Dewatering of an underground uranium mine in Saskatchewan, Canada

Rashid Bashir[1], James Hatley[2]

[1]Senior Geotechnical Engineer, Golder Associates, 1721 8th Street East, Saskatoon, Saskatchewan, Canada S7H 0T4, rbashir@golder.com

[2]Director, McArthur River Extension, Major Projects Division, Cameco Corporation, North 48 Centre, 838 – 48th Street East Saskatoon Saskatchewan, Canada S7K 3Y4, james_hatley@cameco.com

Abstract

The Cigar Lake Project is an underground uranium mine under construction in Northern Saskatchewan, Canada. The test mining program at Cigar Lake Project demonstrated the effectiveness of artificial ground freezing to control water inflows. However an inflow event occurred on October 26th 2006 on the 465 level of an unfrozen section of the development. The inflow was hypothesized to be result of the of ground failure of a relatively thin (about 8 m) beam of weak, fractured rock exposed in the roof of the drift and being loaded from above by relatively high hydrostatic pressure (about 4.2 MPa). The mine was flooded as the result of the inflow event. This paper documents the various activities of remediating and dewatering the mine carried out over a three year period.

Keywords: uranium mining, Northern Saskatchewan, inflows, dewatering

Introduction

Athabasca Basin in Northern Saskatchewan, Canada, has been a prolific uranium production region since 1953. It has been estimated that more than 272,000 tonnes of uranium has been produced from the Athabasca Basin to date. The Cigar Lake deposit is located 40 km inside the margin of the eastern part of the Athabasca Basin. It is an unconformity related uranium deposit and occurs at the unconformity contact between rock of the Athabasca Group and underlying lower Proterozoic Wollaston Group metasedimentary rocks, an analogous setting to the Key Lake, McClean Lake, Collins Bay and McArthur River deposits.

Two primary challenges in mining the unconformity type deposits in Athabasca Basin are the control of groundwater and the ground support in areas of weak rock. These challenges occur concurrently in the immediate area of massive mineralization, in areas where the rock is fractured and faulted, and in the overlying sandstone. Artificial ground freezing of these areas to: (1) minimize the risk of water inflows into the mine from the water bearing rock above the unconformity, (2) provide a reduction the radiation exposure resulting from radon dissolved in the water, and (3) increase the stability of the rocks being mined.

The jet boring mining system (JBS), a non-entry mining method, has been selected to mine the Cigar Lake deposit. Jet boring mining consists of cutting the ore with a high pressure water jet using the JBS (Schmitke, 2004). The JBS mining units cut cavities of approximately 4.5 m diameter in the previously frozen ore from each set-up, producing approximately 230 t of ore for a typical 6.0 m ore thickness. Following mining, each cavity is backfilled with concrete.

On October 23, 2006, the Cigar Lake Project was flooded following a water inflow at 465 level (corresponding to the approximate depth below surface in metres). In response to the incident, Cameco developed and proceeded with its remediation plan to restore the underground workings. In 2008, the source of the October 2006 water inflow was sealed and the effectiveness of the seal was demonstrated via hydrogeological testing. Dewatering of the mine commenced in July 2008. It was suspended on August 12, 2008 when the rate of the inflow to the mine significantly increased when water level had been pumped down to 430 m below surface. Subsequent investigation indicated that the new source of the inflow is located in a tunnel on the 420 level. Another remediation effort was initiated and executed with installation of another seal on 420 level. Following the hydrogeological evaluation of the new seal, dewatering of the mine was completed in February 2010. This paper presents some of the pertinent hydrogeological information collected and analyzed as part of remediation and dewatering effort for the Cigar Lake Project.

Basic Hydrogeology

There are four major hydrostratigraphic units at the Cigar Lake Project including, from the stratigraphically highest to the lowest: post-glacial overburden, unaltered upper and lower sandstones, alteration in vicinity of orebody, and the basement rock. Each of these major units can be subdivide into further sub units, details of which are provided are in the following sections. Figure 1shows the horizontal hydraulic conductivity (K_h) values derived from the packer tests in the various coreholes drilled at the Cigar Lake Project. Assuming the ground-water system is essentially hydrostatic (i.e. no significant differences in hydraulic heads with depth) and the phreatic surface above the site is at a depth of about 20-30 m, the pore pressure at the unconformity at a depth of 448 is about 4.2 MPa.

