Risk-based Modelling of Soil Cover for Rehabilitation Planning of Coal Discard Facility in South Africa to Achieve Groundwater Quality Criteria

Albert van Zyl[1] Philip Barnard[2]

[1]Terrasim CC, Suite 87, Private Bag X8, Elarduspark, 0047, South Africa, avanzyl@terrasim.co.za

[2]Golder Associates Africa (Pty) Ltd., P.O. Box 6001, Halfway House, 1685, Midrand, South Africa

Abstract

Costly covers with a geo-synthetic liner system are required for discard facilities according to waste related legislation in South Africa. A risk-based approach is allowed to determine the requirements for an alternative pollution control barrier for mine residue facilities on a case-by-case basis.

Risk-based source-pathway-receptor modelling for an unlined discard facility optimised the soil cover design to achieve set groundwater TDS quality targets. It was concluded that thick soil covers can be a cost-effective alternative option that can outperforms a geo-synthetic liner with a growth medium in the long-term (>140 years) in mitigating seepage impact.

Keywords: Mine residue deposits, Outcomes based modelling**,** Store and release covers, **Source-pathway-receptor modelling,** Groundwater seepage impact mitigation

Introduction

Thick soil covers over coal discard facilities in arid and semi-arid regions are considered an important cost-effective measure to mitigate the impacts of leachate seeping into groundwater. With the National Environmental Management: Waste Amendment Act 26 of 24 of South Africa mine residue deposits and stockpiles were included in the definition of waste under the Waste Act. This results in a requirement for costly covers that include a geo-synthetic liner system for unlined discard facilities. In a statement released by the Department of Water Affairs and Sanitation of South Africa in June 2016, the Department conceded that they will consider a risk-based approach to determine the requirements for an alternative pollution control barrier for mine residue facilities on a case-by-case basis. When a soil cover is motivated as a cost-effective alternative option, the applicants must demonstrate that the influence of leachate on the receiving environment will be acceptable. This primarily points towards the achievement of a specified groundwater quality. An example of risk-based source-pathway-receptor modelling described in this article demonstrates a cover design process to meet a set quality target in the receiving groundwater at a discard facility.

The Mean Annual Potential Evaporation (Penman-Monteith equivalent (Allen et al. 1998)) of 1710 mm/yr. for the study area exceeds Mean Annual Precipitation (MAP) of 430 mm/yr by 4 times. Rainfall is highly seasonal with 95% of annual rainfall occurring during the October to April rainy season. According to INAP (2009), this climate is suitable for a store and release cover.

Qualifications and Limitations

Receiving Groundwater Environment is groundwater directly below and within 100 m of the final rehabilitated footprint of the discard facility, and includes the monitoring boreholes. TDS (total dissolved solids) concentrations represent leachate concentrations as it enters the receiving groundwater. Further dispersion, deposition or dilution of TDS in surrounding areas was not considered.

Acceptable Groundwater Quality was defined for TDS as the constituent of concern. Values of 1000, 2400 and 3400 mg/L as acceptable, tolerable and unacceptable concentrations were considered according to the upper limits of the DWAF (1999) water quality guidelines for domestic use. In general the background water quality was not good. Some monitoring boreholes showed natural TDS concentrations exceeding the 1000 mg/L target for acceptable drinking water quality. Hence the target value used for this study was the tolerable level of 2400 mg/L TDS.

Stable Climate Conditions were assumed for this study. While, on a regional level, there are indications that the 430 mm MAP used in this study has decreased, and is likely to decrease further due to climate change, there was not sufficient local data available to accurately model changes in precipitation, evaporation and temperature into an uncertain future.

Assumptions

*Spatial Representativeness***.** Moisture and contaminant flow profiles are spatially representative of the flows and contaminant leaching that would occur in the rehabilitated discard facility. Numerical vadose zone profiles defined from six monitoring boreholes immediately surrounding the facility and other available information represented moisture and contaminant flows that would occur through the vadose zone below the discard facility.

*Material Representativeness***.** Hydraulic and geochemical properties of materials used for modelling are spatially representative of the cover materials and of the coal discard. This is a fair assumption as a wide range in cover materials, coal discard and coal samples were collected, and analysed.

