Environmental Impact of Mine Water from Chemical Extraction and Underground Uranium Mining – Straz pod Ralskem, Czech Republic

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Abstract
During the second half of the 20th century, there was large-scale exploration and production of uranium ores in the Czech Republic. The biggest uranium deposit area was found in the North-Bohemian Cretaceous area in the mid-1960s. During 30 years of production, approximately 30,000 tons of uranium concentrate was produced. More than 15,000 drill holes were drilled in the area and almost 11,000 of them were cased and used as production and monitoring (hydrogeological) wells. Both classical underground (room and pillar) mining and in situ leaching (ISL) methods were used in the area. A mill and two tailings impoundments were also constructed in the area. Sulphuric acid was used as leaching agent to process ore from both mining methods. More than 4 million tons of sulphuric acid was injected into the ground for the ISL method. This affected approximately 338 million m^3 of groundwater (limit 0,25 $g.l^{-1}$ SO_4^{2-}) over an area of more than 26 km^2. The adverse influence of these activities has yet to be mitigated.

Key words: uranium mining, in situ leaching, chemical extraction, groundwater contamination, Cretaceous basin, Czech Republic

Introduction

Czech Republic's uranium ore deposits are found in North Bohemia, in an area adjoining the towns of Mimon, Straz pod Ralskem, and Krizany, in the Liberec region. Uranium ore bodies within the Bohemian Cretaceous Basin were discovered while checking on an anomaly encountered at the HJ-1 borehole in 1963. A total of eight deposits were found but uranium ore was extracted at only three deposits: the Hamr pod Ralskem deposit (Mine Hamr I & Mine Hamr II), the Brevniste deposit (Krizany Mine), and the Straz pod Ralskem deposit (using chemical extraction). The uranium ore is found at the base of Cenomanian sandstones.

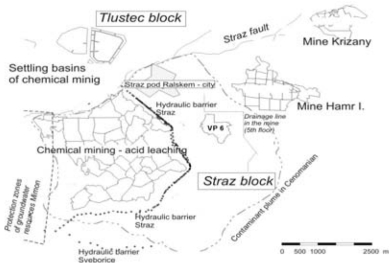
Two different methods were used to mine the uranium. Classical underground mining, which requires pumping the water out of the area to be mined, was used at Mine Hamr I and at Krizany Mine. In situ leaching (ISL) with diluted sulfuric acid, where effective pumping is contingent on the highest possible groundwater piezometric level, was applied at the chemical extraction mine. This gave rise to a hydraulic dipole: the piezometric level of the Cenomanian aquifer was more than 100 m higher at the ISL area than it was 2.5 km away at Mine Hamr I. The process solutions were leaking from the chemical extraction leaching sites towards the depression cone of Mine Hamr I. The Straz hydraulic barrier was built to mitigate the flow of the process solutions to Mine Hamr I. A piezometric divide came to be established in the Cenomanian aquifer between the two mine areas. A system of drainage ditches was created at the Hamr I Mine to hold the solutions that leaked out, with wells bored at an upward angle (from the 5th mine floor) to contain the escaped solutions. The coexistence of these two different exploitation techniques called for complicated engineering and hydraulic interventions and has had a serious impact on groundwater quality and the environment.

Geologic and Hydrogeologic Conditions

The territory belongs to the Bohemian Cretaceous Basin and, specifically, the Luzice area. The deposits at Straz pod Ralskem, Hamr pod Ralskem, and Brevniste are part of a tectonic unit known as the Straz block, representing Cretaceous strata reaching from the Cenomanian up to the Middle Turonian. The Straz block, extending over an area of 194 km^2, is bounded along its entire periphery by tectonic lines (Luzice fault to the NE, Straz fault to the NW, the Devil's Walls zone of neovolcanites to the SE, and the Hradcany fault to the SW). At its NW boundary the Straz fault separates the Straz block from another Cretaceous plate – the Tlustec block, featuring a subsidence of as much as 600 m against the Straz block. The overall thickness of the Cretaceous sediments is 140-300 m.

Within the Straz block, there are two basic groundwater aquifers with porous or porous-fractured permeability where nearly all groundwater flow and accumulation take place. These aquifers, the Middle Turonian and Cenomanian sandstones, are separated by an aquitard, the Lower Turonian formation (marlstones).

