Disposing of Maud Creek mine water by sustainable irrigation

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A study commissioned by URS Australia Pty Ltd
October 2007

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EXECUTIVE SUMMARY

As part of the EIS associated with the development of an underground mine, located at Maud Creek in the Northern Territory, our client was required to dispose of the water, both currently filling the open cut pit (≈ 300 ML), and that likely to interfere with future mining operations from aquifer inflow (assumed to be ≈ 1000 ML/yr), in an environmentally sustainable way. This study explores the potential for irrigated pasture, grown on a medium to heavy black clay soil or a lighter sandy loam soil, to utilise mine waste water, while minimising potential environmental degradation. A simulated water balance of Bambatsi panic (*Panicum coloratum var. mararikariense*) using 107 years of climate data (1900-2007) was used as an analogue for the proposed sward.

This simulation analysis included a number of irrigation management scenarios to quantify potential impact from excess water under a range of irrigation rates. Natural drainage occurs during the wet season (December-March) in this environment subject to levels of vegetation cover, soil type and seasonal climate variability. Excess water as drainage or runoff reflect levels of applied irrigation over and above that of the natural background flow expected during the wet season. The range of applied irrigation rates varied from 2.5 to 20 mm/day and length of irrigation duration (5 -12 months). Results suggest that higher irrigation rates lead to increased deep drainage on both soil types, with more significant levels on the sandy loam. Levels of runoff remain relatively consistent across application rates and irrigation periods for a particular soil type. Rates differ significantly between sandy loam and clay soils under higher irrigation rates (10 mm/day), with greater runoff occurring on the black clay.

Risk management options such as, decreasing irrigation rate during the wet season will reduce annual drainage to environmentally acceptable levels for this system. Production from the pasture sward has significant influence on the overall water balance and will be critical in utilisation of irrigation water and in minimising excess water as drainage or runoff. Maintaining high levels of green transpiring biomass is a critical issue over any applied irrigation period. A winter active species that is known to respond under irrigation such as Rhodes grass (*Chloris gayana*) offers a more long-term manageable solution than the poor unmanaged pasture currently growing at the site. Grazing management or slashing will also increase water use of the pasture.

1.0 INTRODUCTION

1.1 Background to the study

As part of the EIS associated with the commissioning of an underground mine, located at Maud Creek in the Northern Territory, our client was required to dispose of the water, both currently filling the open cut pit (≈ 300 ML), and that likely to interfere with future mining operations from aquifer inflow (assumed to be ≈ 1000 ML/yr) in an environmentally sustainable way. CSIRO was commissioned to study the potential for the production of biomass from irrigated forage cropping which would utilize all of the available water, without contributing to potential environmental degradation through off-site overland flows leading to uncontrolled discharge or deep drainage.

1.2 Objectives of the study

The aim of the study was to explore the potential for a grass/weeds pasture, grown on a medium to heavy black clay soil or a lighter sandy loam soil, to evapotranspire mine waste water, minimising deep drainage and runoff impact on the environment.
The study was a simulation water balance modelling exercise to explore the potential to:

1. utilize the mine water resource to produce pasture under a number of logical management and irrigation scenarios;
2. to quantify impacts from applying a range of irrigation treatments over extended periods on deep drainage (below the rooting zone) and surface runoff over a four year time frame; and
3. provide information on excess water (drainage & runoff) for use in further hydrological risk assessments by the client regarding mine water disposal.

1.3 Research approach

This analysis links biophysical modelling of a pasture system with on-site water storage and irrigation management to address the project aims. The biophysical modelling utilises APSIM (Keating, *et. al*., 2002), a comprehensive, computer-based agricultural production systems simulator with capacity to address production and sustainability issues associated with those systems. Bambatsi panic (*Panicum coloratum var. mararikariense*) was used as an analogue for the proposed pasture sward.

A number of scenarios were discussed and negotiated with the client that explored irrigation timing and quantity, to maximise water use without significantly impacting on deep drainage and runoff. Simulated biomass production, leaf area index and cover were assessed and compared with known bambatsi production levels in Queensland and the Northern Territory. Final scenarios focus on irrigation strategies to maximise excess water use over a four year period, whilst minimising environmental impacts through ground water recharge and runoff from applied irrigation water.

As requested by the client, this report assesses the impact of irrigated mine water disposal in terms of increasing deep drainage and surface runoff risk. Although the initial focus is the disposal of 300 ML of water (the inventory in the existing pit) through either transpiration (green biomass production) or evaporation from soil or water storage surfaces within the first

12 month period. Ongoing irrigation during subsequent seasons will be required to manage pond water inventory on the mine site, the actual quantity being influenced by seasonal rainfall capture and aquifer inflow after the wet season.

The simulation analysis concentrates on quantifying the rate of water that can be applied to the soil surface under a perennial pasture system on two local soil types. The extent of irrigation area required to utilize available water from the mine site is not considered in this report. The client will evaluate the scaling of irrigation area required to minimise environmental impacts from irrigation.

Figure 1 illustrates rainfall distribution for the Katherine area. Bureau of Meteorology values for pan evaporation for the Katherine region suggest a range of 150 to 200mm per month from April to September and represent the potential limits for water use under conventional situations. Simulated potential evaporation values (Eo) for each month are presented in Figure 2. Selected irrigation treatments reflect local management strategies for centre pivot irrigation systems. Northern Territory experience suggests that, to minimise soil surface ponding and potential runoff on a medium to heavy clay soil, applied irrigation should be limited to 20 to 25 mm over a 24 hour period. Rates of >25mm are known to have been applied on sandy soils but little information on drainage rates is available. These limits reflect a centre pivot system covering 44ha, with flow rates of between 100 and 130 l/s. A range of irrigation application rates resulting in 2.5 to 20mm of applied daily irrigation were initially evaluated. Models, using a soil layer structure and tipping bucket water balance on a daily time step, can over estimate soil evaporative losses where small irrigation amounts are applied. To minimise this potential error, higher irrigation rates are applied on a 2 and 4 day frequency to allow infiltration below the surface layer to occur.

