PERFORMANCE OF AN ENGINEERED COVER SYSTEM FOR A URANIUM MINE WASTE ROCK PILE IN NORTHERN SASKATCHEWAN AFTER SIX YEARS

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ABSTRACT

The Claude waste rock pile at Cluff Lake uranium mine in northern Saskatchewan's Athabasca basin contains ~7.2 million tonnes of waste rock, upon which an engineered enhanced store-and-release cover system was constructed. The primary design objectives of the cover system are to reduce percolation of meteoric waters into the waste rock pile, attenuate radiation emanating from stored waste to acceptable levels, and provide a growth medium for development of a sustainable vegetation cover. Instrumentation was installed during construction of the cover system to evaluate cover performance under site-specific climate conditions. Field data collected was input to water balances to quantify the volume of net percolation that occurred during the frost-free periods of 2007 to 2012. Based upon these water balances, the Claude waste rock pile cover system is performing as designed based on field monitoring data and observations collected since 2007.

Key Words: field performance monitoring, water balance, net percolation

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 is planning to demolish the last buildings on-site including the existing camp, airstrip facilities, and warehouse in 2013 and 2014. AREVA is awaiting regulatory approval to continue its environmental monitoring program through four site visits per year.

Decommissioning of Cluff Lake mine included placement of a multi-layer cover system over a waste rock pile (WRP) known as Claude WRP. The cover system was completed in 2006, and monitoring of its performance has been on-going since then. This paper reviews the design and construction of the cover system for reclamation of the Claude WRP, and focuses on hydrologic performance of the cover system based on six years of field monitoring data.

BACKGROUND

The Cluff Lake site is situated in a semi-arid environment; the mean annual precipitation and potential evaporation for the region is approximately 450 mm and 600 mm, respectively. Approximately 30% of the 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 pile is approximately 30 m high and covers an area of 26.4 hectares to the south of the Claude pit (see 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.

Figure 1 Photo of the Claude waste rock pile in about 2003 prior to pile re-grading and cover system construction (Claude pit being backfilled in the foreground).

The pile 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). This indicates that acid mine drainage is occurring and will continue to occur until the source is depleted. This finding was confirmed and quantified through a detailed waste rock characterization 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.

COVER SYSTEM DESIGN AND CONSTRUCTION

Cover system field trials (test plots) were constructed and instrumented in 2001 on the Claude WRP to examine the 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 10 cm thick (nominal) reduced permeability layer (RPL) overlain by a 100 cm thick (nominal) layer of local silty-sand till. The RPL comprised weathered waste rock material that was compacted *in situ*; field compaction trials were completed in advance to determine the preferred techniques for RPL construction. Field data were collected and interpreted over a 5-year period including net percolation rates, *in situ* volumetric water content (automated and manual measurements), matric suction (negative pore-water pressure), and temperature of the cover and waste materials. 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 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 (nominal) layer of compacted waste rock overlain by 100 cm (nominal) of non-compacted silty-sand till with a grass and legume vegetation cover. The primary design objectives of the cover system are to:

1. reduce percolation of meteoric waters to attenuate peak concentrations for 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; and
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 1 m (nominal) 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; and
- Applying revegetation seed and fertilizer mixture (a drill seeder as opposed to a hydroseeder was used to minimize erosion of grass seeds and maximize availability of fertilizer to the seeds).

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, moisture conditioning was not required to achieve the specified density. In general, the majority of the re-graded waste rock surface contained sufficient fine-textured materials to produce a relatively smooth surface (see Figure 2). Areas of the WRP that were visually determined to be too open-graded 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 is 10^{-5} to 10^{-6} cm/s.

Figure 2 Photo of the re-graded Claude WRP being compacted in 2005 prior to till cover placement.

Instrumentation was installed in August 2006 to enable monitoring of 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 and upper waste rock materials. Figure 3 shows a layout of the instrumentation installed on the Claude WRP cover system. 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 (e.g. during spring snowmelt and storm events).

