Making the most of moisture in Eden Valley



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Principal Investigator: **Mark Dale**

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GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Research Organisation: **Eden Valley Wine Grape Growers Group**

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1.Abstract

The vineyards in the hilly Eden Valley district of the Barossa wine region of South Australia yield high quality wine grapes. There is higher rainfall in this area than many other districts in SE Australia but supplementary irrigation is required for four months or more during summer.

Conventional scheduling systems would indicate a requirement in the order of 2.5 to 3.0 ML/ha annually but water supplies limit most vineyards to 1 ML or less.

Monitoring of yield and irrigation from 19 vineyards over a 4 year period showed no formally significant response to annual irrigation amount although it showed that commercially acceptable yields were possible from as low as 0.5 ML/ha per year.

This project showed that Eden Valley vineyards were capable of thoroughly drying the soil profile to 1.5 metres during summer. This demonstrates the topsoil and subsoil combined could provide about 1ML/ha of moisture storage.

2.Executive summary

The Eden Valley Wine Grape Growers Group (EVWGGG) is the main representation organisation for vignerons in the district. They face common irrigation management problems in the district: constrained water supplies; imposition of regulation of those supplies and the threat into the future of less rainfall and harsher summers from climate change.

The "Making The Most of Moisture in Eden Valley" project was started in order to characterise and compare different irrigation management currently practised in the district and to introduce if necessary, modified proven best practice systems.

Mark Dale was the project manager who collated data from 19 vineyards that eight collaborating vineyard managers had volunteered for the project.

All vineyards were characterised for readily available water (RAW) storage in the topsoil and individual vineyard irrigation management recommendations were calculated. These were derived from the median vineyard topsoil RAW; the moisture holding capacity of the wetted soil envelope around each dripper and the delivery rate for the dripper.

A scheduling system for local conditions was developed based on the premise that the best use of limited irrigation water was to confine as far as possible, application to within the topsoil where the feeder roots and most nutrients occur and to minimise seepage into the underlying subsoil. The subsoil can be considered as a reservoir that is recharged annually in winter by rainfall. It supplies the moisture for the vines to keep healthy, if somewhat stressed, during summer.

Conventional irrigation management systems usually ignore most of the subsoil as there are few easily observable roots and often the lower subsoil is an inhospitable environment for roots. In Eden Valley there is compelling evidence from project findings that the subsoil is not necessarily hostile to vine roots. In this district where irrigation is supplementary to rainfall, this part of the soil profile plays an important role in the annual water budget of vineyards.

The project initially was planned for a year but funding was found from various sources to continue the project to a fourth and final year. Analyses of all four years' irrigation. amount showed no formally significant trend of yield increase with total irrigation applied.

Overall, the project has shown that in water short Eden Valley, it is possible to raise commercially acceptable crops of wine grapes with what would be considered sub-optimal irrigation amounts (often about 20% of normally recommended). Furthermore some vineyards that suffered drastic reductions in water supply from empty dams or from pump failure were resilient enough to continue to yield satisfactorily for at least that season.

Core sampling of vineyards showed that in many instances the subsoil extended beyond 1.5 m depth. Equipping some of those sample sites with soil moisture sensors showed that vines were capable of drying the profile to at least that depth. This demonstrates that many vines in Eden Valley have about 1 ML/ha stored in the soil profile at the end of winter to help carry them through summer.

The project has revealed hitherto unsuspected irrigation induced changes to soil structure in the wetted envelope of dripper moistened soil. Further work is needed to determine the severity of the problem and whether it is in equilibrium or likely to worsen significantly. It has raised questions about the project recommendations for irrigation scheduling. These recommendations often entail more frequent lighter applications than the norm in the district and possibly make soils more prone to irrigation induced change. The high salt content of some irrigation sources are a more likely influence on soil structure than frequent irrigations derived from this project's irrigation scheduling recommendations.

3.Background

The hilly Eden Valley wine grape district is in the Barossa wine region of South Australia. There is usually sufficient winter and spring rainfall to recharge vineyard soil profiles and provide sufficient moisture for some time after the vines have produced new foliage. According to conventional scheduling models for restricted yield of premium wine grapes, Eden Valley vineyards would require supplementary irrigation in the order of 2.5 to 3.0 ML/ha.

