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Application of Geophysical Methods to Detection of a Preferred Groundwater Flow Channel at a Pyrite Tailings Dam

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ABSTRACT : At the tailings dam of the disused Brukunga pyrite mine in South Australia, reaction of groundwater with the tailings causes the formation and discharge of sulphuric acid. There is a need to improve remediation efforts by decreasing groundwater flow through the tailings dam. Geophysical methods have been investigated to determine whether they can be used to characterise variations in depth to watertable and map preferred groundwater flow paths. Three methods were used: transient electromagnetic (TEM) soundings, direct current (DC) soundings and profiling, and self potential (SP) profiling. The profiling methods were used to map the areal extent of a given response, while soundings was used to determine the variation in response with depth. The results of the geophysical surveys show that the voltages measured with SP profiling are small and it is hard to determine any preferred channels of groundwater flow from SP data alone. Results obtained from TEM and DC soundings, show that the DC method is useful for determining layer boundaries at shallow depths (less than about 10 m), while the TEM method can resolve deeper structures. Joint use of TEM and DC data gives a more complete and accurate geoelectric section. The TEM and DC measurements have enabled accurate determination of depth to groundwater. For soundings centred at piezometers, this depth is consistent with the measured watertable level in the corresponding piezometer. A map of the watertable level produced from all the TEM and DC soundings at the site shows that the shallowest level is at a depth of about 1 m, and occurs at the southeast of the site, while the deepest watertable level (about 17 m) occurs at the northwest part of the site. The results indicate that a possible source of groundwater occurs at the southeast area of the dam, and the aquifer thickness varies between 6 and 13 m. A map of the variation of resistivity of the aquifer has also been produced from the TEM and DC data. This map shows that the least resistive (i.e., most conductive) section of the aquifer occurs in the northeast of the site, while the most resistive part of the aquifer occurs in the southeast. These results are interpreted to indicate a source of fresh (resistive) groundwater in the southeast of the site, with a possible further source of conductive groundwater in the northeast.

INTRODUCTION

Electrical and electromagnetic surveys have been carried out at a tailings dam at Brukunga in South Australia. The aims of these surveys were to:

- Determine the depth to watertable, and map this depth over the whole site;
- Investigate whether any of the methods could be used to detect and map preferred channels of water flow.

An electromagnetic (EM) survey had already been carried out in the area by Williams, Pannewig (1994). The nature of the method that they used is such that profiling can be carried out, but depth information cannot be obtained quantitatively. Geophysical surveys were carried out in June, 1996. The methods can be used either for profiling, i.e., to map the areal extent of a given response, or for soundings, i.e., to determine the variation in response with depth. With our methods, soundings were carried out specifically to provide this information.

Three types of methods were used:

Transient electromagnetic (TEM) sounding;

- Direct current (DC) sounding and profiling;
- Self potential (SP) profiling.

Soundings were made to determine in particular the depth to watertable, while DC and SP profiling was carried out to determine whether preferred channels of water flow existed.

DESCRIPTION OF GEOPHYSICAL SURVEYS

Details of TEM methods used for soundings are given by Spies, Frischknecht (1991), while its use for profiling is described by Nabighian, Macnae (1991). An elementary description of the DC and SP methods is given by Parasnis (1996). Applications of the EM, DC, and SP methods to environmental studies are described by McNeill (1990), Ward (1990), and Cor-

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win (1990), respectively.

Fig. 1 shows a map of the mine tailings dam at Brukunga. Detailed surveys with TEM, DC, and SP were carried out in June 1996. TEM soundings were made with a 25-m single loop geometry centred at drillholes KAN40, KAN41, KAN43, KAN45, KAN 48, KAN51, and KAN52.

DC soundings were made with the Schlumberger array centred at the same drillholes where the TEM soundings were made, and additionally at the positions marked S1 to S8 in Fig. 1. The maximum current electrode separation of this geometry was 120 m. Wenner array profiling was carried out on Lines 1 to 4 shown in Fig. 1. Measurements were made with this array at station intervals of 20 m, and electrode separations of 5, 10, 15, and 20 m were used at each station.

