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Sishen Iron Ore Mine
Recommended Groundwater Monitoring System

Report - Draft

July 2011

Anglo American PLC

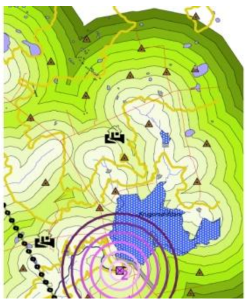
Kumba Iron Ore

Sishen Iron Ore Mine

GCS Project Number: 10-387/2

Client Reference: P.O. no 4504860864

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1 INTRODUCTION

GCS (Pty) Ltd was appointed by Sishen Iron Ore Company Pty Ltd. (SIOC) to complete a groundwater study at the Sishen Iron Ore Mine (SIOM) near to Kathu in the Northern Cape. Part of the study was to recommend a groundwater monitoring system. The groundwater monitoring system is required to determine the impact of the Sishen Iron Ore Mine (SIOM) dewatering on the surrounding aquifer and groundwater users.

The monitoring system is also required to determine other impact on the groundwater regime of the catchment such as other abstractors, water quality and to be able to verify predictions. The monitoring system is also aimed at providing a solid database to measure the impact and to protect SIOM against spurious and unfounded claims in the future.

This report forms part of a series of reports completed by GCS (Pty) Ltd for SIOM in terms of contract P.O. no 4504860864. The reports are:

- GCS Ref 10-387/1: Hydrogeological Database for the D 41J catchment;
- GCS Ref 10-387/2: Recommended Groundwater Monitoring System;
- GCS Ref 10-387/3: Review of the available Numerical Groundwater Models;
- GCS Ref 10-387/4: Impact of mining on the Gamagara River Aquifer; and
- GCS Ref 10-387/5: Assessment of Socio-Economic Impact of Dewatering At Sishen Mine on Selected Adjacent Farms.

2 SCOPE OF WORK

SIOM conducts regular monitoring of water levels and quality in selected boreholes around the mine. The water quality and water level data is kept on a SIOM database. The mine also relies on surrounding farmers to submit data regarding water levels in private boreholes. There are a number of other users in the catchment that also monitor water levels and quality. Some of this data is reported to the Department of Water Affairs in terms of the requirements of the Water use Licenses issued to various users in the catchment.

In addition, the Tshiping Water Users Association manages the D41J catchment. The agreed GCS scope of work was to assess the existing SIOM Monitoring System and make recommendations for the monitoring around the SIOM and also for the D41J catchment:

- Establish a monitoring system for the D41J catchment to monitor the impacts of users on the groundwater levels and quality;

- The monitoring should incorporate existing monitoring systems developed by the users in the D41J catchment and recommend additional monitoring where there were data deficiencies;
- Investigate telemetry systems to record information at strategic boreholes. Link the system to a database for download of information. Allow certain data to be accessed by all parties. Five strategic boreholes are to be selected; and
- Asses the existing SIOM monitoring system and make recommendations.

3 METHODOLOGY

The following methodology was employed by GCS in assessing the SIOM and the D41J catchment:

- Assessment of all data collected for the D41J catchment GCS Report Ref 10-387/1&4;
- Assessment of the SIOM monitoring system; and
- Discussion of the monitoring undertaken by other users.

4 OBJECTIVES OF THE SUGGESTED MONITORING SYSTEM

The primary goal of any monitoring system is to assess and manage the impacts on groundwater quantity and quality. The aquifer response and quality trends are measured and provide key inputs for this goal (Tuinhof et al., 2006).

According to Tuinhof et al (2006), certain key factors are important to ensure success of a monitoring system viz.

Network Design

- Objectives should be defined and program adapted accordingly;
- Groundwater flow system should be understood; and
- Sampling locations and monitoring parameters should be selected.

System Implementation

- Field equipment and laboratory facilities should be acceptable;
- A complete operational protocol and data handling system should be established; and
- Groundwater and surface water monitoring should be integrated where applicable.

Data Interpretation

- Data quality should be regularly checked through internal and external controls;
- Decision makers should be provided with interpreted management-relevant datasets; and
- Programs should be periodically evaluated and reviewed.