Eden Valley vineyards have limited supplies of irrigation water. In practice most vineyard managers apply between 0.5 ML/ha and 1.0 ML/ha yet raise commercially acceptable crops of premium wine grapes. These irrigation amounts are too low for conventional irrigation scheduling systems. Accordingly individual property managers have developed their own irrigation management strategies.

The project has twofold aims, firstly to compare irrigation management to determine if any physical and management combinations are more successful than others and secondly to make recommendations incorporating the basic principals of soil characteristics and irrigation management used in conventional scheduling models.

The "Making The Most of Moisture in Eden Valley" project comprises 19 vineyards spread over 8 properties. Each vineyard was monitored by the vineyard manager for rainfall, individual irrigations and for tonnage of fresh grape yield at harvest. Mark Dale characterised topsoils by a grid survey of topsoil depth and predominant topsoil texture. He also measured lateral wetting from drippers and derived a median wetted volume to provide a limit of total litres per dripper at each irrigation. This figure was individual to each vineyard.

4.Project Aims and Performance Targets

A total of 19 vineyards were compared annually for irrigation management and yield. One aim was to identify any existing benefits from inherent vineyard differences and from the different irrigation regimes applied by managers. The other aim was to recommend some

modification of irrigation management based on the vineyard soil characteristics that affected moisture storage.

These modifications were made on the premise that the best use of limited irrigation was to confine applications of water to the topsoil where most nutrients and feeder roots occur. The vines could rely on stored moisture from rainfall in the subsoil for the bulk of vine moisture use during summer.

4.1 Performance Targets

Milestone 1 *Subsoil investigation and characterisation of soil RAW in 6 typical soil types within the Eden Valley, which includes the collection of key irrigation and vine growth data in the 2007/08 growing season.*

Date: *March 31st 2008* ***Amount:*** *$7,000*

The characteristics of the subsoil moisture reservoir were unknown in the project vineyards. It was possible to extend the range of sampling beyond the six soil types. A truck mounted soil core sampler was hired and all but one of the vineyards were sampled at five separate trellis panels. Each core was divided into zones and a sample taken of each zone and then assessed for texture and moisture holding capacity.

In each case, the core from one panel from each vineyard, in its sample box for display, was given to the vineyard manager.

The six Riesling vineyards in the study had cane number counted in the same five panels for comparison with the topsoil RAW recorded for that panel.

Milestone 2 *Analysis of results by Mark Dale, with other technical input from Mike McCarthy.*

Date: *October 31st 2008* ***Amount:*** *$3000*

Topsoil characteristics, irrigation, rainfall and the yield from the first two seasons (06/07 and 07/08) were compared and analysed by a biometrician. The results for 08/09 were collated and summarised in other reports. This report includes the analyses of all four seasons.

Dr Mike McCarthy raised the risk of soil sodicity arising from Mark Dale's recommendations. These recommendations lead to frequent irrigations in vineyards with shallow soils. The Barossa valley experience is that many small, frequent, irrigations are associated with salt accumulation and sodicity. Leaching of any salt accumulated during summer would only be leached by winter rains.

Consequently vineyards were sampled in the soil zone most likely to be affected and the samples subjected to a simple test for sodicity. Subsequently opinion was sought from Dr Robert Murray an acknowledged specialist in salinity and sodic soils.

Milestone 3 *Running costs for two "Making the most of moisture in the Eden Valley demonstration / field days.*

Date: *March and October (TBC) in 2008* ***Amount:*** *$3000*

Farm walks were held in October '08, November '09 and December '10. These annual events in Eden Valley were mostly but not entirely concerned with reporting of results from this project.

In addition, Mark Dale regularly made progress reports to EVWGGG meetings. On a number of occasions these were open to the public for a formal presentation of results and progress.

Milestone 4 *Preparation and printing of final report and technical article*

Date: *February 2009* ***Amount:*** *$2000*

This technical report covering all 4 seasons is due by 30th Sept 2010 by negotiation with GWRDC. A technical article will be prepared following acceptance of the report and will be submitted for publication in an industry journal.

4.2 Changes to original targets

When the request for funding was originally lodged it was expected that the project would end with results from 2007/08. As it happened, both GWRDC and state NRM approved funding for that year and so it was agreed by GWRDC that the combined funds be used to extend the project for a further year. Subsequently Barossa Grape and Wine Association funded a further fourth and final year. While this has had little impact on Milestones 1 to 3, it has delayed Milestone 4 by a year.