A fixed-base SP profiling was carried out on Line1 at intervals of 10 m.

RESULTS OF GEOPHYSICAL SURVEYS

In this section, examples of the results are given to illustrate the possibilities of the methods used.

DC Profiling with Wenner Array

The result of DC profiling with the Wenner array along Line1 is presented in Fig. 2. Since on this line the watertable depth at KAN51 is 10.9 m and at KAN41 is 10.1 m, dipole spacings of 10 m and more are expected to show any variations related to groundwater depth and resistivity on this line. As can be seen, the response with these dipole spacings is fairly uniform along this line, and it is not expected that there would be large variations in groundwater depth or resistivity along this line. These results are verified by inversion results of the TEM and DC sounding data (see below).

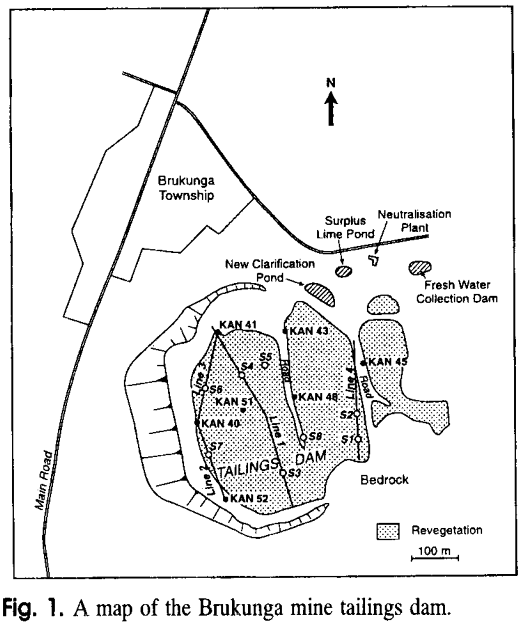


Fig. 1. A map of the Brukunga mine tailings dam.

The Wenner DC apparent resistivity profile results along Line4 (Fig. 3) show a marked change from one end of the line to the other. With all electrode spacings, high apparent resistivity at the south end (near station 0) drop to low values at the north end (near station 250). Soundings results (see below) indicate that the lower resistivity at the north end of Line 4 is caused by an increase in electrical conductivity of the aquifer. Presumably, at the north end of Line 4 dissolved minerals in the groundwater increases its conductivity, while fresh groundwater occurs at the south end of Line 4.

SP Profiling

The fixed-base configuration SP profile along Line1

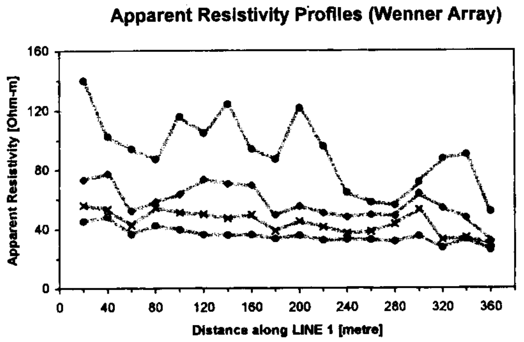


Fig. 2. Wenner DC profiling results on Line 1 of tailings dam survey.

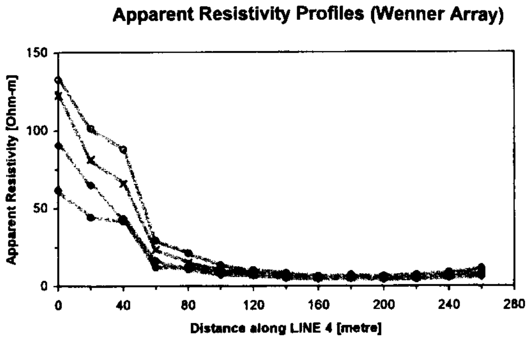


Fig. 3. Wenner DC profiling results on Line 4 of tailings dam survey.

