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Infiltration of Rain into Constructed Landform Profiles

Tropicana Gold Project

AngloGold Ashanti Australia Ltd
and
Independence Group NL

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EXECUTIVE SUMMARY

The proposed Tropicana Gold Project (TGP) is located 330km east north-east of Kalgoorlie on the western edge of the Great Victoria Desert. The TGP is a joint venture (JV) between AngloGold Ashanti Australia Limited (70%; manager) and Independence Group (30%).

Mining at the proposed TGP will involve stripping and stockpiling of topsoil and subsoil (largely dune materials) and excavation and stockpiling of waste materials. A proportion of these waste materials will be potentially acid-forming (PAF) and will need to be carefully managed to minimise the risk of acid generation and liberation into the surrounding environment. The planned capping profile – based on the expectation that the PAF material can be adequately managed by co-dumping it with non acid-forming (NAF) material at depth – involves covering the co-dumped NAF and PAF with a 10.0 m thick layer of NAF materials, followed by placement of a further 1.0 m of growth medium over the NAF layer.

Landloch was engaged by AngloGold Ashanti on behalf of the JV to assess the potential for rain to infiltrate through the capping profile and interact with the co-dumped NAF and PAF materials. The WAVES model was used to simulate water movement in the capping profile using climate data for the region. Four different capping materials were used in the WAVES simulations.

Simulated drainage from the vegetated capping layer was predicted to be insensitive to vegetation vigour and soil hydraulic conductivity, as vegetation effectively has sufficient opportunity between rainfall events to utilise all rainfall that infiltrates into the growth medium. Further, water is lost from the profile through soil evaporation.

The WAVES model predicts that sufficient water holding capacity exists in a 1.0 m thick layer of vegetated growth medium to essentially store and utilise all rainfall that occurs. Drainage of rain from the soil surface to depths below the capping profile (1.0 m of growth medium and 10.0 m of NAF) was not predicted to occur over the 100 years simulated when vegetation was present.

WAVES simulations predict that – for the topsoil of lowest soil water holding capacity - failure to establish vegetation within 5-10 years of construction will result in rain infiltrating to soil profile depths at which neither soil evaporation nor plant transpiration can extract it from the profile. If this situation (no vegetation within the first 5-10 years) occurred and continued indefinitely, deep drainage would continue and would eventually reach the underlying NAF/PAF materials.

Further investigations should be undertaken once mining has commenced and when actual NAF materials are available. These investigations should confirm the properties of the NAF and validate the modelling performed in this report that used generic properties for the NAF materials.

1 BACKGROUND

1.1 Tropicana Gold Project

The proposed Tropicana Gold Project (TGP) is located 330km east north-east of Kalgoorlie on the western edge of the Great Victoria Desert (Figure 1). The TGP is a joint venture between AngloGold Ashanti Australia Limited (AngloGold; 70%; manager) and Independence Group (30%) The project area is located within the Great Victoria Desert Bioregion (Figure 1).

Figure 1: *Location of the Tropicana Gold Project relative to the Great Victoria Desert Bioregion (bounded in blue), and selected localities.*

The climate is arid, with mean annual rainfall of approximately 202 mm[1]. The majority of rainfall tends to fall during the summer and autumn months. Daily rainfall depths range from 19 mm for events with a one year recurrence interval, 39 mm for a one in ten year event, to 59 mm for a one in one hundred year event. The TGP is likely to experience an average of 78 rain days per year with 74 of these rain days (95%) yielding less than 10 mm/day. Given that so few rain events of significant size occur, there is little opportunity for runoff or for penetration of infiltrated water to depths below the soil profile. Most of the rain that falls is lost to vegetation interception, soil evaporation, or vegetation transpiration.

The prevailing landscape includes linear aeolian dunes and swales covered by open woodlands with some ground cover. Soils in the region typically have sandy or sandy loam texture and are non-saline. Soils in the swale areas tend to have higher clay contents compared to soils located in the dunes (particularly on the surface of the dunes).

1.2 Potentially-acid-forming materials

Mining at TGP will involve stripping and stockpiling of topsoil and subsoil (largely dune materials) and excavation and stockpiling of the waste materials. Waste materials will be a combination of weathered saprolite, gneiss, and schist materials, and fresh rock comprised mainly of granitic gneisses. Potentially-acid-forming (PAF) materials are likely to be generated over the life of the project and will need to be effectively managed within the constructed waste landforms such that the risk of acid generation and liberation into the surrounding environment is minimised.

Currently, the mine plan manages PAF material by co-dumping it with non-acid-forming (NAF) material and capping this mixture with:

a) 10.0 m of NAF waste rock materials followed by,
b) 1.0 m of growth media (dune materials).

The current suggested capping profile – based on the expectation that the PAF materials can be adequately managed – is shown in Figure 2.

The dune materials will form the basis of the growth medium for the capping profile. NAF materials placed between the co-dumped NAF/PAF materials will act as a “buffer zone” to limit water infiltration and air penetration to the PAF at depth.

[1] Rainfall values reported are based on synthetic climate data generated for the Tropicana Gold Project site. This data was derived using stochastic techniques that are outlined in this report.

Figure 2: *Current capping profile to be constructed at TGP.*

1.3 Scope of works

Landloch was engaged by AngloGold on behalf of the JV to assess the potential for rain to infiltrate through the planned capping profile and interact with the co-dumped NAF/PAF materials. To meet this requirement, the WAVES model was used to simulate water movement in one-dimension using a 100-year climate sequence for the region. Four different growth media (all dune materials) were used in the WAVES simulations.

2. PROPERTIES OF CAPPING MATERIALS

Samples of the growth media used as part of the modelling were analysed for soil physical properties required for the simulation of soil-water-plant interactions. Samples of four sandy/sandy loam materials were provided to Landloch by AngloGold staff for analysis. Dune materials at TGP typically contain 50-60% coarse sand, 30-40% fine sand, 1-2% silt, and approximately 10% clay. Swale materials can contain as much as 20% clay, with the coarse sand fraction reducing to accommodate the increased clay.

Properties of the NAF materials were unable to be measured (no mined NAF material currently exists), and values of the physical properties were derived based on:

1. published values for soil water properties of a fractured rock profile, and
2. saturated and air dry water content values measured by Landloch on similar rocky profiles.

Importantly, it was assumed that the NAF materials had

a) very high saturated hydraulic conductivities, and
b) very low moisture holding capacity.

Further investigations should be undertaken once actual NAF materials are available to confirm that their properties are similar to those assumed in this report. Further soil water balance modelling should also be conducted using these data to validate the modelling performed using generic properties for the NAF.

Materials with these properties are free draining, and have little ability to hold large volumes of water against gravitational forces that act to move water downwards. The soil physical properties of each material used in the assessment of rain infiltration are provided in Table 1.

Table 1: *Properties of materials required for rain infiltration assessment.*

Material	Moisture contents at various soil suctions					K_{sat} (m/day)
	Saturation (%)	10kPa (%)	33kPa (%)	100kPa (%)	Residual (%)	
TPRC 182	39.79	11.49	6.53	6.00	5.40	8.71
TPRC 204	39.64	5.99	3.23	2.92	2.20	10.89
TPRC 250	33.44	13.73	6.10	4.40	3.40	10.51
TPRC 291	38.48	15.69	10.86	8.51	4.30	2.63
NAF	30	3	2	2	2	10

2.1. Impact of soil properties on water movement

2.1.1. Soil texture

Sandy soils generally have larger and less tortuous pore spaces than clay soils. Consequently, sandy soils tend to hold most of their water at comparatively low soil suctions (Figure 3) relative to clay soils. Soil suction is low when soils are close to saturation and increases as soils dry.

Sandy soils also tend to have less water available to plants. Most of the pores are large, and drain freely as the soil dries from saturation. Sandy soils typically have smaller total pore space volumes. Figure 3 shows that for the same soil suction, the water content of a sandy soil is typically lower than that of the clay soil.

In arid environments where significant rainfall events are infrequent, soil profiles are typically dry and able to hold water readily. In comparison, in wetter environments, soils are wetter for longer periods, and the chance of rain occurring on already wet soil is higher. In addition wetter areas tend to have a larger proportion of significant rainfall events. Hence, the probability of deep drainage occurring is higher in wetter areas.

