WaterPro - Northern Runoffs into Profits

T1 Good Practice Tools and Guidance

Output T.1.2.

An Inventory of Good Management Practices for Nutrients Reduction and Recovery from Agricultural and Mineral Extraction Runoff

Good Management Practices for Nutrients Reduction from Mineral Extraction Runoff

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Background

Mineral extraction sites, which include strip mines, quarries, and underground mines, contribute to surface and groundwater pollution, erosion, and sedimentation. The mining processes can involve the excavation of large amounts of rock material to be able to extract the desired ore minerals. This process creates mining wastes such as waste rock and tailings. Waste rock is the material that has not enough desired ore minerals but is necessary to excavate to get the ore extracted. Tailings are the waste material coming from the enrichment plant after the minerals are processed. Both waste rock and mine tailings are usually stored in large, above-ground piles and containment areas (tailings impoundments and waste rock piles). Depending from the ore type, these waste piles and impoundments may pose a considerable problem to the environment due to harmful element pollution and acid mine drainage. This acid runoff also dissolves heavy metals such as lead, copper, and mercury, resulting in surface and groundwater contamination (Artiola et al, 2004).

The nutrient load from mineral extraction is generally caused by the use of explosives that contain nitrogen (N) (Revey 1996). Most minerals and rocks contain relatively low concentrations of nitrogenous compounds. Even though the nutrient load from mineral extraction is generally caused by N from the explosives, in certain cases processing phosphorous (P) minerals (phosphates e.g) can significantly increase the phosphorous load to receiving water systems and cause eutrophication. The growth limiting nutrient in receiving bodies of water may be nitrogen or phosphorous and therefore the environmental impact of certain nutrient (N or P) must be observed case by case.

The sources of nitrogen in opencast and underground mines depend from the specific circumstances at the particular mine. Blasting of the rock material often involves the use of ammonia-based explosives such as ammonium nitrate fuel oil (ANFO), gunpowder, etc. This will contribute to elevated nitrate levels in open-cast and underground mining as residues from the blasting are disposed with the waste rock or remain behind in the excavation, ending up into dewatering waters (Patel, 2016). Jermakka et al (2015) highlighted that the rate of explosive-originated nitrogen discharges depends on the hydrological conditions present at the site. Moreover, that in the Nordic conditions, the seasonal variations in precipitation and temperature may play a significant role in the nitrogen loading (Karlsson & Kauppila 2016).

Once excavated, overburden material and waste rock are disposed in large rock dumps, where the process of nitrification continues as a result of exposure to the atmosphere. When the nitrate in the rock dumps is dissolved due to exposure to rain, it leaches from the rock dumps and can enter surface and groundwater resources. In some cases, surface run-off from rock dumps is contained in leachate-water systems, but this is not always the case and even when such systems are in place, they are not lined and the nitrate can reach the groundwater resources in the area. Rock dumps are therefore an additional potential source of nitrate in groundwater (Patel, 2016).

Best environmental practices for mines management (BEPMm) in the Northern Periphery Area

In the Northern Periphery Area (NPA), mining is practiced in Finland, Sweden, Scotland, Northern Ireland and Ireland. While Iceland has an abundant source of geothermal power, its mineral and metals reserves are limited. Consequently, the mining industry does not play an important role in the country's economy (AzoMining, 2012).

Recently, Politis et al (2017) successfully completed the MIN-GUIDE project funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 689527. One of the major outcomes of project was the development of a major new online repository: Minerals Policy Guide (the MIN-GUIDE) as the major guidance and the latest knowledge collection regarding good practice for minerals policy for decision makers. The project's key objectives were (1) to provide guidance for EU and EU Member States minerals policy, (2) to facilitate minerals policy decision making through knowledge coproduction for transferability of best practice minerals policy, and (3) to foster community and network building for the co-management of an innovation-catalysing minerals policy framework. Our current partner in WaterPro project, Luleå University of Technology, Department of Civil, Environmental and Natural Resources Engineering was one of the partners on this project.

The project also underlined the importance of management of Tailings Facilities (TMFs) which may lead to accidental water pollution. TMFs store large amounts of mine wastes which are generated as a by-product when processing minerals. As such, they can pose serious threats to humans and the environment, especially in case of their improper design, handling or management. Thus, a failure may result in uncontrolled spills of tailings, dangerous flow-slides or the release of hazardous substances, leading to major environmental catastrophes. It has also been recognized that although TMFs are operated with increasing care in many ECE countries, the safety of their operations and their afterlife needs further improvement. Moreover, the project underlined the need for awareness of the new challenges posed by climate change, which may increase the probability of industrial accidents caused by natural disasters, such as earthquakes and flooding that pose a major risk to TMFs.

In consultation with a broad range of stakeholders, the Government of Canada developed and adopted the Environmental Code of Practice for Metal Mines whose major objective is to identify and promote recommended best practices in order to facilitate and encourage continual improvement in the environmental performance of mining facilities throughout the mine life cycle, in Canada and elsewhere. The Code is designed to support the Metal Mining Effluent Regulations (MMER) under the Fisheries Act and includes other subjects that are not dealt with in the MMER that may have an influence on the environmental impact of mining operations (Environment and Climate Change Canada, 2019). All of the Recommended Environmental Management Practices in the Government of Canada Code are pertinent to the NPA Region, and as such are listed in Table 1, below:

Table 1: The Government of Canada Recommended Environmental Mining Management Practices