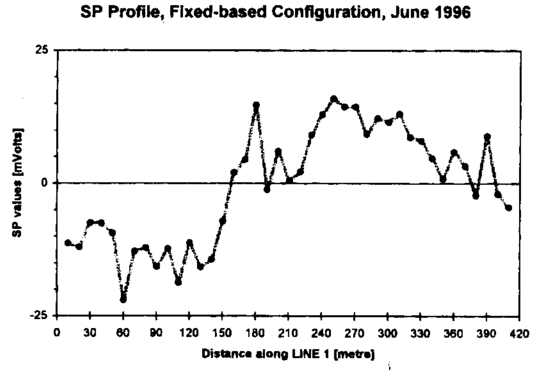


Fig. 4. Fixed-base configuration SP profile results on Line 1.

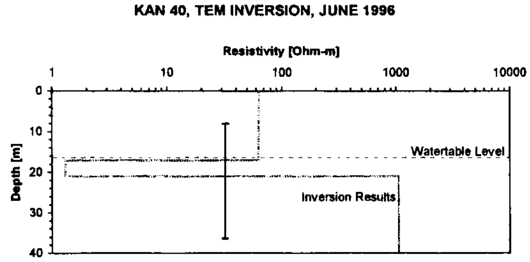


Fig. 5. Inversion results from 25 m a single-loop TEM sounding centred at KAN 40.

is given in Fig. 4. This configuration has a negative response at the south end (near station 0) of the line. Further north, this response becomes positive, while at the northernmost end of the line (near station 400), the response becomes negative again. Given that the survey was carried out at a uniform rate, this trend represents almost a periodic variation of the response with time, with a period of about 3 hours. Thus, it would require monitoring of the SP response over at least 3 hours to establish whether the trend from a negative to a positive SP response on Linel is caused by variations in the characteristics of the ground or is a drift with time of the SP response. There is a negative-going peak between stations 180 and 230 of the SP profile along Line 1. This peak could be caused by a flow of groundwater in a channel.

TEM Soundings

The results of inversion of TEM data collected with a 25 m single loop centred at boreholes KAN40 and KAN51 are presented in Fig. 5 and 6, respectively. These plots show the resistivity of the each layer plotted as a function of depth. Since a layered model has been used, the resistivity within a given layer is constant and changes discontinuously to the resistivity of the adjacent layer at the boundary of the two layers.

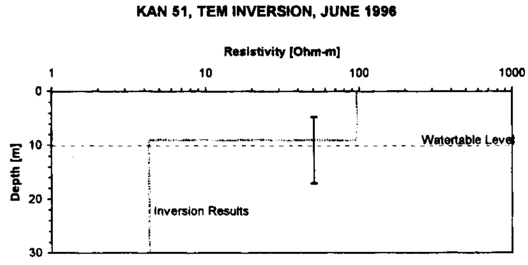


Fig. 6. Inversion results from 25 m a single-loop TEM sounding centred at KAN 51.

For a particular inversion result, the watertable level is identified as the depth to the least resistive (i.e., conductive) layer of the geoelectric section yielded by that inversion. Generally, for TEM inversion results this is the second layer of the geoelectric section; for DC inversion results, where an additional near-surface layer is usually resolved, the least resistive layer is the third layer, except where the watertable is very shallow (e.g., at KAN45), in which case it is the second layer of the geoelectric section.

The watertable level was measured in the piezometer at each position at which a TEM sounding was made, and is shown on each layered section produced from the inversion results. At KAN40, the value of thickness of the first layer obtained from inversion of the TEM data is 17 m. This value is consistent with the measured depth to watertable of 16.3 m. The error bounds on the inversion value are large, and range from 8 to 36 m. At KAN51, the thickness of the first layer from TEM inversion is 9 m with an error bound range of 5 to 17 m, and the measured depth to watertable is 10 m.

DC Soundings with Schlumberger Array

Examples of results of inversion of DC Schlumberger sounding data are given in Fig. 7 and 8 for positions KAN40 and KAN45, respectively. These results show that depth to shallow watertable can be resolved. For example, the depth to watertable at KAN 45 is measured to be 3.2 m, and the depth found from inversion of the DC data is 3 m, with very small error bounds.

