according to thermoclines, rather than rotate to give a balanced mix throughout the ponds. (such as in the spring and fall), an adjustment had to be made. It required that the ponds be overloaded with a mix of 60% jellied and 40% liquid so that chelation, oxidation and deposition would begin immediately and continue through all winter conditions.

TABLE I - UNTREATED WATER ANALYSIS

PARAMETERS	RESULTS 10/20/88
Flow (GPM)	55.0
Temp (°C)	—
pH (Std. Units)	3.3
Suspended Solids	2.0
Dissolved Solids	1266.0
Conductivity (Micrombos/cm)	1650.0
Alkalinity	0
Acidity	99.0
Iron	35.7
Manganese	4.1
Aluminum	4.3
Sulfate	860.0
Turbidity (NTU)	9.6

*NOTE: All parameters reported in mg/l except as noted

The treatment ' system was originally designed to consist of three new ponds and an existing "polishing" pond. The ponds were constructed in October, 1988. Two of the ponds were to be treatment/deposition ponds, 100' long, 28' wide and 5' deep to accommodate for deep ice formation often found at the elevation of the site. A third pond 281 x 281 x 51 was dug to act as a concentrated "breeder pond." The 4th or "polishing pond" had a three to four year collection of sludge from the use of 45% potassium hydroxide. The caustic residue and its embedded metallic salts are even more toxic than the AMD it Is used to control. It was unknown if the microbes could survive this environment.

One lesson learned with this job was to stop before you get into the faulty shale during pond construction. This shale is part of the same formation overlying the Delaware Aquifer. It is loaded with toxic metals, sulfur often exceeding 3,000 ppm, iron greater than 700 ppm, manganese greater. than 400 ppm, aluminum at levels of 400-500 ppm and many other trace metals. such as copper, nickle, zinc and lead. The shale was encountered at 3-1/2 feet down. While the ponds needed to be deeper than 12 to IS inch solar ponds, a depth of three to four feet would have been sufficient to achieve our purpose.

Unfortunately, the ponds leaked badly. Bentonite, in conjunction with mulch. was applied in large amounts to act as a sealer. The ponds finally sealed but it took three weeks to got a steady flow through to discharge, breaking our time sequence. We, had to rely entirely on the jellied masses of microbes to do the brunt of the work when the system became functional.

On November 1, 1988. at 1:20 p.m., a tanker truck loaded with the microorganisms departed from our plant in Ohio. Its bill of lading classification was "Agricultural Food Products." The microorganisms, especially the algae and protozoans, are eaten by pond organisms. such as frogs and salamanders and are. totally harmless to animals, such as dear and raccoons that might drink water from the ponds. As stated previously, all the microorganisms used for the Robin Hood site are indigenous to that site, but not in correct ecological balance.

The tanker arrived at the Robin Hood site at 10.-50 a.m., November 2, 1988, and was able to use gravity flow to hose the microbes and jelly balls into the ponds. The inoculation of the three ponds took, approximately three hours. Water from a nearby sediment pond was pumped into a hydroseeder and then ' the tanker's power pump was used to flush the rest of the microbes and jelly-balls out of the truck into Pond No. 1. A gallon of obligate anaerobes was then added to each pond. As soon as the microbes entered the ponds, a bacterial "scum" started forming and air bubbles could be seen in various areas of Pond No. 1. The air bubbles were most prominent around straw floating on the pond surface. Straw had been used to cover the bottom of the ponds prior to inoculation.

The hydroseeder sprayed the entire site area with green (food color) dyed seeds, mulch and water. Green was used because green pulls the maximum light energy from the sun. Since the hours of available sunlight were rapidly decreasing, it was vital to get maximum energy from all available sunlight.

On November 3, we returned to the site and planted the facultative anaerobes. Most of the water had leaked out of Ponds 2 and 3 and an attempt was made to pump more water from Pond No. 4 Into them. Pond No. 1 did appear to be trying to seal and looked to be about half full. Fluorescent green dye was put Into Pond No. 1 in order to track the seepages but it did not show up in any areas we checked within a mile radius of the pond. However, since the pond colors were already faded from the day before, It was a good indicator that the microbes were actively eating -the dye. Also. since the fluorescent green dye dissipated so quickly, we added ferrocyanin dye to see if we could track the seepage, but there was no Indication of it showing up anywhere in the vicinity.

By November 4, Pond No. 1 finally appeared to have sealed and water was almost to the spillway. Enough water had been pumped into 'Ponds 2 and 3 to keep the jelly balls and microbes wet, otherwise they would have dried up and encapsulated. Every indication was positive that they were working. Pond No. 1 was completely cove ' red with the characteristic "oil slick" condition which is a combination of microbes and chelated metals and the bubbles being given off throughout the pond indicated a high rate of oxidation.

Ponds 2 and 3. were also beginning to hold 'water. Jolly-like red deposition pods had already famed on the bottom and sides of all the ponds. Since iron is the first metal to precipitate and form depositional pods, it was another observable indication that the process was already working, despite all the problems.

By 3:00 p.m. on November 4, the water in Pond No. I finally reached the spillway and started to flow into Pond No. 2. Grab samples were taken and field analyses were performed.

Analytical results were -as follows: the redox was 628 mv, the specific conductance was 1,260 u mohs, the pH was 4.3, the manganese was 9-10 ppm and the iron was <-19 ppm. If the grab samples were any indication, we probably lost half or more of the Jelly balls and 3/4 of the free-flowing bacteria through leakage. Wherever the water was going, the microbes were going with it. However, there were still an adequate number left to do the job and they still appeared to be doubling every 24-36 hours.

As soon as the water breached the spillway* the sandstone rocks and straw showed signs of red deposition and possibly more sulfur deposition. Sandstone is porous and acidic enough to prevent ther kind of discoloration found on limestone, which is why sandstone rocks were chosen for the spillway liner. Straw bales were arranged in a "V" formation and placed in the pond spillways in order to direct the . flow downward into the receiving pond. With 70% or more of the microbes growing on the bottom of the ponds, it is important to do whatever possible to direct the water flow to. the bottom for the most efficient usage of the pond's microbial population.