For the TGP region, a 1 in 10 year daily rainfall event is approximately 39 mm. The growth media at TGP can typically hold approximately 80-100 mm of water per 1.0 m of soil – assuming that the receiving soil is initially dry (Table 2). TPRC 204 is a notable exception, and is only able to hold approximately 30-40 mm per 1.0 m of soil. Assuming that preferential flows do not occur (in reality they do occur, but preferential flows are currently impossible to effectively model), it is unlikely that significant drainage of water will occur in the short to medium term (ten year period) from most soils used to construct the soil profile.

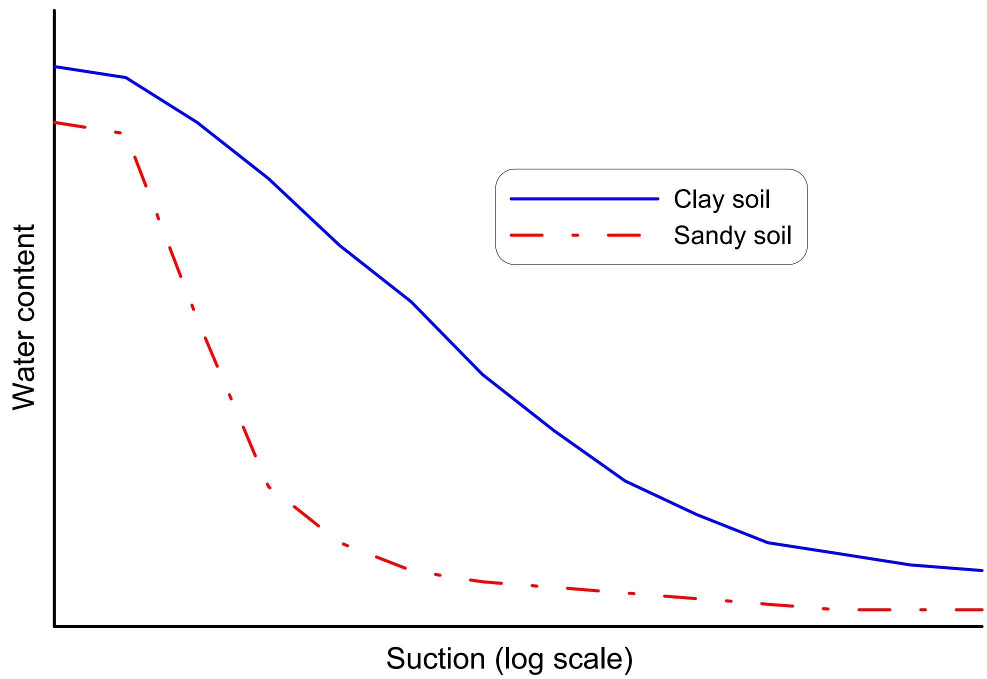

Figure 3: *Relative patterns of soil water content vs. suction for sandy and clay soils.*

2.1.2. Moisture content, suction, and hydraulic conductivity

The impact of soil texture on soil water holding characteristics is extremely important when considering water movement in soils (both upwards and downwards movement).

Water moves within a soil when there is a potential difference in energy – often called soil suction. Water will move from areas of low suction (wet soil) to areas of high suction (dry soil). While it is obvious that water moves downwards through soil, water is also able to move upwards through a soil when a sufficient gradient in suction and sufficient volume of water are present. Dry soils – commonly found in arid environments such as this site –

have discontinuous films of water within their pore spaces, and movement of water (upwards or downwards) is therefore greatly limited when soil is dry.

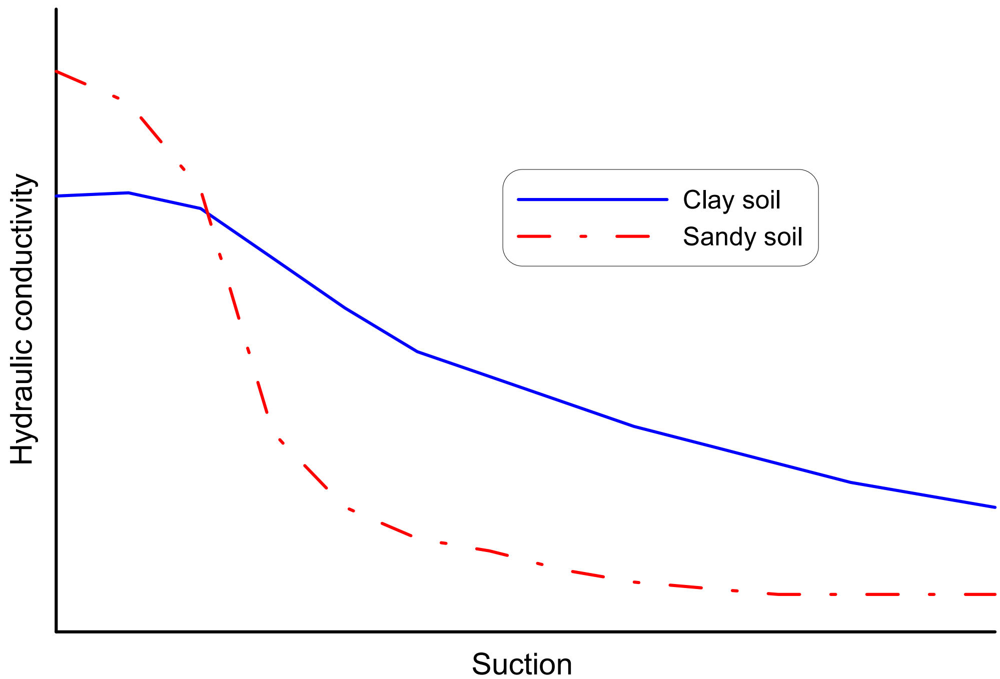

Figure 4: *Representation of the variation of hydraulic conductivity with soil suction.*

The rate of water movement through a soil is described by its hydraulic conductivity. Hydraulic conductivity varies with soil water content, being greatest when the soil is saturated, and declining as the soil becomes drier due to reduction in the thickness and continuity of the water films in the soil pores. Consequently, the variation in hydraulic conductivity with soil water content is an important consideration for water movement in soils, and is strongly affected by soil texture (Figure 4). It is closely related to the variation in soil water content with suction, and Figure 4 shows that sandy soils – which hold less water at high suctions than clay soils – show extremely large decreases in hydraulic conductivity as the soil dries. Sandy soils also tend to have higher hydraulic conductivities at low suctions due to the presence of less tortuous and larger diameter flow paths within the soil.

3. WAVES MODEL

3.1. Overview

The WAVES model is described in detail by Zhang and Dawes (eds, 1998). Briefly, WAVES is a one dimensional energy, water, carbon, and solute balance model. It was designed by CSIRO and has been under development since 1993. The model has been calibrated and validated using data collected from numerous sites, across Australia and internationally.

It is a daily time step model that enables consideration of the interactions between the atmosphere, vegetation and soil systems. WAVES is capable of modelling transpiration and CO_2 assimilation for one or two vegetation layers. Soil infiltration, runoff, and drainage are described by the Richards equation using a numerical solution outlined by Broadbridge and White (1988).

At the beginning of each day, climate variables are set within WAVES. The current values of leaf area are then used to perform the energy balance and set limits on the availability of water to vegetation for the day. Soil evaporation is also calculated at this stage. Vegetation growth is then modelled with gross carbon assimilation, respiration and transpiration, and root growth being calculated. Soil boundary conditions are used to solve the Richards equation, which partitions effective rainfall into runoff, infiltration, drainage, and stored water.

WAVES requires parameterisation to adequately describe the soil, vegetation, and climate processes that determine the state of the balances modelled.

3.2. Model parameters

3.2.1. Climate

Daily climate data are needed for the WAVES model. For each day of simulation, WAVES requires data for the following climate parameters:

- Precipitation (m),
- Precipitation duration (hrs/day),
- Average minimum temperature (ºC),
- Average maximum temperature (ºC),
- Vapour pressure deficit (hPa), and
- Solar radiation (kJ/m²/day).

It is very uncommon for complete historical records of all these climate parameters to exist at the site to be modelled. Precipitation duration is particularly difficult to obtain and must be sourced and processed separately (and laboriously) from rainfall intensity datasets. Sets of observed daily climate data are also invariably discontinuous, often for extended periods of time when observation equipment is maintained or repaired, when observers are not present at the site, or when observation sites are moved.

