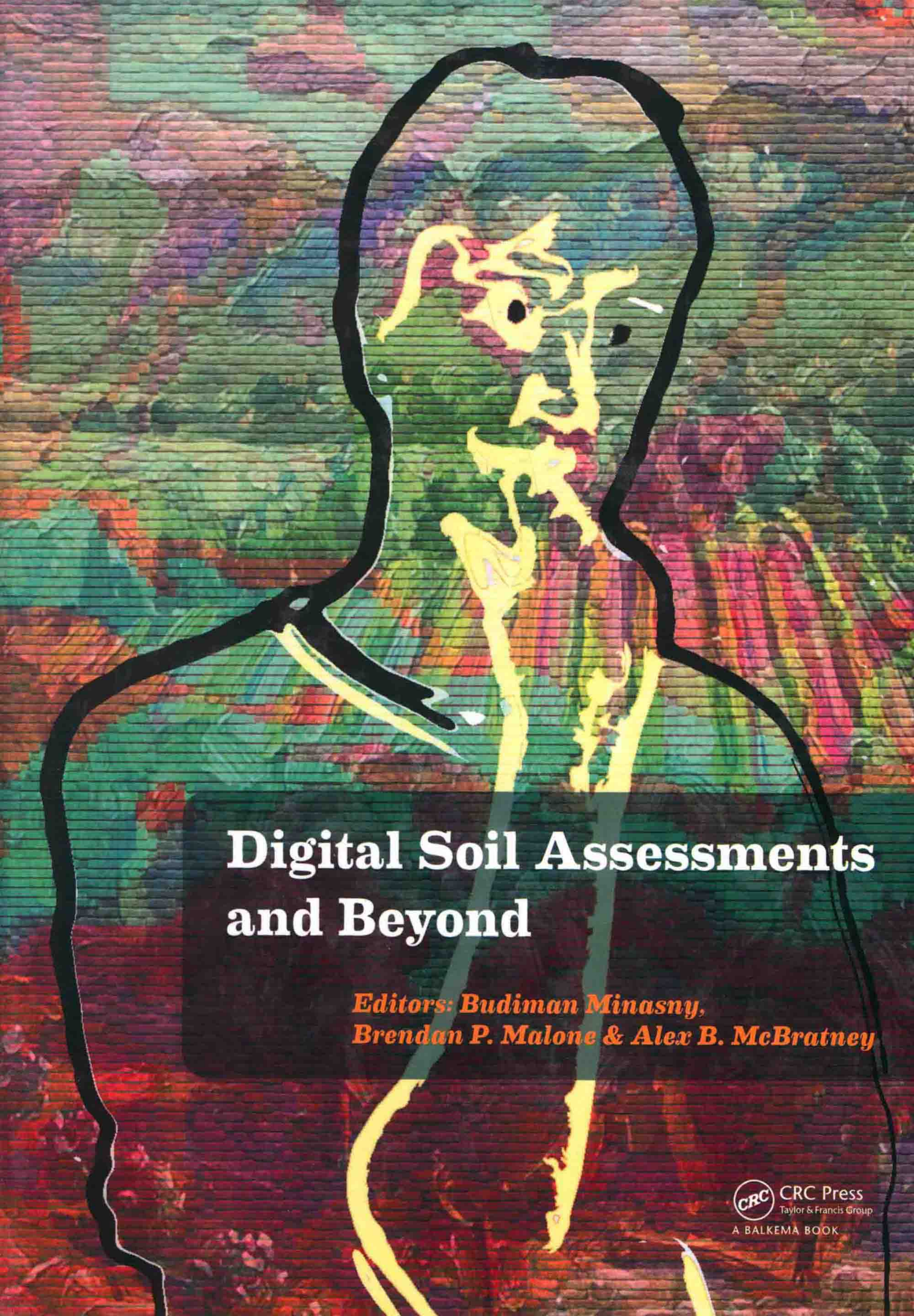

Digital Soil Assessments and Beyond

Editors: Budiman Minasny, Brendan P. Malone & Alex B. McBratney

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A BALKEMA BOOK

PROCEEDINGS OF THE FIFTH GLOBAL WORKSHOP ON DIGITAL SOIL MAPPING, SYDNEY, AUSTRALIA, 10–13 APRIL 2012

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Foreword

Not too long ago it was universally perceived that the golden æons of soil mapping had passed. The mapping was over, done, finished. All that was remaining was a bit of scanning, digitizing and some sort of GIS insertion of the existing soil class maps; work for which no more field work would be required and that could be done by technical specialists. The pedologists and soil surveyors could go home—pedology was dead and buried (White, 1997). Indeed, many soil survey institutions across the world gradually withered, or were even closed, and there was a deep anxiety that soil surveyors were to become an endangered species (Nachtergaele, 1990). The suggestion was made to turn soil survey institutes into soil monitoring institutes (Young, 1991) but that has not been taken up so far, just like the privatization of soil survey institutes has not been overwhelmingly successful.

The reality is that less than one-third of the world has been mapped at a scale 1:1 million or larger; that many of the soil maps do not contain the answers for the current environmental questions; and that some of the data that underpin the soil maps are outdated. This has often been an issue in soil mapping but became particularly noticeable when progress became hampered and no additional (e.g. more detailed and updated) soil surveys were executed. Despite all that, the demand for soil information did not dwindle, it inexorably increased, and so did the science. Computer-based system approaches were used and tested on the digitized and scanned soil map and pedon information (Tomlinson, 1978). Later on, this combination and integration of soil survey information, GIS, geostatistics, environmental modelling, terrain analysis, and remote sensing were melded into a new concept and paradigm entitled *Digital Soil Mapping*.

It is perhaps a bit hard to determine where its origins are, for example, the work of Legros and Bonneric (1979) features many of the elements which we now would recognize as Digital Soil Mapping. The paper "On Digital Soil Mapping" from 2003 (McBratney et al.) brought much of the early work on digital soil mapping together. It has become a seminal paper with well over 300 citations to date which, in soil science, is outstanding. More importantly, the paper presented an elegant framework and soil-environmental model that has triggered a whole gamut of scientific activities. In order to streamline and consolidate global efforts a Working Group of the International Union of Soil Sciences (IUSS) was formed. In the past 10 years a large number of reports, scientific papers and books have been published on this topic and several national and global projects (e.g. *GlobalSoilMap.net*) have started following discussions and activities in this Working Group.

