# ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2012

Scientific Report from DCE – Danish Centre for Environment and Energy No. 55 2013

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# ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2012

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# Data sheet


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|---|---|
| Series title and no.: | Scientific Report from DCE – Danish Centre for Environment and Energy No. 55 |
| Title: | Environmental Monitoring at the Nalunaq Gold Mine, South Greenland, 2012 |
| Authors: | Lis Bach & Gert Asmund |
| Institution: | Aarhus University, Department of Bioscience |
| Publisher: | Aarhus University, DCE – Danish Centre for Environment and Energy© |
| URL: | http://dce.au.dk/en |
| Year of publication: | April 2013 |
| Editing completed: | April 2013 |
| Referee: | Frank Rigét |
| Financial support: | No external financial support |
| Please cite as: | Bach, L. & Asmund, G. 2013. Environmental Monitoring at the Nalunaq Gold Mine, South Greenland, 2012. Aarhus University, DCE – Danish Centre for Environment and Energy, 42 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 55. http://www.dmu.dk/Pub/SR55.pdf |





Abstract: This ninth environmental monitoring programme was conducted in the Nalunaq area, about 40 km from Nanortalik, South Greenland, from 7 to 13 September 2012. The environmental monitoring programme is conducted to trace and avoid unwanted impacts of the mining industry to the environment. Since the monitoring in 2011, the mining company Gold Angel Mining A/S has been breaking new ore and the mining activities are primarily contained inside the mountain. The gold is recovered by the use of chemical extraction (carbon-in-pulp) using cyanide. Due to the use of cyanide to extract gold from the ore, strict control with the outflow of cyanide from the mine to the Kirkespir Valley is performed. Also an extensive monitoring programme is conducted to reveal spreading and effects of elements into the Kirkespir Valley and Bay environment. The described impact on the environment of the Kirkespir Valley, both terrestrial, freshwater and marine, is considered to be minor and is generally lower than during the operation in 2004-2009.



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| Keywords: | Environment, monitoring, elements, blue mussel, brown seaweed, shorthorn sculpin, Arctic char, lichen, transplantation, Nalunaq Gold Mine, Greenland |
| Layout: | Graphics Group, AU Silkeborg |
| Front cover photo: | Lis Bach |
| ISBN: | 978-87-7156-002-2 |
| ISSN (electronic): | 2245-0203 |
| Number of pages: | 42 |
| Internet version: | The report is available in electronic format (pdf) at: http://www.dmu.dk/Pub/SR55.pdf |

# Contents

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# Summary

This ninth environmental monitoring programme was conducted in Nalunaq area, about 40 km from Nanortalik, South Greenland, from 7 to 13 September 2012. The environmental monitoring programme is conducted to trace and avoid unwanted impacts of the mining industry to the environment. Since the monitoring in 2011, the mining company Angel Mining Gold A/S has continued to break ore in the mine. The gold is recovered by the use of chemical extraction (carbon-in-pulp) with the use of cyanide. Due to the use of cyanide to extract gold from the ore, there is strict control with the outflow of cyanide from the mine to the valley.

Blue mussels, seaweed and sculpins were collected at 4-5 stations in the Kirkespir Bay, Arctic chars were caught in Kirkespir River and lichens, *Flavocetraria nivalis*, were collected at 23 stations in Kirkespir Valley and around the bay area. Lichens were also transplanted from an unpolluted area (AMIT) to the Kirkespir area. All samples were analysed for 12 elements: arsenic (As), gold (Au), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn). The results were compared with background levels measured in 1998-2001 and with the results of previous monitoring studies.

In the terrestrial environment, lichens from the fields at the pier, the depot of crushed waste rock and mine and the camp showed significantly elevated concentrations of Cu, Cr, As and Co compared to background levels as in previous years. The concentrations of metals in the transplanted lichens were lower in 2012 than in 2007 and 2008 and are comparable to concentrations measured in 2010. The measured elevated element concentrations are supposed to be due to mining activities related to outdoor crushing at the 300 m portal and from gravel road related dust spreading.

The relations between the concentrations of Cu, Cr, As, and Co in the lichens and the perpendicular distance to the gravel road were examined for the period from 2005-12. For all metal concentrations, there is a significant decrease with increasing distance to the road. Elevated levels of Co and As were found at a distance of up to approx. 1300 and 1500 m from the gravel road, respectively, while the Cr and Cu concentrations reached the background levels approx. 750 m from the road.

Elements were measured in the freshwater system of the mining area – from upstream the camp, the water discharge supply from the mining wastewater, through the sedimentation pond and further downstream the Kirkespir River. Both water and sediments showed elevated concentrations of several elements in the mining wastewater discharge compared to upstream concentrations. After the settlement pond only the concentrations of Cu could not meet the water quality criteria. There was however no indications of elevated Cu concentrations or any of the other measured metals in livers of Arctic char.

Kirkespir River runs out in Kirkespir Bay, where blue mussels, seaweed and sculpins were collected. The marine environment was in 2012 only slightly affected by mining activities. While seaweed and mussels were impacted by the outflow of elements by the Kirkespir River and had slightly elevated

concentrations of most elements and particularly at the marine stations closest to the estuary, no significantly elevated element concentrations were found in sculpin livers at any of the marine stations.

The environmental impact from spreading of elements on the environment of the Kirkespir Valley and Bay, terrestrial, freshwater and marine, due to mining is considered to be minor and there is no need for further actions to reduce the environmental impact.

# Sammenfatning

Dette niende miljøovervågningsprogram blev gennemført i Nalunaq-området, omkring 40 km fra Nanortalik, Sydgrønland, 7-13. september 2012. Miljøovervågningsprogrammet udføres for at spore og undgå uønskede virkninger af mineindustrien til miljøet. Efter overvågningen i 2011 har mineselskabet Angel Mining Gold A/S fortsat med at bryde malm i minen. Guldet udvindes ved anvendelse af kemisk ekstraktion (carbon-in-pulp) ved anvendelse af cyanid. På grund af anvendelsen af cyanid til at udvinde guld fra malmen, føres der streng kontrol med udstrømningen af cyanid fra minen til dalen.

Blåmuslinger, tang og ulke blev indsamlet på 4-5 stationer i Kirkespirbugten, fjeldørred blev fanget i Kirkespirelven og snekruslav blev samlet på 23 stationer i Kirkespirdalen og ved bugten. Laver blev ligeledes transplanteret fra et uforurenet område (AMIT) til Kirkespirdalen området. Alle prøver blev analyseret i 12 elementer: arsen (As), guld (Au), cadmium (Cd), cobalt (Co), chrom (Cr), kobber (Cu), jern (Fe), kviksølv (Hg), nikkel (Ni), bly (Pb), selen (Se) og zink (Zn). Resultaterne blev sammenlignet med baggrundsniveauer målt i 1998-2001 og med resultaterne af tidligere moniteringsstudier.

I det terrestriske miljø var der i laver fra områderne ved kajen, depotet for knust gråbjerg og ved minen og lejren signifikant forhøjede koncentrationer af Cu, Cr, As og Co sammenlignet med baggrundsniveauer som i de tidligere år. Koncentrationerne af metaller i de transplanterede laver var i 2012 lavere i forhold til 2007 og 2008, men sammenlignelige i forhold til 2010. Forhøjelserne formodes især at skyldes mineaktiviteter i forbindelse med udendørs knusning ved 300 m portalen samt spredning i forbindelse med vejstøv.

Forholdet mellem koncentrationerne af Cu, Cr, As og Co i lav og den vinkelrette afstand til vejen blev undersøgt for perioden 2005-12. For alle metalkoncentrationer var der et signifikant fald med stigende afstande til vejen. Der blev fundet forhøjede koncentrationer af Co og As i en afstand af op til ca. 1300 m samt 1500 m fra vejen, mens Cr og Cu nåede baggrundsniveauet ca. 750 m fra vejen.

Elementer blev målt i ferskvand systemet fra mineområdet opstrøms lejren, gennem udledning fra minedrift spildevandet, gennem sedimentationsbassinet og videre nedstrøms Kirkespirelven. Både vand og sedimenter viste forhøjede koncentrationer af flere elementer i minedrift spildevandet i forhold til opstrøms koncentrationer. Efter sedimentationsbassinet viste kun koncentrationerne af Cu ikke at opfylde vandkvalitetskriterierne. Der var dog ingen tegn på forhøjede Cu koncentrationer eller nogen af de andre målte metaller i lever fra fjeldørred.

Kirkespirdalen River ender i Kirkespirdalen Bay, hvor blåmuslinger, tang og ulke blev indsamlet. Det marine miljø var i 2012 kun lidt påvirket af minedriften. Mens tang og muslinger var påvirket af udledning af elementer fra Kirkespirelven og havde let forhøjede koncentrationer af de fleste elementer, og især på de marine stationer tættest på flodmundingen, blev der ikke fundet signifikant forhøjede koncentrationer i ulke lever på nogen marine stationer.

Miljøbelastningen fra spredning af elementer fra minedriften på miljøet i Kirkespirdalen og Kirkespirbugten, både terrestrisk, ferskvands og marint, anses for at være begrænset, og der er ikke behov for yderligere tiltag for at reducere miljøbelastningen.

# Eqikkaaneq

2012-imi septemberip ulluisa 7-ianiit 13-iannut avatangiisinik misissuinerit arfineq sisamassaat kuultisiorfiup Nalunap, Kujataani Nanortalimmiit 40 kilometeri missaanni ungasissuseqartup eqqaani ingerlanneqarpoq. Aatsitassarsiorfiup avatangiisinut sunniutai kissaatigineqanngitsut paasisinnaajumallugit pinngitsoorsinnaajumallugillu avatangiisit misissuiffigineqartarput. 2011-imi misissuinerup kingorna aatsitassarsioqatigiiffik Angel Mining Gold A/S ujaqqanik kuultitalinnik piiaanerminik ingerlatsiinnarsimavoq. Kuulti cyanid atorlugu puttallartitsinikkut immikkoortiterneqartarpoq (Carbon-in-Pulp). Kuultip ujaqqaniit immikkoortinneqarnerani cyanidip atorneqarnera pissutigalugu cyanidip qooqqumut aniatinneqartup killiliussanik qaanngiinnginnissaa sukangasumik nakkutigineqarpoq.

Uillut, qeqqussat kanassullu Iterlassuarmi sumiiffinni assigiinngitsuni 4-5-imi pisariortorneqarput, Napasorsuup qooruata kuuani eqallut kangerluanilu pisarineqartarput. Aammattaaq qillinernik sumiiffimmi mingutsitaanngitsumiit (AMIT) aatsitassarsiorfiup eqqaanut nuussisoqarpoq. Misissugassatut tigooqqakkat tamarmik pinngoqqaatinut 12-inut misissuiffigineqarput: arsen (As), kuulti (Au), cadmium (Cd), kobalt (Co), krom (Cr), kanngussak (Cu), savimineq (Fe), kviksølv (Hg), nikkeli (Ni), aqerloq (Pb), selen (Se) aammalu zinki (Zn). Paasisat 1998-2001-imi aatsitassarsiorneq sioqqullugu uuttortakkanut kiisalu misissuisarnerni siusinnerusukkut ingerlanneqartuni paasisanut sanilliunneqartarput.

Nunami avatangiisit eqqarsaatigalugit qillinerni (ujaqqat naanerini) talittarfiup, ujaqqanik aserortikkanik ilioqqaaviup kiisalu aatsitassarsiorfiup tammaarsimaffiullu eqqaanni Cu, Cr, As aammalu CO ukiuni siuliini sanilliussivinnut sanilliullugit annertungaatsiaqaat. Qillinerni nuussani 2012-imi saffiugassat 2007 aamma 2008-imut sanilliullugit annikinnerupput, kisiannili 2010-mut assersuunneqarsinnaallutik. Qaffariaataat pingaartumik isaarissami 300 meterinik qatsissusilimmi silami aserorterinermik kiisalu aqqusinerniit pujoralatserinermik pissuteqarsimassangatinneqarpoq.

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Tammaarfimmiit qutsinnerusumi, aatsitassarsiorfiup imikoorutaaneersut, kitsitsivimmeersut kiisalu kuummi atsinnerusumiittut sananeqaatit annertussusii uuttortaavigineqarput. Imeq kitsitsivillu tamarmik kuummi qutsinnerusumut sanilliullugit aatsitassarsiorfiup imikoorneranik pissuteqartumik sananeqaatinik akoqarnerupput. Kisitsiviup Cu-mik akui erngup pitsaassusissaa pillugu piumasaqaatinik naammassinninngillat. Taamaattorli eqaluit tinguini Cu-p imaluunniit saffiugassat uuttortarneqarnertut allat annerulersimaneranik malunnartoqanngilaq.

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uillullu sananeqaatinit Napasorsuup qooruata kuuatigut aniatinneqartunik sunnerneqarsimapput annikitsunnguamillu avatangiisinut naleqqiullutik sananeqaatinik arlalinnik akoqarnerullutik, pingaartumik kuup akuata eqqaaniittut, taamaattorli kanassut tingui misissugassanik tigusiffiit arlaannaanniluunniit annerusumik akoqanngillat.

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# 1 Introduction

## 1.1 Mining activities

'Nalunaq' is the Greenlandic name of Greenland's first gold mine and means 'the place that is hard to find'.

The Nalunaq Gold Mine (NGM) is located in Kirkespir Valley 40 km north-east of Nanortalik in the southernmost tip of Greenland and is a Proterozoic narrow-vein, high-grade gold deposit.

Nalunaq Mountain, which hosts the gold deposit, is located in a wide glacial valley reaching into the Saqqaa Fjord about 9 km from the mine site. The terrain is a glacial valley with mountain peaks reaching 1,200-1,600 m above sea level. A river runs through the valley, fed by mountain streams of melting snow, and runs to the fjord.

The first opening of NGM in 2004 was a milestone for Greenland, being the first gold mine and the first new mine to be developed in the country for 30 years. The Maarmorilik mine opened in 1972 and closed in 1990. In 2004 the mining company Crew Gold Corporation was granted a license to exploit the gold deposit at Nalunaq. The license covered an area of 16 km² around the mine site. Before commencing mining operations, Crew completed over 30,000 meters of diamond drilling and established that the gold is in a quartz intrusion in a granite like host rock. The structure is quite uniform with the quartz varying in thickness from 0.75 meter to 1.5 meters and with an unevenly dispersed gold distribution. The ore sheet has an average strike angle of 35º inside the Nalunaq Mountain being 1,340 meters high. Production commenced in mid-2004 and continued until the end of 2008. Over the period, Crew completed more than 19,000 meters of tunneling and produced 8,000 kg of gold. The mined ore was shipped first to Spain and later to Canada for processing. Rising oil prices and shipping costs made however the economics progressively more difficult and the mine closed with the last shipment of ore in March 2009.

