



ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2015

Scientific Report from DCE - Danish Centre for Environment and Energy

No. 181

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Data sheet

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Abstract:	This twelfth environmental monitoring programme was conducted in the Nalunaq area, about 40 km from Nanortalik, South Greenland, from 18-31 August 2015. The environmental monitoring programme is conducted to discover and avoid unwanted environmental impacts of the former mining industry. Since the monitoring in 2014, the area has been without any activity. The mining company Angel Mining Gold A/S closed its gold production in November 2013 where after the Nalunaq area was affected by decommissioning and restoration until August 2014. The gold was extracted by chemical extraction with cyanide (carbon-in-pulp). Due to the use of cyanide to extract gold from the ore, there was strict monitoring with the outflow of cyanide from the mine to the valley during the production period, and monitoring will continue for 5 years after the closure. Also, extensive monitoring is conducted to reveal release of metals into the Kirkespir Valley and Kirkespir Bay environment. The content of metals in the terrestrial, freshwater, and marine environment in the Kirkespir Valley and Bay is decreasing and is considered minor. DCE/GINR assess that no requirement for further actions to reduce the environmental impact is needed. Environmental monitoring will continue in 2016 and 2019.
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Summary

This twelfth environmental monitoring was conducted in the Nalunaq area to discover and avoid unwanted environmental impacts of the former mining industry. Since the monitoring in 2014, the area has been without any activity. The mining company Angel Mining Gold A/S closed its gold production in November 2013 whereafter the Nalunaq area was affected by decommissioning and restoration until August 2014. The gold was extracted by chemical extraction with cyanide (carbon-in-pulp). Due to the use of cyanide, the outflow of cyanide from the mine to the Kirkespir Valley has been monitored during the production period, and monitoring will continue for five years after the closure. Also, extensive monitoring has been conducted to reveal release of metals into the Kirkespir Valley and the Kirkespir Bay environment. The content of metals in the terrestrial, freshwater, and marine environment in the Kirkespir Valley and Bay is decreasing and is considered minor. DCE and GINR assess that no requirement for further actions to reduce the environmental impact is needed.

Environmental monitoring will continue in 2016 and 2019.

Sammenfatning

Denne tolvte miljøovervågning blev gennemført i Nalunaq-området for at spore og undgå uønskede miljøpåvirkninger i den tidligere mineindustri. Siden overvågningen i 2014 har området været uden nogen form for aktivitet. Mineselskabet Angel Mining Gold A/S lukkede i november 2013 for minedriften og en lokal entreprenør overtog oprydning og naturgenopretning af området. Oprydning og genopretning blev afsluttet sommeren 2014. Under minedriften blev guldet ekstraheret ved kemisk ekstraktion med cyanid (carbon-i-pulp). På grund af anvendelsen af cyanid blev det udledte spildevand fra minen til Kirkespirdalen overvåget løbende i produktionsperioden, og overvågningen vil fortsætte i fem år frem efter lukning af minen. Desuden er en omfattende overvågning blevet gennemført for at spore en eventuel spredning af metaller i Kirkespirdalen og Kirkespirbugten. Indholdet af metaller i det terrestriske, ferskvands- og havmiljøet i Kirkespirdalen og bugten er faldende og anses for at være ubetydelig.

DCE og GN vurderer, at der ikke er grundlag for yderligere tiltag for at reducere miljøbelastningen.

Miljøovervågningen vil fortsætte i 2016 og 2019.

Eqikkaaneq

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1 Introduction

The twelfth environmental monitoring programme was conducted in the Nalunaq area, about 40 km from Nanortalik, South Greenland, from 18-31 August 2015. The purpose of the environmental monitoring is to discover and prevent unwanted environmental impacts from the former goldmine. Since the monitoring in 2014, the area has been without any activity. The mining company Angel Mining Gold A/S decommissioned the mine in November 2013 and remediation and restoration processes continued until August 2014, where the license area was left.

With the closure of the mine in November 2013, it was expected that the element concentrations in the environment would decrease even further. A small increase in dust dispersal could possibly be occurring during remediation and restoration of the landscape in 2013/2014 and was correspondingly observed in the monitoring in 2014 (Bach et al. 2015). As the area since 2014 was left without any kinds of activities, the level of dust dispersal is expected to have decreased in 2015.

Environmental monitoring will continue at least three years after the closure and will also take place in 2016 and 2019. The environmental monitoring was planned with a less intensive programme in 2014 and 2015 compared to the programme that was in force during the active operation of the mine. The programme includes a reduced number of samples of lichen, as the dust impact is assumed to be greatly reduced due to the termination of the outdoor crushing and road use. Furthermore, a reduced number of marine specimens is included, as the discharge of metal residues through the wastewater from the mine is presumed to be greatly reduced. The reduction in sample numbers is based on results from previous monitoring, where the dispersal of metals into the environment was relatively stable, though declining. However, it is important to follow the development of environmental impact, as there may be unexpected nonconformities. The environmental monitoring in 2014 was reported in a note form, whereas the environmental monitoring in 2015, 2016 and 2019 will be reported as scientific reports.

2 Monitoring programme

Requirements for monitoring of the environment in relation to the mining activity were set by the Mineral Resources Authority (MRA) of the Greenland Government. These requirements are described in the MRA exploitation license of 19 March 2010, Phase 6, §§19/43, chapter 8.

Prior to the mine start, a number of environmental baseline studies were performed. The first study was on the Arctic char population in the Kirkespir River in 1988 (Boje 1989). During the exploration phase, freshwater samples from the Kirkespir River were analysed for metals and general parameters (Lakefield 1998a, b, 1999a-d). In comprehensive baseline studies performed during 1998-2001, fish, mussels, seaweed, snow crab, sea urchin, benthic macro fauna and sediments were collected and analysed for different metals (Glahder et al. 2005). The above and other studies were included in the Environmental Impact Assessment by SRK Consulting (2002). Based on the above-mentioned studies and the mining methods and current procedures, the monitoring programme presented below was designed.

