Ghaghoo Mine Dewatering and Injection of Excess Water

Andrew Johnstone[1], Danielle Kriel[2], Danie Vermeulen[3]

[1]*GCS (Pty) Ltd Johannesburg South Africa andrewj@gcs-sa.biz*
[2]*Gem Diamonds (Pty) Ltd Johannesburg, South Africa. Danielle Kriel dkriel@gemdiamonds.com*
[3]*Institute of Groundwater Studies, University of the Free State Bloemfontein, South Africa, VermeulenD@ufs.ac.za*

Abstract

Ghaghoo Mine is situated in the Central Kalahari Game Reserve in central Botswana. Ghaghoo is mining a Kimberlite pipe that vertically intruded into host sediments and basalts. The Kimberlite, sediments and basalts are overlain by 80m of unconsolidated and unsaturated aeolian Kalahari Sands. Regional groundwater level is 100m below surface in the fractured basaltic aquifer and the underlying dual porosity sedimentary aquifers.

In order to mine, Ghaghoo has to be dewater to a depth of 350m. The volumes from the dewatering exceed the mine water demand by 6500m^3/day and as a result the mine has an excess water balance. Ghaghoo is require to dispose of the excess water environmentally sustainable manor. The mine is situated 42km from the nearest settlement (outside the national park) and groundwater has a TDS of 7000mg/l making it unsuitable for domestic and agricultural purposes. The mine investigated a number of different options to manage the excess water and the most environmentally sustainable and economical option is to inject the water into the unsaturated Kalahari Sands. This paper discusses the hydrogeology of the dewatering operations and the injection of excess water.

Introduction

Botswana is world renowned for its diamonds with the majority being mined from large open cast pits in the vertical kimberlite pipes that have intruded into the host rock (Orapa, Jwaneng & Letlekane) These mines are significant contributors to the Botswana economy and provide employment and foreign revenue. A number of smaller kimberlites are now being developed in Botswana, including Ghaghoo being developed by Gem Diamonds. In the case of Ghaghoo, the kimberlite is overlain by 80m of unsaturated Kalahari Sands and as a result is an underground mine. The proposed Ghaghoo mining operations will extend below the regional groundwater level and as a result the mine has to be dewatered to ensure safe mining conditions. The volumes of groundwater from the dewatering operations exceed the mine requirements necessitating the handling of excess water.

Ghaghoo investigated a number of different options to dispose of excess water consisting of evaporation and forced evaporation, constructed wetlands, water treatment for agriculture and/or domestic supplies and game watering. The most economical and environmentally sustainable option, given Ghaghoo's location, is to inject the groundwater back into the unsaturated Kalahari Sands. Ghaghoo has been granted permission by the Botswana Ministry of Water to undertake a pilot study of the injection process.

The mine plans to mine to a depth of 350m below surface some 250m below regional groundwater level. The Kimberlite is 15ha in extent and consist of 2 lobes, an outer and the richer inner lobe which will be mined for 10 years at a rate of 60 000 ton/month. The mine will be required to dispose of 6500m^3/day over a 10 year life of mine with an estimated total volumes of 23,75 M m^3 of water.

The initial desk top investigation proved that the Kalahari's Sands have sufficient storage capacity for the dewatering volumes, without excessive recirculation and the water will gradually be released back into the underlying aquifer.

Location and Physiography

Ghaghoo is situated 40km west of the eastern boundary of the Central Kalahari Game Reserve (CKGR) in Central Botswana and about 360km north west of the capital city Gaborone (figure 1).The area is on average 1000 mamsl (ranging from 985to 1033mamsl) and is very flat, with minor changes in topography being related remnant dunes. There are no significant drainage systems due to the topography and the thick unsaturated sands. The area experiences summer rainfall and cold dry winters. Mean annual rainfall is 350 mm/annum and the potential evapotranspiration is 1 825mm/annum. Numerous studies have been undertaken to determine the rate of rainfall related recharge in the area (De Vries & Von Hoyer 1998).The studies conclude that very limited rainfall related recharge occurs in areas of excess unsaturated Kalahari sand cover.

The Ghaghoo mining lease area is 4400ha and is situated in the CKGR which is a national game reserve. Permit conditions stipulate that any mining associated activities have to be undertaken within the mining lease area. As a result the injection system must be within the mining lease area which necessitated the development of a preliminary groundwater model to determine potential recirculation of water back to the mine.