The IUSS Working Group, currently led by Dr. Janis Boettinger of Utah State University, holds biennial global workshops (Montpellier in 2004, Rio de Janeiro in 2006, Logan in 2008, Rome in 2010); this book presents most of the papers presented at the 5th Global Workshop on Digital Soil Mapping. It was held in April 2012 in Sydney, Australia and skillfully organized by the editors of this book. The papers in this book are grouped into ten sections that deal with a wide range of subjects like proximal, remote sensing and spectroscopy of soil, soil maps, legacy data & covariates, sampling and monitoring, or cyber infrastructure and expert systems. It is noteworthy that there are quite some papers on fieldwork and sampling. Such activities are an essential part of digital soil mapping and are better targeted and more optimalised following the digital exploration and mining of the available soil survey and map data.

This book presents a snapshot in time and space of activities and accomplishments across the globe. Comparing this book to the proceedings of earlier Global Workshops, it becomes apparent how much progress has been made both scientifically as well as in its global spread of activities. The subject has branched out in the applications and achieved depth in several of its scientific activities. A logical result of that all is the branching and spread of accomplishments results in a widening net of research questions and issues. For example, how much validation is needed, or is there a decision tree for assessing the uncertainty in the maps, or how to use the digital soil maps for evaluating soil functions and other assessments. The knowledge, model and data desiderata needs in digital soil mapping have recently been well-formulated which could serve to initiate research agendas nationally and at the global level (Finke, 2012). There are practical and technological issues to be solved as several countries have produced digital soil property maps on a national scale (e.g. Denmark, Nigeria, USA, South Korea, Chile) and the question arises how the information can be stitched together in a seamless supranational or global soil map.

Plenty of work remains, fortunately, and a discipline that has no clear view of its sense of direction or research needs is bound to be dead and buried indeed. So, the mapping ain't over, some of it is just beginning. There are few certainties in this world but it is quite assuring to state that digital soil mapping has become a vibrant subdiscipline in soil science and has revitalised soil survey activities in many countries. It will continue to do so across the globe.