It is also important to note that while the sun is on the ponds (these get. the morning sun, which is the best) the microbial "mats" will rise to the top. On very cold- and/or overcast days, and at night, the mat drops to the bottom 3-31/2' of the ponds' Energy to "run" the system is both photosynthetic (requiring sunlight) and chemosynthetic, due to the many chemolithotrophs and related organisms in the ponds. There is no Oxygen produced by chemosynthesis, however, so the photosynthetic activity is the more desirable of the two.

Luckily, November, December and January were extremely mild for Boone County and the ponds did appear to achieve a balanced system. Ponds five feet deep were used at the Robin Hood site to allow for a freeze as deep as three feet with no compromise to the system. With ice on top, all water goes to, and stays sit the bottom, where the majority of the "bugs" function. In the summer, even in drought conditions. the ponds are deep enough to maintain continuity of cleaning. During the spring and fall. the natural "turning of the waters" in a cyclical pattern from bottom to top and back maintains equilibrium. In the situation we have been in all winter, with no cyclical pond activity and no freezing. the eighteen inch deep Pond No. 4 acts as a solar pond to continue the chelation/oxidation/deposition cycle until water from this pond Is discharged Into a soda ash bed to raise the pH for discharge into a nearby stream.

As previously mentioned, the basic data determined by the site study produced soil and water samples that showed the existence of 53 bacteria, 47 algae and 15 protozoans that are Indigenous to the soil and/or water at the Robin Hood mine site. These are, however, in their existing state, totally out of ecological balance. The result is acid mine drainage and the subsequent acidification of the soil and water coming in contact with the effluent discharged from the site.

Analysis of *the coal fines produced microbes that were indigenous to the same area three to four hundred million years ago when the coal was being formed. The microbes ability to decompose plant material into fossil fuel and metals, and soil into ores made them highly desirable in the final stages of the process. The other presently existing microbes, In ecological balance, showed tremendous potential for the chelation, oxidation and deposition of metals, even to the point of neutralizing the acidic drainage back to the historical norm of the area (pH 4.8 is normal for Boone County).

The hybridization of the microbes made them larger and stronger, with thicker "slime coats" (enhancing their chelation potential). These hybrids also reproduced faster than the normal strain. Even the algae and protozoans demonstrated the ability to produce similar protective coatings under extreme environmental stress. With these coats,, they can encapsulate and/or ensporolate until the environmental conditions are once again to their liking,, and then return very quickly (in a matter of hours) to their normal state. Their performance was in no way diminished by this process.

It would have been ideal to have Inoculated the ponds in the spring or even early fall. By knowing the problems normally encountered by microbes in a winter ecosystem, we were able to plan for the worst and maintain balanced ponds without the added advantage of. the weather conditions and the natural cyclical "turning over" of the ponds, which occurs In the spring and fall. Once ' thermocline layering is achieved In the winter and summer, it is exceedingly difficult to get the blend of microbes needed throughout the ponds. Despite a November 2- planting date, when the thermoclines would be well established in distinct layers. an acceptable balance was reached in all four of the ponds.

The major problem was the leaking pond. When shale was encountered at 3-1/2 feet in digging the ponds, the engineering drawings should have been modified to show a 3-1/2 foot pond instead of a five to six foot deep pond. Our intrusion into the shale bad (which is exceedingly heavy in toxic metals) made the ponds difficult to seal. Core samples, compaction tests and sedimentation tests should have been utilized prior to construction. West Virginia's sandstone/shale rock produced soil is difficult to seal even under ideal conditions because of the lack of clay and other natural adhesive material in the soil.

RESULTS AND PRELIMINARY CONCLUSIONS

Water analyses have shown the iron and manganese to-be progressing toward compliance since January. Table 11 Indicates that the discharge from Pond No. 3 has shown an average decrease in iron of 45% and a slight decrease in manganese.

Also, as seen in Table III, Pond No. 4 has also provided some interesting results. Not only did the microbes survive in this "toxic" environment, they have established themselves as a permanent cleaning system and have pulled out the metals embedded in the sludge and oxidized them into harmless compounds. and redeposited them. Gradually, the sludge pond is being restored as a viable part of the wetlands cleaning system.

Considering all the factors involved and the brief time the ponds have been in operation, it would appear that the process is a successful demonstration of the ability of a single treatment of microorganisms to reduce metallic leachate from refuse sites. The iron influent is between 33 and 53 ppm and the manganese between 7 and 22 ppm. Effluent from Pond 4 has ranged from 1.8 to 22 ppm Iron and 0.9 to 4.0 ppm manganese. The ponds. for the most part. have maintained a high turbidity level and the deposition pods are' appearing in a very predictable manner. with iron and sulfur deposition followed by manganese- and aluminum deposition. While the approach and processes are unique,, this system has unlimited potential to give us clean water and soil while saving the mining industry millions of dollars now spent on treating AMD.

