LONG-TERM MONITORING OF KIDSTON'S "STORE/RELEASE" COVER SYSTEM OVER POTENTIALLY ACID FORMING WASTE ROCK PILES[1]

David J. Williams[2], Daniel J. Stolberg,[3] and Nicholas A. Currey[4]

Abstract. 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. The "store/release" cover developed to manage acid rock drainage from mineralized waste rock piles at Kidston Gold Mines' open pit operations in the semi-arid, seasonal, sub-tropical climate of North Queensland, Australia, has been monitored for nine years. The paper describes the philosophy behind the "store/release" cover design and its adaptation over time to suit Kidston's conditions. The results of monitoring of a number of covers over the nine years since the first cover was constructed are presented, together with data on seepage flows and water quality emanating from the piles, and estimates are made of the overall water balance of the rock piles. The Kidston story is a valuable case study of a successful approach to remediating an identified source of acid rock drainage in a semi-arid climate, which has actively engaged all Stakeholders.

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[2]David J. Williams is Associate Professor of Geomechanics, Department of Civil Engineering, The University of Queensland, QLD 4072, AUSTRALIA. [3]Daniel J. Stolberg is Research Assistant, Department of Civil Engineering, The University of Queensland, QLD 4072, AUSTRALIA. [4]Nicholas A. Currey, General Manager Sustainability, Placer Dome Australia Limited, Level 2, 189 Coronation Drive, MILTON, QLD 4064, AUSTRALIA.

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Site Setting

Kidston Gold Mines are located in North Queensland, Australia, approximately 360 km south west of Cairns (Williams *et al.*, 1997). 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 Mining and Milling

Kidston Gold Mines' low grade porphyry Au deposit was mined by two open pits using truck and shovel methods, commencing in 1984, with the first Au poured in April 1985. Wises Hill Pit was mined to a depth of about 240 m in 1996, when the surface area reached 52 ha. The adjacent Eldridge Pit was mined out to a depth of typically 270 m in June 2001, when the surface area reached 55 ha. Milling and conventional carbon-in-pulp (cyanide) processing was employed out at an average throughput of 750 tph, and ceased in July 2001. About 100 t (3.5 million ounces) of Au was produced. A total mass of about 250 Mt (about 93 Mm^3) of rock was excavated from the open pits, comprising about 155 Mt (about 86 Mm^3) of waste rock and about 95 Mt (about 59 Mm^3) of tailings. The total area disturbed by mining and milling operations was about 830 ha.

Overview of Surface Waste Rock Disposal

The waste rock included oxide (weathered) waste rock, fresh (inert) barren waste rock, and mineralized 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 mineralized 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 dump. The waste rock types were selectively placed, based on their identified geology and inferred acid rock drainage potential. All of mineralized waste rock excavated from Eldridge Pit was dumped into the mined out Wises Hill Pit, along with thickened tailings. The final surface waste rock pile footprint covered about 340 ha and the piles contain about 120 Mt of waste rock.

Geochemical Characterization of Mineralized Waste Rock

The sub-economic mineralized waste rock is potentially acid forming. It has a Au content in the range from 0.55 to 0.7 g/t, a typical total S content of 0.9%, an Acid Neutralization 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 mineralized waste rock to produce acidity was realized when the pH of the seepage emanating from the South (mineralized 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 construction of the rock piles.

Philosophy Behind Store/Release Cover System

The mineralized 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 cover over the mineralized waste rock and fresh barren waste rock lateral encapsulation to limit rainfall infiltration and hence limit any acid drainage, with any reduction in oxygen ingress being a bonus. It was recognized that in Kidston's highly seasonal and variable semi-arid climate, a rainfall-shedding cover would not be a sustainable means of minimizing rainfall infiltration into the mineralized 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 recognized 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.

South Waste Rock 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 Fig. 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) 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 layer.