Climate data for the TGP region were sourced from a) SILO patched point data set, and b) Bureau of Meteorology rainfall intensity stations.

Daily rainfall, temperature, radiation, and vapour pressure data were sourced from the SILO patched point data set. This dataset is derived from Bureau of Meteorology observation stations. Observed daily data from nearby weather stations have been gridded (approximately 5 km square grid), and missing data patched using values from nearby stations or average data where data for the area is completely missing. Rainfall duration data were sourced from the Bureau of Meteorology's rainfall intensity station at Leonora. These disparate data sources were used to produce a 100-year synthetic climate sequence using the CLIGEN stochastic weather generator. CLIGEN has been extensively assessed for a wide range of climates in Australia (Yu, 2003). Yu (2003) also contains a detailed description of CLIGEN. Details on the development of the climate file for the TGP can be found in Appendix A.

The synthetic climate sequence preserves the frequency and size of rainfall events and the monthly climate averages (rain, temperature and solar radiation), and can be expected to interact with the other model parameters within WAVES in the same way that observed data would.

The majority of rainfall tends to fall during the summer and autumn months. The site experiences very hot summer days and mild nights, while winter months can be quite cold. Daily rainfall depths at TGP are highly variable (Figure 5), with larger rainfall events being infrequent.

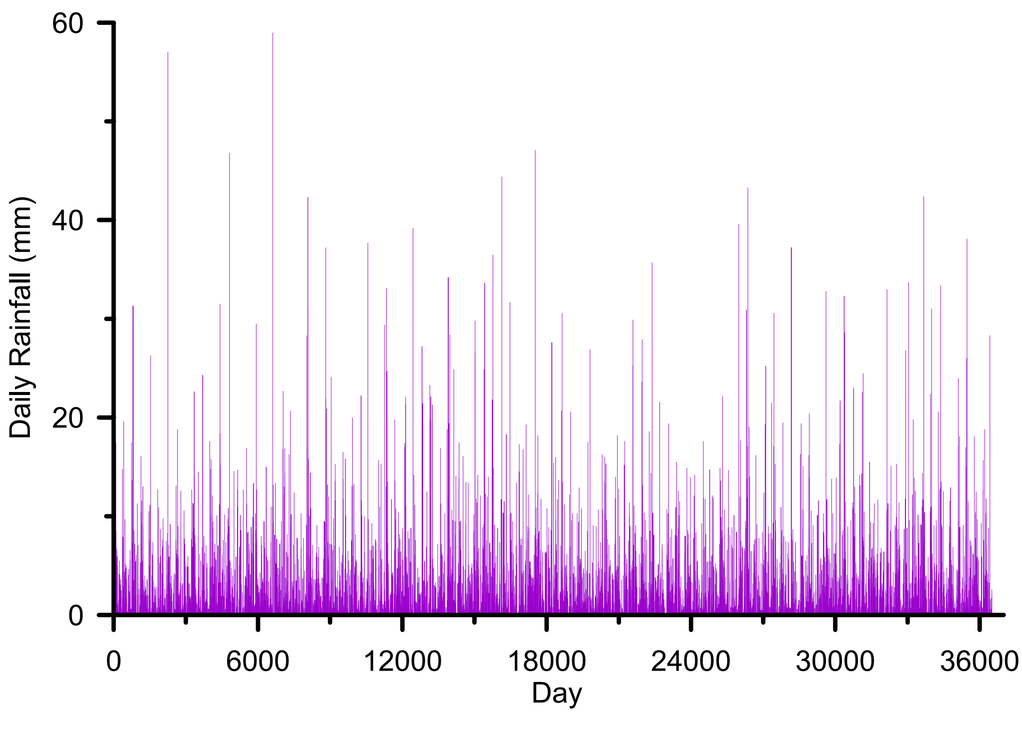

Figure 5: *Daily rainfall events for 100 years of climate file used by WAVES.*

Figure 6 shows the magnitude of daily rainfall events for differing average recurrence intervals (ARI). The majority of rainfall events are small, with only one event per year (on average) yielding as much as 19 mm. The largest rainfall event in the 100-year file is 59 mm.

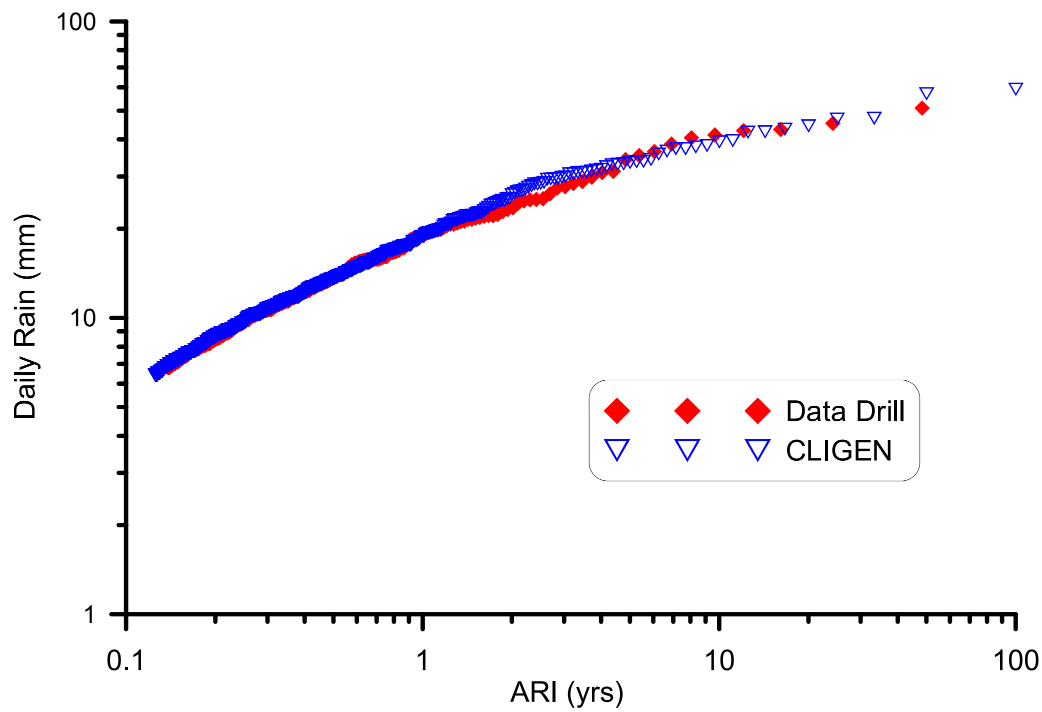

Figure 6: *Daily rainfall compared with its average recurrence interval for the climate file used by WAVES (CLIGEN data) and for BOM Data Drill dataset.*

3.2.2. Vegetation

Vegetation forms the link between the soil and atmosphere. WAVES utilises 26 vegetation parameters for both the understorey and overstorey vegetation. Data for parameters were sourced from available literature. Dawes *et al.* (1998) provide an excellent summary of typical parameter values based on an extensive literature survey and measurement of values during several field experiments.

Understorey parameter values were sourced from Dawes *et al.* (1998) who give data for C_3 pastures for a range of productivity levels. Low parameter values for leaf and root respiration, rainfall interception, maximum soil suction, and nutrient requirements were used to reflect the arid environment at TGP. Dawes *et al.* (1998) also provide overstorey vegetation parameters for an arid eucalypt woodland, located near the New South Wales, South Australia, and Victoria borders. These parameter values were largely adopted. Interestingly, the sensitivity analysis shows that drainage is relatively insensitive to plant growth because of the infrequency of larger rain events that cause drainage, and the typically dry moisture status of the soil receiving that rain when it occurs.

The WAVES model was calibrated by fitting modelled overstorey and understorey carbon storage with reported values sourced from the Australian Natural Resources Atlas (Australian Government, 2008). The Australian Natural Resources Atlas reports total annual carbon storage for the TGP region of 0-10 t/ha. Maximum (carbon) production rate and specific leaf area for the overstorey and understorey vegetation were adjusted until carbon stored in vegetation approached 10 t C/ha. Vegetation parameters used in the WAVES modelling are listed in Table 2.