*Material Hydraulic Properties***.** Water retention and permeability of the cover materials and coal discard were determined by the particle size distribution and not by the formation of clods or cracks. Proposed cover materials and discard are not prone to the development of soil structure (clods).

*Preferential Flow***.** Simulated matrix flows through the cover assumed no preferential flows, such as flow through cracks. Proposed cover materials are not prone to the development of desiccation cracks and have a low risk for increased percolation rates associated with preferential flows through desiccation cracks.

*Geochemical Controls***.** Geochemical solubility controls within the dump were determined in laboratory kinetic tests (Naicker *et. al* submitted).

*Interstitial Water Contaminant Concentrations***.** Interstitial (pore water) TDS concentrations remained constant during active discard. Concentrations will initially vary post-closure, increasing with reduced percolation rates.

*Declining Source-term***.** With limited aeration below a cover layer, the generation of contaminant loads will decrease and contaminant TDS in interstitial water will become leached out with infiltrated rainwater over the long post closure period simulated in this study. TDS concentrations (and TDS loads) were simulated to decline over time.

Synthetic liner degradation. Ambient temperatures of above 40 degrees Celsius decrease the half-life of the impermeable characteristic of the liner to 70 years. This combined with the presence of hot areas on the discard facility, due to spontaneous combustion, reduces the long term suitability of a synthetic liner to the extent that perpetual replacement could be required.

Methods

Integration of a number of models and processes was required for this study, in an iterative process that repeatedly refined the design to achieve a desired long-term water quality impact with the most cost effective cover design (Figure 1).

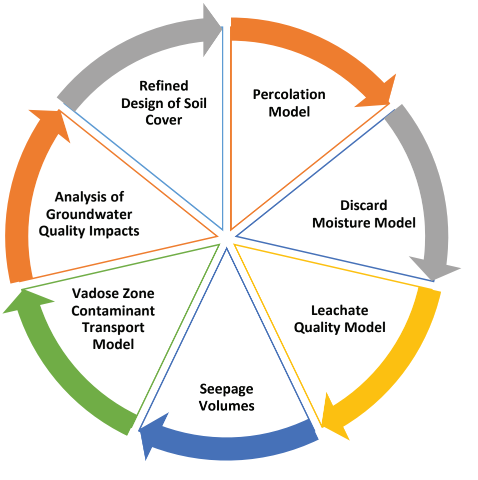

Figure 1 *Work Flow Chart.*

Percolation Modelling used the SVFlux finite element unsaturated flow model developed by SoilVision Systems (2016) to predict net percolation (moisture ingress) rates into the discard facility. Percolation was modelled for an uncovered discard facility, store-and-release soil covers and for a geo-synthetic liner system with a growth medium layer, and predictions were based on rainfall, climate, material hydraulic properties, vegetation characteristics and cover configuration. Climate model inputs included 40 years of daily rainfall recorded at site and available daily climate data. Hydraulic properties of soil cover materials and growth media available on site and of the discard were used as model input, as well as expected vegetative cover characteristics. Outputs of the model are net percolation rates into the discard facility.

Liner Leakage Modelling used the Landsim probabilistic liner leakage model (Golder Associates 2007) to predict the leakage rates from the cover with a geosynthetic liner system. Liner leakage was predicted based on predicted net percolation rates for the 30 cm growth medium, properties of the geo-composite drain, base slope and length of the upper surface and outer wall, as well as the defect rates, onset and rate of degradation of an installed geomembrane in ambient temperatures exceeding 40 degrees Celsius during summer. Predicted liner leakage rates were used as net percolation rates into the discard facility for the geosynthetic cover.

Discard Moisture Modelling used predicted net percolation rates together with information on the age, depth and profile of discard material. Moisture contents determined for samples collected from test pits at the upper surface and outer wall of the facility provided a base-line of gravimetric moisture contents within discard profiles. This provided some validation of the moisture contents predicted by the unsaturated flow model.

Leachate Quality Modelling used the ChemFlux finite element unsaturated contaminant transport model developed by SoilVision Systems (2016a) interactively coupled with SVFlux unsaturated flow model was used to predict a time series of interstitial/pore water TDS concentrations in the coal discard. Inputs included analytical results of humidity cell kinetic tests (Naicker *et. al* submitted) and of predicted time series of moisture content in discard profiles.