TABLE III

POND NO. 4 - DISCHARGE

1989

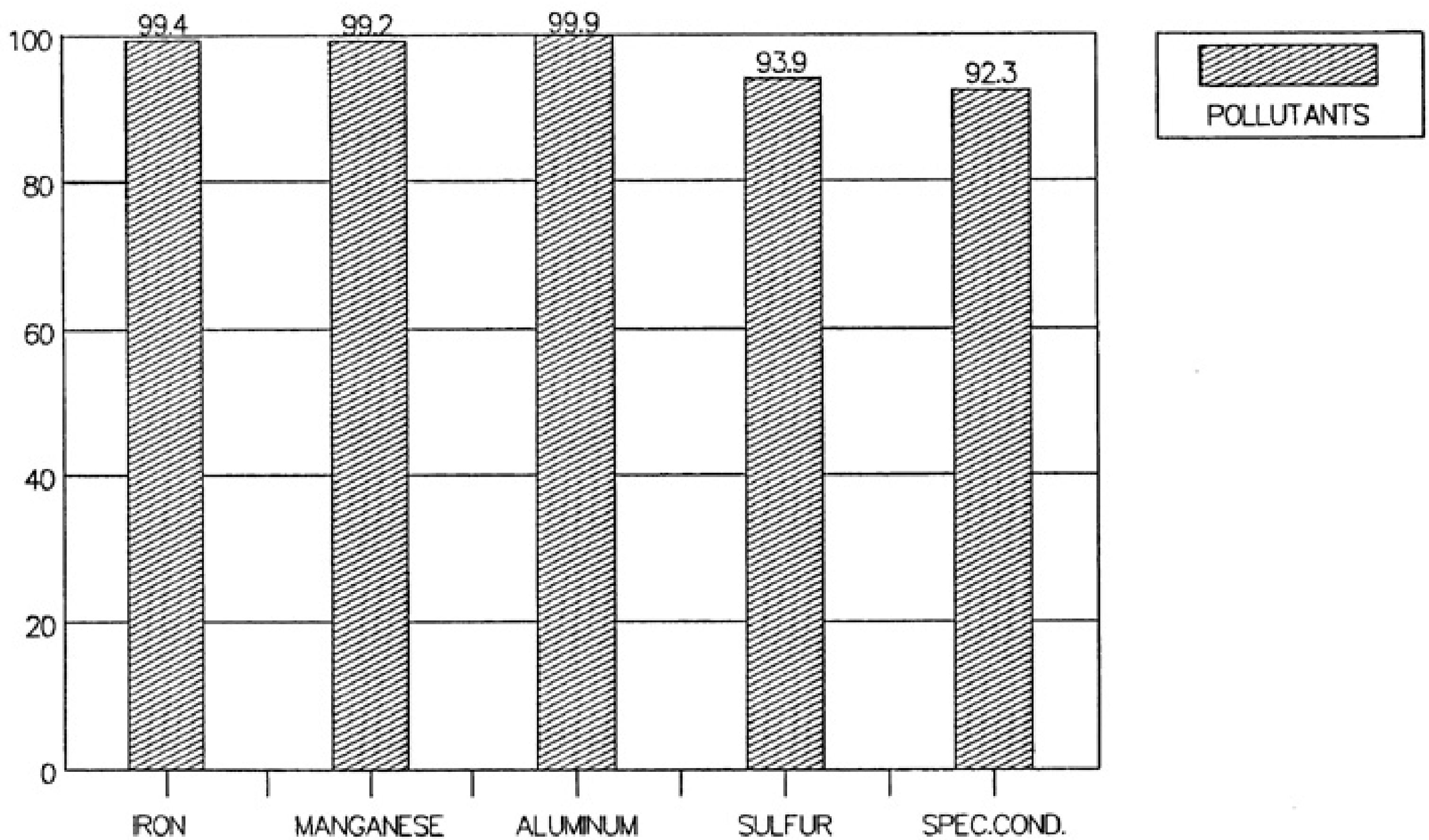
PARAMETERS	1/25	1/31	2/3	2/9	2/23	3/23*	3/27*	3/30*	AVG. VALUES
Flow (GPM)	40.0	65.0	60.0	60.0	60.0	60.0	60.0	65.0	58.8
Temp (°C)	8.5	9.7	11.0	11.1	11.0	19.6	19.8	20.0	13.8
pH (Std. Units)	3.7	3.4	7.8	5.5	7.1	6.1	5.9	4.6	5.5
Suspended Solids	--	34.0	2106.0	6.0	68.0	--	222.0	--	487.0
Dissolved Solids	--	1270.0	498.0	1158.0	856.0	--	1405.0	--	1037.0
Conductivity (Micromhos/cm)	--	1620.0	700.0	1380.0	1070.0	--	1610.0	--	1276.0
Alkalinity	--	0	143.2	5.8	33.8	--	8.7	--	38.3
Acidity	--	62.0	-104.1	28.4	-18.4	--	29.5	--	-0.52
Iron	12.0	11.6	22.0	7.6	1.8	9.2	14.1	12.7	11.4
Manganese	4.0	3.9	1.2	2.4	1.1	1.1	4.3	0.9	2.4
Aluminum	--	3.4	11.6	0.9	0.4	--	2.8	--	3.8
Sulfate	--	862.0	284.0	444.0	532.0	--	920.0	--	608.0
Turbidity (NTU)	--	33.0	36.0	13.0	45.0	--	100.0	--	45.4

