EVALUATION OF A LIMESTONE CHANNEL AND WETLAND SYSTEM FOR TREATING ACID MINE DRAINAGE[1]

Fred J. Brenner and Patrick Pruent[2]

Abstract. The Carpentertown Coal and Coke Company operated two drift mines on the site for 17 years closing in December 1987, but the company continued to operate a cleaning plant and coal refuse disposal site until the company declared bankruptcy in June 1989. In summer of 1993, eight acid seeps developed from the 2 ha coal refuse site with a combined flow of 36 l/min with iron and manganese loading rates of 419 and 576 gm/day. In 1995, a 212 m (700 ft) open limestone channel (OLC) and a 344 m^2 (1142 ft^2) and a 2110 m^2 (43,750 ft^2) aerobic wetland was constructed as a passive treatment system. Over the 34-month monitoring period, the acid loading to the receiving stream was reduced by 88 % with a corresponding increase of 111% in alkalinity. The iron and manganese loading to the receiving stream was reduced by 91% and 57%, respectively.

Additional Key Words: acid mine drainage, abatement.

Introduction

During the last two decades, a variety of passive treatment technologies have been developed to treat acid mine discharges. These primary passive treatment systems include constructed wetlands, anoxic limestone drains (ALD), vertical flow wetlands (VFW), limestone ponds, and open limestone channels (OLC). numerous studies (i.e. Hedin 1989, Brenner et al.1993, 1995, Brodie 1993, Hellier et al. 1994, Stark et al. 1994, Kleinmann 1998) have demonstrated the effectiveness of wetlands in removing metal from acidic mine discharges. But, the effectiveness of these systems decline when mine sites have a net acidic discharge. Many of these passive treatment systems, therefore, often include a combination of limestone drains or channels to increase alkalinity, settling basins for precipitated Fe flocs and a series of aerobic wetlands for the additional removal of Fe and Mn (Brodie 1993). Although ALDs are effective in reducing acidity and removing metal from acid discharges, elevated aluminum concentrations may precipitate to clog the drain so that the system is no longer functional in treating AMD. This problem, however, does not occur with open limestone channels (OLCs) designsigned to introduce alkalinity into acidic discharges by limestone dissolution (Ziemkiewicz 1994). It is often assumed that the amorization of limestone by Fe and Al hydroxides decreases its effectiveness in reducing the acidity. But

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Ziemkiewicz et al. (1997) reported armored limestone to be 50 to 90 % as effective in neutralizing acid as unarmored limestone, while seven OLCs reduced acidity in mine discharges from 4 to 62%. Other studies (Pearson and McDonnell 1975, Ziemkiewicz et al. 1994) demonstrated that armored limestone continues to dissolve after coating at between 20-50% of that of unarmored limestone. Skousen (1997) suggested that utilizing OLCs in conjunction with other passive systems can maximize treatment and metal removal. Therefore, because of the potential problem with aluminum precipitate (4-6 mg/l) in ALDs, OLCs were incorporated in an aerobic wetland system to treat acid discharges at the Carpentertown Coal and Coke Company site located in Pine and Boggs Township in Armstrong County in southwest Pennsylvania.

The Carpentertown Coal and Coke company operated drift mines and a cleaning plant on the site from the early 1970s until December, 1987, but the cleaning plant continued to operate until the company declared bankruptcy in June 1989. The Mahoning Creek No 1 Mine was opened in the early 1970s and operated until the Mahoning Creek No 2 Mine was permitted in 1983, which operated until December 1987 when the mine was sealed. In December 1994, the company was issued a coal refuse permit to operate a 2 hectare (5 acre) coal refuse disposal on the site which was re-issued in October 1991. Although no acidic discharges resulted from either of the Mahoning Creek mines (Table I), by the summer of 1993, 8 acidic discharges with an average combined flow of 36.3 l/min (range 26.4 - 46.2 l/min.) and iron and manganese loading rates of 419 and 576 gm/ day, respectively, developed in the area of the reclaimed cleaning plant and coal refuse disposal site, impacting Scrubgrass Creek. During this same period, erosion and sedimentation control structures were not being maintained and erosion problems existed along the haul roads on the site in violation of the Pennsylvania Clean Streams Law.