In July 2009, Crew concluded the sale of Nalunaq Gold Mine to Angus and Ross plc – now Angel Mining Gold A/S. Included in the sale was an environmental bond of 16 million DKK, expected to be sufficient for all anticipated mine closure liabilities (Angel Mining 2009; Crewgold 2009). The target annual production rate is approximately 680 kg of gold per year and since the first pure of gold in May 2011, the Nalunaq Mine has till the end of 2012 produced more than 350 kg of doré extracted from ore exploited from new drilling and from ore stored at the pier by the former mining company that has now been transported back to the mine (Angel Mining 2012).

Most of the mining work from 2009 and until the actual production in 2011 dealt with the excavation of a production chamber inside the mine and the preparation of a chemical gold separation (Carbon-In-Pulp, CIP) including cyanide use and optimization of the processes.

The processing plant is one of the first underground cyanide leaching plant and the on-site plant enables the company to eliminate the costs of shipping and external processing of ore material, which proved to be a costly burden for the previous operation.

The CIP method employs massive tanks aligned whereby gold is dissolved into slurry (pulp) through a chemical process incorporating agitation, oxygen and cyanide. Once dissolved, the gold in aqueous solution requires separation. At this stage, activated carbon pellets are introduced to the circuit. Activated carbon is charged in such a way that it adsorbs the aqueous gold. The gold loaded coarse grained carbon can then be screened from the water and the fine grained ore. The loaded carbon is then introduced to a cyanide solution under heat and pressure with the purpose of stripping the gold from the carbon. Hereafter is the gold electroplated onto stainless steel cathodes and melted into dore bars. Metallurgists strive for the best recovery with the least loss of gold from the circuitry through tailings, and the CIP process leads to an app. 90% recovery of gold from the ore.

As described above the gold extraction involves addition of cyanide. Cyanide is however a compound that exerts high acute toxic effects even in low concentrations, but is easily degraded under light and/or oxygen to nontoxic levels. In the mining process cyanide is added in the first extraction tank as sodium cyanide. After its use the cyanide is treated by sodium metabisulphite and air in order to decompose the cyanide into cyanate. The cyanide is, however, not decomposed completely, and the rest of the cyanide will follow the tailings into the under-ground tailings chamber and a small amount will be discharged by wastewater from the process. The tailings chambers are outmined areas in the mine.

Associated to the mining process there are in particular two main environmental risks:

- The risk of spreading of released elements (metals) due to the crushing effects of the body rock, deposition of waste-rock and driving on the gravel road. The environmental risks are associated with discharge of wastewater from the process and to spreading of elements as dust particles.
- The risk of discharging of cyanide in toxic concentrations to the environment. The risks are associated with discharge of mining process waste water or accidental spills of cyanide e.g. from traffic accidents or incorrect pumping of cyanide solutions

As a result of those risks an environmental monitoring programme has been developed to trace and avoid unwanted impacts to the environment.

## 1.2 Environmental baseline studies

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 macrofauna 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 activities used at present, the monitoring programme presented below was designed.

## 1.3 Monitoring programme

Requirements for monitoring of the environment in relation to the mining activity have been set by the Bureau of Minerals and Petroleum (BMP) of the Greenland Self-Government. These requirements are described in the BMP exploitation license of 19 March 2010, Phase 6, §§19/43, chapter 8.

The objective of the monitoring is to document any environmental impacts associated with the mining activities.

### 1.3.1 Cyanide monitoring programme

Due to the mining activities and the use of the CIP method involving cyanide, an intensive monitoring programme for detection of cyanide in the environment is being conducted. The mining company is responsible for conducting the monitoring programme (i.e. sampling and sample analyses) and must forward the data on a regular basis to BMP.

The cyanide monitoring programme consist of a frequently collection of water samples that are being analysed for cyanide. One process water sample is taken inside the mining area and 5 environmental samples are taken outside in the environment to ensure that cyanide concentrations in the environment do not exceed the limits set by BMP (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 must not exceed 0.005 ppm (mg/l, measured as WAD cyanide).

### 1.3.2 Element monitoring programme

The element monitoring programme is divided into three compartments: the marine, the freshwater and the terrestrial environment. For the marine environment brown seaweed, blue mussel and shorthorn sculpin are sampled at stations that are placed relatively close to, and on each side of the shipping facility. For the freshwater environment the sampling station is placed at the first site downstream the mining area, where Arctic chars are occurring. Sampling stations for the terrestrial environment are placed both in connection with the above mentioned marine stations and around existing or former ore stockpiles around the 300 m portal and along the road.

The following samples have to be collected at the number of stations specified:

Marine environment:
- Brown seaweed at 4 stations with 2 samples per station; a total of 8 samples.
- Blue mussels at 4 stations with 2 samples (2 different size groups) per station; a total of 8 samples.
- Liver from 5 shorthorn sculpins at 4 stations with a total of 20 specimens.

Freshwater environment:
- Liver from Arctic chars at 1 station of 4 specimens.

Terrestrial environment:
- Lichens at 18 stations; a total of 18 samples.

The samples collected are analysed for the following elements: arsenic (As), gold (Au), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), lead (Pb), nickel (Ni), selenium (Se), and zinc (Zn).

BMP may demand changes to the scope and content of the environmental monitoring if the existing monitoring programme is considered inadequate based on the results obtained and on experience from the mining operation. Samples must be collected on an annual basis during operations and closure and for a period of minimum two years after closure. The samples must be collected and analysed in accordance with guidelines prepared by DCE-AU shortly after being collected. The analytical findings must be data processed, and a report prepared.

**Photo 1.1.** Shorthorn sculpins are caught at the marine stations – here station M2 at the barge of the pier in the Kirkespir Bay (photo by L Bach).

### 1.3.3 Monitoring studies 2004 – 2011

Since the official opening of the Nalunaq Gold Mine in August 2004, every year during July or August NERI has performed a monitoring study in the area. The monitoring studies are reported in the Nalunaq monitoring reports (Glahder& Asmund 2005, 2006, 2007; Glahder et al. 2008, 2009, 2010, 2011; Bach et al., 2012) and they can be found on the DCE-AU web address: http://www.dmu.dk/en/publications/ and Scientific reports. Danmarks Miljøundersøgelser, DMU or National Environmental Research Institute, NERI is from 2011 replaced by DCE - Danish Centre for Environment and Energy, Aarhus University.

### 1.3.4 Monitoring studies 2012

Year 2012 is the second year with production in the area using of cyanide and the present report also describes the cyanide monitoring results.

#### Cyanide monitoring programme

The cyanide monitoring programme is conducted by the mining company with a frequency of reporting to BMP two times a week. In September 2012, the programme including the water sampling and the analytical part was inspected by DCE-AU.

#### Element monitoring programme

The monitoring study was performed in the Nalunaq area during 7-13 September 2012 by DCE-AU.

Sampling was carried out in accordance with the monitoring programme described in the exploitation license (and in chapter 1.3.2) with the following divergences:

In this year's monitoring studies like last year, both blue mussels and brown seaweed were sampled at two more stations; one additional new marine station close to the river discharge to the bay, M5, and at AMIT, a reference site on the north-east side of the Amitsoq Island about 15 km north of the Kirkespir Bay (figure 2.2).

Furthermore livers of shorthorn sculpin were sampled at four marine stations (U1-U4) in the Kirkespir Bay and the reference station AMIT, 4-5 specimens a site, except site M3, where only two sculpins were caught. A total of 21 livers were sampled.

At the freshwater environment, 5 Arctic char livers were sampled from the Kirkespir River near the waterfall and 5 Arctic chars were caught at a reference river (st 25), in order to be able to give a more precise judgment of the trace element levels in the trout livers. Besides, water and sediment samples were collected in the river at five sites where also passive samplers (DGT-devices) were deployed.

Lichens were collected from the six transplantation stations (M2-t, 5-t, 6-t, 11-t, 12-t, and 20-t) established during 2007-2012 in Kirkespir Bay and Valley. New stations were established this year 22-t, 23-t and 24-t and lichens, collected at AMIT, were transplanted to these nine stations, in order to evaluate the dust spreading due to the outdoor crusher.

Lichen was not collected at station 1 and 2 due to logistic matters.

Analyses were performed according to the programme, however 96 samples were analysed instead of 54 and the following 3 elements were added to the analytical programme: nickel (Ni), selenium (Se) and gold (Au).

## 1.4 Acknowledgements

We wish to thank the staff at Nalunaq, Angel Mining Gold, for their help and assistance during the tight monitoring programme. Sigga Joensen and Anna Marie Plejdrup laboratory technicians at DCE-AU are thanked for sample preparation, analyses and delivery of analytical results.

# 2 Methods

## 2.1 Cyanide monitoring programme

### 2.1.1 Collection of samples

Water samples were collected at 6 different sampling stations. Sample 1, 2 and 3 are collected and analysed daily, while sample and analyses of sample 4, 5 and 6 are performed weekly (figure 2.1 and table 2.1).

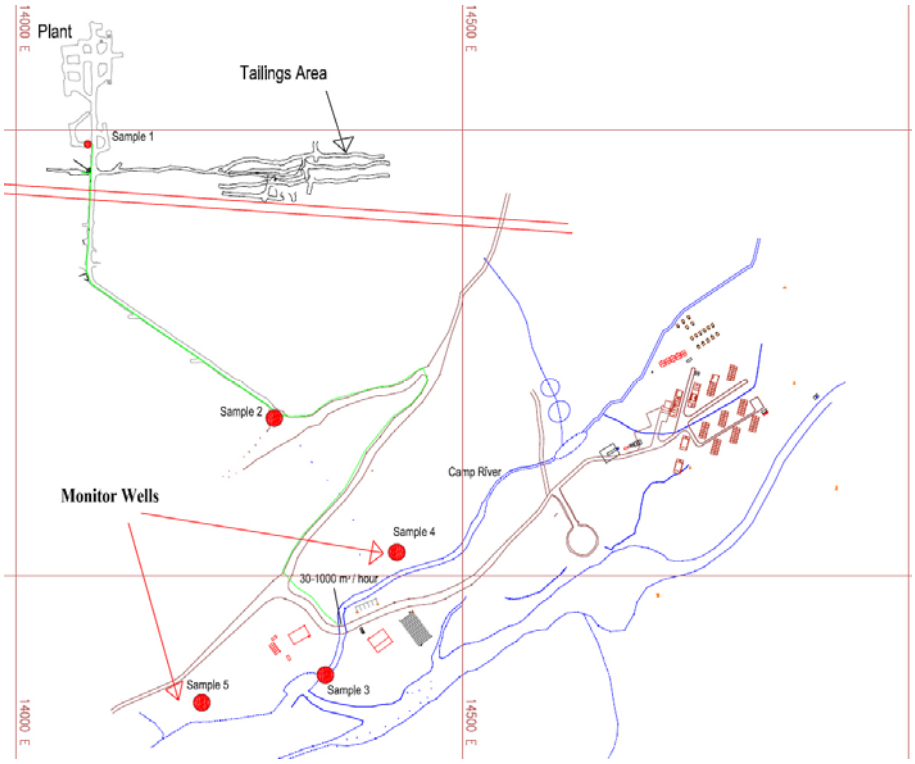


**Figure 2.1.** Sampling stations for cyanide monitoring. Sample 1 is taken from the tailings water, sample 2 is taken at the 300 m mine entrance, where wastewater is discharged. Sample 3 is taken at the sediment pond and sample 4 and 5 from monitoring wells. Sample 6 is taken further down the Kirkespir River and is not shown in the map.

**Table 2.1.** Cyanide sampling programme and maximum limit values in ppm (parts per million or mg/l).* Monthly averages with maximum allowed value of 10.0 ppm of single samples.

| Sampling Station | Location | Monitoring frequency | Maximum cyanide concentration |
|---|---|---|---|
| **1** | Process water/tailingswater | Daily | 4.0 ppm in winter* / 2.0 ppm in summer* |
| **2** | Wastewater discharge from mine process area/ditch | Daily | 0.20 ppm |
| **3** | Sedimentation pond | Daily | 0.20 ppm |
| **4** | Monitoring well a | Weekly | 0.005 ppm |
| **5** | Monitoring well b | Weekly | 0.005 ppm |
| **6** | Kirkespir River - waterfall | Weekly | 0.005 ppm |

### 2.1.2 Analyses

Water samples were processed shortly after the sampling at the laboratory facilities in the camp. After filtration the samples were analysed for cyanide using the Hach-Lange LCK315 method and a Hach-Lange DR2800 instrument. This method is fast and easy and has a factory guarantied measuring range of 0.01– 0.60 ppm, within which precise results are obtained. The practical detection limit is judged to be about 0.002 ppm with careful operation of the instrument

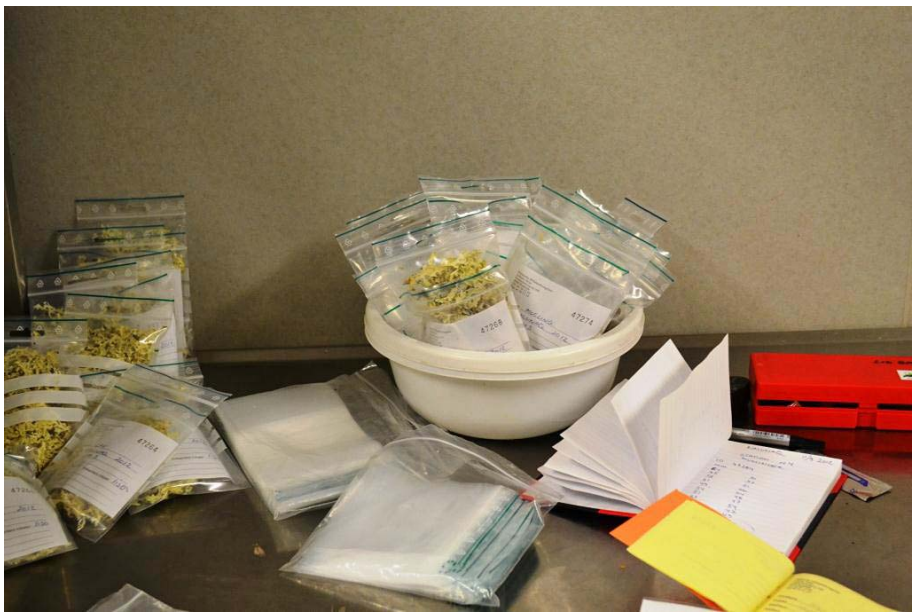

**Photo 2.1.** Sample preparation (photo by L Bach).

## 2.2 Element monitoring programme

### 2.2.1 Collection of samples

Sampling in the Kirkespir Bay and at the north-eastern point of Amitsoq Island (AMIT) was performed with a motor boat. Sampling of blue mussels and seaweed was performed at low tides (Danish Maritime Safety Administration 2011).