NOTE: All parameters reported in mg/l except as noted

* Water level reduced from 24" to 3" or less

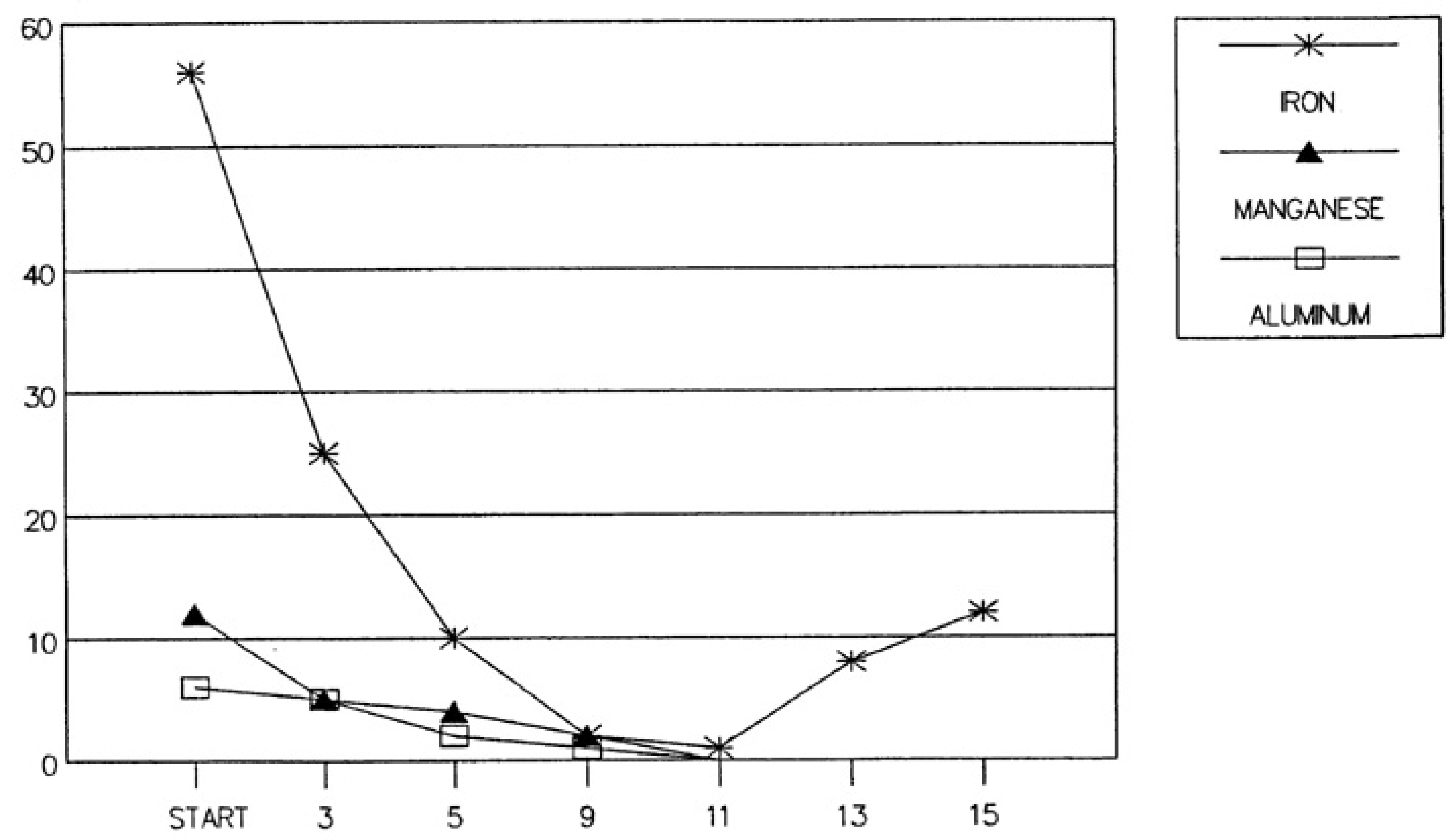
PERCENT OF POLLUTANT REMOVAL

ROBIN HOOD MINE 11/88–2/89