The overburden consists primarily of till, which varies from 20 to 50 m thick within the vicinity of the Cigar Lake Project. Beneath a 1 to 2 m thick disturbed zone, the till is generally dense and compacted and is relatively impermeable. Groundwater levels in the overburden are controlled by the surface topography and elevations of the various surface-water bodies. As most of the underground workings are more than 420 m below the overburden, any inflow to the mine workings will not get any major contribution from the overburden.

The sandstone outside the ore zone is the typically unaltered Athabasca Sandstone, which is approximately 450 m thick. Based on the vertical distribution of the hydraulic conductivity values derived from the packer tests, the lower portion of the sandstone is generally more permeable than the upper portion (Figure 1). Therefore, the unaltered sandstone can be divided into upper and lower sandstones, with the latter more permeable. This is a rather unusual relationship of hydraulic conductivity with depth (the norm being a decrease with depth). A possible explanation this increase is that they are a result of the fluids that moved through them and above the unconformity as part of the ore-forming process. The hydraulic heads from various multi-level piezometers indicate that the hydraulic heads on the south side of the ore zone are generally higher than the hydraulic heads on the north side of the ore zone resulting in groundwater flow direction in the sandstone to be from south and southwest toward the northeast.

Highly altered sandstone and basement rock occur in the vicinity of the orebody. These alteration zones include i) altered basement, ii) extremely clay-altered sandstone, iii) altered sandstone, iv) fractured sandstone, and v) friable sandstone. Among these zones, the altered sandstone, fractured sandstone, and friable sandstone are considered to be more permeable than the unaltered sandstone.

The basement consists of pelites, graphitic pelites, augengneiss, and arkose units that are all less permeable than the sandstone. Most of the development at Cigar Lake Project is in basement rock and experience to date from Cigar Lake and other mines in the Basin indicates that basement rock is generally of low to very low permeability.

Mine Inflow of 2006

The test mining program at Cigar Lake Project demonstrated the effectiveness of artificial freezing to control water inflows. However, in the development area, to the south side of the orebody, it was decided that ground conditions were satisfactory and it was an acceptable risk to develop a portion of the 465 production level in unfrozen ground (Cigar Lake, 2007). It was in this unfrozen section of development that the October 2006 water inflow occurred.

The inflow event occurred on October 26th 2006 in the 465-944 drift on the 465 level of mine (Bashir and Hatley, 2010). The inflow event was hypothesized to be result of the of ground failure of a relatively thin (about 8 m) beam of weak, fractured rock exposed in the roof of the drift and being loaded from above by relatively high hydrostatic pressure (about 4.2 MPa). It is further hypothesized that the initial seepage through the incipient roof failure resulted in eroding the fracture infilling (clay and sand) resulting in further rock collapsing. The roof gradually and then catastrophically chimneyed, up into and above the unconformity where it enabled water from the extensive sandstone aquifer above the unconformity to flow in at a rate limited only by the permeability and thickness of the overlying aquifer.

According to various estimates the initial mine inflow rate was between 1000-1500 m^3/hr. At the time of the October 2006 ground fall, Cigar Lake had underground pumping capacity was in the order of 500 m^3/hr. Bulkhead doors to isolate various areas of the mine were an important part of the inflow management strategy. As the inflow rate exceeded the pumping capacity, attempts were made to close the bulkhead doors. Problems with a gasket on one of the doors restricted the ability of the door to provide a seal with little to no leakage. The underground workings were flooded as the result of the inflow event.