Mussels were collected at five stations M1-M5 and AMIT and in two size groups for each station (see Appendix 3). Each sample consisted of approximately 20 individuals. The mussels were opened and allowed to drain, the soft parts cut free and frozen in plastic bags for later element analysis.

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

Shorthorn sculpins were jigged for from motor boat at the stations U1, U3, U4 and AMIT. Sculpins at U2 were caught from the barge at the pier. In total 21 shorthorn sculpins were caught. All sculpins were measured and weighed and the livers were taken out and frozen in plastic bags.

Sediment samples (upper 2 cm) were sampled in both freshwater and marine area, sieved to 1 mm and frozen in plastic bags. Water samples were collected and filtered to 0.45 µm immediately after sampling at site.

Passive samplers (DGT devices) were deployed in the freshwater system in a plastic tube with a floating device to ensure correct placement in the water column.

Resident Arctic chars were fished in the Kirkespir River at the waterfall pond and 5 resident char were sampled. Further, 5 chars were caught at a reference river further down the valley. In the laboratory each fish was measured, weighed and the liver was dissected out. Resident Arctic chars 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. The migratory chars spend the summer feeding in the Kirkespir Bay and the Saqqaa Fjord.

Lichens were sampled at 23 stations: Nine from the Kirkespir Valley downstream the camp, two stations in the camp area, three north from the camp, five in the Kirkespir Bay area and one in the north-eastern part of Amitsoq Island (station AMIT) (figure 2.2). Lichens at station 1 and 2 were not sampled due to logistic problems. Lichens sampled at AMIT were transplanted to t-stations M2-t, 5-t, 6-t, 11-t, 12-t, 20-t, 21-t, 22-t, 23-t and 24-t after transplanted lichens from 2011 were sampled and the stations cleaned (Appendix 2).

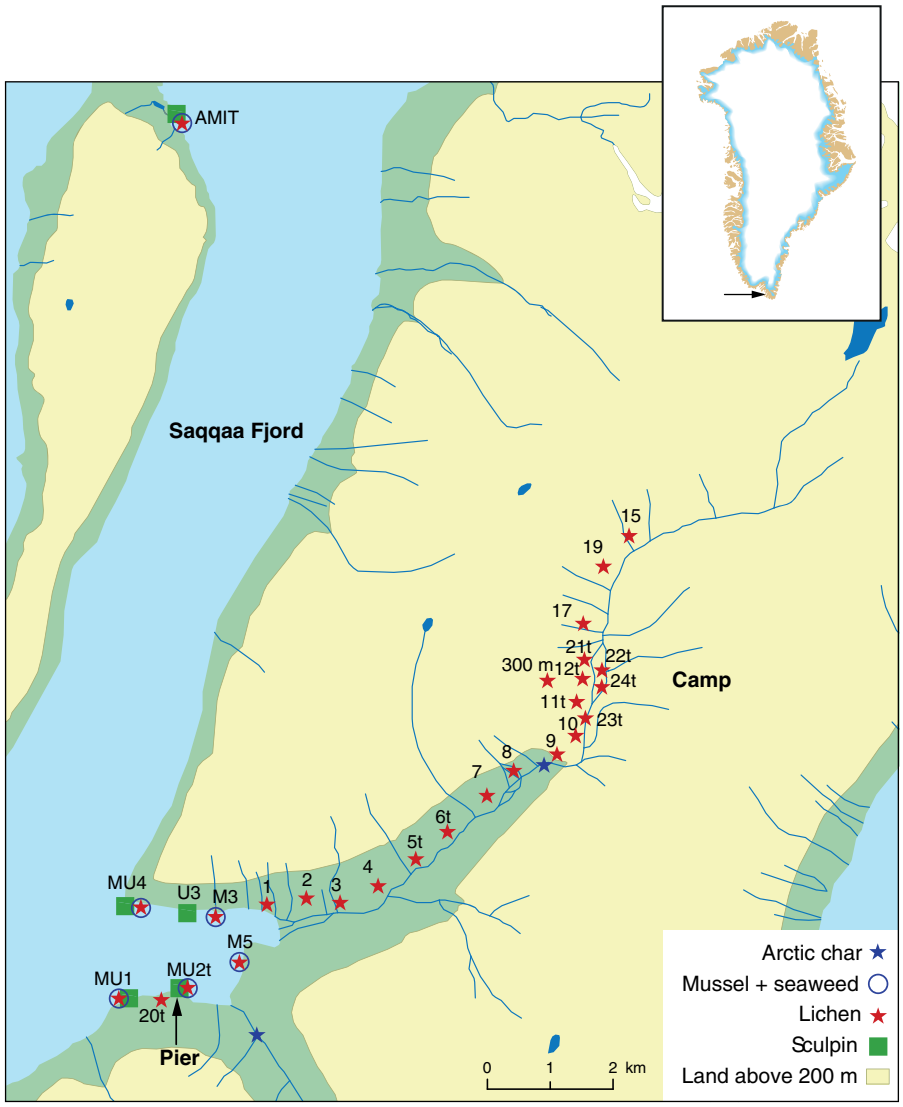


**Figure 2.2.** Sampling stations in the Nalunaq Gold Mine area, Nanortalik, South Greenland. M: Marine stations: Blue mussel and brown seaweed. U: Shorthorn sculpin stations. Arctic chars were caught near the lichen station 9 at the waterfall station and in a reference river. Lichens were sampled at 23 stations (station 1 and 2 were left out due to logistic matters). Lichens transplanted in 2011 from AMIT were sampled at stations M2-t, 5-t, 6-t, 11-t, 12-t and 20-t and replaced with new lichens from AMIT. Further, four new lichen stations 21-t, 22-t, 23-t and 24-t were established. The mine entrance is west of the camp area.

### 2.2.2 Analyses

All samples were transported either frozen directly to DCE-AU. A total of 96 samples of blue mussel (12), brown seaweed (12), livers of shorthorn sculpin (21), sediment (7), freshwater (5), DGT-devices (5), livers of Arctic char (10) and lichens (23) were analysed for the following 12 elements: arsenic (As), gold (Au), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn).

#### Chemical analyses

Following freeze drying of blue mussels and brown seaweed at DCE-AU, subsamples of 0.3-1.0 g of biota were digested in half-concentrated Suprapure nitric acid under pressure in Teflon bombs in a microwave oven. The samples where then diluted to ca. 25 grams with milliQ water and all elements were analysed by ICP-MS (an accredited method according to DANAK, accreditation No. 411). Hg and Co are not included in this accreditation. All chemical results are listed in Appendix 4. 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. In appendix 1 the analytical results of the certified reference materials are compared to the certificate values. As shown, the analytical results are close to the certificate values.

The filtered water samples were stabilized with 2 g/l nitric acid and then analysed by ICP-MS. The DGT capsules were disassembled in the laboratory and the ion exchange material extracted with nitric acid. The acid was then analysed by ICP-MS.

### 2.2.3 Statistical data analyses

Data obtained in this monitoring programme (2012) was compared with data obtained in the baseline studies (data from 2000-2002) that were conducted before the gold mining started in the area. Further, the monitoring stations were compared to the reference station, AMIT, which is situated 15 km away from the mining area and is assumed not be affected by mining activities.

Differences in element concentrations in brown seaweed, mussels, shorthorn sculpins and Arctic chars 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 of differences between sites and background. The level of statistical significance used was $p < 0.05$.

We tested separately the following two areas, 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 2004-2012 compared to background concentrations using a one-way ANOVA. Prior to the analyses data were logarithmic (base e) transformed to meet the assumptions of normal distribution and variance homogeneous of the tests. Post hoc Tukey's studentized range tests were applied to test differences between years and background. The level of statistical significance used was $p < 0.05$.

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.

# 3 Results and discussion

## 3.1 Cyanide monitoring programme

Cyanide concentrations are measured in water samples collected in the freshwater system around the mine area and in the Kirkespir River. Water sample data has been forwarded BMP 1-2 times a week and evaluated. Cyanide concentrations in the samples are considered elevated if the values exceed the maximum concentration limit in Table 3.1 except for station 1, where the values given in the table is the monthly average values that must not be exceed.

**Table 3.1.** Cyanide monitoring programme. Monthly average values of cyanide in ppm (mg/l) ± std dev. At station 1 the maximum concentration is 2.0 ppm in the summer time and 4.0 ppm in the winter time. nm indicates that the sample has not been collected due to inaccessibility caused by deep snow in the field.

| | | Station 1 | Station 2 | Station 3 | Station 4 | Station 5 | Station 6 |
|---|---|---|---|---|---|---|---|
| **max ppm** | | **2.0/4.0** | **0.20** | **0.20** | **0.005** | **0.005** | **0.005** |
| **January** | *average* | 3.223 | 0.099 | 0.030 | nm | nm | 0.002 |
| | *std dev* | 2.071 | 0.056 | 0.038 | nm | nm | 0.002 |
| **February** | *average* | 0.257 | 0.099 | 0.006 | nm | nm | 0.001 |
| | *std dev* | 0.147 | 0.043 | 0.004 | nm | nm | 0.001 |
| **March** | *average* | 0.428 | 0.153 | nm | nm | nm | 0.000 |
| | *std dev* | 0.417 | 0.042 | nm | nm | nm | 0.000 |
| **April** | *average* | 0.261 | 0.095 | 0.001 | nm | nm | 0.001 |
| | *std dev* | 0.368 | 0.054 | 0.003 | nm | nm | 0.002 |
| **May** | *average* | 0.493 | 0.088 | 0.013 | 0.000 | 0.000 | 0.000 |
| | *std dev* | 0.493 | 0.054 | 0.021 | 0.001 | 0.000 | 0.000 |
| **June** | *average* | 0.480 | 0.098 | 0.013 | 0.001 | 0.000 | 0.001 |
| | *std dev* | 0.370 | 0.057 | 0.016 | 0.002 | 0.000 | 0.001 |
| **July** | *average* | 0.612 | 0.128 | 0.028 | 0.000 | 0.000 | 0.000 |
| | *std dev* | 0.371 | 0.059 | 0.035 | 0.000 | 0.000 | 0.000 |
| **August** | *average* | 0.526 | 0.118 | 0.027 | 0.000 | 0.000 | 0.001 |
| | *std dev* | 0.456 | 0.051 | 0.026 | 0.001 | 0.000 | 0.001 |
| **September** | *average* | 0.612 | 0.102 | 0.016 | 0.000 | 0.000 | 0.000 |
| | *std dev* | 0.391 | 0.056 | 0.020 | 0.000 | 0.000 | 0.000 |
| **October** | *average* | 0.181 | 0.070 | 0.016 | 0.000 | 0.002 | 0.000 |
| | *std dev* | 0.203 | 0.057 | 0.032 | 0.000 | 0.002 | 0.000 |
| **November** | *average* | 0.721 | 0.106 | 0.061 | 0.001 | 0.000 | 0.001 |
| | *std dev* | 0.402 | 0.052 | 0.052 | 0.001 | 0.001 | 0.001 |
| **December** | *average* | 0.722 | 0.078 | 0.039 | 0.000 | 0.001 | 0.001 |
| | *std dev* | 1.418 | 0.098 | 0.059 | 0.001 | 0.001 | 0.001 |

Strict control on cyanide concentrations in process water, wastewater and in recipients is exercised to avoid risk of adverse effects on the environment. The cyanide concentrations appeared rather stable most of 2012 and the monthly average values were below the maximum limit concentrations set by the BMP. In September DCE-AU inspected the cyanide analytical programme. During winter time the company is experiencing difficulties in taking the samples 3, 4, 5 and 6 in a safe and secure way due to high snow levels.

**Conclusions on the cyanide monitoring programme**

In general, the measured cyanide concentrations have been kept at a stable and low level as expected. There is strict control on the discharge to the freshwater environment with frequent monitorings.

**Photo 3.1. .** Water sampling at the sedimentation pond, where the mine processing wastewater is lead through before entering the Kirkespir River (photo by L Bach).

## 3.2 Element monitoring programme

Element concentrations are obtained from biota sampled in the marine environment in the Kirkespir Bay, in the freshwater environment in the Kirkespir River and in the terrestrial environment of the Kirkespir Valley (figure 2.2). The analytical results and detection limits, as well as background concentrations from Glahder et al. (2005) are given in Appendix 4. Element concentrations in the species analysed are considered elevated if they are significantly ($p< 0.05$) higher than the background concentrations.

### 3.2.1 The marine environment

Samples from the Kirkespir Bay were collected at five mussel and seaweed stations (M1-M5), at four sculpin stations (U1-U4) and at the reference station (AMIT) (figure 2.2).

In mussels few metals were found elevated compared to the reference station (AMIT) and/or background measurements with small, but significant, elevations at few stations mostly M3, M4 and M5 for Au, Co, Cu, Fe, Ni and Se (one-way ANOVA). Most pronounced were however the concentrations of Au at all stations with concentrations at M3 up to 8 times, what was found at AMIT.

In brown seaweed, significant, but small, elevated average concentrations of Au and Cu were found at all the stations compared to AMIT concentrations (one-way ANOVA). The Cu concentrations were also higher than background concentrations (data from 2000). Further, significantly elevated concentrations were found for Co at station M3 and M5 and Zn at station M3 compared to background concentrations. Significant higher values were found for Ni at station M3 compared to AMIT. No elevated concentrations of other elements analysed were found at any of the other seaweed stations (Appendix 4).

In sculpin liver, average element concentrations were not significantly elevated compared to the background concentrations (data from 2000). Sediment element concentrations are in the same range as last year.

#### Conclusions on the marine environment

As in previous years, the impact from the mining activities on the marine environment in 2012 in terms of elevated metal concentrations was found to be very low.