A groundwater monitoring network is an iterative system whereby the network should constantly change and adapt in response to data trends and mining and other activities. This D41J monitoring system was designed especially for water level monitoring as the primary driver, with groundwater quality as secondary. The proposed network focuses on assessing the extent of dewatering of SIOM, the impact on the Gamagara River aquifer and the response of the natural groundwater environment to climatic factors.

This proposed groundwater monitoring network should thus be dynamic. In addition, the regular monitoring is a statutory requirement in terms of the National Water Act (Act No 36 of 1998) and the associated water use licenses

5 GROUNDWATER MONITORING

The groundwater monitoring was assessed in terms of the SIOM monitoring system and the D 41J catchment monitoring system.

5.1 SIOM Groundwater Monitoring

At present SIOM have two monitoring systems; and internal and external system. The internal system is used to monitor water levels and quality in the mining lease area for management of the dewatering system.

The external (outside the mining lease area) was recommended by Meyer (2009c) to monitor the impacts on the regional groundwater level associated with the SIOM dewatering. Furthermore Tredoux (2011) recommended that implementation of a groundwater quality monitoring network of selected boreholes in proximity to the Gamagara River. The monitoring program proposed by Tredoux (2011) included water level measurements in additional to groundwater quality of the selected boreholes. These monitoring networks are being implemented by SIOM. The aim of the SIOM external monitoring programme is to determine SIOM impact on water levels and surrounding users.

One of the deficiencies identified is the formalisation of these SIOM monitoring programs. The monitoring systems should be incorporated into the SIOM ISO 14001 Environmental Management System.

5.2 D41J Catchment Monitoring

The purpose of this study was to establish a monitoring system for the whole D41J catchment. This system should therefore assess the impacts of the following users:

- Khumani Mine;
- Farmers;
- Other mines;
- Kathu Municipality; and
- SIOM.

No comment can be made on the internal water level and quality monitoring conducted by SIOM for the dewatering management. However the external monitoring program was selectively incorporated into the D41J monitoring system.

Groundwater monitoring in the D41J network should cover the following areas: inside the dewatered zone, along the reported boundaries of the dewatered zone, along Gamagara River and potential receptors or future zones of impact. Furthermore monitoring of the background water quality and groundwater levels is also required. The groundwater monitoring aims to assess:

- The impact of mine dewatering on the surrounding aquifers. This will be achieved through monitoring of groundwater levels in the monitoring boreholes;
- Groundwater quality trends. This will be achieved through sampling of the groundwater in the boreholes at the prescribed frequency; and
- Regional groundwater levels to determine natural fluctuations and to be able to differentiate between natural groundwater fluctuations and those caused by SIOM.

The borehole monitoring positions were recommended based on the extent of the Meyer 2010 dewatering zone extent. The monitoring network should furthermore act as an early warning system, whereby water levels can be used to predict future trends. The system should provide information to differentiate between the natural fluctuations and those influenced by the mine. This network will also confirm the dewatered extent of the Meyer dewatering zone as depicted in Figure 5.1. The network should also assist in resolving the discrepancies between the R. Meyer July 2010 and the GPT impact/dewatered zone. It was minuted in a meeting that GPT and R. Meyer will confederate on the delineation of the zone of dewatering. The meeting minutes of the Sishen Groundwater Study can be seen in Appendix A.

The proposed network discussed below complies with the previously mentioned criteria. It is envisaged that the frequency of groundwater level monitoring remains on a monthly basis. The telemetry boreholes are on a continuous monitoring system, whereby water levels can be measured every minute to perhaps 12 hourly, the exact frequency can be adjusted.

As mentioned previously monitoring of groundwater quality is not the primary goal. The current cone of depression is likely to cause any mine related contaminants to migrate towards the mine. Therefore outside the dewatered zone groundwater quality is unlikely to be affected by contaminants emanating from the mine. As a result only certain boreholes should be monitored for groundwater quality outside the dewatered zone, mainly to assess regional groundwater quality trends. The requirements of the Water use license must be incorporated into the monitoring system. This can also be done during the formulation of the ISO 14001 monitoring procedure. A summary of the monitoring program can be seen in Table 5.1.

