Performance evaluation of reclamation soil cover systems at Cluff Lake mine in northern Saskatchewan

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Abstract

Cluff Lake uranium mine, owned and operated by AREVA Resources Canada Inc., is located in northern Saskatchewan’s Athabasca Basin. Cluff Lake mine operated from 1980 to 2002, and decommissioning work began in 2004 following an environmental assessment. Decommissioning of Cluff Lake mine included construction of reclamation cover systems over a tailings storage facility and waste rock pile. The objective of this paper is to review the design, construction, and performance of the cover systems based on field monitoring data. The primary design objectives of the cover systems are to reduce percolation of meteoric water into the waste, attenuate radiation emanating from stored waste to acceptable levels, and provide a growth medium for development of a sustainable vegetation cover. The waste rock cover system is an enhanced water store-and-release design, while the tailings cover system is a water store-and-release design. Both cover systems, which were completed in 2006 and seeded with agronomic and native plant species, incorporate positive drainage to promote runoff during wet precipitation conditions. Instrumentation was installed during construction of the cover systems to facilitate evaluation of their hydrologic performance over time under site-specific climate conditions. Field data have been collected and analysed since 2006, for a total of eight full years of monitoring. The cover systems are performing as expected and are on a trajectory to design net percolation rates and sustainable vegetation cover. Soil-plant-atmosphere numerical modelling is planned to facilitate further understanding of the current and long-term performance of the cover systems at Cluff Lake.

1  Introduction

Cluff Lake uranium mine, owned and operated by AREVA Resources Canada Inc. (AREVA), is located in northern Saskatchewan’s Athabasca basin, approximately 75 km south of Lake Athabasca and 15 km east of the provincial border with Alberta. The mine operated from 1980 to 2002, and decommissioning work began in 2004 following an Environmental Assessment. The majority of decommissioning work was complete by the end of 2006. The project is now in the post-decommissioning and follow-up monitoring stage. AREVA has demolished the last buildings on site including the camp, airstrip facilities, and warehouse. AREVA is continuing its environmental monitoring program through four site visits per year.

Decommissioning of Cluff Lake mine included placement of a cover system over a waste rock pile (WRP) known as Claude WRP, and a tailings management area (TMA). The cover systems were completed in 2006, and monitoring of performance has been on-going since then. This paper reviews the design and construction of the cover systems for reclamation of the Claude WRP and TMA, and focuses on hydrologic performance of the cover systems based on eight full years of field monitoring data.

2  Background

The Cluff Lake mine site is situated in a region with a mean annual precipitation and potential evaporation of approximately 450 mm and 600 mm, respectively. Approximately 30% of annual precipitation occurs as snow. Numerous lakes, swamps and rivers dominate the relatively flat topography of the region.
The Claude WRP was constructed between 1982 and 1989 and contains waste rock from the Claude pit. The WRP is approximately 30 m high and covers an area of 26.4 hectares to the south of the Claude pit (Figure 1). It contains approximately 7.23 million tonnes of waste, with an estimated volume of approximately 4.1 Mm$^3$ based on a dry density of 1,750 kg/m$^3$. The Claude WRP was developed by end-dumping and contains well-developed traffic surfaces between lifts of dumped material. No attempt was made to segregate waste placed in the Claude WRP by chemical composition. The Claude WRP has shown high levels of uranium (200 mg/L) and nickel (43 mg/L) in piezometers around the toe of the pile (COGEMA, 2001). The high levels of uranium and nickel indicate that acid mine drainage is occurring and will continue to occur until the source is depleted. The occurrence of acid mine drainage was confirmed and quantified through a detailed waste rock characterisation program completed in 1999. AREVA determined that the Claude WRP would be decommissioned in-place, meaning that an engineered cover system would be required for closure.

Figure 1 Aerial photo of the Claude waste rock pile after cover system construction

The TMA contains tailings leftover from milling operations throughout the life of the mine (COGEMA, 2001). The TMA contains approximately 2.67 Mm$^3$ of tailings, and was comprised of four major components: a solids containment area, water decantation area, water treatment facilities and settling ponds, and diversion ditches. The containment and decantation areas were located in a topographic low, and tailings solids and liquids were retained behind a main dam. Thickened tailings were pumped to solids ponds where consolidation and liquid decantation occurred. Liquids then collected in the decant area where further solids were settled out. Liquids from the decant area, as well as tailings thickeners and pumped water from the pits were then fed through treatment facilities. Settling ponds allowed further settling of precipitates, after which treated water was fed to another treatment facility. Treated water was then pumped to a final settling pond prior to discharge into the environment. Monitoring wells adjacent to the main dam have shown that mean concentrations of U, Cl, Ra-226, and SO$_4$ have stabilised (CNSC, 2003). AREVA determined that the TMA would be decommissioned in-place, meaning that an engineered cover system would be required for closure.