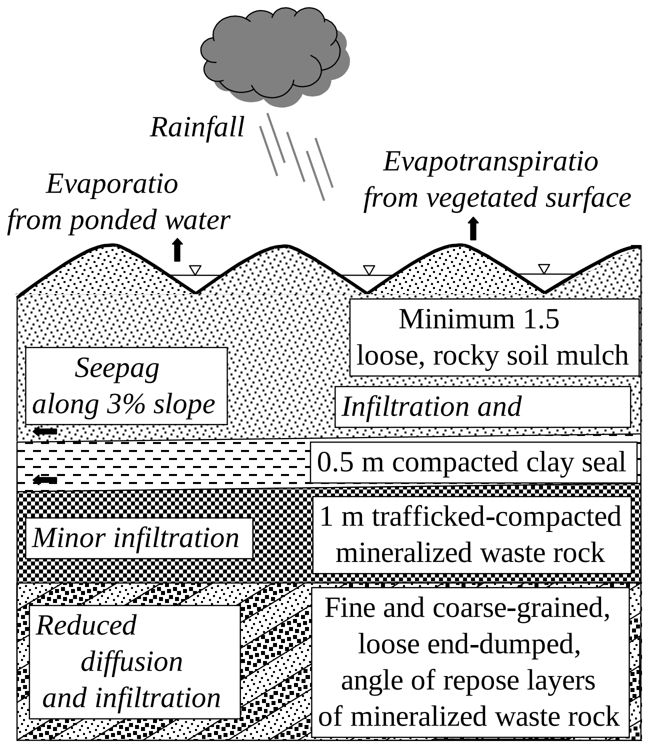

Figure 1. Schematic of original store/release cover system used for South Waste Rock Pile cover trial.

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 mineralized waste rock and the fresh barren waste rock lateral encapsulation, to avoid rainfall infiltration through the side slopes of the pile intercepting mineralized 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 fertilized.

Laboratory falling head testing of compacted clayey oxide waste rock gave saturated hydraulic conductivity values of between 5 x 10^{-10} m/s and 2 x 10^{-8} m/s (between 15 mm/year and 630 mm/year). Field permeability testing of the compacted clayey oxide waste rock indicated a typical saturated hydraulic conductivity of about 10^{-8} m/s (315 mm/year). The particle size distribution of the clayey oxide waste rock used to form the sealing layer comprised typically 10% clay (passing 0.002 mm), 15% silt (0.002 to 0.06 mm), 35% sand (0.06 to 2 mm) and 30% gravel (2 to 60 mm).

Above the sealing layer, rocky oxide waste rock was loose paddock-dumped in mounds. The particle size distribution of the rocky oxide waste rock used for the mulch layer comprised typically 2% silt, 26% sand and 72% gravel-size and larger. Oxide waste rock with between 25% and 45% passing 2 mm provides reasonable erosion resistance without adversely affecting revegetation potential. The loose dumping ensured a porosity of about 0.25, which is available for the storage of rainfall infiltration. A 1.5 m thick mulch layer can therefore store up to 350 mm of infiltration (about half the average annual rainfall). Any excess water will serve to maintain the sealing layer near-saturated and can pond between the mounds. Provided the sealing layer remains near-saturated, it will limit the diffusion of oxygen into the underlying potentially acid forming waste rock. The mound surface was fertilized and seeded with pasture grasses and native trees. Subsequent field permeability testing of the dozed surface of the loose rocky soil mulch layer, using both the Guelph and CSIRO ring permeameters, indicated a typical saturated hydraulic conductivity of about 2×10^{-6} m/s.

Figure 2 shows the placement of the rocky soil mulch layer by loose paddock dumping on the compacted clayey layer on the South Dump. The revegetation comprised grasses planted from seed, plus planted acacias and eucalypts, and volunteer acacias. Two years after planting, the grass growth was somewhat diminished due to the consumption of the initial fertilizer application, and acacias were the only other species that survived. More fertilizer was subsequently added to ensure sufficient ongoing consumption of stored water through transpiration, so avoiding the gradual wetting up of the cover over time. However, this additional fertilizer was also exhausted over time and the state of the vegetative cover was further diminished by the prevailing extended dry conditions. While the dry conditions would limit the potential for infiltration through the cover, the lack of a good vegetative cover could also limit the release of infiltration stored in the cover should a wetter than average period occur.