Table 5.1: Groundwater monitoring program

Monitoring position	Sampling interval	Analysis	Water Quality Standards
All monitoring boreholes	Monthly: measuring the depth of groundwater levels	N/a	N/a
Monitoring boreholes outside dewatered zone	Annual: sampling for water quality analysis	Full analysis	South African Water Quality Guidelines: Domestic Use, livestock watering Variations from ambient
Telemetry boreholes	Continuous monitoring	N/a	N/a
Rainfall	Daily at the rain gauges	N/a	N/a

5.3 Groundwater monitoring network

The proposed monitoring network can be seen in Figure 5.1 and listed in Table 5.2 and Table 5.3. In Table 5.2 all the boreholes derived from SIOM or related studies were tabulated (94 boreholes). SIOM is currently monitoring 52 of these 94 boreholes. The boreholes include those identified by GCS during the Gamagara hydrocensus (23 boreholes), other hydrocensus sources (6 boreholes), the NGDB (8 boreholes) and Sishen (57 boreholes). The boreholes classes are discussed below:

- 'GCS Hydrocensus': GCS conducted a hydrocensus along the Gamagara River as part of the Gamagara River study. The selected boreholes were chosen to obtain a representative spread of groundwater level monitoring along the river;
- 'NGDB': Boreholes classes as NGDB were obtained from National Groundwater Archive (NGA). They were only selected in the areas where boreholes from other sources were not available. The coordinate accuracies of these boreholes are questionable and should be verified in the field'
- 'Other source': The database of borehole information developed by GCS contained hydrocensus data of varies studies in the D41J catchment. These boreholes were thus obtained from this information;
- 'Sishen Database': These boreholes are not currently monitored by SIOM, but are found in their database. Their existence should be verified;
- 'Sishen (new)': The Meyer (2009c) report recommended the additional installation of boreholes around the mine. These boreholes are those recommended by the study; and
- 'Sishen Monitoring': Used to manage dewatering in mining lease area, These are the boreholes which are monitored by SIOM. These boreholes were refined and reduced considerably especially around the pit areas. Extensive monitoring around the pits are not essential for this monitoring system, however some of the data is required.

Although SIOM cannot control monitoring on Khumani Mine, the use of data from their monitoring system will add value to the SIOM monitoring system. In Table 5.3 , all the Khumani Mine related boreholes were listed to be monitored (22 boreholes). The boreholes monitoring data collected by Khumani Mine should be submitted to Tshiping Water Users Association to be incorporated into the newly developed database for the D41J Catchment. It must be mentioned that this report does not include the potential impact of Khumani Mine. The boreholes in Table 5.3 were classed as those obtained/drilled by Khumani Mine (classed: 'Khumani') and those identified during a GPT hydrocensus for Khumani Mine in 2010.

Table 5.2: Proposed groundwater monitoring network boreholes (Sishen related)

