WATER SEEPAGE INVESTIGATION USING GEO-ELECTRIC STREAMERS.

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SUMMARY

Seepage from canals and reservoirs can be identified using geo-electric streamers. About 10 kilometres of canal can be surveyed by two people in one day. In electrical conductivity (EC) imagery created, seepage pathways through the substrate reflect the EC of surface water from which seepage was sourced as well as substrate permeability and clay content which enhances EC. Seepage tends not to occur readily through clay and the result, within EC imagery, is generally clear definition of seepage pathways through the substrate. In Australia, canals are typically situated on clayey low flow regime sedimentary deposits where evapotranspiration has concentrated salt in shallow sediment, particularly clays, and seepage has preferentially flushed out this salt resulting in a very clear EC signature regardless of water table depth. In high flow regime environments such as much of New Zealand, seepage pathway anomalies are usually more conductive than the host substrate which is usually cobbles, glacial rock flour and air.

A practical imaging system has been created using a submerged streamer towed behind a floating waterproof equipment capsule housing geo-electric, DGPS, sonar, data logging, and often other instrumentation. The capsule is towed either behind a boat or by two ropes pulled by walkers on each canal bank. Operation is via a wi-fi connection. The capsule is light enough to lift over the numerous obstacles that cross most canals. Imaging is presented in 3D within Google Earth so that water managers can readily handle and use the data.

Key words: Seepage, resistivity, canals, channels, rivers.

INTRODUCTION

Canal and reservoir water loss via seepage is a critical factor in water use efficiency. Direct measurement of seepage on anything but the scale of entire channel-ponds or reservoirs is an inexact and notoriously difficult science due to sensitivity of sediment beds to disturbance, presence of gas-creating micro-organisms and possible extreme macro-heterogeneity of sediments (especially cracking clays). Even seepage estimates from water balances conducted on entire channel-ponds are difficult due to uncertainty regarding evaporation rates, metered flow uncertainty and unmetered extractions. Although direct seepage measurement is difficult, relative seepage measurement is feasible using electrical conductivity (equivalent to the inverse of resistivity) imaging combined with some geomorphological reasoning. Due to different sediment types beneath structures, seepage is, in many cases, highly localized. Perched water trapped by clays some depth beneath structures sometimes prevents seepage even where the base of structures is sand (in this case local waterlogging occurs). In other cases, deep sands, gravels and cobbles beneath structures are overlain and partially sealed off by thin impermeable near-surface layers. These complications call for cost-effective, thorough, robust multi-depth imaging beneath water holding and carrying structures. My solution using geo-electric techniques for seepage investigation is given here. The logistics of the approach are evident in Figure 1. The type of data output is presented in Figure 6.

Figure 1 A Georesistivity meter, DGPS and sonar in a floating waterproof enclosure towing a submarine geo-electric streamer and towed by two walkers. Control and monitoring is via a WiFi link to the enclosure computer.

DEVELOPMENT OF GEO-ELECTRIC EQUIPMENT FOR WATERBORNE SURVEY

Streamer design

Waterborne geo-electric arrays (streamers) have been applied by the author (Allen, 2007) and others (Ball et al, 2006) to canal seepage and sub-river imaging over the last 16 years. Properly designed streamers simply slide freely through obstacles present in waterways. For gathering very fine detail on water body beds, submerged arrays can be used with fine electrode spacings, while for deeper survey, floating arrays should be used simply due to the practicality of towing a streamer that must be about five times as long as its maximum focus depth.

Of great importance to the viability of waterborne geo-electric survey is the array configuration used. In many cases, multi-channel receivers are used so, unlike for terrestrial surveys, every quadrupole (group of two transmitting, and two receiving electrode) in the streamer must then use the same transmitter electrodes and be sampled for equal time. Even with single channel multiplexed systems, it is better to keep the transmitter electrodes common to reduce switching instability. The transmitter electrodes must be widely spaced

in order to create signal at distant receiver electrodes sampling deep effective depths. Receiver electrodes of quadrupoles sampling deep effective depths must be spaced widely, in order to maximize signal strength, either by placement of them on opposite sides of the transmitter electrodes or far apart on the same side. Two basic array designs have proven to be appropriate, the first – exponential Bipole arrays (Allen, 2007, Allen and Merrick, 2007) have all receiver electrodes spaced exponentially from the end of one transmitter electrode. This way most of the wires and the heavy transmitter electrodes and wires need only extend a short distance from the boat and array weight can be minimized. The small, focused near-surface footprint of this array type results in little invalidity of assumptions of 1D inversion in moderately 3D heterogeneous ground.

