Why Waste Rock Piles will Seep for Many Years after Being Covered

D.J. Williams

Introduction

The rehabilitation of potentially acid forming waste rock is site specific, being a function, among other factors, of the rock types, the dumping and storage method employed, and the climatic setting. At Kidston Gold Mine in north Queensland, Australia, a vegetated "store/release" cover was developed (Williams *et al*., 1997) for the flat top surfaces of the encapsulated mineralised waste rock piles, to manage acid rock drainage in this semi-arid, seasonal, sub-tropical climate. The covers were instrumented with moisture and suction sensors and lysimeters, and have been monitored for up to nine years.

The paper describes the philosophy behind the "store/release" cover design and its adaptation over time to suit Kidston's conditions are described. The results of monitoring of the cover are presented, together with data collected on seepage rates and water quality, and projected seepage rates over time.Site Setting

Kidston Gold Mines are located in North Queensland, Australia, approximately 280 km south west of Cairns (Williams *et al.*, 1997; Kidston Gold Mines Limited, 2000). The elevation of the site is about 540 m Australian Height Datum (AHD). The climatic setting of Kidston Gold Mines is semi-arid, sub-tropical, with pronounced wet and dry seasons. On average, 82% of the annual rainfall falls between November and April, with high intensity storms being common. The annual rainfall averages about 700 mm, but it can range from a low of 400 mm/year to a high of 1,500 mm/year. The average pan evaporation is about 2,800 mm, four times the average annual rainfall. Average daily winter temperatures range between a minimum of -2 C and a maximum of 22 C. Average daily summer temperatures range between a minimum of 23 C and a maximum of 36 C. The prevailing wind direction is from the east to south east.

The topography of the site is generally gently sloping, with rocky "knolls" rising about 50 m above the surrounding topography. The site vegetation is an altered open woodland, comprising native grasses, ironbark trees and Gilbert river boxes, supporting semi-domestic cattle, wild pigs, native animals and a prolific bird life.

Overview of Surface Waste Rock Disposal

The waste rock included oxide (weathered) waste rock, fresh (inert) barren waste rock, and mineralised waste rock. The waste rock from Wises Hill Pit was truck dumped in surface engineered piles surrounding the pit. The 20 Mt (about one sixth of the total waste rock placed in surface piles) of mineralised waste rock excavated from Wises Hill Pit was placed in the South and North Waste Rock Piles on a pad of fresh barren waste rock, with a wide encapsulation (up to 60 m horizontally) of fresh barren waste rock. The waste rock piles were typically constructed to a height of about 36 m by end-dumping over the crest of the pile. The waste rock types were selectively placed, based on their identified geology and inferred acid rock drainage potential. The final surface waste rock pile footprint covered about 340 ha and the piles contain about 120 Mt of waste rock.

Geochemical Characterisation of Mineralised Waste Rock

The sub-economic mineralised waste rock is potentially acid forming. It has a gold content in the range from 0.55 to 0.7 g/t, a typical total sulphur content of 0.9%, an Acid Neutralisation Capacity (ANC) of 54 kg of $CaCO_3$ per t of material, a Net Acid Producing Potential of -24 kg of $CaCO_3$ per t of material, and an ANC/MPA (MPA = Maximum Potential Acidity) of 1.8. The potential for the mineralised waste rock to produce acidity was realised when the pH of the seepage emanating from the South (mineralised waste rock) Pile dropped suddenly during the extreme 1990/91 wet season from about 7.5 to about 4.5, about 4 years after the start of construction of the pile.

Store/Release Waste Rock Pile Cover

Philosophy Behind Store/Release Cover System

The mineralised waste rock that comprised about one sixth of the total waste rock stored in surface piles at Kidston was placed on a pad of fresh barren waste rock and encapsulated laterally by fresh barren waste rock. It was required to construct a low permeability cover over the mineralised waste rock to limit rainfall infiltration and hence limit any acid drainage, with any reduction in oxygen ingress being a bonus. It was recognised that in Kidston's highly seasonal and variable semi-arid climate, a rainfall-shedding cover would not be a sustainable means of minimising rainfall infiltration into the mineralised waste rock. During the long dry season, the oxide waste rock available for cover construction would desiccate leading to vegetation die-back. The subsequent summer storms would then erode the desiccated, poorly vegetated surface, with the likelihood of breaking through the cover.

Instead, a store/release cover system was developed for Kidston (Williams *et al.*, 1997), which recognised the need to avoid desiccation and the eroding effects of rainfall runoff, and relied on storage within the cover of rainfall infiltration during the short wet season and its release during the long subsequent dry season through evapotranspiration.