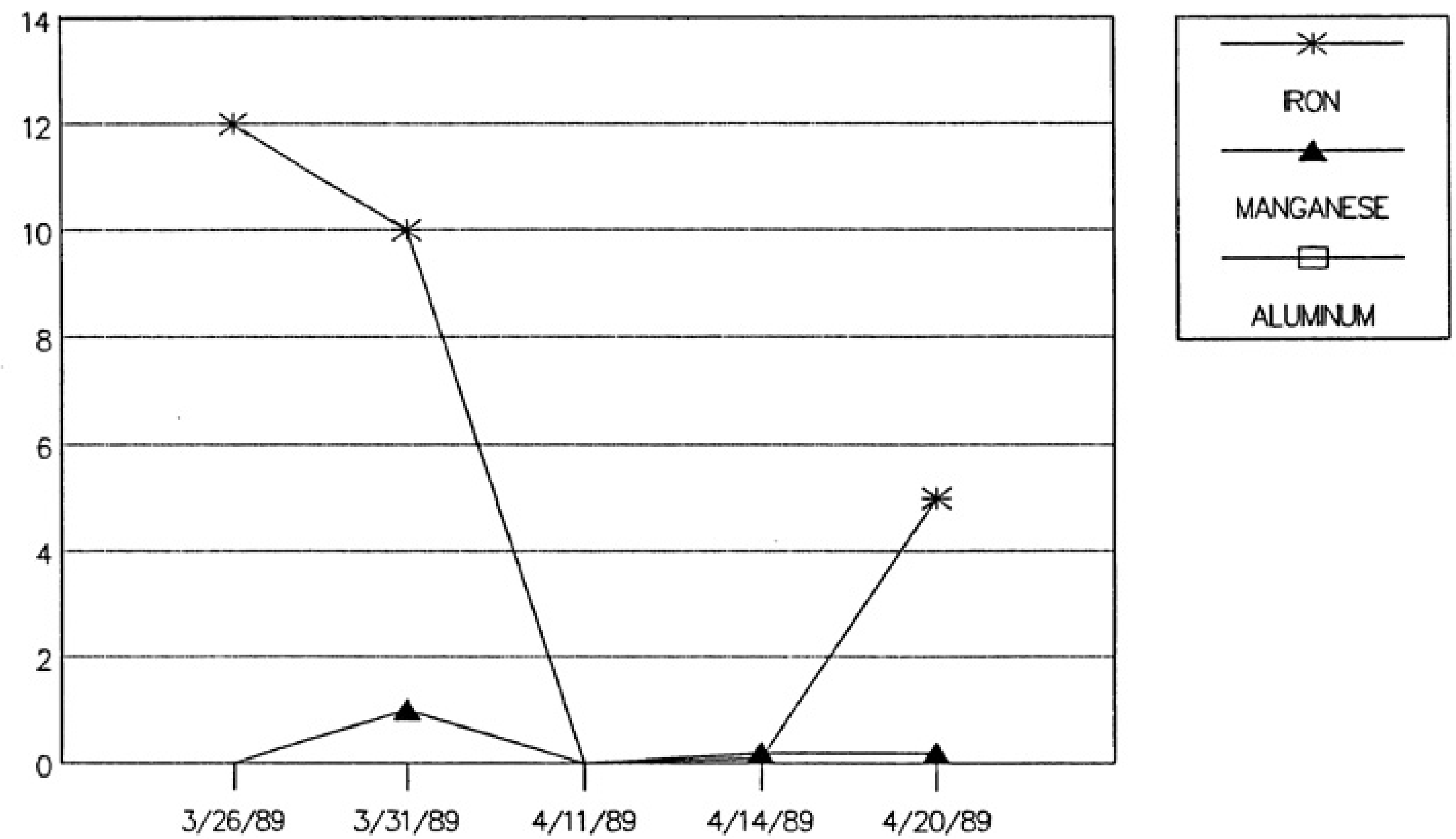
ROBIN HOOD MINE

REDUCTION OF METALIC POLLUTANTS



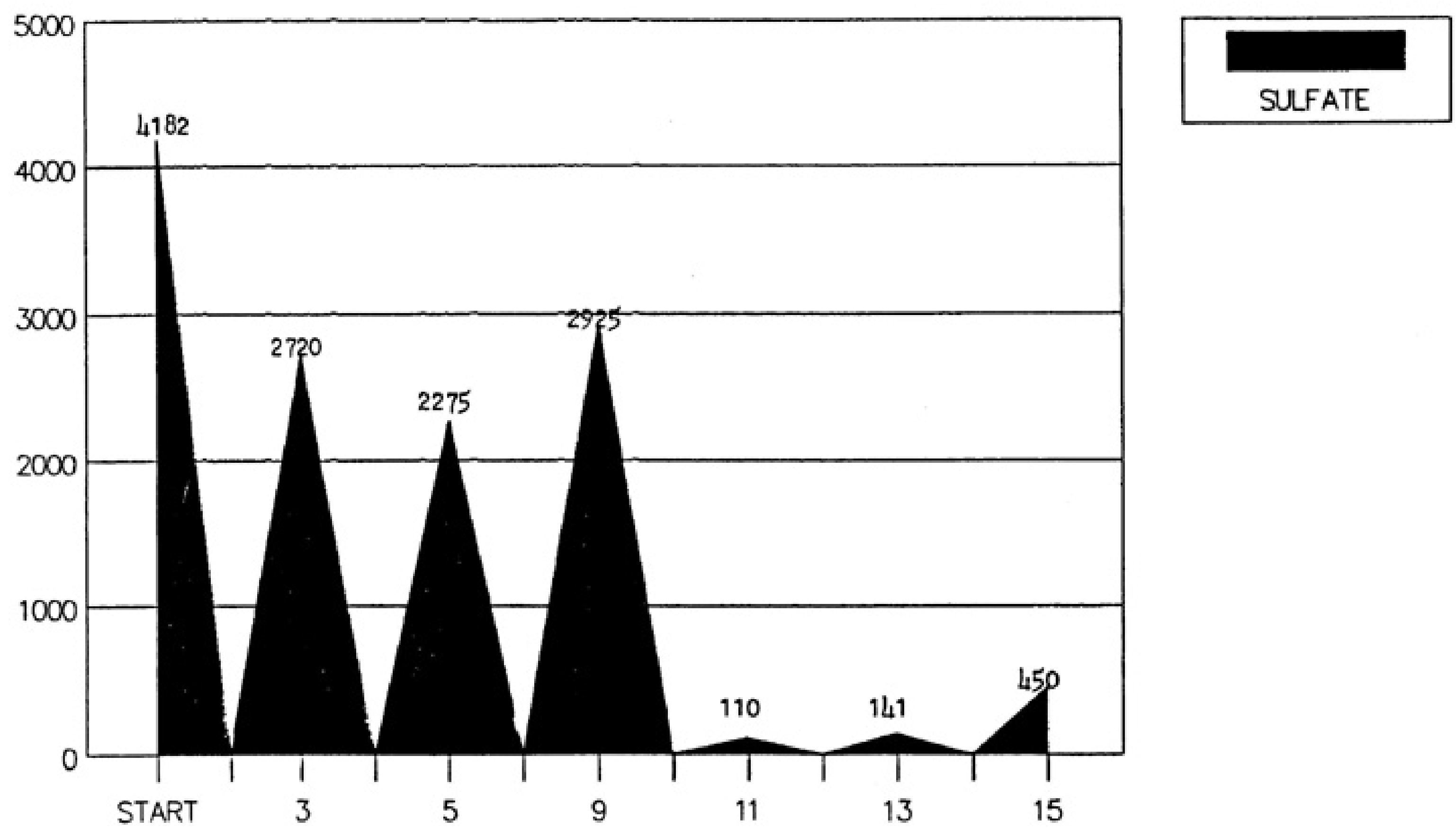
ROBIN HOOD MINE

REDUCTION OF METALIC POLLUTANTS