Recommended Environmental Mining Management Practice	
1. Recommendations for Environmental Management Tools: In the context of the Code of Practice, environmental management tools can be broadly defined as an organized set of activities, actions, processes, and procedures that go beyond legal requirements in aiding mine owners and operators to ensure that their operations have minimal impact on the environment. 1.1 Environmental Policy Statement 1.2 Environmental Assessment 1.3 Environmental Risk Management 1.4 Environmental Management Systems (EMS) 1.5 Pollution Prevention Plans 1.6 Environmental Management Plans 1.7 Environmental Performance Indicators 1.8 Monitoring and Inspection of Environmental Management Facilities 1.9 Environmental Monitoring 1.10 Traditional Ecological Knowledge 1.11 Emergency Planning 1.12 Environmental Training and Awareness 1.13 Closure Planning - Designing for Closure 1.14 Environmental Auditing 1.15 Public Involvement 1.16 Product Stewardship 1.17 Adaptive Management	
2**. Environmental Management Practices for the Exploration and Feasibility Phase:** Environmental management plans should cover the full range of activities related to exploration, including land acquisition, surveys, access, camp and associated facilities, stripping, trenching, drilling and sampling. Environmental management practices should address water management and water quality, waste management, land disturbance, air quality, reclamation and closure.	
Activity	**Recommended Practices**
Site Selection	• Where possible, natural clearings should be used to avoid the necessity of clearing vegetation • Topsoil and organic matter should be stored for future rehabilitation needs • Nesting, breeding and migration areas and endangered species should be protected • Thawing of permafrost should be prevented to the extent practicable • Tree removal and compaction of soil should be minimized in areas of permafrost
Water Supply	• Withdrawal of water from streams should be done in a manner that protects fish populations

	• Withdrawal of water from streams should not exceed 10% of low flow of stream
Sewage and Domestic Washwater Disposal	• Pit toilets or sewage lagoons should be used for sewage disposal • Sewage disposal facilities should be a minimum of 100 m from any water body • Domestic washwater should not be discharged directly to any water body
Solid Waste Disposal	• Waste minimization practices should be implemented • Solid waste should be incinerated, hauled from site or buried on site • Landfills should be capped with a minimum of 1 m of soil • Drainage from landfills should not affect any watercourse • Waste should not be buried in permafrost
Infrastructure	
Access Roads	• Surface water control/diversion structures should be provided • Sedimentation and erosion control features should be installed • Except for crossings, roads should be located a minimum of 100 m from water bodies • Care should be taken in siting roads to avoid thin and sensitive vegetation covers
Aircraft Operations	Aircraft should: • remain 500 m above wildlife concentration areas; • remain 3000 m above special areas such as goose staging areas; • fly low only when required; • not make repeated low-level passes or circle over animals; • not overfly raptor colonies or colonies of nesting birds; and • stay clear of migration areas.
Docks	• Clearing of forested shores should be kept to a minimum • Rock-filled drums used for docks should be clean and readily removable • Wooden docks should be made of untreated lumber • Spill contingency supplies should be available for refuelling areas • Fuel hoses should be equipped with shut-off valves at both tank and nozzle ends
Fuel Storage and handling	• Fuel should be stored a minimum of 100 m from any water body • Spill containment dikes should be constructed of clay or hydrocarbon-resistant plastic • Fuel transfers should take place within the dike area • Fuel absorbent materials should be kept on site • Equipment should be repaired/serviced at least 100 m from any water body
Stream Crossings	• Stream crossings should be a minimum of 500 m from spawning areas • Gentle approaches should be selected with cut/fill at banks to a minimum • Fisheries and wildlife habitat should be protected and preserved • Stream bank erosion and sedimentation should be prevented • Intermittent stream channels should not be filled
Drilling and Trenching	• Drilling fluid should be biodegradable, and it should be contained and recycled • Trenches should be refilled and regraded after sampling
Off-road Vehicle Operation	• In northern areas, low-ground-pressure equipment should be used to mitigate the disturbance and erosion of permafrost active zones • Permafrost areas should be accessed via aircraft to the extent practicable
3. Environmental Management Practices for the Planning and Construction Phase	3.1 Water Management 3.2 Prediction of Wastewater Quality 3.3 Waste Rock and Tailings Disposal Planning 3.4 Long Term Stability of Waste Rock Piles and Tailings Management Facilities 3.5 Planning and Construction of Wastewater Treatment Systems 3.6 Cyanide Management Planning 3.7 Other Considerations 3.8 Climate Change and Adaptation
4. Environmental Management Practices for the Mine Operations Phase	4.1 Water Management 4.2 Management of Waste Rock and Tailings 4.3 Monitoring of Waste Rock and Tailings 4.4 Management of Treatment Sludge 4.5 Management of Other Water Quality Concerns

	4.6 Management of Air Quality Issues 4.7 Management of Noise and Vibration 4.8 Engine Operation and Maintenance 4.9 Progressive Reclamation
5. Environmental Management Practices for the Mine Closure Phase	5.1 Evaluation of Revision of Existing Environmental Plans 5.2 Financing of Mine Closure and Long-Term Monitoring, Maintenance or Treatment 5.3 Suspended Operations and Inactive Mines 5.4 Aspects to be Considered in Mine Closure 5.5 Decommissioning of Underground and Open Pit Mine Workings 5.6 Decommissioning of Ore Processing Facilities and Site Infrastructure 5.7 Decommissioning of Waste Rock Piles and Tailings Management Facilities 5.8 Water Management and Treatment 5.9 Mine Site Rehabilitation and Revegetation 5.10 Monitoring

NordMin Water Conscious Mining (WASCIOUS) project 2014-2016

Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland, and Åland. In 2014, NordMin - a Nordic Network of Expertise for a Sustainable Mining and Mineral Industry, funded a two year project titled "Water conscious mining" (WASCIOUS) project (Nordic Council of Ministers, 2014; Nordic Co-operation, 2019).