The store/release cover system had the following aims.

- To provide a cover with sufficient water storage capacity to "store" the bulk of the 3-month summer wet season rainfall, without causing saturated breakthrough into the underlying mineralised waste rock, limiting rainfall infiltration through the cover to < 5% of annual rainfall.
- To "release" the stored water through evapotranspiration during the 9-month dry season, while maintaining the compacted clayey layer at the base of the cover moist to preserve its integrity. The vegetative cover plays a key role in ensuring that this aim is met.
- To provide a cover system that cycles annually between wet and dry states, without progressively wetting up or drying out.

An encapsulation of inert waste rock under the base and around the sides of the mineralised waste rock was provided, over which the store/release cover extended. The side encapsulation was wide enough to ensure that any rainfall infiltrating the sides of the pile will not intercept mineralised waste rock and generate acid drainage. The outer batter slopes were left at the angle of repose of the inert waste rock (nominally 38°) and over-dumped with oxide waste rock from the crest to facilitate revegetation.

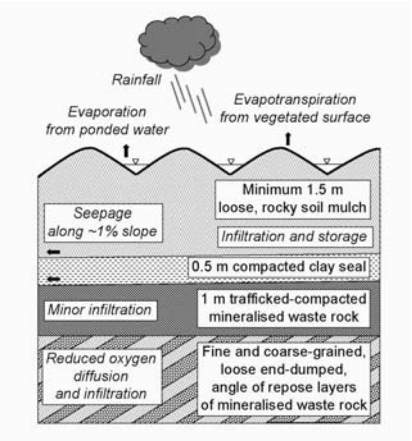

Figure 1. Schematic of original store/release cover system used for South Pile trial.

South Pile Store/Release Cover Trial

A schematic of the original store/release cover system used for the 23 ha South Waste Rock Pile trial cover is shown on Figure 1. Prior to the construction of the store/release cover, the top of the rock pile was sloped to prevent the ponding of any water that penetrates the cover. A near-saturated 0.5 m thick compacted clayey (fine-grained oxide waste rock) sealing layer was then placed, overlain by a loose rocky soil mulch (coarse-grained oxide waste rock) layer a minimum 1.5 m thick, which serves as the store/release layer and protects the underlying compacted clayey sealing layer.

Figure 2. Placement of rocky soil mulch layer on South Pile cover trial.

The rocky soil mulch layer was placed by paddock dumping from haul trucks, forming a hummocked surface profile that prevented rainfall runoff, which would erode the cover. The surface was vegetated to ensure sufficient transpiration to just remove the stored water without excessively drying out the cover. The store/release cover extended over both the mineralised waste rock and the fresh barren waste rock side encapsulation, to avoid rainfall infiltration through the side slopes of the pile intercepting mineralised waste rock. The pile side slopes were left at the angle of repose of the fresh barren waste rock, ensuring both adequate geotechnical and erosional stability. Oxide waste rock was over-dumped from the crest and the slope aerially grass seeded and fertilised. Figure 2 shows the placement of the rocky soil mulch layer by loose paddock dumping on the compacted clayey layer on the South Pile. Figure 3 shows an aerial view of the typical revegetation achieved on the store/release covers within two years.

Performance Monitoring of South Pile Trial Cover

Instrumentation of the South Waste Rock Pile trial store/release cover comprised a full weather station established on the top of the pile, large size (2.5 m diameter and height), non-wicking lysimeters used to monitor the effectiveness of the cover in limiting rainfall infiltration, and volumetric water content and matric suction sensors within the cover to provide its seasonal and long-term performance, and any seepage from the toe of the pile was collected (Williams *et al.*, 2006).

The climatic data were used as input to the computer program SoilCover (Unsaturated Soils Group, 1997) to predict the performance of the cover. Calculations using SoilCover indicated that the average annual rainfall would produce about 1% net infiltration, while twice the average annual rainfall could produce a net infiltration of 5% of incident rainfall.

The lysimeter data have shown that infiltration through the trial store and release cover into the mineralised waste rock of the South Pile has averaged less than 0.25% of incident rainfall, with a maximum recorded infiltration of 1.1% of incident rainfall since the cover was constructed. A net infiltration of 1% of the average annual rainfall or 7 mm/year, which is equivalent to an unsaturated hydraulic conductivity of 2.2×10^{-10} m/s, is comparable to natural infiltration rates.