ROBIN HOOD MINE

REDUCTION OF SULFATE



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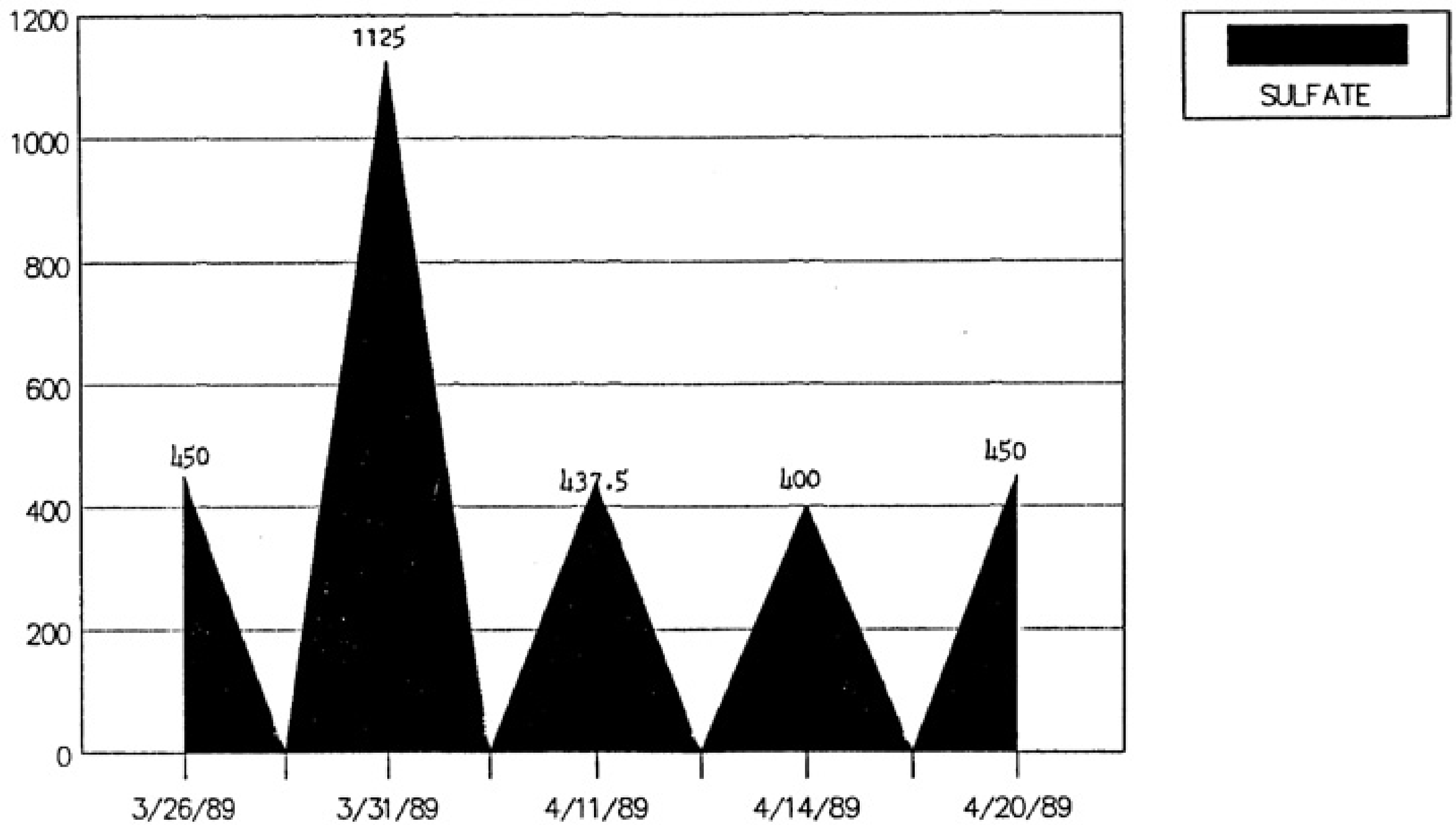
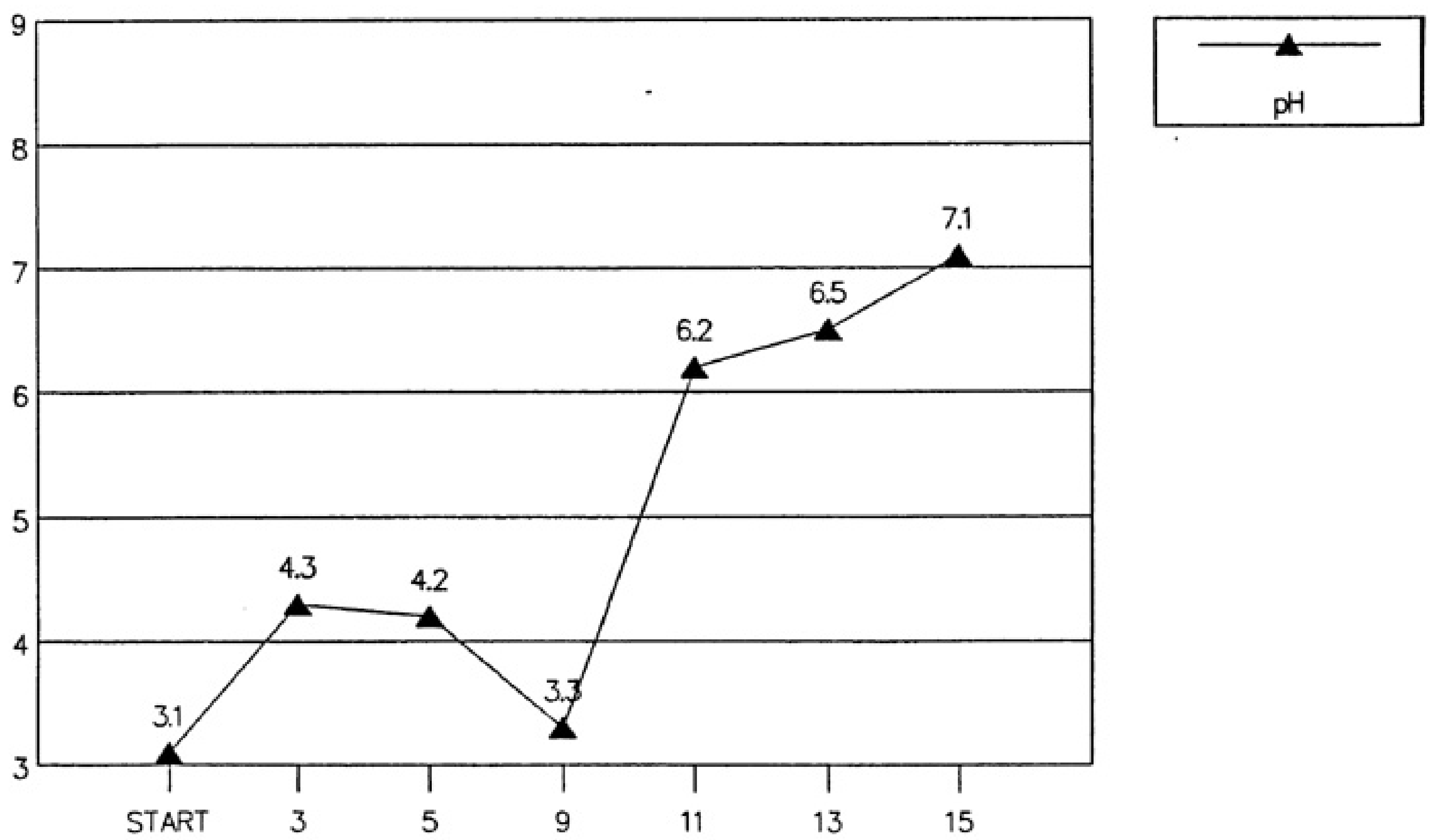