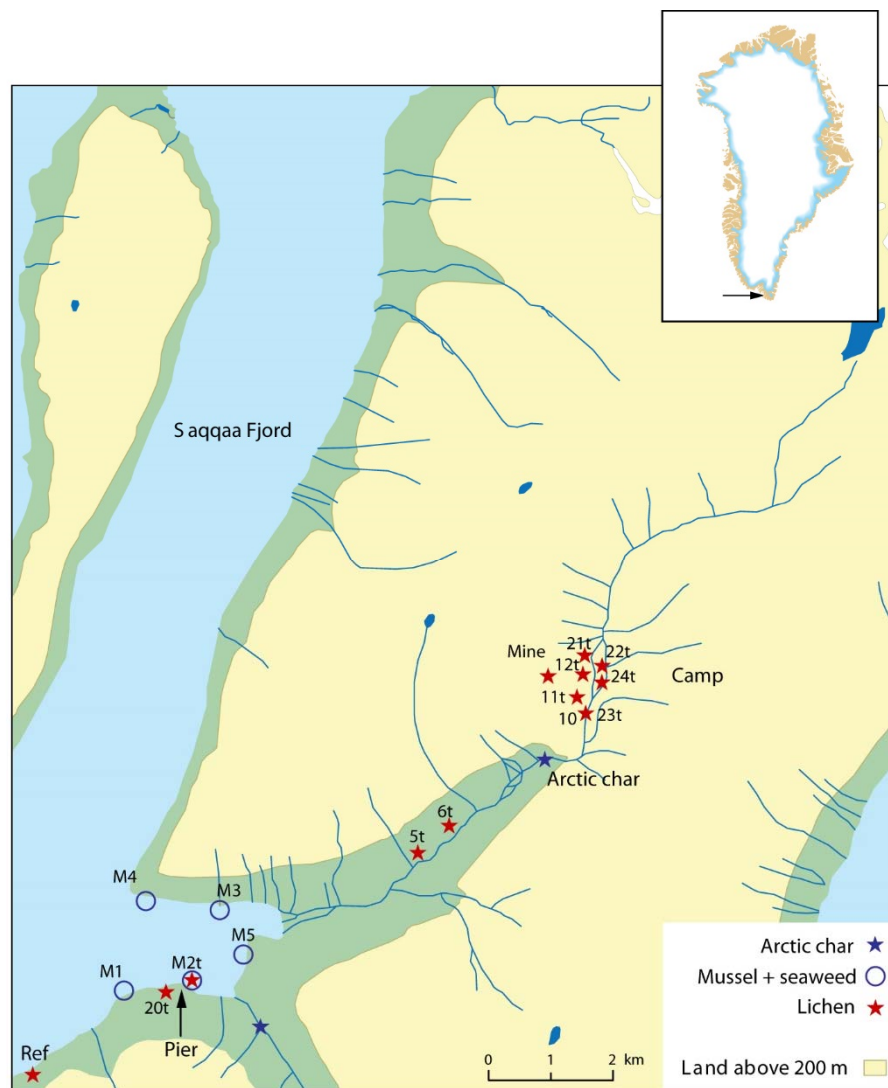
2.1 Element monitoring programme

The element monitoring consists of three focus areas: the marine, the freshwater and the terrestrial environment. For the marine environment brown seaweed (*Fucus vesiculosus*) and blue mussel (*Mytilus edulis*) were sampled at stations that are placed relatively close to, and on each side of the Kirkespir River outlet.

For the freshwater environment the sampling station is placed at the first site downstream the mining area, where resident Arctic charrs (*Salvelinus alpinus*) are occurring. For the terrestrial environment, the lichen (*Flavocetraria nivalis*) stations are placed around existing and former ore stockpiles, along the road, and in the area around the 300 m portal, where waste rock was placed and outdoor crushing took place.

In 2015 the number of samples was reduced compared to previous years, but similar to the number taken in 2014. All samples collected at the stations are specified in Appendix 1.

Figure 2.1. Sampling stations in the Nalunaq Gold Mine area, Nanortalik, South Greenland. M: Marine stations: Blue mussel and brown seaweed. Arctic chars were caught at the waterfall station. Lichens transplanted in 2014 from reference station (Ref) were sampled at stations M2t, 5t, 6t, 11t, 12t, 20t, 21t, 22t, 23t and 24t, and replaced with new lichens from the reference station. The mine entrance is west of the camp area



2.1.1 Collection and analyses of samples

Terrestrial environment

Lichens were sampled in the Kirkespir Valley south-west of the camp, in the camp area, and in the pier area (*figure 2.1*); sampling stations where lichens were transplanted to in 2014. The sampling consisted of lichens sampled at a new reference station in an area about 1.2 km from the pier (N 60.32611; W 44.92278) and lichens sampled at the stations M2t, 5t, 6t, 11t, 12t, 20t, 21t, 22t, 23t and 24t. The lichens at the latter t-stations consisted of lichens transplanted to the sites in 2014 and after the 2014 lichens were sampled and the positions cleaned, new lichens collected at the reference site were placed for collection in 2016. The transplantation of lichens from an unpolluted area into a monitoring area followed by collection at a later stage provides the possibility to assess the relative spatial and temporal variations in dust deposition of metals. The application of transplanted lichens, as opposed to resident lichens, has the advantage that the exposure time of the lichens is known and any change in the lichen metal composition relative to the original composition can be related to that site and period (Søndergaard et al. 2013).

Freshwater environment

Water samples were collected in the Kirkespir River and the samples were filtered to 0.45 µm membrane at site immediately after sampling.

Resident Arctic charrs were caught in the Kirkespir River at the waterfall pond. This population consists of both non-migrating and migrating charrs and if possible non-migrating charrs are preferred. Resident Arctic charrs stay all their life in the Kirkespir River, whereas the migratory form leaves the river during May and returns around August to spawn and winter. This year, 5 charrs were sampled. In the camp, each fish was measured, weighed and the liver was dissected.

Marine environment

Sampling in the Kirkespir Bay was performed with a motor boat. Sampling of blue mussels and seaweed was performed at low tides (DMI 2015).

Mussels were collected at five stations M1-M5. Each sample consisted of approximately 20 individuals. The mussels were opened with a scalpel and allowed to drain; the soft parts were cut free and frozen in plastic bags for later elemental analysis.

Seaweed was collected at two spots within an area of approximately 20 m at each station and mixed into one sample per station. The growth tips of seaweed from this year were cut, washed in freshwater, and frozen in plastic bags. The stations were identical to the blue mussel stations M1-M5.

Photo 2.1. Mussels and seaweed are collected at low tide for chemical analyses of elements (photo L. Bach).



Analyses

All samples were transported frozen directly to Aarhus University, DCE. A total number of 40 samples was collected, including blue mussel (5), brown seaweed (5), freshwater (15), livers of Arctic char (4) and lichens (11). All samples were analysed for the following 11 metals: arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn). Au is not a part of the obligatory monitoring program and was not measured this year.

Following freeze drying at DCE subsamples of 0.3-1.0 g were digested in half-concentrated Suprapure nitric acid under pressure in Teflon bombs in a microwave oven. The samples were then diluted to approx. 25 g with milli-Q water and all metals were analysed by ICP-MS (accredited analysis method according to DANAK, accreditation no. 411). All the analysed metals, except Hg and Co, are included in this accreditation. All chemical results are listed in Appendix 1. Simultaneously with the Nalunaq samples, blind samples, duplicates and certified reference materials (Dorm-3, Dolt-4 and Tort-2) were analysed as part of the laboratory quality control. The filtered water samples were stabilized with 2 g/l nitric acid and then analysed by ICP-MS.

2.1.2 Analyses

Data obtained in this monitoring programme (2015) were compared with data obtained in the baseline studies (Boje 1989; Lakefield 1998a, b; Lakefield 1999a-d; Glahder et al. 2005) which were conducted before the gold mining started in the area. Results from the previous monitoring programmes (Bach et al. 2015; Bach et al., 2014; Bach & Asmund 2013; Bach et al., 2012; Glahder & Asmund 2005, 2006, 2007; Glahder et al. 2008, 2009, 2010, 2011) are also included in the analyses for comparisons.

Differences in element concentrations in brown seaweed, mussels, shorthorn sculpins and Arctic charrs were tested using one-way analysis of variance (ANOVA) after logarithmic (base e) transformation of all data to meet the assumption of normal distribution and variance homogeneity. Post hoc Tukey's studentized range tests were applied to test for differences between sites and background. The level of statistical significance used was $p < 0.05$.

We tested separately the stockpile of crushed waste rock and the camp area for differences in concentrations of Cu, Cr, As and Co in lichens in the years 2004-2014 compared to background concentrations using the same statistical method as described above. Finally, the relations between concentrations of Cu, Cr, As and Co in lichens and the distance to the gravel road and the crusher were analysed with linear regression analyses using logarithmic transformed element concentrations as dependent variable and logarithmic transformed distance as independent variable.