Borehole no	Coordinates*		Borehole Elevation (mamsl)	Borehole Class
	X	Y		
DG01	-12320.12	-3054491.70	1114.993	GCS hydrocensus
DG15	-12102.94	-3056185.71	1115.997	GCS hydrocensus
BP05	-6501.43	-3076708.67	1172.074	GCS hydrocensus
BP06	-10857.97	-3079552.14	1178.35	GCS hydrocensus
BW04	-10065.40	-3067462.32	1138.883	GCS hydrocensus
DEM01B	7541.92	-3080322.01	1218.645	GCS hydrocensus
DEM02B	8976.51	-3079950.65	1223.955	GCS hydrocensus
DEM10	4756.07	-3080296.21	1215.285	GCS hydrocensus
LM14	-9157.22	-3071430.12	1147.961	GCS hydrocensus
MA07	-1554.09	-3080345.47	1189.462	GCS hydrocensus
DM01	-11378.48	-3058358.40	1118.171	GCS hydrocensus
DV03	-9593.20	-3064130.95	1135.494	GCS hydrocensus
EE05	-8811.97	-3074163.69	1157.798	GCS hydrocensus
EL05	-4889.28	-3078037.93	1178.905	GCS hydrocensus
FE02	-3719.87	-3079233.23	1179.873	GCS hydrocensus
LBH1	-20921.45	-3083820.66	1221.797	GCS hydrocensus
OD1	-25850.19	-3088328.23	1267.391	GCS hydrocensus
MA06	-1675.45	-3080364.99	1189.143	GCS hydrocensus
MA09	-1124.60	-3080263.97	1191.361	GCS hydrocensus
DEMSW319	8683.74	-3080476.81	1223.627	GCS hydrocensus
WBRU31	80.69	-3079508.70	1199.953	GCS hydrocensus
WT06a	-9034.29	-3075788.75	1159.801	GCS hydrocensus
WT11	-7477.08	-3075580.13	1159.778	GCS hydrocensus
BH21	9474.35	-3085780.02	1260.93	GPT hydrocensus
BH27	-213.60	-3089766.85	1236.06	GPT hydrocensus
BH41	-1909.10	-3086687.37	1219.7	GPT hydrocensus
BH43	-1052.57	-3086086.63	1219.784	GPT hydrocensus
BH57	-1516.61	-3083869.22	1205.65	GPT hydrocensus
2722DD00193	-604.87	-3079668.68	1199.354	NGDB
2723CA00100	3417.82	-3068648.08	1214.568	NGDB
2723CC00131	4204.83	-3085142.34	1219.421	NGDB
2723CC00162	3773.00	-3089877.16	1250.666	NGDB
2723CC00295	6678.08	-3087634.50	1239.768	NGDB
2723CD00006	39515.00	-3092902.50	1405.696	NGDB
2723CD00028	27873.24	-3076974.95	1321.864	NGDB
G00271NC	10206.94	-3079946.08	1234.718	NGDB
BES02	7143.50	-3064343.25	1231.85	Other source
CY7	-7459.66	-3097025.58	1268.197	Sishen DB
SN2794	-1691.96	-3076528.43	1197.94	Sishen DB
SN2801	-1875.14	-3077262.02	1196.44	Sishen DB
SW155	-758.57	-3079522.42	1199.781	Sishen DB
SW361	-1222.93	-3076072.95	1201.47	Sishen DB
SW740	-509.27	-3059808.68	1175.444	Sishen (new)
SW741	-2032.27	-3056939.69	1159.38	Sishen (new)
SW742	-2560.34	-3071734.63	1199.948	Sishen (new)
SW743	-4137.61	-3071735.06	1187.961	Sishen (new)
SW744	-5813.46	-3071735.75	1177.45	Sishen (new)
SW745	-3348.00	-3075280.91	1187.739	Sishen (new)