The main objective of the project was to develop a technology concept for water conscious mining, where innovative water and tailings treatment technologies provide good-quality water for recycling and discharge and enable safe disposal or utilization of tailings. The work also included a comprehensive survey on current practices and requirements in Nordic mines and laboratory and pilot scale development of several technologies. Computational simulations of water treatment and recycling practices were performed for a feasibility study of some technology alternatives and technologies for dewatering of tailings were evaluated. As an important outcome of the project, a future Nordic research platform was established related to environmental issues in mining for the Nordic region, enabling exchange of ideas and collaboration in future project calls, and facilitating ideas for future projects (Wahlström et al, 2017; Nordmin, 2019).

Based on a review of the requirements in mine water permits and discharge levels in Nordic mines at the time the project was formulated (2014), the project group decided to focus on the removal of sulphate, specific metals (Cu, Ni, Zn), and to a limited extent on the removal of nitrogen (N) compounds. The overall objective was to develop a proposal with suitable technologies for the concept of "Low-water footprint mine" (Wahlström et al, 2017). Several potential technologies (either are already proven and implemented under different conditions or are in the development stage) were experimentally tested by the project partners from Finland (VTT Technical Research Centre of Finland Ltd and Lappeenranta University of Technology (LUT), Outotec Oyj, ÅF-Consult Ltd, Dragon Mining Oy, Boliden Kevitsa Mining formerly FQM Kevitsa Mining FinnMin – Finnish Association of Extractive Resources Industry), Sweden (Luleå University of Technology, LKAB Luossavaara-Kiirunavaara AB, SveMin – Swedish Association of Mines, Mineral and Metal Producers), Norway (SINTEF Stiftelsen and Norwegian University of Science and Technology, NTNU), Iceland (ÍSOR Iceland Geosurvey) and Denmark (VEOLIA Water Technologies). In addition, process simulation models were built using HSC Chemistry - a chemical reaction and equilibrium software developed by Outotec (Outotec, 2019).

The main technologies tested by the partners were:

- Biosorbents: VTT.

- Precipitation processes: VTT, Veolia.
- Eutectic freeze crystallization and solid-liquid separation: NTNU.
- Electrochemical processes and solid/liquid separation: LUT.
- Membrane processes: SINTEF, LUT, VTT, Veolia.
- Biological processes: Veolia.
- Process modelling: LTU.
- Tailings management: VTT.

The results revealed that 1) *sulphate precipitation as ettringite* was the best removal method for sulphate, followed by *electrocoagulation* and *ultrafiltration membranes*. *Eutectic freeze crystallization* showed promising results for waters with high salt concentrations, but the technology was in development stage at the time. Several pilot and demonstration projects are described in Aweimagazine (2019); 2) Biosorption was not found to be a suitable method for sulphate removal; 3) The most appropriate processes for metals removal were precipitation/coagulation/sedimentation process and coprecipitation processes. Ettringite precipitation, electrocoagulation and Eutectic freeze crystallization (after 2-3 washing times of the ice) also reduced metal content; 4) Membrane processes removed about 50% of the metals in average; 5) the Biological fixed film process MBBR was efficient in N removal and 6) Further work is needed especially for electrocoagulation, freeze crystallization and membrane based technologies. In addition, the applicability of different combinations of the studied technologies should be investigated (Wahlström et al, 2017).

The overall conclusions of the project were that similarly to municipal sewage and industrial effluents, the choice of suitable technology depends on the water quality required and the discharge requirements for pollutants that need to be removed. The possible use of the treated water as process water or discharge to the receiving water body determines the goals and level of water treatment that will need to be applied. The effects of arctic conditions in terms of cold weather and flow variation were also highlighted. The simulation of different processing and technology alternatives provides important information on both water flows and rough operational costs for comparison. For a feasibility study, also information on CAPEX and OPEX are crucial (Wahlström et al, 2017).

In our WaterPro project, the main focus concerning the extractive industry has been on investigation of technologies for N removal. A short summary for each of the partner countries is provided bellow:

Finland

The growth of Finnish extractive industry has created the need to investigate and monitor its impacts on the environment. In 2010, the Tekes Green Mining Programme and the industry funded the MINIMAN project which aimed to provide comprehensive understanding on the nitrogen issue in the extractive industry. The project enabled collection of crucial data on the nitrogen (N) compounds occurring in the environments of mines and quarries, as well as one of the most comprehensive reviews of the currently available technologies for the treatment of N containing mine water (Jermakka et al, 2015). In 2017 there were 44 active mines in Finland (TUKES 2018). Of these, nine were metal ore mines and the rest were industrial mineral or industrial rock mines. The amount of extracted rock material was 120 Mt which generated 48 Mt of ore. Mining activities in Finland are regulated. The summary of rules and legislation is presented in Appendix 1.

Research into the best management practices for limiting nitrogen (N) runoff is still ongoing and the majority of methods have been tested only on the laboratory scale (see for example Mattila et al., 2007, Kauppilla et al, 2011; Jermakka et al., 2015a). A recent study about the design parameters for nitrogen removal by constructed wetlands (CW) treating mine waters in Finland was published by Kujala et al. (2019). In the study, six CWs treating mine waters were compared for N removal efficiency. All the studied CWs were observed to remove N efficiently during the warm growing season but the amount of N released increased significantly during the cold season. According to the results, the peat-based CWs were slightly more efficient in N removal than pond-type CWs. On the other hand, purification efficiency was steadier and higher for pond-type CWs, as lower hydraulic load or longer water residence time seem to compensate for purification performance.