***Figure 1** Straz pod Ralskem – location of both chemical and classical underground uranium mining.*



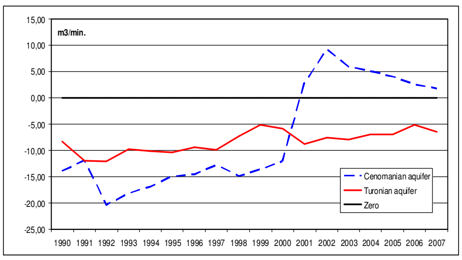
The Turonian Aquifer

The Turonian aquifer is linked to the Middle Turonian formation, a fine-grained to coarse-grained sandstone. Within the area of interest, the thickness of the Turonian aquifer is about 70 m. The Turonian aquifer has an unconfined groundwater level throughout the Straz block area. The aquifer is replenished across the entire area of interest by rainwater recharge. The general groundwater flow within the Turonian aquifer occurs from the NE to SW direction. The piezometric groundwater level in the Turonian aquifer ranges from 445 m above sea level in the NE section of the Straz block to 265 m above seal level in the SW section of the Straz block. The hydraulic conductivity of the Turonian aquifer is about 10^{-4} to 10^{-5} m.s^{-1}.

The Cenomanian Aquifer

The Cenomanian aquifer is linked to the Cenomanian marine sandstone formations, which contain low-permeability sandstones and other sediments of freshwater continental origin at its base. The thickness of the Cenomanian aquifer is approximately 70 m. The Lower Turonian aquitard, with a thickness of ca. 60 m, separates the Cenomanian and the Turonian aquifers. The recharge area of the Cenomanian aquifer is situated at the Luzice fault. The groundwater piezometric level around that location varies from ca. 305 to 320 m above sea level and the remote Labe river valley constitutes the main drainage area. The Cenomanian aquifer has a confined groundwater level in the area of interest. Before uranium mining was begun in the region, the natural direction of groundwater flow within the Cenomanian aquifer was from the NE to SW. Currently, the dominant direction of groundwater flow is toward the center of the depression cone being flooded at Mine Hamr I. The piezometric groundwater level of the Cenomanian aquifer in the ISL area is influenced by the implementation of remediation technologies. The hydraulic conductivity of the Cenomanian aquifer is about 10^{-5} to 10^{-6} m.s^{-1}.

***Figure 2** Balance of water pumping and injection in Cenomanian and Turonian aquifers 1990 - 2007.*



Minewater and Groundwater Management

Management of the water in the area of classical underground mining and chemical extraction of uranium in the northern part of the Bohemian Cretaceous Basin dates back to the mid-1960s and the early 1970s. The pumping, decontamination, and drainage of water in the area came to involve large volumes and affected the entire Straz block and its surroundings (both the Cenomanian and the Turonian aquifers). This paper will only discuss the hydraulic impact exerted on the Cenomanian and Turonian aquifers in the Straz block and its vicinity, caused by these mining and leaching activities.

Timeline of Important Events during the Development of the Hydraulic System at the Mine Hamr I (MH) and Brevniste Mine (Krizany Mine, MK) - Underground Mining

