The closure of the Stekenjokk mine in Northern Sweden and 15 years of post-closure follow-up

Keywords: Mine Closure, tailings pond, water cover, reindeer, follow-up

Abstract:
The closed Stekenjokk mine in Northern Sweden serves as an important source of experience as it was closed 15 years ago to high biodiversity standards. The site location, in an environmentally sensitive area which also is of strategic importance for the Lappish reindeer breeding community, called for extraordinary measures and detailed follow-up. An important driving force for the closure planning were the excellent stakeholder relations that were maintained throughout the operational period of the mine.

The Stekenjokk mine is located above the tree limit at 800 m above sea level in the Lapland mountains in northern Sweden. The site location sets extreme requirements for management of biodiversity as it is located in the middle of an important Lappish reindeer breeding land and it is crossed by a salmon bearing creek. This was fortunately understood already at the time of planning the mine in the beginning of the 1970s, even though closure planning was not an integral part of the mine site development at the time. From 1976 to 1988 Boliden mined and processed a total of 8 Mton of the pyritic copper, zinc and silver ore. Practically all mining took place underground as cut-and-fill mining using the coarse fraction of the flotation tailings as back-fill material. The fine fraction of the pyrite rich tailings was deposited in a 110 ha tailings and clarification pond nearby the concentrator. In total 4.4 Mton of tailings were deposited until November 1988, when the operations ceased.

Prior to closure, the preparations for the decommissioning had started with the objectives to:

1) prevent the area from becoming a major source of ARD;
2) removal of facilities that could be hazardous to humans or wild life; and
3) adapting the area to the surrounding environment.

Apart from the tailings pond, the decommissioning work at the site included reclamation of small waste rock dumps originating from ramp drifting and over burden stripping, a small open pit and various surface installations.
Figure 1. A view of the Stekenjokk mine during operation (1976 until 1988). The mine is located in an environmentally sensitive area with also is a strategic area for the reindeer breathing Lappish community.

During the operation of the mine, the ecological balance of the sensitive surroundings had been maintained through a range of protective measures. A constant dialogue was maintained with the Lappish community and other stakeholders throughout the operational period, as well as during closure and after-closure. Potential ARD formation from the closed tailings pond was the primary environmental concern at closure, however, aspects related to reindeer keeping and visual impacts related to tourism have also been of high importance. The reclamation of the surface installations and the underground mine were relatively straightforward, however, several alternative methods for the reclamation of the tailings pond were studied, including flooding, dry covering, de-pyritisation and buffering. A careful evaluation of the alternatives favoured the flooding alternative, which was found safe, more efficient and by far the most cost effective method at the site. Dry covering, which was the only realistic alternative, would have implied trucking in enormous amounts of cover material from far away and would not have resulted in better discharge water quality. A hydrological investigation provided the basis for the final design of the water cover, assuring the performance of the water cover even in the case of the 1000 years drought. Geochemical tests and modelling showed the water cover would result in an acceptable discharge water quality and acceptable water quality in the receiving creek.

The closure work was initiated in the summer of 1990 and completed in summer 1992. All surface installations were removed, the open pit was flooded and the waste-rock was used for constructing break-waters in the tailings pond and
for improving the long-term stability of the downstream dam. All disturbed areas were re-vegetated with grass which turned out to be very attractive reindeer grazing areas. The tailings pond closure work included: lowering the water level to facilitate the work; raising the dams; moving 90 000 m$^3$ of tailings to deeper parts of the pond; construction of breakwaters in the shallow part of the dam; construction of a long-term stable spillway; and, finally, raising the water level (figure 2).

The effect of the decommissioning is closely followed up by means of a monitoring program, which initially focused on tailings pond effluent water flow and quality (figure 3), water level fluctuations, re-suspension of tailings and breakwater stability. Over time the follow-up has also come to include monitoring the success of the re-vegetation, dam safety issues and biological monitoring mainly focussed on the establishment of fish in the decommissioned tailings pond (figure 4).

Several research projects have also been carried out studying the effects of the water cover with respect to reduction in

Figure 2. Schematic figure of the performed closure of the Stekenjokk tailings pond.
sulphide oxidation rates. Initially the follow-up was planned to continue for a five year period after the raising of the water level in the pond, but has now continued for 15 years as has also the post-closure dialogue with the Lappish community and other stake holders. The reclaimed mine site is now an integrated part of the landscape, figure 5.

![Evolution of Zinc concentration in outlet (1992 - 2007)](image)

*Figure 3. The development of the zinc and sulphate concentration in the discharged water from the flooded Stekenjokk tailings pond.*
Figure 4. Results of fish inventory in the Stekenjokk tailings pond performed in year 2002. Char (Salvelinus Alpinus) has naturally established and are reproducing in the pond.

Figure 5. A view of the closed Stekenjokk mine.
Challenges & Lessons

The planning, construction, operation and closure of the Stekenjokk mine was performed long before International Guidelines on biodiversity or mine closure were commonly available. This meant developing and “retrofitting” a closure concept to the mine site that could be acceptable to stakeholders and the sensitive environment. Never the less, if the mine was to be planned today, the concept would probably not be very different. It has shown to be effective with respect to the set objectives and with respect to biodiversity issues. Main improvements that would be possible if the site was designed today would be:

- The design, building and closure of modern long-term stable dams according to ICOLD recommendations.
- Adding a thin diffusion barrier of inert material on top of the deposited tailings to further reduce sulphide oxidation rates and the release of weathering products to the water column in the short- and medium-term.
- To lead the creek through the flooded tailings pond instead of around it. This is an additional improvement that is still possible with only small modifications. This would significantly speed up the establishment of a sustainable ecosystem in the closed pond.
- Avoid the use of high sulphide waste-rock in the support fill of the downstream dam.

Over the years minor corrective measures have been necessary to ensure the performance of the closure. These include repeated re-vegetation efforts limited specific areas due to erosion and harsh climate, improving dam safety by increasing the discharge capacity and covering the downstream dam with moraine due to its unexpected content of sulphides.
Conclusions

Stekenjokk serves as an important source of knowledge and experience as it was closed to high standards 15 years ago. Stakeholder relations have been and continue to be excellent which has been important throughout the life-cycle of the mine and it has served as an important motivation for the closure works. Even though no formal ESIA was performed at the time of permitting the mine, nor at a later stage in time, stakeholder interests were always taken into account, which is especially true with regard to the final closure of the site and the opinions of the Lappish community. This has resulted in a closed mine site that is completely open for access and well integrated in the surrounding beautiful landscape. From a geochemical point of view the implemented closure measures have surpassed the objectives and all expectations. Follow-up and corrective measures have been ongoing for longer than anticipated originally, but it has resulted in a lot of experience gained which serves as a platform for future mine closures.

Annex:

Figure 1. A view of the Stekenjokk mine during operation (1976 until 1988). The mine is located in an environmentally sensitive area with also is a strategic area for the reindeer breathing Lappish community.
Figure 2. Schematic figure of the performed closure of the Stekenjokk tailings pond.
Figure 3. The development of the zinc and sulphate concentration in the discharged water form the flooded Stekenjokk tailings pond.
Figure 4. Results of fish inventory in the Stekenjokk tailings pond performed in year 2002. Char has naturally established and are reproducing in the pond.
Figure 5. A view of the closed Stekenjokk mine.