Table 2: *Vegetation parameters of overstorey and understorey vegetation adopted for use by WAVES.*

Parameter	Unit	Overstorey Vegetation	Understorey Vegetation
1 minus canopy albedo	-	0.75	0.85
1 minus soil albedo	-	0.80	0.85
Rainfall interception coefficient	m/day/LAI	0.0001	0.0001
Light interception coefficient	-	-0.40	-0.65
Maximum production rate	kg/m²/day	0.009	0.008
Stomatal conductance model slope	-	0.9	0.9
Maximum plant available soil water suction	m	-300	-150
Integrated rate method weighting for water	-	2.1	2.0
Integrated rate method weighting for nutrients	-	0.3	0.2
Ratio stomatal:mesophyll conductance	-	0.2	0.2
Temp. when growth rate is ½ of optimum	°C	15.0	15.0
Temp. when growth rate is optimum	°C	25.0	20.0
Year day of germination	-	-1	-1
Degree-daylight hours of growing season	-	-1	-1
Saturation light intensity	µmoles/m²/d	1000	1000
Maximum rooting depth	m	5.00	2.00
Specific leaf area	LAI/kg	40.0	30.0
Leaf respiration coefficient	-	0.0004	0.0005
Stem respiration coefficient	-	0.0001	-1.000
Root respiration coefficient	-	0.0001	0.0001
Leaf mortality rate	-	0.0001	0.0001
Above-ground partitioning factor	-	0.25	0.60
Salt sensitivity factor	-	0.6	0.6
Aerodynamic resistance	-	10.0	30.0
Crop harvest index	-	0.0	0.0
Crop harvest factor	-	0.0	0.0

3.2.3. Soils

Soil-based parameters used in WAVES define the capping profile (layering) and the way in which water movement will occur. WAVES requires information on soil layer depths as well as the following information for each layer:

- **Initial soil water suction** – The growth media and NAF materials were assumed to be relatively dry, as would be expected from recently disturbed stockpiled materials in an arid environment. Initial soil water suction was set at -30 m. Initial soil water suction has little impact on long-term water balances in arid regions.
- **Initial root carbon mass** – Used to define existing root structure within the soil at the start of simulation. Initial root carbon was assumed to be 0.01 kg/m² to a depth of 0.1 m. Below 0.1 m, root carbon was assumed to be zero. Initial root carbon mass has little impact on long-term vegetation carbon storage.

Soil hydraulic properties are required for each material type. These data are determined from each material's moisture retention curve. WAVES uses the Broadbridge and White numerical solution of the Richards equation (Broadbridge and White, 1988; White and Broadbridge, 1988). A non-linear function is fitted to measured values of soil suction and moisture content using four parameters:

i) Saturated soil water content, θ_s;
ii) Residual water content, θ_r – water content at which vegetation can no longer extract water;
iii) Macroscopic capillary length, λ_s; and
iv) Shape factor, C – the shape factor changes the slope of the fitted curve.

The Broadbridge and White (1988) equation is:

$$\Psi(\Theta)/\lambda_s = -(1-\Theta)/\Theta - C^{-1} \,.\, \ln\{(C-\Theta)/[(C-1)\Theta]\} \qquad \text{where } \Theta = (\theta - \theta_r)/(\theta_s - \theta_r).$$

$\Psi(\Theta)$ is the soil suction at a moisture content defined by Θ.

Moisture retention curves fitted to measured values of soil suction and water content using the Broadbridge and White numerical solution are given in Appendix B.

Saturated hydraulic conductivity (K_{sat}) of material is also required, and was measured using the constant head method outlined in Klute (ed., 1986). The Broadbridge and White numerical solution then adjusts actual hydraulic conductivity based on saturated hydraulic conductivity, soil suction, and moisture content. Table 3 lists the hydraulic parameters used for the four different growth media samples and the NAF material.

Table 3: *Hydraulic properties of materials sampled from Tropicana Gold Project and adopted for use by WAVES.*

Material	θ_s (%)	θ_r (%)	λ_s (m)	C (-)	K_{sat} (m/day)
TPRC 182	39.79	5.40	0.100	1.040	8.713
TPRC 204	39.64	2.20	0.075	1.250	10.892
TPRC 250	33.44	3.40	0.215	1.100	10.506
TPRC 291	38.48	4.30	0.400	1.500	2.626
NAF	30	2	0.020	1.001	10

3.2.4. Other parameters

WAVES requires input regarding the nature of the lower soil boundary. It was assumed that the lower boundary of the capping profile was free draining and did not interact with the groundwater.

4. WAVES SIMULATIONS

Water balance simulations using the planned capping profile were performed using the 100-year climate sequence for TGP. Simulations performed include:

1. Sensitivity analysis of selected input parameters in terms of their impact on predicted deep drainage. The analysis used TPRC 182 as the growth medium;
2. Current capping profile using TPRC 182, TPRC 204, TPRC 250, and TPRC 291 as growth media. Vegetation was assumed to be present. Simulations were performed for a 100-year period, with assessment of deep drainage from the NAF layer (i.e. from 11.0 m below the constructed soil surface) made after 100 years.
3. Current capping profile using TPRC 182, TPRC 204, TPRC 250, and TPRC 291 as growth media. Vegetation was assumed to be absent. Simulations were performed for a series of 5-year periods. The 5-year periods were derived by considering a distinct 5-year period within the larger 100-year climate sequence. Essentially, years 1-5, 6-10, 11-15, etc were considered discretely. Further simulations were performed on selected materials using 10-year simulation periods.

4.1. Sensitivity analysis

The sensitivity of the WAVES model input parameters on simulated deep drainage was assessed by varying selected input parameters by ±10% and ±25%. Selected over-storey and under-storey parameters were modified simultaneously. Parameters that have no impact on drainage (salt sensitivity factor for example) were not assessed. Table 4 lists model parameters assessed and the change in simulated deep drainage.

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Table 4: *Sensitivity analysis of input parameters, using TPRC 182 as the growth media.*

Input parameter	Simulated deep drainage (mm after 100 years)		Simulated deep drainage (mm after 100 years)	
No change		0.1		
	+10%	-10%	+25%	-25%
K_{sat} – TPRC 182	0.1	0.1	0.1	0.1
K_{sat} – NAF	0.1	0.1	0.1	0.1
1 minus canopy albedo	0.1	0.1	0.1	0.1
1 minus soil albedo	0.1	0.1	0.1	0.1
Rainfall interception coefficient	0.1	0.1	0.1	0.1
Light interception coefficient	0.1	0.1	0.1	0.1
Maximum production rate	0.1	0.1	0.1	0.1
Maximum plant available soil water suction	0.1	0.1	0.1	0.1
Integrated rate methodology weighting for water	0.1	0.1	0.1	0.1
Integrated rate methodology weighting for nutrients	0.1	0.1	0.1	0.1
Temperature when growth rate is ½ of optimum	0.1	0.1	0.1	0.1
Temperature when growth rate is optimum	0.1	0.1	0.1	0.1
Maximum rooting depth	0.1	0.1	0.1	0.1
Specific leaf area	0.1	0.1	0.1	0.1
Leaf respiration coefficient	0.1	0.1	0.1	0.1
Stem respiration coefficient	0.1	0.1	0.1	0.1
Root respiration coefficient	0.1	0.1	0.1	0.1
Leaf mortality rate	0.1	0.1	0.1	0.1
Aerodynamic resistance	0.1	0.1	0.1	0.1

For the TGP, predicted drainage from the base of the NAF layer is insensitive to vegetation vigour and soil hydraulic conductivity. This is a result of the low rainfall and long periods between rainfall events that are typically associated with movement of water through the soil profile. WAVES predicts that the growth media are able to hold water within the profile for a sufficient period of time for it to be either lost through soil evaporation, or used through plant transpiration. Figure 7 shows this trend (evapotranspiration is a combination of both soil evaporation and plant transpiration). For the data shown, evapotranspiration effectively utilises all rainfall in 4-8 days depending on the rainfall amount and the number of consecutive rain days.