Generally, the DC data have enabled resolution of layer parameters for depths less than about 10 m, while the TEM data provides sounding data at depths beyond 10 m. The joint inversion of the two sets of data would therefore be expected to hive more reliable values of the inversion parameters and produce a more complete geoelectric section.

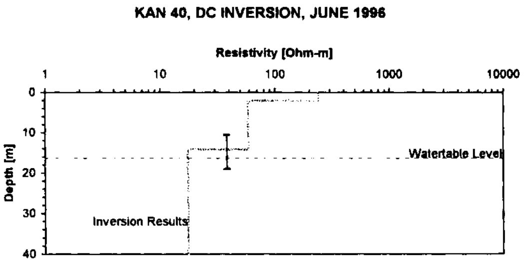


Fig. 7. Inversion results from Schlumberger DC sounding centred at KAN 40.

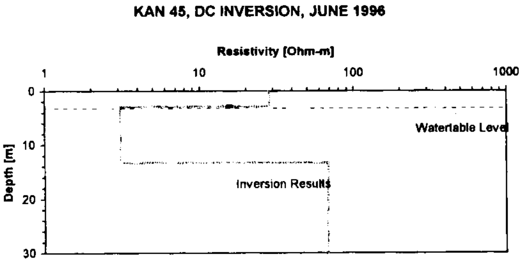


Fig. 8. Inversion results from Schlumberger DC sounding centred at KAN 45.

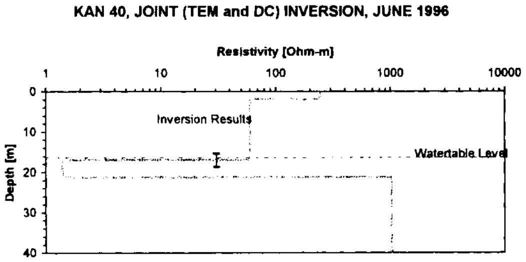


Fig. 9. TEM-DC joint inversion results from soundings centred at KAN 40.

Joint TEM and DC Inversions

Examples of results of joint inversion of TEM and DC sounding data are shown in Fig. 9 and 10 for KAN40 and KAN51, respectively, where the watertable level at the tailings dam is deeper. In both cases, excellent agreement is obtained between the measured watertable level and the inversion value obtained for the depth to the least resistive(i.e., most conductive) layer of the geoelectric section. For example, a comparison between inversion results obtained at KAN40 from DC data alone (Fig. 7) and from joint inversion of TEM and DC data (Fig. 9) shows that with joint inversion, the value of watertable level is closer to the measured value and has smaller error bounds.

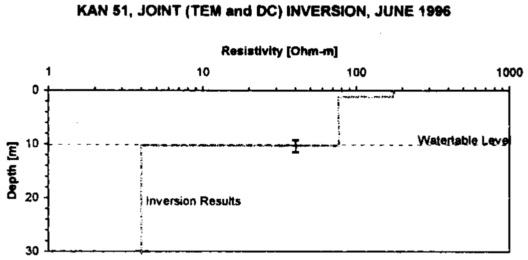
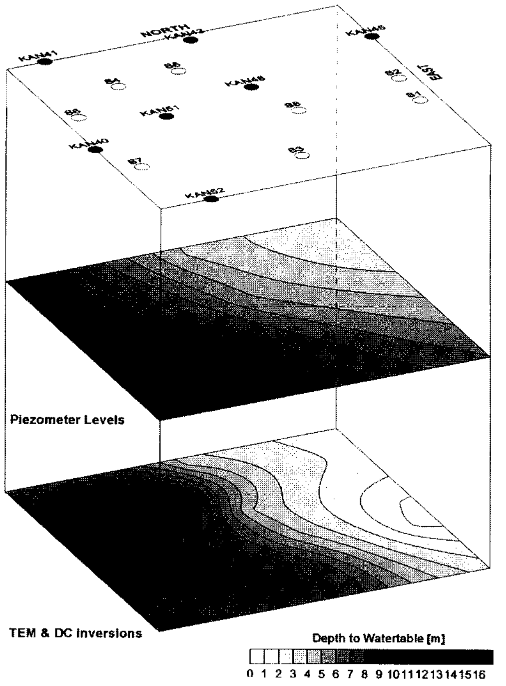


Fig. 10. TEM-DC joint inversion results from soundings centred at KAN 51.