The best environmental practices for metal mining (BEPMm) in Finland were compiled by Kauppila et al. (2011). This document includes information on mitigation techniques to reduce emissions and environmental impacts (Chapter 6) and over 30 pages on BEPMm (Chapter 8). More recently, Gabarino et al (2018) provided the Best Available Techniques Reference document for management of Waste from the Extractive industries. This document gives guidance, in accordance with directive 2006/21/EC, for monitoring mine water quality to prevent and control discharge of nutrients and other unwanted substances to seepage-, drainage-, and groundwater.

At present, removing nitrogen from waste waters is rare in Finland due to costs associated with the removal process (Kauppila et al., 2013). Also, the cold Nordic climate sets some limitations on the use of different N removal methods and for example the effectiveness of biological methods is often limited by the low temperatures. Currently the most common method for limiting N runoff is circulating mine water through tailings ponds where long retention times lower N concentrations through the natural hydrological cycle (Kauppila et al., 2013). Most of the larger scale mines also have closed or partially closed water cycles, meaning that most of the water from the tailings- or settling ponds is recycled and used again as process water. A large portion of the total discharge from mines usually occurs after heavy rainfalls when the capacity of the ponds is exceeded. This also means that the discharged water is largely rainwater which has lower environmental impact than regular mine discharge (Heikkinen et al., 2005).

In Finland, some N runoff from mining is caused by the use of different process chemicals but the majority of emissions results from the use of ammonium nitrate explosives (Kauppila et al., 2013). It is recommended that the use of blasting agents that contain high amounts of easily soluble N (like the commonly used ammonium nitrate fuel oil ANFO) is reduced and less soluble blasting agents, like emulsion or gel based explosives should be favored instead (Mattila et al., 2007). In a test done by Wiber et al. (1991), ammonium runoff from some studied mines was decreased by over 30 percent by training mining personnel to take caution on the water solubility of explosives and to treat explosives as recommended. This shows the importance of properly instructing the personnel handling water soluble explosives. The training should include simple things like closing ANFO bags after use, making sure that explosives aren't spread outside drill holes and that the drill holes are dry before loading (Forsyth et al., 1995). Mines should also aim to collect seepage water from barren rock piles, ensure sufficient aeration of tailings to promote in-situ nitrification of ammonium and discharge all mine waters at a single location to make treatment of waters easier to conduct. Nitrate removal systems are generally recommended to be placed on the point of discharge to the aquatic environment in order to treat high water volumes with low suspended solids (Mattila et al., 2007).

Jermakka et al. (2015) provided methods for N removal that have demonstrated effectiveness and are suited for mine wastewater treatment in Finland (Table 2). The same methods are used in Canada and can be applied throughout the NPA region.

Table 2: Methods for N removal that have demonstrated effectiveness and are suited for mine wastewater treatment in Finland

Method	**Reported removal rate or efficiency**			**Advantages/ Disadvantages**	**Suitability for mine wastewater treatment**
	NO_3^- / NO_2^-	***NH_4^+***	***Organic N***		
				Advantages: - > 99% efficiency can be achieved - Moderate operational costs	Good, but toxicity and low temperatures may limit the applicability

Biological N removal methods including bioreactors	60–99%[1]	12–97%[1]	ND	*Disadvantages*: - May require waste disposal for the biomass - pH and temperature effects are important - Pre- and post-treatment might be required	
Electrochemical methods	98%[2]	>97%[2]	90%[2]	*Advantages*: - No waste disposal - No significant temperature effects - High removal efficiency - Moderate operational costs *Disadvantages*: - pH effects might influence effectiveness - Post-treatment may be required	Good
Sorption, precipitation and ion exchange methods	3.5–11 mg/g (HDTMA-zeolite) 60–82 mg/g (Mg/Al LDH) 6–10 mg/g (activated C)	6–28 mg/g (Zeolite) >70%	ND	*Advantages*: - Removal efficiency varies with sorbent and / but can be targeted to specific contaminants - Moderate operational costs *Disadvantages*: - May require disposal of saturated / spent sorbent or waste brine - pH and temperature effects are important - Post-treatment may be required	Good
Air stripping	ND	>95% (pH >10.5)	ND	*Advantages*: - Relatively cheap *Disadvantages*: - Requires high pH	Fair when used in combination with others
Combined technologies	Variable	Variable	Variable	*Advantages*: - Can be optimized to treat a particular wastewater *Disadvantages*: - Research / testing may be required to optimize treatment system for individual applications	Good

ND = No Data
1 Depends on conditions in reactor / wetland. Efficiency is good when optimal conditions for microbial processes are achieved.
2 Depends highly on the electrochemical method selected.

In the WaterPro project The Finnish Geological Survey and Savonia University of Applied Sciences tested adsorbents such as vermiculite and zeolite for treatment of ammonium-rich wastewater in variable temperature and pH conditions (Heikkinen, 2017; Solismaa, 2019). The study revealed that zeolite material seemed to have better ammonium reduction ability compared to vermiculite. However, the material leached large amounts of sodium, which made it less suitable for field applications. On the other hand, the research indicated that vermiculite could be reused as a nitrogen fertilizer after ammonium adsorption, for example in forested areas. Both minerals adsorbed unwanted metals such as Zn, Al, Mn. The more detailed description of this study is included in the Objective T2 outcomes along with the other Pilot sites.