In contrast, if Kevlar is used for strength in a streamer rather than the conductors themselves, then array weight can be minimized and a symmetrical array with transmitter electrodes in the middle can be used. Such arrays add together the stronger monopole voltage components rather than subtracting them from each other resulting in higher signal strength but less depth resolution and a much greater near-surface footprint (Allen, 2007).

Figure 2 presents the configuration of 3 arrays used for waterborne survey with electrodes of each quadrupole plotted at their respective effective depths (i.e. the depth from above which half of signal is contributed in homogeneous earth). Figure 3 presents a comparison of signal contribution of quadrupoles of each array versus depth in homogeneous earth. Figure 4 summarizes the information of Figure 3 by plotting signal to noise ratio versus effective depth for all quadrupoles of the three arrays. Observe that the dipole-dipole array lacks shallow resolution and has very poor signal to noise ratio at deeper investigation depths so it should rarely be used for waterborne survey. The exponential bipole array covers a broad range of investigation depths without severe signal to noise ratio decay at larger investigation depths. The symmetrical bipole array (differing from an inverse Schlumberger array in that its inner electrodes definitely must be considered as a bipole rather than a dipole) has excellent signal to noise ratios at all investigation depths and still covers a reasonable range of effective depths but does have a lot of electrodes.

A similar simpler array is used by the author for submerged survey and its signal contributions are given in Figure 5. In this array receiver electrode spacings on opposite sides are staggered so that they can each be used in two rather than one quadrupole thus almost halving the necessary number of electrodes at some expense to the standard deviation of the signal contribution with respect to depth curves. Having the transmitter electrodes near the centre of the array rather than near the boat has the added advantage that, should the boat end of the streamer lift off the bed of the canal, then impact on the data is relatively small. This is because electric current flow lines are near horizontal further away from the transmitter electrodes. An additional enhancement to the shallowest quadrupole can be made, bringing its effective depth down from 0.23m to 0.16m by switching it (using existing electrodes) to a bipole-bipole configuration.

Navigation

Navigation of most water bodies is challenging unlike popular tourist and fishing waterbodies. Navigation of canals can be challenging due to numerous obstacles crossing canals. Figure 1 presents a submerged geo-electric array being towed by a small enclosed floating equipment enclosure designed so that it can be simply lifted over or through canal obstacles by two people. This walking method is not the fastest on ideal canals but far superior where flexibility and lack of cumbersome overheads helps passing obstacles. Other solutions are towing of such an enclosure by a manned powered boat or by a very long boom extending sideways from a vehicle travelling along a prepared and maintained canal-side track.

Other sensors

Also important are GPS or DGPS, used for positioning and Sonar. Sonar is used for correction for and display of water depth.

More signal to noise ratio considerations

As an electrode is drawn through the water, electrical noise is generated. This noise is an order or two of magnitude greater than if the electrodes and water were still. The more speed, the more electrical noise. Thus waterborne systems must be designed to give far greater signal to noise ratios than conventional resistivity systems. Analysis of this type of noise has lead to development of acquisition techniques that minimize its impact.

Processing

Data is suitably merged, offset and cleaned (removing points collected with electrodes out of water or straddling metal infrastructure. It is then converted to submerged, or conventional apparent resistivities or inverted (matrix inversion) (Allen, 2007). With good streamer design, the additional benefit of inversion becomes smaller. Presentation is conducted as in Figure 6.

Interpretation

Seepage pathways through low flow regime facies, typical of Australian Irrigation Areas tend to be through higher resistivity coarser grained sediment. As seepage has occurred, it tends to have removed salt in the process, again increasing resistivity. The result, in resistivity images is a picture of evidence of past seepage.

In high flow regime environments, such as much of New Zealand's irrigation areas, the substrate is generally very poorly saturated except where seepage is occurring. The result is that relatively conductive features represent seepage in such environments. Actual active seepage is indicated. Note that the conductive features here are, however, more resistive, than typical resistive features in low flow regime substrate facies – the electrical conductivity indicative of seepage always reflects the electrical conductivity of the seeped water regardless of whether it is more or less electrically conductive than the host.

Many substrate features evident in geo-electric data will be identifiable from their shape, correlation with surface features, and depth. Seepage into a dry coarse grained substrate will appear as downward pointing fingers. Palaeochannels will appear as concave-up features and bedrock will appear as convex-up features. Canals crossing faults and slump structures will often correlate with surface topography inflections.