2.2 Cyanide monitoring programme

Due to the mining activities and the gold extraction method involving cyanide, an intensive monitoring programme for detection of cyanide in the environment was conducted while the mine was in production. While the mining company was responsible for conducting the daily monitoring programme (i.e. sampling and sample analyses) and forwarding the data on a regular basis to EAMRA, DCE conducted a yearly monitoring.

The cyanide monitoring programme consisted of frequent collection of water samples for analysis for free cyanide to ensure that cyanide concentrations in the environment did not exceed the limits set by EAMRA (identical to the Ontario Province Quality Objectives). To protect organisms and in particular the resident Arctic char from toxic effects, the cyanide concentration in the Kirkespir River should not exceed 0.005 mg/l (measured as WAD CN, Week Acid Dissociable cyanide). Due to dilution in Kirkespir River and retention time facilitating natural degradation in the settlement pond, the company was allowed to discharge water from the mine with a cyanide concentration

of 0.20 mg/l. For further description of water management, see the company's EIA and the previous years' monitoring reports and notes.

At the closure situation of the plant, DCE recommended that it should be ensured that no water containing WAD cyanide in concentrations higher than 0.20 mg/l would be able to flow out from the mine.

Photo 2.2. Water samples were taken in the water flowing from the mine at the 300 m portal for analyses of cyanide and elements (photo L. Bach).



2.2.1 Collection and analyses of samples

During the monitoring in 2015, the mine was briefly re-opened and DCE/GINR had access to the underground mine. Water samples were taken inside the mine and analysed for free cyanide.

Cyanide has the ability to bind in complexes with many metals. The toxicity of the complex-bound cyanide depends on the strength of the bindings in the complex. Iron cyanide complexes are for example very stable and therefore much less toxic than free cyanide, but exposure to sunlight can break down the complexes and release the cyanide. To evaluate if cyanide complexes were present in the water inside the mine, two of the water samples were also analysed for total cyanide (accredited analysis at an external laboratory). The analysis reports can be found in Appendix 2.

Analyses

Water samples for WAD cyanide were processed shortly after the sampling at site. After filtration, the samples were analysed for free cyanide using the Hach-Lange LCK315 method and a Hach-Lange DR2800 instrument. This method is quick and effective, and has a factory guaranteed measuring range of 0.01-0.60 mg/l, within which precise results can be obtained. The practical detection limit is judged to be about 0.002 mg/l.

Water samples for total cyanide were analysed by ALS-Denmark after the DS/EN ISO 14403:2002.

3 Results and discussion

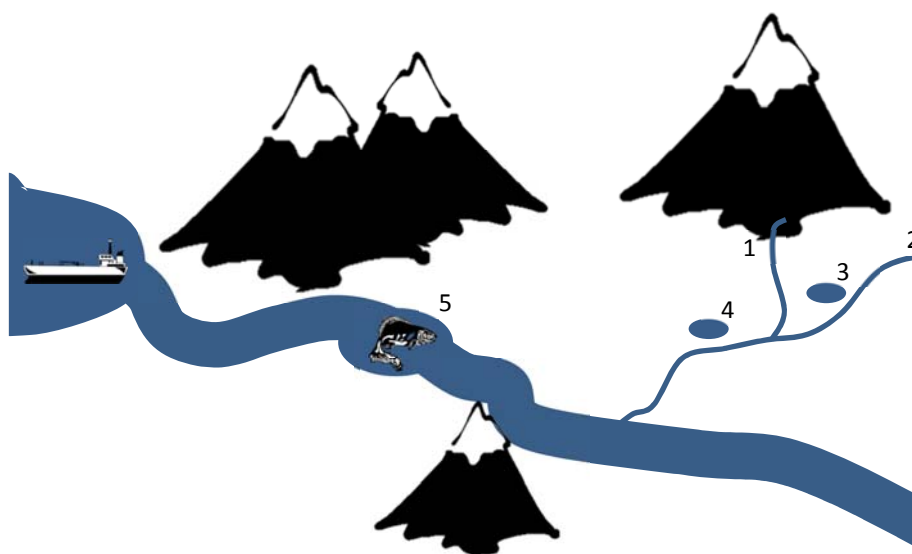
3.1 Cyanide monitoring programme

3.1.1 Environment

Water samples were taken from the outlet at the 300 m portal (1), upstream the small river (2), monitoring wells (3 and 4), and Kirkespir River (5) (figure 3.1).

In 2014, cyanide was detected in the water flowing out of the 300 m portal. The concentrations fluctuated greatly and overall it was assessed by modelling that the amounts of cyanide flowing out from the mountain would be harmless due to very high dilutions in the river. In 2015, no cyanide (free cyanide) could be detected in any of the water samples in the environment.

Figure 3.1. Illustration of sampling sites for cyanide monitoring in the environment.



3.1.2 Underground mine

Water samples were taken underground the mine in the water exiting the processing area, the detox-tanks, the CYP-tanks and in the ditch to and from the 'new' tailings chamber and one sample from the overlying water in the 'old' tailings chambers.

An additional two samples were taken in the water exiting the processing area and in the 'old' tailings chamber for analysis of total cyanide.

While no free cyanide (WAD) could be detected in any of the samples taken in the underground mine (all samples were below the detection limit), the total cyanide analyses showed concentrations of 1.0 and 0.003 mg/l in the samples from the processing area and from the overlying water in the 'old' tailing chamber, respectively.

The results from the analyses of cyanide in water samples showed that no free cyanide was found neither in the water inside the mine nor in the water leaching out of the mine or in the Kirkespir river receiving the water from the mine. Relatively low concentrations of complex bound cyanide were detected in the two water samples analysed for total cyanide. This indicates

that a minor part of the cyanide remain in the water as complex-bound cyanide, while the main part of the cyanide is lost through volatilization and/or degradation. The measured concentration of total cyanide does not pose a risk to the environment.

3.2 Element monitoring programme

3.2.1 Terrestrial environment

Eleven elements were analysed in the lichens collected in the terrestrial environment. As in previous years, elevated concentrations were only found for Cu, Cr, As and Co. The concentrations of these four metals in lichens were compared between years from 2004 to 2015. Three areas (see *figure 2.1* for station numbers) were selected: 1) the stockpile of waste rock (stations 5t and 6t), 2) the camp and mine area (stations 11t, 12t, 21t, 22t, 23t and 24t) and 3) the area around the pier, which was previously used as an ore stock pile area (stations M2t and 20t). For the other elements, measured concentrations can be found in *table 3.1* with indications of elevated concentrations. In 2014, lichens were transplanted from an uncontaminated area (station AMIT) to these stations. In 2015, these transplanted lichens were collected for elemental analyses.

The results are shown in *figure 3.2* (Area 1), *figure 3.3* (Area 2) and *figure 3.4* (Area 3).

Table 3.1. Metal concentrations in the lichen, *Flavocetraria nivalis*, in mg/kg dry weight. Background concentrations are from baseline studies. * indicates slightly elevated concentrations (2-5 x background concentration), ** elevated (5-10 x background concentration) and ***highly elevated (> 10 x background concentrations). The Ref concentrations are used to confirm low element concentrations before transplantation.

