Next steps in Precision Viticulture – Spatial data for improved design of vineyard (re-)planting



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Important Note:

At the time of finalisation of data analysis and preparation of this report, Colin Hinze was absent from work on a lengthy period of sick leave following major surgery. It was therefore difficult to get his input to sections of the report pertaining to vineyard design. In agreement with GWRDC, and mindful of the other commitments of the project team, it was therefore decided to proceed with this report in the absence of Mr Hinze's substantive input, on the understanding that a supplement would be provided following his return to work later in 2009.

Cover Photograph: Preparations for vineyard replanting at Taylor's Wines, August, 2008.

Photographer: Dr Rob Bramley, CSIRO Sustainable Ecosystems.

Abstract

By convention, and in some cases statutory requirement, vineyard design in Australia has been primarily based on soil survey using pits located on a 75 m grid. Previous work has suggested that this approach may have some shortcomings. One reason for this is that vineyards have been shown to be highly variable with respect to vigour, yield and quality with this variation being attributed to variation in the soil and land underlying the vineyard. This project therefore sought to examine the opportunity for spatial data, especially at high resolution, to better inform vineyard design. Using an area of more than 80 ha at Taylor's Wines in the Clare Valley for our study site, we used analysis of past yield maps and remotely sensed imagery along with EM38 soil survey and elevation modelling to inform a vineyard replanting project. We also used spatial analysis to try to extract useful information from the 75 m grid data additional to that provided in the conventional vineyard soil map format. Whilst the merits of our approach need evaluation at some point in the future once the new vineyard has reached maturity, our work indicates that the use of spatial data and its analysis can provide a much improved basis for vineyard design compared to conventional approaches.

Executive Summary

Previous research conducted by CSIRO Sustainable Ecosystems (CSE) and partners in industry and the former Cooperative Research Centre for Viticulture (CRCV) established that:

- vineyards are variable (eg yields typically vary by ten-fold within a single block, with quality also varying);
- vineyard variability shows marked spatial structure;
- variation in vineyard performance is primarily driven by variation in the land (soil, topography) underlying the vineyard; so that
- patterns of variation tend to be stable in time; meaning that
- some form of 'targeted management', often based on identification of zones of characteristic performance, is more appropriate than the conventional approach in which all parts of a block receive the same management, and has the potential to deliver very significant economic benefits to both grapegrowers and winemakers.

It follows from the above that prior knowledge of such variation could be valuable in informing vineyard design. This project sought to see whether this was so.

A large vineyard re-planting program is presently being implemented at Taylor's Wines, near Auburn in the Clare Valley. We used an area of around 80 ha of the Taylor's property that was intended for replanting as the focus for this project. As has been conventional practice, and also as a part of the requirement for irrigation licensing, Taylor's commissioned a soil survey of the site from a commercial provider. This survey was based on inspection of back-hoe pits dug on a 75 m grid. Pit location and elevation data were also provided and these data, along with the resulting soil maps and reports, were used to inform one design option.

Taylors have adopted elements of Precision Viticulture into their business in recent years. Accordingly, we were able to use yield maps and remotely sensed imagery as input to a second design option. Spatial analysis of these data, along with those obtained from a high resolution soil survey using EM38 sensing and real-time kinematic GPS, from which a digital elevation model was produced, formed the basis of the second design option.

In addition, we used spatial analysis of the 75 m grid survey data to try to add value to the normal outputs that are delivered from conventional vineyard soil survey.

Proper comparison of the merits of the design options depends on economic analysis of the redesigned vineyard from a production perspective, along with an assessment of vineyard variability once the redesigned block has reached an appropriate level of maturity – something that is not possible for between 5 and 10 years. Nevertheless, our results suggest that the use of spatial data and its analysis can provide a much improved basis for vineyard design compared to conventional approaches. Our approach does not replace the need for the input of an expert soil surveyor, but it does offer a means by which greater value, at little cost, can be extracted from their endeavours.

Table of Contents

Abstract iii

Executive Summary iv

A. Background 6

B. Objectives 6

C. Methods 7

C1. Study Site and project strategy 7

C2. The 'non-PV' approach 9

C3. The PV approach 9

C3.1 Soil analysis 13

C4. Extracting additional value from grid survey data 14

D. Results and Discussion 14

D1. The 'non-PV' approach 14

D2. The PV approach 17

D2.1 Variation in past crop performance 17

D2.2 Soil and topographic variation 19

D2.3 Calibration of EM38 data against soil analysis (wet methods and MIR) 21

D2.4 Integration of production data with the other biophysical information 28

D2.5 Adding value to grid survey data 29

D2.6 A modified vineyard design based on (high resolution) spatial data 31

E. Conclusions and Recommendations 31

F. Acknowledgments 32

G. Communication 32

I. References 33

J. Staff 34

K. Budget Reconciliation 34

A. Background

Previous research conducted by CSIRO Sustainable Ecosystems (CSE) and partners in industry and the former Cooperative Research Centre for Viticulture (CRCV) has established that:

- vineyards are variable (eg yields typically vary by ten-fold within a single block, with quality also varying);
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- some form of 'targeted management', often based on identification of zones of characteristic performance, is more appropriate than the conventional approach in which all parts of a block receive the same management, and has the potential to deliver very significant economic benefits to both grapegrowers and winemakers.

However, in spite of the success of the recent research effort and its clear demonstration of benefits (eg Bramley, 2005b; Bramley et al., 2005), adoption of the tools of Precision Viticulture (PV; Proffitt et al., 2006) has been patchy, and there is a perception amongst some industry personnel that the success of the research has not been matched by the level of industry adoption. Irrespective of the basis for this perception, there is no doubt that growers who have not begun to use spatial data to manage variability in their businesses are missing out on the opportunity to gain greater control over their production system, extract greater efficiencies in their businesses and to be more profitable and sustainable as a result. 'Demonstration Projects' in which industry is guided through the process of applying spatial data to viticultural decision making therefore have much merit.

This project was established with a view to providing such a demonstration, with a particular focus on vineyard design and re-planting. Appropriate vineyard design, in which new plantings (and plans for their subsequent management) are matched to the variation in the inherent characteristics of the land supporting the new vineyard, is a key step which managers of new plantings should take advantage of and which, for obvious reasons, is not possible in established blocks. Our idea was to use the available PV technologies to help understand the inherent soil and land characteristics of a vineyard and the potential for this to assist in the design and layout of a vineyard re-development. Our premise was that such data may be invaluable: getting the vineyard designed properly at the start may well help save growers huge amounts of time and financial resources in the future. In particular, improved matching of land use to land use suitability can have important implications for environmental sustainability (minimise the risk of on and off-site impacts) and business profitability (optimise efficiency of input use and of outputs to desired product streams) with significant social and community benefits accruing as a consequence.

B. Objectives

With the foregoing in mind, this project sought to demonstrate and communicate to industry the utility of spatial data (high resolution soil survey, remote sensing and yield mapping) in informing vineyard (re-)design and (re-)planting.

Accordingly, the following outputs and performance targets were foreshadowed:

Outputs	Performance Targets
1. A basis for design and management strategy for a Clare valley vineyard replanting	Acquisition, collation and analysis of available spatial data
2. Articles in industry media	At least one article and at least one presentation to an industry technical meeting describing the project
3. Final report to GWRDC	Report submission

Note therefore, that the project was focussed on highlighting the potential utility of high resolution spatial data as an input to vineyard design rather than the particulars of specific sites. What is important here is the approach taken to acquire and use information that may be brought to bear on vineyard design, rather than detailed analysis and discussion of particular aspects of the available data or of specific established methodologies. For this reason, and also the limited resourcing made available to this project, this report does not provide extensive detail on either the specific soil properties of the study site or amelioration of problem areas within it, or of the application of established methodologies (eg grid or EM38 soil survey); nor does it, at this stage, provide a definitive measure of the relative benefit of the various approaches to vineyard design used. It is not possible to provide such a measure until the redesigned vineyard has been in production for a few years, at which point a follow-up project would be appropriate.

C. Methods

C1. Study Site and project strategy

The project was conducted in collaboration with Taylor's Wines at their Auburn vineyard, and was focussed on an area which was intended for redevelopment (Figure 1). The study site of approximately 86 ha (81.6 ha of planted vines prior to redevelopment) is bounded to the north by the Wakefield River and, to the south, by another creek which drains into the Wakefield River. Both of these streams are ephemeral.

Prior to redevelopment, the vineyard was organised into 6 blocks which were planted to Cabernet Sauvignon and Chardonnay on own roots in either 1981 (block B), 1982 (blocks A, E and F) or 1983 (blocks C and D). The present redevelopment was motivated by a desire for a variety mix better matched to market opportunity, the availability of improved clones, and the need to address an increasing problem with *Eutypa* in the existing plantings.

At the start of the project in August 2008, blocks A and B were still under vine; blocks C, D and F had all been cleared after vintage 2008 and had been planted to a fallow cereal crop; whilst block E had been cleared after vintage 2007 and had also subsequently been planted to cereals which were then ploughed in as a green manure. The soil in this block had then been ripped, re-worked and the block marked out for irrigation installation and replanting; the cover photo of this report shows this block at the start of the project at which time, irrigation infrastructure was being installed.

Taylor's plan was to clear blocks A and B after vintage 2009 and to then progressively redevelop the land previously under blocks A, B, C, D and F during 2009 and 2010. However, the economic climate following vintage 2009 led to a decision to put re-planting on hold, albeit with a clear intention that the land would go back under vineyard in due course.

Our strategy in this project was to use high resolution spatial data, collected using the tools of PV, to provide a basis for the viticulturist to come up with a design for the redevelopment of Blocks A, B, C, D and F, and to compare this with the design developed using a 'non-PV' approach. Quite deliberately, neither the viticulturist nor his colleagues involved in planning the re-development

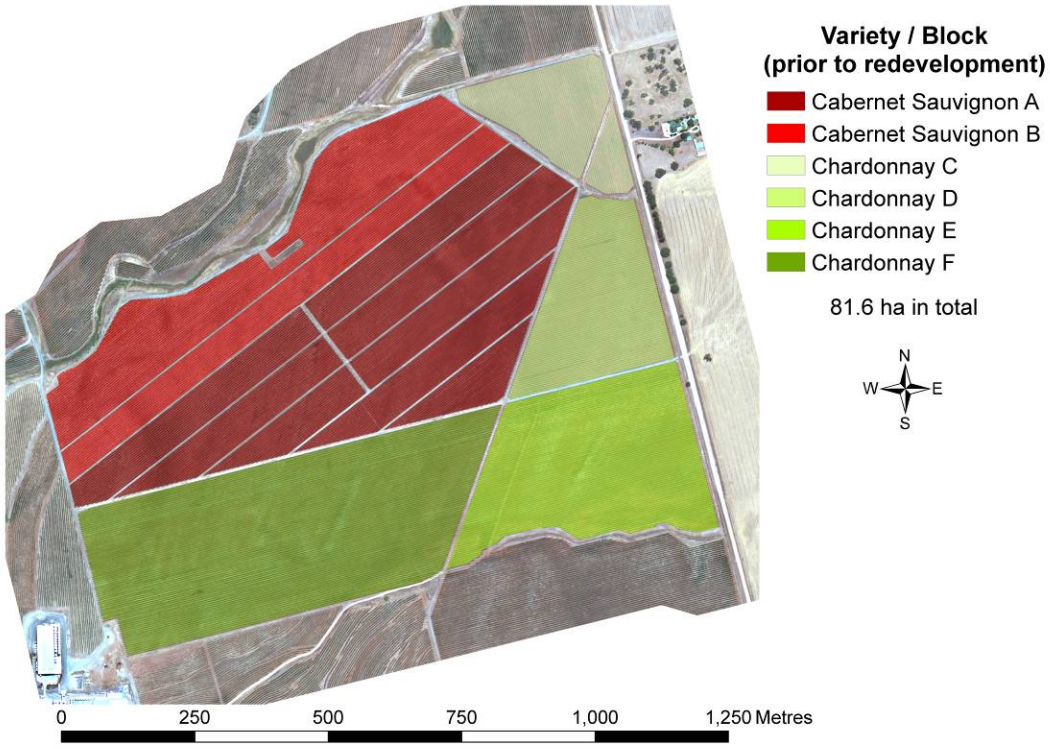


Figure 1. The project study site and its configuration prior to redevelopment.

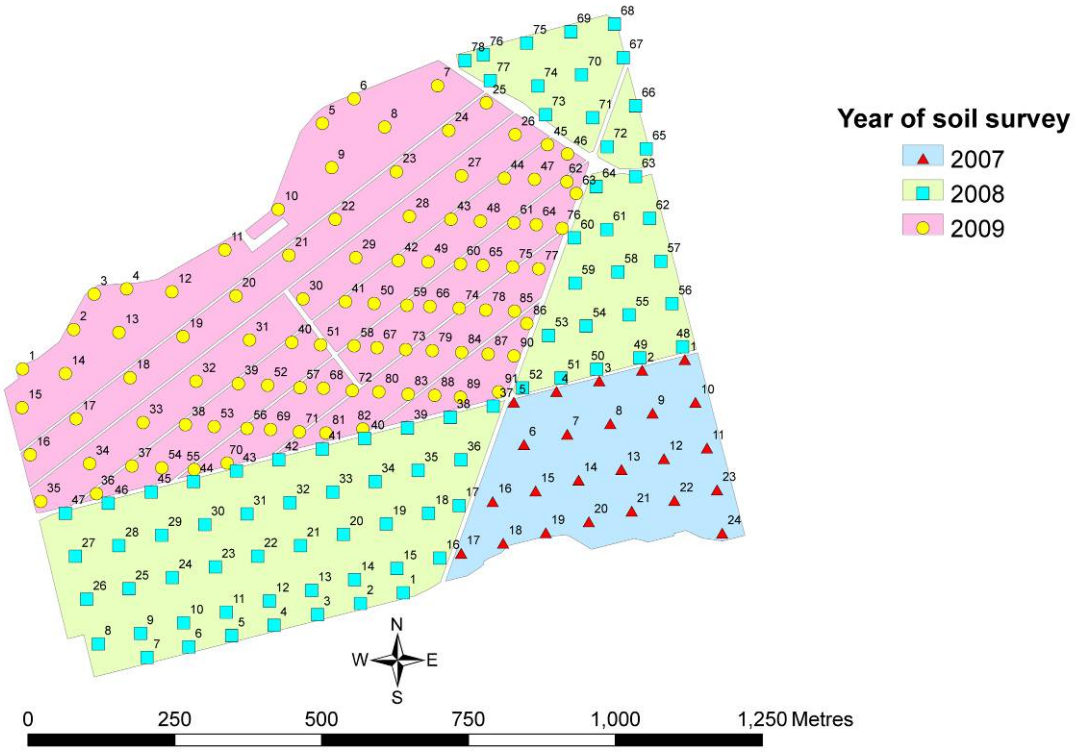


Figure 2. Date and pit location of 75 m grid soil survey. Note that the pit numbers restart at 1 for each stage of the survey.

were shown the results of our spatial analysis until after their 'non-PV' design had been drawn up. It should be noted however, that Taylor's have been making use of remotely sensed imagery and yield mapping since vintage 2006, albeit in the absence of most of the methods of data analysis and integration described below. It should also be noted that a constraint to the vineyard design, irrespective of the means of arriving at it, was the existence of a buried gas pipeline running diagonally across the block in a SW-NE direction along the line of the existing boundary between blocks E and F and blocks B and D and the existing headland which dissects block C. Taylors were also reluctant to remove the road running between blocks B and F and D and E (Figure 1). There is also a natural waterway which runs SE-NW between block C and blocks A, B and D.

