THE USE OF INNOVATIVE GROUNDWATER SEEPAGE DETECTION TECHNIQUES

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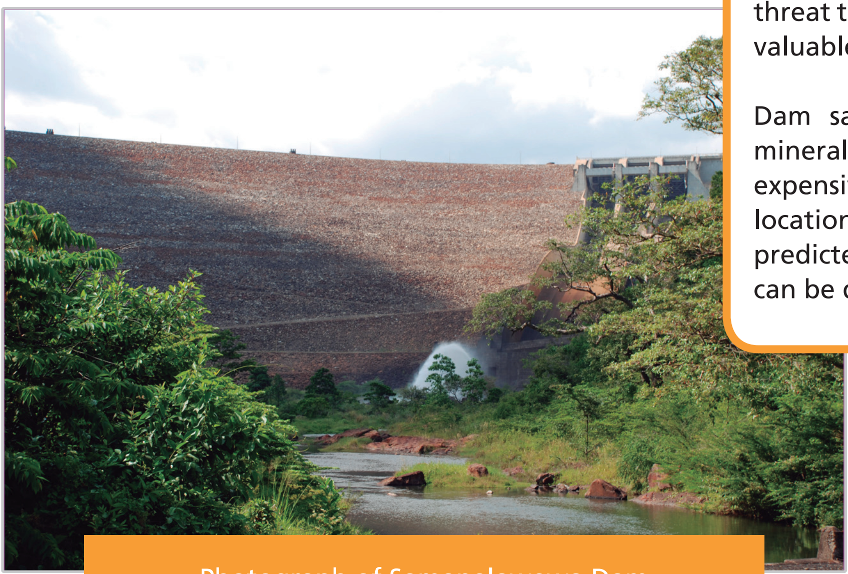
INTRODUCTION

Groundwater seepage can exacerbate environmental pollution through contaminant transport, pose a threat to dam safety and can also be associated with valuable mineral deposits.

Dam safety, environmental remedial works and mineral location normally involve comparatively expensive techniques, but, if the extent and location of groundwater seepage can be accurately predicted, then the amount of work, and thus costs, can be dramatically reduced.



Photograph of Samanalawewa Dam

THE SAMANALAWEWA DAM

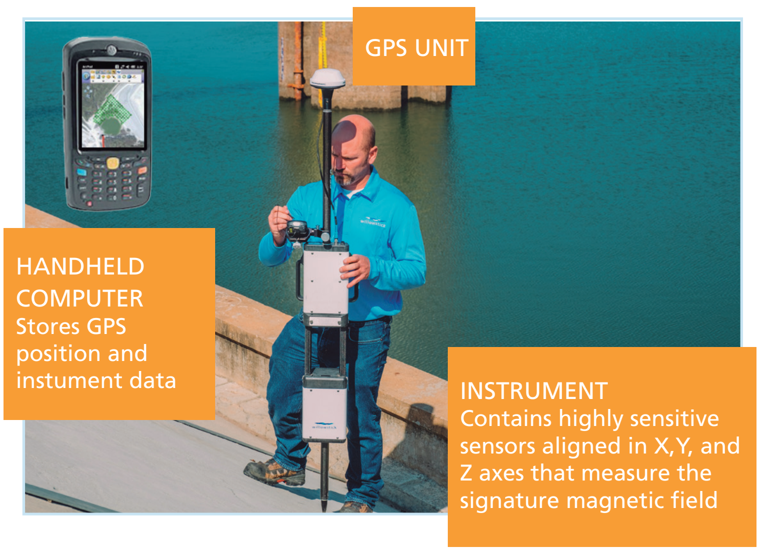
Numerous challenges complicate the effort to identify the source and character of groundwater seepage. Traditional investigative techniques, which involve the chance intersection of drilled bore holes and seepage paths, can become very expensive when required to cover large areas. The Willowstick diagnostic method, detailed in this paper, significantly mitigates these problems. By charging the subsurface with a low-voltage, low-frequency electric current, and mapping the resulting magnetic field, this method effectively and efficiently charts groundwater flow in complex environments, at significant depths, and over large areas.