Remediation of 2006 Inflow

During the first phase of remediation a number of holes were drilled 465 m down from the surface to the underground workings. Some of these holes were drilled to the source of water inflow and others to nearby tunnels. A specially designed concrete mix was poured into these locations. Four additional holes were drilled to 500 level of the mine and were installed with borehole pumps to be used for dewatering the mine for the second phase of the remediation plan. This pumping system was used to assist with mine dewatering, and continue to be available for

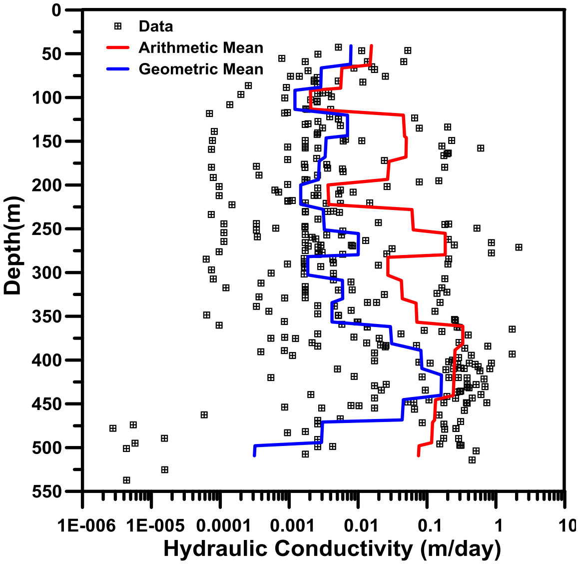

Figure 1 *Variation of hydraulic conductivity with depth.*

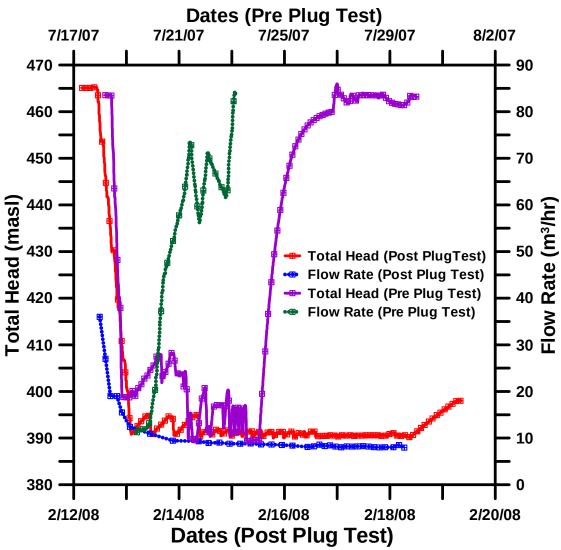

Figure 2 *Results from pre and post plug tests*

use for emergency dewatering during the remainder of construction and operations. Following the installation of the concrete plug from surface a drawdown test was performed to test the effectiveness of the plug. The water level was pumped 100 m below ground surface in shaft # 1. The water level was held constant at this level and inflow to the mine workings under the imposed head was estimated by measuring the volume of water that needs to be pumped out to maintain the water level. The estimated amount of inflow to the mine workings was compared to a similar drawdown test done prior to the installation of the concrete plug. Figure 2 shows that results from pre and post plug drawdown tests. From this figure it can be seen that the installation of plug resulted in reduction of inflow to the mine workings by almost 89% under the imposed head. Following the drawdown test, a decision was made to dewater the mine in increments.

Dewatering Attempt and Mine Inflow of 2008

The water from the mine workings was pumped out in increments with the water level held constant for a period of time at predetermined intervals. The water level was held at these predetermined intervals to estimate the amount of inflow as the head on the workings was increased and to provide enough time for the excess pore pressure to dissipate. The rate for dewatering the mine (the rate at which head was applied to mine workings/rate at which water level was lowered) was decided after a detailed geotechnical stability study by a third party geotechnical expert. Figure 3 shows the inflow rates estimated during the dewatering attempt. The projected inflow to mine workings under fully dewatered conditions was slightly in excess of the pre inflow value.