C2. The 'non-PV' approach

Consistent with standard practice, the non-PV design for the vineyard was based on data collected during a conventional grid soil survey of the area by a commercial soil surveyor, along with the maps, reports and soil management recommendations provided as a part of that service (Wendy Meech, WJB Consulting – pers. comm.). It was then left to the viticulturist to make use of these data, maps and reports in developing his design for the new vineyard layout. Note that the soil survey used here was staged over a 3 year period consistent with the redevelopment of the site (Figure 2). In addition to these data, the soil pit locations had been georeferenced by the surveyor using an RTK GPS from which elevation contours had been interpolated. Figure 3 illustrates three soils in block B.

As stated in the reports provided by Wendy Meech (WJB Consulting), the soil survey "was undertaken to determine soils information for vineyard suitability, irrigation design and management, soil amelioration and to satisfy requirements… for the purposes of water allocation." The survey involved the digging of pits by backhoe in a grid (spacing of approximately 75 m with pits dug to a depth of approximately 1.8 m where possible) and description of the soils in terms of the following attributes:

- Depth and texture of each soil layer as assessed by the hand texturing method;
- Carbonate (lime content) of each soil layer as determined by soil reaction to 1N hydrochloric acid;
- Depth and classification of carbonate layers;
- Colour of each soil layer as determined from a Munsell colour chart;
- Moisture content of each soil layer;
- Estimated crop rootzone for vines; and
- The pedality (soil structure) of each soil layer.

Limited laboratory analysis of a small number of samples was also carried out. This survey approach is sometimes referred to as the 'ICMS-Wetherby system' (McKenzie, 2000). It was criticised by Bramley (2003a) on the grounds that, for general soil reconnaissance it represents expensive oversampling, and in instances where the management of vineyard variability is a goal, is too coarse for elucidation of possible soil drivers of variation in vine performance.

C3. The PV approach

The PV approach used here seeks to address the criticisms of grid soil survey (Bramley, 2003a), and also to make use of all available spatial information in vineyard design, with the aim of ending up with blocks, the fruit from which can be delivered to the winery in more uniform parcels than would be possible had such spatial information not been brought to bear on the design. In particular, the focus is on the use of spatial information at a much higher resolution than that provided by the 75 m grid survey. Thus, in addition to the data derived from the 75 m grid soil survey (above), a number of additional layers of data at high spatial resolution were either already available or were acquired as part of this project. Further to Taylor's adoption of PV approaches to vineyard management, remotely

a



b



c



Figure 3. Soil variation along a single vine row in block b. (a) Pit 26 (Figure 2), (b) Pit 27 and (c) Pit 32.

sensed imagery (50 cm resolution, acquired at veraison), from which the plant cell density index (PCD) was derived (PCD is the ratio of reflected infrared to red light), and yield maps (derived from data collected using an ATV yield monitor (www.atv.net.au) and differential GPS) were available for the seasons ending at vintage 2006, 2007 and 2008.

In addition to remotely sensed imagery and yield maps, an EM38 soil survey was carried out (Figure 4) in 2 stages (2 days each) during August and September 2008. Given the shallow soil depth over much of the study area, this survey was conducted in the horizontal dipole only (reflecting approximately the 0-75 cm depth range). In blocks C-F, this survey was conducted on transects 6.6 m apart using RTK GPS for georeferencing so as to also enable derivation of a digital elevation model. 6.6 m was chosen as the transect spacing to reflect the intended 3.3 m row spacing of the redeveloped vineyard and previous success with EM38 / RTK survey using alternate rows (eg Bramley, 2003b). In blocks A and B, the spacing was 7.2 m reflecting the fact that at the time of the survey, these blocks were still under vines in rows with a 3.6 m spacing.

All data were processed and analysed using methods established in GWRDC projects CRV99/5 and CRV95/N (Bramley and Lamb, 2006), with additional detail available in Bramley and Williams (2001), Bramley (2005), Proffitt et al. (2006 and references therein) and Bramley et al. (2008). In the case of the remotely sensed imagery and yield maps, normalised data ($\mu=0$, $\sigma=1$) were used in an attempt to remove inter-seasonal effects (eg Bramley and Hamilton, 2004).

The remotely sensed imagery, yield and EM38 maps are shown in Figure 5. Subsequent to the production of these maps, and during discussion of the fact that the patterns within them were both 'noisier' and less temporally stable than might have been expected (Bramley and Hamilton, 2004), it was agreed that data for the 2007 season should be omitted from the analysis on account of the severe frost experienced that year; the effects of this on yield are especially evident in the NE part of blocks A and B and indeed, block C was so severely affected that it was not harvested at all in 2007.

As with previous work (Bramley and Lamb, 2006; Bramley and Williams, 2007), the digital elevation model was used to derive a number of topographic indices using either THAL (John Gallant, CSIRO Land and Water, Canberra – pers. comm.) or SRAD (Wilson and Gallant, 2000). THAL was used to generate maps of aspect, slope, contributing upslope drainage area and flow direction, whilst SRAD was used to assess radiation and temperature variation over the site.

The Clare High School weather station (Bureau of Meteorology (BOM) site number 021131) data were used for monthly average maximum and minimum air temperatures and mean daily solar exposure, whilst cloud transmittance, sunshine fraction and atmospheric transmittance were calculated using day length and irradiance values generated by the ETRAD program for the latitude of the site, daily solar exposure values for Clare, and daily sunshine hours based on Adelaide (Kent Town); although somewhat distant, this was the closest BOM station for which this parameter is reported. In addition, SRAD requires a number of site specific input parameters. The majority of these were not readily available as was the case with the Bramley and Lamb (2006) work, and so the indicated typical values detailed in the SRAD program notes were used for the circumsolar coefficient (0.25 for all months), albedo (constant at 0.25 for all months), surface emissivity (0.96), the transmissivity lapse rate (0.00008), elevation lapse rate of average surface temperature (7.30 for each month) and elevation lapse rate of minimum air temperature (6.00 for each month). In addition, we assumed a season length based on typical phenology for Shiraz grown at Taylors (bud burst on September 15 and harvest on March 20). Shiraz was chosen on the basis of its phenology being typically in between that of Chardonnay and Cabernet Sauvignon, the previously grown varieties, and because at least some of the redeveloped area will be planted to Shiraz. Nevertheless, the choice of variety for the season length estimation is largely academic since the starting point prior to developing a design for replanting is assumed to be bare or fallow land, and the objective of this part of the analysis was to simply gain some idea as to likely temperature variation across the site.



Figure 4. EM38 soil survey. A Geonics™ EM38 sensor is housed in the polypropylene sled towed behind the ATV fitted with RTK GPS. This photo was taken towards the northern side of Block F looking in a roughly north-westerly direction.

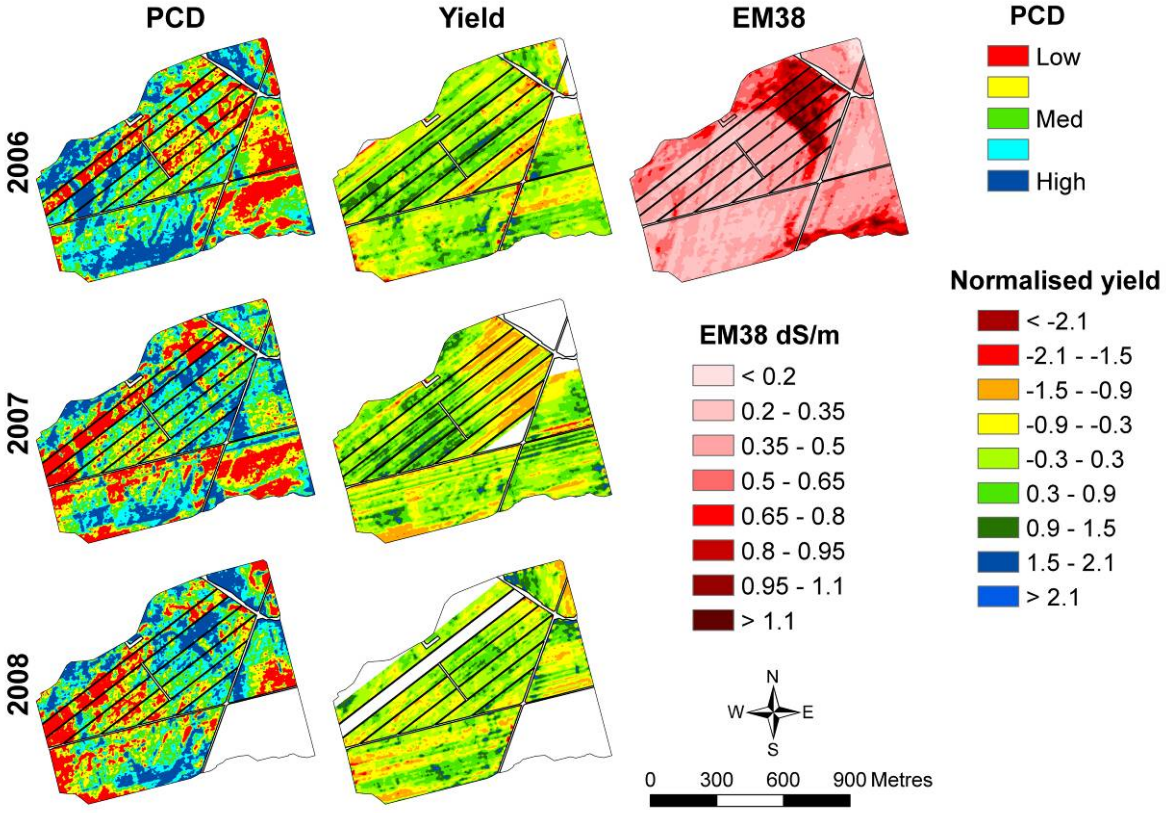


Figure 5. Remotely sensed imagery (PCD) and yield maps for the seasons 2006-2008 and soil bulk electrical conductivity (EM38 – horizontal dipole for the study area). These data, along with a digital elevation model, formed the basis of the 'PV approach' to vineyard design.

Map interpolation was done using VESPER (Minasny et al., 2005) with other spatial analysis and display done using ArcGIS 9.3 (Arcview desktop licence) with the Spatial Analyst and 3D Analyst extensions (ESRI, 2008). Statistical analysis, including *k*-means clustering of map layers, was carried out using JMP 7.0 (SAS, 2007).

C3.1 Soil analysis

For the purposes of calibrating the EM38 soil survey, a number of locations were chosen for soil sampling (Figure 6). Our intention was to sample the soils in 2 depth increments – 5-15 and 35-45 cm and, given the large number of samples involved and the budget constraint of the project, to analyse these using mid-infrared reflectance spectroscopy (MIR; see for example, Bramley and Janik, 2005 and references therein). MIR provides a surrogate estimate of a range of soil properties at a much reduced cost compared to standard 'wet' laboratory methods (eg Rayment and Higginson, 1992). However, the accuracy of soil property prediction using this methodology is dependent on the spectral database used for interpreting spectra obtained from the samples of interest, containing data for soils with similar attributes and provenance. The prediction is also made problematic by high levels of carbonate in the soil which we knew were quite likely to be encountered in this work given the dolomitic geology and the attention paid to soil carbonates in the soil survey reports (Wendy Meech, WJB Consulting – pers. comm.). Accordingly, a soil sampling strategy was derived, based on our budget constraint, which allowed the maximum number of samples to be analysed using MIR, but which also allowed sufficient samples to also be analysed using standard 'wet' methods for calibration purposes. This was considered important given our major intention in this part of the work, of being able to correlate the EM38 signal with meaningful soil properties. The other requirement of our soil sampling strategy was that it covered the full range of variation in EM38 values (Bramley, 2003a,b). The final sampling strategy is shown in Figure 6. Unfortunately, some of the deeper samples could not

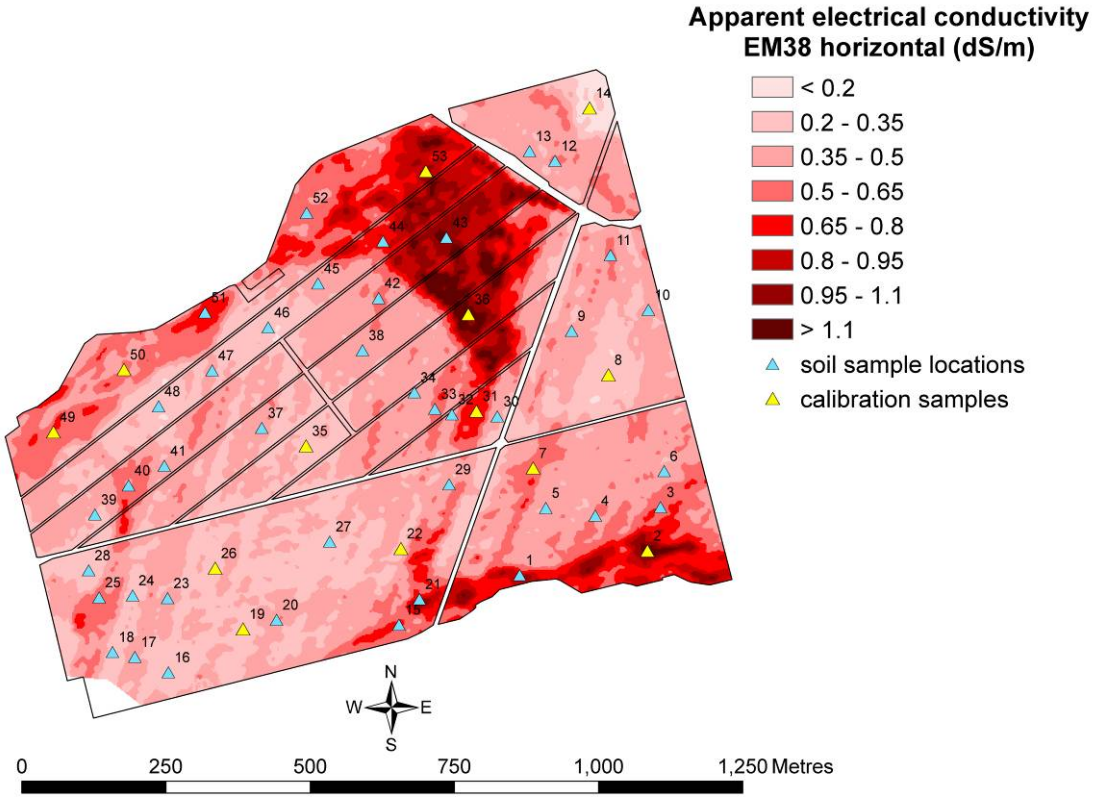


Figure 6. Locations of soil samples chosen for correlation of the EM38 signal with soil properties. Sites marked as 'calibration samples' show the locations of samples used for assessing the merits of the MIR soil property prediction based on standard 'wet' methods.

be taken due to shallow depth, and some of the 35-45 cm depth samples which we were able to collect could not be analysed with confidence using the MIR due to the presence of carbonate. Care was taken in selecting the samples chosen for 'wet' analysis to avoid those for which a robust MIR analysis was not possible. The 'wet' analyses carried out were: pH (in water and 0.01 *M* $CaCl_2$), EC and Cl in a 1:5 soil:solution extract; organic C, exchangeable cations and cation exchange capacity (CEC) by NH_4Cl exchange; carbonate content and particle size distribution.

