A STRATEGIC PLAN FOR THE EFFICIENT MONITORING OF TRENDS IN GROUND WATER QUALITY AFFECTED BY GOLD MINING IN SOUTH AFRICA.

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ABSTRACT

South Africa has a long history of gold mining that has impacted on ground water quality in several different catchments to varied degree from mild to severe. Ground water clean up requires assessment of the background water quality and the monitoring of chemistry prior to, during and following remediation. Successful and accurate monitoring requires a strategy that ensures results are representative, adequate and cost effective. A strategic plan that uses thermal imagery, geophysics, target drilling, sampling protocol and reporting has been devised for the gold fields of Vaal River Operations, West Wits and Welkom. It includes isotope analysis, mass balance calculations and ground water modeling.

1 INTRODUCTION

Mining associated activities involve the exposure of sulphidic minerals to the atmosphere – resulting in oxidation and possible leaching into water. Acid Mine Drainage (AMD) water may be produced that contains undesirable concentrations of dissolved minerals posing a risk to surface and ground water. The uncontrolled discharge of untreated AMD to the environment has the potential to devastate downstream aquatic ecosystems and as such AMD has been recognized has an International problem of the highest priority for the Mining Industry. Furthermore, unlike industrial pollution, acid mine drainage can continue indefinitely, well past the cessation of mining.

South Africa has a long history of gold mining and this has impacted on ground water quality in several different catchments to varied degree from mild to severe. In order to plan the remediation of affected areas, a detailed characterization of the contamination of the ground water is required including an assessment of the original background water quality. This requires a representative network of monitoring boreholes strategically placed within the contamination emanating from mining activities.

Anglogold and KLM Consulting Services (KLMCS) have developed a cost effective strategy to ensure that the boreholes are sited optimally and the chemical analyses obtained from ground water samples are relevant and acceptable to Regulatory requirements.

2 APPROACH

In order to assess the impacts of sub-surface seepage from mining operations on the ground water, thermal imagery scans were flown for Anglogold's Vaal River, West Wits and Free State operations. The aim was to try to monitor trends by siting the monitoring boreholes optimally on contaminated water bearing features. In order to track the ground water quality, water samples were taken in accordance with site specific protocols developed to meet the "Minimum Requirements for Water Monitoring At Waste Management Facilities" (Department of Water Affairs and Forestry 1998) and other internationally acceptable guidelines.

2.1 Thermal Imagery

A thermal image is a scan of the earth's temperatures (emitted energy) just before dawn and is scanned from an aircraft flown at about 2000 feet above ground level, preferably in winter when there is minimum soil moisture. Cold is shown as black and represents cooler deep seated ground water due to sub surface seepage and underground cavities. Hot is white and shows areas of evaporation or warmer surface water bodies.

Figure 1 is an example of a thermal scan for a mine site where seepage from slimes dams and a rock dump are clearly shown as darker shades whilst surface water dams and the slimes dams themselves are lighter in colour. The irrigated greens of the local golf course also show up clearly.

Figure 1 **THERMAL IMAGE SHOWING SEEPAGE FROM SLIMES DAMS AND ROCK DUMP**

2.2 Geophysical Surveys

Once the subsurface seepage zones associated with potential contamination have been identified, geophysical surveys are conducted to target drilling positions on water bearing structures as accurately as possible. Water bearing features have high conductivity (low resistance) and contaminated water with high concentrations of total dissolved salts will be even more conductive. Highly weathered zones with clay minerals are also good conductors. Dry, fresh rock in contrast, is very resistive.

Resistivity (profiling and soundings) and frequency-domain electromagnetic profiling are the techniques, which have been successfully used to determine the presence of surficial conductors.

Figure 2 shows a section where red is highly resistive and blue very conductive. From this section the location of possible sinkholes, a near vertical water bearing fault and horizontal layering interpreted as weathering and possible seepage zones are identified.