SW746	4049.38	-3056996.76	1184.755	Sishen (new)
SW747	8685.63	-3060656.02	1244.646	Sishen (new)
SW748	8970.51	-3075727.03	1232.608	Sishen (new)
SW749	9648.11	-3091020.30	1281.615	Sishen (new)
SW750	3249.88	-3093898.15	1276.845	Sishen (new)
SW753	-16151.15	-3081607.77	1196.847	Sishen (new)
SW754	-12606.91	-3079941.30	1180.962	Sishen (new)
SW755	-19620.70	-3067982.51	1175.639	Sishen (new)
SW756	-15871.91	-3069195.99	1180.992	Sishen (new)
SW757	-10850.62	-3060990.20	1122.258	Sishen (new)
Gamagara1	-4370.05	-3073247.89	1186.045	Sishen monitoring
Gamagara2	-4880.96	-3073659.40	1179.739	Sishen monitoring
Onverwacht1	-6195.65	-3069450.53	1166.431	Sishen monitoring
Nooitgedacht1	-7864.82	-3064963.01	1149.666	Sishen monitoring
Nooitgedacht2A	-4628.45	-3063961.04	1174.18	Sishen monitoring
Sacha1	-4338.65	-3063671.70	1172.594	Sishen monitoring
Sacha2	-3931.33	-3061874.20	1165.037	Sishen monitoring
Curtis1	-5517.11	-3061441.21	1158.007	Sishen monitoring
SA1865	-4348.33	-3067485.33	1202.884	Sishen monitoring
SA2170	-4347.44	-3069131.62	1189.09	Sishen monitoring
SW306	-1880.44	-3066867.75	1195.62	Sishen monitoring
SW312	5373.03	-3064021.44	1227.02	Sishen monitoring
SW377	7041.27	-3063441.63	1229.873	Sishen monitoring
WSEC5	3353.71	-3068294.64	1209.18	Sishen monitoring
SEKGAME4	4843.91	-3066211.24	1221.279	Sishen monitoring
SEKGAME8	7016.78	-3072556.13	1219.855	Sishen monitoring
SEKGAME9	6114.16	-3072578.09	1211.277	Sishen monitoring
SEKGAME11	7142.94	-3069749.79	1224.873	Sishen monitoring
SEKGAME13A	5840.48	-3066414.16	1226.729	Sishen monitoring
SEKGAME14	6509.00	-3069604.26	1221.582	Sishen monitoring
SEKGAME16	5830.48	-3066395.97	1226.733	Sishen monitoring
SEKGAME17	6337.74	-3065942.76	1231.084	Sishen monitoring
KU3	6388.77	-3062294.88	1228.522	Sishen monitoring
SA427	-2646.41	-3064994.71	1187.364	Sishen monitoring
SW192	585.43	-3061331.55	1179.848	Sishen monitoring
SW270	1154.66	-3066462.80	1201.47	Sishen monitoring
SIM428	772.11	-3063714.37	1193.135	Sishen monitoring
SW361	-1222.36	-3076072.79	1202.25	Sishen monitoring
SW570	-1178.27	-3073706.26	1200.346	Sishen monitoring
SW529A	-417.20	-3076174.21	1167.902	Sishen monitoring
SW595	-1372.70	-3074471.42	1200.383	Sishen monitoring
PA8	-1526.67	-3082057.59	1201.645	Sishen monitoring
MOK2	3459.42	-3086564.44	1224.447	Sishen monitoring
KING1	-1166.23	-3084400.35	1212.049	Sishen monitoring
SEKGAME6	8926.27	-3069751.63	1233.392	Sishen monitoring
SW603	-1782.80	-3070279.00	1201.618	Sishen monitoring

* - Coordinates are WGS84, Transverse Mercator LO23

Table 5.3: Proposed groundwater monitoring network boreholes (Khumani related)

Borehole no	Coordinates*		Borehole Elevation (mamsl)	Borehole Class
	X	Y		
AAK2/45	1358.01	-3084484.62	1253.727	Khumani
AAK3/27	1754.79	-3084884.41	1247.892	Khumani
ABK2/42	504.86	-3084484.47	1225.311	Khumani
ABK2/46	304.37	-3084483.93	1219.93	Khumani
AGK1/89	1655.73	-3085686.83	1255.884	Khumani
AGK2/87	1255.32	-3085684.09	1244.632	Khumani
AIK1/45	-152.11	-3085495.89	1219.271	Khumani
AKK4/26	2304.67	-3086883.25	1256.124	Khumani
ALK2/49	1154.00	-3086483.89	1253.575	Khumani
AMK1/47	755.55	-3086483.99	1238.891	Khumani
KMON2	-2346.11	-3080639.88	1188.021	Khumani
QK2/9	149.05	-3082296.29	1218.338	Khumani
QK4/55	354.95	-3083033.86	1219.073	Khumani
QK4/70	103.53	-3083084.54	1215.486	Khumani
Roscoe Mon	4209.71	-3088541.37	1240.822	Khumani
VK1/49	1656.66	-3083484.31	1274.929	Khumani
VK2/81	1555.15	-3083684.13	1265.398	Khumani
VK3/67A	1755.04	-3084083.58	1259.015	Khumani
WK2/35	356.17	-3083433.58	1222.214	Khumani
WK4/70	99.56	-3084096.60	1215.692	Khumani
ZR3/2	-1993.10	-3076785.34	1195.877	Khumani
ZR3/24	-2097.43	-3076875.25	1195.116	Khumani