C4. Extracting additional value from grid survey data

A significant problem with the products usually delivered to land managers following a 75 m grid soil survey is that their interpretation requires a high level of expertise, and familiarity with both the methodology employed, and also the mode of display (eg Figure 7). A further difficulty is that much of the data underpinning them are qualitative. A particular example is soil texture data which is descriptive and based on field assessment by the surveyor and which is nevertheless used as the basis for determining soil water availability and thus irrigation design. Notwithstanding the considerable skill that surveyors are able to draw on in classifying samples according to their field texture, the fact remains that because many of the resulting data are qualitative rather than quantitative, they are very difficult to present as a map surface, which was no doubt a major driver for using the presentation style illustrated in Figure 7.

Recently, Taylor and Minasny (2006) presented an elegant solution to this problem, and we were keen to evaluate it here. In brief, a lookup table, based on the median particle size analysis and field texture of a large number of soil samples from a national soil database (Minasny et al., 2007), was used to provide quantitative estimates of the particle size distribution based on their field textures. Assuming the availability of GPS coordinates for sample location, these data, and the estimates of soil water availability derived from them, can then be interpolated to a smooth map surface using kriging. Taylor and Minasny (2006) present examples from NSW which demonstrate that this procedure has sufficient accuracy to be a useful mapping tool for vineyard soils.

In addition to trying out the method of Taylor and Minasny (2006), we also wanted to try to add further value to the grid survey data through a focus on soil colour. A major reason for this was that whilst conducting the EM38 soil survey, it was apparent that parts of the study site showed significant variation in soil colour, and in particular, the redness of the soil surface (Figure 8). Soil colour data (Munsell colour system) were collected as part of the soil characterisation used during the grid survey.

Whilst the Munsell system does not lend itself to mapping due to the use of a mix of text and numeral descriptors for detailing hue, chroma and value, Viscarra Rossel et al. (2006a) have developed algorithms for conversion between different colour space systems (eg Munsell, RGB, Cielab, etc…) and for calculation of a 'redness index'; a piece of software, 'Colosol' (Viscarra Rossel, 2006), is available which performs these conversions. Here, we used Colosol to calculate a redness index from the Munsell data for surface soils as reported in the 75 m grid survey data, and as with the texture data, used the GPS coordinates for the soil pits as a basis for interpolating a map of soil surface redness.

D. Results and Discussion

D1. The 'non-PV' approach

The vineyard design derived from the 'non-PV approach is shown in Figure 9. Aside from considering the physical constraints of the site detailed in section C1, the design sought to:

- minimise soil type variability within each block;

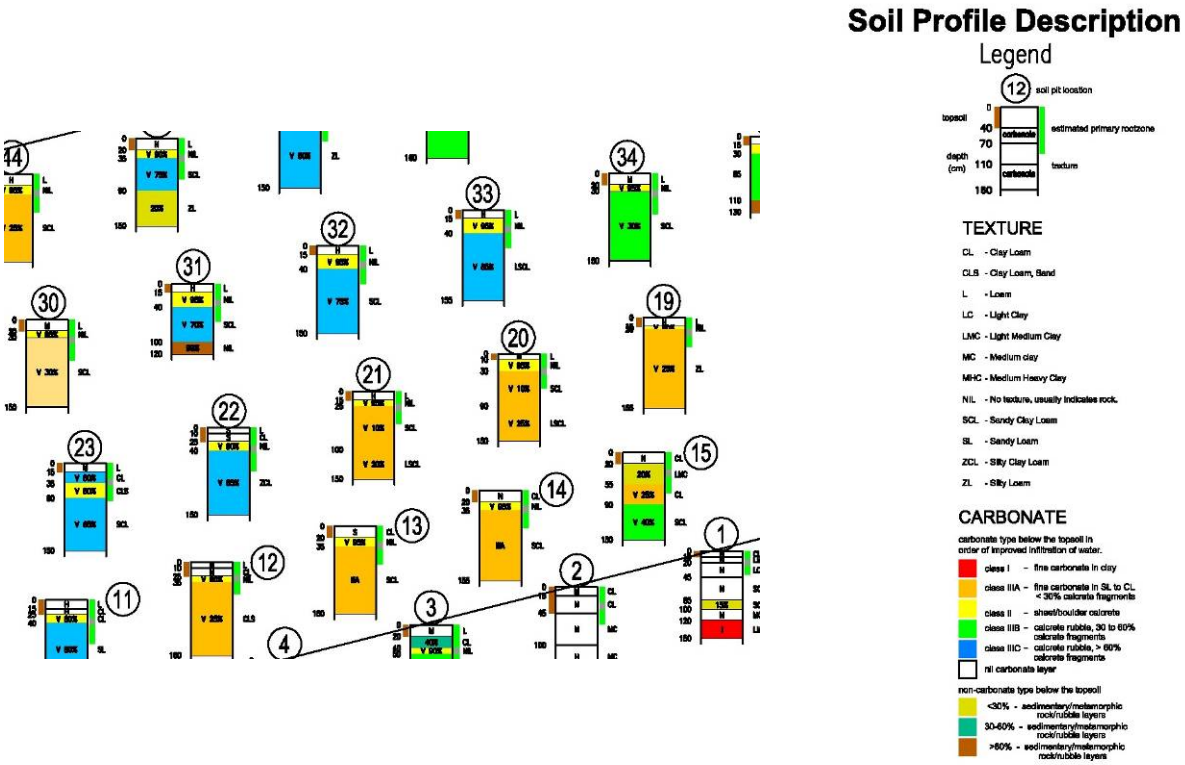


Figure 7. An example of a typical vineyard soil map produced following 75 m grid survey (Data of Wendy Meech (WJB Consulting) and Desmond Elliott (Dunhess Pty Ltd). A map of readily available water (RAW) may also be provided, albeit generally in the similar point format used here (ie not interpolated) as may a map of 'soil units'. The latter is an attempt to aggregate the information shown in the soil profile descriptions (shown here) as a smooth surface. However, the interpolation method, and thus, the basis for locating boundaries between units is unclear.



Figure 8. Variation in surface soil redness, Taylor's Wines, Auburn.

- choose a row orientation which matched the dominant slope of the land, such that rows run up the slope (not across it), at the same time as minimising short rows, tight-turn headlands and soil type variability along the row;

- ensure that headland size and slope was suitable for harvester and multi-row machinery turning; and

- result in a minimum block size of around 2.5 ha in order that block yields (whole blocks) are suitable yield for commercial vinification.

The preliminary design was generated using data provided by WJB consulting. The contour and soil units maps were the main resources used, plus regular reference to the detailed soil pit analysis. In brief, the process for the design in Figure 9 was as follows.

Beginning with the original Cabernet Sauvignon planting (blocks A and B), the decision was made that the row orientation would run parallel with the natural SE-NW waterway adjacent block C. This orientation minimised short rows and tight turns, as well as corresponded with the major slope of this area. Soil pit analysis (and local knowledge) determined that there was a major soil type difference adjacent to the Wakefield River on the northern side of the study site. This area is relatively flat, so two separate blocks (2A and 2B) were created. The row orientation for these blocks will be approx NE-SW, to maximise row length. The gap between 2A and 2B is an area which is too steep for the chosen row orientation. Divisions between blocks 2C, 2D and 2E are based on changes in soil units.

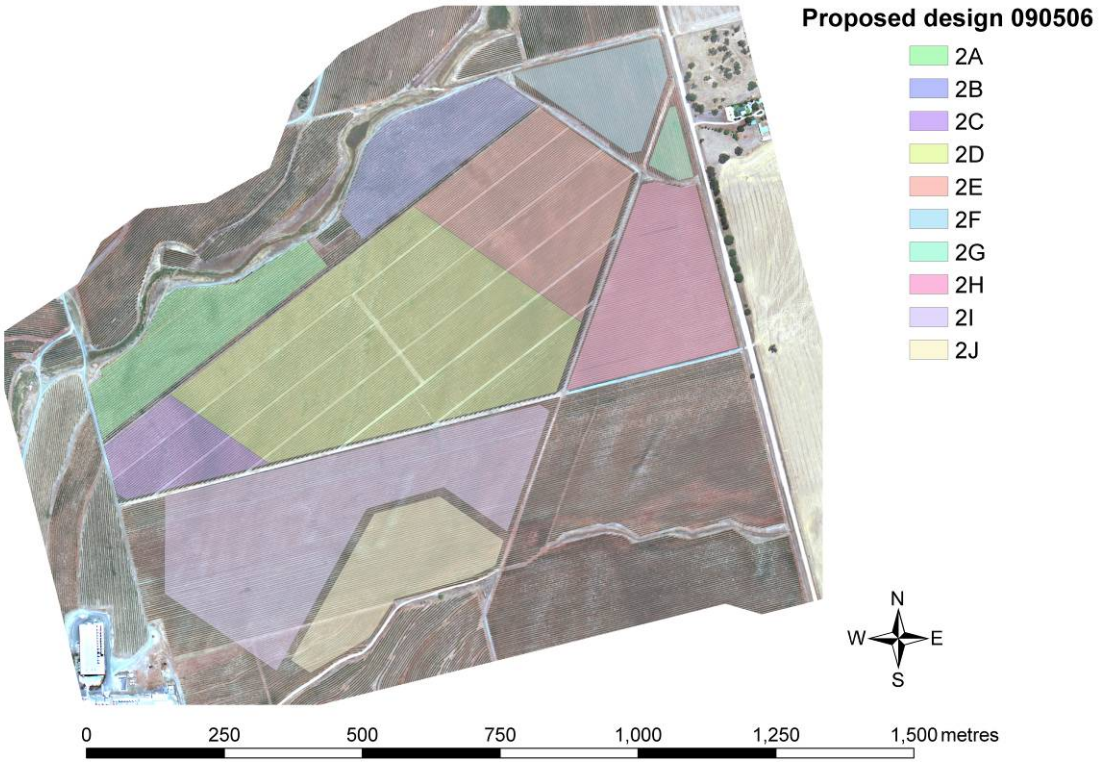


Figure 9. Proposed design for the vineyard redevelopment based on 75 m grid soil survey and contours derived from RTK GPS survey of soil pit locations. Note that this design includes an area to the south of Block F (Figure 1) which we were unaware was under consideration as part of the redevelopment when conducting our field survey and data analysis (southernmost part of 2I and 2J).

Moving to the original block F, the row orientation chosen for 2C, 2D and 2E also matches the major slope of this area. While it is not critical for these two sections to have identical row direction, this could be an advantage for some machinery operations. Due to the shape of this patch, some short rows are unavoidable. Block 2J is separated from block 2I based on a change in soil units. Additional vacant land to the south of the study area is incorporated into this plan. Block 2H is kept essentially the same as the original block D, with rows oriented approximately E-W. Block 2F will also be oriented approximately E-W, to run with the major slope. Block 2G may not be replanted, because it is a relatively small area restricted by the gas pipeline and natural waterway.

As is apparent from comparison of Figures 1 and 9, there are strong similarities between the old and proposed designs, notwithstanding the change in row orientation from across slope, to up and down slopes, which is intended, in particular, to facilitate safer operation of machinery.