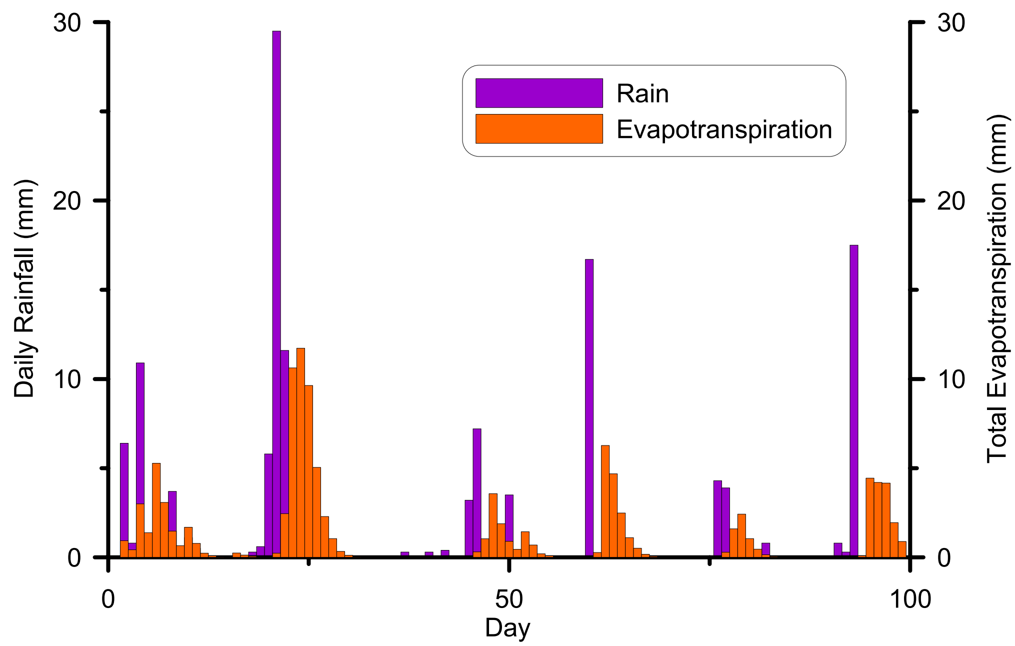

Figure 7: *Relationship between daily rain and simulated transpiration.*

4.2. Deep drainage from NAF materials under vegetation

Figure 8 shows the predicted change in moisture content at the base of the growth medium layer (using TPRC 182 as an example). Simulated moisture contents range from 5.4% (equivalent to the residual moisture content) to a maximum of nearly 9.8%. Saturated soil at the base of the growth medium layer is never predicted to occur, significantly reducing the possibility for water to move rapidly through the NAF materials. While the NAF material has high saturated hydraulic conductivity, it has very low unsaturated hydraulic conductivity.

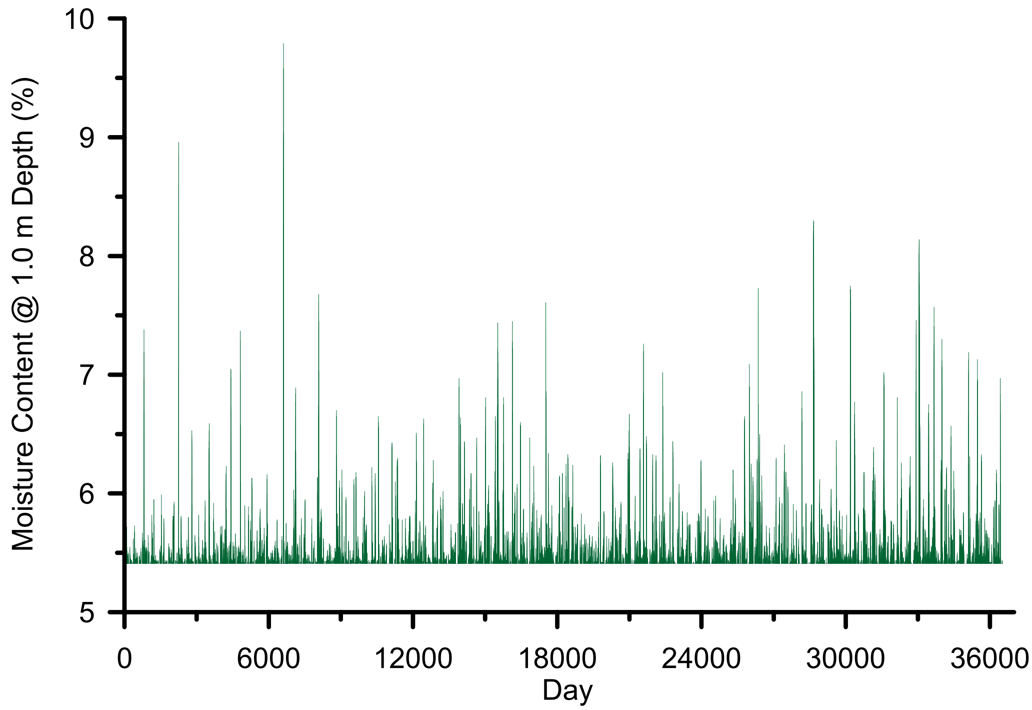

Figure 8: *Predicted moisture content at the bottom of the growth medium layer (1.0 m depth) for 100 years of simulation.*

Irrespective of the growth medium used, drainage from the base of the NAF layer is not predicted to occur over the 100 year simulation period. Therefore, 1.0 m of growth media is likely to be sufficient to effectively eliminate drainage of rain to the depth of the co-dumped NAF/PAF materials. This assumes that sufficient vegetation is readily established in the growth media to utilise the incident rainfall and act in conjunction with soil evaporation to reduce soil moisture levels. Importantly, the vigour of that vegetation is not an important factor in its ability to prevent deep drainage.

4.3. Drainage potential from profiles with no vegetation

The current capping profile will only effectively act to reduce the risk of drainage occurring from the NAF layer if vegetation is successfully established. However, during the early stages of rehabilitation, transpiration rates will be less than that expected from an established stand of vegetation. Conversely, soil evaporation rates from bare soils can be expected to be higher than for soils that support a vegetation canopy. Changing the magnitude of these two water balance components is likely to change the likelihood that drainage will occur.

WAVES simulations were conducted for unvegetated soil profiles using the four growth media. For each growth medium, WAVES was used to simulate drainage from the NAF layer after a 5-year period.

Predicted maximum drainage depth for each 5-year period[2] is given in Table 5. The predicted maximum drainage depth varies with growth material due to their different soil water characteristics. Drainage is predicted to be greatest when TPRC 182 is used as the growth medium, with water infiltrating to 2.25-4.00 m (average maximum drainage depth for the 20 periods simulated is 3.0 m).

Table 5: *Maximum predicted drainage depth for an unvegetated soil profile 5 years after construction.*

5-year Period	Maximum Predicted Drainage Depth (m) over 5-year period			
	TPRC182	TPRC204	TPRC250	TPRC291
1-5	2.75	2.00	1.40	1.20
6-10	2.75	2.50	1.80	1.20
11-15	2.75	2.25	1.40	1.00
16-20	3.00	2.75	1.60	1.40
21-25	3.25	3.75	2.00	1.40
26-30	2.75	2.25	1.60	1.20
31-35	2.75	2.25	1.40	1.00
36-40	2.75	2.25	1.80	1.20
41-45	3.50	3.25	2.25	1.20
46-50	3.00	2.50	1.60	1.00
51-55	2.25	1.60	1.20	1.00
56-60	3.00	2.50	1.60	1.00
61-65	3.00	2.25	1.80	1.00
66-70	2.75	2.25	1.60	1.00
71-75	3.50	3.25	2.25	1.20
76-80	3.25	3.00	2.00	1.00
81-85	3.00	3.00	1.80	1.00
86-90	4.00	3.75	3.00	1.60
91-95	3.75	3.50	2.50	1.40
96-100	3.25	3.25	2.00	1.20

The TPRC 182 material was further assessed. WAVES was used to simulate predicted drainage for this growth media (unvegetated) material using 10-year simulation periods[3]. The results – maximum drainage depth – of these simulations are given in Table 6.

[2] For this assessment, t*he 100-year climate file was broken into twenty 5-year periods, with each period being run separately to determine the possible range of outcomes that may occur over a 5-year period*

[3] *In this assessment, the 100-year climate file was broken into ten 10-year periods, with each period being run separately to determine the possible range of outcomes that may occur over a 10-year period.*

Table 6 shows that soil evaporation is effective in limiting drainage to depth, as doubling the simulation period resulted in less than a doubling in the maximum drainage depth. Further, once water drains below the growth media layer (where all soil evaporation effectively occurs), water drains freely and can be expected to drain from the NAF layer over time.