	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Background conc.	0.238	0.082	0.151	0.557	0.953		0.034		1.068		21.555
Detection limit 2015	0.021	0.004	0.003	0.034	0.014	0.398	0.007	0.046	0.008	0.012	0.123
5t	0.402	0.083	0.278	0.332	0.652	157	0.027	0.446	0.737	0.104	13.1
6t	*0.709	0.082	**0.866	0.281	0.950	123	0.024	1.07	0.592	0.067	21.4
11t	**2.14	0.076	*0.623	*1.19	**5.77	479	0.034	1.25	0.914	0.105	11.4
12t	0.330	0.139	*0.462	0.340	*1.93	128	0.026	0.996	0.814	0.076	15.2
20t	*0.743	0.162	*0.667	0.425	0.881	202	0.023	0.861	0.770	0.128	29.5
21t	*0.554	0.076	*0.431	0.525	*4.26	226	0.021	1.16	1.34	0.100	12.2
22t	**2.20	*0.174	***3.27	*1.26	***37.3	484	0.026	6.01	1.04	0.148	18.3
23t	***4.22	0.127	***2.32	**4.06	***10.7	1615	0.033	6.88	1.63	0.156	24.8
24t	*0.745	*0.304	**1.00	0.758	*2.03	327	0.024	1.87	0.921	0.106	28.7
M2t	**1.21	0.104	*0.598	0.570	1.21	245	0.028	0.830	1.15	0.112	16.1
Ref	0.110	0.040	0.053	0.169	0.395	56	0.022	0.195	0.276	0.100	8.9

Concentrations of all four metals in Area 1, which are stations 5t and 6t, have been decreasing from 2009 to 2013. In 2014, there was, however, small increases in dust metal spreading for Cu, Cr and Co in this area. In 2015 the levels were decreasing and except for Co all concentrations were found lower than in 2013. The area was previously used for a stockpile of waste rock, and the increase in 2014 might indicate that the area was restored during restoration of the landscape. In 2015, the concentrations of all metals were, however, close to background levels and elevated concentration of As and Co were found at station 6t.

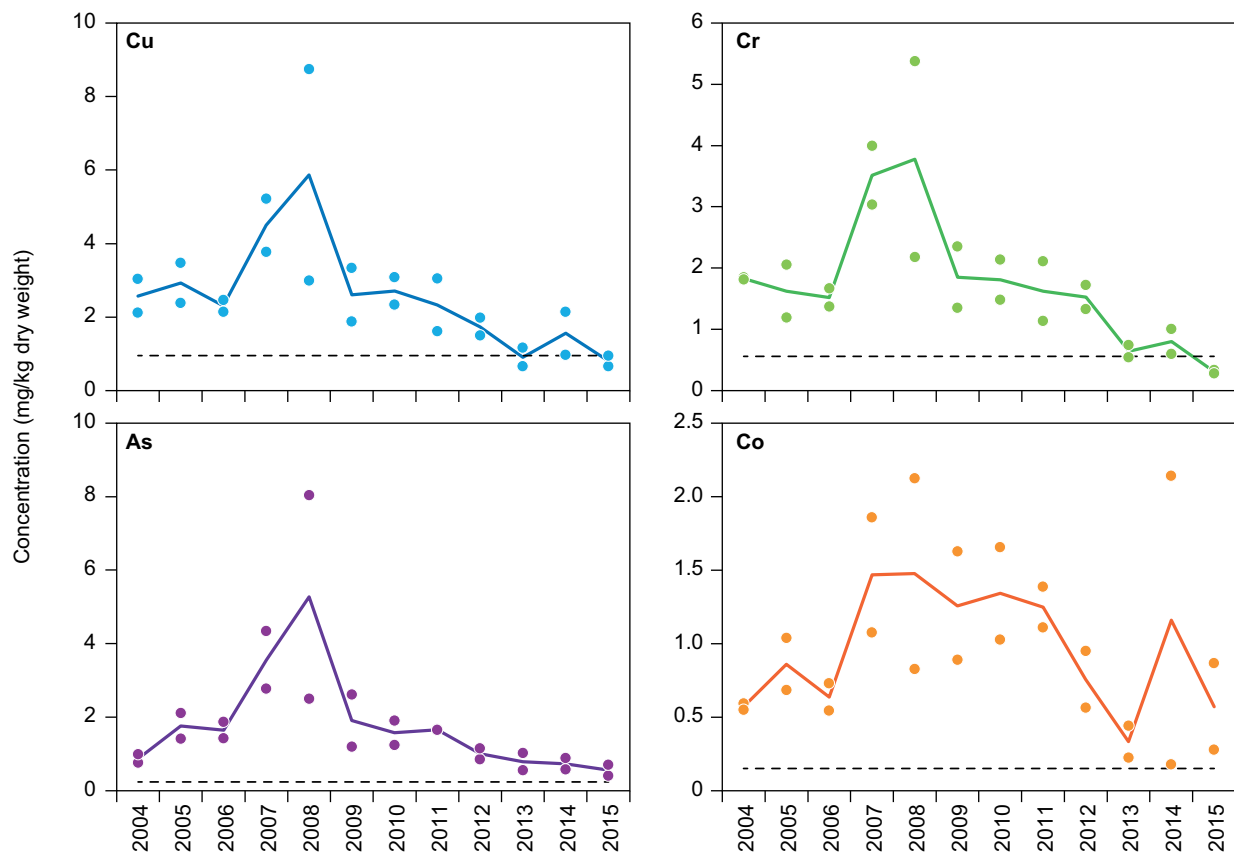


Figure 3.2. Temporal trends in concentrations of Cu, Cr, As and Co in lichens from Area 1 during 2004-2015. Area 1 is the stockpile of crushed waste rock (stations 5t and 6t). From 2008 onwards metal concentrations are from transplanted lichens. Solid lines show the average values. Baseline average concentrations from 1998 are shown as dashed lines.

The lichens collected in Area 2, which is the area around the camp and downhill the mine (stations 11t, 12t, 21t, 22t, 23t and 24t) had decreasing concentrations of the four metals towards 2010, but was slightly fluctuating with peaks in metal concentrations in 2011, which probably was due to the restart of the mining activities and for Cu and Co minor peaks in 2013, which decreased again in 2014. In 2015, a single high concentration of Cu at station 22t (37.4 mg/kg) was regarded as atypical and left out. While Co and Cu showed tendency towards increasing concentrations, both Cr and As were found in concentrations which have been stable since 2012. The reason for the increased concentrations in 2015 of Co and in particular Cu in lichens in this area is unknown, but might be ascribed to changes in wind speed and/or direction or other atypicalities.