D2. The PV approach

D2.1 Variation in past crop performance

A feature of the imagery and especially the yield maps shown in Figure 5 is their 'noisiness' or speckled appearance, which is in marked contrast to the majority of winegrape yield maps we have analysed previously which show much stronger spatial structure in the data. A possible explanation for this is the *Eutypa* infection in the block – one of the major drivers behind the redevelopment – given that a previous examination of variation in Eutypa infection in an Eden Valley vineyard showed no spatial structure at all (Unpublished data of Colin Hinze, formerly of Foster's Wines). Also apparent from the yield maps are a number of anthropogenic effects as evidenced from their stripiness. Whether these were due to missed spray treatments, problems with the yield monitor, irrigation differences or some other cause is unclear. However, the collective effects of the noise in the data suggested that some local smoothing may be useful. Accordingly, the maps shown in Figure 5 were smoothed using local means calculated for squares of 30 m (15 pixels x 15 pixels), equivalent to approximately 9 row widths. The resulting maps (Figure 10) have a more readily discernible spatial structure than those in

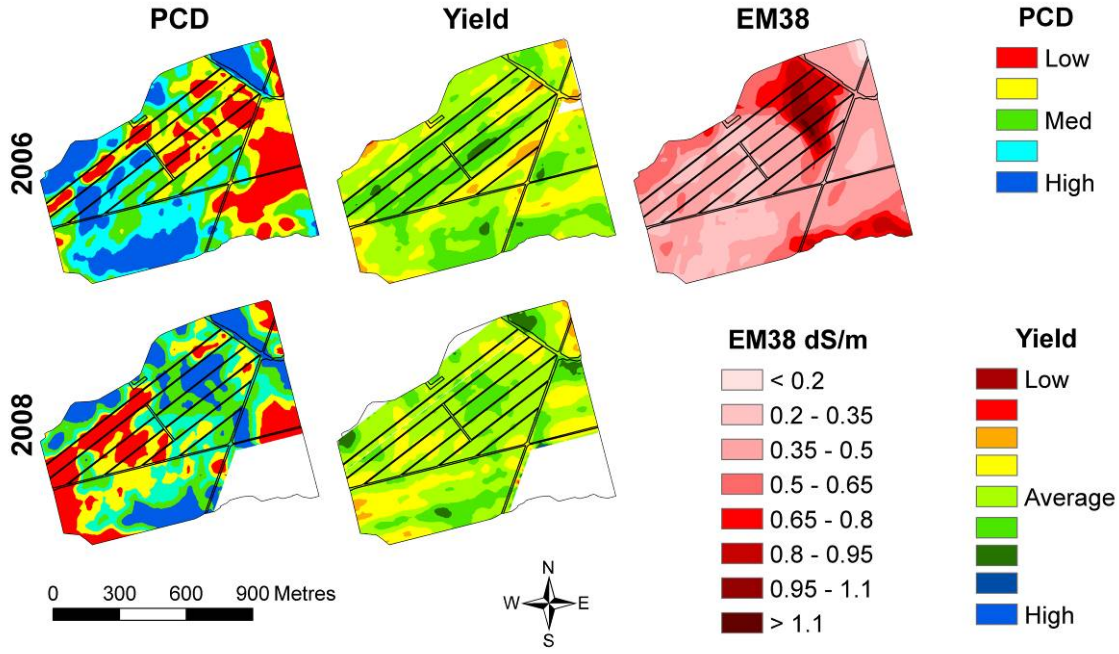


Figure 10. The results of smoothing the map layers shown in Figure 5 using local averaging over 30 m.

Figure 5 and therefore assist in understanding the nature of vineyard variation at this site, and in effect, removing the impact of *Eutypa* infection from maps intended to illustrate the effects of inherent underlying variation. Figure 10 also suggests that, whereas it is recommended that yield maps be projected onto 2 m grids (Bramley and Williams, 2001), when these are being produced for the purposes of examining variation at the property scale (ie as in this study) rather than for the purposes of managing at the sub-block scale, interpolation onto coarser grids may be appropriate. Further investigation of this issue is warranted. The utility of smoothing is also emphasised by the results of *k*-means clustering of the 2006 and 2008 map layers for PCD and yield (recall that 2007 data have been omitted from the analysis due to the effects of severe frost in that season). Thus, for example, Figures 11 and 12 show clustered PCD data (3 cluster solutions) when either the raw (Figure 5) or smoothed (Figure 10) data are clustered. As can be seen in Figure 11, whilst 3 apparently markedly contrasting clusters may be identified, there are few areas which are sufficiently spatially contiguous for targeted management to be justified. Figure 12 is in marked contrast to this. It should be noted however, that the cluster means for the two years are somewhat different after smoothing. As would be expected, the 'lows' are not as low after smoothing as before, and the 'highs' are not as high. One consequence of this is that vigour in 2006 is not seen to be different between the low and medium zones derived from smoothed data.

With respect to management decision making, one could reasonably argue that a result such as Figure 12 could promote the wrong management decision being made. However, as has often been stated (eg Proffitt et al., 2006), remotely sensed imagery *must* be ground-truthed before being used as the basis for decision making. On the other hand, Figures 11 and 12 highlight the fact that management zones are *not* uniform – something which it is essential for PV practitioners to remember. They are, however, less variable than the block as a whole, as both Figures 11 and 12 illustrate when compared to both Figures 5 and 10. Nevertheless, it should also be remembered that our objective here is to bring useful information to bear on the design of a vineyard that may be expected to have a life of 30 years or more, and the vagaries of vineyard performance in one or two years are arguably of minor

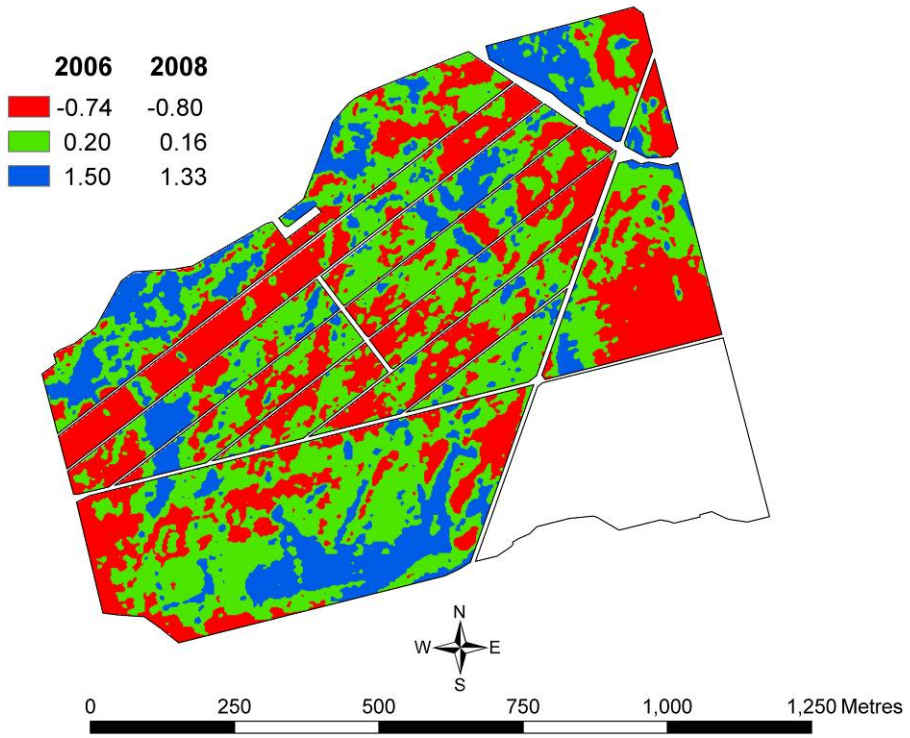


Figure 11. Identification of vigour zones by *k*-means clustering of PCD imagery obtained at veraison in 2006 and 2008 (50 cm imagery filtered to 2 m pixels).

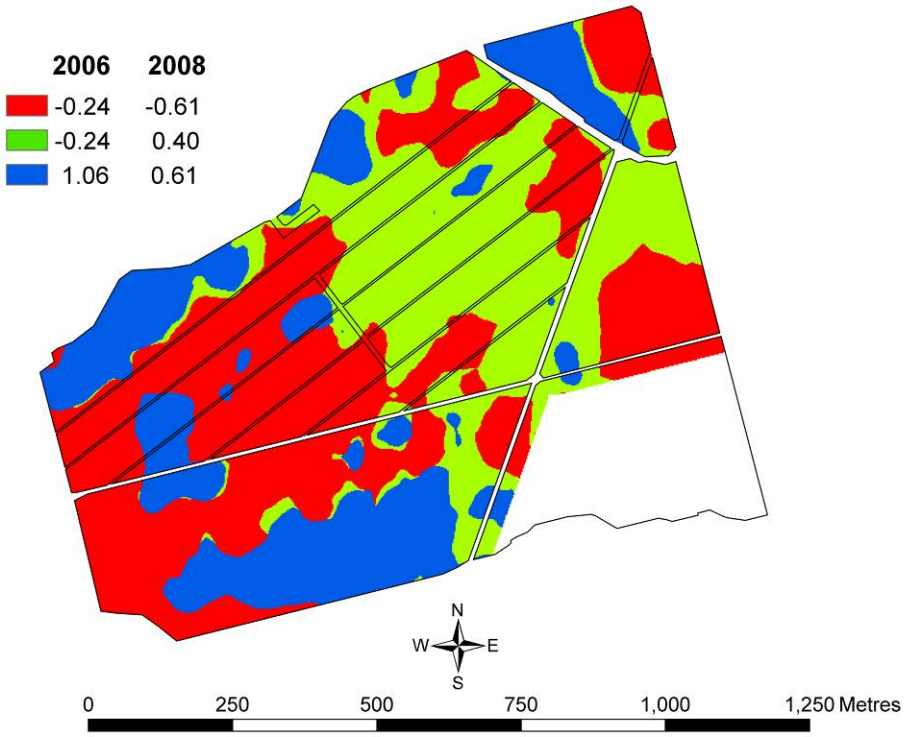


Figure 12. Identification of vigour zones by *k*-means clustering of PCD imagery obtained at veraison in 2006 and 2008. In this instance, the imagery (2 m pixels) has been further smoothed using local moving averaging on a 15 x 15 pixel (30 m x 30 m) basis.

importance compared to long term trends. Of course, in an ideal situation, many years of imagery and yield maps would be available to the vineyard designer, and it should therefore be remembered that a part of our objective here is to illustrate the approach through which such data might be brought to bear on a vineyard design problem. Furthermore, it is arguable that for optimal design, these data need integration with other data describing variation in the soils and land underlying the vineyard (see below).

D2.2 Soil and topographic variation

The results of the EM38 soil survey are shown in Figures 5 and 6; a smoothed version of the map is shown in Figure 10. These maps are characterised by an area to the NE of Blocks A and B with quite high apparent electrical conductivity (EC_a), areas of moderate to high EC_a along the creek banks, and a generally narrower range of variation in EC_a over the remainder of the site; a rough rule of thumb is that in non-clayey soils, EC_a values greater than about 0.6-0.7 dS/m may indicate salinity. However, a striking feature throughout the non-smoothed map is the short-range 'striping' in a SW-NE direction. This is a feature which we have not seen before in EM38 maps in vineyards, including in the Clare Valley (eg Bramley, 2003b). However, inspection of the regional geology map (Figure 13) indicates that the area to the NE of Auburn where the study site is located is characterised by patterns in the rocks which run in the same SW-NE direction. A feature of the geology of the Clare Valley is the presence of fractured rock aquifers; a possible explanation for the striping in the EM38 map is the formation of clay soils in and above the fractures (Dr Peter Cook, CSIRO Land and Water – pers. comm.). Verifying this was beyond the scope of this project.

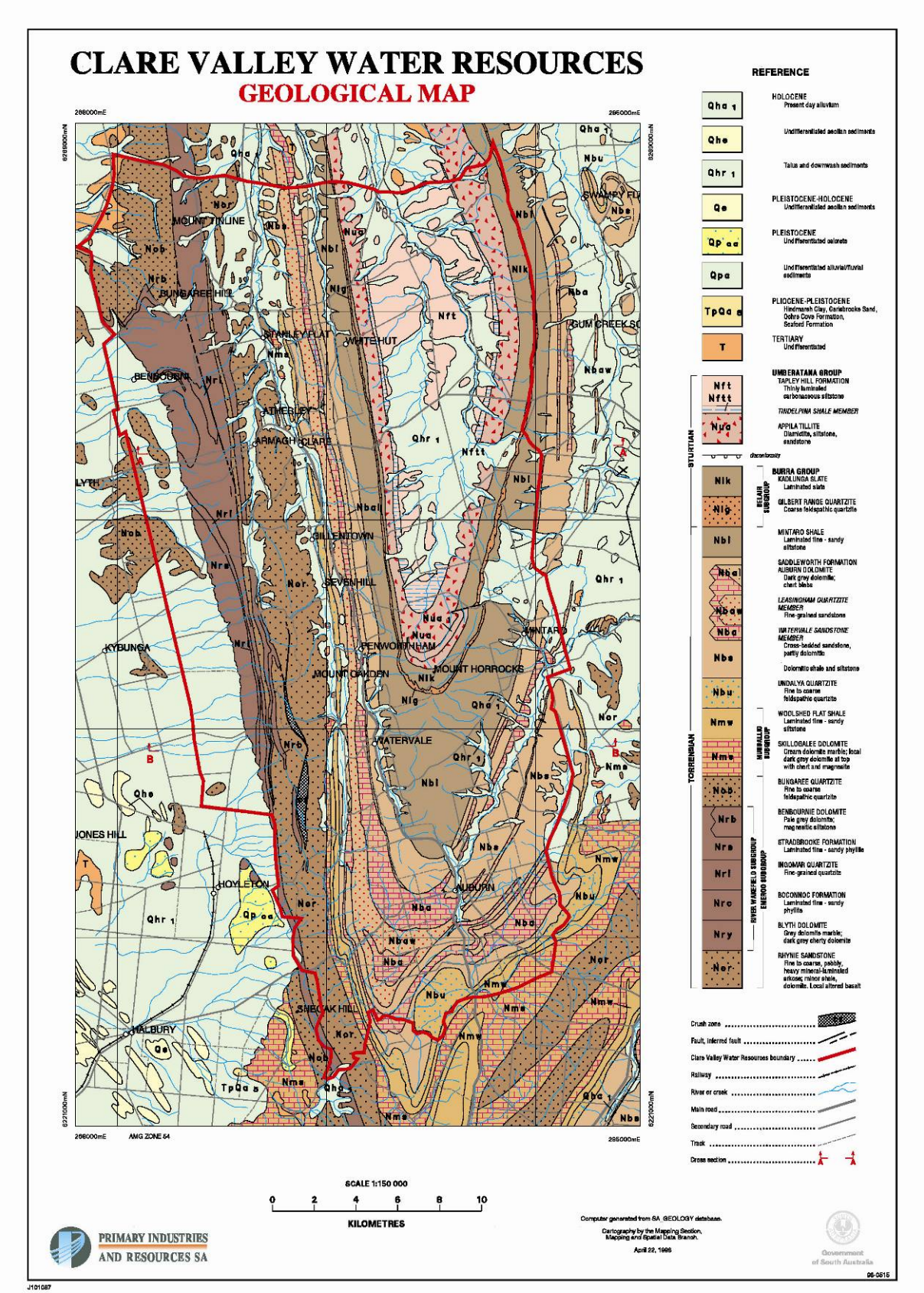


Figure 13. Geology of the Clare Valley. Note the SW-NE orientation of the geology in the area to the NE of Auburn. Data supplied by PIRSA.

