Stimulation of Natural Attenuation of Metals in Acid Mine Drainage through Water and Sediment Management at Abandoned Copper Mines

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Abstract Abandoned mining sites represent a substantial environmental challenge especially when acid mine drainage (AMD) is affecting surface water (Nordstrom 2011). Comparison of abandoned copper mines in Norway shows a clear difference in the environmental impact as indicated by the fish population in the receiving waters. Local hydrological and geochemical conditions were investigated to address the environmental fate of the copper release and the influence on the available copper fraction. Remedial solutions are designed based on stimulating the natural on-going attenuation processes. Management of hydrological and sedimentary processes can give an immediate improvement while long-term solutions for source removal are implemented.

Key words acid mine drainage, natural attenuation, water quality, aluminium, copper

Introduction

Sulitjelma is an abandoned copper mining area located in Northern Norway. A total of 26 million tons of ore have been extracted between 1887 and 1991 from several mines in the area. Drainage from the mine and exposed tailings has resulted in severe contamination of the local lake Langevatn (fig. 1). Langevatn is composed of 3 natural basins draining from east to west, covering a total area of 5.5 km^2 and 150 mill m^3 of water. The main run-off from the mines flows into the first basin. The Norwegian Environment Agency has imposed a regulatory limit of 10 µg Cu/L at the western outlet of the lake to protect the ecological quality of the watercourse downstream of the lake. The study aims at understanding the on-going attenuation processes in the lake and finding ways to improve them.

Methods

Water and sediment samples were collected in the field to study the geochemical changes in the lake system and the contributory rivers and streams. Large volumes of water were collected from the mine (Grunnstollen), the surface water leaving the primary lake basin (Langvatn) and the Lomi river. Dilution series of the mine water with respectively lake water and river water were composed for detailed studies of the complexation and precipitation processes under laboratory conditions. Lake water was sampled at different depth in addition to sediment samples to study the sedimentary processes.

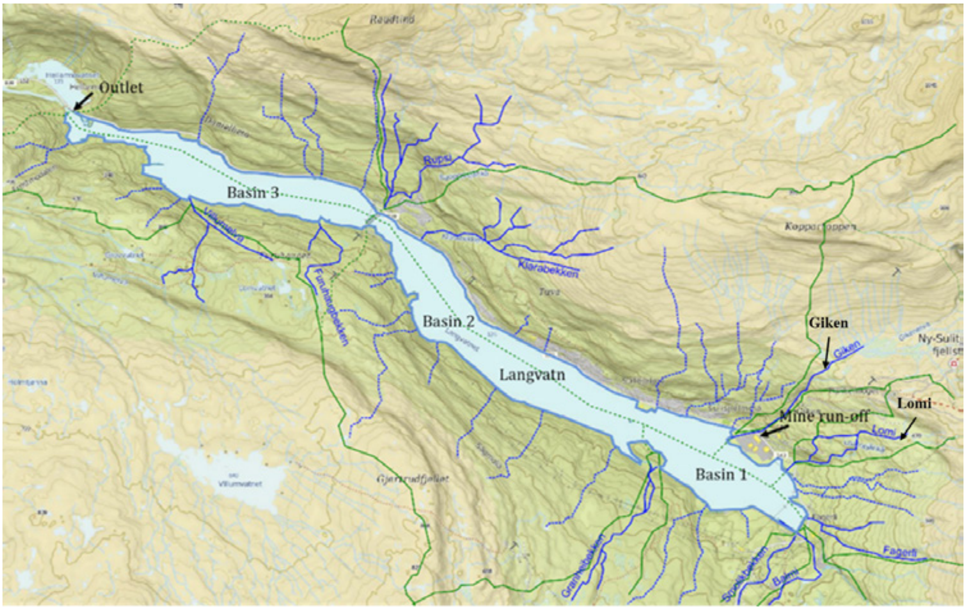

Figure 1 *Overview over rivers and streams contributing to Langevatn, Sulitjelma.*

Results

The run-off from the mine has a pH of 2.97, whereas the surface water of the lake has a pH of 6.58 and the Lomi river of 6.91. Table 1 presents some of the key water quality data for the three water sources.

Table 1 *Selected water quality parameters in samples taken at the run-off of the mine (Grunnstollen), the receiving lake (Langvatn) and a river draining to the same lake (Lomi) used in the dilution experiments.*

Sampling site	pH	Ca (mg/L)	Fe (µg/L)	Al (µg/L)	Cu (µg/L)	Zn (µg/L)	SO_4^{2-} (mg/L)	HCO_3^- (mg/L)
Grunnstollen	2.97	208	13600	20500	13900	12300	984	<2
Langvatn	6.58	5.2	60	54.2	37.2	36.5	6.74	9.27
Lomi	6.91	13.1	5	13.3	1.37	0.765	<5	45.8

Upon dilution of run-off from the mine with Langvatn by a factor of 25, the pH increases to 5.56, while the conductivity decreases from 1742 to 120 µS/cm and the redox state decreases from +645 mV to +398 mV. The dilution results in significant changes in the speciation of aluminium, while copper remains predominantly in the dissolved state (fig. 2a, b). Upon dilution with Lomi to a dilution factor of 25, the pH increases to 6.41, the conductivity and redox state decrease to 157 µS/cm and +356 mV respectively. This results in an increased precipitation of both aluminium and copper (fig. 2c, d), which can result in removal from the water column (Lee et al. 2003).