* - Coordinates are WGS84, Transverse Mercator LO23

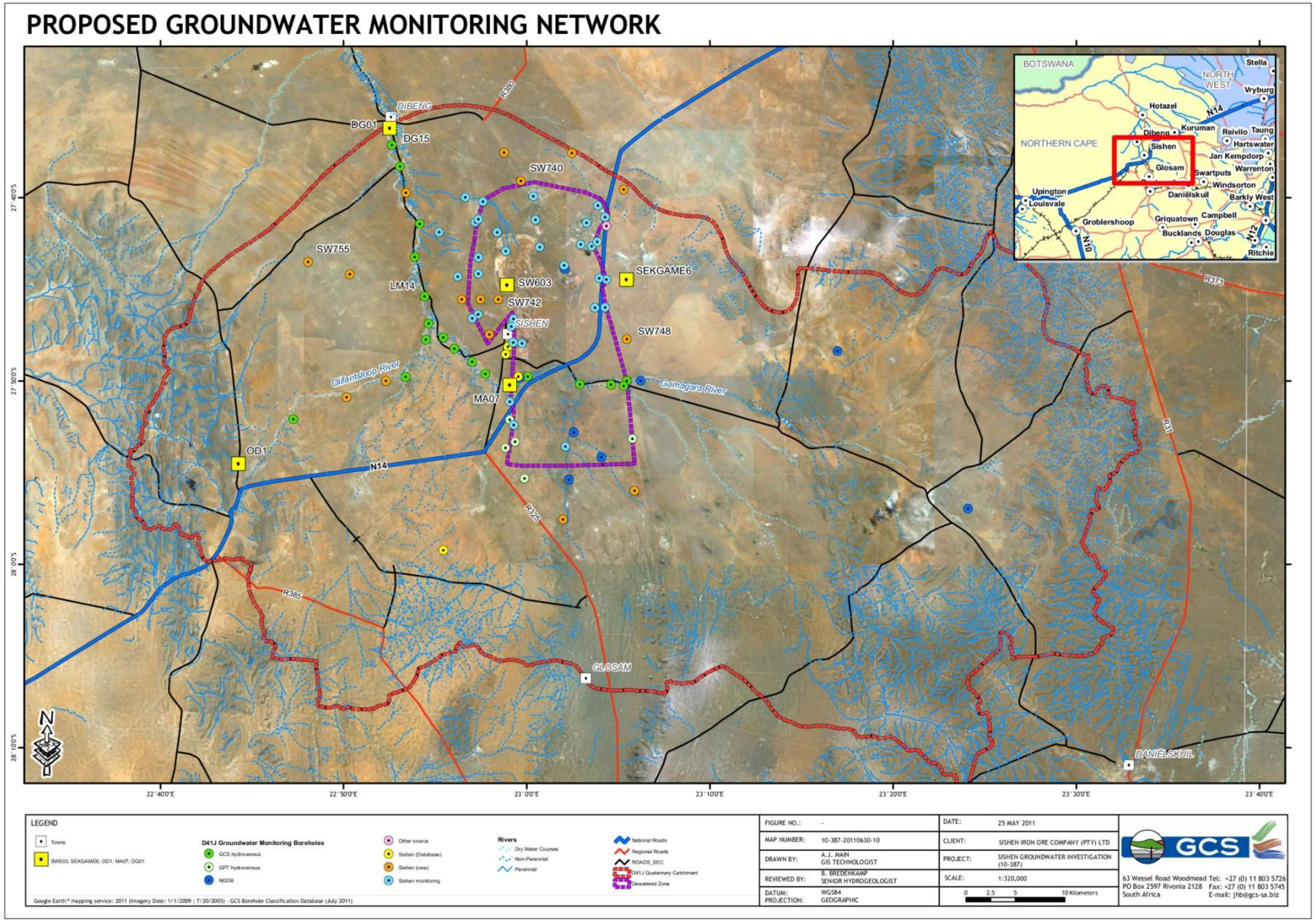

Figure 5.1: Proposed groundwater monitoring network

5.4 Monitoring Parameters

Groundwater levels are the primary monitoring parameter. Additionally, the identification of the chemical monitoring parameters is crucial and depends on the chemistry of possible pollution sources and regional groundwater hydrochemical signatures. As mentioned previously, the groundwater quality monitoring is focused on the regional groundwater quality around the mine outside the dewatered zone. In Table 5.4 the proposed regional water quality monitoring boreholes can be seen, these boreholes are found the monitoring network. The parameters comprise a set of physical and/or chemical parameters. The parameters should be revised after each sampling event.