3 Cover system design and construction

3.1 Claude waste rock pile cover system

Cover system field trials, known as test plots, were constructed and instrumented in 2001 on the Claude WRP to examine construction feasibility and hydrologic behaviour of the preferred cover system design alternative. One test plot (TP#1) was constructed on a relatively horizontal surface, while a second (TP#2) was constructed on a 4H:1V sloped surface. Both test covers had the same profile design, consisting of a nominally 10 cm thick reduced permeability layer (RPL) overlain by a nominally 100 cm thick layer of local silty-sand till. The RPL comprised weathered waste rock material compacted in situ. Field compaction trials
were completed in advance to determine the preferred techniques for RPL construction. Field data collected over a 5-year period included in situ volumetric water content (automated and manual measurements), matric suction (negative pore-water pressure), and temperature of the cover system and waste materials. These data were interpreted and used to develop estimates of net percolation through the cover systems into the underlying waste. The collected field data were used to aid in calibration of a soil-plant-atmosphere (SPA) numerical model as part of the cover system design process for full-scale WRP decommissioning.

Based on the success of the cover system field trials, an enhanced store-and-release cover system was selected as the preferred design for closure of the Claude WRP. The final design included a 20 cm thick layer of compacted waste rock overlain by 100 cm of non-compacted silty-sand till with a grass and legume vegetation cover. The primary design objectives of the cover system were to:

1. Reduce percolation of meteoric waters to attenuate peak concentrations of contaminants of concern in natural watercourses to levels that can be assimilated without adverse effects to the aquatic ecosystem.
2. Attenuate radiation emanating from stored waste to acceptable levels.
3. Provide a growth medium for development of a sustainable vegetation cover.

Decommissioning of the Claude WRP was completed between 2005 and 2006 and involved the following primary work activities:

- Re-contouring the side-slopes to a maximum slope angle of 4H:1V.
- Compacting the WRP surface to meet density specifications over a minimum depth of 0.2 m.
- Placing nominally 1 m of local silty-sand till material over the compacted waste rock surface.
- Constructing surface water drainage channels to handle the 24-hour, 100-year design storm event.
- Applying re-vegetation seed and fertilizer mixture with a drill seeder.

Compaction of the waste rock surface was accomplished using a Caterpillar CS583 roller (AREVA, 2007). Generally, two passes were required to meet the required minimum dry density of 95% of Standard Proctor Maximum Dry Density. Due to the unseasonably wet weather encountered during the waste rock compaction effort, water conditioning was not required to achieve the specified density. In general, the majority of the re-graded waste rock surface contained sufficient finer-textured materials to produce a relatively smooth surface (Figure 2). Areas of the WRP that were visually determined to have too much void space were re-graded to blend in additional fines with either waste rock or till and re-compacted. The estimated field saturated hydraulic conductivity of the compacted waste rock layer was $10^{-5}$ to $10^{-6}$ cm/s.

Figure 2  Photo of the re-graded Claude WRP being compacted in 2005 prior to till cover system placement
Instrumentation was installed in August 2006 to enable monitoring the hydrologic performance of the Claude WRP cover system over time under site-specific climate conditions. Field data being collected on the cover system include precipitation, net radiation, runoff, and volumetric water content, matric suction, and temperature of the cover system and upper waste rock materials (Figure 3). Monitoring stations were located at various slope positions and aspects due to potential differences in cover system performance at these different locations. Also, the monitoring system was automated to the extent possible to avoid missing collection of field response data during key times of the year, such as during spring snowmelt and storm events.

Figure 3  Performance monitoring instrumentation installed on the Claude WRP cover system (from OKC, 2006)

3.2  Tailings management area cover system

A cover system test plot was constructed and instrumented in the fall of 1999 on the TMA to examine construction feasibility and hydrologic behaviour of the preferred cover system design alternative. One test plot consisting of a 1.5 m thick layer of sandy-till was constructed over a relatively horizontal surface in a coarse tailings area. Several instruments were installed at the time of construction to collect data at the soil-atmosphere interface and within the unsaturated and saturated zones at the test cover system site. The collected field data were used to aid in calibration of a soil-plant-atmosphere (SPA) numerical model as part of the cover system design process for full-scale TMA decommissioning.

A store-and-release cover system was selected as the preferred design for closure of the TMA, based on the success of the cover system field trial. The final design of the TMA soil cover system consisted of a nominally 100 cm thick layer of non-compact ed, silty-sand till with a grass and legume vegetation cover (Figure 4). The
primary design objectives of the cover system are the same as the design objectives for the Claude WRP cover system.