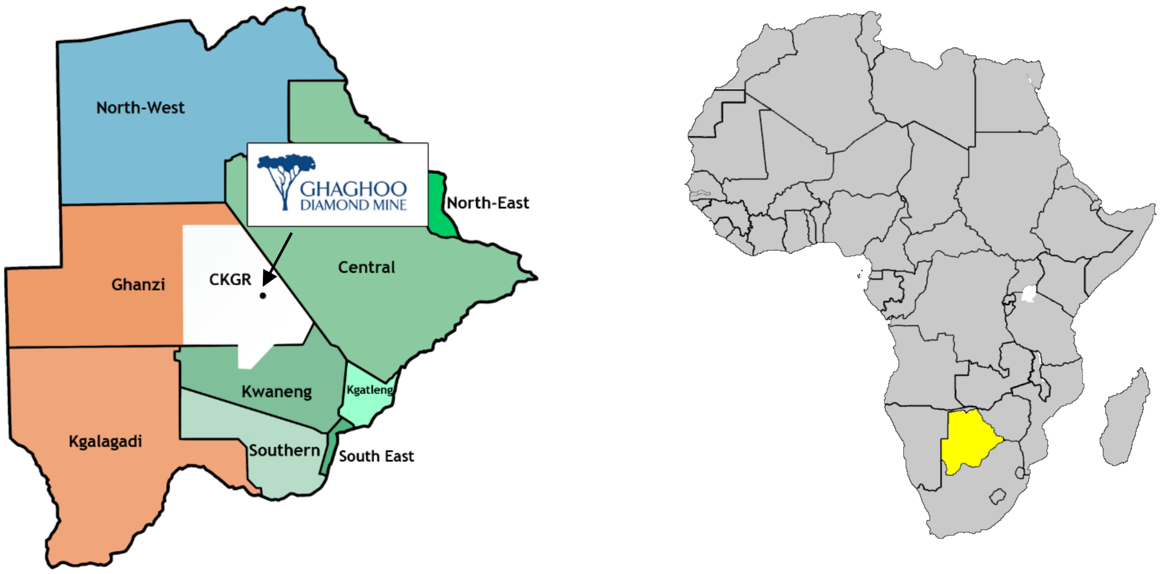


***Figure 1:** Locality of Ghaghoo Mine in Botswana*

Hydrogeology

The hydrogeology of Ghaghoo consists of unconsolidated and unsaturated Kalahari sediments to a depth of 80 m below surface, which are underlain by saturated fractured basalt from 80 to 260m below surface and which is in turn underlain by sediments of the dual porosity confined Ntane formation from 260 to 340m below surface. The lithostratigraphy of the Ghaghoo area is shown in Table 1. The exact recharge mechanism in the Central Kalahari has been studied by De Vries JJ & Von Hoyer M (1988) and the general consensus is that very little recharge occurs due to the climatic conditions and the thickness of sand cover. The Kalahari sand cover increases in thickness from east to west. Groundwater gradients and an increase in the salinity of the groundwater occurs from east to west, further supporting the theory that the majority of recharge occurs in the outcrop areas in the east.

The Stormberg basalt is a typical fractured rock aquifer with zones of secondary permeability and storage being associated with fractures, faults and geological contacts. The Ntane aquifer is an important aquifer in Botswana and supports a number of wellfields. The Ntane aquifer at Ghaghoo is confined and has dual porosity, with the primary porosity being associated with the poorly cemented aeolian sand and the secondary porosity being associated with post deposition faults and fractures and contact zones of kimberlite or dolerite intrusions.

***Table 1:** Lithostratigraphy of Ghaghoo Area.*

Supergroup	Group	Formation	Lithological Description
-	Kalahari	Kalahari Beds	Loose sands, calcrete layers, calcareous sandstone and mudstone
Karoo	Stormberg	Ramoselwana Volcanics	Crystalline, massive amygdaloidal basalts
	Lebung	Ntane	Fine to medium grained, clean, friable sandstone. Often calcretised in zones
		Mosolotsane	Red/brown greenish mudstones and siltstones with fine to medium, occasionally coarse intercalated sandstone. Basal conglomerate in places.
	Ecca	Marakwena	Conglomerate and sandstone intercalated with silty mudstone
		Tale	Fine-grained meta-arkoses, shale and minor sandstone
Damara	-	Kgwebe	Porphyry, felsite's, diabase and tuffaceous sandstone
		Ghanzi	Sandstone, siltstones quartzite's and minor carbonates

The ambient groundwater quality at Ghaghoo has a TDS of 7000 mg/l and can be classed as a sodium chloride water. The raw water is used in the processing plant and for domestic consumption after being purified by means of reverse osmosis. The ambient groundwater quality is shown in Table 2.