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

Performance Monitoring of South Waste Rock Pile Trial Store/Release Cover

Instrumentation of the South Waste Rock Pile trial store/release cover comprised a full weather station established on the top of the dump, 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.

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 mineralized 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 cumulative rainfall (together with the annual totals) recorded on the top of the South Waste Rock Pile is shown on Fig. 3. All but the 2000/01 annual rainfall totals were significantly below the average. Ponding of water between the mounds has been observed during the wet season, and no significant cracking of the surface has been observed during the dry season.

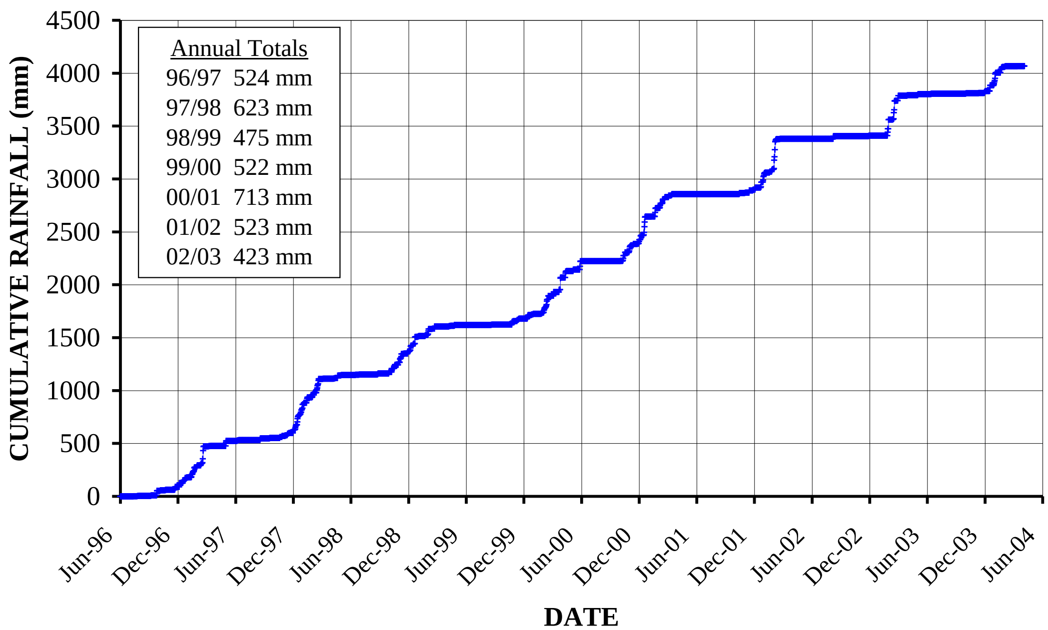

Figure 3. Cumulative rainfall recorded on top of South Waste Rock Pile.

As shown on Fig. 4, the store/release cover undergoes 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%). The slight increase in the volumetric water content in the winter dry seasons of 1998 and 1999 was related to a diminished vegetative cover, which was corrected by re-fertilizing. The subsequent increase in the volumetric water content in the winters of 2001 and 2002 was related to a further diminished vegetative cover, caused by extended dry weather, but this was addressed by re-fertilizing and tree seeding with eucalypts.