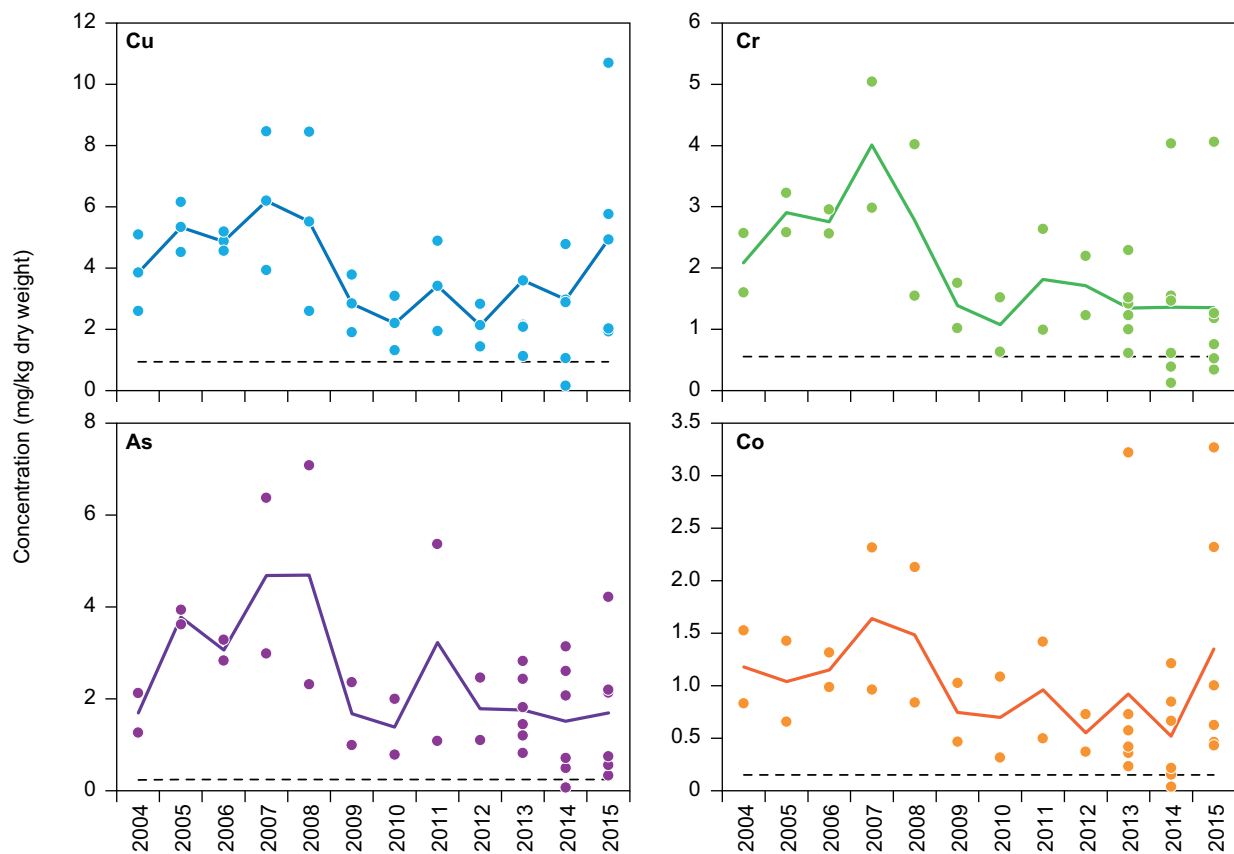


Figure 3.3. Temporal trends in concentrations of Cu, Cr, As and Co in lichens from Area 2 during 2004-2015. Area 2 is the camp and mine area (stations 11t, 12t, 21t, 22t, 23t and 24t). From 2008 onwards concentrations are from transplanted lichens. Solid lines show the average values. Baseline average concentrations from 1998 are shown as dashed lines.

A third particular area of interest is the former stockpile area of ore around the pier (Area 3). During the last mining period, large stockpiles of ore were placed in the field above the pier, intended for shipping off. As the Crew Mine closed in 2009, a stockpile was left and the ore was transported back to the mining area for processing between 2011 and 2012. In 2011, concentrations of the four metals in the pier area (stations 20t and M2t) were found to be 2-29 times higher than the background concentrations. Towards 2014, however, only As was found slightly higher than baseline concentrations (data from 1998). In 2015, the four metals and in particular Co were increased compared to 2013 and 2014. These results indicate that the metal dust pollution around the pier was temporary and directly related to mining and processing activities during the first mining period where ore was loaded and shipped. The reason for the increased concentration in 2015 of Cu and more pronounced Co in lichens in this area is, as described for the Area 1, unknown, but also here the increases might be ascribed to changes in wind speed and/or direction or other atypicalities.

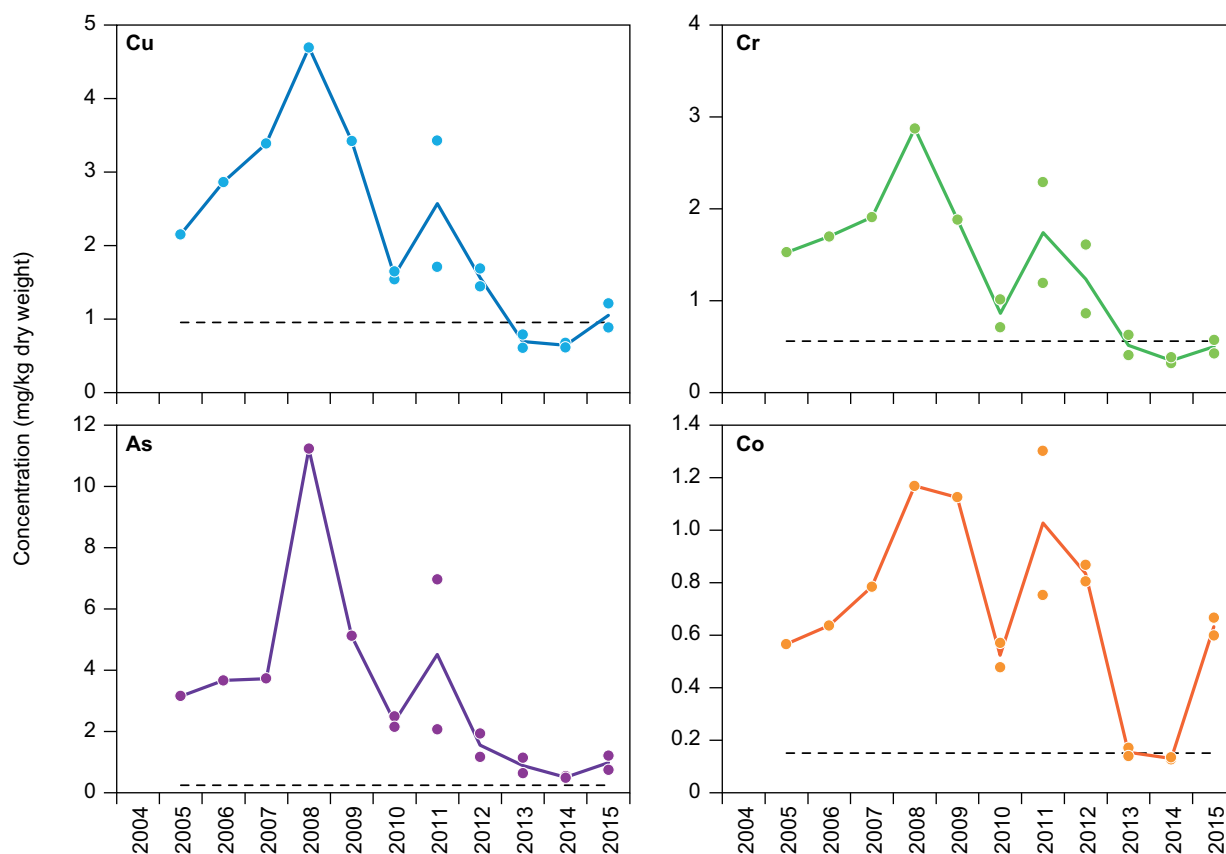


Figure 3.4. Temporal trends in concentrations of Cu, Cr, As and Co in lichens from Area 3 during 2004-2015. Area 3 is the area around the pier (stations M2 and 20t). From 2008 onwards concentrations are from transplanted lichens. Solid lines show the average values. Baseline average concentrations from 1998 are shown as dashed lines.