Table 2: *Ghaghoo Ambient Groundwater Quality*

Parameters		Unit	Value
- pH	pH	pH unit	7.62
- Electrical Conductivity	EC	mS/m	1104
- Total Dissolved Solids	TDS	mg/L	7006
- Total Alkalinity	T-Alk	mg $CaCO_3$/L	64
- Bicarbonate	HCO_3	mg/L	78.1
- Carbonate	•CO_3	mg/L	0
- Total Hardness	T-Hard	mg $CaCO_3$/L	1170
- Calcium Hardness	Ca-Hard	mg $CaCO_3$/L	1110
- Calcium	Ca	mg/L	444
- Magnesium	Mg	mg/L	14.6
- Potassium	K	mg/L	10.5
- Sodium	Na	mg/L	2182
- Sulphate	SO_4	mg/L	810.55
- Chloride	Cl	mg/L	3249.3
- Fluoride	F	mg/L	0.598
- Orthophosphophate	PO_4 as P	mg/L	0.003
- Iron	Fe	mg/L	3.45
- Manganese	Mn	mg/L	0.36
- Nitrate as NO_3	NO_3 as NO_3	mg/L	0.638

Dewatering and Injection

Dewatering will occur from the confined Ntane Sandstone from a series of bores which will terminate in the relatively impermeable Mosolotsane formation. The Ntane will be targeted for the dewatering bores due to the high yield of bores in this aquifer. As the Ntane is depressurized water levels in the overlying basalt will decline. Boreholes will be sited to intersect post deposition fracture zones both in the basalt and the underlying sandstone. These bores will pump to a central reservoir from where the water will be pumped to the injection wells downgradient of the mining area. This is graphically presented in Figure 2.

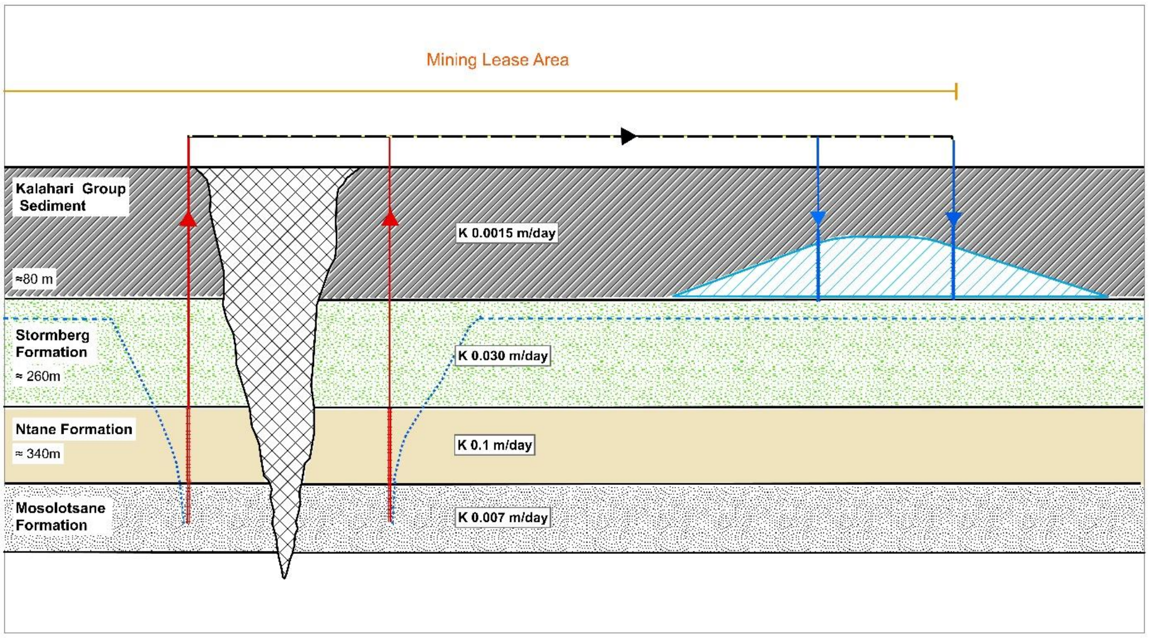


Figure 2: *Schematic of the Dewatering and Injection System*

The unsaturated Kalahari Sands has an average storage of capacity of 20% and is some 3 orders of magnitude greater that the confined Ntane Sandstone (s= 0.0001). This will result in substantially less volume of Kalahari sands being statured for the same volumes of dewatering of the Ntane and basalt aquifers.