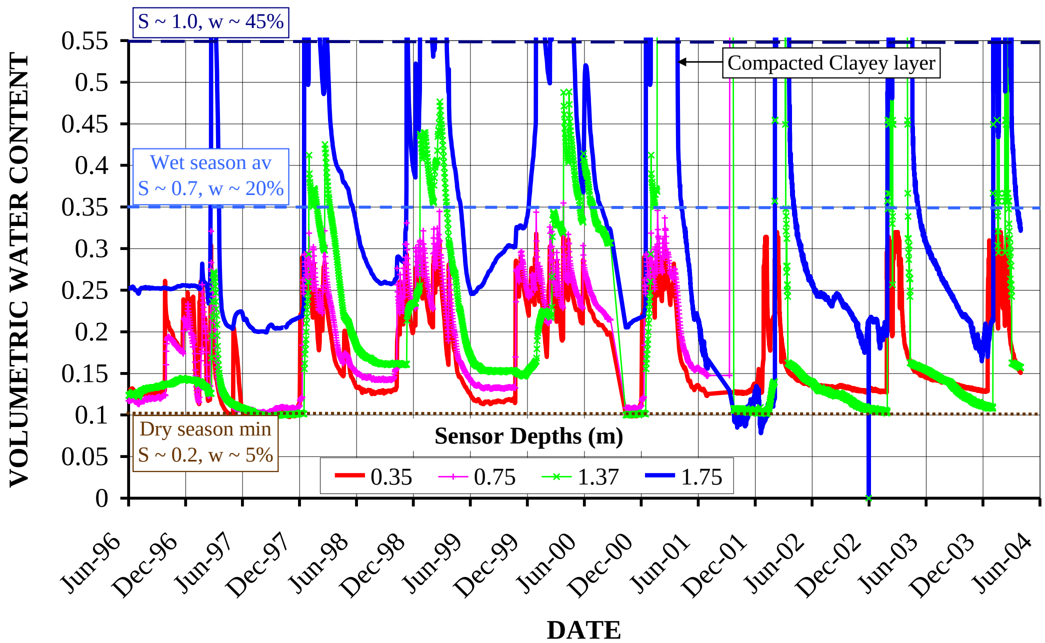

Figure 4. Wetting and drying cycles of South Waste Rock Pile trial store/release cover.

Laboratory and Field Soil Water Characteristics for South Waste Rock Pile Trial Cover

Figure 5 compares the fitted (using the method of Fredlund *et al*. (1997), including the program SoilVision) field Soil Water Characteristic Curves (SWCCs), based on the data collected from the South Waste Rock Pile trial store/release cover, with average laboratory fitted SWCCs for the compacted clayey and rocky soil mulch layers. There is reasonable agreement between the fitted laboratory and field SWCCs. Figure 6 shows the laboratory and field unsaturated hydraulic conductivity functions derived using the method of Fredlund *et al*. (1994) from the fitted SWCCs and measured saturated hydraulic conductivities for the South Waste Rock Pile trial store/release cover materials.

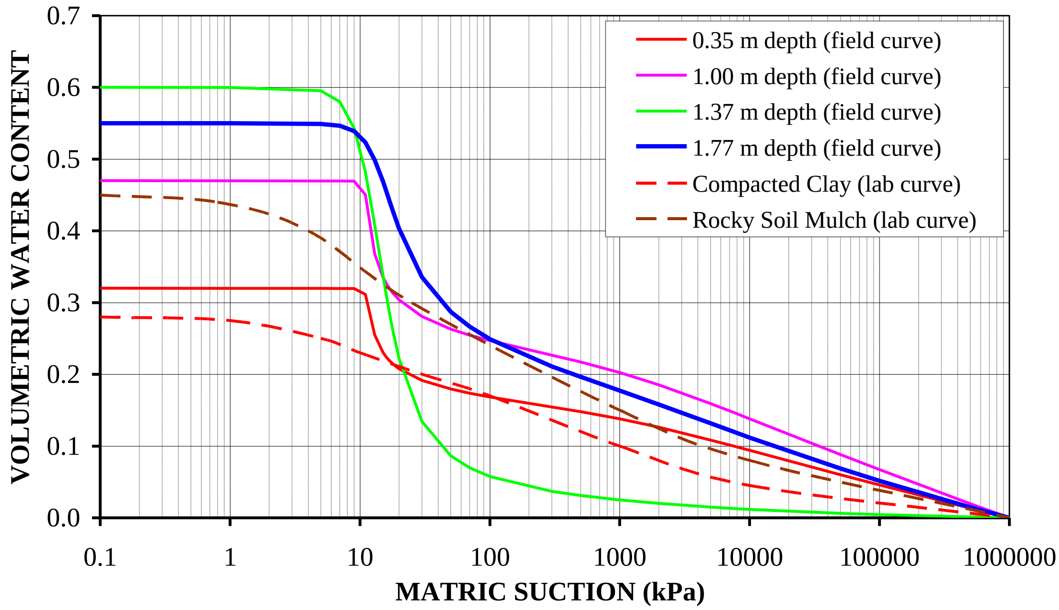

Figure 5. Fitted laboratory and field SWCCs for South Waste Rock Pile trial cover.