Seepage Volumes reporting to the base of the facility were derived from the predicted net percolation rates, facility height and footprint area, including incremental increase in the discard footprint. Flow through the facility is retarded due to discard moisture retention, which was accounted for in the modelling.

Vadose Zone Contaminant Transport Modelling simulated seepage through the unsaturated pathway (represented by the soil profile and by the weathered- and fractured zones between the base of the discard facility and the groundwater table). Model results predict a time series of TDS loads that report to the groundwater over time. Model verification used hydraulic properties of materials, predicted seepage rates, contaminant loads and vadose zone characteristics as inputs into ConSim (Golder 2005) and ChemFlux contaminant transport models. The predictions of these models were compared to measured groundwater TDS concentration at six monitoring boreholes immediately surrounding the facility.

Analysis of Receiving Groundwater Quality Impacts was limited to the comparison of the results of vadose zone contaminant transport models with groundwater quality objectives, represented by target TDS values. For the risk based (or outcomes based) approach, the cover design was revised and the facility re-modelled until the quality objectives were met.

Design or Re-design of the Soil Cover was the central element of all modelling. Initial cover design options included rain/water-shedding covers as previously regulated in South Africa, and store and release covers composed of the wide range of soils available on site. In this arid to semi-arid climate, design options became limited to thick single- and dual-layer store and release covers constructed with soils that have a low risk of undesirable structure development.

Results

Time series of TDS seepage loads were generated (modelled) for:

- Conditions prior to discard placement based on natural groundwater recharge rates and background TDS loads.
- Progressive discard placement over the footprint of the facility.

- Post closure conditions with the following cover scenarios:
  - Base case representing an uncovered facility
  - Store-and-release cover, and
  - Cover that includes a 30 cm growth medium and geo-synthetic liner system.

The TDS seepage loads time series into the receiving groundwater were used to predict the impact of discard leachate on:
- Six monitoring boreholes immediately surrounding the facility, for both the pre-discard placement conditions and the period of discard placement.
- Facility footprint for both the pre-discard placement scenarios and period of discard placement, as well as for post closure with various cover scenarios.

Predictions of Groundwater TDS Concentrations at Monitoring Boreholes closely matched monitored TDS concentrations and minimum refinement of the models was required. The break-through of discard leachate into the receiving groundwater was retarded by 6-8 years at the footprint area underlain by basalt with a shallower (10-12 mbgl) resting groundwater table. Discard placement commenced in these areas providing sufficient time for leachate to seep through the vadose zone. Peak TDS concentrations have been reached at areas where discard placement started. TDS interstitial water concentrations of the vadose zone have equilibrated to discard leachate concentrations.

Break-through of leachate through the vadose zone was not predicted for the area underlain by sandstone by 2016, which is confirmed by monitored TDS concentrations. This can be ascribed to the long travel time for the discard leachate through the thick (8-9 m) soil horizon and relatively thick weathered zone (8 to 20 mbgl) to the relatively deep (22-41 mbgl) groundwater table. Future leachate break-through was predicted.

Predictions for the cover that includes a geo-synthetic liner show that water quality initially improve comparable to natural (ambient) TDS concentrations, which indicate an over-design (Figure 2). The geo-synthetic liner will, however, degrade due to high ambient temperatures. Increased TDS concentration in the groundwater is delayed for at least 120 years, but not significantly mitigated over the longer period of seepage impact (centuries).