Design Criteria

A passive treatment system consisting of a 212 m (700 ft) open limestone channel, a 344 m^2 (1142 ft^2) settling basin and a 2110 m^2 (34,750 ft^2) aerobic wetland was designed to treat the discharges from the reclaimed mine site. The wetland was divided into two cells with limestone rip rap between each of the cells to provide alkaline addition. The wetland discharged into a previously existing 138 m^2 (1500 ft^2) cement retention basin and then into Scrubgrass Creek (Fig.1). Seven of the eight discharges were collected into the OLC and the remaining seep discharged into a limestone rip rapped 236 m (780 ft) intermittent stream channel with 4 limestone gabons placed in the channel at approximately 76m (250 ft) and 91m (300 ft) intervals along the channel (Fig 1). The size of the wetland was based on metal loading according to the criteria proposed by Hedin (1991) where: wetland size m^2 = iron load/ 10 + manganese load / 0.5. According to these criteria, a 1030 m^2 (11,236 ft^2) wetland would be required to treat the 8 discharges occurring on the site; however, in order to insure adequate treatment, the size of the wetland was increased by 48.8% to provide for a total retention time of 41 days within the wetland system. The wetland substrate conisted of 30 cm (12 inches) limestone

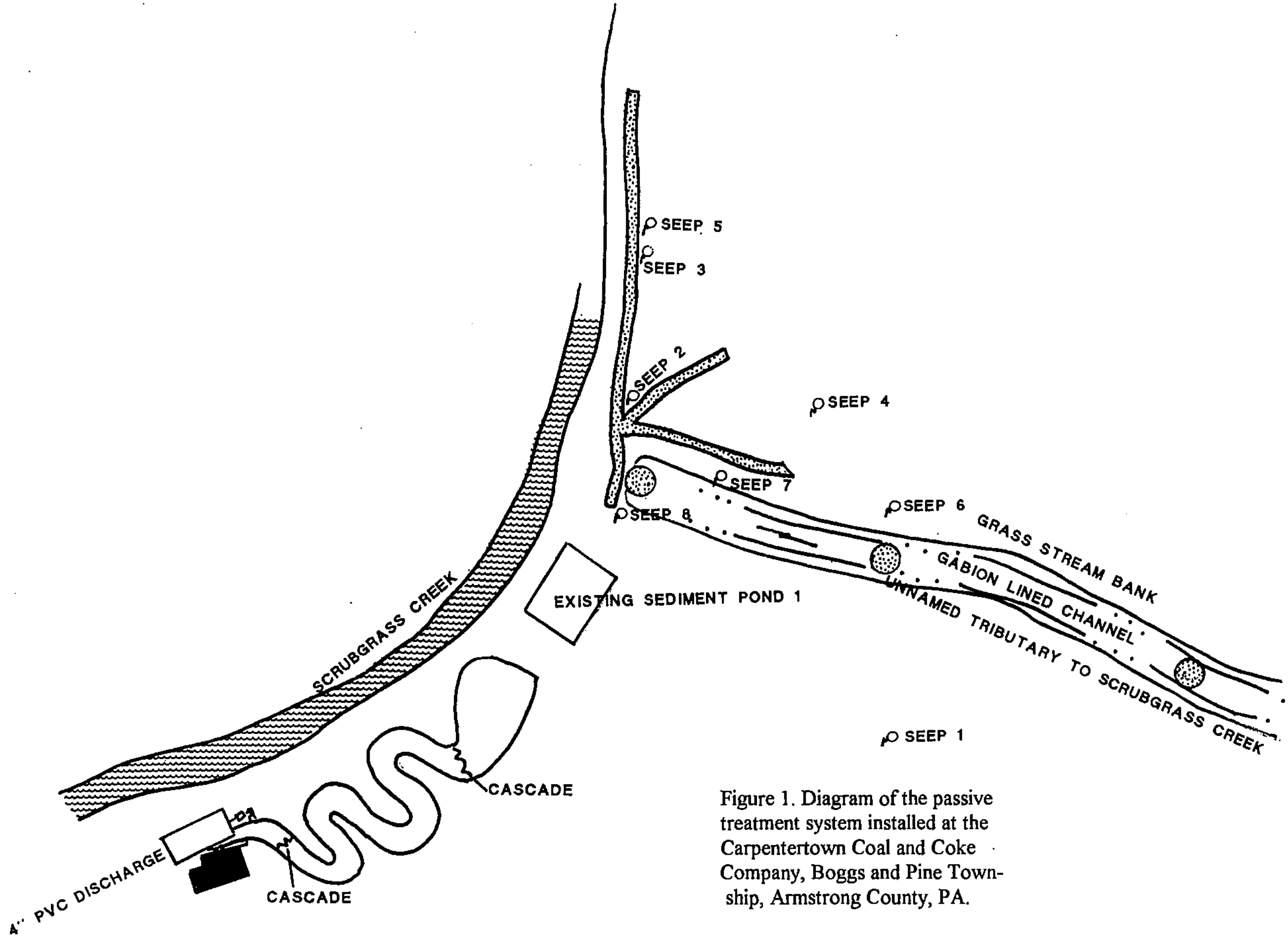

Figure 1. Diagram of the passive treatment system installed at the Carpentertown Coal and Coke Company, Boggs and Pine Township, Armstrong County, PA.

Table 1. Comparison of the water quality parameters from the Mahoning Creek No 1 and No 2 mines at the Carpentertown Coal and Coke Company, Pine and Boggs Township, Armstrong County, Pennsylvania (N=35/mine).

	Mahoning Creek No 1		Mahoning Creek No 2	
Parameter	Mean	Range	Mean	Range
Ph	7.86	6.90-8.33	8.01	7.00-8.31
Alkalinity (mg/l)	288	272-312	316	266-344
Acidity (mg/l)	<2	--------	<2	---------
Total Iron (mg/l)	0.18	<0.5-0.45	1.69	0.37-3.43
Manganese (mg/l)	0.10	<0.5-0.25	0.14	<0.05-0.24
Aluminum (mg/l)	0.05	0.13-0.15	0.38	0.15-1.15
Sulfates (mg/l)	161	87-198	188	125-230
Suspended Solids (mg/l)	11	2-18	9	<2.0-22