The digital elevation model (DEM) of the site is shown in Figure 14. Also shown are maps of a range of topographic variables derived from the DEM using the THAL software. Of note is that the area in the NE of Blocks A and B corresponding to the zone of high EC_a (Figure 6) is an area of flattish to low slopes (hence the predominantly low values for the upslope drainage area), but one that, as a consequence of its relative flatness, is characteristically wetter than much of the rest of the study site – as evidenced by the topographic wetness index (TWI). Nevertheless, both the elevation model and the map of flow direction indicate that this area also contains a drainage line which runs from the 'ridge' dividing the southern third of the site from the remainder, down into the low lying area in the NE of Blocks A and B. Thus, when the EM38 map is draped over the DEM (Figure 15), it can be seen that whilst the area of high EC_a is predominantly located in the low-lying part of the landscape in the NE of Blocks A and B, this area also extends to the top of the slope marked by the road dividing Blocks B and F and marks the aforementioned drainage line.

The significance of the area of high EC_a as a 'wetter' zone than the remainder is highlighted when selected topographic indices are clustered along with the EM38 data. Thus, the area of high EC_a is the area of lowest slopes and highest TWI (Figure 16). Conversely, areas with the lowest EC_a occur on substantially steeper slopes and, presumably as a consequence, are drier. Note however, that many of the higher parts of the site, which also have lower slopes (they are the flattish tops of an undulating landscape) are similarly drier, but with EC_a values that are intermediate between the other zones. The NW section of Block A which is low-lying has similar characteristics to the 'tops' inasmuch that it surrounds another zone of wetness and is intermediate between this wetter area, which also has high EC_a, and the surrounding more steeply sloping land. When slope is omitted from the clustering (Figure 17), only two clusters are clearly identified, with one being characterised by high EC_a and wetter soils and the other being drier with lower EC_a. Thus, in terms of the soil property or properties being reflected by the EM38 survey, this area in the NE of Blocks A and B is quite clearly different to a major portion of the remainder of the study site.

In spite of the apparent importance of topography for soil variation (Figures 14-17), radiation and temperature modelling with SRAD indicated much less variation (Figure 18) in contrast to previously reported results from the Eden Valley (Bramley and Lamb, 2006; Bramley and Williams, 2007). Mean January temperature varied over the site by only a few tenths of a degree (this was also the case in the Eden Valley), whilst the range in season degree days was approximately 72, equivalent to about 4 days in terms of harvest date, with the uppermost areas being the coolest, as expected. (Note that in Figure 18, the range in season degree days appears less than 72 due to use of only 5 legend classes which more appropriately reflect the predominant values modelled by SRAD). However, unlike the Eden Valley study, the pattern of variation in season degree days did not closely follow the pattern in January short-wave irradiation. Comparison of the latter with aspect suggested, not surprisingly, that N and NW facing slopes received the greatest radiation whilst S and SE facing slopes received the least (Figure 18). However, the fact that neither the irradiation nor aspect map bears much resemblance to the temperature maps suggests that the slopes at this site are not great enough for aspect effects to be significant. Interestingly, the range in elevation of the Riesling block at the Eden Valley site studied by Bramley and Lamb (2006) and Bramley and Williams (2007) was similar here, although the slopes were considerably steeper.

D2.3 Calibration of EM38 data against soil analysis (wet methods and MIR)

Even when based on a subset of samples (Figure 6) for which the analysis did not appear to be adversely affected by high levels of soil carbonate, the ability of MIR to predict soil property values derived from standard wet methods was variable and not as good as would be expected for soils with a good match to those in the 'global spectral database' using for MIR prediction (Table 1). The reason for this is likely associated with the presence of carbonate in the soil - the 75 m grid survey reports refer – and also a relative paucity of data from the Clare Valley and mid-north of South Australia in the global calibration database used in the interpretation of MIR spectra (Les Janik – pers comm.). It was beyond the scope of this project to develop partial least squares calibrations specific to the Clare

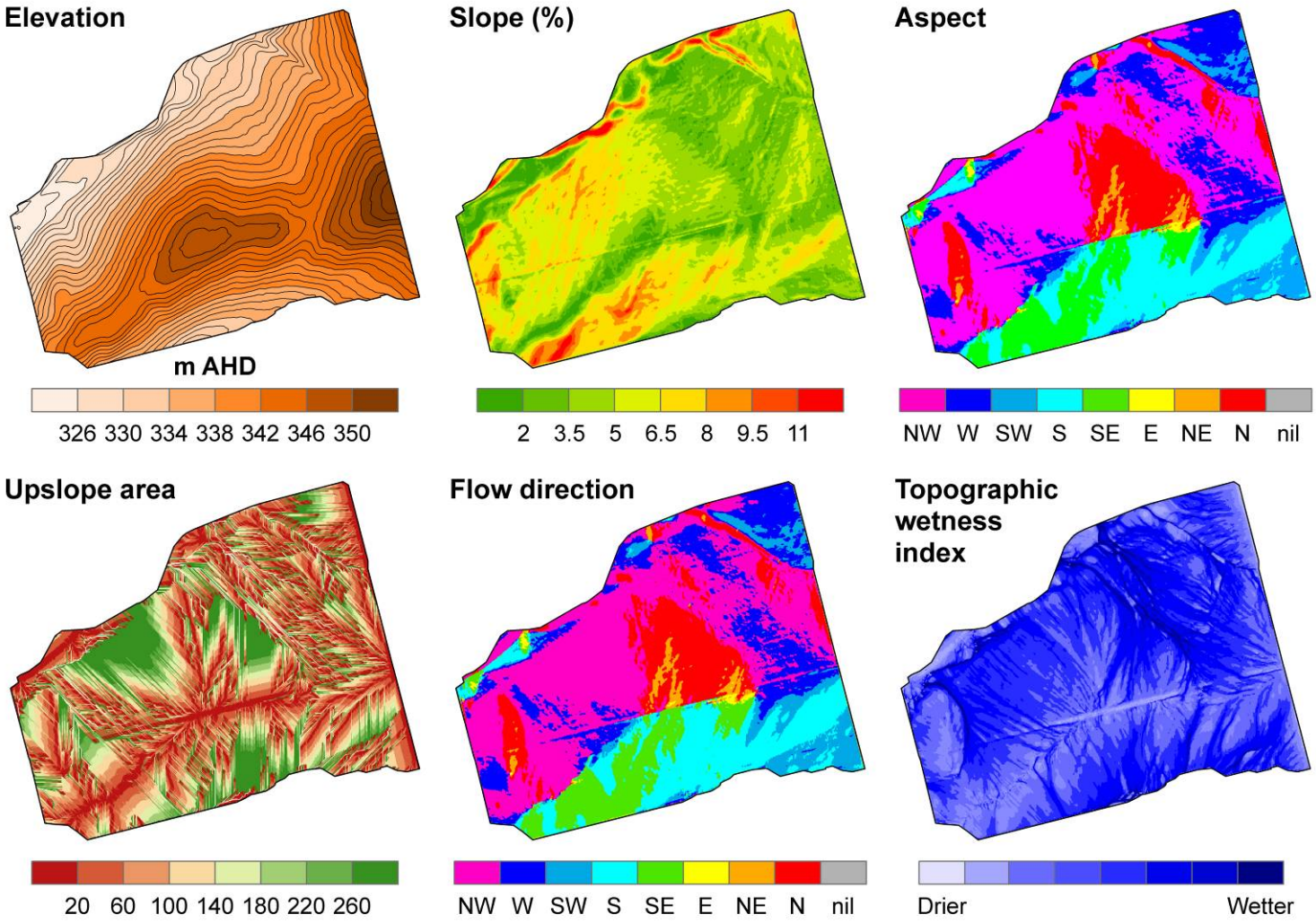


Figure 14. Topographic variation at the study site illustrated by a digital elevation model (DEM) derived from RTK GPS survey data, and a range of variables derived from the DEM using THAL. Further details and definitions of these are available in Wilson and Gallant (2000) The units of upslope area are numbers of pixels.

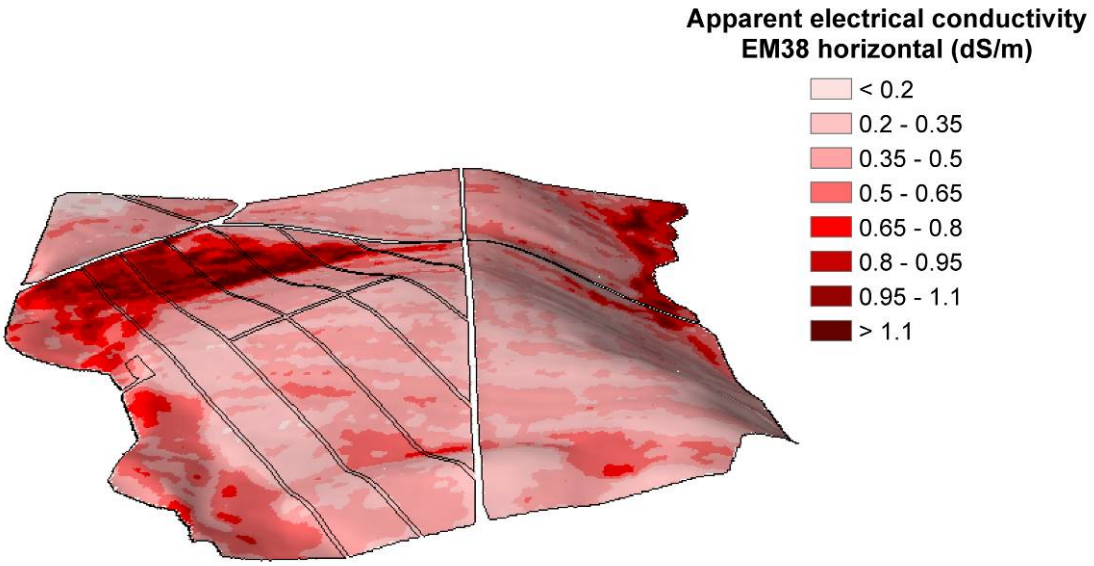


Figure 15. The EM38 soil map draped over the elevation model for the site derived from RTK GPS data. The elevation ranges between 323.7 and 352.9 m AHD with a mean of 339.1 m AHD.

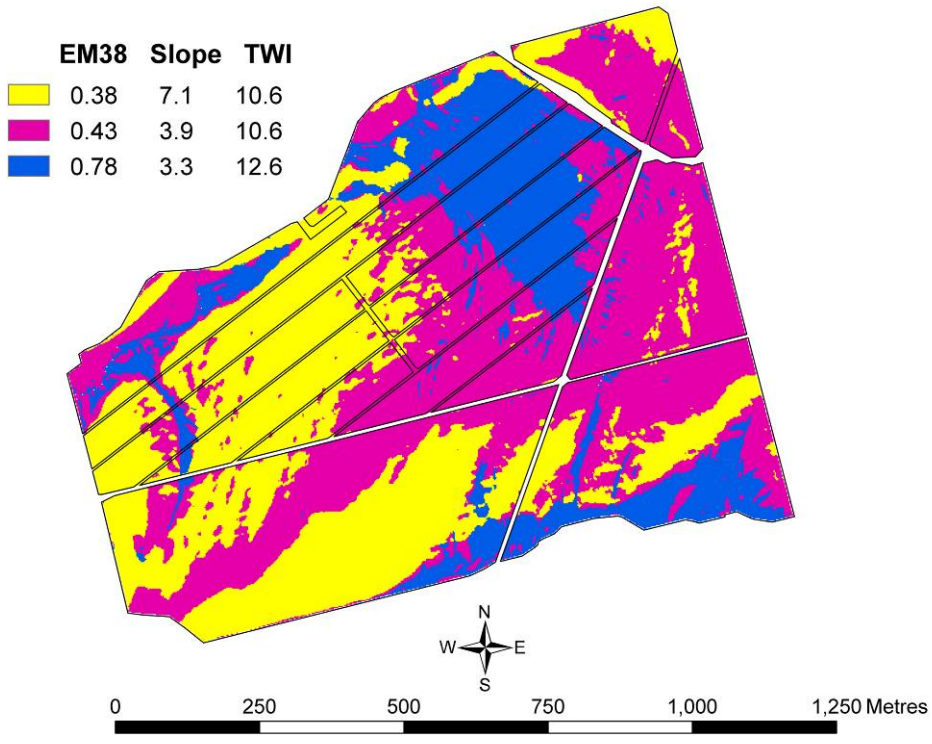


Figure 16. Zones identified on the basis of *k*-means clustering EM38, slope and topographic wetness index (3 cluster solution).

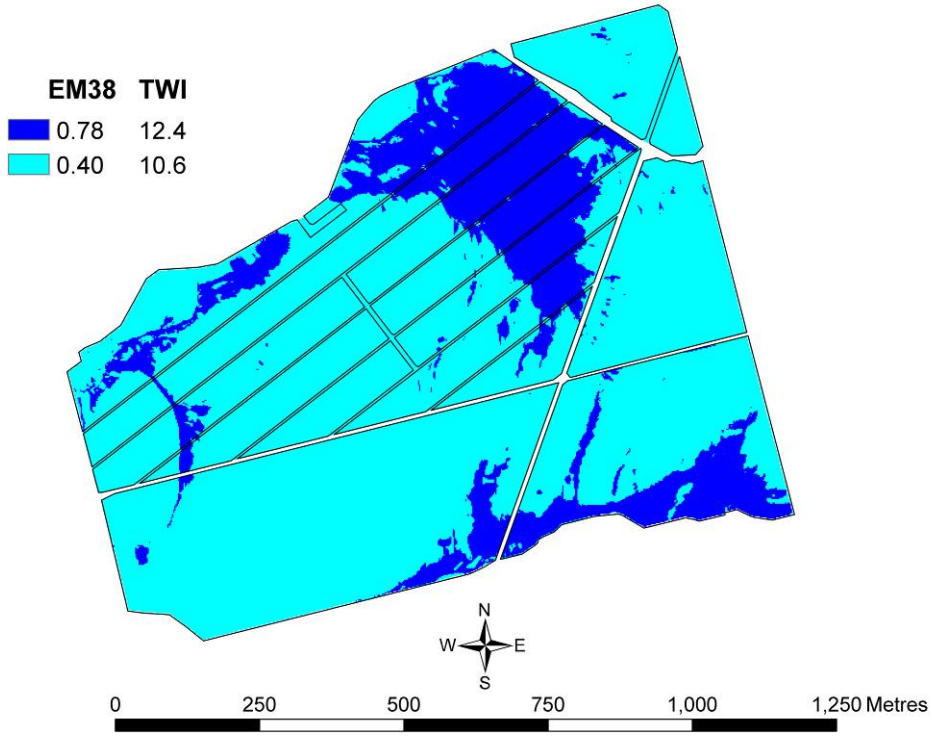


Figure 17. Zones identified on the basis of *k*-means clustering EM38 with topographic wetness index (2 cluster solution).

