TREATMENT OF DISCHARGE FROM A HIGH ELEVATION METAL MINE IN THE COLORADO ROCKIES USING AN EXISTING WETLAND

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Abstract. During the summer of 1986, discharge from the Pennsylvania Mine was diverted into a natural sedge wetland in an experiment to assess the metal removal capability of a wetland type common to the higher elevations of the Rocky Mountains. The Pennsylvania Mine is an abandoned metal mine located at an elevation of 3355 m in the Peru Creek basin of Central Colorado. Surface discharge from the mine averages 380 L/min with a mean pH of 3.6 and average concentrations (in mg/L; n = 6) of the following metals: Fe, 50; Zn, 25; Mn, 20; Al, 15; Cu, 6; Sr, 0.7; Cd, 0.1; Ni, 0.1; and Pb, 0.1. During the course of the investigation it was determined that the wetland was heavily contaminated with metals prior to the experiment, apparently coming from metal-laden surface and colluvial waters. Soil metal concentrations (mg/kg; n = 12) averaged: 23,195 for Al; 100,899 for Fe; 159 for Mn; 3876 for Cu; 3713 for Zn; 3.17 for Ni; 42.2 for Cd; and 921 for Pb. Total soil metals per se was not correlated with the qualitative health of plants in the wetland, but high concentrations of copper, zinc, nickel and cadmium were associated with poor plant health. Because of the low hydraulic conductivity of the peat soils (10^{-3} to 10^{-4} cm/sec) the ability of the fen to accommodate drainage from the adit was limited and the experiment was terminated. However, the study demonstrated that the plant species present (mainly *Carex aquatilis*) have a high tolerance for metals and low pH and thus have good potential for use in constructed wetland treatment systems in the Rocky Mountains.

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INTRODUCTION

Mine drainage and leachate from mine spoil and mill tailings are serious water quality problems in some parts of Colorado. Eight Superfund sites are focused on the clean-up of wastes from decades of mining activity, and a recent study (Lewis et al. 1987) estimated that out of a total of 29,766 km (18,500 mi) of streams and rivers in the state, over 6200 km (3000 mi) have dissolved metal concentrations that exceed basic standards for aquatic life, agricultural use, or domestic water supply. Approximately 2,896 km (1,400 mi) of that mileage is considered to be a direct result of pollution from inactive mining operations. These problems have spawned an interest by Colorado agencies to investigate passive treatment methods for mine drainage abatement. While such methods commonly are used in coal mining regions of the eastern U.S., colder climates, rougher terrain, and greater amounts of heavy metals in the Rocky Mountain mineral belt have impeded direct transfer of this technology to many western areas.

This paper reports the results of one such investigation conducted during the summer and fall of 1986 when a natural high-elevation wetland was used in an attempt to treat discharge from an inactive mine.

While the treatment attempt met with poor success, the project provided an opportunity to assess metal accumulation in soils and native plants, and tolerance of the plants to high metal concentrations. Biological and geochemical processes that are responsible for metal retention in mountain wetlands are poorly documented. The work described here is being conducted with the aim of increasing the knowledge of these processes, thus leading to the development of criteria for the feasibility and design of constructed wetlands to treat mine drainage at high elevations in the Rocky Mountains.

SITE DESCRIPTION

The Pennsylvania Mine, located at an elevation of 3355 m (11,000 ft) near Peru Creek in the Front Range of central Colorado, is an inactive gold and silver mine with thousands of meters and many levels of underground workings. Surface discharge from the mine averages 380 L/min with a mean pH of 3.6 and mean concentrations (in mg/L; n = 6) of the following metals: Fe, 50; Zn, 25; Mn, 20; Al, 15; Cu, 6; Sr, 0.7; Cd, 0.1; Ni, 0.1; and Pb, 0.1. The mine drainage seriously impacts Peru Creek, and in many ways is typical of mine drainage problems in the Colorado mineral belt. Prior to this study, the discharge from the Pennsylvania mine flowed in a ditch from the adit to Peru Creek, dropping approximately 25 m over a distance of 150 m.

