Water Balance Determination in Mine Residue Deposits: Case Studies in the Witwatersrand Basin, South Africa

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Abstract Acid mine drainage is generated by the reaction of mine residue, water and oxygen. To predict this process requires proper understanding of water balance of mine wastes. The study focused on on-site experimental determination of water balance parameters at three mine sites within the Witwatersrand basin. The installed equipment included rain gauge, tensiometers, lysimeters, tipping bucket and slope run-off plots for rainfall, soil tension, percolation, runoff, water content, water level, hydraulic conductivity and particle size. The total water input was higher than output and this was influenced by the period of mine decommission and nature of rehabilitation.

Key Words Water balance, tailings dams, waste rock dump, experimental set-up

Introduction

Gold mine residue deposits tend to make a notable impact on the environment. The impacts vary in severity depending on status of the mine residue deposits; whether the mine residue deposits is operational or decommissioned, the depositional methods used, and the climatic conditions in the area of mine residue deposition in South Africa. The most important environmental impact associated with gold mine residue deposit is the generation of acid mine drainage (AMD), which is produced during the oxidation of pyrite and other metallic sulphides. In order to minimize this problem, prediction of the quality and quantity of acid mine drainage requires proper understanding of water balance. The impact on surface water and groundwater by the reaction of salts from mine waste residues such as nitrates, carbonates with rainwater is a major problem that emanates from mine residue deposits. In order to understand as to whether surface and groundwater are polluted, accurate water balances of mine residue deposits is required.

Waste rock dump refers to waste residue deposits that are characterised of dominantly coarse-grained materials and less fine-grained materials that lock up large amount of minerals that contribute to the change in water quality where as tailings dam particles are relatively uniform in size and, at the very least, exhibit a much smaller size distribution and deposited in layering form like sedimentary rocks (Rosner and Boer 1996 and Rykaart *et al.* 2003). This study focused on site investigation of water balance parameters at three mine sites in the Witwatersrand Basin, namely; Kopanang waste rock dump; Driefontein No 3A and Old North Complex No 3 tailings dams (fig. 1) with emphasis on Kopanang waste rock dump. Details of the selected sites are given in Table 1.

The Kopanang waste rock dump is approximately 80 m high and located at No. 9 Shaft on the side of the Vaal River. Large erosion gullies are observed on the slopes of the dump. The parameters that were determined included rainfall, soil ten-

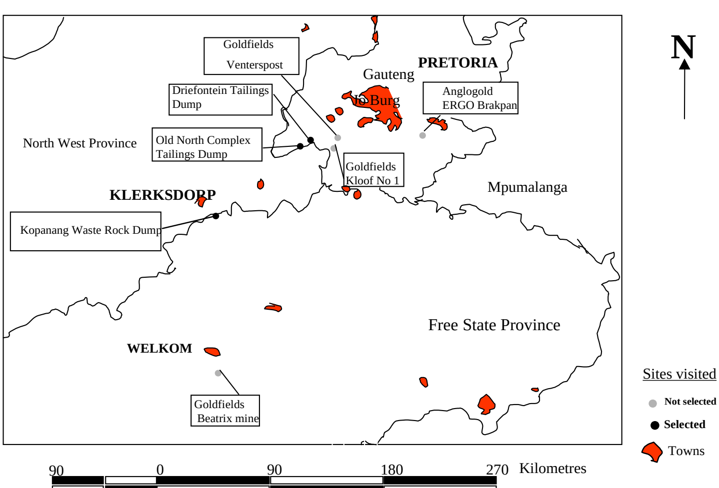

***Figure 1** Location map of the study area within the Witwatersrand Basin.*

Table 1 Selected study sites for water balance determination.

Site name	Mining company	Residue deposit type	Depositional type	Status
Kopanang	Anglogold (West Wits Operation)	Waste Rock Dump	End-tipping off conveyor belt	Operational
Driefontein No.3A	Goldfields	Tailings Dam	Day/night paddock to central	Decommissioned
Old North Complex No. 3	Anglogold (Vaal River Operations)	Tailings Dam	Day/night paddock to central	Decommissioned

sion, percolation, runoff, water content, water level, hydraulic conductivity and particle size distribution.

Materials and Methods

Sampling: Sampling was undertaken at two tailings dams and one waste rock dump of the study sites in the period between September and November 2003. Tailings dam samples were collected from the edge, middle and penstock sites, while waste rock dump samples were collected from the edge, middle and also from the pile near the tip of the conveyer belt using shovel.

Augering and core sampling were the two methods used to collect tailings dam samples. The hand augering method and core sampling by the use of stainless steel rings were selected for their relative inexpensiveness and effectiveness. A total of 126 samples were collected.

