The Use Of Geophysics To Determine Salt Capturing And Fluid Transport Properties Of Ash Dumps

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INTRODUCTION

Coal is used for many different practices and power generation is one of them. In South Africa 95% of energy is derived from coal fired power stations. During power generation fly ash is produced and constitute for the largest amount of residue from the combustion of coal. This use of coal results in two by-products, namely coal ash from heat generation and high-salinity process water from the cooling process. The coal ash is deposited either wet or dry, forming dams and dumps respectively. On wet dams the brines are combined with slurry water. Salts which may be captured in the ash matrix may or may not leach to groundwater or can flow along preferential pathways and cause contamination of the underlying aquifers.

This paper concentrates on two dams (PS1 and PS2) in the Eastern Highveld of South Africa. The land surrounding the two power stations is used for grazing and agricultural purposes. As these aquifers may be at risk to contamination from the overlying ash dams, the potential of these ash dams to leach salts is evaluated. Determining the groundwater velocity, effective porosity, hydraulic gradient and hydraulic conductivity is imperative for studies on fluid and contaminant transport in aquifers[1]. Groundwater investigations often apply tracer tests to determine effective porosity, while constant rate pumping tests are used to determine hydraulic conductivity[1]. These approaches are of little use in the unsaturated media like the ash dams where this study is focused. This paper will therefore take a different approach to determine these variables.

Two dimensional Electrical Resistivity profiling can be used to determine temporal and spatial variations in the subsurface. The total resistivity of the subsurface material is controlled by porosity, water content, material composition, salinity of the pore water, and grain size distribution[2]. The total resistivity dependence on subsurface conditions is described by The Archie law formula[3] that can be solved to calculate effective porosity of the ash. Resistivity surveys were successfully used to define the lateral extent of subsurface changes due to groundwater contamination at various natural and artificial sites[4, 5, 6], including a fly ash disposal site[7]. Previous studies suggest that the use of electrical resistivity imaging can be a useful method to determine several subsurface characteristics, including porosity, moisture content and salt concentration as important parameters that describe the hydrological properties of the ash.

In this paper geophysics and borehole logging are used to determine the physical and chemical characteristics of the ash to evaluate salt capturing and fluid transport properties.

MATERIALS AND METHODS

GEOPHYSICS AND DRILLING

An Abem SAS 1000 terrameter and ES 464 switching unit was therefore used for the field surveys of the three power stations. The RES2Dinv version 3.52-inversion program was used to invert the measured data after being manually and mathematically filtered. Boreholes of all research sites were drilled along the geophysical lines.

Direct circulation air percussion drilling was used to drill the boreholes at PS1 and PS2. Undisturbed ash samples were collected at a depth of 5m by forcing a hollow pipe into the ash, using only the weight of the drill. During drilling samples were collected at 1m intervals, sealed air tight and labeled. Samples were analyzed in the lab for electrical conductivity and moisture content.

In the lab a small portion of each sample was placed in a foil container and weighed to an accuracy of 0.01 g. The samples are then dried in an oven for 24 hours at 105^{o}C thereafter it was weighted for the second time. Gravimetric moisture content of the ash was calculated using the following equation:

$$\phi = \frac{(weight\_of\_wetash) - (weight\_of\_dryash)}{(weight\_of\_dryash)} * 100$$

Equation 2

Where ϕ = moisture content (%)

A 1:10 ratio of dry ash and deionized water is mixed, then the sample is left to settle until the water is clear. Once most of the ash has settled it is placed into a vacuum filter using filter paper with a pore space of 0.45 µm. A handheld EC meter is calibrated at three points, 84 µS/cm, 1314 µS/cm and 18800 µS/cm then used to record data. Pore water electrical conductivity was then calculated by using the following equation:

$$Porewater\_EC = \frac{Lab\_EC * 10}{\phi}$$

Equation 3

Where ϕ is moisture content and lab EC is multiplied by 10 to account for the 1:10 dilution.

POROSITY

Groundwater is ionically conductive due to the salts and water molecules it contains allowing electrical currents to flow into the ground. Archies Law links the information obtained from the electrical currents to geohydrological properties.