In order to determine the potential recirculation of water and to comply with the mining permit conditions, preliminary groundwater model simulations were undertaken with the injection wells downgradient, and along the western boundary of the mine lease area in two configurations as shown in Figure 4. The simulations were run for a period of 10 years to determine the mound and the potential for recirculation into the mine dewatering bores. The mathematical simulations indicate that very limited volumes of water will be recirculated via the Kalahari Sands. The dewatering operations are however going to dewater the basalts around the mine and future investigations will have focus on the leakage through the basalt into the Ntane aquifer and recirculation into the mine dewatering system.

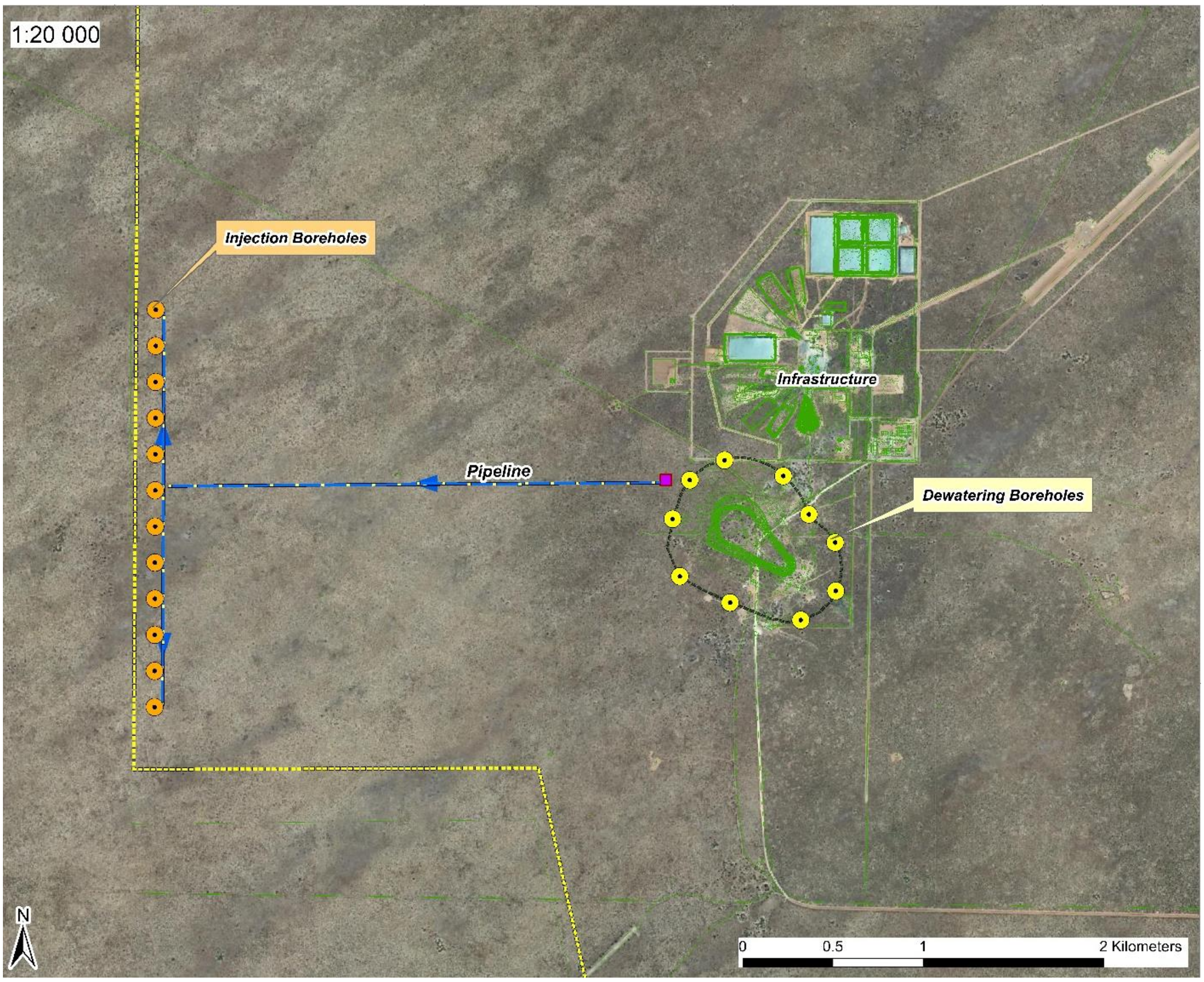
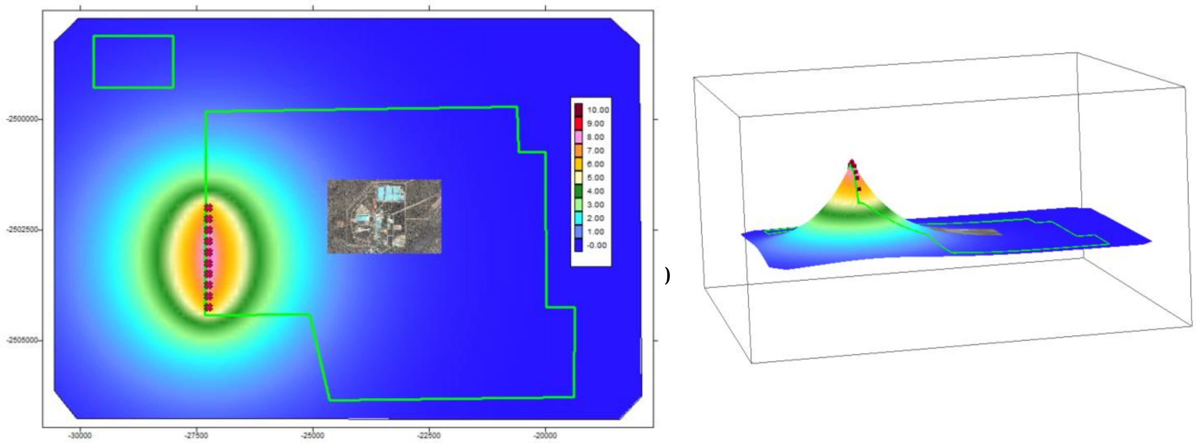