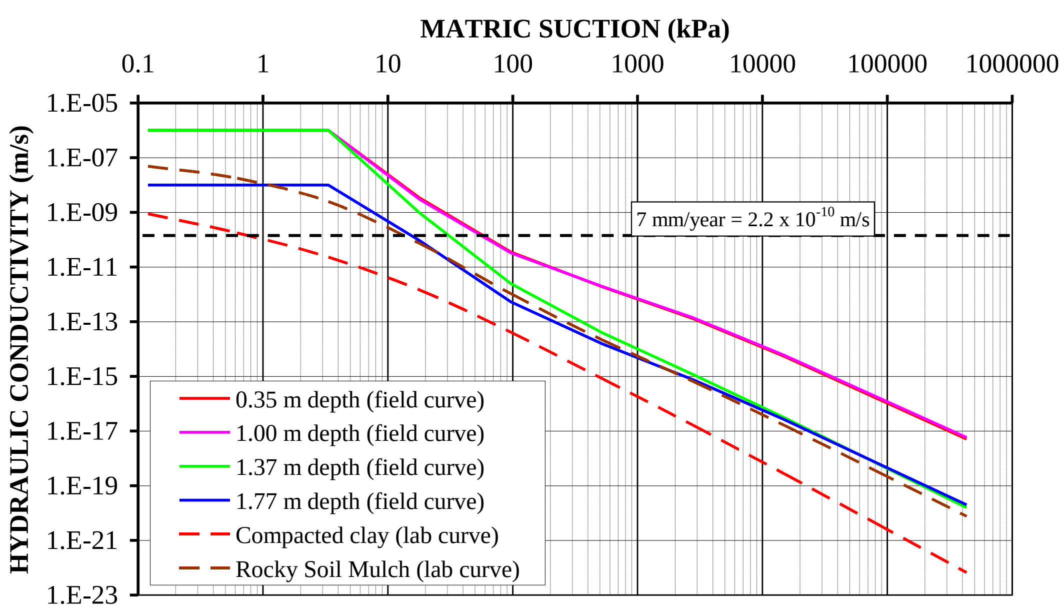

Figure 6. Laboratory and field unsaturated hydraulic conductivity functions for South Waste Rock Pile trial cover.

Seepage Flows and 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, sulfate, and a number of metals, including Al, As, Cd, Cu and Zn. Dissolved Cu and Zn concentrations and pH levels for the main toe seep from the South Waste Rock Pile are plotted against time on Fig. 7, together with some trend lines.