Predictions for thick store and release cov-

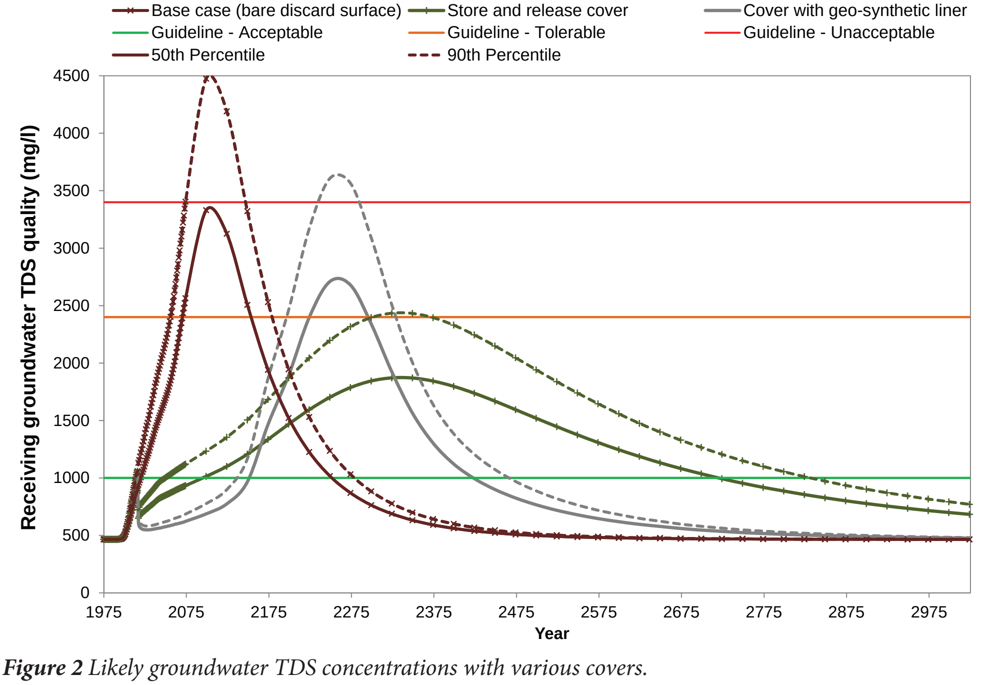

***Figure 2** Likely groundwater TDS concentrations with various covers.*

ers showed that the soil cover outperforms the costly cover with a geo-synthetic liner from about 140 years when liner degradation becomes significant (Figure 2). The thick store and release cover mitigates the impact of the facility to target groundwater quality levels over the full period of seepage impact.

At an effective mean annual seepage rate of 16 mm/yr (3.2% of MAP), source-pathway-receptor modelling indicated that groundwater quality targets can be met. Covers were designed to achieve this target net percolation rate. The modelling of covers showed that the required cover thickness is determined by soil characteristics, level of rehabilitation and probability that good vegetation cover will be established and maintained in the long-term.

Conclusions

The recommended cover with a geo-synthetic liner may improve the groundwater quality to better than natural (ambient) TDS concentrations for the first 120 years, which indicates an over-design. For this facility, a thick store and release cover outperforms a cover with a costly geo-synthetic liner over the long period (centuries) that seepage impact must be mitigated. Construction of store and release covers instead of covers with geo-synthetic liner also represents a substantial cost saving (> 50%).

Source-pathway-receptor modelling, based on site- and facility specific conditions, is necessary to demonstrate that the required groundwater quality criteria can be met.

Acknowledgements

The authors thank Leon Bredenhann for guidance on relevant legislation in South Africa.

References

Allen R. G., Pereire L.S., Raeas D. & Smith M. (1998) Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56, Food and Agriculture Organization of the United Nations, Rome, Italy.

Department of Water Affairs and Forestry (1999) Quality of domestic water supplies. Volume 1: Assessment Guide (second edition), Water Research Commission Report No.: TT 101/98, Water Research Commission, Pretoria, South Africa.

Golder Associates (2007) LandSim Version 2.5.17. Golder Associates UK Ltd.

Golder (2005) Contamination Impact on Groundwater: Simulation by Monte Carlo Method. UK Environment Agency R&D Publication 132.

Naicker K, van Zyl A and Barnard P (Submitted). Prediction of Seepage Quality from Coal Discard Facility in a Semi-Arid Climate, ICARD | IMWA | MWD 2018 Conference, Pretoria, South Africa.

INAP 2009. The International Network for Acid Prevention. Gobal Acid Rock Drainage Guide (GARD Guide), http://www.gardguide.com.

SoilVision Systems 2016. SVFlux Saturated / Unsaturated Finite Element 1D/2D/3D Seepage Modelling Software. SoilVision Systems Ltd., Saskatoon, Canada.

SoilVision Systems 2016a. ChemFlux Saturated / Unsaturated Finite Element 1D/2D/3D Seepage Modelling Software. SoilVision Systems Ltd., Saskatoon, Canada.