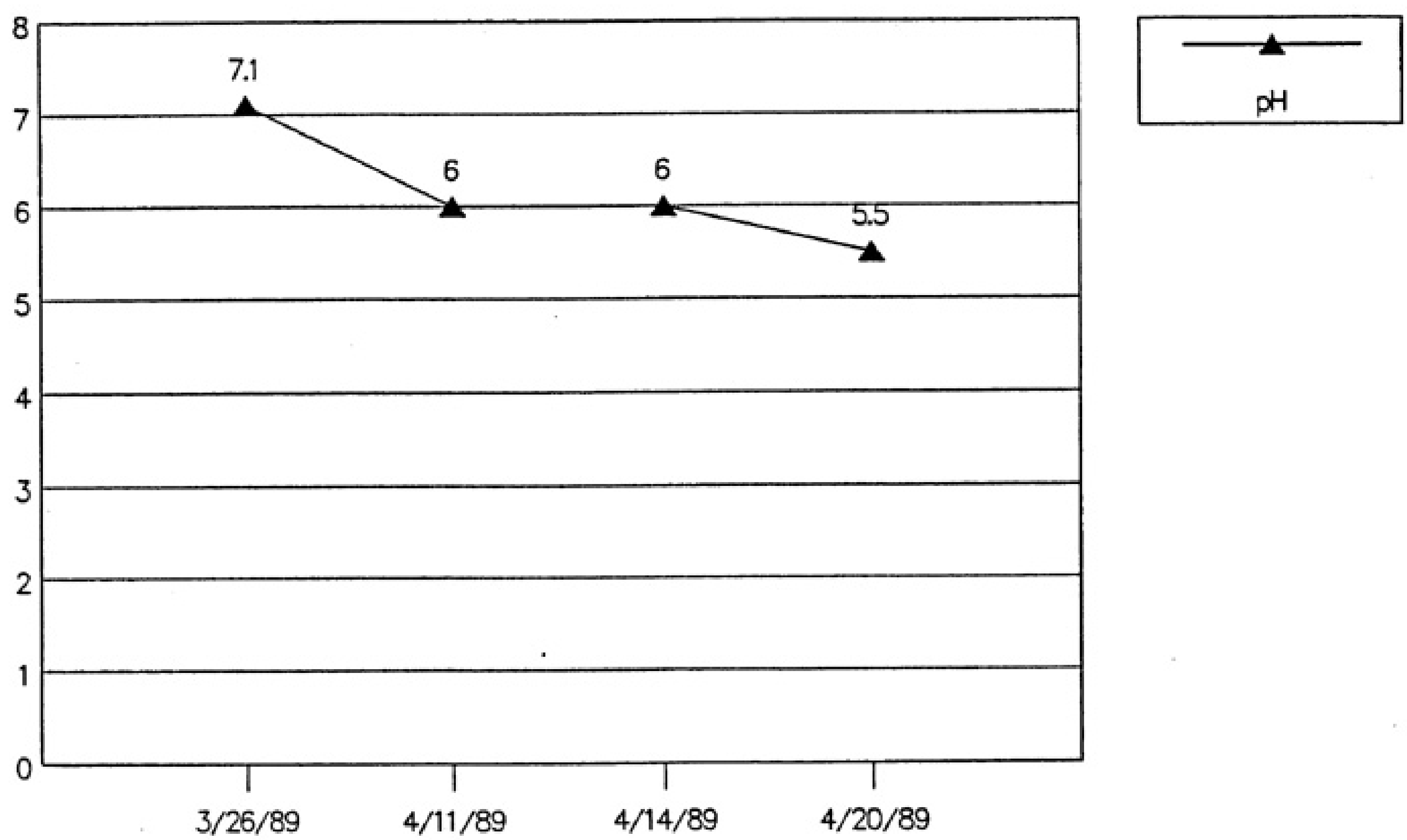
ROBIN HOOD MINE

REDUCTION OF pH



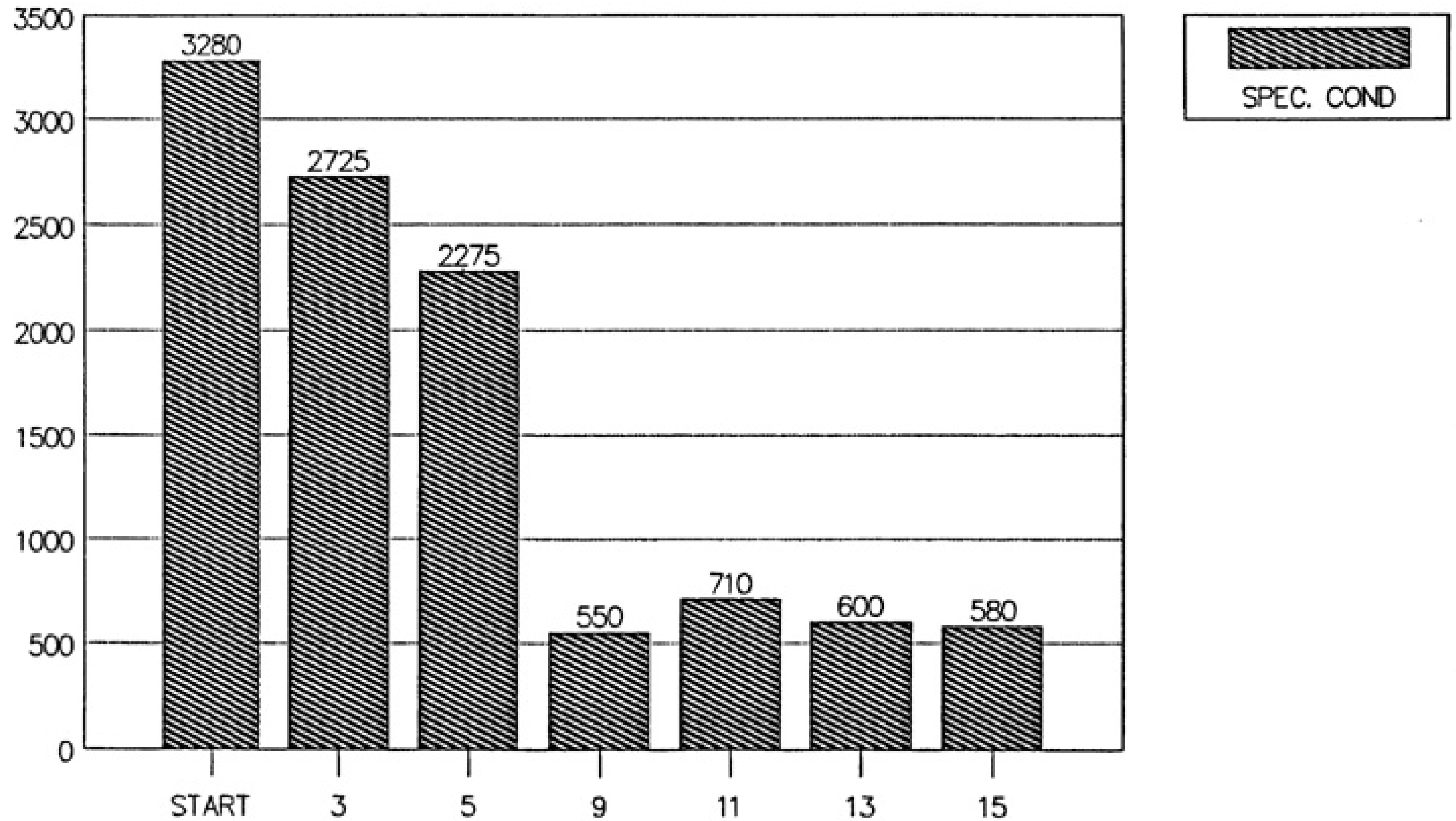
ROBIN HOOD MINE

REDUCTION OF pH