The final report and technical article will be written and supplied to GWRDC without any further request for funds to complete the project.

5.Method

Wine grape growers in Eden Valley manage vineyards that are physically similar to vineyards throughout the Adelaide Hills. They are characterised by being grown on hillsides with shallow sandy loam topsoils. Often they occur as "islands" in the surrounding predominantly pasture and open woodland. The earliest vineyards relied solely on rainfall but the expansion of vineyards on to shallower hillside soils and the need for consistent wine grape yield and quality, led to universal adoption of irrigation. All vineyard irrigation in the district is by drip irrigation.

Unlike other wine growing regions which were targeted for irrigation improvement with regulation, financial incentives and extension programmes to maximise water use efficiency and so minimise salinity impacts, Eden Valley received little external direction. The corporate vineyards had access to technical expertise but the owner-managers of vineyards evolved their own management systems.

Members of the EVWGGG agreed to monitor their vineyards for irrigation and yield and to record rainfall. These collaborators were all, excepting one property, owner–managers. Mark Dale undertook to characterise the vineyards for soils and irrigation wetting patterns. He then compared annual yields and results and attempted to ascribe differences to vineyard characteristics and irrigation management.

In addition Mark Dale provided irrigation management recommendations based on the same principals as conventional irrigation scheduling but modified for Eden Valley conditions.

5.1 Irrigation and rainfall

The amounts applied at each irrigation were recorded. The amount was usually estimated from nominal dripper output and hours of operation. In some instances where the manager was concerned by the fluctuating pressure from changing water source or from filter

blockage, the irrigation amount in mm was calculated from water meter readings and vineyard area.

Rainfall was usually recorded on property but in a few cases a nearby recording station was used.

5.2 Yield

The weighbridge tonnage at the receiving winery was used for vineyard yield of fresh grapes. No quality aspects were included in the study since there was no recorded quality characteristic that was common to all vineyards.

5.3 Topsoil characterisation

None of the vineyards had been surveyed by the now conventional survey of 1.5 m soil pits at a 75 m grid. A rapid topsoil survey using a soil corer was carried out on all the monitored vineyards. This method does not replace the need for a soil pit survey but it does capture the variability of the topsoil moisture store and allows an estimate of a median value for readily available water (RAW) for that vineyard. That RAW value (= the estimate of mm water the soil holds between field capacity and -60kPa tension) can be used for irrigation scheduling.