The dewatering attempt was suspended on August 12, 2008 when the rate of the inflow to the mine significantly increased when the water level as held constant at 430 m below surface. Figure 4 shows the shaft water level rise in the shaft # 1 and the associated calculated inflow rates to the mine workings. The inflow rate was calculated by the summation of pump rates and volume of water required to raise the water level in the shaft # 1. In Figure 4 it can be observed that estimation of flow rate in this manner results in reduced inflow estimates as the 410 and 210 levels were reflooded. Fairly accurate estimates of the underground mine volumes at 210 and 420 levels were available. Taking into consideration the additional amount of inflow required to fill the underground levels resulted in estimates that indicated that the as the water level rises to the 420 level the inflow rate increased from approximately 400 m^3/hr to approximately 1320 m^3/hr. This fourfold increase in inflow rate was found to be anomalous as post 420 level flooding inflow rate was approximately 600 m^3/hr. The fourfold increase in inflow at the start of the 420 level flooding and then its reduction post flooding was not supported by the piezometer data recorded close to the mine workings.

Figure 5 provides a time line of the inflow event, the time of flooding of 420 and 210 levels are clearly marked. A close look at the multi-level piezometers readings indicates that, at the onset of the inflow a response can be observed before any increased inflow was observed in the shaft # 1. However, if the inflow rate would have suddenly increased fourfold at the time when water level reached 420 level, a sudden change in piezometer readings should have been observed. The piezometer readings neither support an increase in flow rate at the start of the 420 level flooding nor inflow rate reduction post 420 level flooding.

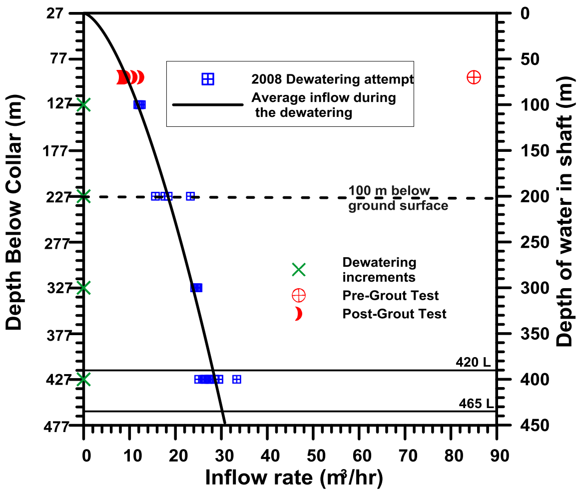

Figure 3 *Flow rates for the 2008 dewatering.*

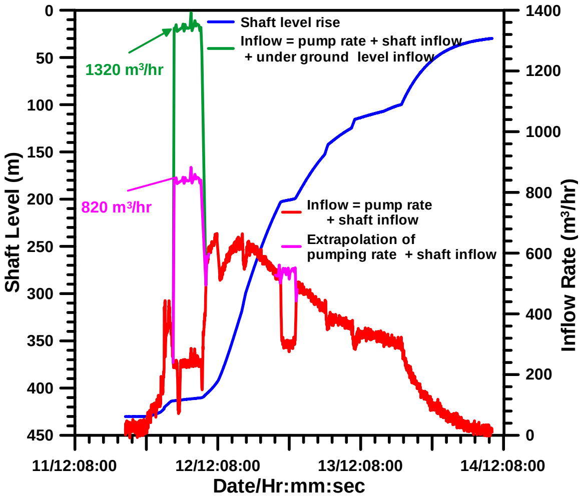

Figure 4 *Shaft water levls and flow rates for 2008 inflow*

Figure 6 shows the inflow rate calculated as the summation of the pumping rate and volume required to raise the water level in the shaft as a function of shaft water level. Extrapolating the inflow data by fitting a 2nd degree polynomial (coefficient of determination R^2 of 0.99), it was estimated that the water inflow rate could potentially be approximately 820 m^3/hr when the shaft # 1 water level was drawn to 430 m level. Two 20m drawdown tests conducted post the 2008 inflow event are also shown in the same figure and plot directly over the data collected during the inflow event. The extrapolated inflow rate is also plotted in Figure 4 and it can be observed that even this increase of inflow rate during the

420 level flooding seems unlikely when piezometer readings from Figure 5 are taken in to consideration. Therefore it was hypothesized that the inflow rate during the inflow event was in the range of 660 to 820 m³/hr.