This method was recently used at the Samanalawewa Dam, a large and important hydroelectric power project on Sri Lanka's Walawe River. The Samanalawewa Dam is a 105 meter high rockfill dam surrounded by karstic geology, which has long complicated the effort to account for and remediate seepage through the dam. The Willowstick method proved effective at mitigating the particular challenges associated with groundwater seepage at this site. The results represent an important advancement in the ongoing quest for better ways to monitor and remediate seepage. This paper discusses the Willowstick diagnostic tool, which allows individual seepage points to be mapped at depths of more than 100 meters to an accuracy of less than 100 millimeters.

THE WILLOWSTICK TECHNIQUE

EQUIPMENT

The equipment used to measure the magnetic field, induced by electric current flowing through the groundwater of interest, includes: three magnetic sensors oriented in orthogonal directions (x-, y-, and z-axes); an integrated digital signal processor used to collect, filter and process the sensor data; a high resolution GPS used to spatially define the measurement locations; and, a Windows based handheld computer used to couple the GPS data with the magnetic field data and store it for subsequent reduction and interpretation. All of this equipment is attached to a surveyor's pole and hand carried to each field measurement station.



INTERPRETATION AND MODELING

After data is collected, one or more footprint maps are created to reveal the patterns of electric current flow in the subsurface, by showing contrast between areas of high and low electrical conductance. Interpreting magnetic field contour maps can be compared to reading a topographic map. On a topographic map, the ridge lines connecting the peaks could be thought of as the pathways offering the least resistance to traverse. In the same way, these lines in the magnetic field maps

represent paths of least resistance for electric current to follow. By identifying these high points and ridges, and connecting them together through the study area, the center position of strong preferential electric current flow can be identified.

In the majority of cases, electric current flow paths produce very tight and revealing anomalies that can be modeled with a fairly high degree of accuracy (depths to within 10% error). Occasionally, electric current flow patterns are not as distinctive and the depth and character can only be roughly estimated—in which case, it is very important to have additional data to help characterize the groundwater zone of interest, such as, well logs, piezometric data, or other geophysical or hydrological data. In any case, the horizontal-position of electric current flow paths is generally determined with a high degree of consistency and accuracy.

The results, obtained from a Willowstick geophysical investigation, are to be used to make informative decisions concerning how to further confirm, monitor and possibly remediate groundwater problems through a given area of investigation.

EXAMPLE OF THE WILLOWSTICK SYSTEM IN PRACTICE

One example of the Willowstick system in practice is the Samanalawewa Dam, located in Sri Lanka, approximately 160km southeast of the capital city Colombo. The construction of the Samanalawewa Dam was started in 1986 and was completed in 1991. The dam and resultant reservoir are one of Sri Lanka's largest storage facilities. The dam is a zoned rockfill embankment with a clay core. The dam is roughly 105m high and 530m long and retains a reservoir with a capacity of 254 Mm3. The catchment area of the dam covers nearly 350km2.

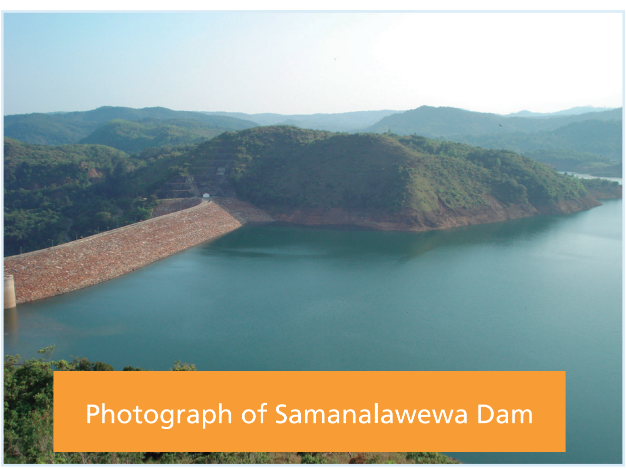
GEOLOGICAL SETTING

The dam's right abutment and right rim areas consist of karstic terrain. Karst conditions develop from the dissolution of the host rock along fractures, joints and/or bedding planes, which become enlarged over time from the saturation and flow of groundwater along these features.

During the investigation and construction phases of the reservoir, it was recognized that, karstic features were likely to be common in the right bank.

A karstic feature, that is a cave, was discovered during the construction phase, 300 meters upstream of the proposed axis of the dam on the right abutment.