**Figure 4  Aerial photo of the TMA after cover system construction**

Decommissioning of the TMA was completed in 2006 and involved the following primary work activities:

- Re-contouring of the tailings surface to provide positive drainage and promote runoff.
- Placing nominally 1 m of local silty-sand till material over the tailings surface.
- Infilling the liquids pond with local till material.
- Constructing surface water drainage channels to handle the 24-hour, 100-year design storm event.
- Buttressing the main dam structure to ensure long-term stability.
- Applying revegetation seed and fertilizer mixture with a drill seeder.
Gamma radiation measurements were completed following WRP and TMA cover system construction to confirm gamma radiation emanating from the stored waste materials were below maximum dose criteria. Instrumentation was installed in August 2006 to enable monitoring the hydrologic performance of the TMA cover system over time under site-specific climate conditions (Figure 5). Field data being collected on the cover system include precipitation, air temperature, relative humidity, wind speed and direction, net radiation, as well as volumetric water content, matric suction, and temperature of the cover system and upper tailings. In addition, groundwater level data at two wells (CN1000G and CS1100G) are collected.

4 Monitoring program results

Performance of cover systems is reflected primarily in estimated net percolation rates and in qualitative assessment of vegetation growth. Water balances are a tool to determine net percolation rates that use field measured, calculated, or residual data as inputs to solve the water balance equation (1) on a daily basis during frost-free periods. In this way, the water dynamics of the cover system can be characterised.

\[
PPT = R + AET + NP + \Delta S + LD
\]

Where:

- **PPT** = precipitation (rainfall plus snow water equivalent (SWE)),
- **R** = runoff and sublimation,
- **AET** = actual evapotranspiration,
NP = net percolation,  
ΔS = change in water storage, and
LD = lateral drainage.

Daily water balances for monitoring locations on the cover systems were estimated during frost-free periods (Tables 1 through 4). The period of April 1st to October 31st was used as the frost-free period for the purposes of this analysis.

### Table 1  Annual water balance fluxes for the plateau area of the Claude WRP from April to October (from OKC, 2015a)

<table>
<thead>
<tr>
<th>Year</th>
<th>PPT (mm)</th>
<th>AET</th>
<th>ΔS</th>
<th>R</th>
<th>NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>450</td>
<td>231</td>
<td>34</td>
<td>6</td>
<td>179</td>
</tr>
<tr>
<td>2008</td>
<td>272</td>
<td>297</td>
<td>-96</td>
<td>6</td>
<td>66</td>
</tr>
<tr>
<td>2009</td>
<td>387</td>
<td>290</td>
<td>31</td>
<td>5</td>
<td>61</td>
</tr>
<tr>
<td>2010</td>
<td>358</td>
<td>303</td>
<td>12</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>2011</td>
<td>271</td>
<td>182</td>
<td>9</td>
<td>2</td>
<td>58</td>
</tr>
<tr>
<td>2012</td>
<td>430</td>
<td>317</td>
<td>33</td>
<td>5</td>
<td>105</td>
</tr>
<tr>
<td>2013</td>
<td>408</td>
<td>255</td>
<td>-4</td>
<td>40</td>
<td>67</td>
</tr>
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</table>

### Table 2  Annual water balance fluxes for the sloping areas of the Claude WRP from April to October (from OKC, 2015a)

<table>
<thead>
<tr>
<th>Year</th>
<th>PPT (mm)</th>
<th>AET</th>
<th>ΔS</th>
<th>R</th>
<th>LD</th>
<th>NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>419</td>
<td>239</td>
<td>17</td>
<td>58</td>
<td>0</td>
<td>104</td>
</tr>
<tr>
<td>2008</td>
<td>261</td>
<td>308</td>
<td>-85</td>
<td>50</td>
<td>-57</td>
<td>45</td>
</tr>
<tr>
<td>2009</td>
<td>396</td>
<td>314</td>
<td>15</td>
<td>41</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>2010</td>
<td>371</td>
<td>320</td>
<td>4</td>
<td>22</td>
<td>-21</td>
<td>46</td>
</tr>
<tr>
<td>2011</td>
<td>295</td>
<td>231</td>
<td>3</td>
<td>19</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td>2012*</td>
<td>422</td>
<td>310</td>
<td>51</td>
<td>24</td>
<td>0</td>
<td>92</td>
</tr>
<tr>
<td>2013</td>
<td>482*</td>
<td>247</td>
<td>12</td>
<td>113</td>
<td>0</td>
<td>68</td>
</tr>
</tbody>
</table>

*Upslope data only.