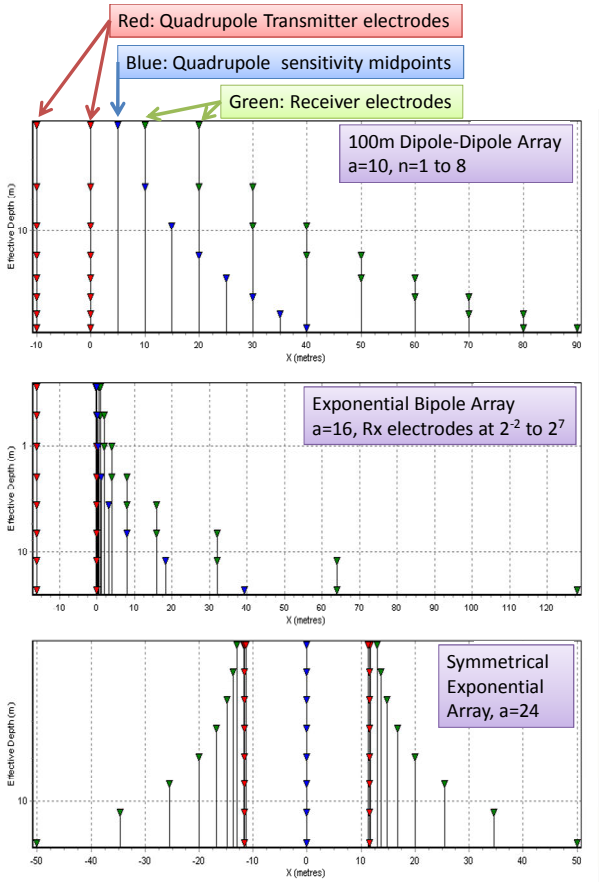

Figure 2 Positions of electrodes of quadrupoles of geo-electric streamer configurations designed for inland waterway survey all plotted with respect to effective depth of each quadrupole (see Allen, 2007 for formulae).

CONCLUSIONS

Geo-electric imaging, appropriately configured, is a most cost effective way of detailing seepage problems in preparation for remediation. It can not only indicate seepage pathways, but also trace them to some depth into the substrate so as to facilitate rejection of many false anomalies. Electrode array design is critical to system practicality with exponentially distributed electrodes being critical for large ranges of depth of investigation. A small enclosed WiFi monitored and controlled floating equipment capsule is very appropriate for canal survey. Results, presented over aerial images in 3D, can be easily used by canal managers. Seepage pathways always appear reflecting the surface water resistivity regardless of the general substrate resistivity.

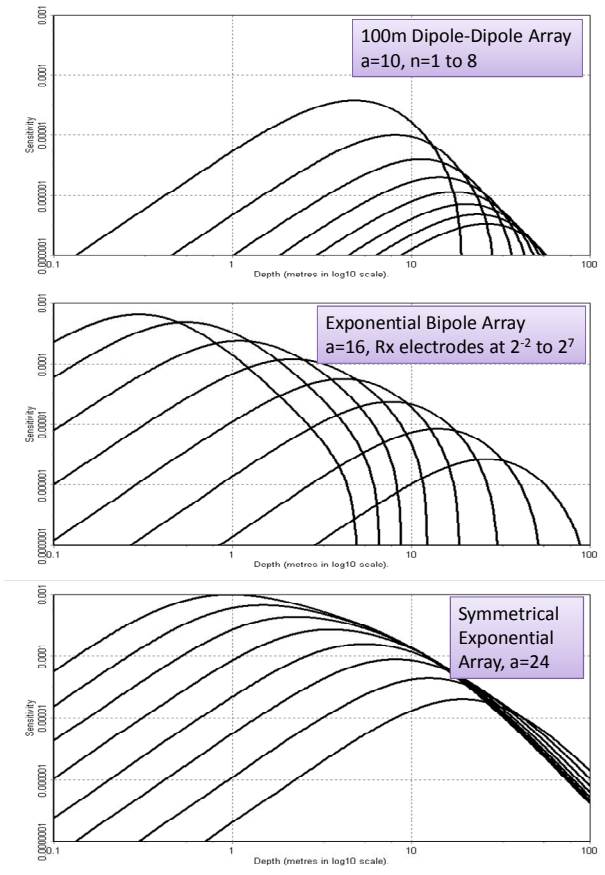

Figure 3 Signal contributions versus depth for quadrupoles of the array configurations given in Figure 2 valid over homogeneous ground (see Allen, 2007 for formulae).

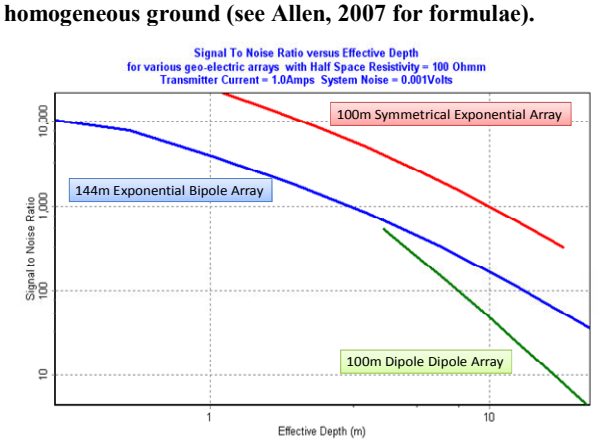

Figure 4 A comparison of signal strength versus effective depth of each quadrupole of the array configurations of Figure 2.