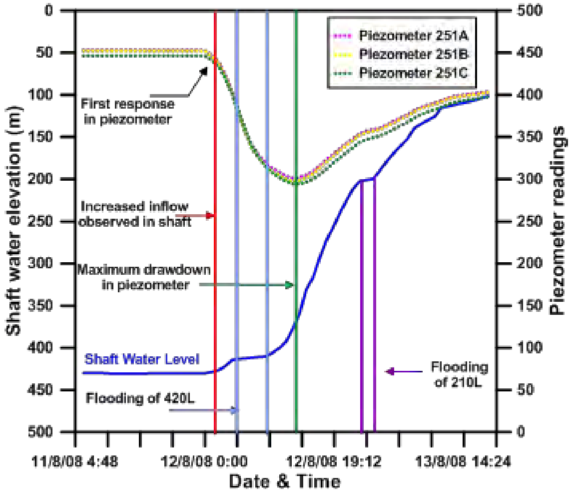

Figure 5 *Timeline for 2008 inflow event*

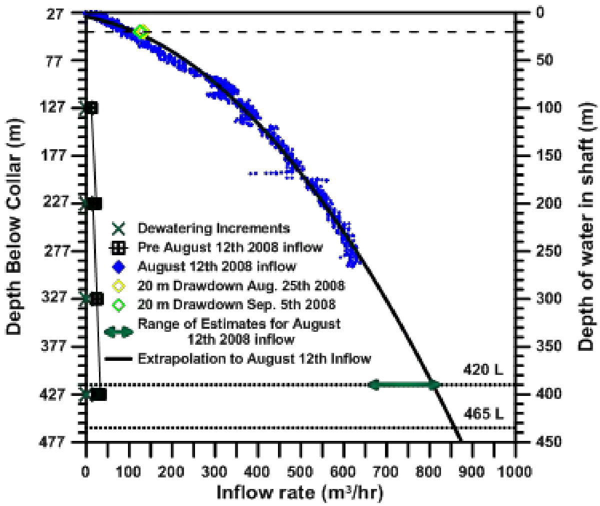

Figure 6 *Extrapolation of the 2008 inflow data*

If the complete volume of 420 level is considered for inflow calculations, the anomalous flow rates were assumed to be related to the possible entrapment of air within the 420 level workings or that much or all of the inflow event occurred into 420 level. This would also imply that there is a possibility of debris dams within this level.

Final Dewatering of the Mine

Unlike the 2006 inflow, the location or cause of the August 2008 inflow was not immediately known. As part of the assessment, drawdown tests at staged intervals were carried out. Submersible remotely operated vehicles (ROVs) were used to conduct visual inspections of water flows and temperature changes inside the mine during draw-down tests to track down the inflow source. The source of inflow was identified as a fissure located in a tunnel on the 420 m level. The 420 m level was developed in sandstone in the early stages of the project to assess the practicality of developing a working level above the orebody. Further development on the 420 m level proved not to be feasible due to poor ground conditions. A phased recovery plan to seal the 420 m level and remediate the shaft workings was developed. Using ROVs, access to the inflow area was secured by dredging sediment and removing equipment. A bulkhead was placed in the tunnel where the inflow occurred using a specially designed high strength bag that was positioned using ROVs and then filled with grout pumped from the surface to block the tunnel (Figure 7). Once the bag was fully inflated, concrete was pumped through drill holes from surface to backfill the development behind the seal with concrete and grout.