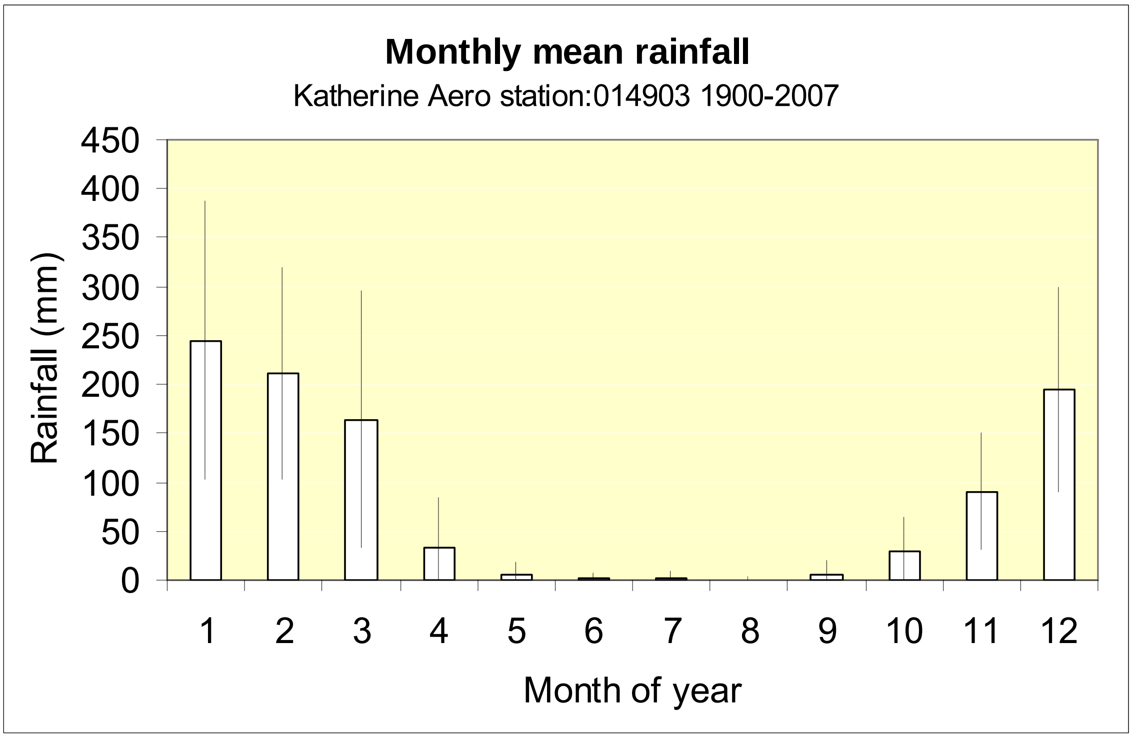


Figure 1. Mean monthly rainfall for the Bureau of Meteorology station 014903, Katherine Aero, Northern Territory from 1900 to 2007. Error bars represent standard deviations from the mean.

2.0 METHODS

2.1 Model parameters

Information provided by the client indicates that the area immediately adjacent the Maud Creek mine site (approximately 22 km east of Katherine) is a black soil floodplain with natural low, sparse woody savannah vegetation. Some distance (< 10km) away is the Blain sand, with areas that have already cleared paddocks. A soil parameter file was developed for each site using a Cununurra Clay (Bridge, 1982 , Muchow, 1998) with a Plant Available Water Capacity (PAWC) of 190 mm to 190cm soil depth (for the black soil floodplain) and a Blain Sandy Loam with a PAWC of 40-75mm per metre of soil (Appendix B). The Katherine Bureau of Meteorology (BoM) station (#014903: Katherine Aero) from the SILO patched point database was selected as the nearest long-term climate record (1900 to 2007) with a mean annual rainfall of 978mm (Figure 1). APSIM was parameterized for the simulation of a perennial bambatsi pasture (Appendix A: Tables 1a, 1b) with access to unlimited irrigation water from the mine**.**

2.2 Irrigation rules

To evaluate the rate of water application that minimised the potential for runoff and deep drainage, irrigation treatments of 2.5, 5, 10 and 20 mm per day were applied at 2 and 4 day intervals under non water limiting conditions. Application rates of 40mm applied every 2 days (20mm /day), 20mm applied every 2 days (10mm /day), 20mm applied every 4 days (5mm /day) and 10mm applied every 4 days (2.5mm /day) were simulated for both the clay and sandy loam soils. Daily irrigation rates were applied for periods of 5, 7, 9 and 12 months. Aquifer inflow was not included. No limitations were applied to pumping capacity and simulations assumed 100 percent efficiency in transporting irrigation water to the field. No overland flow onto the irrigation area from the adjacent catchment was considered.

2.3 Simulation

Four year production cycles of perennial bambatsi pasture are simulated by APSIM using 107 years of climate record with soil water, soil nitrogen and surface cover reset in October at the end of each cycle. Additional nitrogen of 150kg/ha (irrigated) and 50kg/ha (dryland) was applied annually on the 1st May with the bambatsi cut and biomass removed at the end of September each year.
Seasonal climatic variability effects annual pasture production, surface runoff and drainage with results captured by long-term simulation. Results represent a long-term mean of each 4 year cycle as influenced by the climate record (Oct: year 1 to Sep: year 5). Bambatsi was configured to extract water to 1.9m on the clay and to 2.5m on the sandy loam soil. Monthly and annual totals for water use, drainage beneath the rooting zone, surface run-off and biomass production were simulated from 1900 to 2007. Potential evaporation (Eo), soil evaporation (Es), biomass transpiration (Ep) and irrigation amounts were recorded. Surface residue cover of 2000 kg/ha of pasture material is reinitialised at the start of the 4 year production cycle.

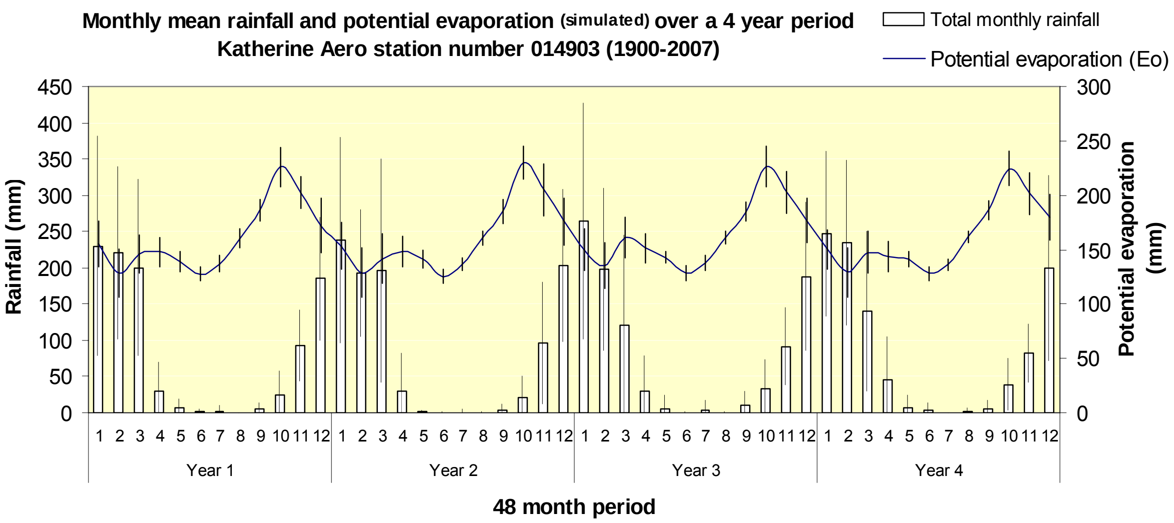


Figure 2. Mean monthly rainfall totals (mm) and potential evaporation (simulated Eo) over a 48 month period. Values result from 26 periods of 48 months between 1900 and 2007, based on the Katherine Met Bureau station 014903. Error bars represent standard deviations from the mean.