This and other signs of possible leakage, through the right abutment area, resulted in an extensive grouting program. Six large cavities were found and sealed with concrete during construction.


Photograph of Samanalawewa Dam

MEASURES TO LIMIT WATER LOSSES

During the construction of the dam, four adits were driven along the axis of the dam. Despite the effort to cutoff seepage through the right abutment area, a small spring appeared downstream of the dam upon the reservoir's initial filling (June 1991). The seepage was large enough to suspend filling the reservoir.

Additionally, a flat water table was observed, along the reservoir's right rim, responding to the reservoir levels up to a distance of 2.5km from the dam. As a remedial measure, a 1,880m-long tunnel was drilled beneath the right rim area. From inside the tunnel, a 100m-deep by 1,600m-long grout curtain was constructed.

'LEAKAGE INCIDENT' AND SUBSEQUENT REMEDIATION

In an effort to slow seepage from flowing out of the reservoir into suspected ingress areas, the client dumped clay into the reservoir from barges. However, after installing nearly 50,000m3 of clay, the leak still was not stopped.

WILLOWSTICK RESULTS

The Willowstick investigation of the right abutment study area, initially employed one electrode configuration to energize the subsurface study area.

Shortly after the fieldwork was initiated, and based on preliminary results, Willowstick suggested a second survey. This second survey targeted possible seepage through the right rim where the client had previously installed a grout curtain.

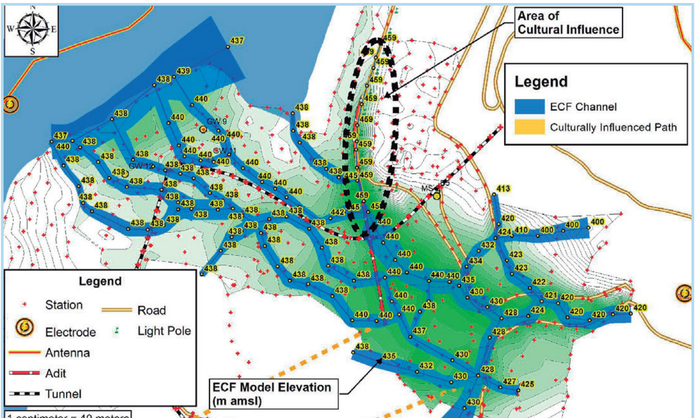
The intention of this additional survey was to identify any possible major seepage path(s) through the grout curtain.

The above figure shows an interpretation of the results from Survey 1—which shows the positions of the modelled flow paths (vertical and horizontal alignment).

Themodel suggests that seepage north of the tunnel occurs above the tunnel and finds an opening in the adit's grout curtain at the 440m elevation.

CONCLUSION

The results of the investigation suggest that there are a series of braided seepage flow paths, north and south of the tunnel, that run beneath the right abutment study area. Seepage appears to concentrate around the right side of the dam, rather than underneath or through the dam's earthen embankment. There is some seepage occurring along the right rim within the grout curtain, but not to the extent that it is flowing through the right abutment study area. It has been recommended, any seepage through karst topography needs to be carefully characterized, monitored and possibly remediated, to ensure the integrity of the reservoir as well as the safety of those residing downstream of the dam.



Electric Current Flow Model with Posted Elevations

REMEDIAL WORKS

The Willowstick survey has confirmed two main areas where the cutoff wall is compromised – one on the bend of the tunnel and the other where the original cutoff wall crosses the tunnel. Having identified the location of what we believed to be the two largest sources of leakage through the right abutment area, it is possible to undertake cost effective remedial works at The Samanalawewa Dam. These remedial works will to ensure the safety and integrity of the dam and bring the reservoir back to its proposed top water level and; retaining its ability to generate energy.

THE REMEDIAL WORK WILL INVOLVE THE FOLLOWING MEASURES:

1) Close two significant gaps in the existing supplementary grout curtain

2) Locate and fill major karstic features at approximate elevation of 438m.

- DR. ANDY HUGHES

Dr. Hughes has over 25 years experience in the study, design and project management of water supply and flood alleviation schemes, asset management and risk studies and reservoir safety works. He is an All Reservoirs Panel Engineer under the UK's legislative system, and is a geotechnical engineer, hydraulic engineer and hydrologist.