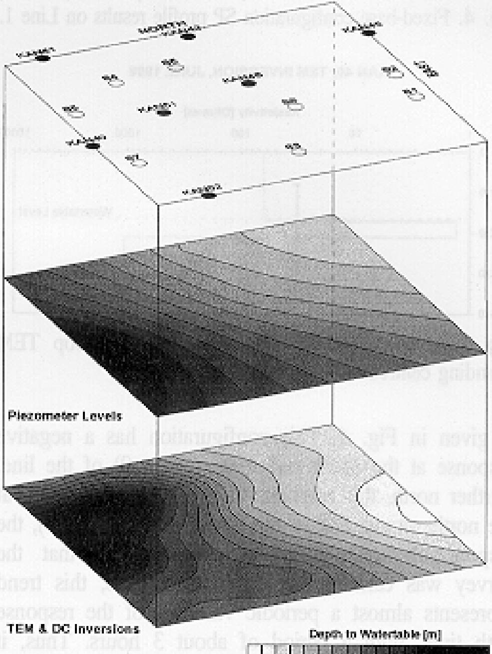
Comparison of Watertable Depth from Piezometer levels and Geophysical Inversion BRUKUNGA, JUNE 1996

Fig. 11. Contours of the depth to watertable measured in piezometers at the Brukunga tailings dam compared with contours of this depth obtained from the joint inversion of TEM and DC sounding data.

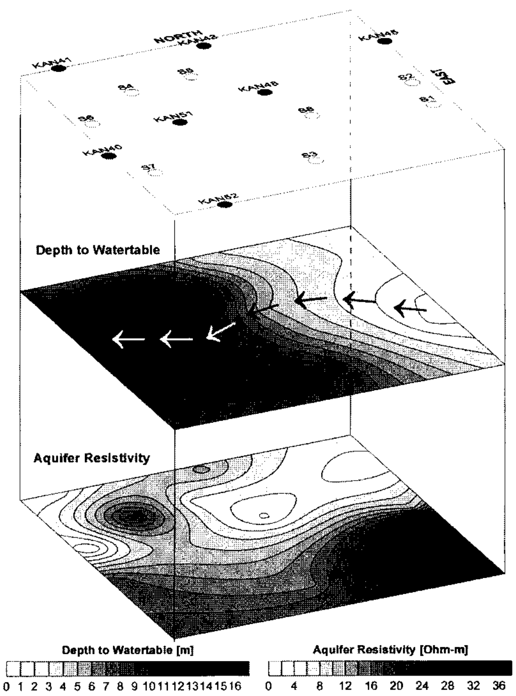
DC and Joint TEM-DC Inversion Results of Whole Site

In this section, we discuss the DC and joint TEM-DC inversion results obtained at all the stations for the depth to watertable and the resistivity of the aquifer.

Fig. 11 presents a plot of contours of the depth to watertable measured in the piezometers compared with the contours of this depth obtained from DC



Comparison of Watertable Depth from Piezometer levels and Geophysical Inversion BRUKUNGA, JUNE 1996



Inversion Results from TEM and DC Surveys
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Fig. 12. Depth to watertable and resistivity of the aquifer in the Brukunga tailings dam derived from joint inversion of the TEM and DC soundings at the site. A possible preferred direction of groundwater flow is shown on the watertable level contour plot.

and joint TEM-DC inversion of the sounding data, More detail is obtained from the geophysical data because soundings were made at a total of 15 stations, compared with watertable measurements in 7 drillholes. The inversion results show that the watertable is shallowest at the southeast area of the site and deepest in the northwest.