Earlier in the mining history elevated concentrations of Cr were found in sculpin livers and of Co in blue mussel in the bay in 2004. Also, in seaweed elevated concentrations of especially Cr were found, and elevated concentrations of Cu, Co and Zn were found in both 2004 and 2005. Later in 2006-2009, only Co was found to be elevated (by a factor 2-3) in seaweed at station M3 in the marine environment. In 2012, most significantly elevated concentrations (> 10 times) is Cu and Au, and it is primarily the stations closest to the estuary (M3 and M5) that are mostly impacted.

In general, during the past six years (2006-2012), the concentrations of metals in the marine environment have been low and not remarkably different from the background levels.

### 3.2.2 The freshwater environment

In livers from resident Arctic char caught in Kirkespir River concentrations of Au, Fe and Se were significantly higher than the concentrations found in chars from the reference river. No concentrations were however found to be different from the background data (data from 2000) (Appendix 4).

Sediment samples collected at the mine process waste water outflow show much higher concentrations of several elements (As, Au, Co, Cr, Cu, Fe, Ni and Zn) than in sediments collected upstream the mine area. High concentrations are also found in the sedimentation pond, but further down the Kirkespir River before the water enters the fjord (close to lichen station 3), the element concentrations in the sediments are similar to the upstream concentrations.

Water samples were also taken in the Kirkespir River along with measurements using DGT-devices. Replicates of DGT-devices were deployed and some divergences between the replicates were observed especially in the lower concentration range. In general, the measured water concentration of the elements corresponded to the DGT measured concentrations. Element concentrations were followed in the water upstream the mine, the outflow of process water, sedimentation pond and to the waterfall, and it is clear that the discharge of wastewater from the process adds elements to the river water. Significant amounts of As, Au, Cd, Co, Cu, Fe, Mn and Ni were measured in the discharged wastewater and in the sedimentation pond.

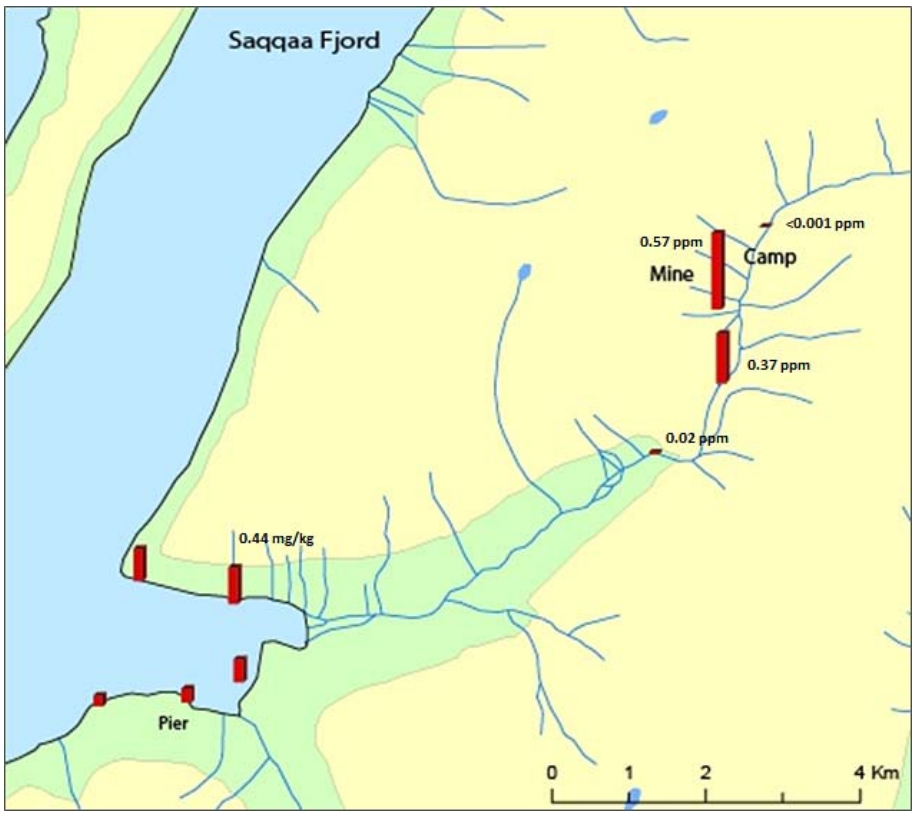


**Figure 3.1.** An example of an element concentration (here gold, Au) in the water systems in the Kirkespir Valley (ppm (µg/L) for water and mg/Kg for mussels). Upstream the mining activities, the concentration is <0.001 ppm, and where there is a large outflow by the discharge waste water from the mine (20 ppm – not shown at the figure), the water is mixed with a small creek diluting the concentration to 0.57 ppm as measured at the inflow to the sedimentation pond. The sedimentation pond seems very efficient to remove particles but not to remove all dissolved elements. The outflow water concentration is thus 0.37 ppm. This water runs together with the Kirkespir River and concentrations at the Waterfall stations have decreased further (0.02 µg ppm). Further out in the Kirkespir Bay organisms as mussels (shown in figure) and seaweed accumulate the metal, with highest concentrations measured at station M3 (0.44 mg Au/Kg).

The sedimentation pond seems very efficient and when the water is leaving the sedimentation pond the element concentrations have decreased (figure 3.1 for measurements of gold, Au, as an example). Measurements at the Waterfall station show that for all elements, except for Cu, the concentrations are below the Greenland Water Quality Guidelines (BMP Guidelines, 2011). Cu seem to be naturally present in high concentrations in the area and concentrations below the guideline value were close to be met at the Waterfall station.

### Conclusions on the freshwater environment

No elevated element concentrations were in 2012 found in Arctic char in the Kirkespir River compared to background concentrations for the area. It is concluded that the elevated concentrations measured in 2011 of Cd and Pb were due to natural annual variations. Increased concentrations have previously been observed in 2011, 2006 and 2004, but no elevated concentrations were however found in 2005 and during 2007-2010. Elevated concentrations of several elements were found in both water and sediments in the Kirkespir River as a result of the discharge of wastewater from the mine. The sedimentation pond seems however to work and retains a large fraction of the elements and only low concentrations, generally below the water quality guidelines, are measured downstream in the Kirkespir Valley.

**Photo 3.2.** Resident Arctic chars (*Salvelinus alpinus*) are caught in the Kirkespir River at the water fall station (photo: L Bach).

### 3.2.3 The terrestrial environment

Concentrations of four metals (Cu, Cr, As and Co) were compared in lichens (*Flavocetraria nivalis*) during 2004-2012. Two areas were selected, the stockpile of crushed waste rock (stations 5 and 6) and the camp and mine area (stations 11 and 12). In 2011 as in previous years, lichens were transplanted from an uncontaminated area (station AMIT) to these four stations: M2-t, 5-t, 6-t, 11-t and 12-t. In 2012 these transplanted lichens were analysed together with lichens growing naturally in the Kirkespir Valley.

The method of transplanting lichens from an uncontaminated area to the mine area was derived from studies performed at the lead-zinc mine at Maarmorilik; these studies showed that metals were excreted from the lichens at a low rate, if at all (Johansen et al. 2008). As a consequence, a reduction in the dust pollution can be difficult to detect within a few years period. In 2007, lichens were started to be transplanted from the uncontaminated Amitsoq Island (station AMIT) to the Nalunaq area (Kirkespir Valley) in order to determine the annual amount of dust pollution.

Average concentrations in each of the two areas were compared with background concentrations and Cu, Cr, As and Co were significantly elevated in the years 2004-2012 (Tukey's post hoc test). Elevations in the two areas in 2011 were 3-5 times for Cu and Cr, up to 22 times for As and 10 times for Co (figure 3.2, Appendix 4). This year (2012) the concentrations of the four metals had decreased to about 7 times for As and 5 times for Co. Concentrations of these four metals were not significantly different between the years 2004-2012, except for As in area 1 where concentrations in 2008 were significantly higher than in 2004 (Tukey's post hoc test).

The temporal trends in concentrations of the four metals were compared in the two areas described above. The results are shown in figure 3.2 (Area 1) and figure 3.3 (Area 2). Concentrations of all four metals in Area 1, which are station 5-t and 6-t, seem to have stabilized or are even decreasing since 2009. This area was previously used for a stockpile of waste rock. Area 2, which is the area around the camp and downhill the mine (station 11-t and 12-t), seemed to stabilize for

the four metal concentrations towards 2010 but was slightly peaking in metal concentrations in 2011 probably due to the restart of the mining activities.

A third particular area of interest is the area around the pier, the stockpile area. During the last mining period, a large stockpile of low graded ore was placed in the field above the pier, intended for shipping off. As the Crew mine closed, the stockpile was left and the ore was transported back to the mining area for processing between 2011 and 2012. The stations M2-t and 20-t represent lichens in this area. Concentrations of the four metals at the pier (station 20-t and M2-t) were in 2011 found to be 2-29 times higher than the background concentrations (figure 3.5), but the concentrations were in 2012 found to have decreased to same level as in 2010.

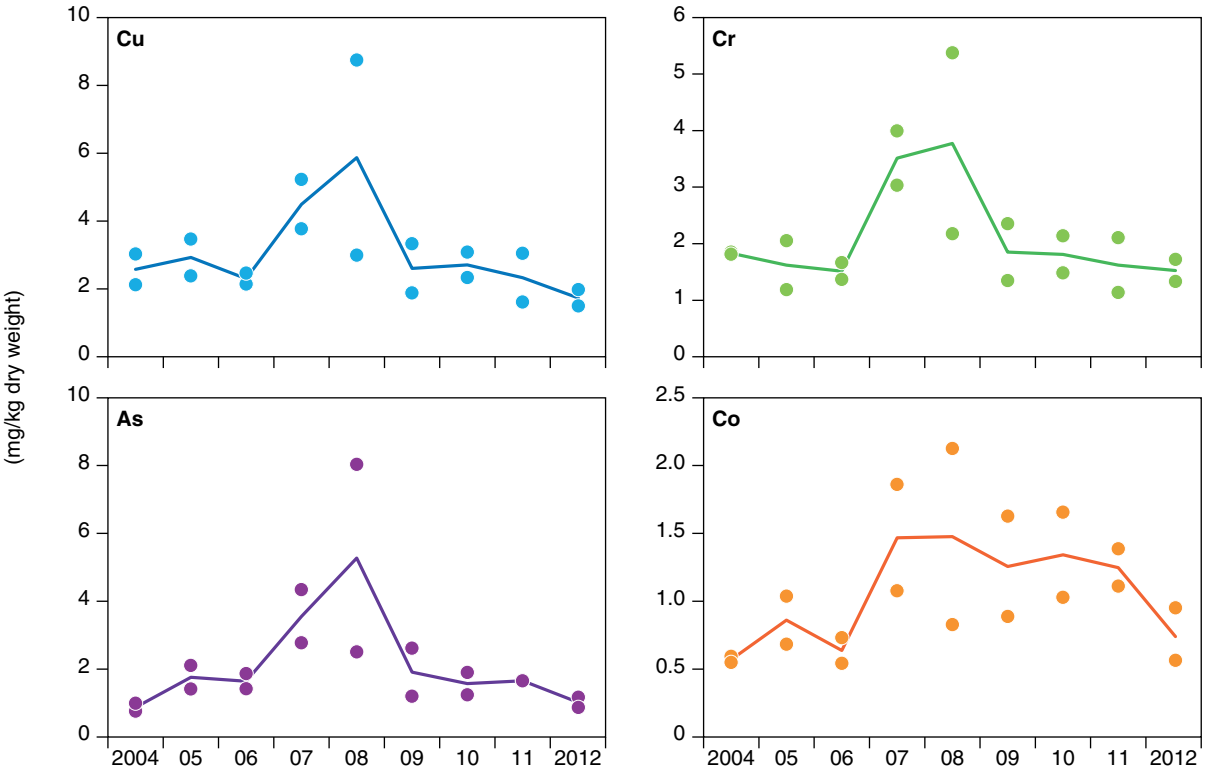


**Figure 3.2.** Temporal trends in concentrations of Cu, Cr, As and Co in lichens from Area 1 during 2004-2012. Area 1 is the stockpile of crushed waste rock (stations 5-t and 6-t). From 2008 onwards concentrations are from transplanted lichens. Baseline average concentrations from 1998 are shown as dashed lines.

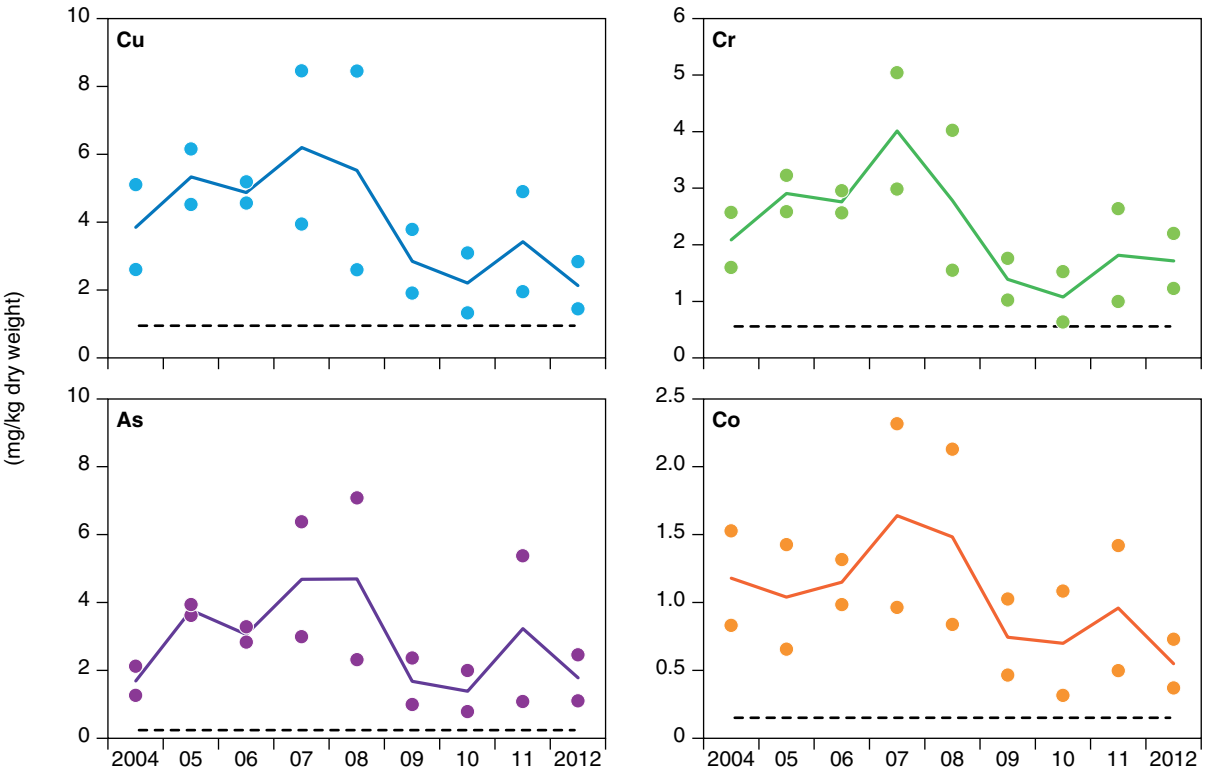


**Figure 3.3.** Temporal trends in concentrations of Cu, Cr, As and Co in lichens from Area 2 during 2004-2012. Area 2 is the camp and mine area (stations 11-t and 12-t). From 2008 onwards concentrations are from transplanted lichens. Baseline average concentrations from 1998 are shown as dashed lines.