5.4.1 Full analysis

Physical Parameters:

- Groundwater levels;
- Chemical Parameters;
- Field measurements: pH, EC; and
- Laboratory analyses: Anions and cations (Ca, Mg, Na, K, NO_3, Cl, SO_4, F, Fe, Mn, Al, & Alkalinity); Other parameters (pH, EC, TDS)

Laboratory analysis techniques should comply with SABS and SANAS guidelines. The groundwater monitoring database should be updated on a monthly basis as information becomes available. The database will be used to analyse the information and evaluate trends.

Table 5.4 Proposed regional water quality monitoring borehole

Borehole no	Coordinates		Borehole Elevation (mamsl)	Borehole Class
	X	Y		
BP06	-10858	-3079552	1178.35	GCS hydrocensus
OD1	-25850.2	-3088328	1267.391	GCS hydrocensus
BH21	9474.35	-3085780	1260.93	GPT hydrocensus
2723CD00006	39515	-3092902	1405.696	NGDB
2723CD00028	27873.24	-3076975	1321.864	NGDB
CY7	-7459.66	-3097026	1268.197	Sishen
SW741	-2032.27	-3056940	1159.38	Sishen (new)
SW747	8685.633	-3060656	1244.646	Sishen (new)
SW748	8970.505	-3075727	1232.608	Sishen (new)
SW750	3249.882	-3093898	1276.845	Sishen (new)
SW755	-19620.7	-3067983	1175.639	Sishen (new)
SEKGAME11	7142.935	-3069750	1224.873	Sishen monitoring
SW603	-1782.8	-3070279	1201.618	Sishen monitoring

6 TELEMETRY SYSTEM

The telemetry system entails automated groundwater level measurements at prescribed intervals. The data is downloadable and viewable via a website. This ensures that any responses of the groundwater system can be measured. GCS has selected NZ Instrumentation to supply the instrumentation for 5 strategic boreholes. Details of the instrumentation are shown in Appendix B This system can be interlinked with the system that Khumani Mine will install in their boreholes.

A logger is installed in the borehole which measures the piezometric head (water pressure). The data is then transferred from the logger using a GPRS modem to a web server. The data can then be viewed and downloaded via a website. A list of proposed telemetry boreholes can be seen in Table 6.1 below. Five (5) preliminary boreholes were selected to be equipped with a telemetry system. The final boreholes should be selected from the list below by GCS, SIOM and the Tshiping Water Users Association. The positions of the proposed telemetry boreholes can be seen in Figure 5.1. It can be seen that no telemetry boreholes were selected to the south of Sishen. Khumani mine will installed a telemetry system in boreholes in proximity to the Khumani Mine.

Table 6.1: Proposed Telemetry boreholes

Outside dewatered zone	In dewatered zone	In Gamagara River aquifer	Background levels
SEKGAME6	SW603	MA07	OD1
		DG01	

7 CONCLUSIONS

A groundwater monitoring system has been established for the D41J catchment by following a systematic process. The existing SIOM monitoring network was refined and incorporated into this network. However the Tredoux (2011) Gamagara River groundwater quality network was not included. Groundwater quality is a secondary objective of this monitoring system currently. However annual quality monitoring of selected boreholes outside the dewatered zone can be conducted.

A total of 94 boreholes should be monitored by SIOM, while Khumani should monitor a minimum of 22 boreholes on a monthly basis in terms of water levels. Five boreholes were selected as preliminary boreholes for the telemetry system. This proposed network should be dynamic and may change as more information becomes available.

8 RECOMMENDATIONS

Additional groundwater monitoring is required further up-gradient of the farm Demaneng in the Gamagara River in both the Danielskuil and the Postmasburg tributaries. Boreholes were identified in the area from NGDB data, but should be verified. Should these boreholes be destroyed then boreholes should be drilled.

The scope of this study was to establish a monitoring system for the D41J catchment. However given the findings of the Gamagara River study, further groundwater monitoring along the Gamagara River to the north of Dagbreek in the D41K catchment should be conducted.

9 REFERENCES

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APPENDIX A – SISHEN GROUNDWATER STUDY: MEETING MINUTES

APPENDIX B – N&Z INSTRUMENTATION