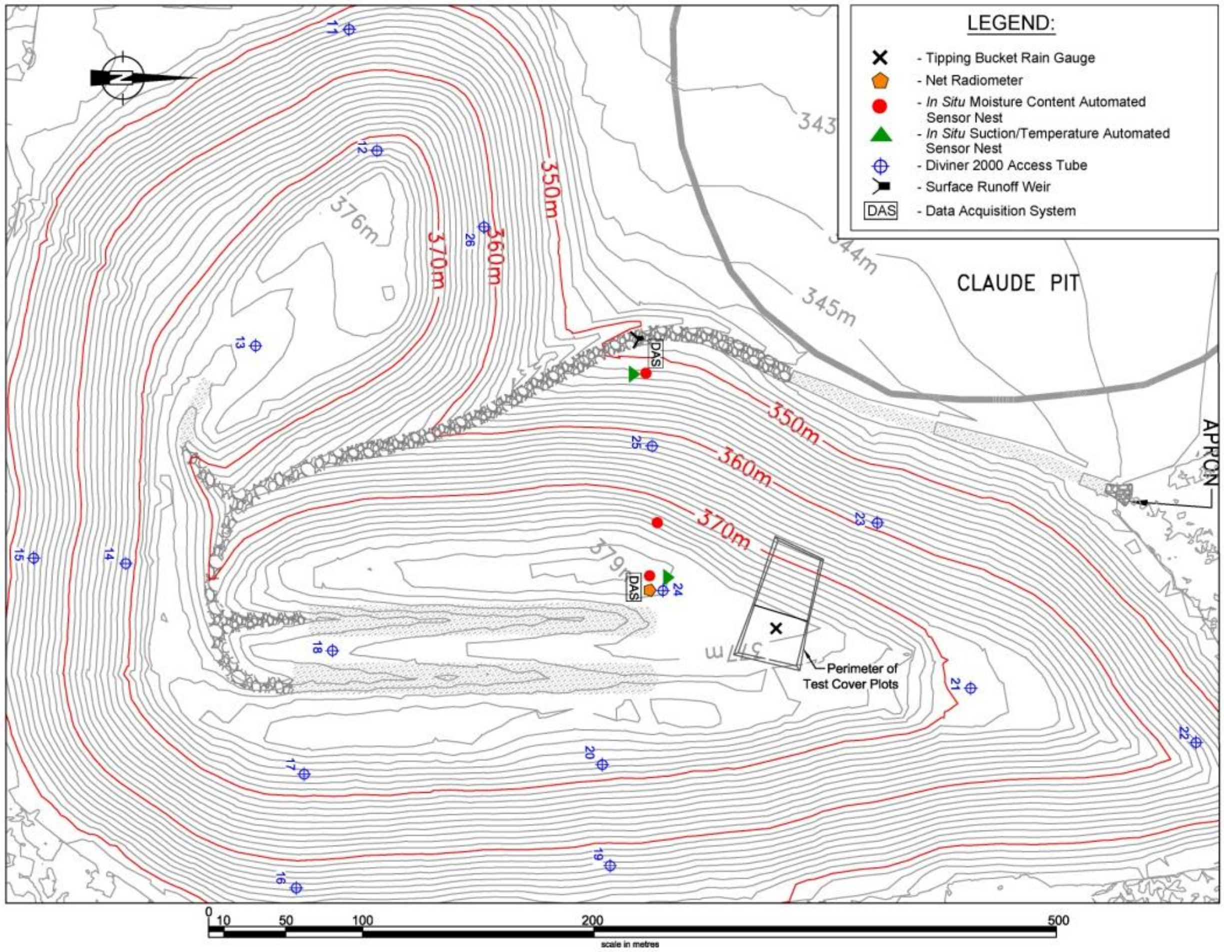

Figure 3 Performance monitoring instrumentation installed on the Claude WRP.

MONITORING PROGRAM RESULTS

Potential evaporation (PE) at the Claude WRP has been greater than rainfall for all years since the onset of monitoring (Table 1). PE estimates are based on the Penman (1948) method and climate data collected at the site, and represent a theoretical maximum evaporation of a free water surface. When PE is greater than rainfall, the capacity for the cover system to store precipitation and release it back to the atmosphere is greatly improved, thereby improving performance of the cover system by reducing net percolation rates.