3.2.2 Freshwater environment

In livers from non-migrating Arctic char in Kirkespir River no elements were found elevated (*table 3.2*) compared to the background data (data from 2000). While concentrations of As was found significantly higher in 2015 than 2014, concentrations of Co, Cr, Cu and Se were found significantly lower this year.

Table 3.2. Metal average concentrations in livers of Arctic char (mg/kg wet weight) in 2015 and 2011-2014. Background concentrations are from baseline studies. * indicates slightly elevated concentrations ($2 \times$ background concentration). dl: detection limit.

		As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
<i>Background concentrations</i>		0.448		0.071	0.042	0.026	9.882		0.025		0.006		34.8
<i>Detection limit 2015</i>		0.021		0.004	0.003	0.034	0.014	0.398	0.007	0.046	0.008	0.012	0.123
2015	average	0.535		0.117	0.047	< dl	4.62	119	0.018	< dl	< dl	0.887	28.1
	+/- std	0.138		0.047	0.013	-	2.73	103	0.004	-	-	0.260	2.96
2014	average	0.203	0.529	0.079	*0.097	0.036	18.5	282	0.014	< dl	< dl	1.53	28.6
	+/- std	0.038	0.208	0.028	0.004	0.010	6.03	157	0.006	-	-	0.268	2.11
2013	average	0.249	0.055	*0.159	< dl	< dl	9.37	68.4	0.020	< dl	< dl	0.942	29.6
	+/- std	0.123	0.071	0.110	-	-	5.97	31.1	0.012	-	-	0.275	2.27
2012	average	0.322	0.035	0.142	< dl	0.032	8.60	228	*0.061	< dl	< dl	0.909	32.5
	+/- std	0.175	0.036	0.047	-	0.021	6.02	105	0.041	-	-	0.216	5.60
2011	average	0.289	0.064	*0.173	0.068	0.048	19.6	279	0.039	< dl	0.027	1.29	35.1
	+/- std	0.210	0.091	0.102	< dl	0.027	17.2	225	0.025	-	0.021	0.563	6.45

Water samples were taken in the Kirkespir River upstream the mine, at the outflow of the process water, in the settlement pond, and downstream at the waterfall (*table 3.3*). Furthermore, samples were taken underground in the mine at several spots (*table 3.4*). The data demonstrated that the discharge of wastewater from the mine added metals to the river water. In 2014, a natural high concentration was found for Cu in the upstream mine water. Cu was found in less high concentration this year. Concentration above EAMRA guidelines was only detected for As in the monitoring well. Measurements of water at the Waterfall station in the Kirkespir River showed concentrations below the Greenland Water Quality Guidelines (MRA Guidelines 2011).

Photo 3.1. Arctic charrs are collected for analyses of accumulation of elements in livers (photo L. Bach).



Table 3.3. Metal concentrations in samples of outflow water from the mine, surface water and groundwater ($\mu\text{g/l}$) in 2015.

* indicates when the EAMRA Guideline values are exceeded. dl: detection limit.

	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
<i>EAMRA Guidelines</i>	4	0.100		3	2	300	0.050	5.00	1		10
<i>Detection limit 2015</i>	0.1	0.009	0.003	0.25	0.06	0.74	0.017	0.11	0.01	0.17	0.1
River upstream camp	2.20	0.006	0.137	0.43	0.53	21.0	< dl	0.28	0.183	0.20	2.92
Outflow 300 m mine portal 1	32.2	0.019	0.183	0.5	1.55	7.78	< dl	1.12	0.072	<dl	5.65
Outflow 300 m mine portal 2	29.3	0.017	0.227	0.33	1.24	4.31	< dl	1.46	0.106	0.19	3.03
Outflow 350 m mine portal	35.4	0.071	5.59	0.38	3.26	6.21	< dl	16.9	0.051	0.21	9.46
Monitoring well 1	1.50	0.046	0.045	0.31	0.38	3.47	< dl	0.19	0.091	0.17	0.84
Monitoring well 2	*12.9	0.019	0.223	0.28	1.39	6.87	< dl	1.02	0.056	0.22	1.80
Kirkespir River	3.00	0.031	4.72	0.51	1.60	87.2	< dl	1.11	0.109	0.45	4.61

The data on water chemistry from samples collected underground the mine demonstrated high concentrations of As, Co, Fe, Ni and Zn compared to the general water quality of the area assessed from data from the River upstream camp. The concentrations are considered as a result of water entering the mine through cracks and crevices and when flowing down through the mountain, the water will absorb the leached metals. The high concentrations of some of the metals in the underground mine water are most likely due to different geochemical conditions (pH, oxygen, redox conditions, etc.). Measuring geochemical parameters were not part of this monitoring. It is also expected that the water in the mine has a relatively long retention time, meaning that the water is relatively old, compared to the melting water in Kirkespir River. A longer retention time is likely to increase the concentration of metals if the geochemical conditions and the chemical equilibrium favour the dissolution of elements.

Table 3.4. Metal concentrations in water samples from underground (UG) mine ($\mu\text{g/l}$) in 2015. dl: detection limit.

	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
<i>Detection limit 2015</i>	0.10	0.009	0.003	0.25	0.06	0.740	0.017	0.110	0.01	0.17	0.10
CIP area	218	0.094	16.6	0.41	1.12	73.8	< dl	8.38	0.037	0.98	27.2
Detox area	107	0.074	9.95	0.51	4.55	86.5	< dl	3.41	0.756	0.78	546
Flow from process area	316	0.179	35.0	0.4	0.87	321	0.030	2.13	0.073	0.58	18.9
Flow to new tailings from process area	225	0.110	23.6	0.42	1.19	223	0.021	2.7	0.045	0.50	8.43
Flow to new tailings from mountain	89.8	0.029	6.23	0.47	1.36	16.5	< dl	15.2	0.066	0.50	3.03
Flow to new tailings after mix	216	0.094	22.4	0.37	0.86	229	< dl	2.8	0.062	0.54	7.53
Flow from new tailings area	285	0.037	27.6	0.45	2.45	261	0.03	0.94	0.024	0.30	1.08
Overlying water in 'old' tailings area	66.5	0.038	3.01	0.40	1.41	14.8	< dl	8.73	0.175	0.20	39.6

3.2.3 Marine environment

Mussels and seaweed were collected at five stations (M1-M5) (figure 2.1). Data were compared to the background data from 2000 (table 3.5 and table 3.6). Concentrations were considered slightly elevated when the mean of the measured concentrations exceeded the background levels by a factor 2, slightly elevated when concentrations were between 2-5 times the background concentrations and highly elevated above 10 times background concentrations.

In brown seaweed (*Fucus vesiculosus*) elevated concentrations were found at some stations when compared to background values (table 3.5). The Cr concentrations were found slightly higher than background concentrations at stations M1, M3 and M5. The Cu concentrations were slightly elevated at stations M3 and M5, while Co was only found slightly elevated at station M3.

Table 3.5. Metal concentrations in the seaweed, *Fucus vesiculosus*, in mg/kg dry weight. Background concentrations are from baseline studies, when available, or based on the data from 2013 on seaweed from reference site. * indicates slightly elevated concentrations (2-5 x background concentration).