3.0 RESULTS

3.1 Establishing a sustainable irrigation rate

The first stage of this analysis sought to establish a sustainable irrigation rate that would maximise pasture production, maintain a high green Leaf Area Index (LAI) and transpiration rates whilst managing drainage (below the root zone of the pasture) and preventing soil surface runoff. Mean monthly pan evaporation rates of 145-245mm over the 12 month have been measured for the Katherine environment. A simulated potential evaporation rate (Eo) used in the analysis is presented in Figure 2 for comparison. Under normal environmental conditions any irrigation applied over this potential rate can result in water that may impact on drainage or runoff levels. Natural drainage occurs during the wet season (December-March) in this environment (Figure 5) the rate dependant on vegetation management and seasonal climate variability. Additional irrigation applied during this period will add to natural drainage rates.

Drainage and surface runoff change with irrigation rate, duration and timing. Simulated values of the drainage and runoff that can occur under a particular irrigation strategy were expressed as an annual mean. To compare rate and duration combinations, results are presented as a table of mean annual values occurring for both drainage and surface runoff. Analysis assumes best management practice in the establishment, growth and maintenance of a perennial pasture over a 4 year period. To address seasonal climate variability, pasture growth using a particular irrigation management is simulated over a 4 year period. The system is reinitialised then run for a further 4 years. This process continues for 107 years of available climate data. Results are summarised stochastically using error bars about the monthly means. Natural drainage and runoff resulting from a pasture grown under rainfed conditions in Table 1 forms the benchmark for assessing impact from additional irrigation. An additional simulation scenario without an actively growing pasture has been included for comparison. Runoff and drainage levels from a pasture system grown without supplementary irrigation can account for 30% to 46% of annual rainfall dependant on soil type.

Table 1. Simulated mean annual runoff and drainage rates (mm) on a sandy loam and black clay soil from a bare* soil paddock and a bambatsi pasture grown under rainfed conditions only. Values representing a 10% chance of exceeding the 90th percentile for runoff and drainage are presented for comparison with mean values.

		Mean annual rates of:				10% chance of exceeding:	
Cover	Soil type	GL/100ha	Irrigation (mm	Runoff (mm)	Drainage (mm	Runoff (mm)	Drainage (mm)
Bambatsi	Sandy loam	0	0	80	372	157	619
Bambatsi	Clay	0	0	259	34	456	120
Bare soil	Sandy loam	0	0	153	477	250	688
Bare soil	Clay	0	0	279	231	448	365

*Note: Bare soil treatment is initialised with 2000 kg/ha of surface residue at the start of the 4 year simulation period. No weeds are considered.

From preliminary analysis and discussion, and application capacity and current commercial experience with centre pivots in the Katherine region, a range of irrigation rates were selected for testing in this analysis. Irrigation rates of 2.5 to 20mm applied at 2 to 4 day intervals over 5 (May-Sep), 7 (Mar-Sep), 9 (Jan-Sep) and 12 (Oct-Sep) month periods were evaluated for impact on additional excess water over that of natural occurring drainage and runoff.

Table 2. **Sandy loam soil -** Simulated mean annual irrigation, runoff and drainage (mm) for effective applied irrigation rates of 2.5 to 20 mm per day over periods of 5 to 12 months. Values are the mean of excess water occurring annually as a result of 4 irrigation management strategies. Water applied as irrigation is given in GL per 100ha. Values representing a 10% chance of exceeding the 90th percentile for runoff and drainage are presented for comparison with mean values.

Sandy loam soil		Mean annual rates of:				10% chance of exceeding:	
Irrigation	Period	GL/100ha	Irrigation (mm)	Runoff (mm)	Drainage (mm)	Runoff (mm)	Drainage (mm)
2.5mm	May-Sep	0.4	383	69	264	142	561
2.5mm	Mar-Sep	0.5	535	71	317	140	614
2.5mm	Jan-Sep	0.7	683	76	435	147	737
2.5mm	Oct-Sep	0.9	913	78	516	144	821
5mm	May-Sep	0.8	765	71	386	140	747
5mm	Mar-Sep	1.1	1070	79	586	158	1019
5mm	Jan-Sep	1.4	1365	85	861	166	1287
5mm	Oct-Sep	1.8	1826	93	1178	172	1516
10mm	May-Sep	1.5	1530	79	1126	157	1503
10mm	Mar-Sep	2.1	2140	85	1684	171	2078
10mm	Jan-Sep	2.7	2730	92	2258	177	2654
10mm	Oct-Sep	3.7	3653	107	3054	195	3384
20mm	May-Sep	3.1	3060	90	2695	177	2985
20mm	Mar-Sep	4.3	4280	95	3869	188	4159
20mm	Jan-Sep	5.5	5460	104	5034	199	5310
20mm	Oct-Sep	7.3	7305	123	6706	225	6970

Table 3. **Black clay soil -** Simulated mean annual irrigation, runoff and drainage (mm) for effective applied irrigation rates of 2.5 to 10 mm per day over periods of 5 to 12 months. Values are the mean of excess water occurring annually as a result of 3 irrigation management strategies. Water applied as irrigation is given in GL per 100ha. Values representing a 10% chance of exceeding the 90th percentile for runoff and drainage are presented for comparison with mean values.

Black clay soil		Mean annual rates of:				10% chance of exceeding:	
Irrigation	Period	GL/100ha	Irrigation (mm)	Runoff (mm)	Drainage (mm)	Runoff (mm)	Drainage (mm)
2.5mm	May-Sep	0.4	383	252	31	451	117
2.5mm	Mar-Sep	0.5	535	262	44	453	144
2.5mm	Jan-Sep	0.7	683	285	109	471	263
2.5mm	Oct-Sep	0.9	913	314	122	482	276
5mm	May-Sep	0.8	765	258	31	454	119
5mm	Mar-Sep	1.1	1070	273	89	459	220
5mm	Jan-Sep	1.4	1365	301	291	475	480
5mm	Oct-Sep	1.8	1826	353	396	515	626
10mm	May-Sep	1.5	1530	267	557	460	664
10mm	Mar-Sep	2.1	2140	281	985	463	1190
10mm	Jan-Sep	2.7	2730	310	1487	480	1706
10mm	Oct-Sep	3.7	3653	360	2117	517	2352

As requested by the client, daily applied irrigation rates have been used for irrigation management across all simulations. Excess water as drainage reflects levels of applied irrigation over and above that of the natural background flow expected during the wet season (Figure 5). Figure 6 compares irrigation applied at an effective rate of 10mm/day over a 12 month period with irrigation applied during the dry season (May-Sep) only. Applying irrigation continually at a rate of 10 mm/day over 12 months increases the amount of water applied by 2123mm (> 2.1GL /100ha). This results in an increase in drainage from a mean of 1126mm to 3054mm per annum on a sandy loam (Table 2). Results suggest that higher irrigation rates applied over a longer irrigation period lead to increasing levels of deep drainage when compared with pasture grown under rainfed conditions only (Figures 3 & 4). This is evident for both soil types, with more significant levels from the sandy loam as shown in Figures 3 & 4. As requested by the client, 90th percentile values for drainage and runoff are included in Tables 2 & 3. These values represent a 10% chance of exceeding a particular level of runoff or drainage under each irrigation scenario. Figures 3 (sandy loam) and Figure 4 (black clay) compare cumulative probability of annual drainage under an two irrigation rates of 5mm and 10mm per day over 4 periods of 5 to 12 months.