This law is as follows:

$$rock\_resistivity = \frac{a(water\_resistivity)}{porosity^n}$$

Equation 1

Where "a" and "n" are constants which depend on the nature of the rock. In a very rough approximation, "a" can be taken equal to 1 and "n" to 2.

With both total resistivity and pore water EC known Archie's law (Equation 1) can be rewritten to solve porosity. The porosity of the ash can therefore be determined with the following formula:

$$porosity = \sqrt{\frac{waterres*1}{rockres}}$$

Equation 4

SITE AND ASH DESCRIPTION

Geology in this area consists of sandstone, siltstone, mudstones and shale[8] (DWAF, 1999). Both PS1 and PS2 is a wet ashing system that deposits slurry into an engineered dam. The slurry is hydraulically transported from the power station via pipelines and then deposited into these dams. The ash particles then settle and the water is drained via penstocks to the ash effluent dam. This water is then re-used as process water back into the plant. This water is often extremely saline. The absence of a shallow water table would indicate that this site is an unsaturated ash dam.

DATA

The geophysics profiles (Figures 1,3,5 and 7) represents total resistivity of the ash as measured during the 2D electrical resistivity profiling. The arrow on each profile indicates the position at which boreholes where drilled and samples taken for lab analysis. We can therefore compare resistivity data with pore water EC, pore water resistivity, moisture content and effective porosity. These variables are displayed in the graphs below of the ash relative to depth (Figures 2,4,6 and 8).

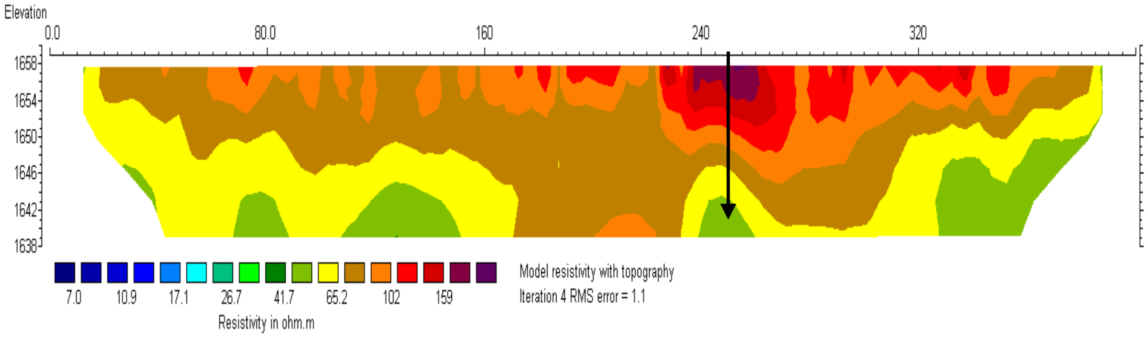

Figure 1. Geophysics line indicating positions of BH 1 on PS1.