Relations between the concentrations of Cu, Cr, As and Co in lichens and the perpendicular distance to the gravel road and to the 300 m portal area were tested. Previously results have shown effects and gravel roads and as the company has been allowed to perform crushing outdoor at the 300 m portal where also waste rock is deposited, the 300 m portal was also included in the analysis. The tests included differences in levels among years. The four metals were tested because they showed the highest concentrations compared to background levels. All concentrations of the four metals showed a significant increase with decreasing distance to the gravel road (log linear regression).

Figure 3.4a shows concentrations of the four elements in lichens from Amitsoq Island, the Kirkespir Bay area and the Kirkespir Valley. Three areas have markedly higher concentrations of the four elements, namely the pier area and the inner valley area counting the stockpile of waste rock and the mining/camp area. The relatively high concentrations in these areas can be explained as an effect of the distance to the gravel road illustrated by figure 3.4b. Before 2009, the higher concentrations in the mining/camp area were explained as an effect of the mine rather than an effect of the road (Glahder et al. 2010). In 2010, a marked decrease was seen at the pier area in the concentrations of all four metals compared to concentrations found in 2009. This indicated that the effect of the road was the main source of contamination after the storage in the pier area and the ship-loading activities have ceased. In 2012, a decrease was observed for all four metals at the pier area, station M2-t, compared to data from 2011, which reflects that the 2011 activity of loading and transporting ore back to the mine area for processing has completed. In 2011 we observed an increase in all four metals at station 11 compared to the metal concentrations in 2010. This indicated that besides the effect of the

gravel road, there also could be an effect of the mining in the area, which might be a result of the outdoor crushing. In 2012, we added further lichen stations to the monitoring programme to reveal that effect, and it is possible that there also is an effect of the mining, though to a lesser extent than the gravel road (figure 3.4a and b).

Figure 3.5 shows how far from the road elevated concentrations of Cu, Cr, As and Co were found in the Kirkespir Valley in 2012. For Co and As background concentrations were met about 1300 and 1500 m from the road, respectively, whereas Cr and Cu reached background levels at around 750 m.

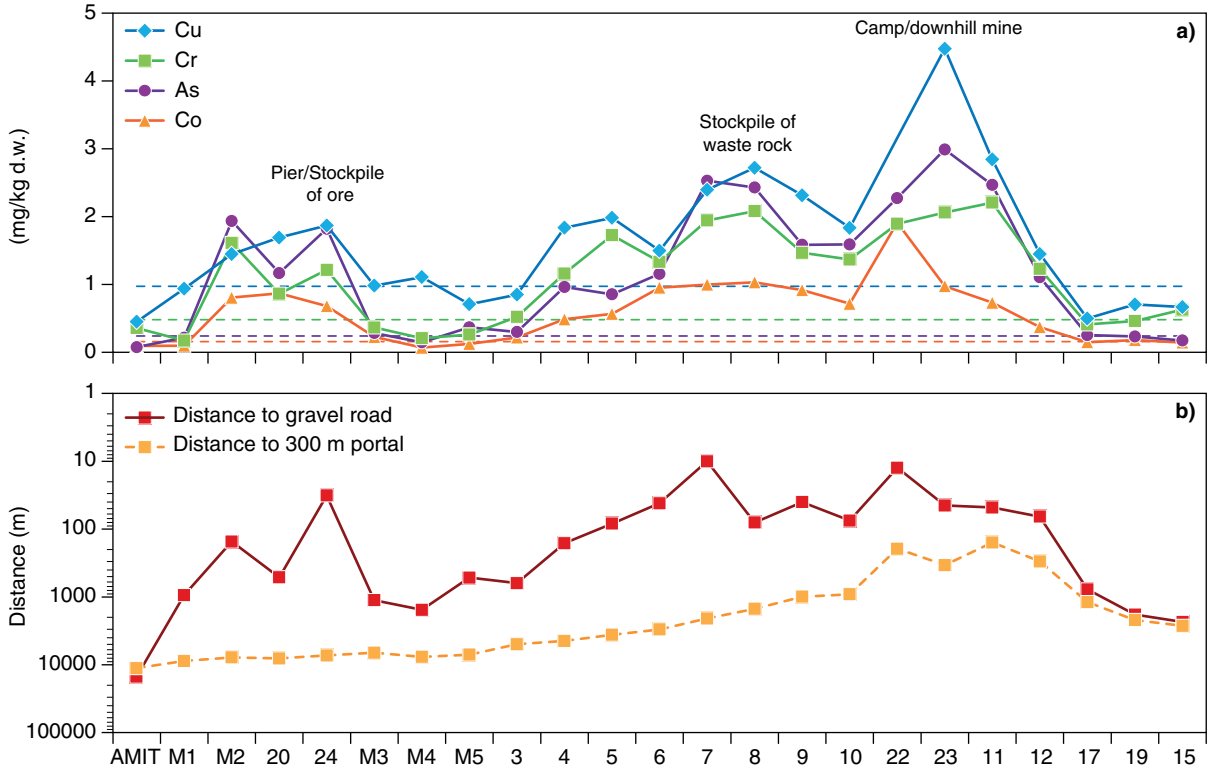


**Figure 3.4.** a) Concentrations of Cu, Cr, As and Co in the lichen *Flavocetraria nivalis* measured at the lichens stations in 2012 and b) distances (in meter on a log scale) from the lichen stations to the road and to the 300 m portal. For localization of lichen stations see figure 2.1. M1-M5 are stations in the Kirkespir Bay area, stations 2-24 are situated in the Kirkespir Valley from the coast (station 1) to up-stream the camp area. The dashed horizontal lines in a) indicate average background concentrations of the four metals (see Appendix 4). d.w. = dry weight.

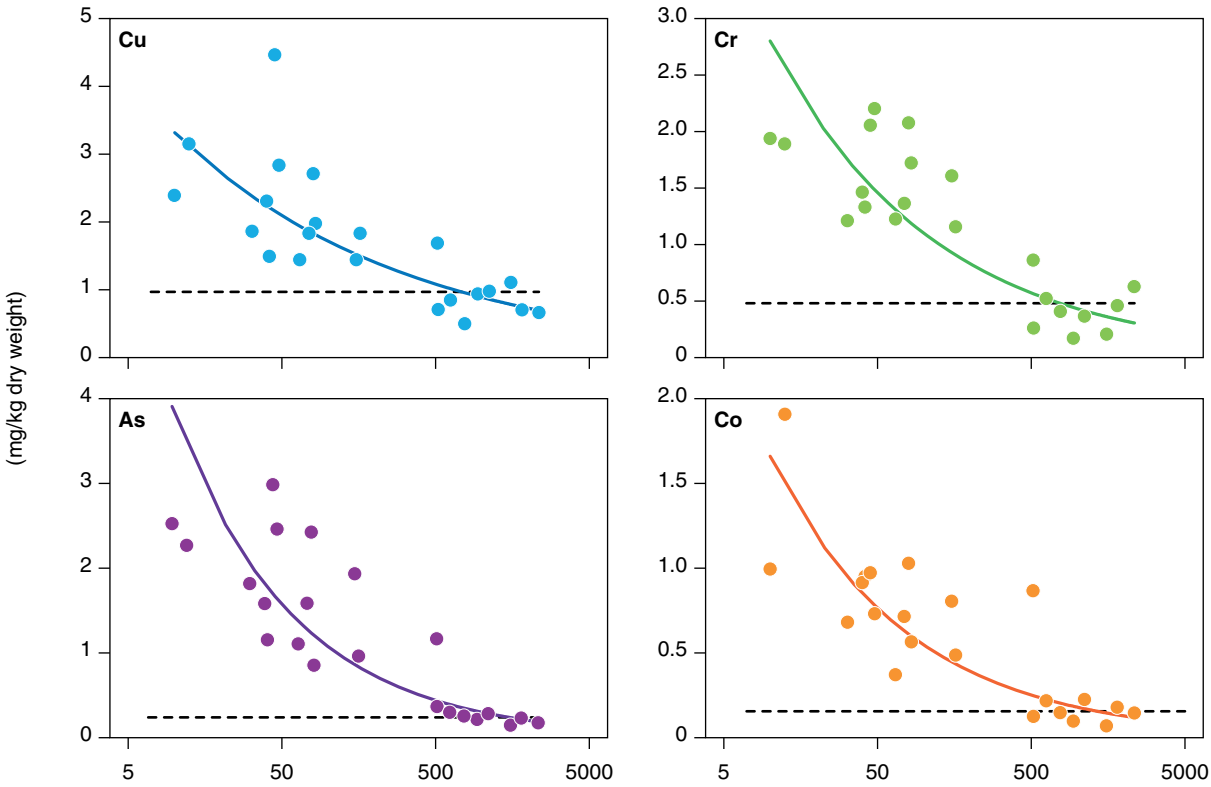


**Figure 3.5.** Concentrations of Cu, Cr, As and Co in the lichens *Flavocetraria nivalis* as a function of the stations' distances to the gravel road (in meters - on a log scale). Background average concentrations are shown with horizontal dashed lines. d.w. = dry weight.

**Photo 3.3.** Lichens (*Flavocetraria nivalis*) transplanted early September 2011 in the Kirkespir Valley were sampled early September 2012. Transplanted lichens were covered by a net secured by stones. Lichens sampled at Amitsoq Island (reference site) in 2012 replaced the sampled lichens (photo: Lis Bach).

### Conclusions on the terrestrial environment

It is concluded that concentrations of Cu, Cr, As and Co in lichens during 2004-2012 were significantly elevated at the pier area, the waste rock stockpile and in the mine area compared to the background levels, with peak concentrations in 2008. Concentrations of all four metals in all three areas decreased toward 2010, but due to new activities the dust pollution increased again in 2011 compared to 2010. In 2012 the concentrations had however decreased again to the same level as in 2010.

The relatively high concentrations in these areas can be explained as an effect of the gravel road with an exception of the most impacted stations (11-t and 20-t), where mining activities may be the reason. Before 2009, the higher concentrations in the mine area were explained as an effect of the mine. In 2010, a marked decrease in concentrations of all four metals was seen in the pier area, indicating that the road at that time was the main source of contamination. However, in 2011 after activities in this area were initiated, the concentrations increased again at both the pier and the mining/camp area. The increases for the pier area had however lowered in this year (2012) sampling programme, as the activities related to loading of trucks at the pier area has been completed.

All metal concentrations showed significant decreases with increasing distance to the road except for the most impacted stations (11-t and 20-t). Concentrations of Cr and Cu met the background level concentrations at ~750 m from the road, while this distance was ~1300 and 1500 m for Co and As, respectively.

# 4 Conclusions

This report describes the results of the ninth year of element environmental monitoring in the Nalunaq Gold Mine area and describes the second year of the cyanide monitoring programme. Most mining work from August 2009 until spring 2011 dealt with the excavation of a chamber inside the mine and the building of a production plant. In spring 2011 the mining and processing of ore was initiated and parts of the low grade ore were since transported from the pier back to the mine for processing. In 2012 the mining and processing of ore have been centered inside the process hall in the mountain and to some extent to some outdoor crushing at the 300 m portal.

Concerning the cyanide monitoring programme, water samples have been taken frequently during 2012 and only low concentrations close to the detection limit were measured in the river (station 6). It is only at very few occasions that there have been reported concentrations above maximum allowed water discharge and none has led to any worrying incidents.

The impact from the mining activities on the marine environment was also this year found to be low. Small elevated element concentrations (most pronounced for Au, Co, Cu and Ni) were however found in blue mussels and brown seaweed at the stations closest to the estuary (primarily station M3). No elevated element concentrations were found in sculpin livers. In general, during the years of 2006-2012 the concentrations of metals in the marine environment have been low and not remarkably different from background levels.

In the freshwater system, highly elevated concentrations of several elements, and in particular As, Au, Cd, Co, Cu, Fe, Mn and Ni, were measured in the discharged wastewater from the mining process and in the sedimentation pond. The sedimentation pond seems very efficient to remove particles and only small elevated concentrations of Cu were measured in the Kirkespir River at the Waterfall station. Also, at the Waterfall station no elevated concentrations were found in Arctic char livers in 2012.

In the lichen, concentrations of Cu, Cr, As and Co in 2012, like in previous years, were significantly elevated compared to the background level at the pier area, the stockpile of crushed waste rock and in the mining/camp area. In 2012, element elevations in these areas were up to 4 times for Cu and Cr, 10 times for As and 12 times for Co.

Temporal trends during 2004-2012 of the concentrations of As, Co, Cr and Cu in the three areas described above showed a non-linear trend with a decrease in 2009 for all elements in all three areas. However, in 2011 a small increase of the elements was observed at the pier and at the camp/mining area, but in 2012 the element concentrations were not higher than in 2010.

The concentrations of Cu, Cr, As and Co in lichens showed a significant decrease with increasing distance to the gravel road, with exception of two of the most impacted stations (11-t and 20-t). Concentrations of As and Co above the background level could be found to a distance of about 1500 and 1300 m from the road, respectively, while concentrations of Cr and Cu met the baseline level about 750 m from the road.