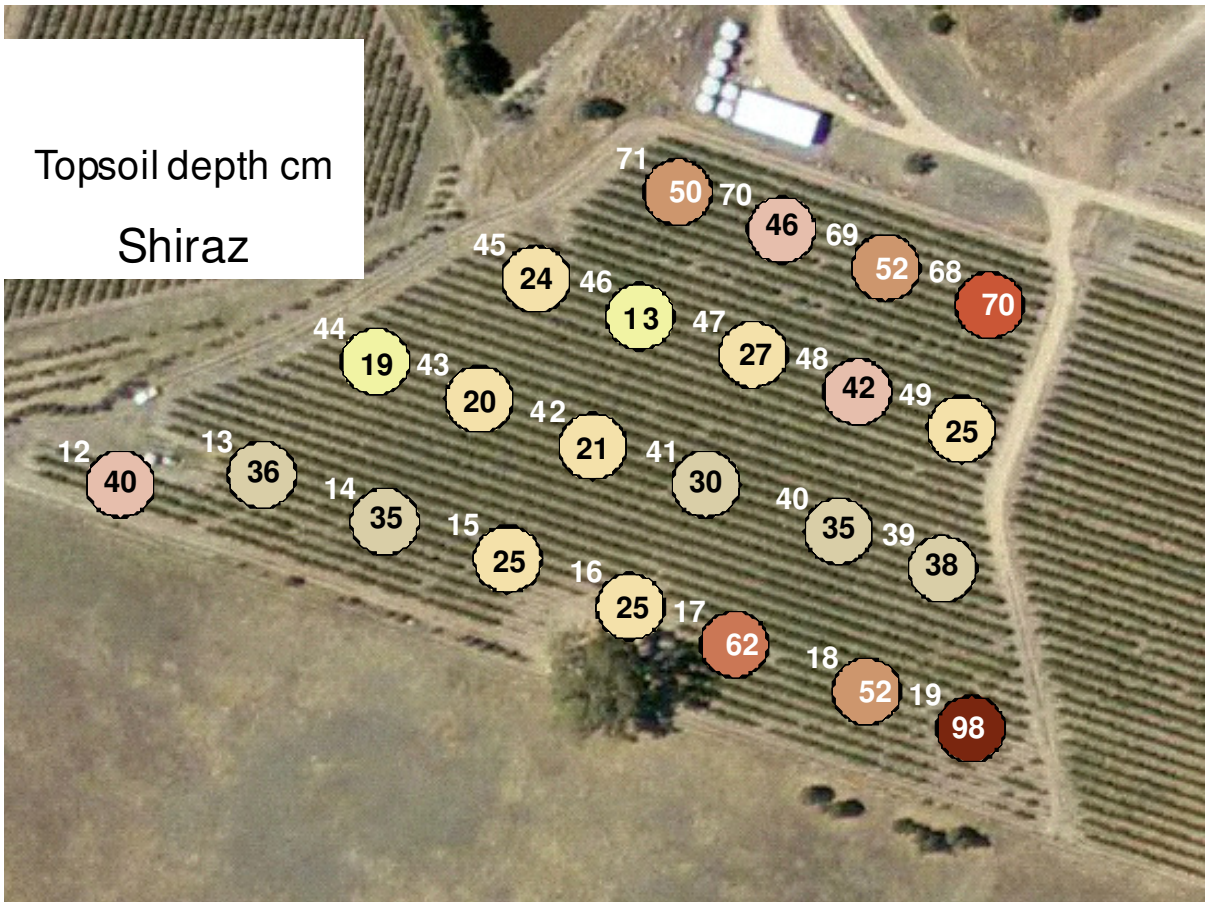


Figure 1. An example of a vineyard topsoil map compiled from a soil corer survey

The topsoil depth when combined with the water holding capacity estimate corresponding to its texture, provides a RAW figure for that sample site (Wetherby, 2002). The RAW figures for this vineyard are shown below in Figure 2.

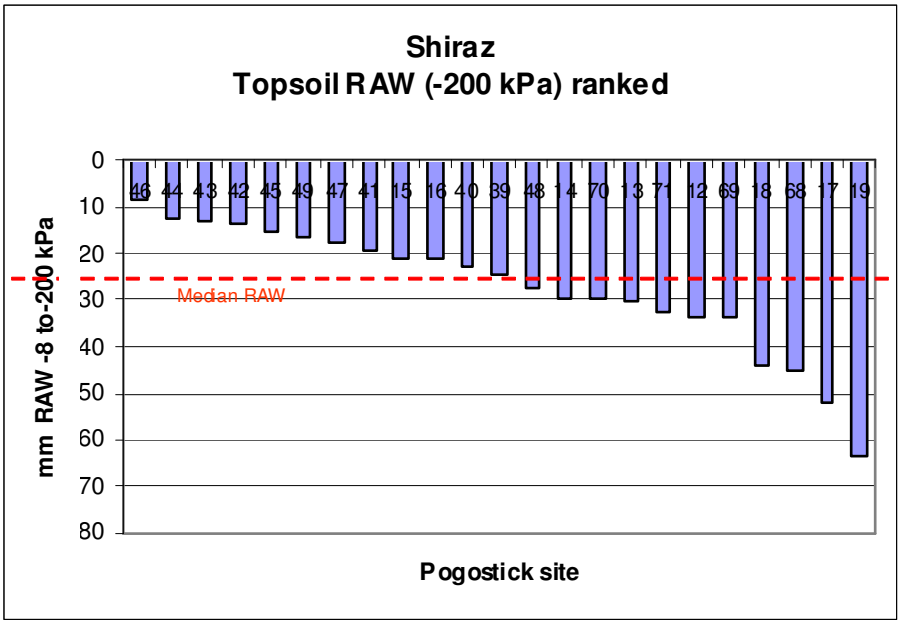


Figure 2. Topsoil RAW mm with median value indicated.

The estimation is done for each irrigation shift. The pattern needs to be regular to avoid bias. There needs to be sufficient samples to capture the topsoil variability of an irrigation shift.