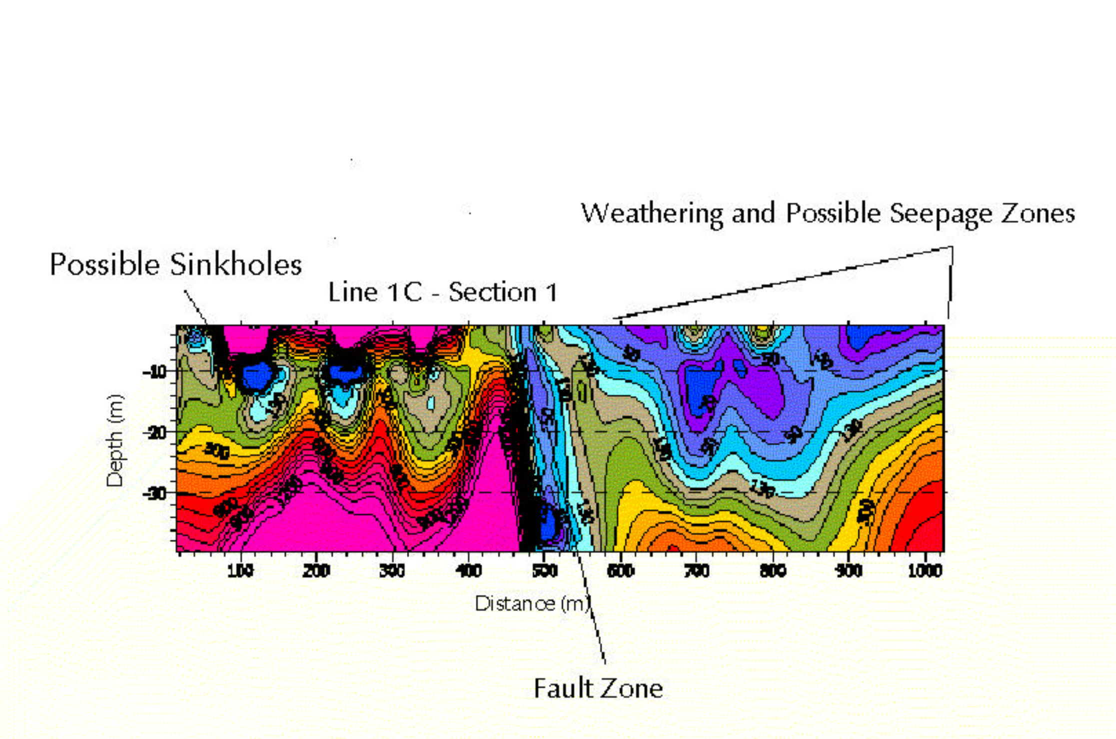
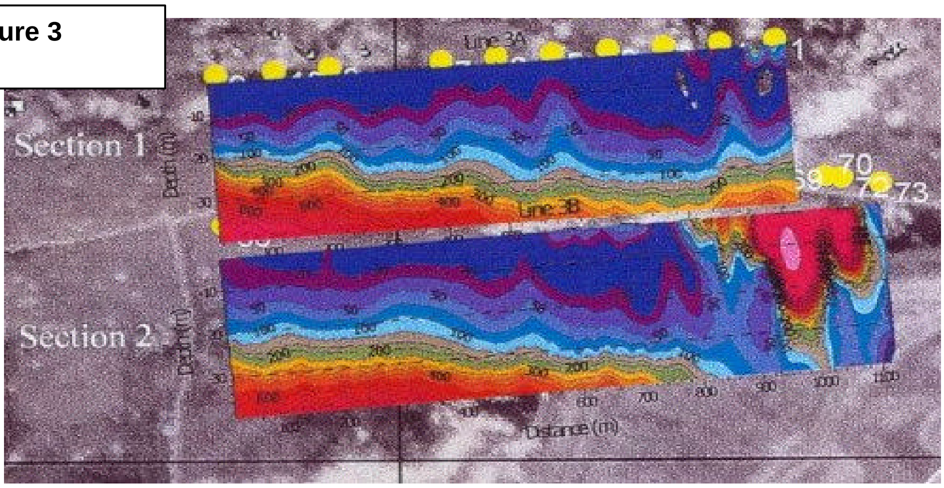


Figure 2	Anglo Gold - Vaal River Operations Typical Geoelectrical Signature Association		

When these profiles are overlain on the thermal image, as shown in figure 3, the exact location of drilling positions can be accurately targeted.

Figure 3



Interpreted Resistivity Traverse on Thermal Image showing Seepage from Slimes Dams

2.3 Drilling

Drilling is carried out under the supervision of a qualified hydrogeologist in order to ensure that all hydrogeological and geological parameters are accurately recorded. This is essential to the correct construction of the borehole such that the section of the ground water most contaminated is suitably penetrated. Where necessary nested piezometers at different depths may be installed to determine whether underlying aquifers have also been contaminated.

Test pumping of the boreholes is required to determine the hydraulic properties such as transmissivity (T), hydraulic conductivity (k) and storativity (s) of the aquifer. Where yields are low, slug tests or falling head tests are used. These parameters are required to determine how far the contaminant plume has moved, and to make predictions for the flow and transport of the contaminants.

2.4 Sampling

It is a minimum requirement that sampling of the boreholes for chemical analyses is carried out according to an acceptable sampling protocol since the data obtained from the chemical analyses is the building block on which all management decisions are based. As all sites are different, a site specific protocol is prepared and includes the chemical elements to be analysed and sample preservation for these elements. The laboratories used for the analyses should be accredited where possible and have a quality assurance (QA) record.

