EXECUTIVE SUMMARY

MOTIVATION FOR THE PROJECT

There is a regular need to undertake studies on the pollution potential of mine waste residue deposits in the gold and coal mining industry. Such studies require the integration of water balance models with geochemical models. Although mines do have rudimentary water balances for their waste residue deposits, on close inspection it is almost always found that these water balances contain numerous unmotivated or unvalidated assumptions. While these inaccuracies may be acceptable for an operational mine where the water balance is being actively managed on a daily basis, these inaccuracies seriously hinder the ability to make reliable predictions of post-closure pollution potential and to properly evaluate environmental management / rehabilitation strategies.

The project was, therefore, structured to address the following three major objectives:

1. To develop a procedure and methodology that can be used by mines, researchers and consultants in developing water balances for gold mine waste residue deposits.
2. To ensure that the outcome of the research is transferred to persons active in the field of pollution assessment from gold mine residue deposits.
3. To provide material that can be used by tertiary educational institutions to incorporate into the standard courses, thereby ensuring that new graduates have the knowledge to undertake accurate water balances of such facilities.

The outcome of this proposed research project will, therefore, significantly enhance the ability to undertake reliable and credible assessments of long-term pollution potential from the range of mine waste residue deposits encountered in the gold mining industry.

SITE SELECTION

Potential tailings dams and waste rock dumps to be visited as part of the site selection process were identified by approaching several mining companies. Although not all the mining companies approached were willing to participate, Anglogold and Goldfields agreed to make a number of their facilities available. While it was originally planned to visit 6 potential sites to select 3 for detailed study purposes, the project team visited 10 tailings disposal facilities and 2 waste rock dumps.

From the perspective of this research project, the project team could distinguish the following different types of deposits that should be included in the research project:

1. Gold tailings dam constructed with traditional day/night paddocks and beaching to a central penstock.
2. Gold tailings dam constructed through cycloning.
3. Gold waste rock dump constructed by end-tipping of waste off a conveyor.

The following criteria were used for a mine residue deposit to be selected as a study site:

- A residue deposit with already installed piezometers.
- A site with good historical records.
- A site that has recently been decommissioned.

In evaluating the suitability of various sites, preference was given to sites that already have installed piezometers in their residue deposits with good historical records. At the outset of the project it was intended to select 3 sites representing the 3 different types of facilities listed above, with facilities that have recently been decommissioned. However, suitable type 2 tailings dams were not available and hence the project team had no choice but to use only the type one tailings dam and two of these were selected. The following sites were eventually selected for further study in the research programme:

- West Wits Old North Complex tailings dam (Anglogold)
- Driefontein No 3A tailings dam (Goldfields)
- Kopanang waste rock dump (Anglogold)

EXPERIMENTAL AND MONITORING PROGRAMME

The following tasks which were in line with the agreed experimental set-up, data collection and monitoring program and the additional tasks specified in the revised scope which was presented to and agreed by the WRC Reference Group and the WRC have been implemented:

- **Sampling and analyses**: All the required samples including undisturbed columns of samples from all experimental sites were collected and all samples were characterised for their hydraulic properties.
- **Instrumentation**: Installation of different probes and apparatus were completed successfully and data collection was successful.
- In-situ measurements of saturated and unsaturated hydraulic conductivity measurements at depths of 2000, 1500, 1000, 500, and 250 mm in all of the experimental sites were completed for both Driefontein and Old North Complex tailings dams. Poor tensiometer data generation which was initially encountered was addressed by installing the following additional equipment:
  - Mini tensiometers together with the lysimeter at the Driefontein site,
  - Six surface and side runoff plots at both the tailings dams,
  - Four deep tensiometer nests (500 mm, 1000 mm 4000 and 6000 mm long tubes)
- **Laboratory analyses**: The laboratory measurements of hydraulic properties such as hydraulic conductivity and water retention characteristics were completed.
- **Tailings evaporation:** The actual evaporation from the surfaces at both tailings dams and transpiration at the Old North Complex are clearly dominant factors in the water budget. This part of the study was enhanced by:
  - Installing manual readable lysimeters,
  - Collection of a large vertical sample for laboratory testing of infiltration/redistribution behaviour and
  - Scintillometer measurements during the 2004/2005 wet season.
- **Rapid assessment of the infiltration redistribution process** was instigated by introducing runoff plots on the surfaces and slopes of the tailings dams as well as extracting large samples for testing in the laboratory.
- Substitution of some of the tensiometers with **WaterMark sensors** for monitoring of the energy status of the tailings was implemented successfully and the response of the watermark sensors to capillary pressure of the tailings was assessed.
- **Volumetric water contents** were measured successfully with TDR100 in the tailings materials. However the TDR100 apparatus was damaged and time constraints prevented installation of TDR probes.

The experimental and data collection task was successfully implemented. The data generated by the instruments and laboratory analyses were collated into a database for use in the project. The relationship between the datasets from the different instruments have been analysed and used in the development of the water balances.