Little change in mean annual runoff on the lighter sandy loam for irrigation rates <20mm per day was observed in the simulations (Table 2). Results demonstrate that potential runoff from irrigation applied to a sandy loam soil is much less than that of the black clay under similar vegetation management. This analysis suggests that applying irrigation to a sandy loam soil may well reduce the potential for environmental impacts from excess water as surface runoff but will increase levels of drainage. Runoff from the clay soil (Table 3) could be reduced through a reduction in applied irrigation but only to the natural wet season levels (Table 1). Risk management options such as, decreasing applied irrigation during the wet season will reduce the overall annual drainage under this system. Tactical management of applying irrigation on a soil water deficit will maximise water use during the dry season and minimise potential runoff or drainage during the wet season. Managing ≈ 1000 ML/yr of potential inflow requires irrigation rates of 1000mm per annum applied over 100 ha of pasture. Results for a sandy loam soil suggest that at low rates of 10mm irrigation every 4 days (2.5mm/day), over 900mm can be applied with a mean annual drainage of 516mm. Increasing application rates to 5mm/day while reducing the period of irrigation (7months) lifts the amount of irrigation applied with minimal change in drainage and runoff. Applied irrigation amounts in GL per

100ha are included in Tables 2 & 3. Increasing irrigation rates on sandy loam soils to 10 mm/day is consistent with irrigation management in the Katherine area and does not increase the risk of runoff. The potential for rising groundwater tables due to increased drainage would need to be monitored. The simulation analysis presents a range of possible outcomes (within the limits of model parameters) that provide a guide to relative differences between irrigation scenarios. Absolute values may vary due to differences between the simulated and actual site conditions but the relative change between treatments should be consistent.

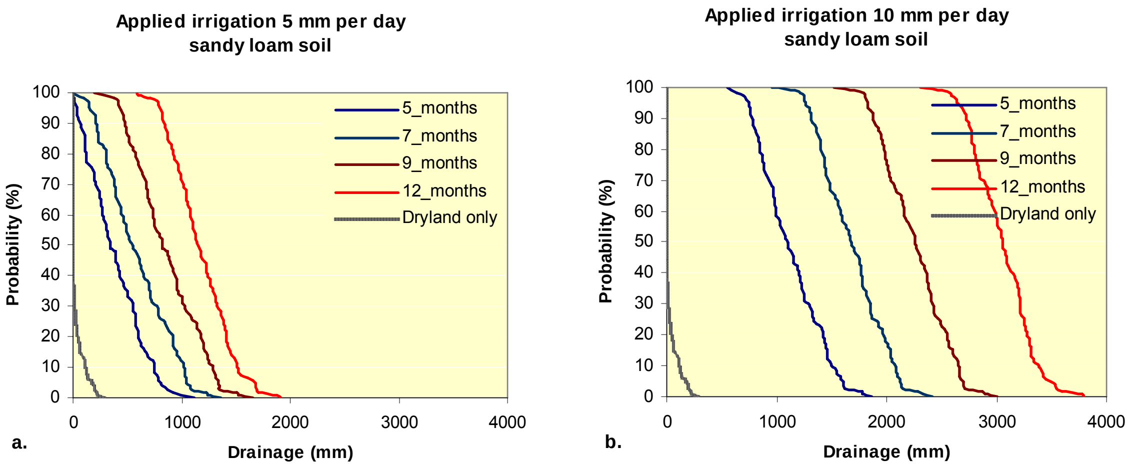


Figure 3. **Sandy loam soil** a) Cumulative probability of annual drainage under an effective 5 mm per day irrigation rate over 4 periods of applied irrigation of 5 to 12 months on a sandy loam soil. b) Cumulative probability of annual drainage under an effective 10mm per day irrigation rate over 4 periods of applied irrigation of 5 to 12 months on a sandy loam soil. Annual drainage from a rainfed bambatsi (dryland only) pasture is included for comparison with applying irrigation. Values represent the probability of exceeding a particular level of drainage (mm).

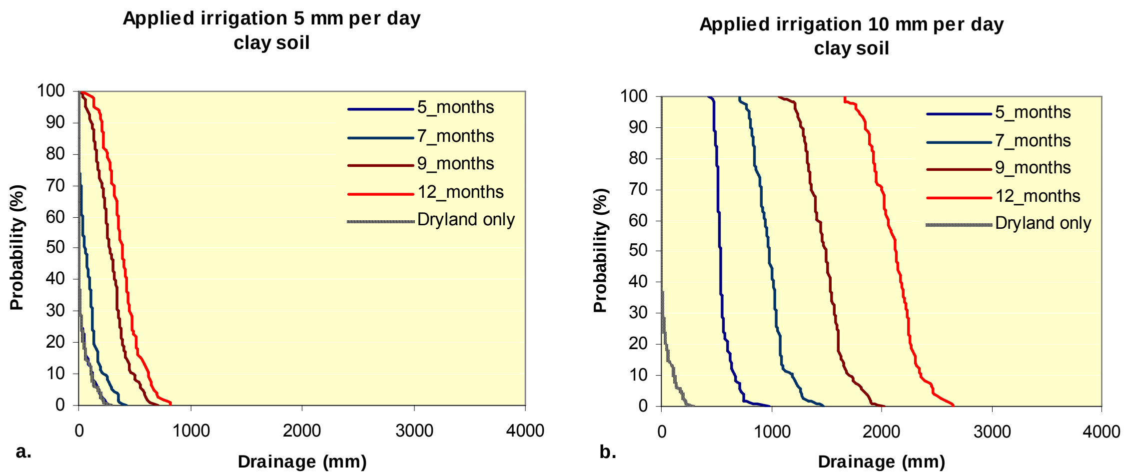


Figure 4. **Black clay soil** a) Cumulative probability of annual drainage under an effective 5 mm per day irrigation rate over 4 periods of applied irrigation of 5 to 12 months on a clay soil. b) Cumulative probability of annual drainage under an effective 10 mm per day irrigation rate over 4 periods of applied irrigation of 5 to 12 months on a clay soil. Annual drainage from a rainfed bambatsi (dryland only) pasture is included for comparison with applying irrigation. Values represent the probability of exceeding a particular level of annual drainage (mm.