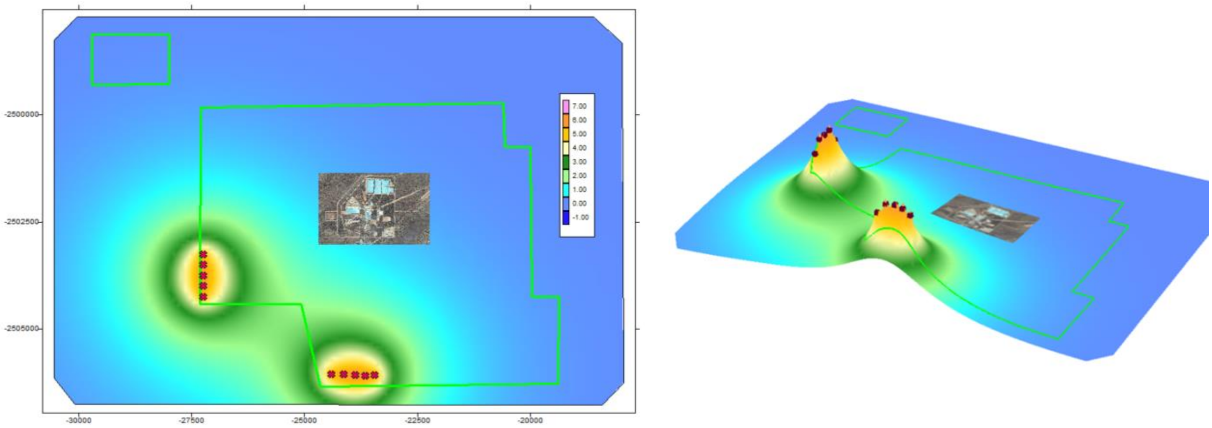
Figure 3: *Schematic layout Dewatering and Injection Systems*

The mathematical simulations of the mounding were undertaken using the Theis equation. Aquifer hydraulic properties were taken from previous groundwater investigations and geotechnical studies (figure 4).The pilot injection study will consist of a number of injection wells and monitoring piezometers to determine the injections rates at different pressures. This will provide additional information relating injections rates, number of bores required to dispose of the excess water. In addition the pilot test will allow for the determination of geometry of the groundwater mound.

The dewatering rates required to ensure dry mining will be determined by groundwater model and the mine plan. This data will then be combined with the mine plan and associated dewatering requirements.



Scenario 1: Single injection system after 10 years



Scenario 2: Western and Southern Injection System

***Figure 4:** Simulated Groundwater Mounds*

Conclusions

Ghaghoo mine must dewater to allow for mining and safe mining conditions. The most economical and environmentally sustainable method of disposing of the excess water is to pump directly from the dewatering wells into an injection system in the unsaturated Kalahari Sands. The sands have sufficient capacity to store and then release the groundwater from the dewatering operation back into the aquifer over time.

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