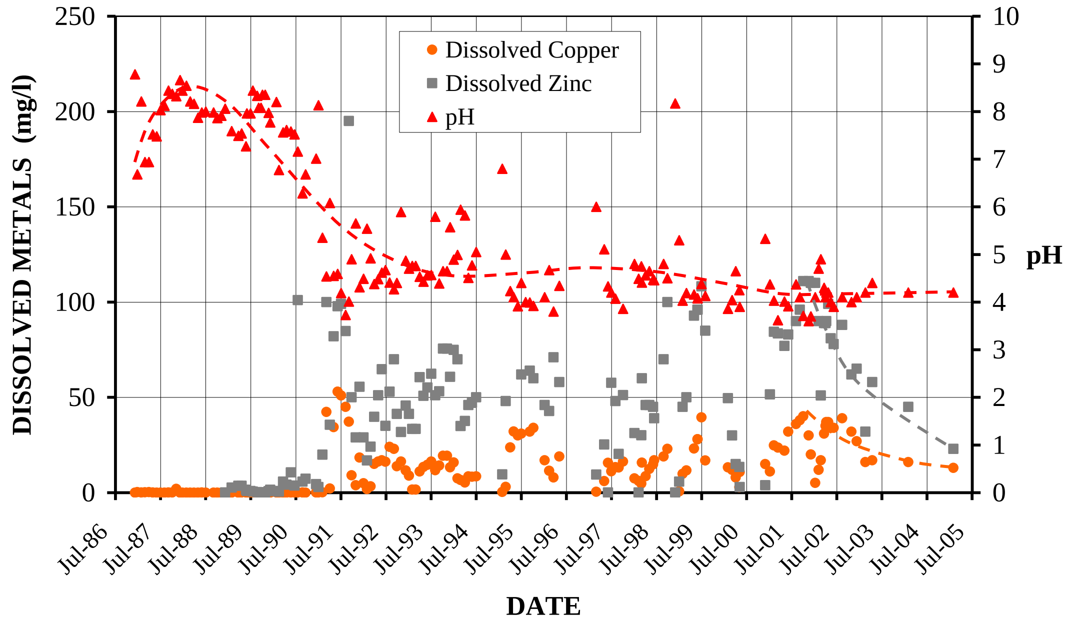

Figure 7. Dissolved Cu and Zn concentrations and pH levels for main toe seep from South Waste Rock Pile versus time.

The SO_4^{-2} concentration, which accounts for most of the electrical conductivity, rose from about 100 mg/l initially to about 1,500 mg/l about 5 years after the first mineralized waste rock was dumped in the South Dump, when the pH started to drop due to the onset of oxidation of the mineralized waste rock (plus some stockpiled low grade ore). Over the next 2 to 3 years the pH dropped steadily to about 4.5, accompanied by an elevation in the SO_4^{-2} concentration to about 5,000 mg/l and the dissolution of metals.

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), SO_4^{-2} (to 6,500 mg/l) and dissolved metals (dissolved Cu to over 50 mg/l and dissolved Zn to over 100 mg/l). Over the next 10 years, the pH remained at about 4.5, and the SO_4^{-2}, dissolved Cu and dissolved Zn concentrations averaged about 3,000 mg/l, 25 mg/l and 50 mg/l, respectively, constituting moderate acid drainage. Dissolved As and Cd concentrations have remained less than 0.01 mg/l and 2 mg/l, respectively.

Following the completion of the store/release cover over the entire South Waste Rock Pile (the trial store/release cover constructed in 1996 covered only 23 ha of the pile), 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 Dump, the water chemistry of the pile seepage began to improve significantly, apart from the pH, which not unexpectedly has remained constant. The SO_4^{-2}, dissolved Cu and dissolved Zn concentrations have reduced to 2,500 mg/l, 15 mg/l and 25 mg/l, respectively.

V-notch weirs were installed at the main toe seeps from the South and North Waste Rock Piles at Kidston in October 2002. Figure 8 shows the measured seepage rates from the main toe seep of the South Waste Rock Pile plotted against time, together with the trend line. The seepage rate is seen to have reduced by 70% over the monitoring period.

The moderately acidic seepage emanating from the waste rock piles is collected and directed through constructed wetlands for polishing, with any excess volumes of treated water automatically pumped to the Eldridge Pit. It is expected that the seepage flows will eventually diminish to the point where evaporation will remove the need to continue pumping water treated in the wetlands, and that seepage water quality will continue to improve.