	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Background concentrations	46.2	1.76	0.211	0.069	1.00	32.7	0.009	0.869	0.107	0.056	7.00
Detection limit 2015	0.021	0.004	0.003	0.034	0.014	0.398	0.007	0.046	0.008	0.012	0.123
M1	64.9	2.11	0.185	*0.165	1.72	51.3	0.008	0.615	0.037	0.040	9.95
M2	59.4	1.00	0.279	0.131	1.95	28.0	0.010	0.638	0.040	0.045	8.42
M3	66.0	1.36	*0.569	*0.217	*2.35	36.8	0.009	1.193	0.060	0.049	9.48
M4	60.0	1.67	0.209	0.121	1.82	17.3	0.005	0.671	0.024	0.040	7.77
M5	54.7	1.32	0.329	*0.154	*2.15	26.7	0.004	0.697	0.030	0.029	9.93

In mussels (*Mytilus edulis*) (table 3.6), no elements were found elevated except for Co and Fe, which were found slightly elevated at station M2 compared to background measurements. Most metal concentrations in mussels were, however found higher than the levels in 2014 but lower or equal to data from 2013.

Table 3.6. Metal concentrations in the mussels, *Mytilus edulis*, in mg/kg dry weight. Background concentrations are from baseline studies, when available, or based on the data from 2013 on seaweed from a reference site. * indicates slightly elevated concentrations (2-5 x background concentration).

	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Background concentrations	11.7	5.470	0.240	0.736	7.60	122	0.132	0.770	1.22	3.38	89.0
Detection limit 2015	0.021	0.004	0.003	0.034	0.014	0.398	0.007	0.046	0.008	0.012	0.123
M1	9.50	4.08	0.292	0.471	6.14	110	0.051	1.20	0.281	3.89	66.1
M2	13.4	3.17	*0.513	1.213	8.94	*393	0.086	1.69	0.837	4.55	82.4
M3	12.0	4.02	0.358	0.851	7.00	223	0.061	1.36	0.624	3.84	64.3
M4	11.1	3.51	0.389	0.841	7.69	177	0.081	1.62	0.782	4.72	81.1
M5	11.7	3.97	0.342	0.796	7.14	240	0.060	1.13	0.495	4.20	67.2

4 Conclusion

This report describes the results of the twelfth environmental monitoring in the Nalunaq Gold Mine operated by Angel Mining during the period 2009-2013. The monitoring was conducted in August 2015. Most mining work from August 2009 until spring 2011 dealt with the excavation of a chamber inside the mine and the construction of a processing plant. In spring 2011, the mining and processing of ore were initiated, and parts of the low grade ore were transported from the pier back to the mine for processing. From then on, the mining and processing of ore took place inside the process hall in the mountain with some outdoor crushing at the 300 m portal. In November 2013, the mine was closed and clean-up and restoration of the area was initiated. Decommissioning and restoration of the landscape was completed August 2014.

Concerning cyanide, no free cyanide was detected neither in the water inside the mine nor in the water leaching out of the mine or in the Kirkespir River receiving the water from the mine. In two underground water samples low concentrations of complex bound cyanide were detected, but the concentrations are not considered to pose a risk to the environment.

The results showed that there was no free cyanide present in the mine or in the surrounding environment. It is estimated that the main part of the free cyanide is lost due to volatilization and degradation, while a minor and insignificant part is still present as complex bound cyanide.

As in previous years, the impact from the mining activities on the marine environment was confined to the area close to the outlet of the Kirkespir River. Small elevations of metal concentrations compared to background levels were, however, found in blue mussels and brown seaweed regardless of sampling station. In general, during the years 2006-2015 the concentrations of metals in the marine environment have been low and are not remarkably different from background levels.

In the freshwater/river system, one elevated concentration (above EAMRA Guideline value) of As was measured in the monitoring well. No elevated concentrations were found in the Kirkespir River. Accordingly, there were no signs of metal accumulation in Arctic char livers at the Waterfall station in the Kirkespir River.

As in previous years, the terrestrial environment was slightly affected by dust spreading. Concentrations of Cu, Cr, As and Co in lichens were elevated at different levels depending on station and element compared to the background level at the stockpile of crushed waste rock and in the mining/camp area. The area around the mine/camp is the area being most affected by dust spreading. It is expected that metal containing dust will be dispersed from the mountain slope where the waste rock was placed, dependent on wind speed and direction.

4.1 Concluding remarks

In 2015, the impact from the gold mine on the local environment was primarily observed in the Kirkespir Valley. The source of the impact was mainly dust dispersed from the road and from the crushing area at the 300 m portal and the mountain slope itself where waste rock was placed. For some metals, there was a small peak in concentrations indicating an increased dispersal compared to 2014 which could only be explained by changes in weather conditions, e.g. wind direction and speed.

In the Kirkespir River and Kirkespir Bay, no elevated concentrations of concern were found in Arctic char and only few elevated concentrations of metals were found in seaweed and blue mussels.

The environmental impact from the spreading of metals due to the decommissioning and restoration of the Nalunaq area was considered to be minor and the impact from the mining is decreasing. It is assessed that no further actions are needed to reduce the environmental impact.

No traces of free cyanide could be detected in the environment.

Based on the present results and with the closure of the mine in November 2013, it is expected that the element concentrations in the environment will decrease even further, though some dispersal of dust from the waste rock is expected to continue years ahead. Environmental monitoring will continue in 2016 and 2019.

Photo 4.1. Fishing for Arctic chars in the Kirkespir River (photo M.B. Larsen).



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Appendix 1 - List of samples and element concentrations

Sample	Station	ID #	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Biological samples														
<i>Detection limit</i>			0.021		0.004	0.003	0.034	0.014	0.398	0.007	0.046	0.008	0.012	0.123
Lichen samples (mg/kg dry weight)														
<i>Flavocetraria nivalis</i>	5t	53923	0.402		0.083	0.278	0.332	0.652	157	0.027	0.446	0.737	0.104	13.1
<i>Flavocetraria nivalis</i>	6t	53927	0.709		0.082	0.866	0.281	0.950	123	0.024	1.07	0.592	0.067	21.4
<i>Flavocetraria nivalis</i>	11t	53929	2.14		0.076	0.623	1.19	5.77	479	0.034	1.25	0.914	0.105	11.4
<i>Flavocetraria nivalis</i>	12t	53926	0.330		0.139	0.462	0.340	1.934	128	0.026	1.00	0.814	0.076	15.2
<i>Flavocetraria nivalis</i>	20t	53930	0.743		0.162	0.667	0.425	0.881	202	0.023	0.86	0.770	0.128	29.5
<i>Flavocetraria nivalis</i>	21t	53925	0.554		0.076	0.431	0.525	4.26	226	0.021	1.16	1.34	0.100	12.2
<i>Flavocetraria nivalis</i>	22t	53922	2.20		0.174	3.27	1.26	37.3	484	0.026	6.01	1.04	0.148	18.3
<i>Flavocetraria nivalis</i>	23t	53924	4.22		0.127	2.32	4.06	10.7	1615	0.033	6.88	1.63	0.156	24.8
<i>Flavocetraria nivalis</i>	2t	53928	0.745		0.304	1.00	0.758	2.03	327	0.024	1.87	0.921	0.106	28.7
<i>Flavocetraria nivalis</i>	M2t	53931	1.21		0.104	0.598	0.570	1.21	245	0.028	0.830	1.15	0.112	16.1
<i>Flavocetraria nivalis</i>	Ref	53921	0.110		0.040	0.053	0.169	0.395	56	0.022	0.195	0.276	0.100	8.85
Arctic char samples (mg/kg wet weight)														
<i>Salvelinus alpinus</i>	WF	53912	0.477		0.100	0.061	< dl	6.14	267	0.015	< dl	< dl	1.27	29.6
<i>Salvelinus alpinus</i>	WF	53913	0.740		0.179	0.053	< dl	2.52	109	0.018	< dl	< dl	0.663	30.1
<i>Salvelinus alpinus</i>	WF	53914	0.450		0.066	0.030	< dl	2.13	37.2	0.014	< dl	< dl	0.722	29.5
<i>Salvelinus alpinus</i>	WF	53915	0.469		0.122	0.044	< dl	7.69	63.8	0.023	< dl	< dl	0.922	23.7