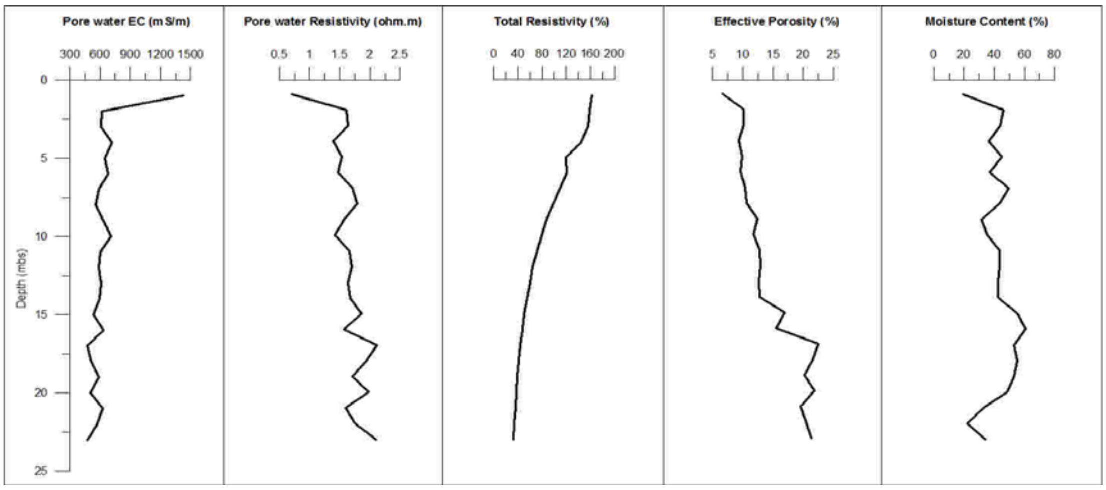

Figure 2. Graphs representing chemical and physical properties of ash profile of BH1 on PS1.

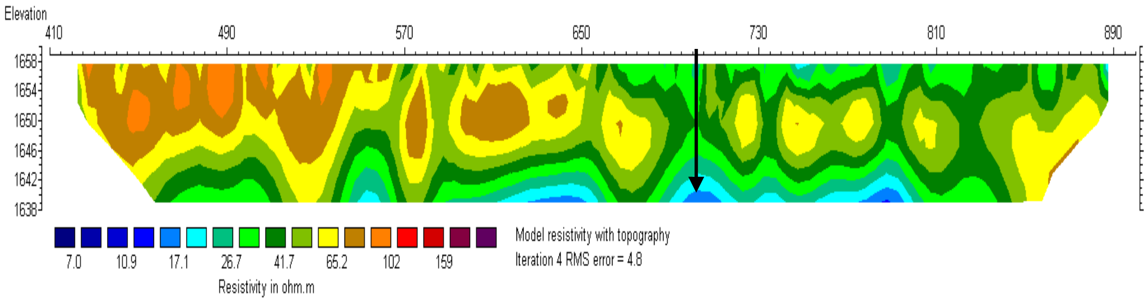

Figure 3. Geophysics line with an arrow indicating positions of BH 2 on PS1.

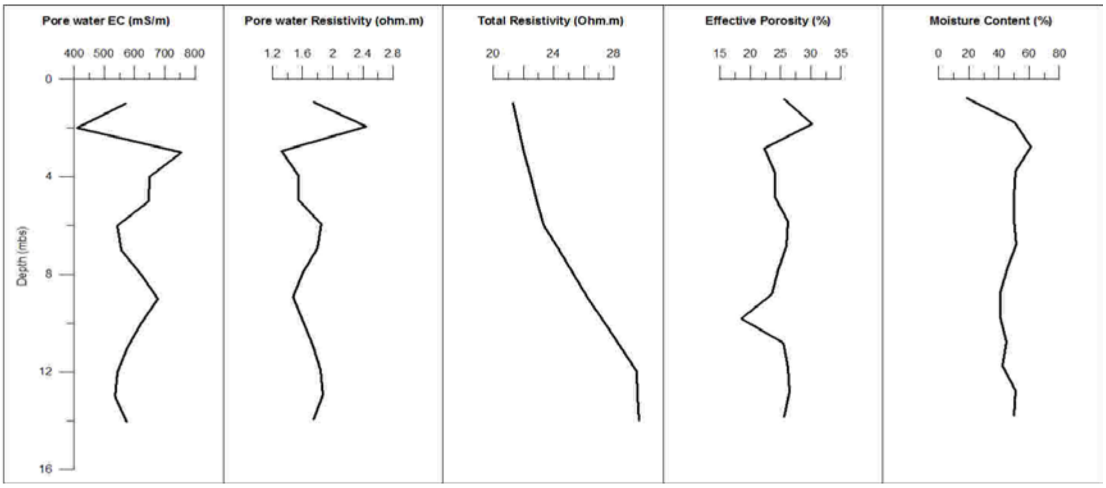

Figure 4. Graphs representing chemical and physical properties of ash profile of BH2 on PS1.