**Photo 4.1.** Kirkespir Valley, with the Kirkespir Mountain covered by clouds in the background (photo: L Bach).

## Overall

In 2012, the impact from the gold mine on the local environment was primarily observed in the Kirkespir Valley and originated mainly from dust dispersed from the road, from the crushing area at the 300 m portal of the mine and from the loading of ore at the area above the pier. Metal concentrations in lichens increased a little in 2011 compared to 2010 due to the mining activities, but by this year, the element concentrations were found at the same level as in 2010. In the Kirkespir River and Bay, no elevated concentrations were found in Arctic char or in sculpins and only few elevated concentrations of elements were found in seaweed and mussels. Compared to the mining operation period in 2004-2009 the environmental impact of elements in 2012 are generally lower, which probably is a result of the underground crushing and processing as well as less transport of crushed ore from the mining area to the harbour.

The environmental impact from spreading of elements on the environment of the Kirkespir Valley and Bay, terrestrial, freshwater and marine, due to mining is considered to be minor and there is no need for further actions to reduce the environmental impact.

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# Appendix 1. ICP-MS analytical results of certified reference materials

| | As | Au | Cd | Co | Cr | Cu | Fe | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Biota-d.l.* | *0.11* | *0.002* | *0.02* | | *0.04* | *0.25* | *1.33* | *0.014* | *0.03* | *0.03* | *0.03* | *0.08* |
| Dorm-4 | 6.27 | 0.004 | 0.282 | 0.263 | 2.119 | 15.70 | 348 | 0.368 | 1.53 | 0.37 | 3.15 | 46.19 |
| Dorm-4 | 6.39 | 0.004 | 0.298 | 0.270 | 1.873 | 16.49 | 336 | 0.389 | 1.28 | 0.38 | 3.56 | 46.81 |
| Dorm-4 | 6.09 | 0.008 | 0.272 | 0.244 | 1.860 | 14.98 | 336 | 0.365 | 1.16 | 0.36 | 2.95 | 45.02 |
| Dorm-4 | 6.29 | 0.005 | 0.296 | 0.243 | 1.993 | 15.02 | 342 | 0.420 | 1.31 | 0.41 | 3.16 | 48.52 |
| Dorm-4 | 6.11 | 0.003 | 0.323 | 0.243 | 1.952 | 17.88 | 345 | 0.423 | 1.37 | 0.41 | 3.29 | 49.51 |
| *Average* | *6.23* | *0.00* | *0.29* | *0.25* | *1.96* | *16.01* | *341.31* | *0.39* | *1.33* | *0.39* | *3.22* | *47.21* |
| *Cf value* | *6.80* | | *0.306* | | *1.870* | *15.90* | *341* | *0.410* | *1.36* | *0.42* | *3.56* | *52.20* |
| *2 x std dev* | 0.64 | | 0.015 | | 0.16 | 0.9 | 27 | 0.055 | 0.22 | 0.053 | 0.34 | 3.2 |
| | | | | | | | | | | | | |
| Dolt-4 | 10.48 | 0.005 | 24.503 | 0.263 | 1.387 | 36.86 | 2082 | 2.741 | 1.16 | 0.11 | 8.22 | 116.47 |
| Dolt-4 | 10.26 | 0.004 | 24.664 | 0.286 | 1.564 | 36.90 | 2129 | 2.813 | 1.12 | 0.12 | 8.15 | 117.32 |
| Dolt-4 | 8.10 | 0.003 | 21.865 | 0.221 | 3.158 | 30.03 | 1704 | 2.477 | 2.29 | 0.15 | 6.54 | 109.06 |
| Dolt-4 | 8.36 | 0.002 | 23.989 | 0.212 | 1.491 | 31.41 | 1770 | 2.943 | 1.05 | 0.44 | 7.73 | 123.50 |
| Dolt-4 | 7.94 | 0.002 | 22.965 | 0.199 | 1.763 | 30.33 | 1785 | 2.799 | 1.19 | 0.21 | 7.28 | 117.78 |
| *Average* | *9.03* | *0.003* | *23.60* | *0.236* | *1.873* | *33.11* | *1893* | *2.75* | *1.36* | *0.21* | *7.58* | *116.82* |
| *Cf value* | *9.66* | | *24.300* | *0.25** | *1.40** | *31.20* | *1833* | *2.580* | *0.97* | *0.16* | *8.30* | *116.00* |
| *2 x std dev* | *0.62* | | *0.8* | | | *1.1* | *75* | *0.22* | *0.11* | *0.04* | *1.3* | *6* |
| | | | | | | | | | | | | |
| Tort-2 | 21.29 | 0.006 | 26.643 | 0.567 | 0.820 | 108.40 | 114 | 0.303 | 2.31 | 0.46 | 5.44 | 176.00 |
| Tort-2 | 21.19 | 0.005 | 26.561 | 0.534 | 0.915 | 108.30 | 121 | 0.290 | 2.34 | 0.45 | 5.24 | 175.28 |
| Tort-2 | 18.48 | 0.013 | 25.934 | 0.477 | 0.949 | 96.69 | 104 | 0.298 | 3.76 | 0.41 | 5.19 | 182.41 |
| *Average* | *20.320* | *0.008* | *26.379* | *0.526* | *0.895* | *104.47* | *112.57* | *0.297* | *2.803* | *0.436* | *5.289* | *177.90* |
| *Cf value* | *21.60* | | *26.700* | *0.510* | *0.770* | *106.00* | *105* | *0.270* | *2.50* | *0.35* | *5.63* | *180.00* |
| *2 x std dev* | *1.8* | | *0.60* | *0.09* | *0.15* | *10.0* | *13* | *0.06* | *0.19* | *0.13* | *0.67* | *6.0* |
| | | | | | | | | | | | | |
| BCR 482 | 0.76 | 0.004 | 0.524 | 0.318 | 3.405 | 7.28 | 834 | 0.427 | 2.33 | 35.45 | 0.25 | 90.78 |
| BCR 482 | 0.65 | 0.002 | 0.488 | 0.298 | 3.422 | 6.92 | 816 | 0.442 | 2.38 | 33.59 | 0.21 | 90.17 |
| *Average* | *0.70* | *0.00* | *0.51* | *0.31* | *3.41* | *7.10* | *824.72* | *0.43* | *2.35* | *34.52* | *0.23* | *90.48* |
| *Cf value* | *0.85* | | *0.560* | | *4.120* | *7.03* | | *0.480* | *2.47* | *40.90* | | *100.60* |
| *2 x std dev* | *0.07* | | *0.02* | | *0.15* | *0.19* | | *0.02* | *0.07* | *1.4* | | *2.2* |
| | | | | | | | | | | | | |
| *Sediment- d.l.* | *1.67* | *0.380* | *0.111* | *0.044* | *0.006* | *4.62* | *63* | *0.236* | *3.63* | *4.57* | *4.69* | *2.10* |
| Pacs-2 | 28.65 | -0.072 | 2.816 | 10.792 | 99.322 | 332.07 | 39262 | 3.487 | 41.38 | 192.91 | 2.98 | 380.95 |
| Pacs-2 | 24.48 | 0.004 | 2.390 | 10.662 | 95.699 | 264.49 | 37670 | 2.981 | 32.53 | 174.23 | 1.62 | 289.66 |
| *Average* | *26.56* | *-0.03* | *2.60* | *10.73* | *97.51* | *298.28* | *38466* | *3.23* | *36.96* | *183.57* | *2.30* | *335.31* |
| *Cf value* | *26.20* | | *2.11* | *11.5* | *90.700* | *310* | *40900* | *3.04* | *39.50* | *183* | *0.92* | *364* |
| *2 x std dev* | *1.5* | | *0.15* | *0.3* | *4.6* | *12* | *600* | *0.20* | *2.3* | *8* | *0.22* | *23* |
| | | | | | | | | | | | | |
| *Mess-3* | 20.96 | -0.020 | 0.277 | 12.295 | 105.38 | 28.35 | 39581 | 0.109 | 33.83 | 22.38 | 2.45 | 126.48 |
| *Cf value* | *21.20* | | *0.24* | *14.4* | *105.0* | *33.9* | *43400* | *0.091* | *46.90* | *21.1* | *0.72* | *159* |
| *2 x std dev* | *1.1* | | *0.01* | *2* | *4* | *1.6* | *1100* | *0.009* | *2.2* | *0.7* | *0.05* | *8* |
| | | | | | | | | | | | | |
| *Hiss-1* | 0.80 | 0.000 | 0.024 | 0.650 | 30.0 | 2.29 | 2460 | 0.010 | 2.16 | 3.13 | 0.05 | 4.94 |
| *Cf value* | *0.80* | | *0.024* | *0.65* | *30.0* | *2.29* | *2460* | *0.01* | *2.16* | *3.13* | *0.050* | *4.94* |
| *2 x std dev* | *0.1* | | *0.009* | | *6.8* | *0.37* | *90* | | *0.29* | *0.40* | *0.007* | *0.79* |

*Information value, not a certificate

# Appendix 2. Samples and stations

| ID-No | Sample type | Latin name | Station | Lat deg | Long deg |
|---|---|---|---|---|---|
| 47286 | Lichen | *Flavocetraria nivalis* | 3 | 60.32639 | -44.90278 |
| 47268 | Lichen | *Flavocetraria nivalis* | 4 | 60.32861 | -44.89389 |
| 45372 | Lichen | *Flavocetraria nivalis* | 5-transplanted | 60.33247 | -44.88003 |
| 45373 | Lichen | *Flavocetraria nivalis* | 6-transplanted | 60.33603 | -44.87183 |
| 47270 | Lichen | *Flavocetraria nivalis* | 7 | 60.34222 | -44.86028 |
| 47269 | Lichen | *Flavocetraria nivalis* | 8 | 60.34556 | -44.85194 |
| 47266 | Lichen | *Flavocetraria nivalis* | 9 | 60.34694 | -44.83722 |
| 47271 | Lichen | *Flavocetraria nivalis* | 10 | 60.34750 | -44.83278 |
| 45377 | Lichen | *Flavocetraria nivalis* | 11-transplanted | 60.35456 | -44.83239 |
| 45376 | Lichen | *Flavocetraria nivalis* | 12-transplanted | 60.35783 | -44.83058 |
| 47299 | Lichen | *Flavocetraria nivalis* | 15 | 60.37861 | -44.81889 |
| 47300 | Lichen | *Flavocetraria nivalis* | 17 | 60.36639 | -44.83111 |
| 45374 | Lichen | *Flavocetraria nivalis* | 19 | 60.37500 | -44.82528 |
| 47267 | Lichen | *Flavocetraria nivalis* | 20-transplanted | 60.31308 | -44.95283 |
| 45378 | Lichen | *Flavocetraria nivalis* | 22-transplanted | 60.35545 | -44.83050 |
| 45375 | Lichen | *Flavocetraria nivalis* | 23-transplanted | 60.35303 | -44.83108 |
| 45383 | Lichen | *Flavocetraria nivalis* | 24-transplanted | 60.35626 | -44.82755 |
| 47262 | Lichen | *Flavocetraria nivalis* | M 1 | 60.31139 | -44.96694 |
| 47287 | Lichen | *Flavocetraria nivalis* | M 2-transplanted | 60.31253 | -44.94639 |
| 47264 | Lichen | *Flavocetraria nivalis* | M 3 | 60.32472 | -44.94681 |
| 47265 | Lichen | *Flavocetraria nivalis* | M 4 | 60.32639 | -44.93750 |
| 47288 | Lichen | *Flavocetraria nivalis* | M 5 | 60.31567 | -44.96028 |
| 47263 | Lichen | *Flavocetraria nivalis* | AMIT | 60.43889 | -44.95111 |
| 47276 | Brown seaweed | *Fucus vesiculosus* | M 1 | 60.31139 | -44.96694 |
| 47277 | Brown seaweed | *Fucus vesiculosus* | M 1 | 60.31139 | -44.96694 |
| 47293 | Brown seaweed | *Fucus vesiculosus* | M 2 | 60.31278 | -44.94639 |
| 47294 | Brown seaweed | *Fucus vesiculosus* | M 2 | 60.31278 | -44.94639 |
| 47278 | Brown seaweed | *Fucus vesiculosus* | M 3 | 60.32472 | -44.93750 |
| 47279 | Brown seaweed | *Fucus vesiculosus* | M 3 | 60.32472 | -44.93750 |
| 47282 | Brown seaweed | *Fucus vesiculosus* | M 4 | 60.32639 | -44.96028 |
| 47283 | Brown seaweed | *Fucus vesiculosus* | M 4 | 60.32639 | -44.96028 |
| 47295 | Brown seaweed | *Fucus vesiculosus* | M 5 | 60.31567 | -44.93463 |
| 47296 | Brown seaweed | *Fucus vesiculosus* | M 5 | 60.31567 | -44.93463 |
| 47242 | Brown seaweed | *Fucus vesiculosus* | AMIT | 60.43889 | -44.95111 |
| 47243 | Brown seaweed | *Fucus vesiculosus* | AMIT | 60.43889 | -44.95111 |
| 47250 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 1 | 60.31306 | -44.96250 |
| 47251 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 1 | 60.31306 | -44.96250 |
| 47252 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 1 | 60.31306 | -44.96250 |
| 47253 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 1 | 60.31306 | -44.96250 |
| 47254 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 1 | 60.31306 | -44.96250 |
| 47225 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 2 | 60.31250 | -44.94611 |
| 47226 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 2 | 60.31250 | -44.94611 |
| 47227 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 2 | 60.31250 | -44.94611 |
| 47228 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 2 | 60.31250 | -44.94611 |
| 47229 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 2 | 60.31250 | -44.94611 |