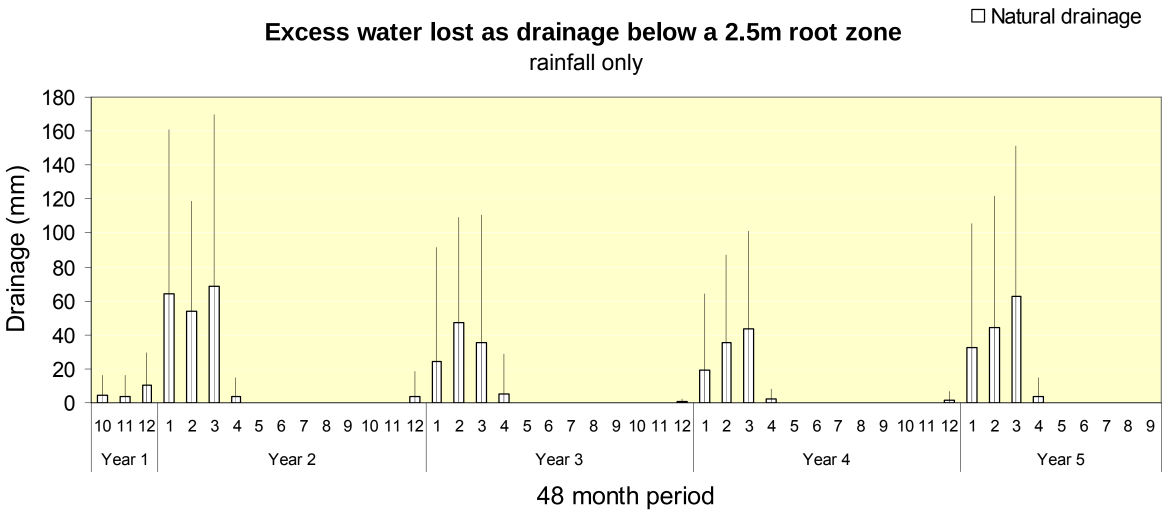


Figure 5. Simulated distribution of mean monthly drainage (mm) occurring over a 48 month period for a bambatsi pasture grown under rainfed conditions on a sandy loam soil. Error bars represent standard deviations from the mean.

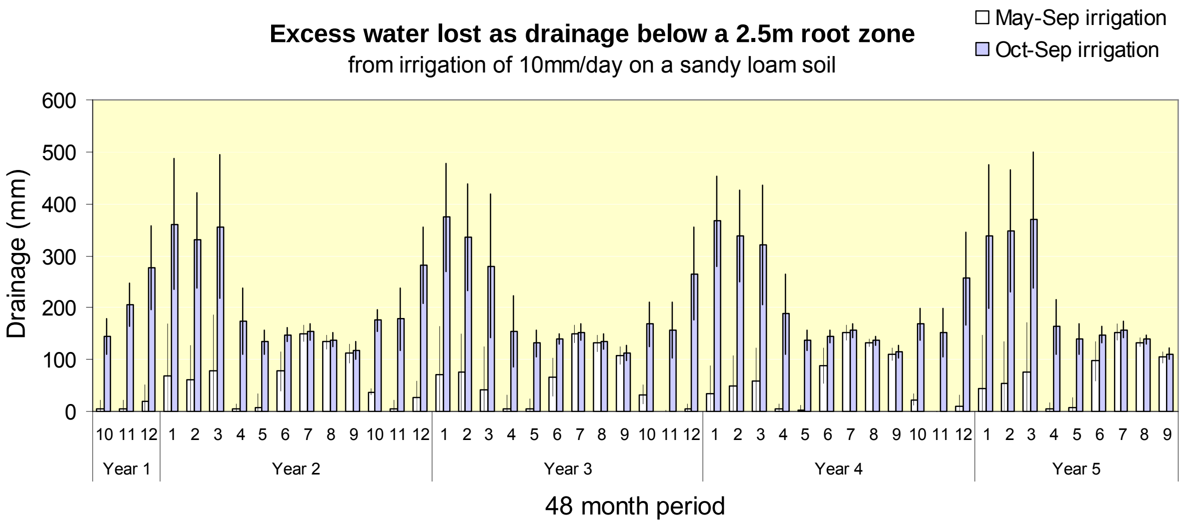


Figure 6. Simulated distribution of mean monthly drainage over a 48 month period for a bambatsi pasture grown on 10 mm/day irrigation applied for 5 and 12 month periods each year on a sandy loam soil. Values include rainfall and irrigation. Error bars represent standard deviations from the mean.

3.2 Pasture production

Production from the pasture sward has significant influence on the overall water balance and will be critical in utilisation of irrigation water and in minimising excess water as drainage or runoff. Maintaining significant cover or LAI (Figure 9a) with high levels of total biomass (Figure 7a) and green transpiring biomass (Figure 7b) is needed to utilise irrigation water efficiently. Reported drainage and runoff rates are the result of biomass levels as influenced by irrigation rates. Differences of >90mm in transpiration between rainfed and irrigated pasture can be observed over the dry season (Figure 8a). The dynamic nature of soil nitrogen processes such as mineralisation or nitrate leaching that occur within the month as a result of irrigation management or rainfall seasonality are not represented. Higher levels of soil evaporation from a wetter surface layer will also occur under irrigation (Figure 8b). Given adequate water from irrigation and potential leaching of nitrate, nitrogen management of the pasture will become significantly more important for maintaining high levels of green cover. Nitrate leaching on sandy loam soils under 10 mm/day of irrigation has to be managed if green cover levels are to be maintained. Figure 9b represents mean monthly levels of available soil nitrate for irrigated and rainfed pasture.

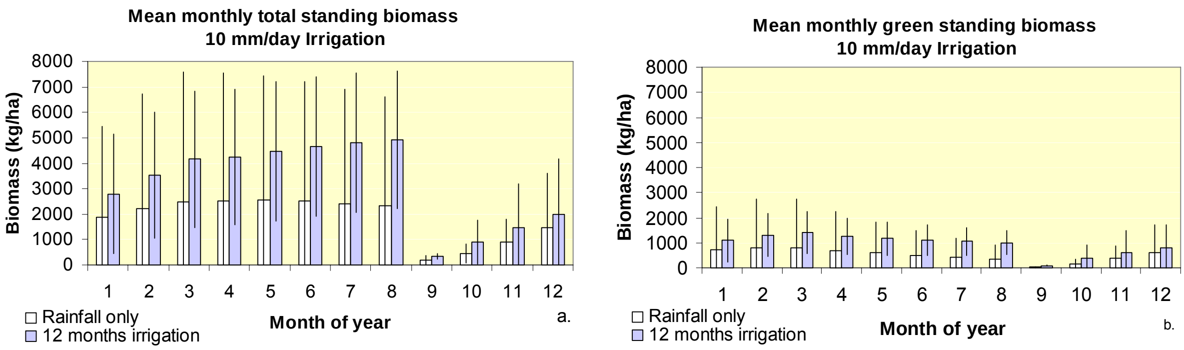


Figure 7. **Sandy loam soil** a) Mean monthly total biomass (kg/ha) of a perennial bambatsi sward, includes green and dead material under rainfed and irrigation of 10 mm/day over a 12 month, period on a sandy loam soil. b) Mean monthly green biomass (kg/ha) only of a perennial bambatsi sward under rainfed and irrigation of 10 mm/day over a 12 month period on a sandy loam soil. Error bars represent standard deviations from the mean.