Valley or Taylors site, but this result highlights the need to both recognise that MIR is a surrogate method of analysis based on prediction, and also, as a consequence, that it should not be used in the absence of some checking of its performance. In other words, it should not be viewed as a replacement for standard wet methods.

It was no doubt due to the variable ability of MIR to predict soil properties (Table 1), that when EM38 values extracted from the map shown in Figure 6 were regressed against soil property values, more robust relationships were generally obtained when the 'wet method' data were used than for MIR-derived data (Table 2). Given the need to analyse at least some samples with wet methods for the purposes of calibrating the MIR data, this finding suggests that for other soil survey tasks, unless the site of interest is known to be in an area for which MIR is known to perform well, there may be no real saving in using it for the purposes of calibrating high resolution survey tools such as EM38. Here, we used the low cost of MIR analysis as the basis for collecting 53 soil cores for the purposes of interpreting the EM38 signal. However, the disappointing performance of the MIR at this site meant that we gained little advantage from its use. On the other hand, and based on the assessment of the MIR predictions provided by the spectroscopist, we did gain useful soil moisture characteristic data from the MIR which would have been expensive and time consuming to obtain using 'wet' methods. In this study, this was important given the statistically significant relationships between EM38 signals and soil moisture characteristic data (Table 2) which are most likely a reflection of varying clay content and its relationship with V% - 15 bar. Thus, MIR data make a critical input to the maps shown in Figure 19.

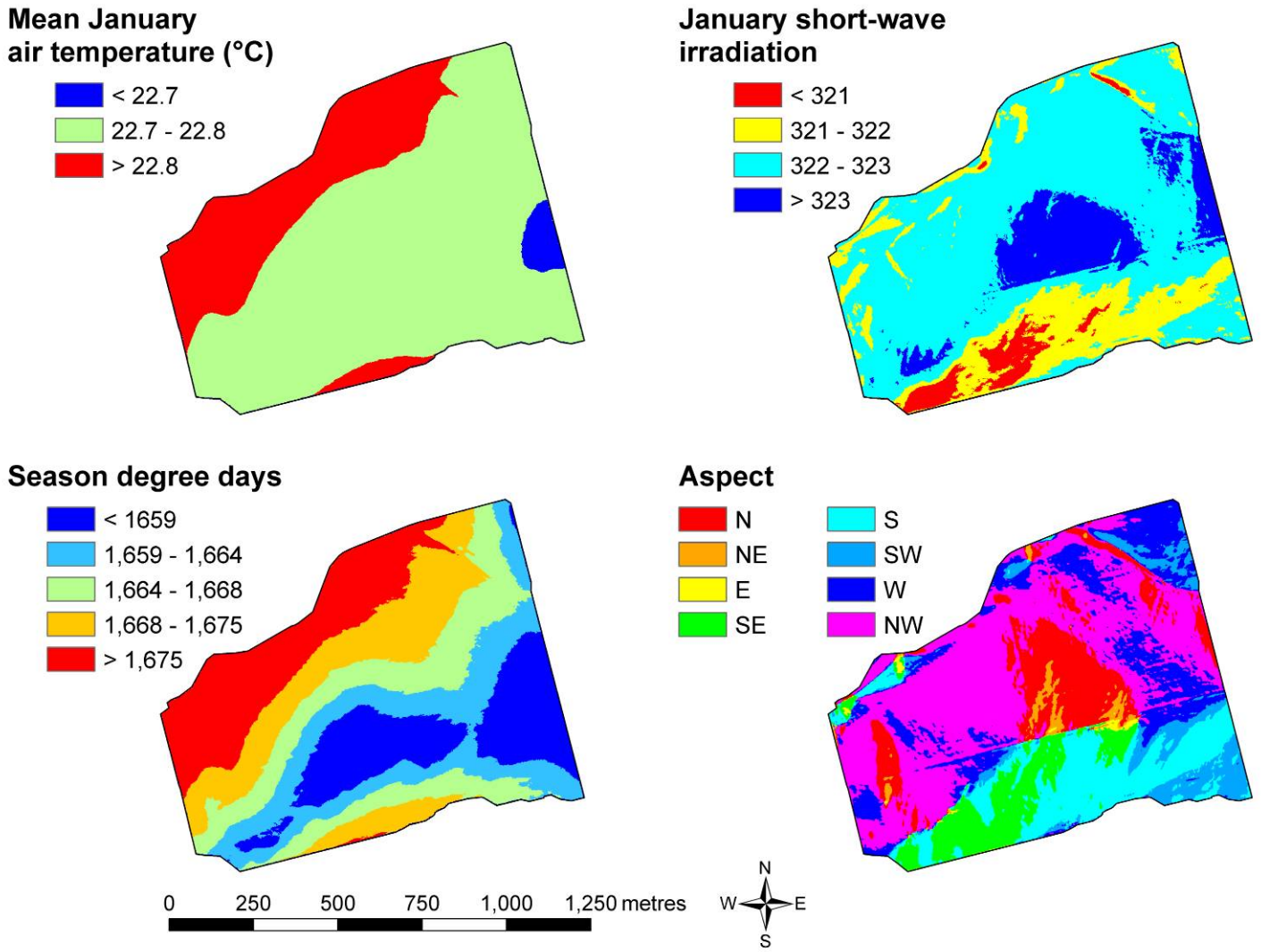


Figure 18. Variation in mean January temperature, the number of season degree days (base of 10°C), January short wave irradiation and its link to aspect.

Table 1. Calibration of MIR predictions of selected soil properties with values obtained through standard 'wet' methods using ordinary linear regression (n=20)[A].

Soil property	Significance of the regression	R^2	Expected R^2
pH (1:5 in water)	p<0.01	0.40	0.82
Total organic carbon	p<0.0001	0.98	0.93
Exchangeable-Ca	p<0.0001	0.57	0.93
Exchangeable-Mg	p<0.0001	0.82	0.80
Exchangeable-Na	p<0.001	0.51	0.72
Exchangeable-K	p<0.001	0.50	0.80
Cation exchange capacity	p<0.0001	0.98	0.95
Carbonate	p<0.0001	0.98	0.93
Clay	p<0.0001	0.86	0.98
Sand	p<0.0001	0.61	0.98

[A]Note that the data used for these regressions comprised 12 top- and 8 sub-soil samples. The expected values for R^2 are those which the spectroscopist would expect given a good match between the soils being analysed and those in the global spectral database use for MIR prediction.

Table 2. Calibration (R^2 and level of significance) of EC_a as measured with EM38 (horizontal dipole) with soil properties[B] analysed using either MIR spectroscopy or standard 'wet' methods.

Soil Property	Top-soils		Sub-soils		Top- and sub-soils	
	MIR	'Wet'	MIR	'Wet'	MIR	'Wet'
Clay (%)	0.37; p<0.05		0.78; p<0.01		0.55; p<0.0001	0.55; p<0.001
Sand (%)		0.29; p<0.05		0.70; p<0.01	0.21; p<0.05	0.49; p<0.001
CEC		0.03; ns		0.78; p<0.01	0.27; p<0.05	0.33; p<0.01
Ex-Mg		0.57; p<0.01		0.77; p<0.01	0.56; p<0.0001	0.58; p<0.0001
V% - 10 kPa	0.14; ns		0.57; p<0.05		0.33; p<0.05	
V% - 50 kPa	0.20; ns		0.64; p<0.05		0.39; p<0.01	
V% - 15 bar	0.41; p<0.05		0.83; p<0.01		0.60; p<0.0001	
n	12	12	8	8	20	20

[B]CEC denotes cation exchange capacity; V% denotes volumetric water content at either 10 kPa (field capacity), 50 kPa or 15 bar (permanent wilting point) matric suction; n denotes the number of samples used in the regression.

Somewhat unexpectedly, we found that better calibrations of MIR data with 'wet' data (Table 1) were obtained when the top- and sub-soil data were combined than when the two depth increments were treated separately. This result may reflect the shallow nature of these soils and the generally low level of soil horizon differentiation within the depth range of sampling. Also of interest was the fact that when EC_a was regressed against soil property data (Table 2), tighter relationships were obtained for subsoil data than for either topsoils or all samples combined. Thus, Figure 19 shows maps of selected soil properties predicted from relationships between EC_a (EM38) and soil data in the 35-45 cm depth range. These maps reflect the dependence at this site of EC_a on soil texture (clay content) and for this reason, the apparent predictive utility of EM38 data for indicating variation in vine water availability (readily available water; RAW) and also cation exchange capacity (CEC) and exchangeable magnesium. Note that these latter soil properties are reflective of both the soil clay content and also the dolomitic nature of the soil parent materials. Nevertheless, the overall EM38 relationships are not

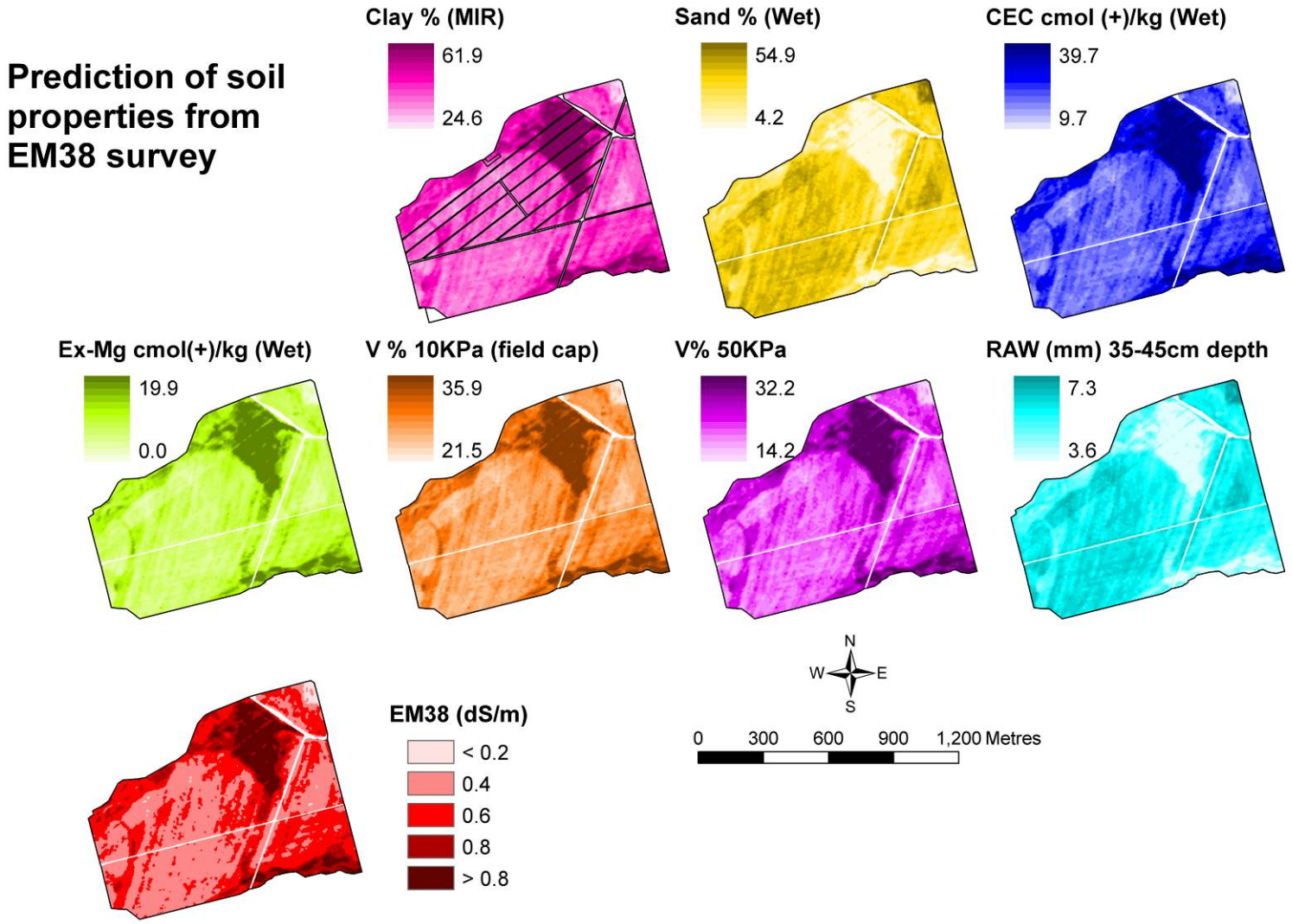


Figure 19. Using EM38 soil survey and linear regression to estimate soil properties. Note that the map of readily available water (RAW) was calculated as the difference between the 10 and 50 kPa maps, and that all other maps are simple linear transformations of the EM38 map; Table 2 gives details of the significance of the regressions used.

as strong as have been seen in other studies (eg Bramley, 2003b) which is why, at this site, we could not recommend EM38 alone as the sole high resolution basis for the new design.

D2.4 Integration of production data with the other biophysical information

Whilst inspection of Figures 5 and 10 does not suggest that the vine performance data are strongly reflective of soil variation, the relationships between the EM38 data and both topographic indices (Figures 14-17) and soil properties (Table 2; Figure 19) suggests that as in previous studies (eg Bramley and Hamilton, 2007), it is appropriate that both should be brought to bear in the delineation of management zones, or in this case, potential vineyard blocks.

Figure 20 shows zones identified on the basis of *k*-means clustering of the EM38 soil survey map with remotely sensed imagery and yield maps obtained in 2006 and 2008 – the source data layers are shown in Figure 10 (smoothed data). Note that a potential problem with this clustering approach is that each data layer is given equal weight in the clustering process ($^1/_5$ if EM38 is clustered with 2 years of yield data and 2 years of PCD imagery). Such an analysis would be biased against soils effects since the EM38 map would retain a weighting of $^1/_5$ whilst PCD and yield effectively have a weighting of $^2/_5$ each or a combined vine weighting of $^4/_5$. To combat this potential bias, simple map algebra was used to calculate mean map layers for PCD and yield on the basis that our expectation based on previous research (Bramley and Hamilton, 2004) is that, in the absence of confounding effects such as disease or frost, the patterns of variation in vine performance are stable in time. Thus, in Figure 20, EM38 has been clustered with the PCD and yield means, and therefore is given equal weight as PCD and yield.