DATA ASSESSMENT AND MODELLING

A tailings storage facility (TSF) consists of variably unsaturated porous media with saturated and unsaturated zones. The proportion of the saturated zone decreases and may even disappear with time in decommissioned dams. The hydrological system of gold TSFs for operational and non-operational tailings dams are conceptually different and as such should be studied differently. Decommissioned tailings dams have the following main characteristics:

- They have spatially varying unsaturated zones, which makes simple physical water balance calculations inappropriate.
- Unlike the operational dam where the saturated zone is near the surface, the entire exposed surface of the non-operational dam is variably unsaturated.

In both decommissioned and operational tailings dams, there would be a spatial variation of the water balance components from the edge to the centre of the dam. This is mainly attributed to the moisture available in the profile, which is governed by the presence and depth of the phreatic surface. Thus infiltration at the edge of the pool is maximum and minimum at the centre of the pool whereas evaporation would be maximum at the centre of the pool and minimum at the edge of the pool. The depth of the phreatic surface and rate of drop of this surface is difficult to estimate accurately.

Any attempt to determine the water balance of a decommissioned tailings dam should establish itself largely on the unsaturated flow processes and must account for the impacts of surface flux boundary conditions. The objectives of such studies should be to predict the actual infiltration rates and subsequently the seepage quantity from the tailings dam through, for example, dam toe drains. The unsaturated zone in a tailings dam is characterised by significant spatial variability and relies heavily on the unsaturated flow principles. This, in turn, requires understanding and solving of the surface flux boundary problem – the result of which should be applied to predict the water balance of the entire tailings dam which is a saturated-unsaturated medium.

Full understanding of the following aspects of the hydrological process in a tailings dam is required:

- vertical pore water flow
- the complex physical parameters
- K (Hydraulic conductivity) is a complex function of volumetric water content, which varies with depth
- K is controlled by hydraulic pressure head
- Particle size distribution (PSD) is the primary factor to study for unsaturated flow processes in porous medium
- Complicating factors – mineralogy & preferential flow paths (fractures/cracks and partings on bedding planes)
- The position of the phreatic surface

All these components were studied in this research project and the report presents detailed recommendations on how these studies should be undertaken for cases where a screening-level water balance is required and for cases where a detailed and accurate water balance is required. For a detailed water balance, some form of numerical modelling will be required and the report provides guidance on what models could be used, what parameters need to be determined and how the required data should be collected.

However, the collected data was also evaluated in order to extract simple ‘rules of thumb’ or ‘general rules’ that could be used to more simply determine the facility water balance when a screening-level water balance is deemed appropriate. These general rules that have been derived are listed below.

Water balance general rules for tailings disposal facilities

<u>GENERAL RULE FOR RUNOFF AND INFILTRATION RESPONSE</u>

- Long term analysis:

Runoff = 0.17*Rainfall, except in well vegetated areas or on steep bare side slopes

- Event analysis:
  No runoff for rainfall event less than 5 mm
  Runoff = 0.235*Rain*(1+(API_{-7})/100)

GENERAL RULE FOR EVAPORATION FROM TAILINGS SURFACE

- Long term analysis (Witwatersrand):
  Evaporation = 0.69*Rainfall,

- Event analysis
  Evaporate at potential rate until 40 m pore water tension then
  Reduce to zero after a further 7 days without precipitation

GENERAL RULE FOR PERCOLATION

- Long term analysis (Witwatersrand):
  Percolation = 0.17*Rainfall

- Event analysis
  Derive response from pore water balance

Water balance general rules for waste rock dumps

GENERAL RULE FOR INFILTRATION INTO WASTE ROCK

- Long term analysis (Witwatersrand):
  Percolation = 0.87*Rainfall

- Event analysis
  No drainage for rainfall events less than 15 mm
  Drainage = 1.1*Rain for events with high antecedent conditions
  Drainage = 0.8*Rain for events with low antecedent conditions

CONCLUSIONS AND RECOMMENDATIONS

The research project was successfully completed and a significant amount of data was collected that is applicable to mine residue deposits in South Africa and that can be used to significantly improve the accuracy and reliability of water balances provided for such facilities. As a water balance is an essential precursor to a geochemical assessment, the water balance information provided in this research report will significantly improve the reliability of impact assessments and predictions undertaken for South African mine residue deposits.

Historically, there has been a need to use international research data to enable the apportionment of the various components of a mine water balance, leading to inaccuracies in the water balance and in impact predictions. While the values for infiltration (and subsequent reporting to seepage) of rainfall into tailings disposal facilities is higher than values often and typically used in water balances prepared in South Africa, it is recommended that the values reported in the 'general rules' shown above be used as default values in all screening level assessments to be undertaken for mine residue deposits, unless site=specific data collection exercises (done in accordance with procedures set out in this report) provide solid evidence for the use of alternative site-specific values.