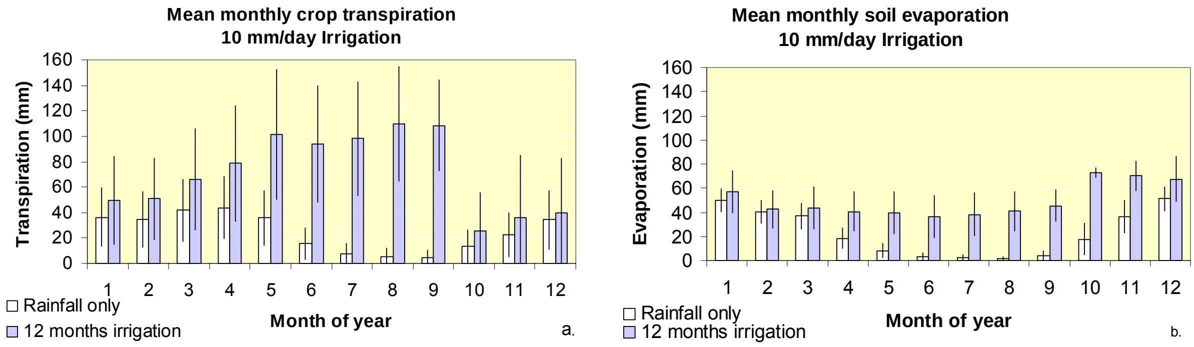
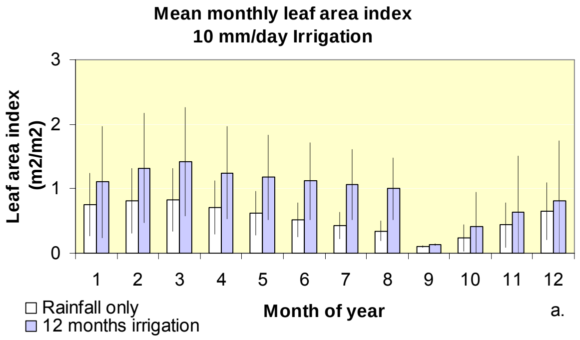


Figure 8. **Sandy loam soil** a) Mean monthly transpiration rates for a perennial bambatsi sward under rainfed and irrigation of10 mm/day over a 12 month period on a sandy loam soil. b) Mean monthly soil evaporation (mm) amounts from a bambatsi sward under rainfed and irrigation of10 mm/day over a 12 month period on a sandy loam soil. Error bars represent standard deviations from the mean.



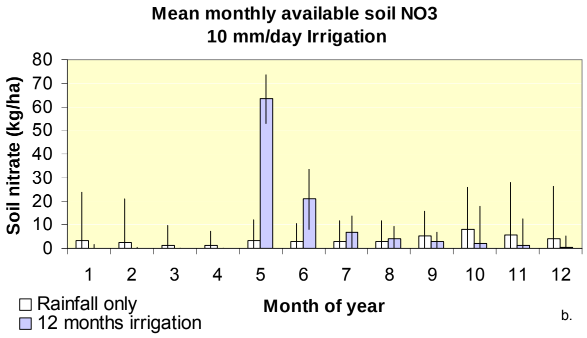


Figure 9. **Sandy loam soil** a) Mean monthly LAI (m^2/m^2) values for a perennial bambatsi sward under rainfed and irrigation of10 mm/day over a 12 month period on a sandy loam soil. Error bars represent standard deviations from the mean. b) Mean monthly soil nitrate (kg/ha) under rainfed and irrigation of 10 mm/day over a 12 month period on a sandy loam soil.

4.0 IMPORTANT CAVEATS

An important consideration with this type of analysis is realistic parameter settings for the model. The client has only specified the discharge requirements and not the operating constraints of the irrigation system. Results of any simulation may be significantly influenced by any number of variables considered. The model assumes best management practice in maintaining the agronomy and health of the pasture sward and in the application and timing of irrigation to the paddock. The model assumes that the above ground pasture biomass is removed at the end of the dry season each September. This is to maintain an actively growing pasture with a high level of green LAI to maximise potential transpiration. A more realistic simulation will depend on detailed management advice, ie. regular grazing or slashing would increase biomass production and water use. Unmanaged swards with increasing levels of dead material reduce the transpiration rate. The simulation has assumed adequate nitrogen management of the pasture. Levels of nitrogen stress will affect potential green LAI and subsequent transpiration rates.

Soil parameters used in the simulation reflect both a generic Sandy Loam and Cununurra black clay. Soils in the proposed irrigation areas may differ in chemical and physical properties (ie. PAWC) to those used in the simulations. The runoff curve number (or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. Curve numbers used for soils in the simulation may differ from that of the actual soils in the irrigation area. Increasing curve number on the sandy loam will increase the potential runoff but may decrease drainage in some situations. Results presented do not consider catchment inflows onto the irrigation area or flooding during the wet season and are based on access to unlimited water for irrigation purposes. Addition overland flow can add significantly to potential drainage rates on the irrigation areas in some extreme seasons and are not considered in this analysis. Consequently ongoing water management or earth works maybe required to control surface inflow during the wet season.

5.0 RECOMMENDATIONS

A high level of green transpiring biomass is a critical factor for water use over any applied irrigation period. Existing unmanaged pasture will not maximise water use and may result in proliferation of a weed problem in the area. Rhodes grass (*Chloris gayana*) a winter active species that is known to respond under irrigation offers a manageable solution. Rhodes grass has been grown commercially under irrigation in parts of the NT. Further information can be obtained from the NT Department of Primary Industry, Fisheries and Mines (Appendix C). Managing the pasture by slashing, grazing or burning during the dry season will stimulate new growth and increase water use. Higher transpiration levels can be expected from new growth compared to unmanaged swards composed of high levels of senesced decaying material. High levels of dry matter also lead to lower potential soil evaporation.

6.0 REFERENCES

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APPENDIX A

Management rules

Table 1a. Benchmarking and scenario simulations.

Simulation	Management	Details
Scenario 1	Bare soil (no actively growing pasture)	No addition irrigation applied. 2000 kg/ha residue initialised on the surface at start of 4 year cycle
Scenario 2	Pasture grown on rainfall only	No addition irrigation applied.
Scenario 3	10mm irrigation applied on a 4 day intervals on 2 soil types. Effective irrigation rate of 2.5 mm/day	Irrigation supply non limiting. 4 irrigation periods 1. 1st May and 30th Sep 2. 1st Mar and 30th Sep 3. 1st Jan and 30th Sep 4. 1st Oct and 30th Sep
Scenario 4	20mm irrigation applied on a 4 day intervals on 2 soil types. Effective irrigation rate of 5 mm/day	Irrigation supply non limiting. 4 irrigation periods 1. 1st May and 30th Sep 2. 1st Mar and 30th Sep 3. 1st Jan and 30th Sep 4. 1st Oct and 30th Sep
Scenario 5	40mm irrigation applied on a 4 day intervals on 2 soil types. Effective irrigation rate of 10 mm/day	Irrigation supply non limiting. 4 irrigation periods 1. 1st May and 30th Sep 2. 1st Mar and 30th Sep 3. 1st Jan and 30th Sep 4. 1st Oct and 30th Sep
Scenario 6	40mm irrigation applied on a 2 day intervals on 1 soil type. Effective irrigation rate of 20 mm/day	Irrigation supply non limiting. 4 irrigation periods 1. 1st May and 30th Sep 2. 1st Mar and 30th Sep 3. 1st Jan and 30th Sep 4. 1st Oct and 30th Sep

Table 1b. Crop management details used for configuring simulations.

Crop	Cultivar	Sowing date	Nitrogen applied (at sowing)	Additional nitrogen applied each year
bambatsi	bambatsi 300 plants/m^2	1st Jan	150 kg/ha	150 kg/ha (1st May) 50 kg/ha (dryland only)

APPENDIX B

The parameters are soil or soil-crop dependent parameters used in all APSIM simulations.