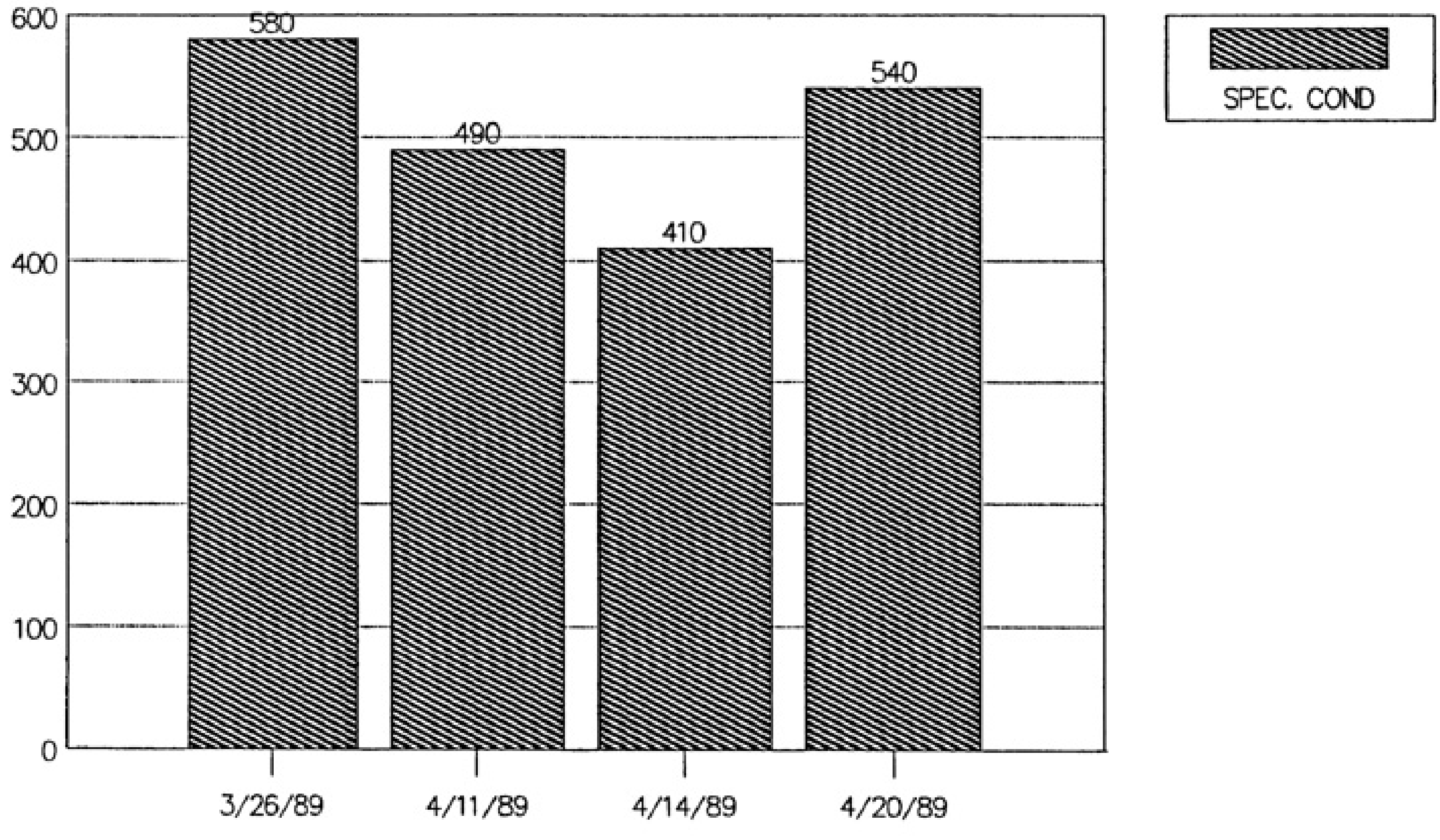
ROBIN HOOD MINE

REDUCTION OF SPECIFIC CONDUCTANCE



ROBIN HOOD MINE

REDUCTION OF SPECIFIC CONDUCTANCE



ROBIN HOOD MINE

REDUCTION OF FERROUS FE