Alfred Hartemink
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Preface

Digital soil assessments and beyond contains papers presented at the 5th Global Workshop on Digital Soil Mapping, held 10–13 April 2012 in Sydney, Australia. The contributions demonstrate the latest developments in digital soil mapping as a discipline with a special focus on the use of the map products to drive policy decisions particularly on climate change, crop and soil security. The workshop involved 140 scientists from 25 countries. This was the fifth biennial workshop in a series that has united formerly separate sub-disciplines in soil science: pedology (study of the formation, distribution and potential use of soils) and pedometrics (quantitative and statistical analysis of soil variation in space and time). Most encouraging was the emergence of a large group of talented young soil scientists from many countries who are building human capacity and outstanding national soil information systems and applying them to some of the key global challenges, namely food security, climate change mitigation and adaptation, and sustainable land management.

This book compiles a range of topics: digital soil assessments, digital soil modelling, operational soil mapping, soil and environmental covariates, soil sampling and monitoring and soil information modelling, artificial intelligence and cyber-infrastructure, and progress in GlobalSoilMap.net. We hope that these topics can encourage new mapping incentives and stimulate new ideas to make digital soil mapping practicable from local to national and ultimately global scales.

The CD-ROM accompanying this book contains digital versions of all contributions, many in full colour. Whenever reference is made in the book to colour images, the reader is kindly requested to consult the CD-ROM.

Sydney, April 2012
Budiman Minasny
Brendan Malone
Alex McBratney

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Table of contents

Digital soil assessments

Digital Soil Assessments and Beyond – Minasny, Malone & McBratney (eds)

Digital soil assessment: Guiding irrigation expansion in Tasmania, Australia

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ABSTRACT: Digital Soil Assessment is being used to model land suitability in recently commissioned irrigation schemes in Tasmania, Australia, in support of Government agricultural expansion policy. The Wealth from Water pilot program commenced in 2010 within a 20,000 ha irrigation district in the Meander Valley in northern Tasmania. The modelling requires comprehensive soil, climate and terrain parameters to rate the suitability of land for seven test enterprises (alkaloid poppies; carrots; hazelnuts; barley; blueberries; pyrethrum; and industrial hemp). Digital soil mapping techniques were used to produce soil information at 30 m resolution for pH, EC, clay and stone content, drainage, and depth to sodic and/or impeding layer based on sampled soil cores and explanatory spatial data. Sites were located using a stratified random sampling design, with environmental covariate datasets including a digital elevation model and derivatives, gamma radiometrics, legacy soil mapping, surface geology, and satellite imagery. Individual soil properties were predicted using MIR and NIR analyses using an Australian calibration dataset, and a sample sub-set with conventional chemical analyses. Temporal climatic grid inputs of frost risk, growing season, chill hours, and rainfall intensity were generated using available weather stations and explanatory terrain data, and improved in resolution and certainty by the collection of spatially intensive temperature and rainfall data from additional temporary field sensors. The land suitability for each enterprise was determined by interrogating each soil and climate parameter with a series of suitability rules. The preliminary soil, climate and suitability surfaces are being evaluated through restricted access by key personnel from Tasmanian Government, academia and industry, with suitability mapping planned for public release in 2012 through a Tasmanian Government web-based Spatial Portal, (the LIST, www.thelist.tas.gov.au).

1 INTRODUCTION

The Wealth from Water Pilot Program commenced in November 2010, primarily to support irrigated agriculture through land suitability assessment. It is a partnership between the Department of Primary Industries, Parks, Water and Environment (DPIPWE), the Department of Economic Development, Tourism and the Arts, the Tasmanian Institute of Agriculture (TIA), and The University of Sydney (through an Australian Research Council Linkage Project).

Piloted in the Tasmanian Meander Valley irrigation districts, Enterprise Suitability Rules were initially developed for seven enterprises; alkaloid poppies; carrots; hazelnuts; barley; blueberries; pyrethrum; and commercial hemp. The system requires soil property parameters rather than soil types; these consist of pH; ECe (saturated extract); clay%; depth to sodic layer; depth to impeding layer; stone%; and drainage class.