Interestingly, after 10 years, water is predicted to drain to an average depth of 4.0 m for profiles with the topsoil least effective in storing water. Given that many overstorey vegetation species (trees) have rooting depth of 4-6 m, results of the WAVES simulations suggests that failure to establish vegetation in the first 5-10 years after construction of the waste dump is likely to result in movement of infiltrated water to the base of the likely root zone. However, continued movement of water through the rooting zone and significant drainage below it would require the continued absence of vegetation. Development of a relatively wet layer at depth in the profile would provide some limitation to penetration of air to depth.

Table 6: *Maximum predicted drainage depth for an unvegetated soil profile 10 years after construction using TPRC 182 as the growth medium.*

10-year Period	Maximum Predicted Drainage Depth (m) over 10-year period
1-10	3.50
11-20	3.50
21-30	4.00
31-40	3.50
41-50	4.50
51-60	3.50
61-70	3.75
71-80	4.50
81-90	4.50
91-100	4.75

5. CONCLUSIONS

Drainage of rain from the base of a vegetated constructed landform profile (1.0 m thick layer of growth media overlying 10.0 m thick layer of NAF) is not predicted to occur. WAVES predicts that all incident rainfall is either intercepted by vegetation, lost to soil evaporation, or utilised by vegetation. Importantly, the vigour of the vegetation considered was not critical to its effectiveness in using soil water.

For the initial stages of landform construction where vegetation will either be absent or present at reduced levels, drainage is not predicted to reach the base of the NAF layer when both 5-year and 10-year periods of no vegetation are considered. After 10 years without vegetation, WAVES output predicts that - for the growth medium having greatest drainage - water will have potentially infiltrated the profile to the base of the likely long-term root zone. Continued water movement to and below that depth would require the continued absence of vegetation. Therefore, establishment of vegetation is required to ensure that the planned capping layer will act effectively to reduce the risk of infiltrating water interacting with the underlying co-disposed NAF/PAF materials.

Potential for deep drainage could also be reduced by selecting growth media with relatively high water storage capacity.

6. REFERENCES

Australian Government, 2008, *Australian natural resources atlas*, viewed 25 June 2008, http://www.anra.gov.au/index.html.

Broadbridge, P. and White I., 1988, *Constant Rate Rainfall Infiltration: A Versatile Nonlinear Model 1. Analytic Solution*, Water Resources Research, 24(1), pp 145–154.

Canadell J., Jackson R.B., Ehleringer J.R., Mooney H.A., Sala O.E. and Schulze E.D., 1996, *Maximum rooting depth of vegetation types at a global scale*, Oecologia 108:4, pp 583 – 595.

Dawes W, Xhang L and Dyce P, 1998, *WAVES V3.5 user manual*, CSIRO Land and Water, Canberra, ACT.

Gifford R., 2000, *Carbon contents of above-ground tissues of forest and woodland trees*, National carbon Accounting System Technical report No. 22, Australian Greenhouse Office.

Jeffrey S.J., Carter J.O., Moodie K.M and Beswick, A.R., 2001, *Using spatial interpolation to construct a comprehensive archive of Australian climate data*, Environmental Modelling and Software, 16:4, pp 309-330.

Klute A.K. (ed), 1986, *Methods of soil analysis. Part 1. Physical and mineralogical methods*, Agronomy monograph No. 9 2nd edn, American Society of Agronomy – Soil Science Society of America, Madison, Wisconsin.

Slavich P.G., Hatton, T.J. and Dawes, W.R., 1998, *The canopy growth and transpiration model of WAVES: Technical description an evaluation*, CSIRO Land and Water Technical Report No 3/98, Canberra, ACT.

White I. and Broadbridge P., 1988, *Constant Rate Rainfall Infiltration: A Versatile Nonlinear Model 2. Applications of Solutions*, Water Resources Research, 24(1), pp 155–162.

Yu, B., 2002. Using CLIGEN to generate RUSLE climate inputs. *Transactions of the ASAE*, 48: 993-1001.

Yu, B., 2003. An assessment of uncalibrated CLIGEN in Australia. *Agricultural and Forest Meteorology*, 119: 131-148.

Zhang L. And Dawes W., 1998, *WAVES. An integrated energy and water balance model,* CSIRO Land and Water Technical Report No. 31/98.

APPENDIX A – GENERATION OF CLIMATE DATA

Invariably, climate data do not exist for sites where modelling is required. In most cases, data must be sourced from locations in close proximity to the site of interest and combined into one climate file. Missing data must be patched using some form of spatial or temporal interpolation. Alternatively, these disparate sets of data can be statistically analysed, with this analysis being used to generate synthetic climate sequences. This latter approach was adopted for this study. Data were sourced from nearby locations and processed using CLIGEN, a stochastic weather generator.

Data Drill data were sourced from the Bureau of Meteorology. The Data Drill accesses grids of data derived by interpolating the Bureau of Meteorology's observed station records. Interpolations are calculated by splining and kriging techniques (Rayner *et al*, 2004). The data in the Data Drill are all synthetic; however the use of Data Drill data is appropriate in situations such as this where no observed data exist for the location.

Pluviograph (rainfall intensity) data are available from the BOM's Leonora weather station (121º19'38.39"E, 28º52'53.74"S), approximately 300 km west of Tropicana. This site contains data from February 1963 until June 2006, with an effective record length of 34.6 years (40.2 years of record at 86 % complete). Other pluviograph stations in the area contain very little data (less than 2 years) or contain highly segmented data. For example, the Kalgoorlie (121º28'20.29"E, 30º44'51".60S) pluviograph dataset contains data for only 67 % of the days between January 1939 and June 2006. The Leonora rainfall intensity dataset was used to generate the rainfall intensity parameters.

Using the data above, the following parameter values were computed and used for the Tropicana site:

- Mean daily precipitation on wet days for each month,
- Standard deviation and skewness coefficient of daily precipitation for each month,
- Probability of a wet day following a dry day for each month,
- Probability of a wet day following a wet day for each month,
- Mean daily max. temperature for each month,
- Standard deviation of daily max. temperature for each month,
- Mean daily min. temperature for each month,
- Standard deviation of daily min. temperature for each month,
- Mean maximum 30-min rainfall intensity for each month, and
- Probability distribution of the dimensionless time to peak storm intensity.

These parameter values for rainfall, temperature, and solar radiation were assembled to create a CLIGEN parameter file for the site.

A 100-year climate sequence was generated using CLIGEN version 5.1 (Yu, 2002). A random seed of 000111000 was used for CLIGEN. This data file contained the following parameters:

- Precipitation (m),
- Precipitation duration (hrs/day),
- Average minimum temperature (ºC),
- Average maximum temperature (ºC),
- Vapour pressure deficit (hPa); and
- Solar radiation (kJ/m²/day).

The quality of the simulated climate sequence when compared with actual data was assessed.

The long-term mean annual rainfall for the Laverton climate file is 197 mm (47.4 years of data from 1960 – 2008), the simulated mean annual rainfall is 203 mm for the 100 years. The discrepancy is only 1.5 %. Figure A-1 shows that mean monthly rainfall is also well preserved. The absolute error in observed and generated mean monthly rainfall was 1.1 mm. CLIGEN slightly over-predicts mean monthly rainfall for February, April, and July.