Experimental set-up: Water balance determination requires measurements of unsaturated and saturated hydraulic conductivity, water retention characteristic, particle size distribution, matric suction and weather data. The instruments that were installed on tailings dam included tensiometers, rain gauges, time domain reflectometry, lysimeters, side slope runoff plots and piezometers, while at the waste rock dump were rain gauge and drainage tipping bucket (fig. 2).

The tipping bucket rain gauges were installed at the centre of the tailings dams and waste rock dump, being mounted on top of a metal rod, 720 mm above the ground. The HOBO logger was used to generate rainfall data. Tensiometer nests were installed at the centre, middle and edge of the tailings dams at depths of 250, 500, 1000 and 2000 mm. They were to monitor the energy status of the tailings dams. The nests were connected to the automatic HOBO logger. Lysimeters were installed at the waste rock dump, at a depth of 2000 mm and an area of 10000 mm^2. The area was connected to a trench, 1400 mm with an outflow pipe and a tipping bucket flow gauge. For the tailings dams, a plastic tube, 340 mm in diameter was fitted at a depth of 700 mm. The readings were recorded by an automatic HOBO shuttle.

The runoff plots were made of metal sheets, gutter, drainage pipe and collection tank. They were installed on the top and side-slope of tailings dams. The surface area of the side-slope runoff was 10000 x 2000 mm, while the tipping bucket was 2 litres. The HOBO logger was used to collect the runoff data. The time domain reflectometry (TDR 100 system) consisted of an electric meter connected to a PC and two rods, placed on the ground for in-situ water content determination at different depths at the edge, middle and penstock of tailings dams. Piezometers were installed in the

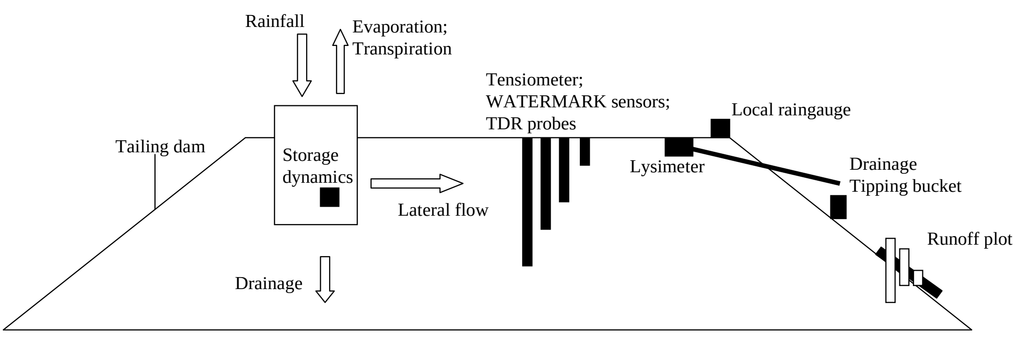

***Figure 2** General experimental set-up for water balance investigation of mine residue deposits in the study areas (Designed by S. Lorentz in 2004).*

tailings dams at the edge, middle and penstock to determine the phreatic water levels. Readings were taken every two weeks from January 2004 to March 2005, using deep water sensors for data generation.

Results and Discussion

The total amount of rainfall recorded for a period of one year at the Kopanang waste rock dump was 431.80 mm with maximum occurring during March (141.20 mm) and minimum in June (0.40 mm). During wet seasons, rapid water movement underground is expected, especially in waste rock dumps. For the Driefontein and Old North tailings dams, the total rainfall for 2004 was 597.40 mm with the highest in December (151.20 mm and 56.00 mm respectively) and minimum in August (0.20 mm) for the former and in January and August (0.00 mm) for the latter.

Initially the tensiometer data frequently showed evidence of a diurnal pattern, apparently, due to loss of contact between the ceramic cup and the tailings pore water. The highest tension recorded was 5800 mm at 250 mm. For the 1000 mm column at the edge of the tailings dam, the capillary pressure head varied between 2800—4000 mm, whereas at the middle and penstock, it was 4000—4800 mm. The tensiometer data indicated that the capillary pressure was higher near the surface, but decreased with depth down to the level of the column.

The value of lysimeter measurements to assess the evapotranspiration and drainage fluxes is dependent on the ability of the lysimeter profile to mimic that of the in-situ profile. The depth of the lysimeter and the hydraulic characteristics of the material determine this ability. The net drainage recorded from the waste rock dump lysimeter at Kopanang amounted to 40% of the rainfall. The low intensity rainfall and events that were less than 15 mm were stored in the fine material of the waste rock dump, while those above 15 mm were discharged (fig. 3). No quantifiable drainage was measured from the lysimeters installed in the tailings dams. For this reason miniature tensiometers were inserted in the tailings lysimeter and this responded better than the standard tensiometer nests. But the data were regularly interrupted by tensiometers loosing contact with the tailings material through drying or excessive tensions in the material (fig. 4).