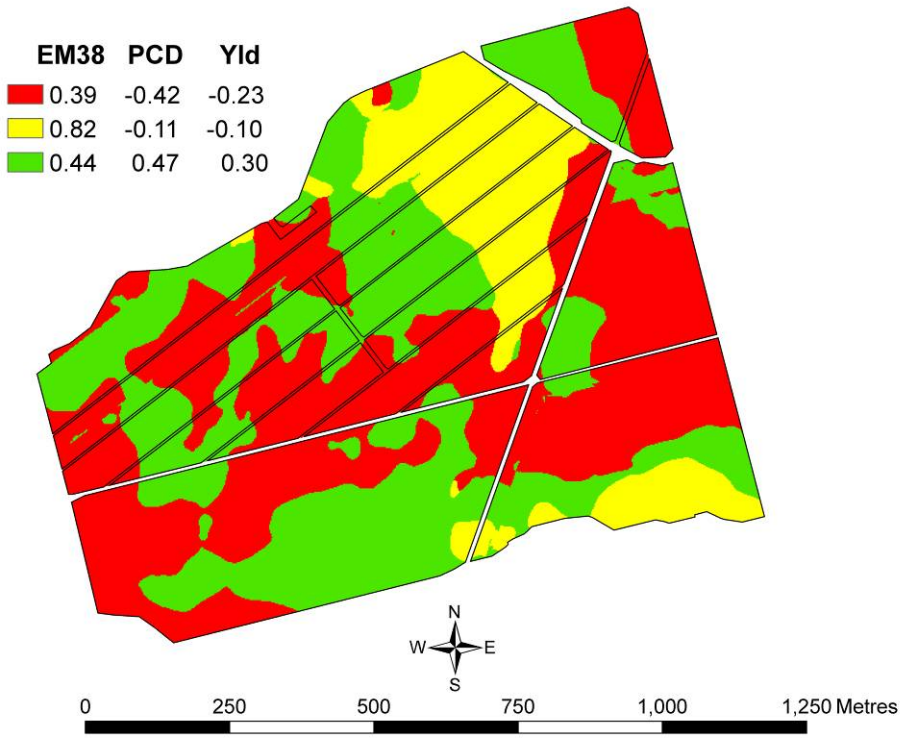


Figure 20. Zones of characteristic performance derived through *k*-means clustering of EM38 data with mean map layers for PCD and yield (2006 and 2008). Note that the PCD and yield data were normalised (μ=0, σ=1). Negative numbers therefore indicate below-average values.

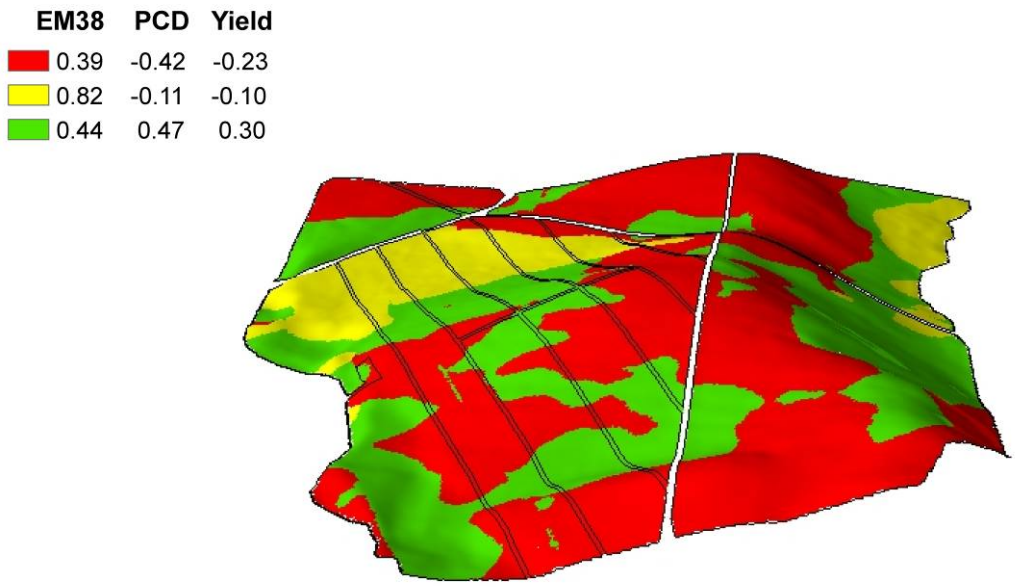


Figure 21. Zones derived from soil and vine performance data (Figure 20) draped over the DEM.

As can be seen, the area of high EC_a is characterised by vine performance (vigour and yield) that is marginally below average, whilst the zone of lowest EC_a is also the area of lowest yield and vigour. This contrasts with an area of similar EC_a in which both yield and vigour are well above average. When these data are draped over the elevation model, it can be seen that the low yielding, low EC_a zone occurs predominantly on the higher parts of the property (Figure 21). Indeed, the spatial structure in Figure 21 closely matches that of Figure 16 and clustering EM38, PCD and yield with slope and TWI (not shown) gives a result that is almost identical to Figure 21, with the high EC_a zone having lowest slopes and highest TWI, the lowest yielding zone occurring on intermediate slopes, and the highest yielding zone being on the steeper slopes and with TWI that is intermediate between that of the other zones.

D2.5 Adding value to grid survey data

Figure 22 shows the results obtained when the protocol of Taylor and Minasny (2006) is applied to the data obtained during the 75 m grid survey; variation in surface redness is also shown in Figure 22. It is important to appreciate that the *support* of these maps - 193 pits - is much less than in the case of the high resolution data (yield and EM38 maps, remotely sensed imagery), which is why these maps appear much smoother than many of the others produced in this study. Nevertheless, the power of the Taylor and Minasny (2006) protocol is seen by comparing Figure 22, and especially the two clustered maps, with Figure 7. Indeed, whilst the clustered maps shown in Figure 22 are a statistical resolution of quantitative soil property variation, as opposed to a largely qualitative, observation-based classification made by a pedologist, it is not difficult to see that the maps of rootzone clay and sand, along with the clustered maps, follow a similar spatial structure to many of the others presented in this report. Also of note is that the maps of both readily (RAW), and stressed (SAW) available water (defined as V% (10 kPa) – V% (5 bar)) suggest that the lowest yielding zones in the highest parts of the landscape (Figure 21) are characterised by low soil water holding capacity. Of interest is the fact that the map of soil surface redness makes good sense in terms of what was observed during field survey (Figure 8), with cluster analysis supporting the view that surface redness is a useful indicator of gross soil variation at this site.

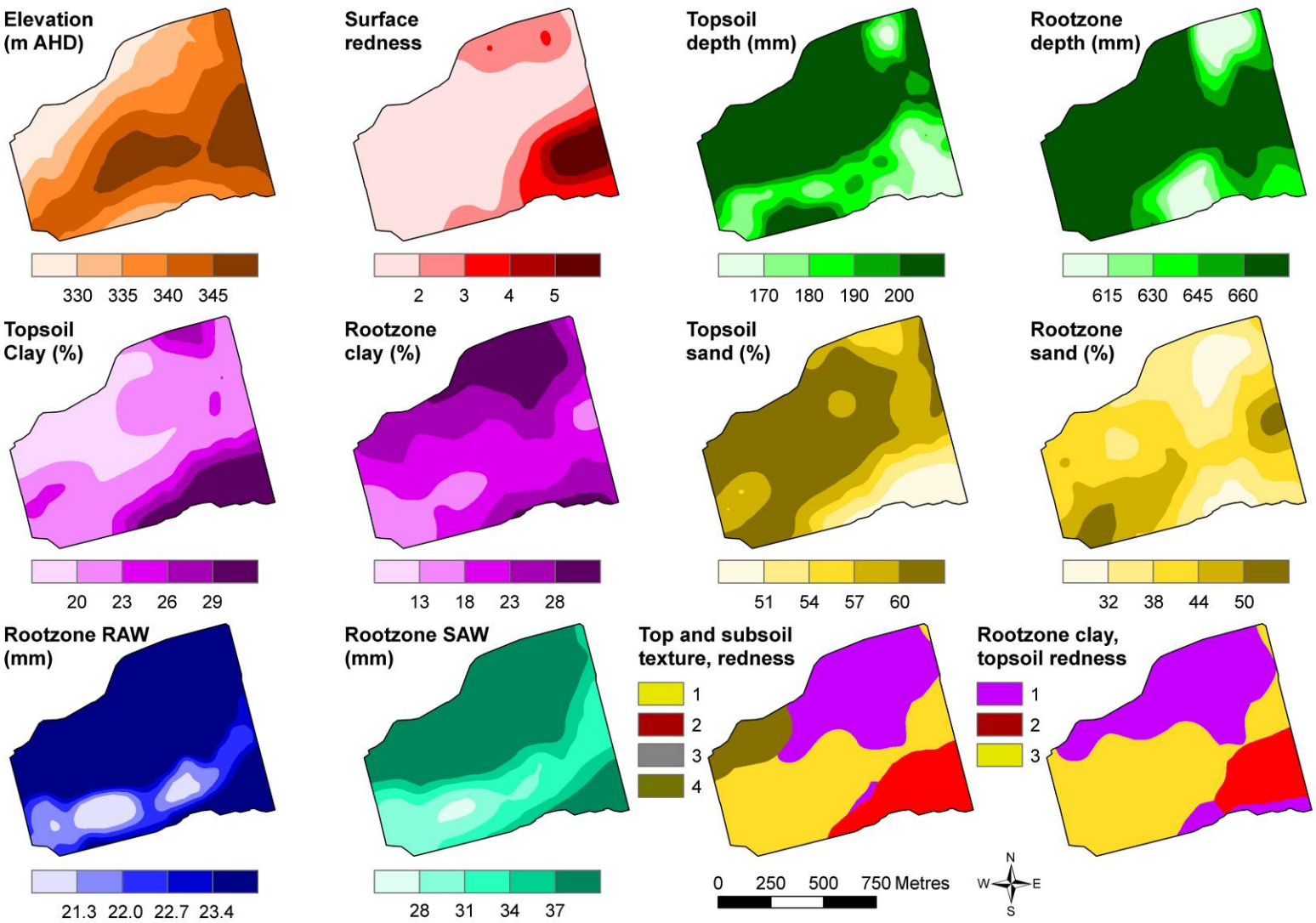


Figure 22. Soil property maps produced from application of the protocol of Taylor and Minasny (2006) to qualitative soil data collected during a soil survey conducted using conventional vineyard methods (75 m grid). Also shown are maps of surface redness, obtained following conversion of Munsell colour data using Colosol (Viscarra Rossel, 2006) and the results of *k*-means clustering selected map layers.

D2.6 A modified vineyard design based on (high resolution) spatial data

As indicated in section C1, the objectives of this project did not include production of a vineyard design based on the 'PV approach'. Rather, we were interested to see how the design drawn up by the viticulturist was impacted by the availability of (high resolution) spatial data. As noted in the frontispiece, the disposition of the viticulturist at the time of writing, along with a delay in the urgency with which a new design was needed, prevents us from presenting a modified design here. However, it is suggested that Figure 21 (and discussion thereof) could form the primary basis for a design. Of course, factors which have not been considered in this project, including particular production objectives (varieties, intended price points, availability of planting material, etc…), will also impact on the final design.

E. Conclusions and Recommendations

The present financial position of the wine industry led to GWRDC funding this project for one year only in the first instance. Whilst the project team is confident that Taylor's Wines will be able to readily convert the outputs from this project to beneficial outcomes, the ability of the broader industry to do this will depend on:

- a commitment from GWRDC and/or other funding sources to fund on-going and follow-up work which will enable an evaluation of the merits of the PV approach to vineyard design once the vineyard has reached full production; desirably, this evaluation work will also be done as the vineyard develops;

- a willingness amongst industry participants to put effort into integrating PV approaches into their management systems.

Nevertheless, on the basis of the work conducted here, we are confident that spatial data, especially that obtained at high resolution using the tools of PV, has the potential to positively improve the vineyard design process, and certainly offers a more informed basis for vineyard design than the outputs of a traditional 75 m grid survey alone. That is not to say however, that the PV approach does away with the need for the soil surveyors' skills. On the contrary, skilled interpretation of pedological variation remains an essential input to vineyard design, especially given the fact that whilst EM38 soil survey provides a high resolution picture of soil variation, in the absence of more advanced statistical analysis than that employed here, it offers the same base map irrespective of the soil property or properties that EC_a is correlated with. For this reason, it is recommended that:

- alternative tools (eg gamma radiometrics) and the integration of data from a range of such tools be evaluated with a view to providing robust predictive maps of a range of soil properties at high resolution.

- further work be undertaken to develop a framework that integrates soil survey information with the outputs of PV tools.

However, the results presented here suggest that rather than following the 75 m grid approach, it would be more effective if the locations of inspection pits were determined from the informed basis provided by such tools as yield monitors, remotely sensed imagery, high resolution soil survey and the spatial analysis of these data. Examination of this issue was beyond the scope of the present project. However, it is suggested that:

- an evaluation of the integration of the Taylor and Minasny (2006) methodology with high resolution approaches such as EM38 through techniques such as co-kriging be conducted with a view to determining how to gain the maximum benefit:cost from soil pit data.

The observation that yield maps and imagery, at the resolution recommended for investigation of within-vineyard variation, may be too detailed for its optimal use as a broader scale vineyard property design tool suggests that:

- further investigation of the optimal map resolution for vineyard design cf vineyard management would be of value.

Finally, and as mentioned above, investigation of the benefit delivered through the use of high resolution spatial data for vineyard design will be incomplete without an assessment of the utility of such approaches in reducing subsequent variability in mature, producing vineyards. Thus, it is suggested that:

- a follow up project be funded in 5-10 years time aimed at characterising production variability at the Taylor's site and partitioning this on the basis of the PV based and non-PV based designs arising from this project. Such an investigation would also need to include consideration of the benefit:cost of these two approaches to vineyard design in light of their true costs of development, and the uniformity and value of fruit parcels derived from them.

F. Acknowledgments

This work was jointly and variously funded by CSIRO Sustainable Ecosystems (CSE), Taylor's Wines and Australia's grapegrowers and winemakers through their investment body the Grape and Wine Research and Development Corporation. Support from the latter was matched by the Federal Government. The project team is grateful to all these organizations for their support.