APSIM parameters that apply to a whole soil

Soil Parameter	Sand	Clay	Description
Cona	4.4	3.5	coefficient of cumulative second stage evaporation against the square root of time
U	1.4	6	amount of cumulative evaporation before soil supply falls below atmospheric demand
Salb	0.10	0.10	bare soil albedo
Diffus_const	550	40	coefficient defining diffusivity
Diffus_slope	26	16	coefficient defining diffusivity
CN2-bare	68	82	runoff curve number for bare soil
CN_red	20	20	reduction in curve number due to vegetation cover
CN_cov	0.8	0.8	fraction of vegetation cover that maximises CN_red
Root CN	25	25	C:N ratio of residual roots
Root Wt	3000	3000	weight of residual roots (kg/ha)
Soil CN	12.5	12.5	C:N ratio for the soil
Pot_decomp_rate	0.1	0.1	Potential decomposition rate of surface residues (day^{-1})
Residue_wt	2000	2000	Initial surface residues (kg/ha)
Residue_cnr	80	80	C:N ratio of surface residues
Residue_type	bambatsi	bambatsi	Type of surface residue (determines specific area of residue)

Soil property values by layers as used for all sites

Cununurra Clay

layer	1	2	3	4	5	6	7	8-19	Layer number
dlayer	150	100	100	100	100	100	100	100	Layer depth (mm)
SAT	0.489	0.485	0.478	0.459	0.449	0.439	0.435	0.441-0.368	Saturation
DUL	0.488	0.484	0.477	0.458	0.448	0.438	0.434	0.44-0.367	Drained upper limit
CLL	0.243	0.314	0.345	0.345	0.345	0.338	0.341	0.346-0.326	Crop lower limit
kl	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	rate of soil water extraction
Xf	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	root hospitality factor
swcon	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	rate of flow of water under saturated conditions
fbiom	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01	proportion of the non-inert carbon in the BIOM pool
Finert	0.43	0.52	0.62	0.74	0.83	0.85	0.85	0.9	proportion of initial organic C assumed inert
Oc	1.4	1.1	0.8	0.6	0.6	0.4	0.3	0.1	Organic carbon (%)
BD	1.1	1.0	1.1	1.1	1.1	1.1	1.1	1.1	Bulk density

Blain sand

layer	1	2	3	4	5	6	7	8-9	Layer number
dlayer	50	100	150	150	150	400	500	500-1000	Layer depth (mm)
SAT	0.344	0.370	0.360	0.370	0.370	0.370	0.35	0.32-0.30	Saturation
DUL	0.097	0.103	0.103	0.12	0.13	0.14	0.15	0.17-0.18	Drained upper limit
CLL	0.025	0.034	0.052	0.07	0.08	0.09	0.091	0.1-0.12	Crop lower limit
kl	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	rate of soil water extraction
Xf	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0-0.0	root hospitality factor
swcon	0.7	0.7	0.4	0.4	0.4	0.4	0.4	0.4	rate of flow of water under saturated conditions
fbiom	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	proportion of the non-inert carbon in the BIOM pool
Finert	0.40	0.50	0.70	0.99	0.99	0.99	0.99	0.99	proportion of initial organic C assumed inert
Oc	0.71	0.42	0.23	0.25	0.25	0.25	0.20	0.1- 0.05	Organic carbon (%)
BD	1.66	1.66	1.68	1.66	1.66	1.54	1.54	1.57-1.60	Bulk density

Soil Property Inputs measured for each site:

CLL Crop lower limit
DUL Soil's drained upper limit
OC Organic carbon (measured in some soils, default values used for other soils)
SW Initial soil water content (volumetric)
pH Soil pH (in 1:5 soil:water suspension)
no3 Initial nitrate N (mg/kg)
nh4 Initial ammonium N (mg/kg)
amp Temperature amplitude (^{0}C) = difference between highest and lowest mean monthly air temperatures calculated from nearest weather station data
tav Mean annual air temperature calculated from nearest weather station data

Values derived from measured values using rules

LL15 Soil moisture at 15 bars pressure; Rule: for all depths LL15 is set to the values used for the CLL of the top three layers
Air_Dry Soil moisture limit to which soil can dry by evaporation; Rule: 50% of LL15 in the top layer, 80% in the second layer and 100% for the rest of the profile
Saturation Saturated soil moisture content; Rule: [(1-BD/2.65) X 100] – 0.03 (sandy soils)
BD Soil bulk density (g dry soil per cm^3 moist soil)

Management input values

sow_pop Population density ($plants/m^2$)
Fert_rate Nitrogen fertilizer rate (kgN/ha)
Fert_day Date fertilizer was added (date)
Start_sw Date sw was initialized (date)
Start_no3 Date no3 was initialized (date)

Bambarsi seedling parameters

Parameter	Value	Description
Age	0.0	Establishment age
Height	50.0 (mm)	Establishment height
Init_pla	0.00005	Initial plant leaf area
Foliage_n_conc	0.03	Foliage nitrogen concentration

APPENDIX C

Contacts:

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URS

TEST PIT LOG TP01

URS Australia
Level 3, 93 Mitchell Street, Darwin 0800
Phone: 08 8980 2900
Fax: 08 8941 3920

Excavation Contractor:		Equipment: 12T Excavator	Project Name: GBS
		Bucket Size: 0.8	Project No.: 42213789
Logged By: J. Stevens	Test Pit Length: m	Relative Level:	Client: GBS Gold
Checked By: C.MacHunter	Test Pit Width: 1.5 m	Coordinates: 759432 mN 8503532 mE	Location:
Date Started: 19-7-07	Test Pit Depth: 3.5 m		
Date Finished: 19-7-07		Permit No:	

Method	Support	Penetration S M H R	Ground Water Data and Comments	Depth (m)	Graphic Log	Classification	DESCRIPTION OF STRATA	Moisture Condition	Consistency Relative Density	Sample Type PID (ppm)	Sampling and Other Testing
				0		SC	SAND; fine to medium grained, brown, trace to some medium plasticity clay, fine grass roots to 300mm	D		B B	
						SC	SAND; fine to medium grained, red brown, some medium plasticity clay	D/M		B B	
						SC	increased clay content @ 750mm	M		B B	
				1							
						SC	increased clay content @ 1300mm			B B	
				2		SC	trace Fe/Mn nodules @ 2000mm			B	
						SC	trace sandstone fragments @ 2500mm			B	
				3		GRVGSND	SAND; fine to medium grained, red brown mottled yellow brown, some medium plasticity clay, trace to some sandstone fragments and Fe/Mn nodules			B B	
							TP01 terminated @ 3500mm refusal on sandstone				
				4							

TEST PIT SECTION

URS

TEST PIT LOG TP02

URS Australia
Level 3, 93 Mitchell Street, Darwin 0800
Phone: 08 8980 2900
Fax: 08 8941 3920