During a portion of this study, mine drainage was diverted into a 1.6 ha wetland located approximately 180 m from the mine and a few meters above the Peru Creek channel. The wetland is technically a fen, since it is underlain by highly organic soils and is receiving nutrients and water from sources other than precipitation (Daubenmire, 1968). It is dominated by a near monoculture of water sedge (*Carex aquatilis*) interspersed with patches of bog birch (*Betula glandulosa*) growing on many of the larger hummocks. The soil surface is covered by 1 to 5 cm of water over much of the wetland throughout the growing season. Soils are characterized by accumulations of peat to depths of up to 2 m. The upper 10 cm of soil averages 41 percent organic matter, with the texture of the inorganic fraction typically loam or clay loam. Over much of the wetland the upper 3-4 cm of soil are oxidized and are characterized by reddish iron oxyhydroxides, and below this depth the soil consists of gray to black reduced sediments with an occasional strong smell of hydrogen sulfide. Ruins of several mine buildings including a small mill are located just above the wetland, and mill tailings cover the surface of the western third of the wetland. The majority of plant and soil samples taken for characterization of "natural" conditions were from the eastern half of the wetland where impacts from mining activities appeared to be minimal. However, several shallow wells augured into the soil in that portion of the wetland indicated lenses of buried sandy material that might have been mill tailings.

DESCRIPTION OF THE STUDY

A mine drainage diversion system was constructed by the Colorado Division of Mined Land Reclamation during the fall of 1985. This system consisted of a PVC pipe that carried the mine water from the adit to a 150 m perforated leach line, which was buried at a depth of 1.5 m along the upper margin of the wetland. In addition, ten 5-cm diameter wells were installed in the organic soil layer of the wetland to monitor metal concentrations in the interstitial water. The wells were grouped into three parallel transects approximately 30 m apart and roughly perpendicular to the expected flow of water through the wetland. The upper transect closest to the leach line was comprised of three wells, the middle transect consisted of four wells, and the remaining three wells were in the lower transect.

A sampling program was carried out during the summer and fall of 1986 and 1987 to monitor metals in Peru Creek and interstitial water in the wetland, as well as metal concentrations in soils and plants. This paper summarizes some of the results of that sampling program, chiefly from the well transects mentioned above, and from six intensive study sites in the wetland where metals in soils and plants were monitored. The leach line system was activated from August 25, 1986, to October 29, 1986. Three series of water samples were collected from the wetland wells prior to the diversion of mine water, and one series was collected 30 days following diversion. During 1987, metal sampling continued in soils and plants, although the leach line system was not reactivated.

All water and soil samples were analyzed by the Colorado State University Soil Testing Laboratory. Water samples were analyzed by inductively coupled plasma emission spectrometry (ICP). Soil metals were determined by nitric-perchloric acid digestion followed by ICP analysis, and cation exchange capacities were measured by displacement using ammonium chloride as the saturating salt, using methods based on Page et al (1982). Metals in plant samples were extracted with sulfuric acid and then analyzed by ICP.

RESULTS

Diversion of Mine Drainage

Introduction of the mine drainage into the wetland via the leach line system was partially successful. Average concentrations of several metals in the upper transect of ground water monitoring wells were significantly higher than before the system was activated (Table 1), indicating percolation of mine drainage into the wetland. However, the relatively low hydraulic conductivity of the peat soils (calculated using Darcy's law to be in the range of 10^{-3} to 10^{-4} cm/sec) did not permit the entire flow from the adit to pass into the wetland, nor did the seepage from the leach line appear to pass beyond the upper well transect. The average metal concentrations in the two lower well transects did not significantly change from the time the system was activated until it was turned off and monitoring was terminated for the winter. While the diversion system was in operation, excess mine drainage that could not be accommodated by the peat soils leaked to the ground surface near the leach line and had to be routed around the wetland with a small interception ditch. The diversion system was not reactivated during 1987.

Metals in Plants and Soils

A preliminary survey of the wetland indicated that while the herbaceous cover consisted almost entirely of one sedge species (*Carex aquatilis*), plant growth and health was not uniform. More intensive vegetation measurements indicated a range in cover from 5 to 56 percent, and peak season standing crops ranging from 18 to 721 g/m^2 (oven-dried weight) of aboveground biomass. Areas of low cover and biomass were characterized by spindly, chlorotic plants, whereas sites of high cover and biomass typically had large, robust, green plants.

Surface water samples collected prior to activation of the leach line contained metal concentrations that, for some elements, mirrored concentrations found in the mine discharge. Table 2 shows data for five sites on the wetland, and illustrates that poor health was not necessarily associated with higher metal concentrations. Sites of poor health were usually found in areas that were poorly drained or in depressions between hummocks.