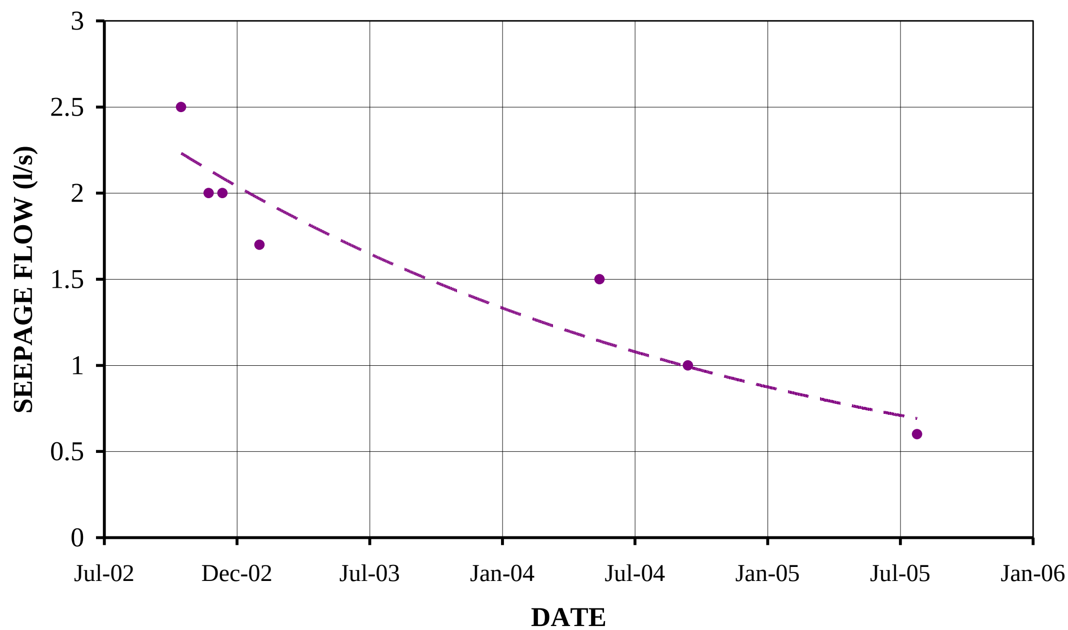

Figure 8. Seepage rate for main toe seep from South Waste Rock Pile versus time.

Overall Water Balance for Waste Rock Piles

The waste rock piles receive ongoing incident rainfall from their 340 ha catchment averaging 2.4 Mm^3/year. An estimated 0.4 Mm^3/year of incident rainfall would fall above mineralised waste rock, which comprises about 17% of the total volume of the waste rock piles. During pile construction, perhaps half of the incident rainfall would have infiltrated the piles, some going into storage and some going to seepage. Over the 10 years that acidic conditions prevailed, prior to covering the piles, perhaps 10 Mm^3 of moderately acidic seepage would have been generated, some of which will continue to seep from the piles over time.

Infiltration will continue into the side slopes, which comprise 10 to 15% of the surface area of the piles, contributing to ongoing relatively clean seepage at a rate of perhaps 0.15 Mm^3/year. This will reduce due to transpiration by the grasses planted in the oxide waste rock dumped over the slope crest and with the gradual generation of further fines through weathering, which will add water storage capacity and increase runoff. With the establishment of the vegetated store/release covers, perhaps only 0.001 Mm^3/year on average will intercept mineralised waste rock. A further source of seepage is flow through the pile along buried natural drainage channels.

Modifications to Store/Release Cover System and North Waste Rock Pile Cover

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 fertilizing and native tree-seeding carried out in the first year, followed by re-fertilizing and grass-seeding in the second year. This allows the native trees to become established, rather than be choked out by grasses.

Instrumentation of the North Waste Rock Pile store/release cover, which was constructed in December 2001 using the modifications described above, showed a similar pattern of seasonal variation in volumetric water content to that observed for the South Waste Rock Pile trial cover (Fig. 4).

Conclusion

The key elements of the Kidston waste rock pile design are a base pad of fresh barren waste rock, with a wide encapsulation (up to 60 m horizontally) of fresh barren waste rock, leaving the side slope at the angle of repose of the material, and end-dumping a partial cover of oxide waste rock from the crest to facilitate revegetation.

The key elements of the store/release cover system developed for Kidston are a 0.5 m thick compacted layer, overlain by a minimum 1.5 m thick rocky soil mulch layer with a dozed mounded surface that is revegetated. Reducing the amplitude of the mounds by means of a single dozer pass helps to seal off possible preferred seepage paths at the interface between paddock piles, and enhances revegetation while retaining internal porosity. The choice of appropriate vegetation to transpire excess stored water from the rocky mulch layer is vital to maintaining the function of the store/release cover system. Trees are best planted in the first year of revegetation, with grasses seeded in the second year. A eucalypt tree cover represents the only sustainable means of achieving sufficient transpiration in the long-term.

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 is improving significantly and the seepage rates are reducing significantly, with the expectation that a point will be reached at which the wetlands will be self-sustaining, with evaporation removing all excess seepage generated.

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