Since only a proportion of the vineyard area is wetted by drippers the next step is to estimate the amount of water held in the volume of soil wetted by a dripper applying water equivalent to the median RAW. This is the amount for a single irrigation. The derivation is shown in Figure 3

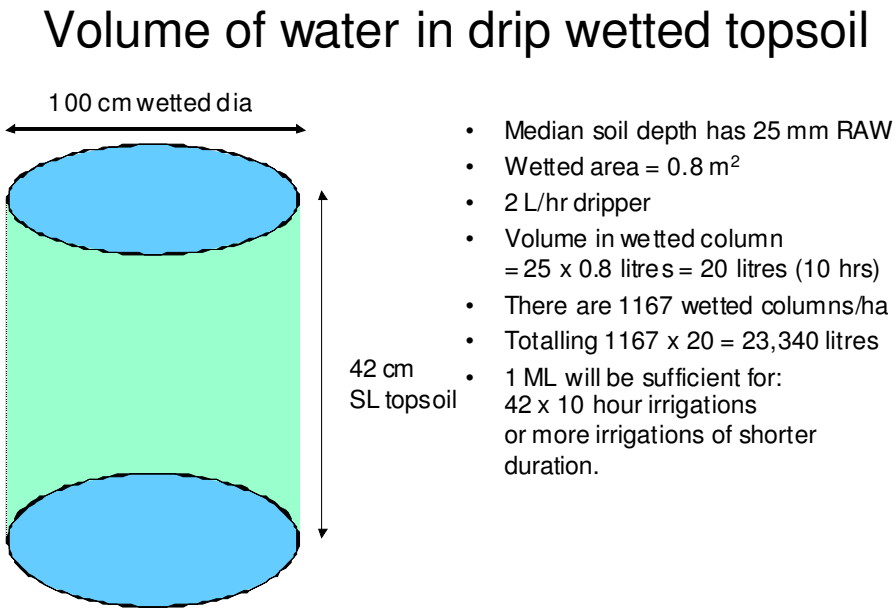


Figure 3. Irrigation application for a 42 cm deep sandy loam topsoil

A soil moisture sensor can be used to start irrigation for the season or after soaking rain. The total number of irrigations is dictated by the available supply (1ML/ha in the example in Figure 3.). The frequency of irrigation will be a series of subjective decisions by the manager. Soil moisture sensor readings, known moisture sensitive stages (e.g. flowering) and degree of evaporative demand can all play a part.

5.4 Subsoil characterisation

Since the topsoil provides limited moisture storage, the inference is that the subsoil provides the bulk of the moisture that enables the vines to thrive, even if stressed, during the summer. This is counter to the conventional wisdom which limits the rootzone to a comparatively shallow depth where roots can be seen in the face of soil pits.

In 2008 the monitored vineyards were sampled with a core sampler capable of penetrating to 3m. This provided preliminary data on the depth of subsoil and some indication on whether it bore any relation to the overlying depth of topsoil.

After core sampling seven core holes were selected and equipped with soil moisture sensors to monitor moisture changes deep in the subsoil that would confirm moisture abstraction by roots.