Runoff data showed that most of the runoff occurred during individual intense rainfall events, thus the intensity at which rainfall occurred determined the runoff as opposed to the volume of rainfall recorded. For example, at Driefontein tallings dam, an overall rainfall of 155.20 mm resulted in 6% of runoff. This is still low runoff rate as compared to one day event on 1st December 2004.

The time domain reflectometry indicated that the upper 100 mm had higher water content than the deeper levels. However, below the 500 mm depth the water content was uniform. The piezometer data indicated that there was a rapid flow of water from the edge towards penstock of the tailings dams.

Water Balance

Water balance elements that characterised hydrological systems of the Kopanang wasterock dump, Driefontein No 3A and Old North Complex No 3 tailings dams were precipitation, rainfall, infiltration, percolation, runoff, evaporation and transpiration. The results of water balance in this study (Table 2) indicated that the inflow was greater than the outflow in all the three study areas. Consequently, there was an increase in the volume of water within the waste material.

Conclusion

The procedures and methodologies that were used for collecting data for water balance determination were the same in all the three mine residue deposits, but the difference was on the characteristics of the specific mine residue deposit.

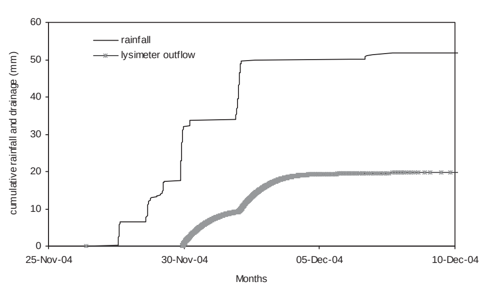

Figure 3 *Drainage from Kopanang waste rock dump showing the relation of rainfall and lysimeter readings*

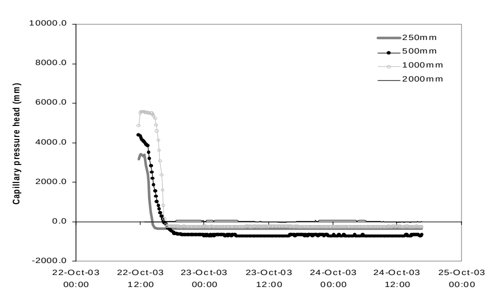

Figure 4 *Drop of tensions due to contact lost between the tensiometer and tailings material at Old North Complex tailings dam.*

Table 2 *Water balance components*

Study sites	***Kopanang waste rock dump***	***Driefontein No 3A tailings dam***	***Old North Complex No 3 tailings dam***
Components			
Imputs (mm/a)			
Precipitation	431.8	597.40	597.40
Inflation	774	265.56	134.40
Percolation	0	48.96	42.84
Total input	**1205.80**	**911.92**	**774.64**
Outputs (mm/a)			
Runoff	570.31	91.50	127.40
Evaporation	498	498	498
Transpiration	0		29
Total output	**1068.31**	**589.50**	**654.40**
Balance	**137.49**	**322.42**	**120.24**

Based on the analysis of the characteristics of mine residue deposits and data obtained from experimental set-up, it was concluded that the water balance differed amongst the earlier and later decommissioned mine residue deposits, suggesting that mine wastes characteristics are determined by the time (period) of decommission and consequently, the water balance components will vary from each site. Relatively few discrete episodes of extreme weather conditions correspond to major water balance components measurement, specifically, infrequent, intense rainfall events were responsible for producing large drainage fluxes even through finer tailings materials.

The water balance indicated that inputs were relatively higher than the outputs in the order of 1205.80, 913.22 and 774.64 mm/annum at Kopanang waste rock dump, Driefontein No 3A and Old North Complex No.3 tailings dams respectively. The Old North Complex No.3 tailings dam that was vegetated had higher output rate (654.40 mm/annum) compared to the non-vegetated Driefontein No 3A tailings dam (589.50 mm/annum).

The use of lysimeter in determining rainwater infiltration through the waste rock dump indicated fast movement into the groundwater at Kopanang waste rock dump due to coarseness of the material. Consequently, the use of lysimeter for the determination of water infiltration in such waste rock dumps is recommended.

Acknowledgement

This was part of a project financially supported by the Water Research Commission (WRC) and administered by Pulles Howard and de Lange (PHD) Incorporated. Their support is highly appreciated. We are also grateful to the staff of the School of Bioresources, Engineering, and Environmental Hydrology (SBEEH), University of KwaZulu-Natal for the opportunity to assist during experimental set-up and also to learn the principles of soil science at their Department.

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