1965, April	Driving begun at the #9P Luzice mine shaft (failure to cope with water inrush; in April, 1966, the driving work was terminated and the shaft flooded - MH). Driving began at the #1 shaft (completed in 1968; provided access to the northern section of the Hamr pod Ralskem deposit - MH)
1966	Work started to drain the Cenomanian aquifer (MH)
1968	Driving begun at #2 shaft (completed 1970; provided additional access to the northern section of the Hamr pod Ralskem deposit - MH)
1971	Driving begun at #3 shaft in the western section of the Hamr pod Ralskem deposit (completed 1975; the main mining shaft of MH)
1972	Mining launched at the experimental Northern Block (MH)
1973, Jan.	Struck the Anezka tectonic zone draining the Cenomanian aquifer; emergency inrush of up to 150 $L.s^{-1}$; MH flooded
1973, Aug.	Driving begun at #4 shaft (completed in 1975 - MK)
1973, Sept.	Driving begun at #5 shaft (completed in 1976 - MK)
1973, Nov.	The Anezka tectonic zone sealed off at its contact with the gallery and pumping of #1 shaft resumed (MK)
1980	Driving begun at #6 and #7 shafts (completed in 1987, 1988 - MH)
1982	Driving of drainage ditches and draining wells begun at the #5 level of the mine (completed in 1987; pumped out the acidic process solutions escaped from chemical extraction)
1983	Driving begun at #13 shaft (completed in 1985; mine water pumping station built - MH); construction of a mine water treatment station was begun to treat the water prior to its discharge into the river (a central decontamination station, completed 1987); mining of panels begun at DK I
1984, May	Breakthrough occurred at MH; the Cenomanian and the Turonian aquifers became interconnected; surface subsidence 150 m from Hamersky Pond
1987	Decision taken to discontinue the development of MH; liquidation of MH ordered (in 1989, the #6 and #7 shafts were flooded)
1990, May	Exploitation terminated at MK
1990, Dec.	Pumping of mine water discontinued; flooding of MK begun
2001, April	Pumping stations at the #5 level of #13 shaft and at the #4 level of #3 shaft shut down; temporarily replaced by emergency pumping using wells at the #3 and #13 shafts (MH)
2001, Aug.	Pushing of alkali-treated water begun from the sedimentation basin to the NW section of MH
2003, May	All pumping of mine water from DH I terminated; the total volume pumped out of MH during the period from 1966 until 2003 was 435.55 million m^3
2003, Oct.	Pushing of water from the sedimentation basin to the north-west section of MH terminated; the total volume pushed in was 4.72 million m^3
2008 onwards	Flooding of the original depression cone at MH is in progress

Timeline of Events of Importance during the Development of the Hydraulic System at the Straz pod Ralskem Deposit (Chemical Extraction Mine CEM)

1966	The first leaching test was carried out using alkaline media at the Hamr pod Ralskem deposit; low enrichment obtained; subsequent leaching tests carried out using sulfuric acid (CEM)

1969	Leaching tests with sulfuric acid begun at the VP 6 leaching sites of the Hamr pod Ralskem deposit; the leaching solutions were leaking out into the depression cone of the #1 and #2 shafts of MH; extraction using the underground leaching method begun at the VP 4 leaching sites of the Straz pod Ralskem deposit
1977	Construction of the Straz hydraulic barrier begun; its operation did not become optimal until as late as 1985 (CEM)
1987	Construction of the Sveborice hydraulic barrier begun; completed in 1988
1993	Operations launched at the last section of leaching sites, VP26 (CEM); the total surface area of the CEM leaching sites reached 6.3 km^2
1996,	Liquidation of CEM declared
1996, June	The first distillate was discharged into Ploucnice river from the acid solutions treatment station (CEM); the stations provided a negative water balance at the Cenomanian aquifer, thus preventing the process solutions used in uranium extraction from penetrating an expanding area during the post-mining period
2008	Presently, in addition to the acid solution liquidation station, there is a neutralization and decontamination station in operation; the two stations combined provide a significant negative balance within the leaching sites of the Cenomanian aquifer

Conclusions

High-intensity drainage of the Hamr I and Krizany deep mines has generated a long-term negative water balance in the Cenomanian aquifer up to approximately -20 m^3 min^{-1}. Due to the proximity of chemical extraction fields, which required, to the contrary, the highest possible groundwater level to provide for higher-efficiency pumping, the difference in water levels amounted to more than 100 m over a distance of 2.5 km.

The hydraulic head between the chemical extraction mine on the one hand and Mine Hamr I on the other hand was also increased by the hydraulic barriers, which generated an artificial divide in the Cenomanian aquifer by pushing water into the line of wells and, thus, assisted in preventing leakage of the process solutions from chemical extraction into the Mine Hamr I area. The water balance of the Cenomanian aquifer only became positive during 2001, at which time pumping at Mine Hamr I was discontinued and flooding of the mine began. Here, the positive balance is caused by the action of the hydraulic barriers.

The hydraulic impact came to be felt not only in the Cenomanian aquifer where the uranium ore was located and mined, but also in the overlying Turonian aquifer. When driving the shafts for underground mining, it was necessary to forestall, by vigorous pumping, any inrush of water into the mine workings from the Turonian. The Turonian water was further used as process water for the part of the Straz and Sveborice hydraulic barrier which separated the different types of mining operations and for the preparation and remediation technologies. Secondarily, the chemical extraction operations also led to moderate groundwater contamination of the Turonian aquifer. In 2007, the Turonian aquifer experienced a negative water balance (–6.41 m^3 min^{-1}), mainly due to pumping of contaminated waters.

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