### Table 3  Annual water balance fluxes for CN1000L station at the TMA cover system from April to October (from OKC, 2015b)

<table>
<thead>
<tr>
<th>Year</th>
<th>PPT (mm)</th>
<th>AET</th>
<th>ΔS</th>
<th>R</th>
<th>LD</th>
<th>NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>449</td>
<td>317</td>
<td>67</td>
<td>25</td>
<td>0</td>
<td>39</td>
</tr>
</tbody>
</table>
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Table 4  Annual water balance fluxes for CS1100L station at the TMA cover system from April to October (from OKC, 2015b)

<table>
<thead>
<tr>
<th>Year</th>
<th>PPT (mm)</th>
<th>AET Water balance fluxes (mm and % of PPT)</th>
<th>Δ S</th>
<th>R</th>
<th>LD</th>
<th>NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>449</td>
<td>266 (59%) 100 (22%) 25 (6%) 0 (0%) 58 (13%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>226</td>
<td>265 (117%) -76 (-34%) 20 (9%) 0 (0%) 17 (8%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>408</td>
<td>299 (73%) 18 (5%) 45 (11%) 0 (0%) 46 (11%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>355</td>
<td>269 (76%) 19 (5%) 31 (9%) 0 (0%) 34 (10%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>351</td>
<td>101 (42%) 68 (29%) 47 (13%) 0 (0%) 22 (9%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>464</td>
<td>294 (63%) 13 (3%) 53 (11%) 0 (0%) 105 (23%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>434</td>
<td>273 (63%) 0 (0%) 64 (15%) 0 (0%) 44 (10%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thermal conductivity (TC) sensors are used to monitor temperatures in the Claude WRP cover system and upper waste rock profiles, and in the TMA cover system and upper tailings profiles. Freeze-thaw cycles in the cover profile are important when interpreting runoff data for the water balance, and understanding when net percolation can be expected throughout the year. The timing and rate of freezing and thawing of a cover system profile in the fall and spring depends on several factors including snow cover accumulation, ambient temperatures, and soil water content. The cover system profiles at the Claude WRP and TMA generally begin to freeze around the end of October or early November, while thaw typically occurs in April or May. Delayed thaw of a cover system surface impedes infiltration into the profile, increasing runoff volumes and increasing performance of the cover system via reduced net percolation. Net percolation through the Claude WRP and TMA cover systems generally occurs in May following thaw of the cover profile, in the summer following intense rainfall events, and in the fall following large storm events and lower rates of evapotranspiration.

The timing of the precipitation can be of consequence to the amount of net percolation. If storm events occur in September and October when evapotranspiration is no longer able to remove stored water from the cover system, greater than expected net percolation can occur. In addition, if the entire soil profile does not completely freeze or freezing is delayed, the water at the base of the cover system can continue to percolate into the underlying waste, further causing conditions for higher net percolation.

Performance of cover systems will evolve over time in response to site-specific physical, chemical, and biological processes (INAP, 2003). Substantial growth of the various grass and legume species has occurred between August 2007 and August 2014 on the Claude WRP cover system (Figure 6) and the TMA cover system (Figure 7), with only minor observed erosion. A mature vegetation cover contributes to lower net percolation volumes through increased interception and transpiration rates, and will also serve to inhibit erosion.
Figure 6  Photos illustrating evolution of vegetation on the Claude WRP cover system
Figure 7 Photos illustrating evolution of vegetation on the TMA cover system

Net percolation has averaged 22% and 16% for the top and sloping areas of the WRP respectively, and 12% for both the CS1100L and CN1000L stations at the TMA since construction of the cover systems in 2006 (Figure 8). In general, the cover systems appear to be performing as designed and net percolation rates will likely continue to improve with evolution of the vegetation cover. Variability in net percolation as a percentage of precipitation occurred during the eight years of monitoring, which is to be expected in response to normal cycles in the local climate. General trends in performance of cover systems cannot be inferred from a single year of monitoring data; it is only when examining net percolation over the long term and in the overall context of normal climate variability that trends in performance can be determined. Natural climatic variability is to be expected and was accounted for during design of the Claude WRP and TMA cover systems.

5 Conclusions

The Claude WRP and TMA cover systems are stable landforms supporting the growth of productive native plant species and attenuating radiation emanating from stored waste material to acceptable levels. Net percolation rates generally reflect expected performance of the cover systems, which will likely continue to improve with vegetation cover evolution. The performance of these cover systems underlines the importance of maintaining a long-term perspective when evaluating cover system performance in terms of reducing the net percolation of meteoric waters. Field monitoring data are currently being used to calibrate a soil-plant-atmosphere model of the cover systems, which will be used to develop a higher level of confidence in the estimated long-term performance of the cover systems.
Figure 8  Annual net percolation rates (%) for the WRP and TMA cover systems since construction

Bibliography