Table 1
Annual rainfall accumulation and potential evaporation at the Claude WRP from 2007 to 2012.

	2007 (mm)	2008 (mm)	2009 (mm)	2010 (mm)	2011 (mm)	2012 (mm)
Rainfall	299	183	318	296	215	357
PE	533	581	503	550	596	536

Water storage data (Figure 4) have demonstrated that the water balance of the cover system during the year is largely controlled by storage of snowmelt/rainfall and subsequent release of water through evapotranspiration. There was an increase in storage following snowmelt and after rainfall events in the summer months, after which a slow decline occurred. The presence of vegetation improved the cycling of water storage by increasing evapotranspiration rates, further improving cover performance.

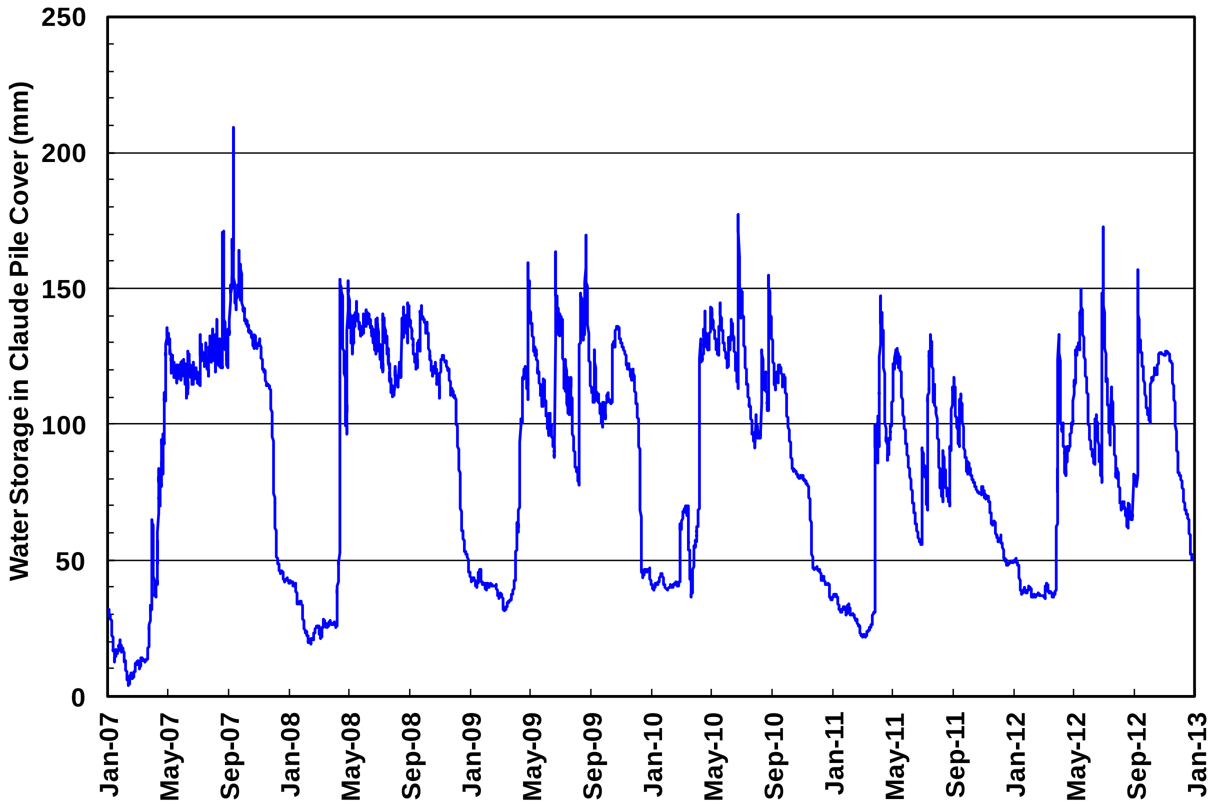

Figure 4 Soil water storage in the till cover profile measured at the upslope monitoring station from 2007 to 2012 (low storage values during the winter seasons reflect frozen ground conditions).