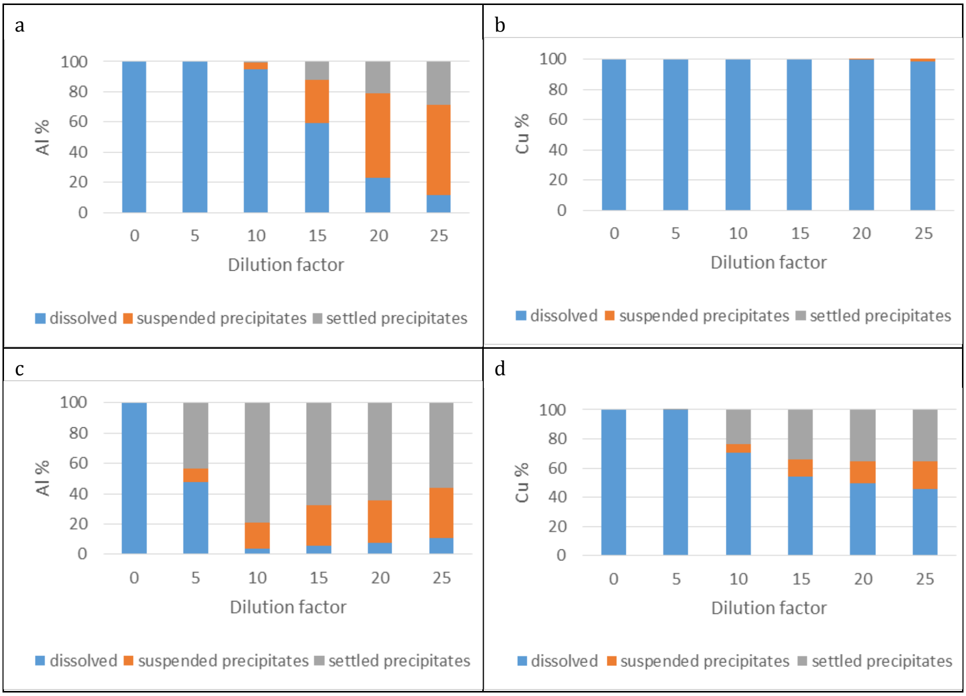

Figure 2 *Distribution of Al (left) and Cu (right) between the dissolved, suspended and precipitated phases upon dilution with lake water (a, b) and Lomi river water (c, d).*

Sediment samples taken in the three basins showed strong accumulation of iron, copper and zinc supporting the laboratory observations (tab. 2).

Table 2 *Selected sediment quality parameters in samples (0-1 cm) taken centrally on the south and north side of the three basins of the receiving lake (Langvatn).*

Sediment samples		Fe (mg/kg)	Cd (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Zn (mg/kg)	TIC (%)	TOC (%)
Basin 1	S	178000	2.11	1890	21.4	1240	0.031	1.29
	N	89000	<0.1	2940	22.5	37.1	0.040	2.47
Basin 2	S	160000	<0.1	6160	27.8	515	0.099	6.38
	N	85900	0.22	9280	25.7	863	0.076	8.10
Basin 3	S	114000	<0.1	5090	35,7	523	0.088	5.68
	N	83900	<0.1	1660	30.3	399	0.040	1.98

Water quality profiles in the receiving lake showed elevated metal concentrations in the bottom water of the inner basin with a pH varying from 7.4 to 7.7. Geochemical analysis gave strong evidence of potential super-saturation (saturation index SI> 0) of several copper minerals that can result in complexation and precipitation (fig. 3) and may explain the observed concentrations in the sediments. In addition will sorption to iron precipitates reduce the copper concentration in the aqueous phase (Lee et al. 2003).

Figure 3 *Saturation index for copper minerals in bottom water of the inner basin of Langevatn, Sulitjelma.*

Conclusions

The dilution series clearly showed the complexation and precipitation reactions of Al that take place when run-off from the mine enters the Lake. However, Cu seems to remain in solution and any observed concentration change is solely a result of dilution. Re-routing the run-off from the mine to the river Lomi could increase the precipitation and complexation for both Al and Cu at an initial stage of the dilution process. Changing the residence time of the mine water through these hydrological measures will potentially improve the environmental conditions in the lower part of the catchment area by increased copper retention in the upper basin.

However, sediment samples show considerable metal accumulation and potential supersaturation of several copper minerals is observed in the bottom water. Reducing the copper load to the lake system will in this case not result in reduction of the existing aqueous copper concentration due to potential re-dissolution of copper stored in historic sedimentary deposits as secondary minerals (Carbone et al. 2013).

Source control is the ultimate goal at abandoned AMD generating mining sites. However, it will take a long-time until the full effect of remedial measures like tailing control through capping can be observed in the receiving waters. In the presented case study, improved attenuation of the contaminants in the inner most part of the lake can create rapid short term improvement and compliance, while long-term measures are implemented.

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