Mean concentrations of metals in soils and in sedge leaves are shown in Table 3. *Carex aquatilis* apparently is able to tolerate high concentrations of aluminum and iron,

Table 1. Mean metal concentrations (mg/L) in groundwater wells before and after diversion of mine water.

		Al	Fe	Mn	Cu	Zn	Ni	Cd	Pb
Upper Transect (3 Wells)									
Before	(n=9	11.85	0.61	6.45	1.55	7.22	0.06	0.04	0.07
	S.D.:	1.02	0.79	1.35	0.17	0.73	0.01	0.01	0.02
After	(n=3)	23.03*	2.33*	9.44	1.58	13.67*	0.10*	0.08*	0.11*
	S.D.:	2.64	1.37	6.14	1.13	2.15	0.01	0.01	0.00
Middle Transect (4 Wells)									
Before	(n=12	3.70	12.56	5.23	0.02	0.94	0.03	0.01	0.06
	S.D.:	3.76	11.13	2.37	0.01	1.42	0.02	0.00	0.02
After	(n=4)	4.53	16.10	4.97	0.05#	0.86	0.33	0.01	0.09
	S.D.:	5.86	2.45	2.40	0.04	1.11	0.03	0.00	0.08
Lower Transect (3 Wells)									
Before	(n=9)	16.28	5.92	9.17	0.10	8.55	0.08	0.05	0.12
	S.D.:	17.79	5.31	4.80	0.15	9.44	0.05	0.06	0.13
After	(n=3)	11.80	9.13	7.14	0.03	4.36	0.06	0.01	0.15
	S.D.:	9.64	4.44	3.46	0.03	5.83	0.04	0.00	0.12

Note: (*) significant increase at 99% confidence level
(#) significant increase at 95% confidence level
S.D. is standard deviation

Table 2. Metal concentrations and pH of five surface water samples collected from the Pennsylvania mine wetland on July 23, 1986, with corresponding plant cover and biomass measured at the sample locations.

Plants			Metals (mg/L)								pH
% Cover	g/m^2	Health	Al	Fe	Mn	Cu	Zn	Ni	Cd	Pb	
8.4	109.9	P	16.4	13.0	2.44	1.74	0.10	0.02	0.01	0.05	3.3
8.8	42.6	P	14.0	0.13	10.3	1.88	10.9	0.07	0.07	0.06	3.6
18.0	68.3	I	15.7	0.22	12.4	1.70	13.9	0.09	0.07	0.09	3.2
28.0	492.0	I-R	12.6	0.56	8.81	2.23	11.2	0.07	0.10	0.05	3.6
44.0	536.0	I-R	12.7	0.50	8.11	2.00	8.55	0.06	0.06	0.06	3.8

Note: P denotes poor, I denotes intermediate, and R denotes robust

Table 3. Mean concentrations of metals (mg/kg) from samples of soils and Carex aquatilis leaves collected during the summer of 1987 (n = 2 for each site).

Plant Health		Al	Fe	Mn	Cu	Zn	Ni	Cd	Pb
				SOILS					
Poor (2 sites)									
		14285	6323	143	8298	10228	9.5	119.8	1037
	S.D.:	4035	3900	17.9	1953	3392	2.9	66.0	855
Intermediate (3 sites)									
		26517	178167	195	2017	370	<1	4.0	750
	S.D.:	6222	58687	31.9	1544	176	0.0	1.8	126
Robust (1 site)									
		31050	58250	85	612	717	<1	3.0	1201
	S.D.:	3950	37850	25	395	199	0.0	0.0	171
				PLANTS					
Poor									
		92.8	372	696	30.1	351	5.0	0.75	5.3
	S.D.:	23.3	243	26	3.3	77	1.2	0.25	0.4
Intermediate									
		114.8	516	621	80.7	427	9.5	1.27	<5
	S.D.:	40.7	134	70	26.8	78	1.5	0.47	0.0
Robust									
		52.5	160	314	28.5	257	3.5	0.80	6.0
	S.D.:	3.5	33	38	5.5	13	0.5	0.20	1.0

Note: S.D. is standard deviation

and under the conditions observed so far at the wetland, we have seen no significant correlation between amounts of these metals in the soils and corresponding plant health. However, high copper concentrations in the soil frequently is associated with poor growth, and to a lesser extent zinc, cadmium, and nickel have shown a similar trend. The highest values of these metals were always associated with sites of poor health, while the lowest concentrations were found on the healthiest sites. We observed no correlation between plant growth and total soil metals, even when total metal concentrations at some sites exceeded 300,000 mg/kg.