| | | | | | |
|---|---|---|---|---|---|
| 47255 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 3 | 60.32528 | -44.94806 |
| 47256 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 3 | 60.32528 | -44.94806 |
| 47261 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 4 | 60.32611 | -44.95861 |
| 47257 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 4 | 60.32611 | -44.95861 |
| 47258 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 4 | 60.32611 | -44.95861 |
| 47259 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 4 | 60.32611 | -44.95861 |
| 47260 | Shorthorn sculpin | *Myoxocephalus scorpius* | U 4 | 60.32611 | -44.95861 |
| 47231 | Shorthorn sculpin | *Myoxocephalus scorpius* | AMIT | 60.43889 | -44.95111 |
| 47230 | Shorthorn sculpin | *Myoxocephalus scorpius* | AMIT | 60.43889 | -44.95111 |
| 47232 | Shorthorn sculpin | *Myoxocephalus scorpius* | AMIT | 60.43889 | -44.95111 |
| 47233 | Shorthorn sculpin | *Myoxocephalus scorpius* | AMIT | 60.43889 | -44.95111 |
| 47280 | Blue mussel | *Mytilus edulis* | M 1 | 60.31139 | -44.96694 |
| 47281 | Blue mussel | *Mytilus edulis* | M 1 | 60.31139 | -44.96694 |
| 47289 | Blue mussel | *Mytilus edulis* | M 2 | 60.31278 | -44.94639 |
| 47290 | Blue mussel | *Mytilus edulis* | M 2 | 60.31278 | -44.94639 |
| 47272 | Blue mussel | *Mytilus edulis* | M 3 | 60.32472 | -44.93750 |
| 47274 | Blue mussel | *Mytilus edulis* | M 3 | 60.32472 | -44.93750 |
| 47284 | Blue mussel | *Mytilus edulis* | M 4 | 60.32639 | -44.96028 |
| 47285 | Blue mussel | *Mytilus edulis* | M 4 | 60.32639 | -44.96028 |
| 47297 | Blue mussel | *Mytilus edulis* | M 5 | 60.31567 | -44.93463 |
| 47298 | Blue mussel | *Mytilus edulis* | M 5 | 60.31567 | -44.93463 |
| 47244 | Blue mussel | *Mytilus edulis* | AMIT | 60.43889 | -44.95111 |
| 47245 | Blue mussel | *Mytilus edulis* | AMIT | 60.43889 | -44.95111 |
| 47234 | Arctic char | *Salvelinus alpinus* | Waterfall | 60.34642 | -44.84225 |
| 47234 | Arctic char | *Salvelinus alpinus* | Waterfall | 60.34642 | -44.84225 |
| 47235 | Arctic char | *Salvelinus alpinus* | Waterfall | 60.34642 | -44.84225 |
| 47236 | Arctic char | *Salvelinus alpinus* | Waterfall | 60.34642 | -44.84225 |
| 47237 | Arctic char | *Salvelinus alpinus* | Waterfall | 60.34642 | -44.84225 |
| 47238 | Arctic char | *Salvelinus alpinus* | Waterfall | 60.34642 | -44.84225 |
| 45385 | Arctic char | *Salvelinus alpinus* | Ref River (25) | 60.30944 | -44.92845 |
| 45385 | Arctic char | *Salvelinus alpinus* | Ref River (25) | 60.30944 | -44.92845 |
| 45386 | Arctic char | *Salvelinus alpinus* | Ref River (25) | 60.30944 | -44.92845 |
| 45387 | Arctic char | *Salvelinus alpinus* | Ref River (25) | 60.30944 | -44.92845 |
| 45388 | Arctic char | *Salvelinus alpinus* | Ref River (25) | 60.30944 | -44.92845 |
| - | Water | | W 1 Upstream | | |
| - | Water | | W 2 Outflow mine | 60.35573 | -44.83399 |
| - | Water | | W 3 In sed. pond | | |
| - | Water | | W 4 Out sed. pond | | |
| - | Water | | W 5 Waterfall | 60.34642 | -44.84225 |
| - | DGT | | W 1 Upstream | 60.35680 | -44.82680 |
| - | DGT | | W 2 Outflow mine | 60.35573 | -44.83399 |
| - | DGT | | W 3 In sed. pond | | |
| - | DGT | | W 4 Waterfall | 60.34642 | -44.84225 |
| 47240 | Sediment | | S 1 Upstream | 60.35680 | -44.82680 |
| 47239 | Sediment | | S 2 Outflow mine | 60.35573 | -44.83399 |
| 47241 | Sediment | | S 3 Sed. pond | 60.35626 | -44.82755 |
| 47273 | Sediment | | S 4 | 60.34642 | -44.84225 |
| 47291 | Sediment | | M 2 | 60.31278 | -44.94639 |
| 47275 | Sediment | | M 3 | 60.32472 | -44.93750 |
| 47292 | Sediment | | M 5 | 60.31567 | -44.93463 |

# Appendix 3. Blue mussel samples

| Station | ID NO | No of mussels | Min length (mm) | Max length (mm) |
|---|---|---|---|---|
| **M1** | 47280 | 18 | 44 | 77 |
| **M1** | 47281 | 16 | 33 | 43 |
| **M2** | 47289 | 18 | 50 | 59 |
| **M2** | 47290 | 20 | 41 | 48 |
| **M3** | 47272 | 20 | 50 | 71 |
| **M3** | 47274 | 20 | 41 | 49 |
| **M4** | 47284 | 20 | 47 | 64 |
| **M4** | 47285 | 20 | 38 | 46 |
| **M5** | 47297 | 11 | 50 | 66 |
| **M5** | 47298 | 20 | 40 | 49 |
| **AMIT** | 47244 | 20 | 46 | 77 |
| **AMIT** | 47245 | 20 | 40 | 46 |

# Appendix 4. Chemical analyses

Concentrations are given in mg/kg dw (dry weight) for mussels, seaweed, amphipods, sediment and lichen and mg/kg ww (wet weight) for livers from sculpins and Arctic chars. Detection limits (DL) are given as well as average background concentrations and standard deviations (*SD*) for each species.

| ID No | Lab. No | Station | As | Au | Cd | Co | Cr | Cu | Fe | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Blue Mussels – Mytilus edulis (µg/g)*** | | | | | | | | | | | | | | |
| ***Detection limits*** | | | *0.111* | *0.002* | *0.013* | *0.017* | *0.112* | *0.479* | *1.021* | *0.017* | *0.313* | *0.039* | *0.052* | *0.121* |
| **47280** | 304 | M1 | 10.62 | 0.080 | 3.411 | 0.314 | 0.598 | 6.664 | 121.2 | 0.068 | 0.948 | 0.467 | 3.10 | 59.65 |
| **47281** | 305 | M1 | 10.47 | 0.084 | 2.247 | 0.294 | 0.472 | 6.940 | 136.6 | 0.058 | 0.957 | 0.296 | 3.19 | 64.86 |
| **47289** | 308 | M2 | 12.65 | 0.157 | 3.414 | 0.396 | 0.718 | 7.386 | 214.3 | 0.061 | 1.278 | 0.416 | 3.19 | 54.05 |
| **47290** | 309 | M2 | 10.83 | 0.149 | 2.538 | 0.337 | 0.597 | 7.022 | 205.4 | 0.051 | 1.023 | 0.290 | 2.92 | 56.07 |
| **47272** | 302 | M3 | 14.49 | 0.443 | 3.454 | 0.497 | 1.219 | 11.31 | 423.5 | 0.081 | 1.343 | 0.614 | 3.95 | 61.93 |
| **47274** | 303 | M3 | 13.46 | 0.435 | 3.526 | 0.455 | 1.076 | 10.67 | 398.6 | 0.070 | 1.229 | 0.470 | 3.93 | 63.40 |
| **47284** | 306 | M4 | 10.79 | 0.317 | 3.857 | 0.409 | 0.707 | 8.568 | 140.0 | 0.077 | 1.511 | 0.458 | 4.21 | 59.38 |
| **47285** | 307 | M4 | 11.55 | 0.341 | 3.640 | 0.446 | 0.849 | 9.655 | 192.5 | 0.076 | 1.283 | 0.476 | 4.08 | 81.66 |
| **47297** | 310 | M5 | 11.78 | 0.266 | 5.551 | 0.365 | 0.740 | 8.379 | 251.8 | 0.068 | 0.932 | 0.516 | 3.19 | 53.11 |
| **47298** | 311 | M5 | 11.57 | 0.331 | 3.469 | 0.344 | 0.699 | 8.349 | 212.9 | 0.056 | 1.024 | 0.376 | 3.37 | 53.32 |
| **47244** | 299 | AMIT | 13.00 | 0.050 | 5.056 | 0.407 | 0.618 | 7.555 | 144.1 | 0.113 | 0.965 | 0.642 | 3.54 | 63.53 |
| **47245** | 300 | AMIT | 12.32 | 0.041 | 5.033 | 0.350 | 0.520 | 6.886 | 129.6 | 0.081 | 0.869 | 0.431 | 3.35 | 62.91 |
| ***Background*** | | *Average* | *11.73* | | *5.47* | *0.240* | *0.736* | *7.60* | | *0.132* | | *1.215* | | *88.95* |
| | | *SD* | *1.85* | | *2.01* | *0.040* | *0.356* | *0.83* | | *0.029* | | *0.424* | | *12.95* |

| ID No | Lab. No | Station | As | Au | Cd | Co | Cr | Cu | Fe | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Brown algae – Fucus vesicolosus (µg/g)*** | | | | | | | | | | | | | | |
| *Detection limits* | | | *0.111* | *0.002* | *0.013* | *0.017* | *0.112* | *0.479* | *1.021* | *0.017* | *0.313* | *0.039* | *0.052* | *0.121* |
| 47276 | 317 | M1 | 55.64 | 0.086 | 1.66 | 0.281 | < dl | 7.33 | 22.32 | < dl | 0.63 | 0.090 | < dl | 9.47 |
| 47277 | 318 | M1 | 62.63 | 0.075 | 1.48 | 0.235 | < dl | 5.42 | 25.62 | < dl | 0.54 | 0.086 | < dl | 7.58 |
| 47293 | 323 | M2 | 57.87 | 0.104 | 1.28 | 0.255 | < dl | 4.71 | 28.87 | < dl | 0.62 | < dl | < dl | 9.56 |
| 47294 | 324 | M2 | 61.11 | 0.124 | 1.15 | 0.301 | < dl | 4.69 | 26.67 | < dl | 0.79 | < dl | < dl | 10.22 |
| 47278 | 319 | M3 | 55.76 | 0.496 | 0.76 | 0.870 | 0.23 | 14.77 | 54.29 | < dl | 1.64 | < dl | < dl | 12.61 |
| 47279 | 320 | M3 | 65.75 | 0.568 | 0.80 | 0.924 | < dl | 18.59 | 53.52 | < dl | 1.79 | 0.050 | < dl | 14.74 |
| 47282 | 321 | M4 | 57.76 | 0.127 | 1.39 | 0.324 | 0.13 | 5.73 | 30.35 | < dl | 0.71 | < dl | < dl | 7.86 |
| 47283 | 322 | M4 | 52.52 | 0.157 | 1.75 | 0.304 | 0.15 | 7.22 | 25.65 | < dl | 0.86 | < dl | < dl | 8.37 |
| 47295 | 325 | M5 | 58.89 | 0.396 | 0.84 | 0.653 | < dl | 11.50 | 65.22 | < dl | 1.09 | 0.054 | < dl | 11.54 |
| 47296 | 326 | M5 | 52.89 | 0.370 | 0.89 | 0.440 | < dl | 10.61 | 35.27 | < dl | 1.03 | 0.039 | < dl | 11.16 |
| 47242 | 314 | AMIT | 44.89 | 0.027 | 1.69 | 0.197 | 0.13 | 1.71 | 31.90 | < dl | 0.54 | 0.071 | < dl | 6.25 |
| 47243 | 315 | AMIT | 54.49 | 0.020 | 1.44 | 0.238 | < dl | 1.83 | 39.31 | < dl | 0.68 | 0.051 | < dl | 7.45 |
| *Background* | | *Average* | *46.248* | | *1.763* | *0.211* | *0.069* | *1.001* | | *0.009* | | *0.107* | | *7.001* |
| | | *SD* | *8.432* | | *0.576* | *0.046* | *0.076* | *0.237* | | *0.006* | | *0.043* | | *2.088* |

| ID No | Lab. No | Station | As | Au | Cd | Co | Cr | Cu | Fe | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Sculpin – Myoxypephalus scorpius (µg/g)*** | | | | | | | | | | | | | | |
| ***Detection limits*** | | | *0.111* | *0.002* | *0.013* | *0.017* | *0.112* | *0.479* | *1.021* | *0.017* | *0.313* | *0.039* | *0.052* | *0.121* |
| **47250** | 405 | M1 | 5.20 | < dl | 0.231 | 0.020 | < dl | 4.09 | 19 | 0.017 | < dl | < dl | 5.20 | 51.53 |
| **47251** | 406 | M1 | 1.78 | < dl | 0.819 | < dl | < dl | 1.18 | 12 | < dl | < dl | < dl | 1.78 | 20.53 |
| **47252** | 407 | M1 | 1.59 | < dl | 0.826 | 0.017 | < dl | 2.06 | 80 | 0.022 | < dl | < dl | 1.59 | 30.36 |
| **47253** | 408 | M1 | 1.55 | < dl | 0.285 | 0.014 | < dl | 0.86 | 11 | < dl | < dl | < dl | 1.55 | 18.54 |
| **47254** | 411 | M1 | 1.62 | 0.006 | 2.343 | 0.082 | < dl | - | 108 | 0.029 | < dl | < dl | 1.62 | 37.71 |
| **47225** | 387 | M2 | 6.07 | < dl | 1.104 | 0.026 | 0.175 | 2.41 | 22 | 0.054 | < dl | < dl | 6.07 | 30.40 |
| **47226** | 388 | M2 | 7.64 | < dl | 0.474 | 0.027 | < dl | 3.14 | 17 | < dl | < dl | < dl | 7.64 | 48.41 |
| **47227** | 389 | M2 | 2.62 | < dl | 0.312 | < dl | < dl | 0.86 | 35 | 0.023 | < dl | < dl | 2.62 | 19.20 |
| **47228** | 390 | M2 | 1.85 | < dl | 0.212 | < dl | < dl | 1.10 | 49 | < dl | < dl | < dl | 1.85 | 28.76 |
| **47229** | 391 | M2 | 1.92 | 0.004 | 0.305 | < dl | < dl | 1.32 | 65 | 0.017 | < dl | < dl | 1.92 | 36.07 |
| **47255** | 412 | M3 | 2.23 | 0.005 | 0.402 | 0.097 | < dl | 0.96 | 109 | 0.012 | < dl | < dl | 2.23 | 29.57 |
| **47256** | 413 | M3 | 2.28 | 0.005 | 0.169 | 0.073 | < dl | 2.20 | 218 | < dl | < dl | < dl | 2.28 | 32.86 |
| **47261** | 414 | M4 | 1.05 | < dl | 0.646 | 0.044 | < dl | 1.34 | 78 | 0.017 | < dl | < dl | 1.05 | 25.56 |
| **47257** | 415 | M4 | 3.78 | < dl | 0.153 | < dl | < dl | 1.37 | 51 | 0.039 | < dl | < dl | 3.78 | 27.26 |
| **47258** | 416 | M4 | 2.53 | 0.004 | 0.686 | 0.038 | < dl | 3.58 | 71 | 0.031 | < dl | < dl | 2.53 | 31.71 |
| **47259** | 417 | M4 | 1.52 | < dl | 0.078 | < dl | < dl | 1.40 | 50 | < dl | < dl | < dl | 1.52 | 19.89 |
| **47260** | 419 | M4 | 1.48 | < dl | 0.207 | < dl | < dl | 0.71 | 29 | < dl | < dl | < dl | 1.48 | 17.26 |
| **47231** | 392 | Amit | - | < dl | 0.498 | 0.029 | < dl | 1.56 | 50 | 0.072 | < dl | < dl | - | 48.26 |
| **47230** | 393 | Amit | 2.49 | < dl | 0.449 | < dl | < dl | 1.41 | 44 | 0.026 | < dl | < dl | 2.49 | 22.80 |
| **47232** | 397 | Amit | 1.53 | 0.002 | 1.416 | 0.026 | < dl | 6.11 | 25 | < dl | < dl | < dl | 1.53 | 24.08 |
| **47233** | 398 | Amit | 1.51 | < dl | 0.242 | < dl | < dl | 1.07 | 45 | < dl | < dl | 0.05 | 1.51 | 26.12 |
| ***Background*** | | *Average* | *2.75* | | *1.094* | *0.017* | *0.017* | *1.88* | | *0.026* | | *0.004* | | *31.81* |
| | | *SD* | *1.90* | | *0.427* | *0.014* | *0.020* | *0.70* | | *0.013* | | *0.003* | | *1.58* |