base and 35 cm (18 inches) of mushroom compost with a maximum depth of 15 cm (6 inches). Cattails (*Typha latifolia)* were planted at an initial density of one plant per 30 cm. In addition to the wetland and limestone drainage channels, the site was regraded and limestone diversion channels were installed along the slopes. The site was seeded with a grass and legume mixture. The overall reclamation plan was submitted to the Pennsylvania department of Environmental Protection on 8 June 1995 and construction of the open limestone drain and wetland was completed in the fall that year. The total cost of the site reclamation and treatment system was $99,244 which did not include engineering and design.

Results and Discussion

Upon completion of the Open Limestone Channel (OLC), the pH of the collected discharges increased from a mean of 4.38 to 5.05 (15.3 %), along with a corresponding decline of 63.4 % in acidity ($\bar{X}$ 154 to 56.3) and the addiition of 26.3 mg/l of alkalinity to the discharge. Once the acidic discharges entered the OLC, it was not possible to sample each discharge before and after treatment within the system. After the first year the pH of the discharge from the OLC prior to entering the constructed wetland increased from 4.68 to 5.25 (12.1%), but the acidity and alkalinity of the discharges entering the wetland did not vary among the three years of study (Table II). Although the effectiveness of the OLC and aerobic wetland varied seasonally, as well as among the three years of the study, the passive treatment sys-

Table II. Comparison of the changes in the parameters before and after passive treatment at the Carpentertown Coal and Coke facility, Boggs and Pine Townships, Armstrong County, PA between 1996 and 1998 .

	1996		1997		1998	
Parameter	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ph						
Before Treatment	4.68	0.18	5.25	0.22	5.21	0.23
After Treatment	7.02	0.56	6.78	0.50	6.31	0.33
% Change	50.0		29.1		21.1	
Acidity						
Before Treatment	60.3	10.9	53.6	17.0	55.1	12.3
After Treatment	4.9	2.1	2.7	1 .7	12.1	3.6
% Change	91.9		95.0		78.0	
Alkalinity						
Before Treatment	21.2	7.2	26.3	6.8	31.5	7.4
After Treatment	43.0	4.9	47.3	8.4	76.6	6.0
% Change	103.3		79.8		143.2	
Iron						
Before Treatment	7.8	2.8	8.1	0.8	6.7	2.5
After Treatment	0.7	0.1	0.8	0.1	0.5	0.1
% Change	90.9		98.7		92.4	
Manganese						
Before Treatment	12.0	2.3	10.7	0.8	11.4	2.5
After Treatment	6.7	1.2	3.2	0.5	4.7	1.1
% Change	41.2		70.1		58.8	
Suspended Solids						
Before Treatment	31.6	8.4	23.8	5.1	18.3	3.4
After Treatment	20.6	8.7	7.7	5.9	8.8	2.8
% Change	53.4		67.6		53.2	