Sweden

Sweden is considered as Europe's leading mining country, accounting for 91% of Europe's iron ore, as well as 9% of the copper and 24-39% of its lead, zinc, silver and gold (Mining for generations, 2019).
In 2013, the mining industry contributed about 11.4 billion euros to Sweden's GDP, which is equivalent to about 3%. Annual investments amount to about SEK 1.1 billion, which is a significant portion of all industry investments. In addition, the industry provides 13,000 jobs and directly contributes to creating an additional 35,000 opportunities for

work. The industry consists of a large mining cluster made up of large and small companies, many of which act as subcontractors to the direct mining industry. Sweden plans to triple its mining production by 2025, which could create more than 50,000 jobs.

The Swedish government has formulated Sweden's mineral strategy with the aim of ensuring long-term sustainable growth while taking ecological, social, and cultural aspects into consideration. However, eutrophication of freshwaters caused by nutrient discharge is a serious concern and a main cause of failing to reach the 2020 target of Good ecological status of waters. Nitrogen input from mining activities can locally make a significant contribution to the N load in freshwaters (Nilsson, 2018).

Nitrogen pollution effects and removal options from mining activities in northern Sweden have been investigated by a number of researchers (e.g. Öhlander et al, 2008; Frandsen et al, 2009; Chlot, 2013; Willquist et al, 2015; Nilsson, 2018). Frandsen et al. (2009) reported that natural total N concentrations in most mining regions in Sweden are usually below 0.3 mg L^{-1}, which is suggested as the upper limit of low concentration by the Swedish Environmental Protection Agency. However, in contrast, N concentrations in waters discharged from mine sites often exceed the 5 mg L^{-1} suggested as the lower limit of extremely high concentrations. Frandsen et al. (2009) provided an overview of a Swedish research programme running from 2008–2011, financed by The Swedish Governmental Agency for Innovation Systems (VINNOVA), the mining companies LKAB, Boliden Mineral AB and The Adolf H Lundin Charitable Foundation. The programme focused on natural attenuation of N in the receiving waters downstream of the two Swedish mine sites at Kiruna and Boliden (Chlot, 2013; Chlot et al., 2011; 2013a,b; 2015).

Sweden has 16 active mines, of which 13 are metal mines (Figure 1).

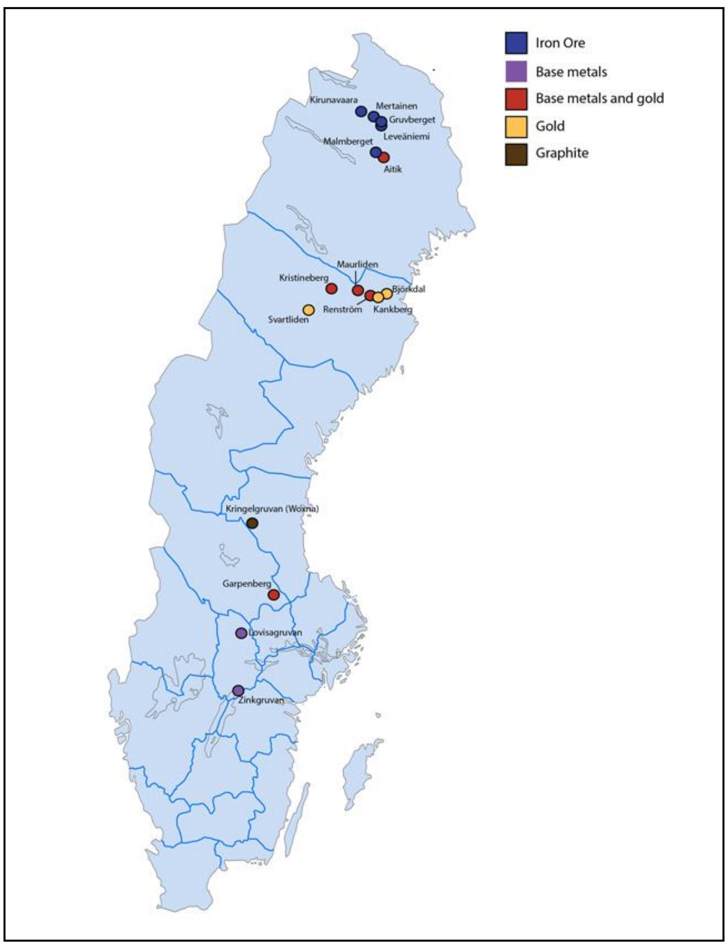

Figure 1. Active mines in Sweden. Source: Mining for generations, 2019.

The Kiruna mine site was also the main research site for N removal investigations by Lulea University of Technology researchers in the WaterPro project (Nilsson, 2018; Table 3). In this project a biogeochemical computer model was developed to predict and simulate N concentrations in cold climate mine ponds (Nilsson and Widerlund, 2018). In addition, it was investigated whether nitrate reduction could be achieved by controlled phosphorus inputs intended to increase phytoplankton growth and denitrification (Nilsson, 2018). Overall, N removal technologies used and investigated in Sweden are similar to those in Finland, Canada and other countries (Table 2).