An important growth factor is the nutrient status of the plants. Metals can inhibit nutrient uptake and metabolism, causing nutrient deficiency symptoms, and mountain soils are often low in certain nutrients (Johnson and Cline, 1965). We examined soil calcium, nitrogen, phosphorus, and potassium, and found that of these four nutrients, only soil potassium concentrations showed a significant correlation with plant cover (Figure 1).

Organic matter in the soils ranged from 5.8 percent to 79.1 percent, with mean percentages of 59.7, 35.8, and 16.5 for the poor, intermediate, and robust sites, respectively. Cation exchange capacities (CEC) were relatively low, with a range of 3 to 24 meq/100g, and a mean of 12.7. As would be expected, CEC values appeared to be closely related to the organic matter content of the soils. Metals extracted (displaced) during the CEC determinations of the soil samples represented from 1 to 12 percent of the total metals in the samples.

DISCUSSION AND CONCLUSIONS

Results of the mine drainage diversion study were inconclusive. The system was not in operation for a long enough period of time to permit percolation of the mine water completely through the wetland. However, given the relatively high pre-existing metal concentrations in the groundwater and soils of the wetland, it is questionable whether the system would have had much of a beneficial impact on water quality.

Analyses of the plants, soils, and surface and subsurface waters subsequently have verified that metal concentrations throughout the wetland are high. The source of the metals is apparently from surface and colluvial waters flowing from the slope above the wetland, probably passing through a portion of the waste rock dump of the mine. Because of the relatively thick peat accumulations, the age of the wetland is probably several thousand years old, and it is possible that it was receiving metals before mining activities began nearly a hundred years ago. We have been conducting studies on other wetlands in this portion of the Colorado mineral belt and have found several sites that are receiving high metal loads of natural origin.

High metals concentrations per se do not seem to limit the growth of Carex aquatilis in the wetland. However, poor growth, characterized by low cover and biomass, spindly shoots, and chlorotic leaves appears to be associated with high soil concentrations of copper, zinc, nickel, and cadmium, as well as with low potassium concentrations. Perhaps the most significant factor adversely affecting plant health is poor drainage, judging from visual observations at the site. The healthiest plants generally are living on microtopographically high spots or on slopes where drainage is obviously better. These sites are also associated with lower percentages of soil organic matter. It is also possible that greater amounts of soil organic matter on sites of poorer health contribute to the formation of metal-organic complexes that may increase the availability of some metal species to the plants (Thornton, 1986). Clearly, the uptake of metals by Carex aquatilis and the factors leading to toxic effects are complex issues that will require a more detailed study than was possible here.

It is apparent that Carex aquatilis is tolerant of high metal concentrations and low pH and thus would be a likely candidate for use as a plant species in wetlands constructed at high elevations. Success of transplanting and rates of establishment remain to be determined for this species.

Metal absorption and retention by the soils from cation exchange appears to be relatively low and less important than other processes. Microbial uptake has not been studied at this site but presumably would play a role in metal retention by the wetland (Tuttle et al, 1969). Given the cold climate and relatively short growing season at mountain sites such as the Pennsylvania mine, it is likely that many of the biogeochemical processes that are responsible for metal accumulation in wetlands would be slower than at lower elevations. While this study has provided some insight into metal accumulation at one high-elevation wetland, a much greater research effort is needed before the feasibility of using a constructed wetland approach in such locations can be determined.

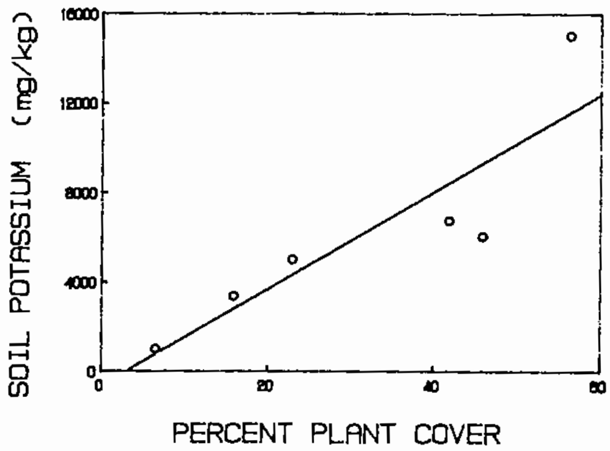

Figure 1. The relationship between soil potassium concentrations and percentage of plant cover on the Pennsylvania Mine wetland.

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