Sample	Station	ID #	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Mussel samples (mg/kg dry weight)														
<i>Mytilus edulis</i>	M1	53934	9.50		4.08	0.292	0.471	6.14	110	0.051	1.20	0.281	3.89	66.1
<i>Mytilus edulis</i>	M2	53901	13.4		3.17	0.513	1.213	8.94	393	0.086	1.69	0.837	4.55	82.4
<i>Mytilus edulis</i>	M3	53903	12.0		4.02	0.358	0.851	7.00	223	0.061	1.36	0.624	3.84	64.3
<i>Mytilus edulis</i>	M4	53902	11.1		3.51	0.389	0.841	7.69	177	0.081	1.62	0.782	4.72	81.1
<i>Mytilus edulis</i>	M5	53935	11.7		3.97	0.342	0.796	7.14	240	0.060	1.13	0.495	4.20	67.2
Seaweed samples (mg/kg dry weight)														
<i>Fucus vesiculosus</i>	M1	53933	64.9		2.11	0.185	0.165	1.72	51.3	0.008	0.615	0.037	0.040	9.95
<i>Fucus vesiculosus</i>	M2	53904	59.4		1.00	0.279	0.131	1.95	28.0	0.010	0.638	0.040	0.045	8.42
<i>Fucus vesiculosus</i>	M3	53906	66.0		1.36	0.569	0.217	2.35	36.8	0.009	1.193	0.060	0.049	9.48
<i>Fucus vesiculosus</i>	M4	53905	60.0		1.67	0.209	0.121	1.82	17.3	0.005	0.671	0.024	0.040	7.77
<i>Fucus vesiculosus</i>	M5	53932	54.7		1.32	0.329	0.154	2.15	26.7	0.004	0.697	0.030	0.029	9.93
Freshwater samples (µg/l)														
Detection limit			0.100		0.009	0.003	0.25	0.060	0.740	0.017	0.110	0.010	0.17	0.100
CIP area		53942	218		0.094	16.6	0.41	1.12	73.8	< dl	8.38	0.037	0.98	27.2
Detox area		53941	107		0.074	9.95	0.51	4.55	86.5	< dl	3.41	0.756	0.78	546
Flow from process area		53943	316		0.179	35.0	0.40	0.87	321	0.030	2.13	0.073	0.58	18.9
Flow to new tailings from process area		53938	225		0.110	23.6	0.42	1.19	223	0.021	2.7	0.045	0.50	8.43
Flow to new tailings from mountain		53939	89.8		0.029	6.23	0.47	1.36	16.5	< dl	15.2	0.066	0.50	3.03
Flow to new tailings after mix		53937	216		0.094	22.4	0.37	0.86	229	< dl	2.8	0.062	0.54	7.53
Flow from new tailings area		53940	285		0.037	27.6	0.45	2.45	261	0.030	0.94	0.024	0.30	1.08
Overlying water in 'old' tailings area		53944	66.5		0.038	3.01	0.40	1.41	14.8	< dl	8.73	0.175	0.20	39.6
Upstream camp		53945	2.20		0.006	0.137	0.43	0.53	21.0	< dl	0.28	0.183	0.20	2.92
Outflow 300 m mine portal 1		53936	32.2		0.019	0.183	0.50	1.55	7.78	< dl	1.12	0.072	< dl	5.65
Outflow 300 m mine portal 2		53910	29.3		0.017	0.227	0.33	1.24	4.31	< dl	1.46	0.106	0.19	3.03
Outflow 350 m mine portal		53911	35.4		0.071	5.59	0.38	3.26	6.21	< dl	16.9	0.051	0.21	9.46
Monitoring well 1		53909	12.9		0.019	0.223	0.28	1.39	6.87	< dl	1.02	0.056	0.22	1.80
Monitoring well 2		53946	3.00		0.031	4.72	0.51	1.60	87.2	< dl	1.11	0.109	0.45	4.61
Kirkespil River		53908	1.50		0.046	0.045	0.31	0.38	3.47	< dl	0.19	0.091	0.17	0.84

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Appendix 2 – Results of total cyanide analyses



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ANALYSERAPPORT

Aarhus Universitet
Frederiksborgvej 399
4000 Roskilde
Att.: Aarhus Universitet

Udskrevet: 23-09-2015
Version: 1
Modtaget: 14-09-2015
Påbegyndt: 14-09-2015
Ordrenr.: 309224

Sagsnavn: Grønland
Lokalitet: Grønland
Prøvested: Nalunaq
Udtaget: 11-09-2015
Prøvetype: Vand
Prøvetager: Rekv/LB
Kunde: Aarhus Universitet, Frederiksborgvej 399, 4000 Roskilde

Prøvenr.:	120579/15	120580/15		
Prøve ID:	Trailingsvand	Udløb fra mølle		
Kommentar	*1	*1		
Parameter			Enhed	Metode
Cyanid CN, total	3.1	1000	µg/l	DS/EN ISO 14403:2002

Kommentar

*1 Ingen kommentar

Trine Kornbeck

side 1 af 1

Laboratoriet er akkrediteret af DANAK. Analyseresultaterne gælder kun for de(n) analyserede prøve(r).
Analyserapporten må kun gengives i sin helhed, medmindre skriftlig godkendelse foreligger.
Oplysninger om måleusikkerhed findes på www.alsglobal.dk

Tegnforklaring:
#: Ikke akkrediteret
<: mindre end >: Større end

ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2015

This twelfth environmental monitoring programme was conducted in the Nalunaq area, about 40 km from Nanortalik, South Greenland, from 18-31 August 2015. The environmental monitoring programme is conducted to discover and avoid unwanted environmental impacts of the former mining industry. Since the monitoring in 2014, the area has been without any activity. The mining company Angel Mining Gold A/S closed its gold production in November 2013 where after the Nalunaq area was affected by decommissioning and restoration until August 2014. The gold was extracted by chemical extraction with cyanide (carbon-in-pulp). Due to the use of cyanide to extract gold from the ore, there was strict monitoring with the outflow of cyanide from the mine to the valley during the production period, and monitoring will continue after closure. Also, extensive monitoring is conducted to reveal release of metals into the Kirkespir Valley and Kirkespir Bay environment. The content of metals in the terrestrial, freshwater, and marine environment in the Kirkespir Valley and Bay is decreasing and is considered minor. DCE/GINR assess that no requirement for further actions to reduce the environmental impact is needed. Environmental monitoring will continue in 2016 and 2019.