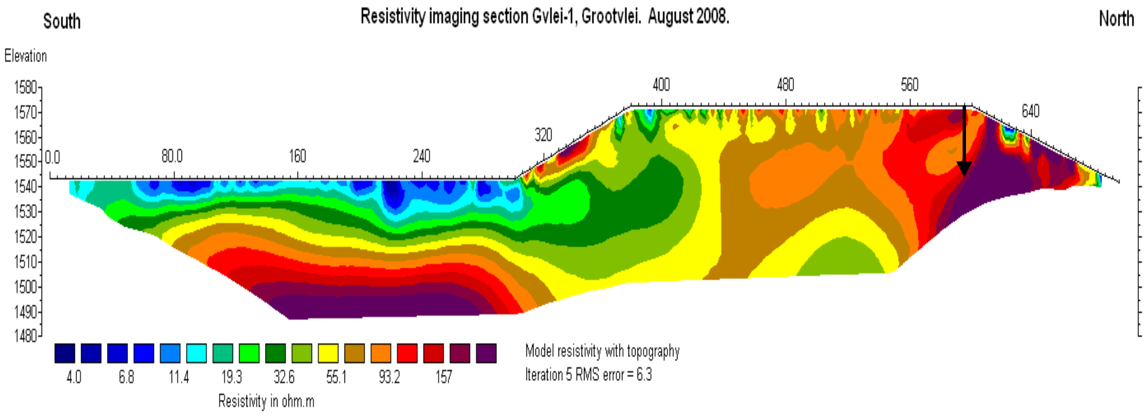

Figure 5. Geophysics line with arrow indicating position of BH1 on PS2.

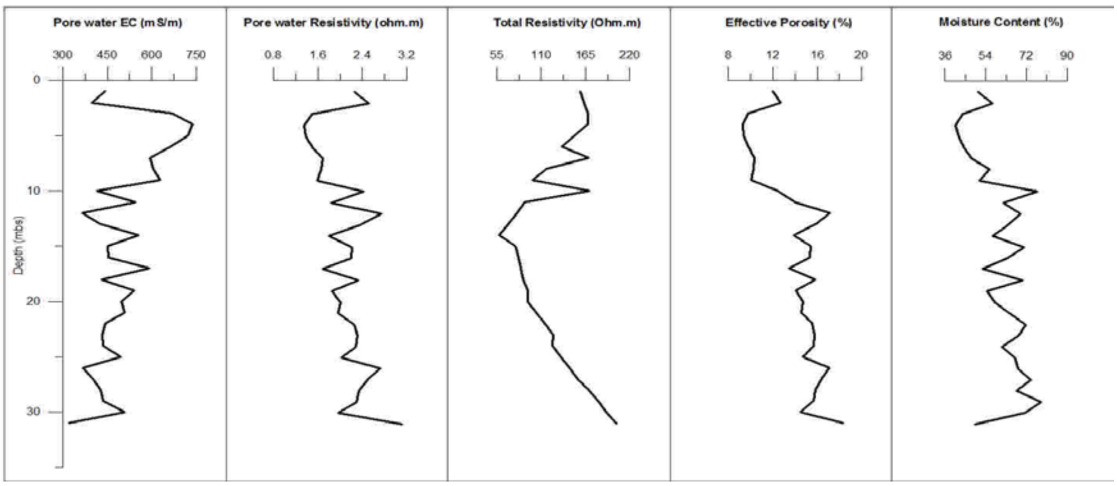

Figure 6. Graphs representing chemical and physical properties of ash of BH1 on PS2.