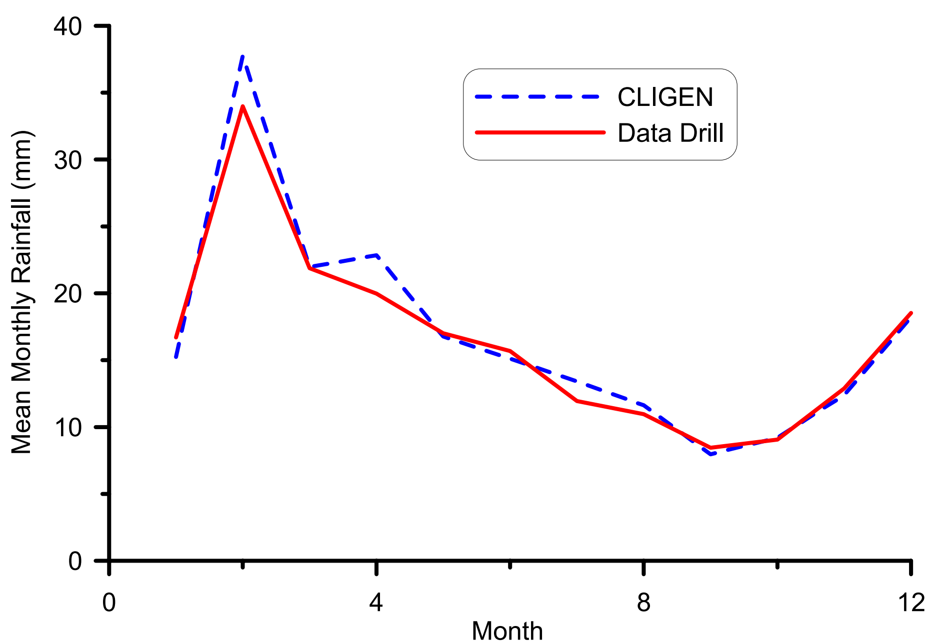

Figure A-1: *Observed and CLIGEN simulated mean monthly rainfall for the Tropicana site.*

The extreme daily rainfall events were also compared. Figure A-2 shows the annual daily rainfall compared with their average recurrence interval (ARI). It can be seen that for this particular simulation run, the observed and simulated maximum daily rainfall totals match quite well, especially given the fact that rainfall at the site is highly variable. It shows that the extreme events in the CLIGEN dataset occur at the same frequency as observed and measured from climate data.