Excavation Contractor:		Equipment: 12T Excavator	Project Name: GBS
Logged By: J. Stevens	Test Pit Length: m	Bucket Size: 0.8	Project No.: 42213789
Checked By: C.MacHunter	Test Pit Width: 1.5 m	Relative Level:	Client: GBS Gold
Date Started: 19-7-07	Test Pit Depth: 4 m	Coordinates: 228524 mN 8395340 mE	Location:
Date Finished: 19-7-07		Permit No:	

Method	Support	Penetration S M H R	Ground Water Data and Comments	Depth (m)	Graphic Log	Classification	DESCRIPTION OF STRATA	Moisture Condition	Consistency Relative Density	Sample Type PID (ppm)	Sampling and Other Testing
				0		SC	SAND; fine to medium grained, brown/red brown, trace to some medium plasticity clay	D			
						SC	SAND; fine to medium grained, red brown, some medium plasticity clay	D/M		B B	
						SC	increased clay content @ 750mm	M		B	
				1						B B	
						SC	increased medium grained sand content @ 1600mm			B	
				2						B	
						SC	sandstone fragments @ 2500mm trace yellow brown mottling			B	
				3						B B	
				4		SC	increased sandstone fragments @ 4000mm			B	
							TP02 terminated @ 4000mm end of excavator reach				

TEST PIT SECTION

URS

TEST PIT LOG TP03

URS Australia
Level 3, 93 Mitchell Street, Darwin 0800
Phone: 08 8980 2900
Fax: 08 8941 3920

Equipment: 12T Excavator	Project Name: GBS	Bucket Size: 0.8	Project No.: 42213789
Excavation Contractor:		Client: GBS Gold	
Logged By: J. Stevens	Test Pit Length: m	Relative Level:	Location:
Checked By: C.MacHunter	Test Pit Width: 1.5 m	Coordinates: 228794 mN 8395412 mE	
Date Started: 19-7-07	Test Pit Depth: 4 m		
Date Finished: 19-7-07		Permit No:	

Method	Support	Penetration (S M H R)	Ground Water Data and Comments	Depth (m)	Graphic Log	Classification	DESCRIPTION OF STRATA	Moisture Condition	Consistency Relative Density	Sample Type PID (ppm)	Sampling and Other Testing
				0		SC	SAND; fine to medium grained, brown, trace to some medium plasticity clay, fine grass roots to 300mm				
						SC	SAND; fine to medium grained, red brown, some medium plasticity clay	D/M		B	
										B	
										B	
										B	
										B	
				1						B	
								M		B	
						SC	increased clay content @ 1600mm			B	
				2							
										B	
				3						B	
										B	
						GRVGSND	sandstone fragments @ 4000mm with yellow brown mottling			B	
				4			TP03 terminated @ 4000mm end of excavator reach Weathered sandstone, mottled fragments < 5mm diameter				

TEST PIT SECTION

URS

TEST PIT LOG TP04

URS Australia
Level 3, 93 Mitchell Street, Darwin 0800
Phone: 08 8980 2900
Fax: 08 8941 3920

Excavation Contractor:		Equipment: 12T Excavator	Project Name: GBS
		Bucket Size: 0.8	Project No.: 42213789
Logged By: J. Stevens	Test Pit Length: m	Relative Level:	Client: GBS Gold
Checked By: C.MacHunter	Test Pit Width: 1.5 m	Coordinates: 227973 mN	Location:
Date Started: 19-7-07	Test Pit Depth: 4 m	8396340 mE	
Date Finished: 19-7-07		Permit No:	

Method	Support	Penetration (S M H R)	Ground Water Data and Comments	Depth (m)	Graphic Log	Classification	DESCRIPTION OF STRATA	Moisture Condition	Consistency Relative Density	Sample Type	PID (ppm)	Sampling and Other Testing
				0		SC	SAND; fine to medium grained, brown, trace to some medium plasticity clay, fine grass roots to 450mm	D		B		
						SC	SAND; fine to medium grained, brown/red brown, trace to some medium plasticity clay			B		
						SC	SAND; fine to medium grained, red brown, some medium plasticity clay			B B		
						SC	increasing clay content @ 750mm	D/M		B		
				1				M		B B		
						SC	increasing clay content @ 1600mm			B		
				2						B B		
				3						B		
						SC	increasing clay content @ 3500mm			B B		
				4			TP04 terminated @ 4000mm end of excavator reach					

TEST PIT SECTION

URS

TEST PIT LOG TP05

URS Australia
Level 3, 93 Mitchell Street, Darwin 0800
Phone: 08 8980 2900
Fax: 08 8941 3920

Excavation Contractor:		Equipment: 12T Excavator	Project Name: GBS
		Bucket Size: 0.8	Project No.: 42213789
Logged By: J. Stevens	Test Pit Length: m	Relative Level:	Client: GBS Gold
Checked By: C.MacHunter	Test Pit Width: 1.5 m	Coordinates: 227977 mN 8396978 mE	Location:
Date Started: 19-7-07	Test Pit Depth: 4 m		
Date Finished: 19-7-07		Permit No:	

Method	Support	Penetration (S M H R)	Ground Water Data and Comments	Depth (m)	Graphic Log	Classification	DESCRIPTION OF STRATA	Moisture Condition	Consistency Relative Density	Sample Type	PID (ppm)	Sampling and Other Testing
				0		SC	SAND; fine to medium grained, brown/red brown, trace to some medium plasticity clay, fine grass roots to 300mm	D		B		
						SC	SAND; fine to medium grained, red brown, some medium plasticity clay	D/M		B B B B B		
				1				M		B		
						SC	increasing clay content @ 1300mm			B B		
				2		SC	increasing clay content @ 2000mm			B B		
				3		GRVGSND	trace to some sandstone fragments below 3000mm			B		
						SC	weathered rock/hard clay			B B		
				4			TP05 terminated @ 4000mm end of excavator reach					

TEST PIT SECTION

URS

TEST PIT LOG TP06

URS Australia
Level 3, 93 Mitchell Street, Darwin 0800
Phone: 08 8980 2900
Fax: 08 8941 3920

Excavation Contractor:	
Logged By:	J. Stevens
Checked By:	C.MacHunter
Date Started:	19-7-07
Date Finished:	19-7-07
Test Pit Length:	m
Test Pit Width:	1.5 m
Test Pit Depth:	4 m
Equipment:	12T Excavator
Bucket Size:	0.8
Relative Level:	
Coordinates:	227232 mN 8797124 mE
Permit No:	
Project Name:	GBS
Project No.:	42213789
Client:	GBS Gold
Location:	

Method	Support	Penetration (S M H R)	Ground Water Data and Comments	Depth (m)	Graphic Log	Classification	DESCRIPTION OF STRATA	Moisture Condition	Consistency Relative Density	Sample Type	PID (ppm)	Sampling and Other Testing
				0		SC	SAND; fine to medium grained, brown/red brown, trace to some medium plasticity clay, fine grass roots to 450mm	D				
						SC	SAND; fine to medium grained, red brown, some medium plasticity clay			B B B B B		
				1		SC	increasing clay content @ 1000mm	D/M		B		
								M		B B		
				2		SC	increase in clay and fine sand content @ 2000mm			B B		
				3						B B B		
				4			TP06 terminated @ 4000mm end of excavator reach					

TEST PIT SECTION