ELECTRICAL CONDUCTIVITY IMAGING OF AQUIFERS CONNECTED TO WATERCOURSES.

A THESIS FOCUSED ON THE MURRAY DARLING BASIN, AUSTRALIA

by

David Andrew Allen, BScHons

This thesis has been submitted for the degree of

PhD in Groundwater Management,

Faculty of Science

University of Technology, Sydney

July 2007

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

_____

ABSTRACT

ELECTRICAL CONDUCTIVITY IMAGING OF AQUIFERS CONNECTED TO WATERCOURSES.

A thesis focused on the Murray Darling Basin, Australia.

by David Andrew Allen

Electrical imaging of groundwater that interacts with surface watercourses provides detail on the extent of intervention needed to accurately manage both resources. It is particularly important where one resource is saline or otherwise polluted, where spatial quantification of the interacting resources is critical to water use planning and where losses from surface waterways need to be minimized in order to transport water long distances. Geo-electric arrays or transient electromagnetic devices can be towed along watercourses to image electrical conductivity (EC) at multiple depths within and beneath those watercourses. It has been found that in such environments, EC is typically related primarily to groundwater salinity and secondarily to clay content. Submerged geo-electric arrays can detect detailed canal-bottom variations if correctly designed. Floating arrays pass obstacles easily and are good for surveying constricted rivers and canals. Transient electromagnetic devices detect saline features clearly but have inferior ability to detect fine changes just below beds of watercourses. All require that water depth be measured by sonar or pressure sensors for successful elimination of effects of the water layer on the data. The meandering paths of rivers and canals, combined with the sheer volume of data typically acquired in waterborne surveys, results in a geo-referencing dilemma that cannot be accommodated using either 2D imaging or 3D voxel imaging. Because of this, software was developed by the author which allows users to view vertical section images wrapped along meandering paths in 3D space so that they resemble ribbons.

Geo-electric arrays suitable for simultaneous imaging of both shallow and deep strata need exponentially spread receiver electrodes and elongated transmitter electrodes. In order to design and facilitate such arrays, signed monopole notation for arrays with

segmented elongated electrodes was developed. The new notation greatly simplified generalized geo-electric array equations and led to processing efficiency. It was used in the development of new array design software and automated inversion software including a new technique for stable inversion of datasets including data with values below noise level. The Allen Exponential Bipole (AXB) array configuration was defined as a collinear arrangement of 2 elongated transmitter electrodes followed by receiver electrodes spaced exponentially from the end of the second transmitter electrode. A method for constructing such geo-electric arrays for use in rivers and canals was developed and the resulting equipment was refined during the creation of an extensive set of EC imaging case studies distributed across canals and rivers of the Australian Murray-Darling Basin. Man made and natural variations in aquifers connected to those canals and rivers have been clearly and precisely identified in more than 1000 kilometres of EC imagery.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENTS

The author wishes to thank the following groups for their contributions to the project:

My Supervisor, N.P. Merrick, and co-supervisor, B. Kelly, of the National Centre for Groundwater Management, University of Technology, Sydney who provided advise, proof reading, funding negotiation and computer code, used as a basis for some code written for this thesis.

The Australian Co-operative Research Centre for Sustainable Rice Production who provided A$105 000 towards this thesis.

The NSW Department of Land and Water Conservation /Infrastructure Planning and Natural Resources / Natural Resources (perpetual name changers) who provided funding for surveys in the vicinity of Mildura. Michael Williams, principle hydrogeologist is thanked for his efforts in securing funding.

The Australian Federal Bureau of Rural Sciences who funded river surveys of the Border Rivers and the Tuckean Swamp – Richmond River

Zonge Engineering and Research Organization who provided equipment on a research rate rather than commercial rate.

Geoforce- who provided the Syscal Pro (1 month) and an assistant (8 days) on research rates.

Barry Porter - South Australian Department of Water, Land and Biodiversity Conservation and Brian Barrett – University of Adelaide, who assisted with organising and facilitating fieldwork at Waikerie.

Richard, Peter and Lorraine Stott – Whitton farmers - who provided access to their rice based farms and assisted with fieldwork in various ways.

Coleambally Irrrigation Cooperative Limited funded survey and reporting on the Argoon Channel and provided personnel and logistical assistance for much of the RiceCRC funded fieldwork.

Murray Irrigation who funded seepage measurement follow-up work on their canals.

Scott McInnes – Zonge Engineering and Research Organization who completed and conveyed to the author a similar geo-electric array appraisal for roll along imaging systems.

Saud Akbar of NSW Agriculture provided Idaho seepage measurements on farm canals.

Niels Christensen of EMmodel and Esben Auken of the Hydrogeophysics Group inverted some of the data so that comparison of inversion techniques could be made.

Andrea Viezolli and James Cull of Monash University who processed and studied some of the induced polarization data.

Dalcrom agricultural consultants who helped with siting of ploughed array tests.

Geoff Beecher and Brian Dunn of NSW Agriculture who provided advice and differential GPS equipment.

Greenspan who provided a pressure sensor and logger at research rates.

Most importantly I thank my wife and family who willingly coped with 3 and a half years of life on low, and at times no, income while I completed this thesis.

GLOSSARY

AXB geo-electric array. Allen Exponential Bipole geo-electric array is a collinear array with two elongated transmitter electrodes followed by receiver electrodes spaced at 2^n from the far end of the second transmitter electrode where *n* increments by any constant value (typically 1 or 0.5).

dBase. A dBase file is a relational database file, with the extension *.DBF following the dBase (now xBase) conventions. It is a very old and well supported format that allows indexing using separate *.MDX files.

EC. Electrical Conductivity (measured normally in µS/cm) is the inverse of resistivity.

EC Ribbon. An EC ribbon is a type of graphical presentation of multi-depth electrical conductivity data, where soundings are stitched together in a vertical image. The vertical image is wrapped along the track of that image presented in a 3D interface such as OpenGL. It is designed for use with towed multi-depth EC surveys.

Forward Modelling. Forward modelling is the process of determining the set of voltages that an instrument would measure over a particular theoretical model.

Geo-electric array. A geo-electric array is a collection of electrodes connected to the earth or water in such an arrangement that they can be used to image the substrate. The array is made up of quadrupoles (see definition) used individually to focus on various depths and/or parts of the substrate.

Inversion. Inversion is the process of iteratively simulating forward models and determining how well they fit field data and then proposing new models until a model that fits the field data well is found.

Quadrupole. A quadrupole is a set of two transmitter electrodes and two receiver electrodes. A geo-electric array contains a whole set of quadrupoles which may, or may not, contain electrodes common with other quadrupoles in the array. Each quadrupole is designed to focus at a particular depth when used to image the substrate.

Resistivity. Resistivity (measured in ohm.m) is the inverse of electrical conductivity

ShapeFile. A geographic format that adds a geo-indexing file (*.SHP) to a dBase file. The *.SHP file may contain points, lines, polygons or more complex features referenced in 2D or 3D. Additional index files and a projection file may supplement the *.SHP file. The format is detailed in a White Paper by ESRI (www.ESRI.com).

SPOT. Seepage penetrating observation tube – A vertical pipe infiltrometer for spot measurement of seepage in locally observed seepage spots (LOSSes). This is a simple reliable device for low accuracy spot measurement of absolute seepage rate at low EC anomalies in canals.