| ID No | Lab. No | Station | As | Au | Cd | Co | Cr | Cu | Fe | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Sediment (µg/g)*** | | | | | | | | | | | | | | |
| ***Detection limits*** | | | *1.67* | *0.380* | *0.111* | *0.044* | *0.006* | *4.62* | *63* | *0.236* | *3.63* | *4.57* | *4.69* | *2.10* |
| **47240** | 144 | Upstream mine | 18.84 | 0.066 | 0.250 | 5.367 | 63.559 | 12.44 | 20823 | < dl | 11.15 | 20.44 | < dl | 31.48 |
| **47239** | 143 | Outflow mine | 295.72 | 1.437 | 0.540 | 37.018 | 198.353 | 164.56 | 63452 | < dl | 88.03 | 11.15 | < dl | 96.76 |
| **47241** | 145 | Sed bassin | 338.91 | 1.081 | 0.500 | 36.198 | 177.486 | 285.38 | 63455 | < dl | 78.27 | 19.50 | < dl | 98.78 |
| **47273** | 146/147 | ~ 3 | 18.09 | < dl | 0.31 | 8.54 | 84.42 | 17.24 | 26250 | < dl | 18.27 | 17.03 | < dl | 36.09 |
| **47291** | 149 | M2 | 5.27 | < dl | 0.274 | 2.193 | 31.662 | 5.44 | 9540 | < dl | < dl | 20.62 | < dl | 22.61 |
| **47275** | 148 | M3 | 12.56 | < dl | 0.210 | 7.523 | 56.469 | 27.04 | 19530 | < dl | 16.61 | 18.71 | < dl | 53.52 |
| **47292** | 150 | M5 | 3.06 | < dl | 0.191 | 3.845 | 36.446 | 6.77 | 13681 | < dl | 6.70 | 22.22 | < dl | 32.72 |

| ID No | Lab. No | Station | As | Au | Cd | Co | Cr | Cu | Fe | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Water and DGT-devices (µg/l)*** | | | | | | | | | | | | | | |
| ***Detection limits*** | | | | | | | | | | | | | | |
| | water | W1 Upstream | 0.862 | 0.001 | 0.005 | 0.012 | 0.102 | 1.86 | 2.62 | 0.013 | 0.294 | 0.289 | 0.030 | 0.232 |
| | water | W2 Out mine | 70.1 | 20.8 | 0.034 | 19.0 | 0.153 | 74.1 | 22.5 | 0.049 | 47.6 | 19.8 | 0.061 | 1.454 |
| | water | W3 In sed-bassin | 13.4 | 0.568 | 0.029 | 2.82 | 0.159 | 9.91 | 12.9 | 0.013 | 15.1 | 2.33 | 0.034 | 0.597 |
| | water | W4 out sed bassin | 8.72 | 0.366 | 0.060 | 2.32 | 0.166 | 8.57 | 12.8 | 0.006 | 15.0 | 2.03 | 0.081 | 0.256 |
| | water | W5 Waterfall | 1.65 | 0.016 | 0.008 | 0.155 | 0.121 | 3.65 | 3.80 | 0.005 | 0.957 | 0.340 | 0.052 | 0.215 |
| | DGT | W1 Upstream | 0.001 | | 0.000 | 0.018 | 0.058 | 0.478 | 4.95 | | 0.405 | 0.205 | 0.044 | |
| | DGT | W2 Out mine | 0.004 | | 0.023 | 1.52 | 0.040 | 100.7 | 47.1 | | 31.7 | 11.4 | 0.229 | |
| | DGT | W4 out sed bassin | 0.006 | | 0.018 | 0.746 | 0.077 | 29.0 | 33.9 | | 20.4 | 3.74 | 0.121 | |
| | DGT | W5 Waterfall | 0.001 | | | 0.060 | 0.065 | 2.05 | 7.32 | | 1.79 | 0.436 | 0.046 | |
| **BMP Guidelines for water quality** | | | 4 | | 0.1 | | 3 | 2 | 300 | 0.05 | 5 | 1 | | 10 |
| | | | | | | | | | | | | | | |

| ID No | Lab. No | Station | As | Au | Cd | Co | Cr | Cu | Fe | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Lichen – Flavocetraria nivalis (µg/g)*** | | | | | | | | | | | | | | |
| ***Detection limits*** | | | *0.111* | *0.002* | *0.013* | *0.017* | *0.112* | *0.479* | *1.021* | *0.017* | *0.313* | *0.039* | *0.052* | *0.121* |
| **47286** | 358 | 3 | 0.30 | < dl | 0.037 | 0.218 | 0.521 | 0.847 | 197.3 | 0.022 | 0.558 | 0.598 | 0.080 | 13.60 |
| **47268** | 343 | 4 | 0.96 | 0.003 | 0.065 | 0.486 | 1.157 | 1.830 | 487.0 | 0.033 | 1.125 | 0.950 | 0.092 | 22.71 |
| **45372** | 347 | 5-t | 0.85 | 0.002 | 0.048 | 0.565 | 1.720 | 1.976 | 800.7 | 0.032 | 1.450 | 1.066 | 0.084 | 12.48 |
| **45373** | 348 | 6-t | 1.15 | 0.034 | 0.084 | 0.951 | 1.330 | 1.493 | 504.0 | 0.027 | 1.455 | 0.624 | < dl | 18.10 |
| **47270** | 345 | 7 | 2.52 | 0.006 | 0.066 | 0.995 | 1.937 | 2.388 | 711.2 | 0.027 | 2.140 | 0.901 | < dl | 23.57 |
| **47269** | 344 | 8 | 2.42 | 0.005 | 0.064 | 1.029 | 2.074 | 2.712 | 729.2 | 0.026 | 2.258 | 1.159 | 0.045 | 16.54 |
| **47266** | 363 | 9 | 1.58 | 0.003 | 0.069 | 0.915 | 1.462 | 2.306 | 520.5 | 0.031 | 1.784 | 1.287 | 0.090 | 21.39 |
| **47271** | 346 | 10 | 1.59 | 0.013 | 0.052 | 0.714 | 1.364 | 1.829 | 488.7 | 0.036 | 1.448 | 1.093 | 0.085 | 18.87 |
| **45377** | 352 | 11-t | 2.46 | 0.026 | 0.075 | 0.730 | 2.200 | 2.835 | 696.7 | 0.034 | 1.589 | 2.313 | < dl | 19.18 |
| **45376** | 351 | 12-t | 1.10 | 0.020 | 0.061 | 0.371 | 1.226 | 1.444 | 472.5 | 0.031 | 0.941 | 0.698 | < dl | 11.94 |
| **47299** | 361 | 15 | 0.17 | < dl | 0.037 | 0.145 | 0.627 | 0.665 | 216.0 | 0.020 | 0.441 | 0.508 | < dl | 10.59 |
| **47300** | 362 | 17 | 0.25 | < dl | 0.023 | 0.148 | 0.409 | 0.496 | 150.3 | 0.020 | 0.393 | 0.466 | < dl | 11.44 |
| **45374** | 349 | 19 | 0.23 | < dl | 0.028 | 0.180 | 0.460 | 0.703 | 166.2 | 0.027 | 0.431 | 0.287 | < dl | 31.36 |
| **47267** | 338 | 20-t | 1.16 | 0.005 | 0.114 | 0.867 | 0.861 | 1.686 | 423.9 | 0.025 | 1.223 | 0.618 | < dl | 32.07 |
| **45378** | 353 | 22-t | 2.27 | 0.051 | 0.223 | 1.906 | 1.889 | nd | 681.8 | 0.032 | 5.105 | 0.925 | < dl | 19.79 |
| **45375** | 396 | 23-t | 2.98 | 0.017 | 0.119 | 0.972 | 2.054 | 4.460 | 783.9 | 0.050 | 4.096 | 1.228 | 0.118 | 22.41 |
| **45383** | 354 | 24-t | 1.82 | 0.063 | 0.062 | 0.680 | 1.211 | 1.863 | 461.6 | 0.025 | 4.475 | 0.795 | < dl | 10.52 |
| **47262** | 333 | M1 | 0.21 | < dl | 0.131 | 0.098 | 0.172 | 0.935 | 63.5 | 0.026 | < dl | 0.352 | 0.078 | 27.11 |
| **47287** | 359 | M2 | 1.93 | 0.006 | 0.084 | 0.804 | 1.607 | 1.443 | 787.9 | 0.034 | 1.217 | 0.904 | 0.084 | 19.83 |
| **47264** | 335 | M3 | 0.28 | < dl | 0.111 | 0.226 | 0.365 | 0.980 | 178.8 | 0.022 | 0.335 | 0.609 | < dl | 21.79 |
| **47265** | 336 | M4 | 0.15 | < dl | 0.025 | 0.070 | 0.207 | 1.105 | 107.5 | 0.024 | < dl | 0.439 | < dl | 22.52 |
| **47288** | 360 | M5 | 0.37 | < dl | 0.060 | 0.125 | 0.260 | 0.707 | 116.4 | 0.023 | < dl | 0.367 | 0.062 | 17.17 |
| **47263** | 334 | AMIT | 0.08 | < dl | 0.024 | 0.093 | 0.357 | < dl | 187.9 | 0.019 | < dl | 0.529 | 0.058 | 9.97 |
| ***Background*** | | *Average* | *0.238* | | *0.082* | *0.151* | *0.557* | *0.953* | | *0.034* | | *1.068* | | *21.555* |
| | | *SD* | *0.264* | | *0.030* | *0.146* | *0.992* | *0.757* | | *0.006* | | *0.338* | | *7.237* |

| ID No | Lab. No | Station | As | Au | Cd | Co | Cr | Cu | Fe | Hg | Ni | Pb | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Arctic Char – Salvenius alpinus (µg/g)*** | | | | | | | | | | | | | | |
| ***Detection limits*** | | | *0.11* | *0.002* | *0.013* | *0.017* | *0.112* | *0.48* | *1* | *0.017* | *0.31* | *0.04* | *0.05* | *0.12* |
| **214/215** | 47234 | Waterfall | 0.51 | 0.016 | 0.144 | 0.042 | < dl | 2.19 | 193 | 0.107 | < dl | < dl | 0.848 | 38.56 |
| **216** | 47235 | Waterfall | 0.15 | 0.010 | 0.177 | 0.039 | < dl | 12.42 | 215 | 0.036 | < dl | < dl | 0.670 | 31.03 |
| **217** | 47236 | Waterfall | 0.29 | 0.031 | 0.222 | 0.083 | < dl | 9.03 | 99 | 0.020 | < dl | < dl | 1.019 | 29.71 |
| **218** | 47237 | Waterfall | 0.16 | 0.033 | 0.063 | 0.089 | < dl | 14.71 | 237 | 0.021 | < dl | < dl | 0.758 | 24.74 |
| **219** | 47238 | Waterfall | < dl | 0.120 | 0.098 | 0.077 | < dl | 17.44 | 465 | 0.025 | < dl | < dl | 1.374 | 26.33 |
| **183** | 45385 | Ref River | 0.16 | 0.003 | 1.195 | 0.092 | 0.190 | 4.29 | 141 | 0.058 | < dl | < dl | 0.656 | 34.37 |
| **184** | 45385 | Ref River | 0.16 | 0.002 | 1.115 | 0.091 | 0.198 | 3.58 | 149 | 0.058 | < dl | < dl | 0.739 | 34.85 |
| **185** | 45386 | Ref River | 0.22 | 0.002 | 0.163 | 0.066 | < dl | 7.53 | 59 | 0.024 | < dl | < dl | 0.530 | 35.01 |
| **186** | 45387 | Ref River | 0.20 | 0.003 | 0.378 | 0.066 | < dl | 2.96 | 49 | 0.039 | < dl | < dl | 0.597 | 34.09 |
| **187** | 45388 | Ref River | 0.18 | 0.002 | 0.223 | 0.034 | < dl | 7.02 | 135 | 0.036 | < dl | < dl | 0.602 | 29.14 |
| ***Background*** | | *Average* | *0.448* | | *0.071* | *0.042* | *0.026* | *9.882* | | *0.025* | | *0.006* | | *34.813* |
| | | *SD* | *0.148* | | *0.024* | *0.014* | *0.025* | *10.977* | | *0.010* | | *0.003* | | *4.444* |

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# ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2012

This ninth environmental monitoring programme was conducted in the Nalunaq area, about 40 km from Nanortalik, South Greenland, from 7 to 13 September 2012.

The environmental monitoring programme is conducted to trace and avoid unwanted impacts of the mining industry to the environment. Since the monitoring in 2011, the mining company Gold Angel Mining A/S has been breaking new ore and the mining activities are primarily contained inside the mountain. The gold is recovered by the use of chemical extraction (carbon-in-pulp) using cyanide. Due to the use of cyanide to extract gold from the ore, strict control with the outflow of cyanide from the mine to the Kirkespir Valley is performed. Also an extensive monitoring programme is conducted to reveal spreading and effects of elements into the Kirkespir Valley and Bay environment. The described impact on the environment of the Kirkespir Valley, both terrestrial, freshwater and marine, is considered to be minor and is generally lower than during the operation in 2004-2009.

ISBN: 978-87-7156-002-2
ISSN: 2245-0203