There are now numerous scientific publications that describe the successful prediction of soil surfaces using digital soil mapping (DSM) methodology. These statistically inferred surfaces can provide superior continuous and quantitative soil property estimates than traditionally developed polygonal surfaces, also having the advantage of statistical validation and associated model uncertainty (McBratney et al., 2003). Soil property mapping using these methodologies was considered the optimal approach to provide suitability model inputs within available time and resources. An "Enterprise Suitability Model" was developed using these soil inputs along with generated climate surfaces for each individual enterprise.

1.1 *Project area*

Meander East and Meander West Irrigation Districts has a total area of 20,000 ha (Figure 1).

The escarpment of the Great Western Tiers dominates the landscape in the Meander Valley. It divides the Central Plateau to the south of the Valley from the Launceston Tertiary Basin. Tasmanian geological structure largely determines the spatial pattern of soils due to the strong influence of rock type upon soil formation. The escarpment is the result of the extensive block faulting which disrupted the surface of Tasmania during the lower to middle Tertiary Period. The Meander project boundary follows two districts of the Meander Irrigation Scheme, and was selected to test a variety of different soils, land uses and landscapes. The area contains soils of the Launceston Tertiary Basin to the East, which comprise a series of alluvial and relict river terraces, consisting of smectite clays in drainage depressions and most recent flood plains, and duplex soil terrace series, with various distributions of aeolian cover sands. Red volcanic soils derived from Tertiary basalt dominate the landscape around the Deloraine area, while poorly drained, complex alluvial soils are found in the Meander township area to the south. Outcrops of Jurassic dolerite are scattered through the area, which produce a variety of different soils, usually high in coarse fragments, (Spanswick & Zund 1999).

1.2 *Project aims*

1. To generate soil and climate surfaces for derivation of land suitability parameters.
2. To undertake land suitability modelling for a range of agricultural enterprises, at a required nominal scale of 1:50,000 (or 30 m resolution).

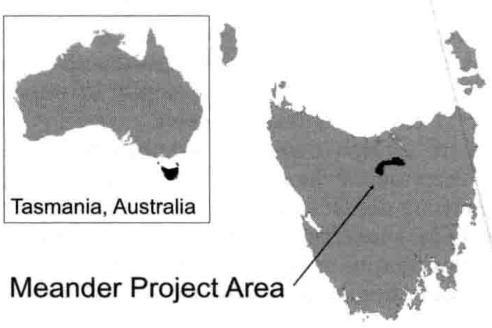

Figure 1. Meander, Tasmania, Australia.

2 MATERIAL AND METHODS

2.1 *Existing soils data and spatial covariates*

Existing soils data was obtained for the Meander East and West pilot areas. The mapping (Quamby 1:100,000) and database site density was not of the scale or quality to produce reliable suitability surfaces at the required scale. Available *scorpan* covariates, (McBratney et al., 2003) were assembled and processed to a common 30 m grid system for the study area using SAGA GIS (System for Automated Geoscientific Analyses, http://www.saga-gis.org). The *scorpan* covariates included:

1:100 000 soil maps; 1:100 000 land capability maps; SRTM digital elevation model 30 m (from CSIRO/Geosciences Australia). Airborne gamma radiometric data (Mineral Resources Tasmania); and 1:25 000 surface geology mapping (Mineral Resources Tasmania). Satellite imagery included: SPOT 2009 multispectral data; RapidEye 2010 multispectral data; and Landsat ETM data. Climate data (BoM, Landscape Logic); land use classes (1:50 000, DPIPWE, 2010) and TASVEG vegetation mapping (1:25 000; DPIPWE 2010) were also retrieved.

Terrain derivates were generated using SAGA GIS from the 30 m SRTM DEM which included: analytical hill-shade, aspect, slope, mid-slope position, slope height, normalised height, curvature, plan curvature, topographic wetness index, distance to channel network, valley depth, MRVBF (multi-resolution valley bottom flatness index and MRRTF (multi-resolution ridge-top flatness index; Gallant & Dowling 2003). From the satellite imagery, SPOT 2009 NDVI (Normalised Difference Vegetation Indices) and FVC (Fractional Vegetation Cover) were derived (ESRI Spatial Analyst®/SAGA GIS). The existing soil mapping was partially disaggregated and extrapolated into un-mapped areas for use as a covariate. Ground-based gamma radiometric mapping was undertaken by CSIRO Land and Water to complete the partial coverage in Meander West.