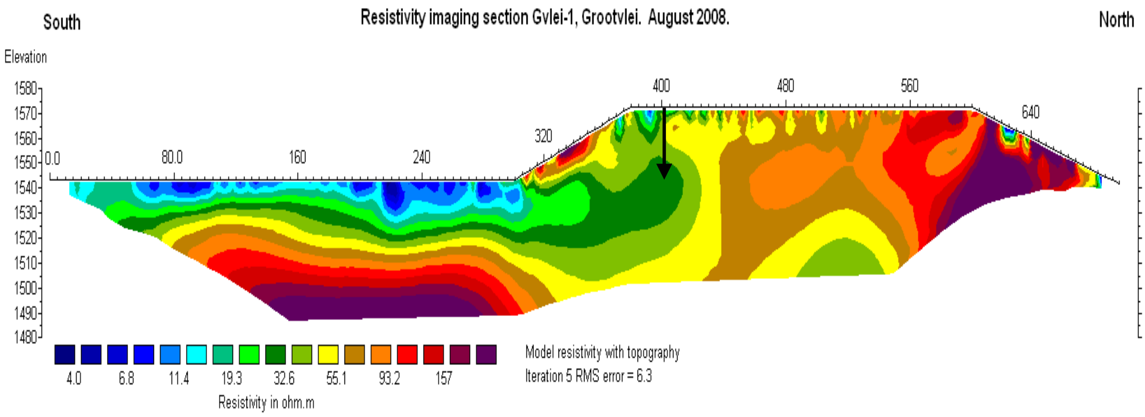

Figure 7. Geophysics line with arrow indicating position of BH2 on PS2.

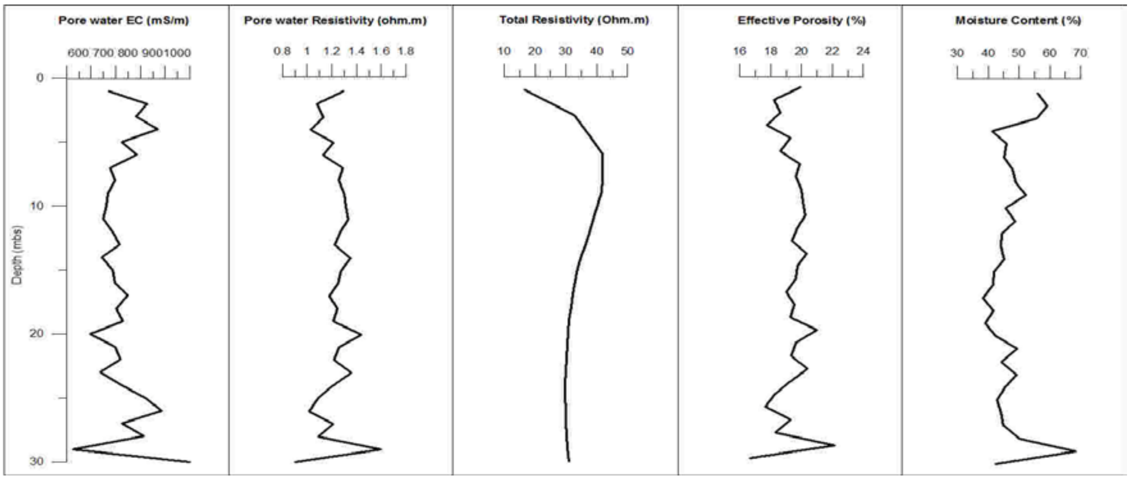

Figure 8. Graphs representing chemical and physical properties of ash of BH2 on PS2.

DISCUSSION

A definite relationship at both sites (PS1 and PS2) is visible between pore water resistivity and effective porosity. An increase in both the pore water resistivity also results in an increase of the effective porosity. It is also observed that porosity increases with decreasing total resistivity. Moisture content on the other hand increases with increasing porosity. This indicates that the higher resistivity is to some extent linked to a drier environment.

The second last column on each of these graphs represents effective porosity as calculated using Archies Law. These values vary from site to site and range between 6-35% depending on moisture content and pore water resistivity. These values represent the porosity that is available for fluid flow. At most sites this value is relatively high and may indicate that the ash act as a good conduit for flow. These values correspond well with the other measured variables. As discussed before[2] , porosity, water content, material composition, salinity of the pore water, and grain size distribution all play a role in resistivity therefore moisture content would be and important factor to consider when calculating effective porosity. These values could possibly be used to determine if any preferential pathways for fluid flow do exist.

CONCLUSIONS AND RECOMMENDATIONS

An identical relationship between effective porosity and pore water resistivity is visible between the two parameters. We therefore assume that it is possible to calculate effective porosity by using electrical resistivity and pore water EC of the ash by means of Archies law as a link. However, moisture content also plays a noticeable role but is not incorporated in the Archies law formula. This method has proven to work successfully in an unsaturated ash environment. It is recommended that porosity values are measured in the borehole profiles to determine to what extent moisture content affect Achies law. In future work tracer test on these sites will also take place so that a comparison of the effective porosity values may transpire.

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