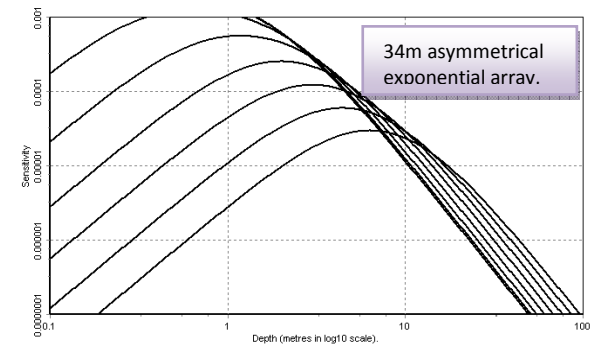

Figure 5 Staggered centred exponential array DIC curves. This is an array typically used for submarine cables where minimization of the number of electrodes is important. Signal strength is as for the symmetrical exponential array (such as in Figure 2c) but depth resolution is reduced due to sharing of electrodes. In comparison with Figure 3c, which is a 100m long symmetric 18 electrode array response, this response is for a similarly designed but 34m long asymmetric 11 electrode array.

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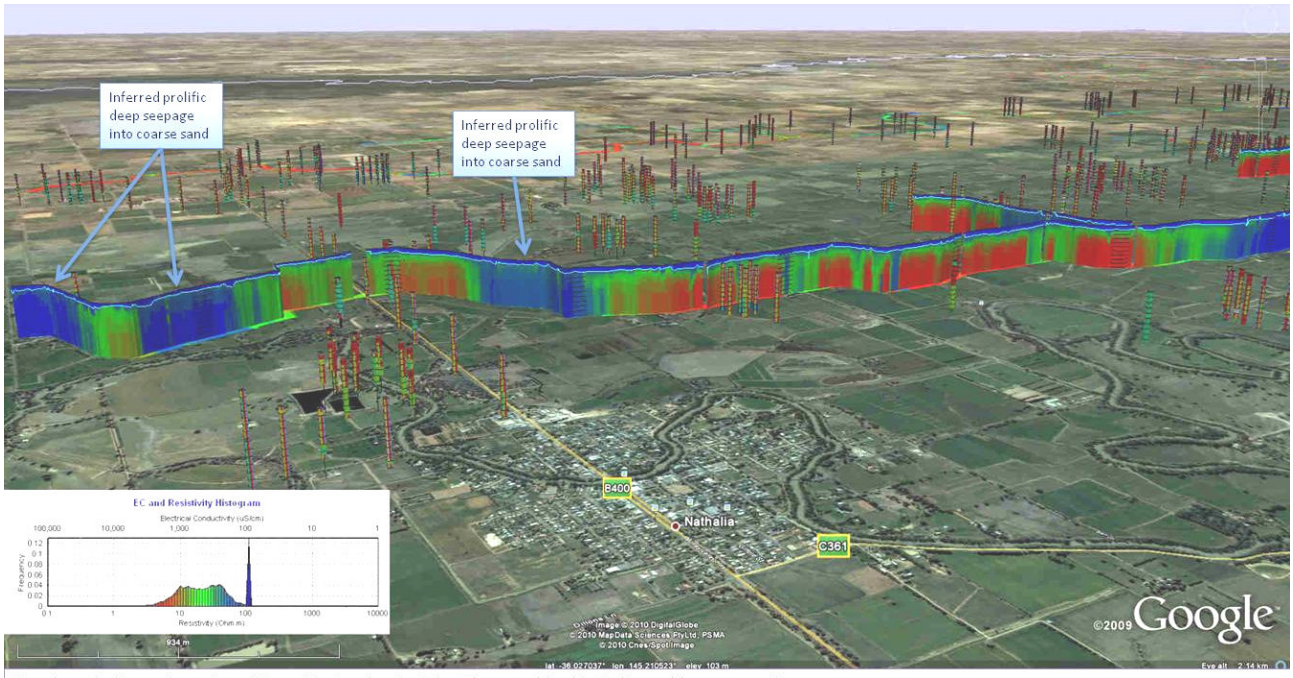

Depth scale linear from 0 to 10m with 1m depth ticks. The canal bed is indicated by an aqua line.

Figure 6 An example of Geo-electric data presented projected 10m above a Google Earth drape. The aqua colour line is the water depth of the canals imaged. Bore graphics were used to help interpret this data.