2.5 Hydrochemistry

Major ion chemistry is plotted on Piper tri-linear graphs and other plots, which are convenient for showing the evolutionary pathway of water composition across a site. They are also used to show the effects of mixing of two waters from different sources.

There is a strong association of metals such as Mo, Zn, Pb, Cu, Co, Ni, Cd, As, Sb, Hg and Mn with sedimentary sulphides and during transformation of these minerals, it is released. Typically under normal pH conditions these metals are not soluble, but as the pH decreases with increasing acidity, they can be mobilized. Inductively-coupled plasma mass spectrometry (ICP) scans are used to conduct a semi-quantitative sweep of up to 70 elements providing a quick, economical means of identifying contaminants in mine waste waters.

2.6 Environmental isotopes

The concentration of isotopes of oxygen and hydrogen in water molecules undergo small changes when water evaporates or condenses, which leads to an increase of the heavier isotope in the water phase. This implies that water will carry an isotopic signature of its history. Unlike the dissolved constituents of water (i.e. salts), which undergo constant modification in contact with the aquifer host rock, the isotopic ratios of oxygen and hydrogen are conservative.

Figure 4 shows a conventional plot of deuterium (hydrogen isotope) against ^{18}O showing sub surface seepage from a tailings dam plotting off the world meteoric line on the lesser sloped evaporative line of the tailings dam water. This is an example where stable isotopes were used to determine the origins of sub surface seepage.

Mass balance calculations have been used in estimating the leakage of tailings dam water based on these stable isotopic ratios.

Tritium (an isotope of hydrogen) analyses are conducted to assist in determining the residence time of ground water in an aquifer. High tritium values in excess of 3 TU suggests active recharge of ground water, whereas vanishing tritium indicates very slow moving sluggish ground water with a mean residence time of a few centuries. From this, sampling frequencies can be extrapolated providing they meet the Minimum Requirements for sampling frequencies at waste management facilities.

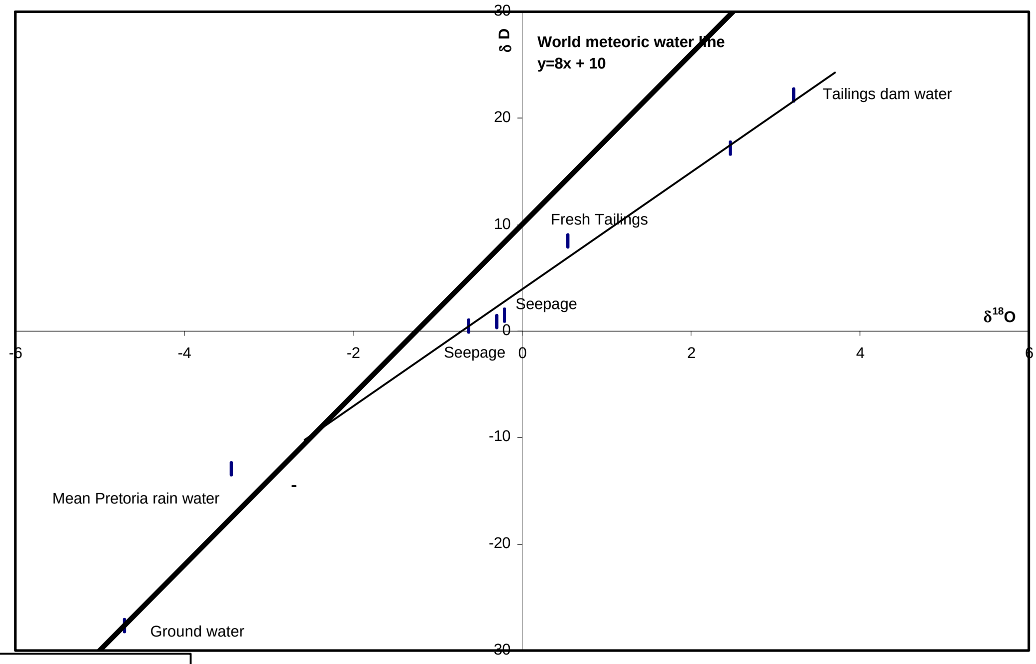


Figure 4 **Plot of Deuterium vs 18O showing seepage from tailings dam**

2.7 Ground water modeling

A conceptual ground water model of the interactive ground system can then be developed as input to a mathematical flow model and contaminant transport model. Input parameters for the models are derived from site measurements and from the analytical work.

3 CONCLUSIONS

Successful and accurate monitoring of contaminated sites requires a strategy that ensures results are representative, adequate and cost effective. A strategic plan that uses airborne thermal imagery, geophysics, target drilling and test pumping, sampling, hydrochemical analyses, isotope analyses and reporting has been devised for the gold fields of Vaal River Operations, West Wits and Welkom.