The store/release cover has undergone wetting up during each wet season, followed by drying during each succeeding dry season, with the dried-out states at each depth showing little net change over time. After each dry season, the volumetric water content of the upper rocky mulch layer drops to a minimum of about 0.10 (degree of saturation S of 0.2 and gravimetric moisture content w of 5%), while after the wet season, the average volumetric water content of the cover rises to about 0.35 (S ~ 0.7 and w ~ 20%).

Subsequent covers involved smoothing the mounded surface of the paddock-dumped rocky soil mulch a single low bearing pressure dozer pass, which helps to seal off possible preferred seepage paths at the interface between paddock piles, and enhances revegetation while retaining internal porosity. The revegetation approach has also been modified, with fertilising and native tree-seeding carried out in the first year, followed by refertilising and grass-seeding in the second year. This allows the native trees to become established, rather than be choked out by grasses.

Figure 3. Aerial view of typical revegetation achieved on store/release covers.

Seepage Water Quality and Flow Rates

Seepage Water Quality

Water quality in the main toe seeps from the South and North Waste Rock Piles has been monitored since late 1986. The monitored water chemistry parameters have included pH, electrical conductivity, sulphate, and a number of metals, including aluminium, arsenic, cadmium, copper and zinc. Dissolved copper and zinc concentrations and pH levels for the main toe seep from the South Waste Rock Pile are plotted against time on Figure 4, together with some trend lines.

The 1 in 140 year 1990/91 wet season, which followed a low rainfall 1989/90 wet season, generated spikes in pH (to a low of 3.2) and dissolved metals (dissolved copper to over 50 mg/l and dissolved zinc to over 100 mg/l). Over the next 10 years, the pH remained at about 4.5, and the dissolved copper and dissolved zinc concentrations averaged about 25 mg/l and 50 mg/l, respectively. Following the completion of the store/release covers over the entire flat top surfaces of the piles by late 2001, the removal and processing in 2001 of the low grade ore stockpiled within the South Waste Rock Pile footprint, and the diversion to Wises Hill Pit of mine water that previously flowed through the South Pile, the water chemistry of the pile seepage began to improve significantly, apart from the pH, which not unexpectedly has remained constant. The dissolved copper and dissolved zinc concentrations have reduced to 15 mg/l and 25 mg/l, respectively.

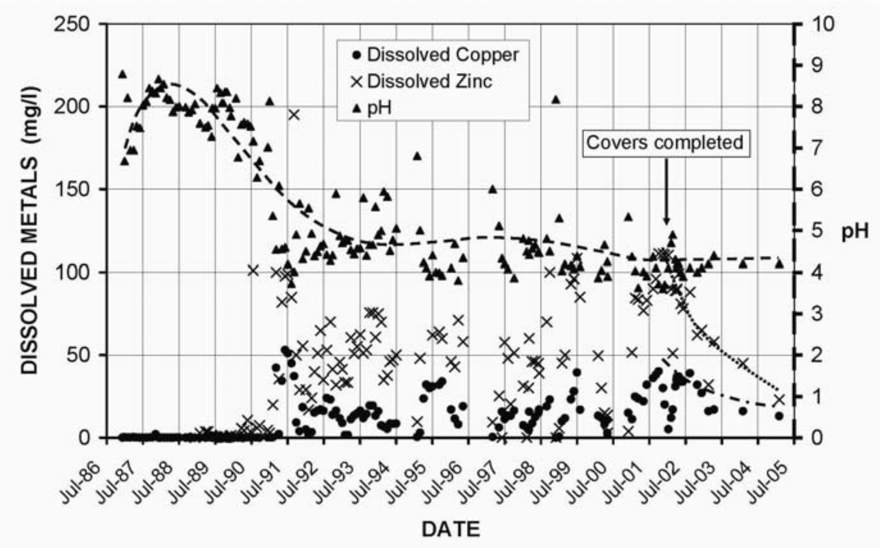

Figure 4. Dissolved copper and zinc concentration and pH levels for main toe seep from South Pile versus time.

Estimation of Ongoing Waste Rock Pile Seepage Post-Closure at Kidston

V-notch weirs were installed at the main toe seeps from the South and North Waste Rock Piles at Kidston in October 2002 and have shown an exponential decline in seepage flow rate over time due to the minimal additional rainfall infiltration since the piles were covered. Based on the estimated wetting up of the piles due to rainfall infiltration during the 15-year operation of the mine (Williams and Rohde, 2006), and the measured exponential decline in seepage flow rate since the piles were covered, the ongoing decline in seepage from the toe of the waste rock piles shown on Figure 5 was predicted. This prediction was based on the determination of the unsaturated hydraulic parameters of the waste rock comprising the piles.