tem was effective in reducing the acidity and heavy metal discharges into Scrubgrass Creek. From 1996 through 1998, the average Ph of the discharge from the wetland system increases approximately 33% ($\bar{X}$ = 5.05 to 6.70). the average acidity declined 89% (X = 56.6 6.6 mg/l) with a corresponding average of 109% in alkalinity ($\bar{X}$ = 26.3 to 55.6 mg/l) (Table III). Although the limestone in the channel became armored over the three years, it remained effective in reducing the total acidity of the discharge. Over the three years of monitoring, the system was effective in removing over 91% and 57% of the iron and mangan-

Table III. Comparison of the changes in chemical parameters during the growing season and winter months at the Carpenter Town Coal and Coke Company, Boggs and Pine Township, Armstrong County, PA

Parameter	Growing Season Mean	S.D.	Winter Months Mean	S.D.	Overall mean	S.D.
Ph						
Before Treatment	5.36	0.80	4.74	0.25	5.05	0.07
After Treatment	6.40	0.41	6.91	0.53	6.66	0.13
% Change	19.4		45.7		31.9	
Acidity						
Before Treatment	56.5	8.4	56.2	14.4	56.3	1.9
After Treatment	6.1	2.2	7.1	3.0	6.6	1.0
% Change	89.2		87.4		88.8	
Alkalinity						
Before Treatment	24.9	2.3	27.6	4.8	26.3	2.3
After Treatment	43.5	7.6	67.8	17.8	55.6	10.1
% Change	74.7		145.7		111.4	
Iron						
Before Treatment	8.3	0.6	6.7	0.5	7.8	0.3
After Treatment	1.0	0.06	0.4	0.01	0.7	0.04
% Change	88.0		94.0		91.0	
Manganese						
Before Treatment	13.0	0.6	9.9	0.9	11.5	0.3
After Treatment	5.5	1.9	4.2	1.9	4.9	0.5
% Change	57.7		57.6		57.4	
Suspended Solids						
Before Treatment	26.0	2.5	23.6	6.7	24.8	3.0
After Treatment	15.0	1.0	9.3	7.4	12.2	3.5
% Change	42.3		60.6		50.8	

ese, respectively, from the discharge. The total iron was reduced from an average of 6.6 mg/l to 0.7 mg/l after treatment and manganese was reduced an average of 6.6 mg/l ($\overline{X}$ = 11.5 to 4.9 mg/l) after passing through the wetland system. The system was also effective in reducing suspended solids with an average decrease of 58% (24.8 to 12.3 mg/l), which is an additional benefit of the system as designed.

Although there was not a seasonal variation in acidity, alkalinity or iron and manganese concentrations in the discharges entering the wetland during the winter months, alkalinity production and metal removal was greater during the winter months (Table III). Alkalinity increased approximately 146% during the winter compared to 75% during the growing season. Likewise, during the winter months, the removal of iron aver- aged 94% compared to 88% during the growing season and manganese removal aver- averaged 67.1% in the winter compared to 44.% during the growing season. A similar phenomena occurred during the winter months compared to 33% in the growing season (Table III). Brenner et al. (1993, 1995) suggested that the seasonal variation in metal removal and alkaline addition in acid mine drainage treatment wetlands may be result of variation in bacteriological activity. These authors also suggested that bacteriological activity and metal reduction was related to pH in that it was significantly greater in more alkaline wetlands, especially if the wetland becomes anaerobic during the winter months. Although bacteriological activity was not determined at the Carpentertown Coal and Coke system, it may be a factor in seasonal variations in metal removal in this system.

The combined OLC and wetland system reduced the acidity loading into Scrubgrass Creek from an average of 2919 to 342 gms/day (88.2%) with a corresponding increase in alkalinity from 1363 to 2882 gms/day (111%). Likewise, iron and manganese loading was reduced from 404 to 36 gms/day (91%) and 519 to 215 gms/day (51%), respectivity and there was a 51% reduction (12- (86 to 632 gms/day) in suspended solids loading into Scrubgrass Creek.

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