Fig. 12 shows inversion results of the depth to watertable and the resistivity of the aquifer (i.e., the resistivity of the most conductive layer of the geoelectric section). The plot of contours of the watertable depth is a repeat of the plot given in Fig. 11, but a possible preferred direction of water flow has been drawn on the plot in Fig. 12. The source of water flow appears to be in the southeast section of the site, where the watertable is shallowest and occurs at a depth of about 1 m. From the inversion results, the thickness of aquifer is between 6 and 13 m. No drillholes exist in this region, and it is recommended that a borehole be drilled to verify these results. Pumping of water from holes in this area could help lessen the flow of water through the site and thereby decrease consequent formation and discharge of sulphuric acid.

The plot at the bottom of Fig. 12 shows contours of the resistivity of the aquifer over the whole site. The least resistive (i.e., most conductive) parts of the aquifer are in the northeast and northwest parts of the site. The most resistive part of the aquifer is in the southeast, where the groundwater is presumably fresh.

The groundwater resistivity contours seem to indicate that the source of groundwater conductivity occurs in the northeast of the site while the watertable depth and resistivity contours indicate that the source of water is in the southeast. There could therefore be a further source of groundwater in the northeast area of the site, but further data north and east of this corner of the site would be needed to verify this hypothesis. From measurements made so far, it appears that remediation measures should initially concentrate in the southeast corner of the site.

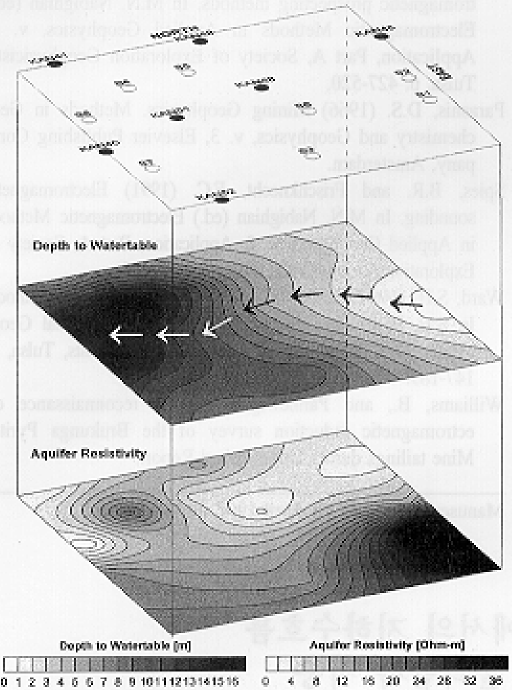
CONCLUSIONS

Inversion of DC sounding measurements shows that an electrical resistivity interface corresponding to the watertable can be identified at each station at which the soundings were made at the Brukunga mine tailings dam. Where the depth to watertable is greater than about 10m, joint inversion of DC and TEM soundings generally gives a more accurate value for this depth.

The inversion results have been used to map the depth to watertable over the whole site. The shallowest depth to watertable (about 1 m) appears to occur in the southeast area of the site, and the aquifer thickness there is predicted to be about 6 to 13 m. Since the depth to watertable increases both north and west of this location (4.8 m at KAN43 and 16.3 m at KAN40), it is hypothesised that the source of water flow at the site is caused by an aquifer in the southeast area of the site.

Contours of the aquifer resistivity show that the most conductive part of the aquifer occurs at the northeast of the site. There could therefore be another source of groundwater here, but further geophysical data would have to be collected north and east of this corner of the site to verify this hypothesis. The most resistive part of the aquifer is in the southeast, where the groundwater is presumably fresh.

SP profiling data show small responses and using these data alone, it is not possible to detect preferred channels of groundwater flow in the tailings dam. Small anomalies on the SP profiles appear to



Inversion Results from TEM and DC Surveys
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correlate with a preferred channel of groundwater flow subtly indicated on the plots of the TEM and DC inversion results. Overall, the results of all the geophysical methods tested at this site indicate that remediation efforts to lessen groundwater flow at the site would best be concentrated initially in the southeast area of the site.

REFERENCES

Corwin, R.F. (1990) The Self-Potential method environmental and engineering application. In S.H. Ward (ed.) Geotechnical and Environmental Geophysics, v. 1, Society of Exploration Geophysicists, Tulsa, p. 127-145.