Figure 5 shows both the predicted seepage flow rate (left hand vertical scale) and the predicted seepage volume (right hand vertical scale). After about 17 years (end of 2018), the seepage flow rate is predicted to approach that percolating through the store/release cover (about 7 mm/year) and the seepage volume will be limited to that percolating through the side slopes, which comprise 10 to 15% of the surface area of the piles, amounting to ongoing relatively clean seepage at a rate of perhaps 0.15 Mm^3/year.

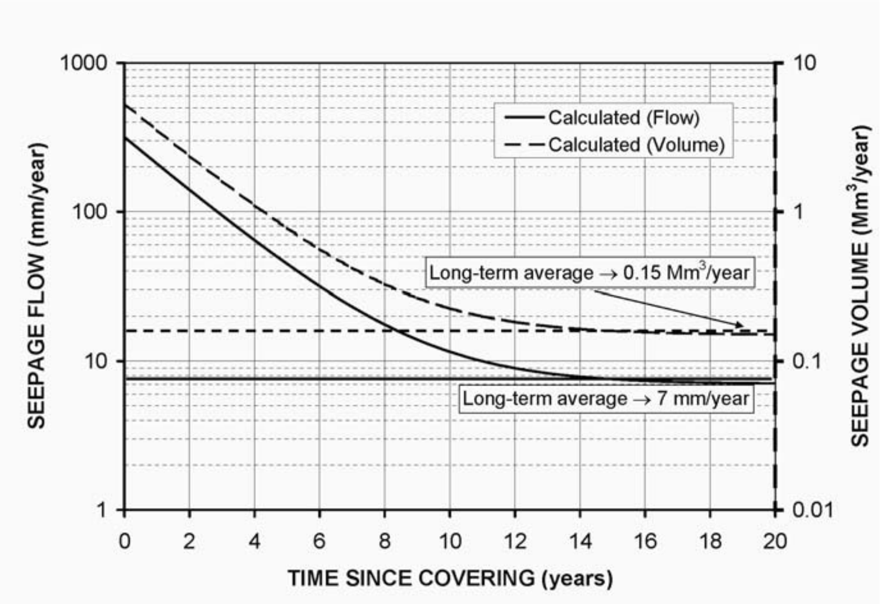

Figure 5. Predicted decline in Kidston waste rock pile toe seepage.

Conclusion

Over the 9 years of monitoring, the maximum recorded infiltration through the trial store/release cover has been 1.1% of incident rainfall, although most of these years have experienced below average annual rainfall. The instrumented store/release covers have undergone annual cycles of wetting up during each wet season, followed by drying during each succeeding dry season, with the dried-out states at each depth within the cover showing little net change over time. The water quality of the seepage emanating from the waste rock piles at Kidston has improved significantly and the seepage flow rate has reduced significantly since the store/release covers were completed. The seepage water quality is expected to improve further and the seepage flow rate is predicted to approach the slow rate of percolation through the store/release cover within about 17 years (by about 2018). This extended period before the seepage flow rate is expected to decrease to the slow rate of percolation through the store/release cover is a consequence of the waste rock piles having been left open to rainfall infiltration and storage for the 15-year duration of mining, and will delay the surrender of the mining lease. This delay could have been reduced by constructing the piles in cells to full height and covering the cells progressively to limit their exposure to rainfall.

Acknowledgements

The authors gratefully acknowledge the management of Placer Dome Asia Pacific for providing access to the data on which this paper is based and for allowing publication of these data.

References

Kidston Gold Mines Limited. (2000). Closure Plan and Environmental Report.

Unsaturated Soils Group. (1997). SoilCover, User's Manual, Version 4.0. Unsaturated Soils Group, University of Saskatchewan, Saskatoon, Canada.

Williams, D.J. and Rohde, T.K. (2006). Rainfall infiltration-induced seepage from waste rock piles. To appear in Water in Mining 2006, Brisbane, Australia, 14-16 November 2006.

Williams, D.J., Stolberg, D.J. and Currey, N.A. (2006). Long-term performance of Kidston's "store/release" cover system over potentially acid forming waste rock dumps. Proceedings of Seventh International Conference on Acid Rock Drainage, St Louis, Missouri, USA, 26-30 March 2006, 2385-2396.

Williams, D.J., G.W. Wilson and N.A. Currey. (1997). A cover system for a potentially acid forming waste rock dump in a dry climate. Proceedings of Fourth International Conference on Tailings and Mine Waste '97, Fort Collins, CO, 13-17 January, 1997, 231-235. A.A. Balkema, Rotterdam.

D.J. Williams, The University of Queensland, Brisbane 4071, Australia, email: D.Williams@uq.edu.au