6. Results

6.1 Estimation of moisture deficits over 4 years

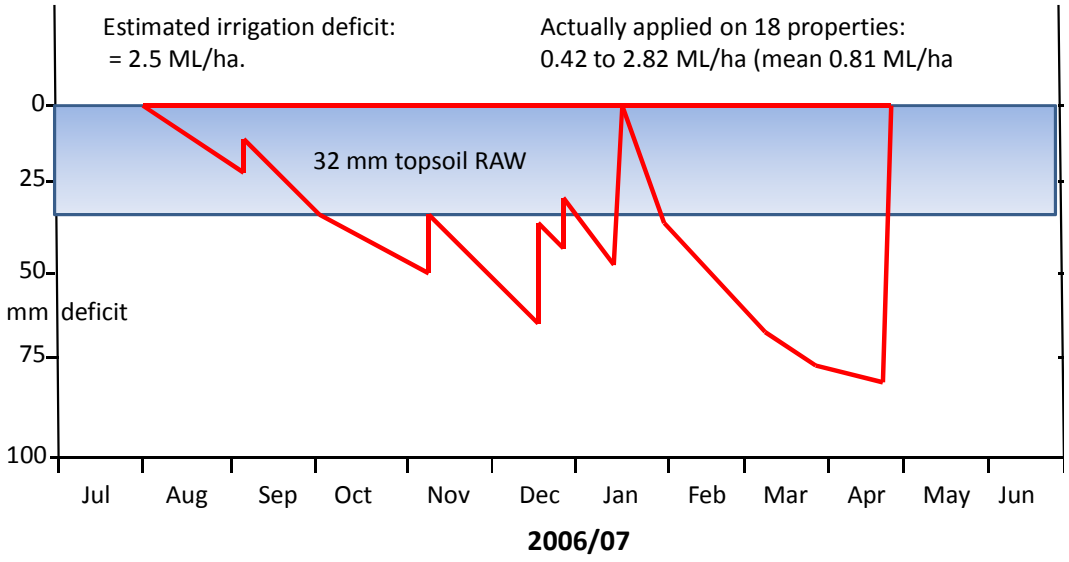
A simulation of water use by a notional vineyard where the vines can abstract moisture to depth of 1.5 m from a soil profile with the water holding characteristics of a sandy loam (SL) is shown in Figures 4(a & b) . The simulation was done with an irrigation scheduling model (Right Amount Right Time or RART) using average monthly evaporation rates and the crop factors recommended in “Annual Irrigation Requirement for Horticultural Crops” for “wine grapes (reduced yield)”. Once topsoil moisture was depleted, the rate of moisture abstraction from the subsoil was assumed to be at 40% of the crop factors. The highlighted red deficit line assumes no irrigation was applied and fluctuations are due only to rainfall as recorded at the Eden Valley General Store. The irrigation deficit is the estimated amount of drip applied irrigation required to keep the deficit within the topsoil throughout the season.

Despite the differences in the shapes of the deficit graphs, the total estimated deficit is similar for all seasons and close to the predicted irrigation requirement for Eden Valley of 2.5 ML in “Annual Irrigation Requirement for Horticultural Crops” (Irrigated Crop Management Service, 2000).

The simulation shows that in all four years there was RAW in the soil profile until well after the hottest months. This emphasises the importance of a deep subsoil as a summer moisture store. In this case it adds 0.64 ML to the water budget of the vineyard

No claim is made for the accuracy of the simulation but the four graphs provide a useful integration of weather effects to allow comparison of the different seasons.

2006/07 season



2007/08 season

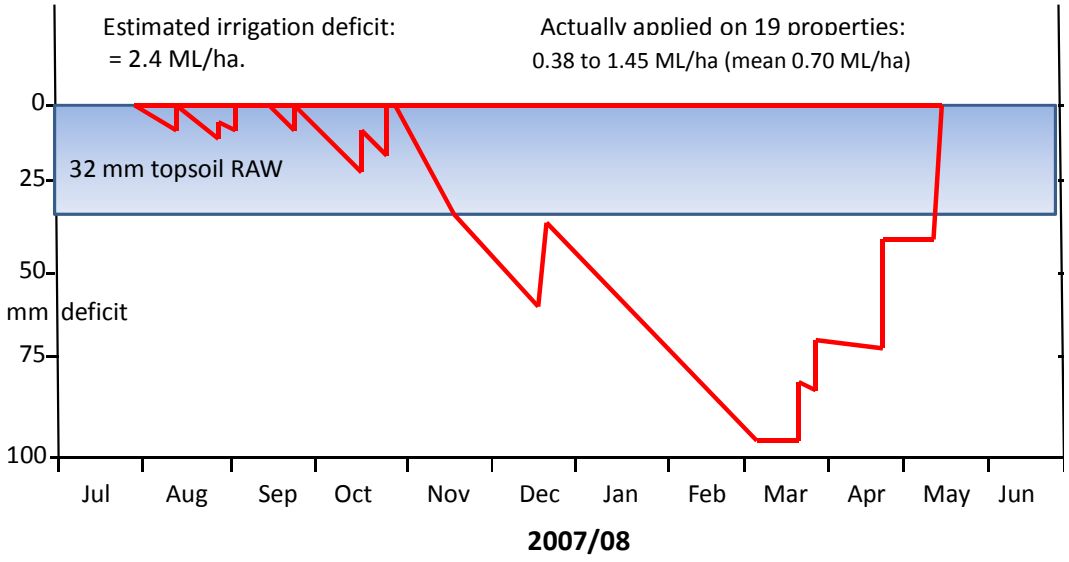
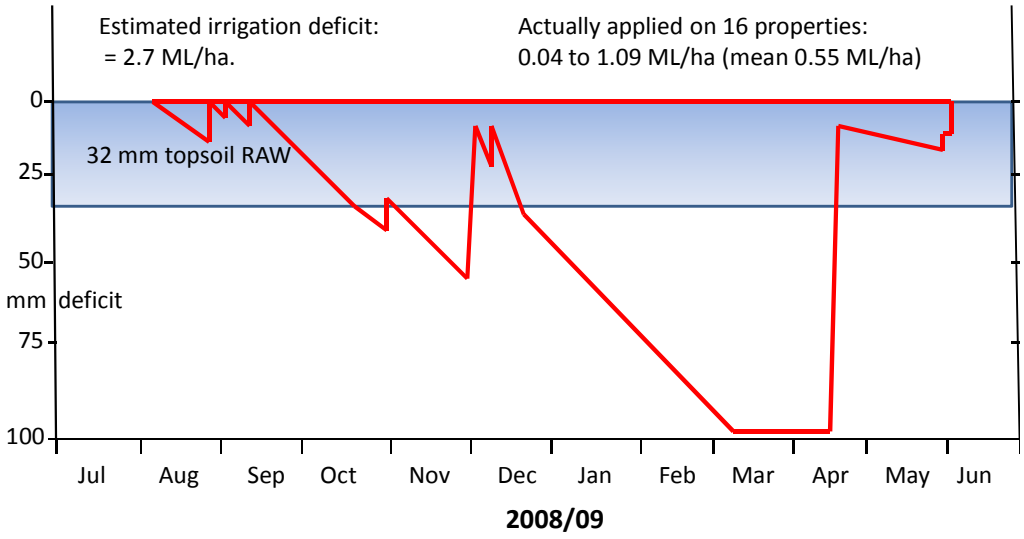