To further address the research need on mining-related nitrogen, project miNing (*Reduction of nitrogen discharges in mining processes and mitigating its environmental impact*) was started in 2013 (project period 2013-2018). Project *miNing* consisted of three sub-projects, each aiming to develop treatment systems that can be used independently or in combination to remove nitrogen from mine waters. The systems involve passive or semi-passive treatment methods that require only a minimal amount of energy to maintain in operation. These systems rely on the activity of efficient microbial communities that transform nitrogen compounds, ultimately to harmless di-nitrogen gas (N_2). The following subprojects were conducted:

- A bioreactor system for nitrogen removal from waste rock leachate and mine drainage designed to develop biofilms rich in denitrifying bacteria that convert nitrate NO_3^- to N_2 gas (Hellman, 2018; Nordström and Herbert, 2018)
- Possibilities to optimize microbial denitrification in mine ponds (Hellman, 2018; Nilsson, 2018)
- Wetland systems for nitrogen removal by phytoremediation by macrophytes and algae and denitrification, requiring an intimate interaction between plants and microorganisms (Hallin et al., 2015; Choudhury et al., 2018)

Table 3: Innovative Management Practices Tested for Mineral Extraction and Landfills Runoff in the NPA Region by WaterPro partners

Partners	Pilot Sites	Purpose	Reference
Geological Survey of Finland, FIN	A) Paroc anorthosite quarry (Lapinlahti) B) Tulikivi soapstone quarry (Juuka) C) Laboratory	A+B: Nitrogen levels after blasting C: Filter material testing for nitrogen removal	Infocards: 1.1. Using Batch Adsorption Experiments for selecting most effective sorbent 1.2. Monitoring explosive based nitrogen (N) emissions
Lulea University of Technology, SWE	Kiruna iron mine	Study nitrogen removal through passive / semi-passive denitrification in mine ponds. Main purpose was to investigate if phosphorus fertilization of mine ponds can increase algal growth that would act as carbon source for denitrification in pond sediments.	InfoCards: 2.1. Nitrogen removal in cold-climate mine ponds, northern Sweden 2.2. Removal of mine-water nitrogen by wetlands in cold climate
Donegal County Council, IRL	Churchtown	Nutrients reduction from landfills via SRC willow and constructed wetlands	InfoCard: 3.1. Runoff Monitoring pilot site at Churchtown

The focus of the research for the remaining WaterPro Project Partners (e.g. Iceland, Faroe Islands, Scotland, Northern Ireland and Ireland) has been on the good management practices for agriculture runoff treatment and management. Therefore only a short summary of the mining industry sector in these countries will be presented:

Iceland

Iceland has a plentiful source of geothermal power, but limited mineral and metals reserves. Therefore, the mining industry does not play an important role in the country's economy which is more dependent on its fishing industry. However, in recent years the abundance of geothermal power has attracted foreign investments to the aluminum sector (AzoMining, 2012; NewYork Times, 2017; Alcoa, 2019).

In November 2016, St-Georges Platinum and Base Metals Ltd. - a Canada listed company (www.stgeorgesplatinum.com) entered in to a binding agreement with Icelandic Resources (https://www.icelandresources.is/) with the ambitious goal to develop new technologies capable to solve the biggest environmental problems in the mining industry (IcelandResources, 2016).

Faroe Islands

Faroe Islands are very rich in various minerals, but the government has not yet established a full-fledged development of each of them. Cryolite has been extracted since the middle of the last century, and despite the fact that the deposits were close to depletion, their extraction is still being carried out. There are also vast reserves of lead-zinc ores, as well as zinc concentrates, which are actively used in industry and communal services (Orangesmile, 2019). Coal has been an important source of energy on the Faroe Islands until the end of World War II. A few miners are still extracting coal from the mines. However, currently there is only one mine (Prestfjall mine) left in operation where coal is of good quality (similar to anthracite). The majority of abandoned mines are located in the northern part of the Suðuroy Island (Krmickova and Krmicek, 2015).

Scotland

The central belt of Scotland contains a wide range of minerals and is the UK's most productive coalfield, containing a third of the UK's igneous rock aggregate quarries and has significant deposits of sand, gravel and clay. These resources are extremely important assets for the current and future economic development. A decade ago, the Scottish Government commissioned British Geological Survey to publish a guide to minerals information in the Central Belt of Scotland (British Geological Survey, 2008).

According to the Guide, the major mineral resources in the central belt are:

Crushed rock aggregate - a hard rock such as igneous rock or sandstone that is crushed for use in a variety of construction applications, such as foundations for roads and buildings. Some rock types have 'non-slip' properties (high Polished Stone Value) which make them extremely valuable for road surfacing. In Scotland, igneous rocks are the main source of crushed rock aggregate.

Sand and gravel which have a variety of construction applications, such as concreting aggregate, or asphalt for road surfacing. In Scotland sand and gravel deposits lie on top of the bedrock geology and were mainly deposited by glaciers and rivers (glaciofluvial).

Coal – in Scotland extracted by opencast mining from sedimentary rocks of Carboniferous age. Although coal accounts for only 15% of Scottish minerals by weight, it accounts for half the total value of all minerals produced in Scotland. Production from this area makes up 45% of the total UK coal production (2006, calendar year).

Limestone - a sedimentary rock consisting principally of calcium carbonate ($CaCO_3$). It can be crushed, ground or calcined (burnt to make lime) for different applications. Major uses include cement manufacture, lime for agricultural or water treatment purposes, and also as an industrial filler in paints and plastics. Limestone in the central belt is generally too soft for use as a building stone or to be crushed for aggregate.