McNeill, J.D. (1990) Use of electromagnetic methods for groundwater studies. In S.H. Ward (ed.) Geotechnical and Environmental Geophysics, v. 1, Society of Exploration Geophysicists, Tulsa, p. 191-218.

Nabighian, M.N., and Macnae, J.C. (1991) Time domain electromagnetic prospecting methods. In M.N. Nabighian (ed.) Electromagnetic Methods in Applied Geophysics, v. 2, Application, Part A, Society of Exploration Geophysicists, Tulsa, p. 427-520.

Parasnis, D.S. (1966) Mining Geophysics. Methods in Geochemistry and Geophysics, v. 3, Elsevier Publishing Company, Amsterdam.

Spies, B.R. and Frischknecht, F.C. (1991) Electromagnetic sounding. In M.N. Nabighian (ed.) Electromagnetic Methods in Applied Geophysics, v. 2, Application, Part A, Society of Exploration Geophysicists, Tulsa, p. 285-425.

Ward, S.H. (1990) Resistivity and induced polarisation methods. In S.H. Ward (ed.) Geotechnical and Environmental Geophysics, v. 1, Society of Exploration Geophysicists, Tulsa, p. 147-189.

Williams, B., and Pannewig (1994) A reconnaissance electromagnetic induction survey of the Brukunga Pyrites Mine tailings dump. Unpublished Report.

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황철석 광산 광미댐에서의 지하수흐름 경로탐지를 위한 물리탐사 적용

황 학 수

요 약 : 호주 남부 부룩캉가지역의 폐광된 황철석광산의 광미댐 (Tailings Dam)에서는 광미와 지하수의 반응으로 황산이 형성, 배출되어 주변의 토양, 하천 및 지하수를 오염시키고 있다. 이와 같은 산성 폐수에 의한 환경오염 확산 방지를 위해서는 광미댐을 통하여 흐르는 지하수의 흐름경로를 파악하고 이를 감소시키는 노력이 필요하다. 본 논문에서는 지하수면 깊이의 변화를 파악하고 이를 통하여 지하수의 주 흐름경로를 확인하기 위하여 기존 유용광물 탐사에 주로 사용된 물리탐사방법들이 사용되었다.본 연구에서 물리탐사방법으로는 시간영역 전자탐사 (TEM), DC 전기비저항탐사 그리고 자연전위 (SP)탐사법들이 사용되었다. SP법에 의하여 측정된 자연전위들은 매우 작았으며, SP자료해석만으로 주 지하수흐름의 경로규명이 어려웠다. TEM과 DC 전기비저항 자료해석을 통하여 지하수면의 깊이를 정확하게 결정할 수 있었으며, DC 전기비저항법은 주로 10 m내의 천부 대수층 구분에 유용한 반면에 TEM법은 심부구조 결정에 더욱 좋은 분해능을 보였다. TEM과 DC탐사자료들의 복합역산 (Joint Inversion)은 각각의 역산 (Inversion)보다 정확한 지전기적 (Geoelectric) 단면도를 제공하였으며, 물리탐사에 의하여 결정된 지하수면 깊이들은 각 측점에 설치된 관측공에서 피에조미터 (Piezometer)에 의하여 측정된 지하수 수위와 거의 일치하였다. 모든 TEM 및 DC탐사 자료해석을 통하여 산출된 지하수 수위도는 탐사지역의 남동부에서 약 1 m의 가장 얕은 수위를 나타나며, 반면에 가장 깊은 심도 (약 17 m)의 지하수 수위는 탐사지역의 북서부에서 위치하였다. 또한, TEM 및 DC탐사 자료해석에 의하여 산출된 탐사지역내의 대수층의 전기비저항 분포도에서는 높은 전기전도도의 대수층은 광미댐의 북동부에 존재하며, 가장 낮은 전기전도도를 갖는 대수층은 댐의 남동부에 분포하였다. 이와 같은 결과들로부터 오염이 되지 않은 신선한 (전기비저항이 높은) 지하수 유입의 근원은 광미댐의 남동부에 있음을 시사한다.