Figure 4(a). Simulation over two years (2006/07 & 2007/08) of water abstraction from an Eden Valley vineyard with a 0.5m deep sandy loam topsoil and with vine roots able to withdraw moisture to a depth of 1.5m.

2008/09 season



2009/10 season

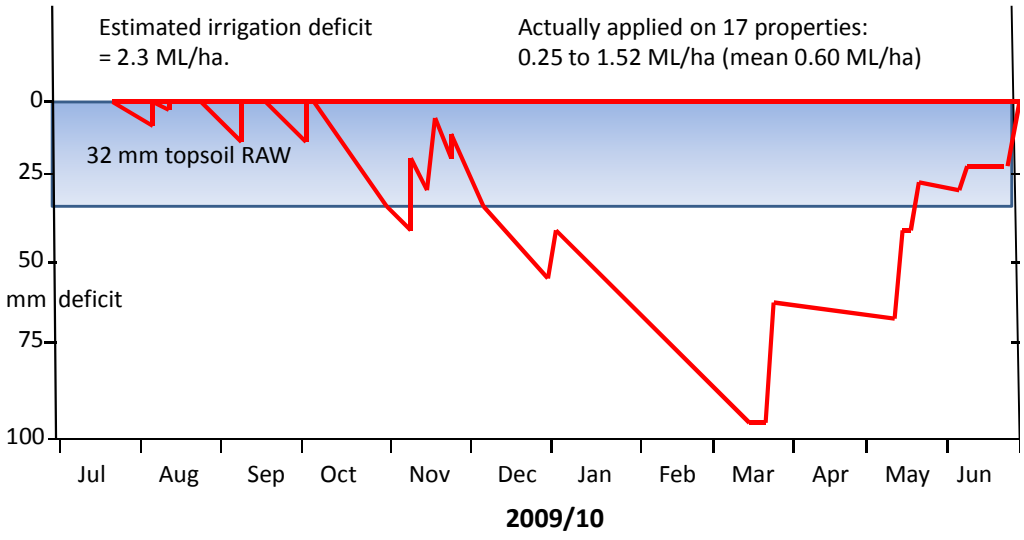


Figure 4(b). Simulation over two years (2008/09 & 2009/10) of water abstraction from an Eden Valley vineyard with a 0.5m deep sandy loam topsoil and with vine roots able to withdraw moisture to a depth of 1.5m.