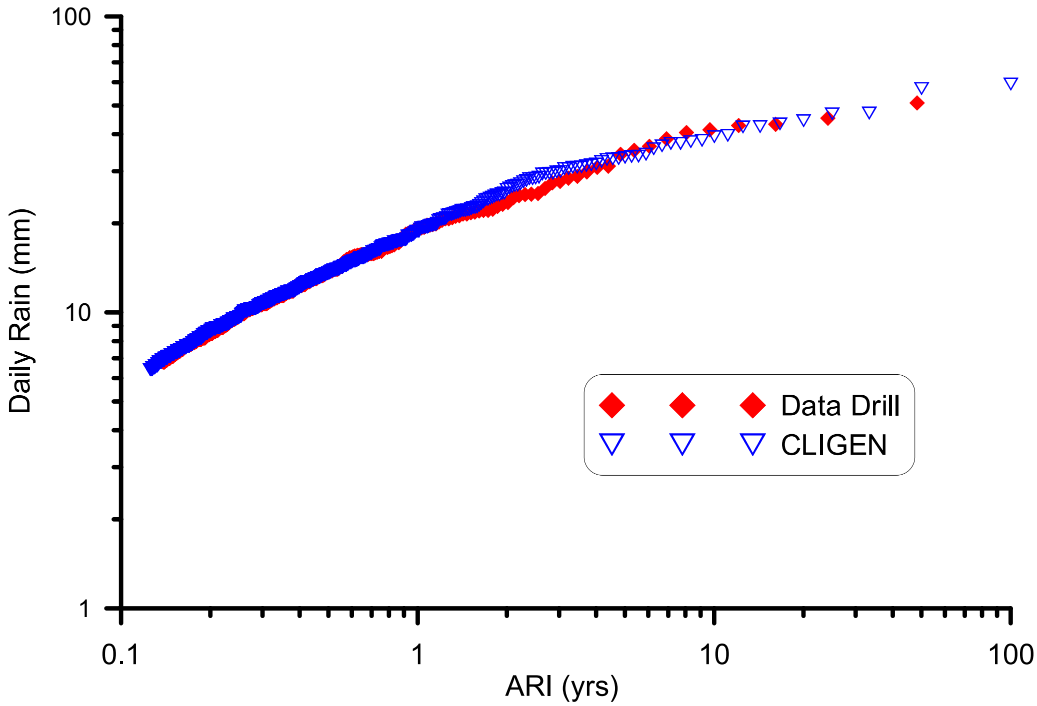

Figure A-2: *Maximum daily rainfall amount versus average recurrence interval.*

APPENDIX B – SOIL MOISTURE RETENTION CURVES

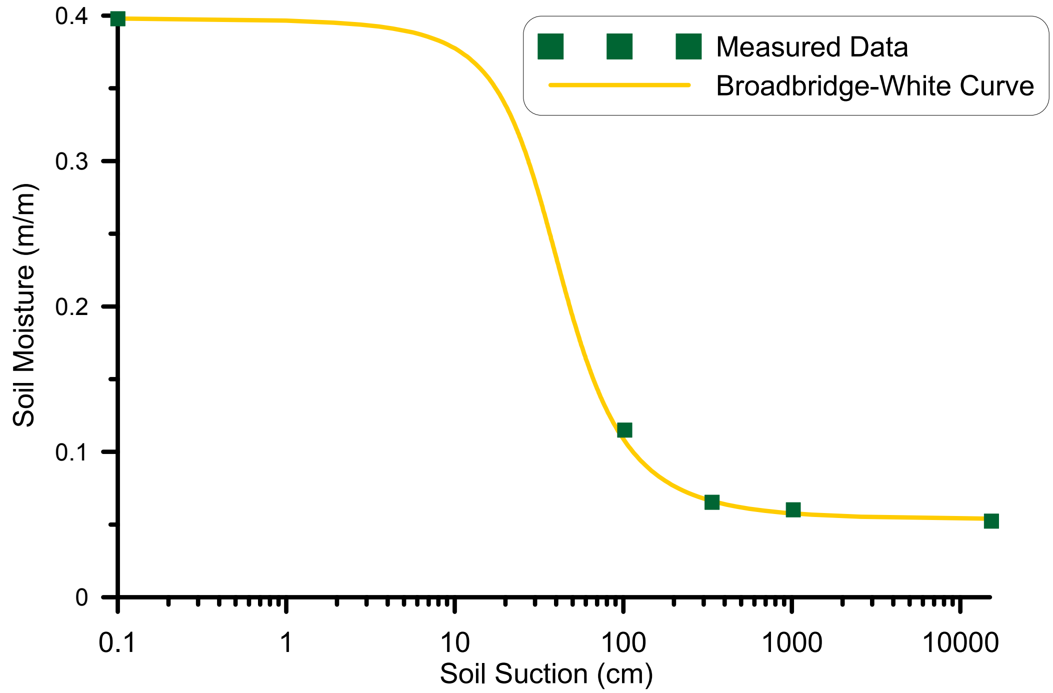

Figure B-1: *Broadbridge-White curve for TPRC 182.*

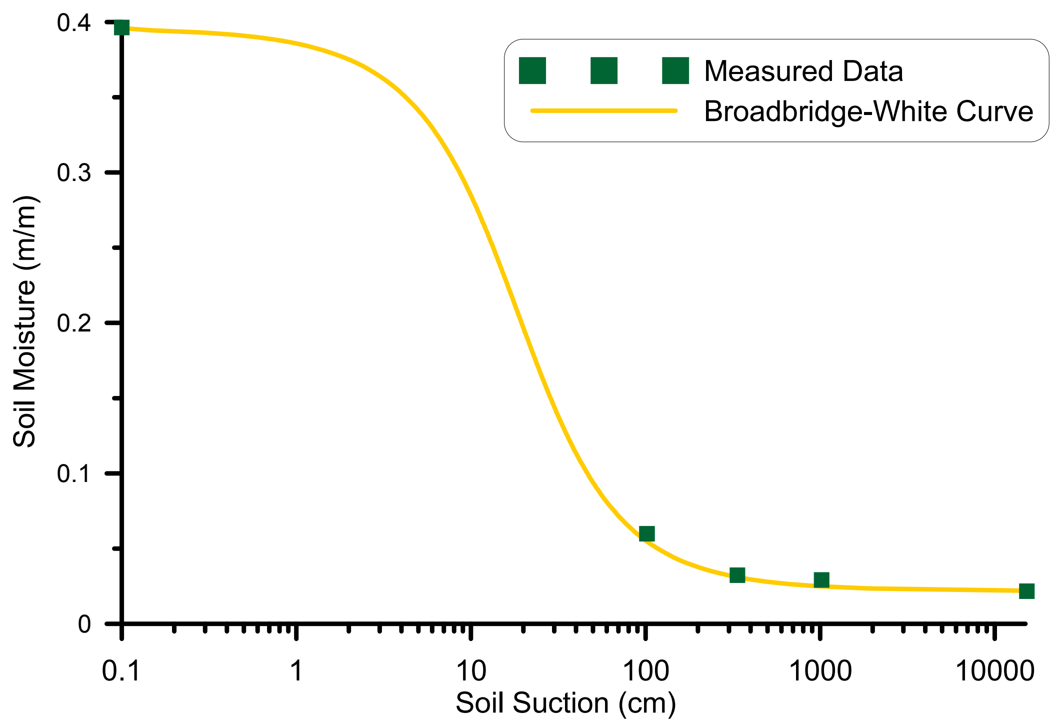

Figure B-2: *Broadbridge-White curve for TPRC 204.*

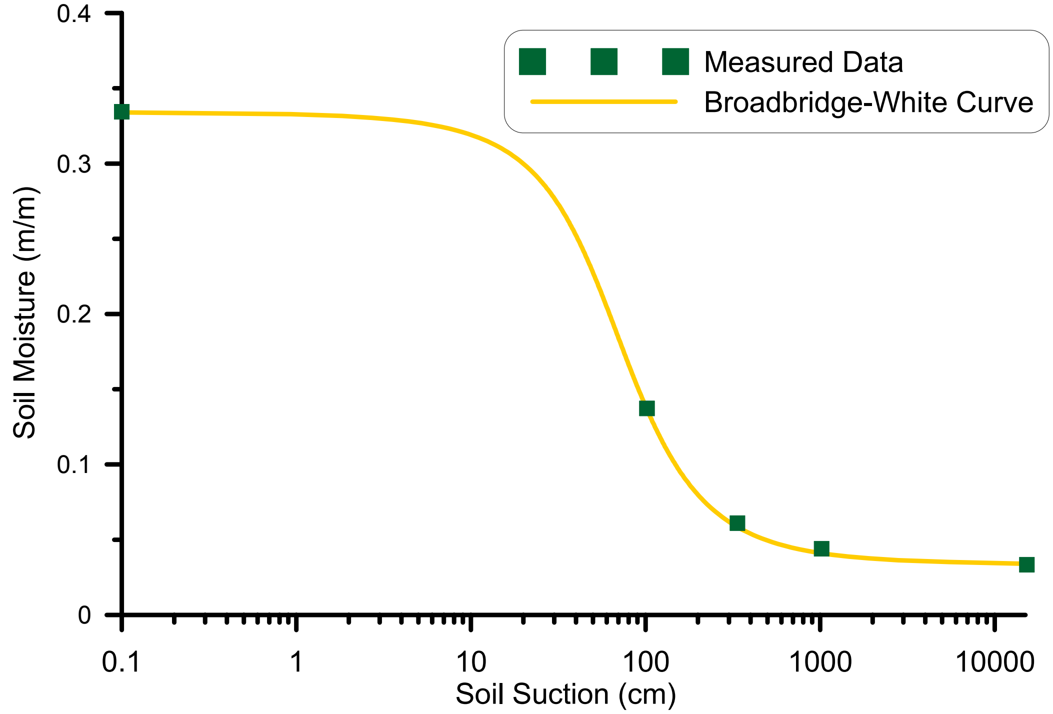

Figure B-3: *Broadbridge-White curve for TPRC 250.*

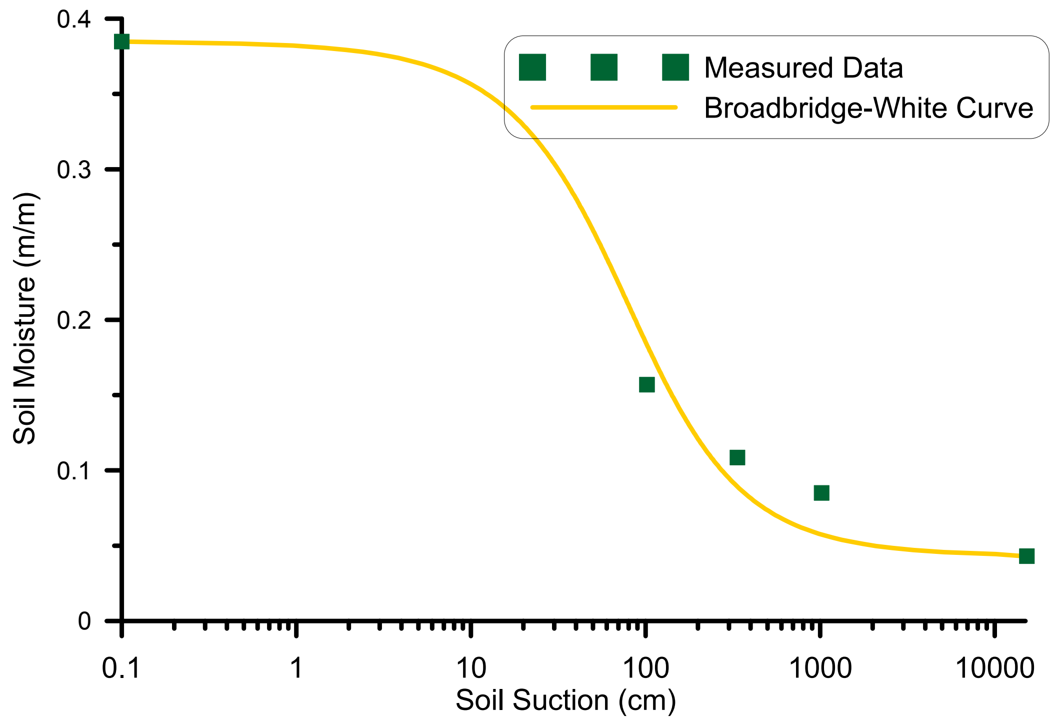

Figure B-4: *Broadbridge-White curve for TPRC 291.*

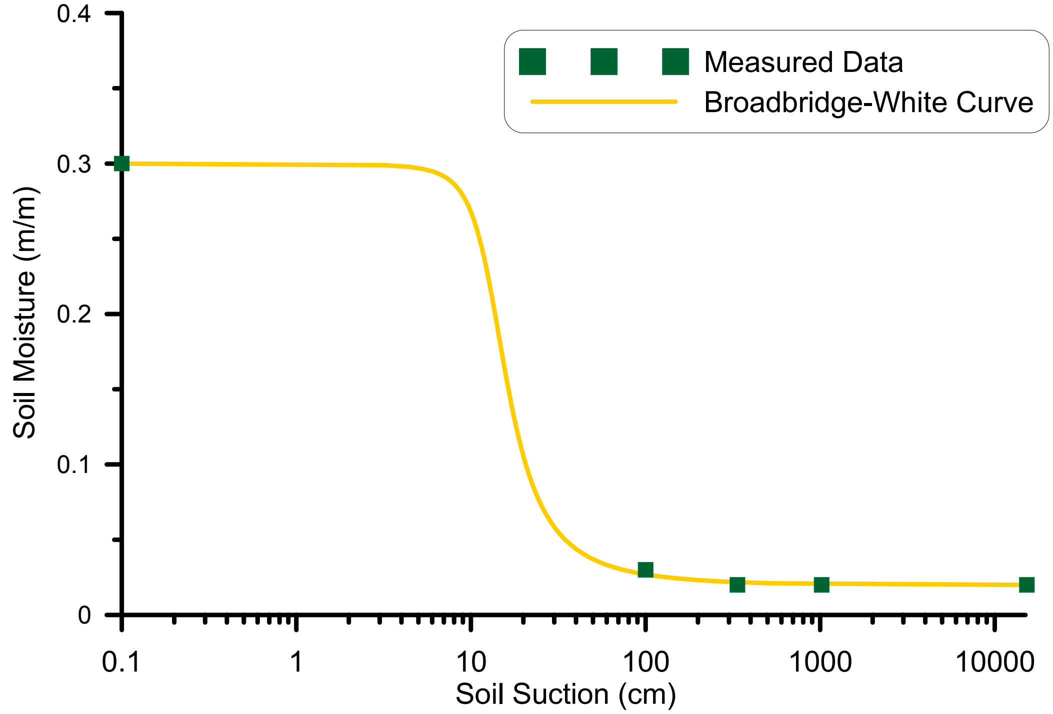

Figure B-5: *Broadbridge-White curve for the NAF material.*