2.2 *Soil sample design*

Two-hundred training sites were determined as appropriate for the required mapping resolution, (Brungard & Boettinger 2010). The sample design followed a Conditioned Latin Hypercube design, a random-stratified sampling approach based on maximally stratifying the full covariate distribution, (Minasny & McBratney 2006). A further twenty-five sites were added to the design as a contingency, for situations where sampling was not possible due to access, physical sampling constraints or site contamination.

2.3 *Independent validation*

An additional sixty sites were sampled independently of the training sites for validation purposes. Although validation is ideally subsequent to modelled surfaces generation, project time constraints could not allow this delay; hence sampling was undertaken prior to completion of DSM predictions. The design was based on fuzzy k-means clustering of all spatial predictors, using *Fuzme* software, (Minasny & McBratney 2002). Six random samples were taken from a computed ten clusters. The validation sample distribution was compared to the overall covariate distribution, which demonstrated a good sample design, (i.e., the sample slope density, mean, inter-quartile range, median and standard deviation values showed little variation from the full covariate population, (Brungard & Boettinger 2010).

Field staff were provided a covariate cluster map, which allowed physically impractical sites to be re-located within clusters to more accessible locations, while still maintaining the same number of samples from each of the clusters. Final validation sample locations also showed little variation in terms of overall covariate distribution, so were still considered a good validation design.

2.4 *Sampling and analysis*

All samples were taken using a 50 mm diameter percussion soil corer to a depth of 1.5 m, and sub-sampled by horizon. Cores and surrounding landscape position were described according to Australian Soil and Land Survey guidelines, (NCST 2009). Spectral-scanning (MIR/NIR) of all training and validation samples was undertaken by CSIRO Land & Water, Canberra to predict required soil properties. Twenty percent of scanned samples were selected and analysed for chemical properties at CSBP Laboratories in Western Australia to provide calibration data for soil property predictions. Full analyses of each sample included pH, EC, exchangeable cations, N, P, K, organic carbon, and particle size distribution.

2.5 *Soil property predictions*

Depth splines (Malone et al., 2011) were fitted to all sampled profiles for each soil property to allow depth specific queries and surface generation for land suitability model inputs. Soil property surfaces were generated across the pilot area. A range of spatial soil prediction functions were assessed which included artificial neural networks, rule-based/decision-tree classifiers Cubist®/See5®, (Rulequest Research), regression kriging (Hengl et al., 2007) and Random Forests (R statistical software).

At the time of publication, incomplete validation spectral predictions and gamma radiometric components (K, U, Th) only allowed preliminary modelling of soil attributes to be tested within the enterprise suitability model. Project funding had also been announced for additional sampling and suitability modelling in adjacent Meander Valley districts in 2012. It was decided to postpone further soil property modelling until the additional Meander sampling and analyses had been completed, potentially improving all predictions through a greater range of covariate distribution and training/validation sites. It is planned to test all listed prediction techniques and available covariates to obtain best possible predictions. Spatial soil properties were predicted using the measured or described properties at each site (Table 1).

2.6 *Climate surfaces*

Available climate data was not at sufficient resolution or sample density to reliably inform the suitability mapping at the desired scale. Production of more detailed climate surfaces was facilitated by installing temperature sensors at a rate of 0.4 /km^2, (80 loggers in 20,000 ha). Sensors were located using the previous fuzzy k-means clustered sampling approach, derived from a range of temperature-related terrain derivatives (from the SRTM 30 m DEM). A further six climate stations were installed to measure rainfall. Three months of data had been processed at time of publication, with climate surfaces generated using this data and terrain

Table 1. Soil properties.

Soil property	Site/sample assessment method	Variable type
pH	MIR prediction	Continuous
ECe	MIR prediction	Continuous
Depth to sodic layer	MIR prediction	Continuous
Soil depth	Field measured (Soil surveyor)	Continuous
Stone% class	Field described (Soil surveyor)	Discrete
Clay%	MIR prediction	Continuous
Drainage class	Field described (soil surveyor)	Discrete