Building stone – which describes rocks used for masonry, walls, pavements and roofing material. Desirable properties include being hard enough to resist years of weathering, but also soft enough to be cut or carved. Most building stones are used locally, so differences in aesthetic properties such as colour or texture impart distinctive local character. Many building stones are of such high quality that they have also been exported. Sandstones of Carboniferous, Permian and Upper Devonian age have been used extensively in Scotland as building stone in the past.
Since late 1990s, Scotland government initiated reopening of dormant building stone quarries for heritage conservation and restoration. Today there are only few remaining working building stone quarries in Scotland. Those that are in operation supply the growing need for restoration stone to help preserve the special characteristics of Scotland's buildings and monuments. For example,

- Of the many closed stone quarries in West Lothian, Binny quarry near Uphall was reopened on a temporary basis in 1997 to supply stone for the restoration of the Scott Monument, Edinburgh. The distinctive pale brown sandstone from Binny can be seen elsewhere in Edinburgh including the National Gallery, the former General Post Office and the City Observatory on Calton Hill.
- The Cullaloe quarry, near Burntisland in Fife, reopened in 2004 to supply conservation needs in Edinburgh after having been closed for nearly 60 years. It extracts a high-quality, pale sandstone of the Strathclyde Group, originally used in the development of Edinburgh, Dundee and Glasgow during the nineteenth century.

Peat – which is formed by decaying organic matter which accumulates in bogs and fens. It is cut locally for fuel, but is mainly extracted for use as a horticultural growing medium. Half the peat extracted in the UK currently comes from Scotland. In the central belt it is currently extracted in South Lanarkshire, Falkirk and Clackmannanshire.

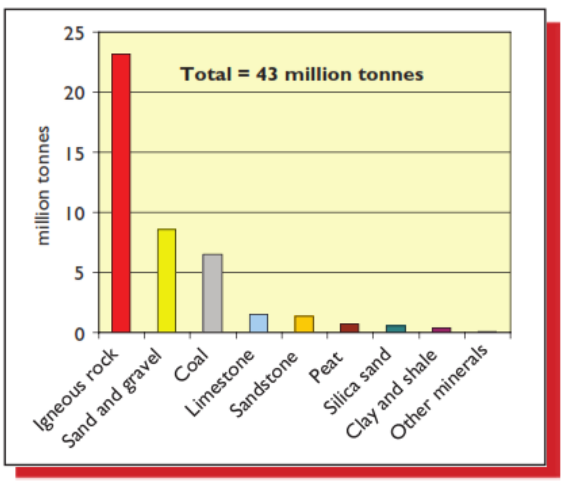

Figure 2: Minerals produced in Scotland in 2006.

One of the earliest investigations of constructed wetlands (CW) technology for acid mine drainage treatment from coal mining was performed in Scotland (Drizo, 1993; Woulds and Ngwenya, 2004). Since that time CWs became a recognized technology and have been used for acid mine drainage treatment across the globe (e.g. Younger et al, 2002; Kalin, 2004; Johnson and Hallberg, 2005; Nyquist and Greger, 2009; Pat-Espadas et al., 2018). The most recent review of CW for acid mine drainage (AMD) highlighted that systems with sub-surface flow have potential to provide an efficient AMD treatment. The principal limitations for CW treating AMD remain the same, e.g. the toxicity effect of heavy metals on CW plants and microorganisms. The authors indicated that these aspects can be solved partially by choosing carefully constructed wetlands components suitable for the AMD characteristics. Finally they underlined that the cost of the CW systems are affected by a number of factors such as the size (land area needed for the system), detention time, treatment goals, media type, pretreatment type, number of cells, source, and availability of gravel media (Pat-Espadas et al., 2018). CWs are also effective in controlling N discharges. A recent article about design parameters for nitrogen removal by CWs treating mine waters was published by Kujala et al. (2019).

Yukon (Canada) Research Centre recently conducted a comprehensive review of Passive Treatment of Mine Impacted Water In Cold Climates (Ness et al, 2014). Treatment systems review included constructed wetlands, bioreactors, and hybrid systems. They reported that some of the challenges associated with implementing Passive Treatment Systems (PTSs) in cold climate include cold temperatures, remote locations and limited access in winter, which can lead to freezing pipes and surface water, variable seasonal flow, and low productivity of microbial and macrophytic communities. Many adaptations have been implemented to address these cold climate challenges including burial of pipes to avoid hydraulic failure, insulation to avoid freezing surface waters, bypasses and overflows to maintain constant flow, summer establishment of microbial and macrophytic communities and the addition of liquid carbon sources to offset reduced organic matter decomposition in cold temperatures. The authors highlighted that while further investigation and development is necessary to fully understand the factors affecting cold climate PTSs, with sufficient research and planning PTSs can be successfully implemented in cold climates.

Northern Ireland

Northern Ireland is considered the most prospective area of the United Kingdom and Republic of Ireland for precious metal deposits. According to the British Geological Survey (2019) alluvial gold has been recovered since Celtic times when it was used to produce ornate artefacts. Modern-day exploration commenced in the late 1970s. A gold metallogeny study of northwest Northern Ireland carried out nearly 25 years ago identified a number of prospective areas (British Geological Survey, 2019).

Mineral exploration and mining throughout the island of Ireland is carried out by the private sector, with the support of the regulatory authorities in both Ireland and Northern Ireland. Neither jurisdiction is directly involved in either exploration or mining activities. In Northern Ireland is administered by the Department for the Economy (DfE) who are advised and supported by the Geological Survey of Northern Ireland (British Geological Survey, 2016). Recently, there has been a burst of mining activity and resistance to it: five companies currently hold 10 mineral prospecting licences for different location across the country. Four companies have lodged applications for six mining licences (Macintosh, 2018). One of these companies is Canadian firm Dalradian which applied for permission to develop the mine near Greencastle in County Tyrone. Dalradian claims that the mine could tap into £3bn in gold and provide a £750m boost to the Northern Ireland economy (Dalradian, 2019). There is a general guidance document in Northern Ireland related to use of water in the quarry and aggregates industry (NIEA & QPANI, 2009).