We are also most grateful to Wendy Meech (WJB Consulting) and Desmond Elliott (Dunhess Pty Ltd) for their invaluable assistance in providing data, reports and maps derived from the 75 m grid soil survey of the study site.

Drs Kerstin Panten (JKI, Germany) and Dean Lanyon (CSE) commented on an earlier draft of this report.

G. Communication

Given the lack of a quantifiable measure of success in this work at this time, opportunities for active communication of this project with industry have been limited. However, it was discussed at one industry meeting and will be discussed at a technical meeting as follows:

Bramley, R., Hinze, C. and Gobbett, D. 2009. Towards better vineyard (re)design. 'Precision Ag and Vit Expo'. Southern Precision Agriculture Association. February 13, Keith, SA. pp. 15.

Gobbett, D., Bramley, R. and Hinze, C. 2009. Towards better vineyard redesign. Poster paper presented at the Surveying and Spatial Sciences Institute Biennial International Conference, Adelaide, 30 Sept 2009

In addition, and further to agreement with the editor of *The Australian and New Zealand Grapegrower and Winemaker*, an article on the project is currently being prepared for GWRDC's *R+D at Work* insertion to the magazine, and following submission of the supplement to this report (see note on frontispiece), we will be providing an article to *The Australian and New Zealand Grapegrower and Winemaker* describing the work more fully.

H. Intellectual Property

This project has focussed on the generation of knowledge for industry. No commercialisable IP has been generated as part of this project which has applied existing techniques to a new situation.

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J. Staff

The following staff have been engaged on this project:

CSIRO Sustainable Ecosystems – Adelaide

Dr Rob Bramley – Principal Research Scientist (0.13 FTE; funded by this project)
Mr David Gobbett – Technical Officer (0.12 FTE; funded by this project)

Taylor's Wines, Auburn

Mr Colin Hinze – Viticulturist (0.05 FTE; in-kind)

K. Budget Reconciliation

A budget reconciliation will be provided by CSIRO under separate cover.

CSL08/01 – Supplement to final report – November 2009

Next steps in Precision Viticulture – Spatial data for improved design of vineyard (re-)planting

Rob Bramley[1] and Colin Hinze[2]
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Important note: This supplement should be read in conjunction with the June 2009 Final Report to GWRDC on project CSL08/01 (Bramley et al., 2009).

Background

In our earlier report (Bramley et al., 2009), we described a process in which high resolution spatial data collected from an area of approximately 86 ha within Taylor's Wines Auburn vineyard, was used as a possible basis for the design of a major vineyard redevelopment project. We also presented the design developed using conventional sources and scales of vineyard survey data (soil pits, contours) and discussed the potential for extracting additional value from conventional 75 m grid soil survey using spatial analysis. The resulting draft design for the vineyard was presented as Figure 9 in our earlier report; it is reproduced here as Figure 23. We were prevented from presenting an alternative design derived from the high resolution data in that report; hence this supplement. Note that this revised design has been developed by the same vineyard management team as developed the original design based on conventional data.

Design Principles

The redevelopment is being undertaken with a view to a replanting of mixed varieties based on market demand and opportunity for those varieties. Taylors aim for a minimum block size of 2.5 ha so that the minimum commercially harvestable parcel is 20 t at an average yield of 8 t/ha. In addition, the key principles underpinning the design used in the Taylor's redevelopment pertained to:

- Row orientation

  Rather than a focus solely on sun orientation, row orientation in this undulating country is driven more by operational slope and potential row length. Taylor's prefer a row orientation which runs up and down the major slope for reasons of safety for major mechanical operations, and also wish to maximise row lengths. These considerations having been accounted for, they nevertheless see some viticultural benefits of E-W rows.

- Headland locations

  Headlands require a minimum space of 10 m and are preferably located on flatter land. Taylor's preference is to match headland locations to major soil changes and/or in the case of higher resolution data, at the boundaries between zones.

- Major Soil / Zone changes

  The design seeks to minimise the occurrence of major soil or zone changes along the row, but to maximise the difference between blocks.

- Frost risk areas

  To the extent possible, the design should assist with cold air movement to minimise frost impact.

Process

Taylor's staff went through a process of looking at each figure provided in the original Final Report (Bramley et al., 2009), to see if the information presented resulted in any re-think of the preliminary design.

Little value was attached to Figure 11 (*k*-means clustering of PCD imagery from 2006 and 2008) as it was considered too patchy with few opportunities for meaningful zone delineation. This was highlighted as a problem in the original report. However, Figure 12 (as per Figure 11 but smoothed on a 30 m x 30 m basis) was seen to suggest some changes assuming the proposed row directions were retained. In particular, Figure 12 suggests a zone split in block D (Figure 23) and the consequent need to move the D/E boundary to the north-east, to divide B along a continuation of this boundary and merge the two halves with D and E. A zone split is also suggested in block H whilst block J could potentially be extended to the west. Figure 12 provides little support for the separation of blocks C and D.

The aspect map (Figure 14) was considered a little complex, but when redrawn with 4 categories (315-45° = 'north', 45-135° = 'east', 135-225° = 'south', 225-315° = 'west'), was considered a useful basis, along with the contour map (Figure 14), for assessing the proposed row orientation. The proposed row orientation of blocks C, D, E, I & J (approx. 305° = 55° W of North) was considered appropriate. It retains row alignment up and down the main slope and will result in the sun being overhead during the mid-afternoon, thus reducing fruit exposure in the heat of the day. Possible changes to the design promoted by consideration of aspect included moving the boundary between blocks I and J to the top of the slope to match the change from N and W aspects to S and E. Contrary to proposed change to the D/E boundary suggested by Figure 12 (see above), consideration of aspect suggested that the first proposed location of this boundary should be retained.

In terms of slope (Figure 14), it was noted that the steepest slope in the area being redeveloped is 16%. This does not present an issue for machinery and is less than the slope in other parts of the Taylor's property. Based on historical frost occurrence, a row orientation focussed on assisting with cold air drainage would be desirable for block B, especially if it is merged into D and E (see above).

Taylor's were unable to import the 3D version of Figure 15 into their GIS. However, examination of the 2D version (Figure 6) supports the location of the originally proposed boundary between D and E, but supports the proposed merging of B into D and E.

Figures 16 (*k*-means clustering of EM38 soil survey, slope and topographic wetness index) and 17 (*k*-means clustering of EM38 soil survey and topographic wetness index) strongly support the proposed delineation of block E, but with block B merged with it. These layers also identify an area (~ 1 ha) of potential concern in the SE corner of J (salinity).

The information provided by Figure 18 (temperature variation derived from the SRAD model) was not considered useful as the range in values was very small.

Finally, Figure 20 (*k*-means clustering of EM38 soil survey with yield maps and imagery for 2006 and 2008) again provided support for the existing D/E boundary and the inclusion of B into D/E, and the shift of the I/J boundary to the west.

Results

As a consequence of the data evaluation described above, Taylor's decided (Figure 24) to:

- Remove block B and merge it into D & E.
- Retain the originally proposed D/E boundary. The zone split within D identified in Figure 12 is not supported by the other maps. However, it was noted that the proposed row orientation was well matched to alignment of the zone split which will enable differential management if this is deemed warranted in the future.
- Retain A as a separate block, albeit with a small change to the NE boundary to align it with the rows in E. This decision is supported by variation in soils (EM38), slope and the topographic wetness index (Figure 16).
- Remove the split between blocks C and D since this split is not supported by any map layer. There is a small zone identified in Figure 16 near this boundary but it is considered that the proposed row orientation will allow exploitation of any significant variation.
- Retain the proposed design for blocks F, G and H, albeit with the suggestion that F and G be merged to increase the block size.
- Modify the design for blocks I and J so that:
    - the split between them occurs on the flat area on the brow of the hill – considered good for machinery operations;
    - the W/SW boundary of I is extended to better match expectations of vigour (Figure 12);
    - the NE boundary of J is extended to approximately the 346 m contour; and
    - the NW boundary between I and J is matched to the zones identified in Figure 16.

After completing the redesign as described above, it became clear that there was a missing opportunity in block D, especially when reviewed against Fig 16. Accordingly new blocks B and C were identified (Figure 24), and the size of D reduced.

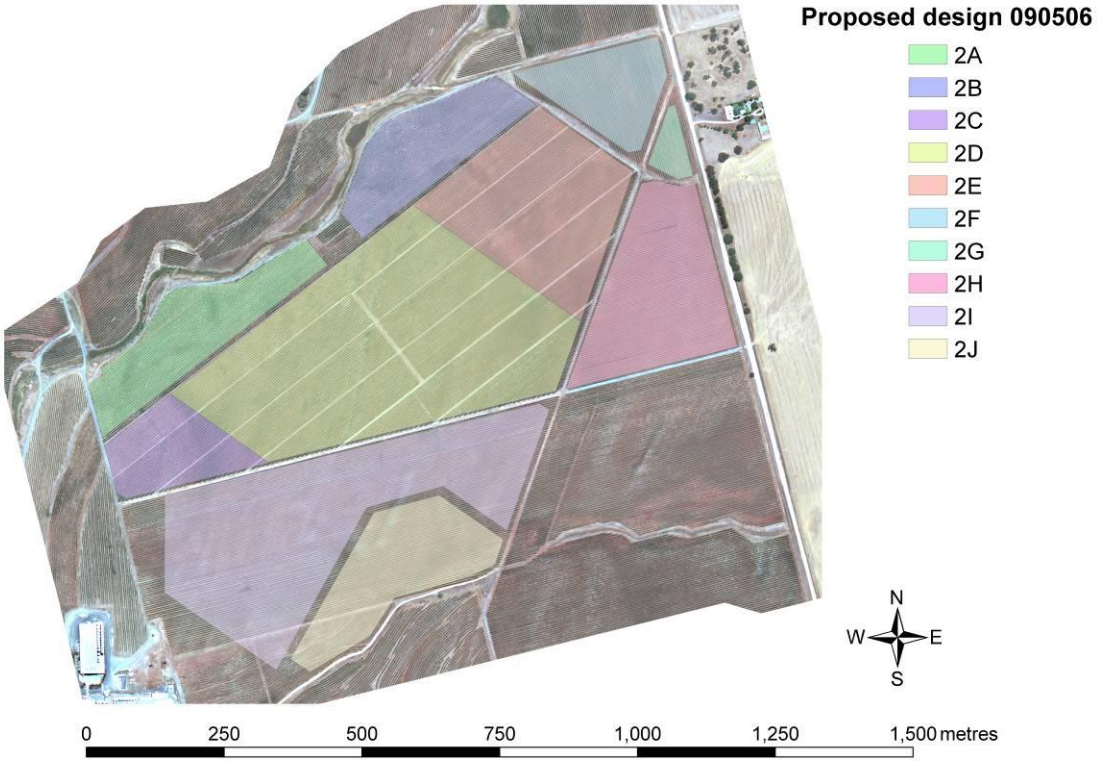


Figure 23. Proposed design for the vineyard redevelopment based on 75 m grid soil survey and contours derived from RTK GPS survey of soil pit locations. Reproduced from Figure 9 in Bramley et al. (2009).

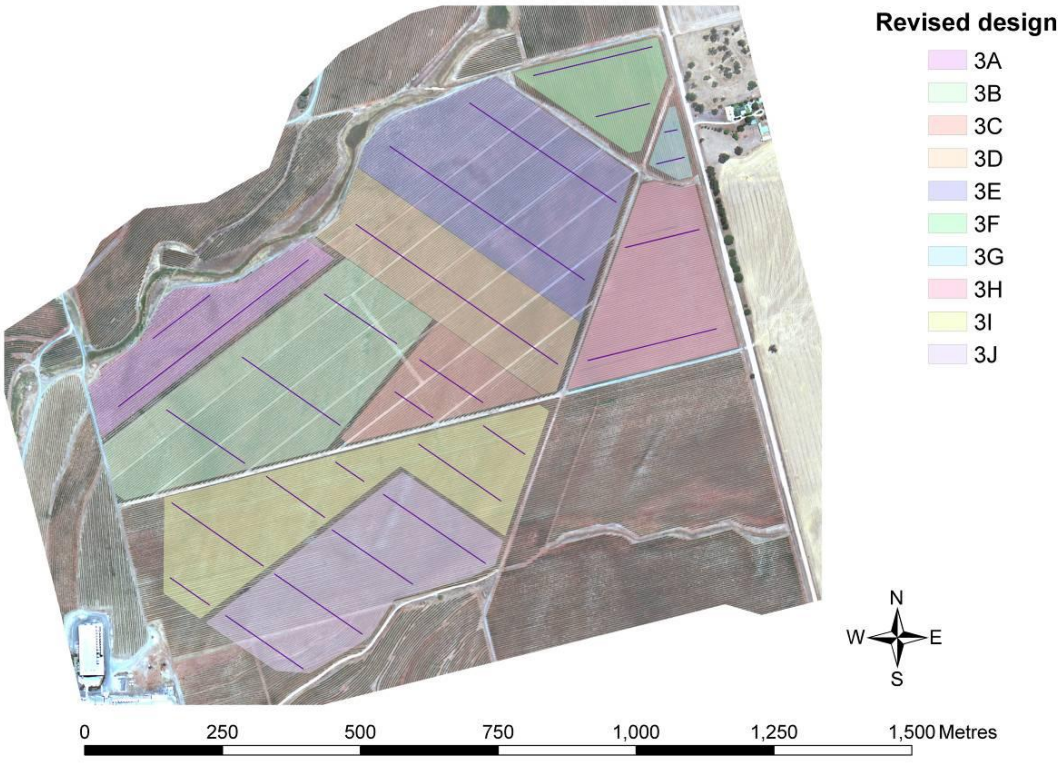


Figure 24. Revised design for the vineyard redevelopment based on analysis of high resolution spatial data collected using the tools of Precision Viticulture. Purple lines indicate the proposed row orientation; this is unchanged from the design shown in Figure 23.

Conclusions

As per our conclusions in the original final report, we believe that this analysis lends considerable weight to the notion that spatial data collected at high resolution using the tools of Precision Viticulture may make a valuable contribution to improved vineyard design. Nevertheless, and as stated previously, robust confirmation of this suggestion will depend on a follow-up analysis being conducted in 5-10 years once the replanted block is in full production. Such an analysis will need to be aimed at characterising production variability across the site, expressed as a function of the boundaries suggested in the two proposed designs (Figures 23 and 24).

Acknowledgments

The assistance of Ben Mitchell (Taylor's Wines) and Michael Wells (PCT-Ag / Precision Viticulture Australia) in this work is gratefully acknowledged.

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