Thermal conductivity (TC) sensors are used to monitor temperatures in the Claude WRP cover and upper waste rock profiles at two different locations. Freeze-thaw cycles in the cover profile are important when interpreting runoff data and understanding when net percolation can be expected throughout the year. The timing and rate of freezing and thawing of the cover profile in the fall and spring depends on several factors including snow cover accumulation, ambient temperatures, and soil water contents. In general, the upper cover profile begins to freeze around the end of October, while complete thaw of the cover profile typically does not occur before mid to late May.

Performance of the cover system 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 June 2012 on the Claude pile cover system (Figure 5), with only minor observed erosion. A more mature vegetation cover will contribute to lower net percolation / seepage volumes through increased interception and transpiration rates.

(a) August 2007 – Plateau Station *(b) July 2008 – Plateau Station* *(c) September 2009 – Plateau Station* *(d) June 2012 – Plateau Station*

Figure 5 Photos illustrating evolution of vegetation on the Claude WRP cover system.

Field measurement data were used to determine net percolation rates through the cover system by using the water balance method:

$$PPT = R + AET + NP + \Delta S + LD \qquad \text{(Eq. 1)}$$

where PPT is precipitation (rainfall plus snow-water equivalent), R is runoff, AET is actual evapotranspiration, NP is net percolation, and ΔS is change in moisture storage (all values in mm). Water balances were estimated on a daily basis during the frost-free period, identified as approximately April 1st to October 31st. Lateral drainage (LD [mm]) is accounted for in sloping systems through an additional term on the right side of Eq. 1. Water balance fluxes at the top and sloping areas of the Claude WRP cover system since the onset of monitoring are given in Tables 2 and 3.

Table 2
Annual water balance fluxes for the plateau area of the Claude WRP for April to October.

Year	PPT (mm)	Water Balance Fluxes (mm and % of precipitation)			
		AET	Δ S	R	NP
2007	450	231 (51%)	34 (8%)	6 (1%)	179 (40%)
2008	272	297 (109%)	-96 (-35%)	6 (2%)	66 (24%)
2009	387	290 (75%)	31 (8%)	5 (1%)	61 (16%)
2010	358	303 (85%)	12 (3%)	2 (1%)	40 (11%)
2011	271	182 (67%)	9 (3%)	2 (1%)	58 (21%)
2012	430	317 (74%)	33 (8%)	5 (1%)	105 (24%)

Table 3
Annual water balance fluxes for sloping areas of the Claude WRP for April to October.

Year	PPT (mm)	Water Balance Fluxes (mm and % of precipitation)				
		AET	Δ S	R	LD	NP
2007	419	239 (57%)	17 (4%)	58 (14%)	0 (0%)	104 (25%)
2008	261	308 (118%)	-85 (-33%)	50 (19%)	-57 (-22%)	45 (17%)
2009	396	314 (79%)	15 (4%)	41 (10%)	0 (0%)	26 (7%)
2010	371	320 (86%)	4 (1%)	22 (6%)	-21 (-6%)	46 (12%)
2011	295	231 (78%)	3 (1%)	19 (6%)	25 (9%)	44 (15%)
2012	422*	310 (73%)*	51 (12%)*	24 (6%)*	0 (0%)	92 (22%)*

*Upslope data only.

As was observed when calculating the 2012 water balance, 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 available 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, the water at the base of the cover system can continue to percolate into the underlying waste, further causing conditions for higher than expected net percolation.

In general, net percolation has decreased since construction of the cover system in 2006. This is likely due to an increase in vegetation cover causing an increase in evapotranspiration rates. However, variability in net percolation as a percentage of precipitation did occur during the six years of monitoring, which is to be expected in response to normal cycles in the local climate. General trends on the performance of the system 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 the design of the Claude WRP cover system.

CONCLUSIONS

The Claude WRP cover system is a stable landform supporting the growth of productive native plant species and attenuating radiation emanating from stored waste rock to acceptable levels. Percolation of meteoric waters through the WRP has generally decreased since construction of the cover system in 2006. This case study serves to underline the importance of maintaining a long-term perspective when evaluating cover system performance in terms of reducing the net percolation of meteoric waters.

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