Ireland

Ireland is internationally renowned as a major zinc-lead mining province. As of 2007, Ireland produced 38% of Western Europe’s zinc and 25% of its lead, from lead and zinc mines including Lisheen Mine, Tipperary, Tara Mine, Meath, and Galmoy Mine, Kilkenny. Over the last 50 years a number of significant base metal discoveries were made, including the giant ore deposit at Navan, Co. Meath. Other minerals being mined in Ireland are Gyspum in Co. Monaghan, Fireclay and Coal in Co. Laois and Marble in Co. Galway (DCCAE, 2019).

There are currently 6 State Mining Licences and 10 State Mining Leases in operation in Ireland. All mining for scheduled minerals requires either a Lease under the Minerals Development Act 1940 for minerals in State ownership, or a Licence under the 1979 Act for privately owned minerals, both are issued by the Minister of Communications, Climate Action & Environment (DCCAE, 2019). Minerals in these Acts do not include stone gravel sand and clay. A State Mining Permission can be issued for very small tonnages of State-owned minerals for limited periods of time. These three permits are collectively referred to as State Mining Facilities (SMF). Applicants must hold a valid Prospecting Licence or existing SMF over the area in question to commence mining. The application fee is charged as set out in S.I. No. 259 of 1996 - Minerals Development Regulations, 1996. Support information will vary with each application, therefore applicants are advised to consult with the Exploration and Mining division (DCCAE, 2019).

SMFs are negotiated on a case by case basis as required by Section 26 of the Minerals Development Act 1940, which also applies to Licences under the Minerals Development Act 1979 (see Section 17 of the 1979 Act). Conditions include adherence to best practice, ensuring full extraction of the minerals, prevention of subsidence, and proper rehabilitation of the mineral workings and financial terms including royalties. Compensation must be paid to private mineral owners where working such minerals is licensed under the 1979 Act (DCCAE, 2019).

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APPENDIX 1 – FINLAND

1) The Current regulations regarding mineral extraction runoff treatment in Finland

Mining activities in Finland are generally regulated by the mining law 621/2011 which came into force 1.7.2011 replacing the old law from 1965. Under the new regulations (2011) the processing and granting of mining permits is governed by the Finnish Safety and Chemicals Agency (Tukes).The mining law regulates the exploration and beneficiation of deposits containing mine minerals (specified in the law).

- The environmental issues of quarrying and crushing are regulated in a specific decree (800/2010).
- Water protection and usage of water regulations are provided in
  - Environmental and Water legislation (Environmental Protection Act 527/2014 and Environmental Protection Decree 713/2014;
  - Water act 587/2011;
  - Act on Water Resources Management 1299/2004;
  - Nature Conservation Act 1096/1996) and
  - decrees (e.g. Decree on Substances Dangerous and Harmful to the Aquatic Environment 1022/2006 and 868/2010).
- The solid wastes generated in mining and quarrying are covered in
  - Decree on Mining Wastes 190/2013;
  - Waste Act 646/2011 and Waste Decree 179/2012;
  - Decree on Landfills 331/2013.
- The safety issues of mining are covered by
  - the law on dam safety (494/2009),
  - the law on detonation and quarrying safety (644/2011),
  - decree on the handling and storage of hazardous chemicals (59/1999) and
  - the law on the handling safety of hazardous chemicals and explosives (390/2005).
- The legislation on explosives is mainly focusing on the safe handling and usage of explosives. Today the environmental aspects are still in minor role in explosive legislation but this is expected to change in the future.
- The emissions to air, the air quality, noise, and soil are mainly regulated in Environmental Protection Act (527/2014) and specific decrees (e.g. Decree on Air Quality 38/2011) given based on Environmental Protection Act.
- The REACH regulations touch the mining industry as a user of chemicals and as a producer of ores and enrichments. The minerals, ores and ore enrichments are not in the scope of REACH if they have not been chemically modified (Jermakka et al., 2015b).

Regulatory requirements for nutrients (phosphorus, nitrogen or both) removal and/or recovery from mineral extraction runoff

In the Council of State decision 1172/1999 on the protection of inland waters in order to protect living conditions of fish there are mandatory and indicative nitrogen limit values for so called salmon and roach waters.
The limit values are given for nitrite, unionised ammonia (NH_3), and total ammonium (NH_4). Direct limit values outside salmon and roach waters are not given in Finnish legislation. However, Finnish Environmental Protection Act (527/2014) states that any discharges that might have harmful environmental impacts are to be prevented or their impacts minimized using the best available technique.

The Council of State decision 366/1994 regulates the quality and monitoring of raw water used to produce potable water. The act gives limit values for nitrate, ammonium and total nitrogen for three water quality categories (A1, A2, A3) requiring different levels of water treatment. Furthermore, the decree 461/2000 (and its change 442/2014) relating to the quality and monitoring of water intended for human consumption gives limit values 50 mg/l and 11.0 mg/l for NO_3^{2-} and NO_3-N, respectively. The maximum allowed nitrite concentration for water leaving the water works is 0.10 mg/l and the sum [nitrate]/50 + [nitrite]/3 may not exceed value 1. For NH_3^{4+} and NH_4-N the values 0.50 mg/l and 0.40 mg/l are given as indicator parameters. The requirements follow mainly the ones given in European directive 98/83/EC on the quality of water intended for human consumption (Jermakka et al., 2015b).

Finally, The Council of State decision 342/2009 lists substances that could be harmful to groundwater quality, disallowing also the release of “agents of eutrophication (in particular nitrates and phosphates)” into groundwater reserves.