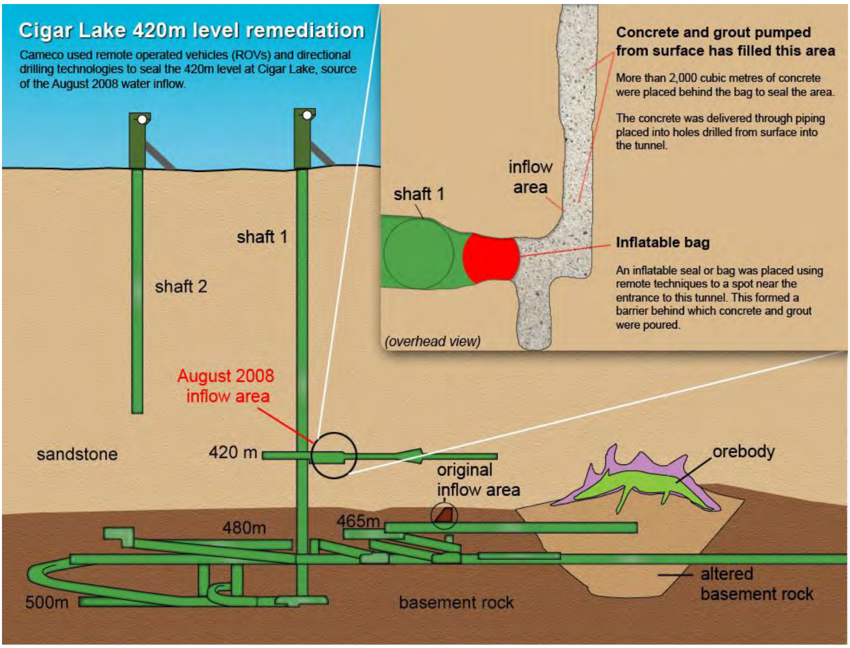

Figure 7 Cigar Lake remediation plan - August 2008 water inflow

Following the installation of the plug, drawdown tests were conducted to estimate the amount of inflow to the mine workings. The water level in the shaft # 1 was drawn down by 20 m and held constant over a period of time. The inflow rates were determined by estimating the volume of the water that needed to be pumped out to maintain the water level constant in the shaft. A comparison of the inflow rates from these tests with tests performed before the installation of plug are shown in Figure 8, this indicates an order of magnitude decrease in inflow rates for a drawdown of 20 m.

Consistent with the previous dewatering attempt the water from the mine workings was pumped out in increments with the water level held constant at for a period of time at predetermined intervals. The inflow rate at each of these predetermined intervals is shown in Figure 8 along with the results from 2008 dewatering. It can be observed inflow rates from the current attempt match closely to the previous attempt before the development of inflow at 420 level. The mine was successfully dewatered.

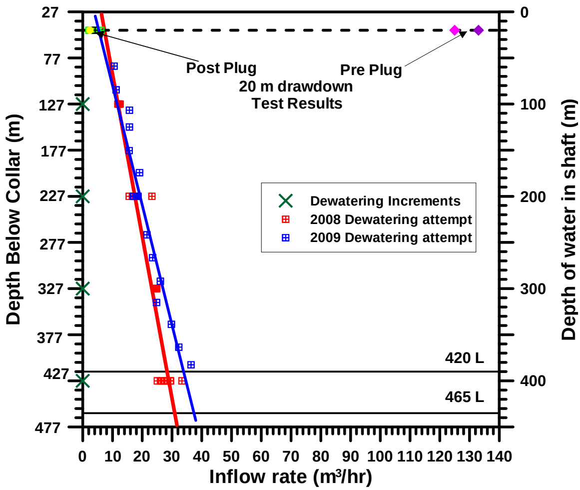

***Figure 8** Data for 2008 inflow remediation and 2009-2010 dewatering*

Concluding Remarks

In February 2010, dewatering of the underground development was completed. Crews re-entered the main working level of the mine at 480 m below surface from where access to the 2006 inflow was obtained. Following the restoration of underground mine systems and infrastructure, underground construction activities have progressed. A number of changes have been made to the mine plan. These include expanded ground freezing and the elimination of the entire 465 m production level, amongst many improvements in design and strategy. Cameco has implemented enhanced procedural controls and technical risk assessments for mine development to reduce the risk of any future inflows. Cameco has fundamentally changed its water management strategy. The use of water bulkhead doors was eliminated. Cameco has installed pumping capacity of 1,550 m^3/hr and plans to increase it to 2,500 m^3/hr (Cameco 2010). The existing installed capacity is sufficient to handle volumes greater than either of the previous two inflows. Expansions in water treatment and surface storage capacity have also been made and provide for an enhanced water management system.

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