6.2 Comparisons of yield with irrigation and estimated topsoil RAW

The mean irrigation and yield totals from the four recorded seasons 2006/07 to 2009/10 are shown in table 1 below. Annual year's records can be seen in Appendix 5

Table 1

Vineyard	Cultivar	Median Topsoil RAW mm	Mean of 4 years ML/ha	Mean of 4 years t/ha	Mean of 4 years t/ML
1	Riesling	20	0.58	6.1	10.5
2	Riesling	33	0.49	8.7	17.5
3	Riesling	28	0.90	8.0	8.8
4	Riesling	29	0.22	8.1	* 77.8
5	Riesling	69	0.38	9.6	24.8
6	Riesling	13	1.11	10.3	9.2
7	Chardonnay	21	1.09	7.4	8.0
8	Chardonnay	36	0.51	11.8	26.3
9	Chardonnay	13	1.68	9.3	6.1
10	Semillon	32	0.95	12.2	14.3
11	Semillon	36	0.40	4.7	5.9
12	Sauv Blanc	30	0.57	10.1	18.3
13	Shiraz	41	0.59	6.3	10.9
14	Shiraz	21	0.53	6.5	13.5
16	Cab Sauv	25	0.30	2.5	7.2
17	Merlot	20	0.30	3.4	5.7
18	Pinot Noir	33	0.87	10.8	13.2
19	Pinot Noir	21	0.26	9.5	* 29.6

Table 1. Estimated topsoil RAW (Median value for each vineyard) and the 4 year means of annual yield and irrigation. The vineyards in red did not have the full 4 years data and 4 year means shown were estimated as missing plot values in analyses. The two values with asterisks in the t/ML column were high because of very small irrigation applications in at least one season. These were omitted from the analyses.

Results from individual season's comparisons of yield, topsoil and annual irrigation total resulted in possible irrigation and soil effects that were apparent in individual years but when the combined 4 seasons were analysed, the overall irrigation effect was minimal. The two vineyards (marked by an asterisk in Table 1) that had very curtailed irrigation did not suffer marked yield loss in the season when irrigation was drastically reduced.

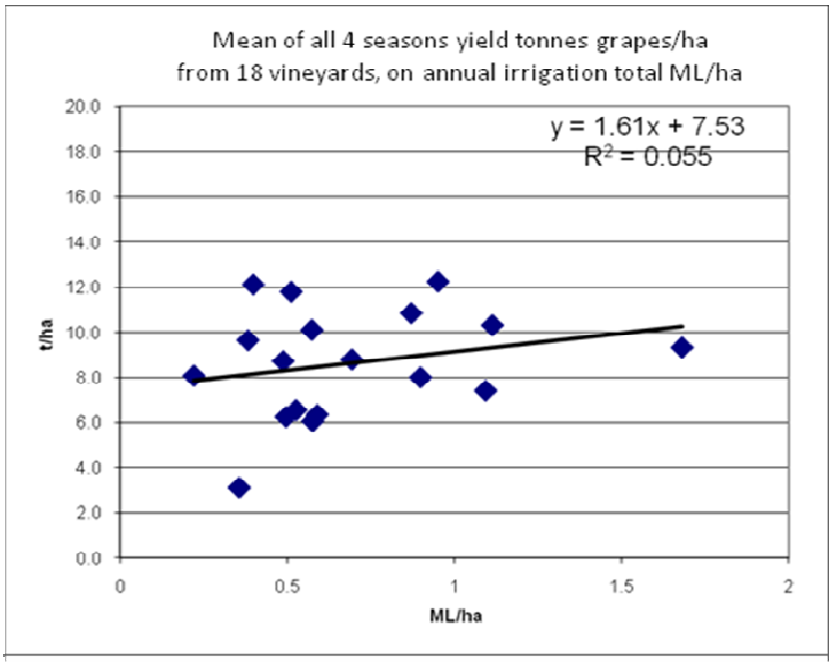


Figure 5. Mean annual yield from 18 vineyards over 4 seasons 2006/07 to 2009/10 according to irrigation amount.

The inference from Figure 5 is that there is little incentive to apply more than about 0.5 ML/ha.

Similarly when yield is compared with topsoil RAW in Figure 6, any evidence of a positive effect of deeper topsoil is masked by variability. (Note that one vineyard on a deep sand has been omitted from the regression as it could exert undue influence.)

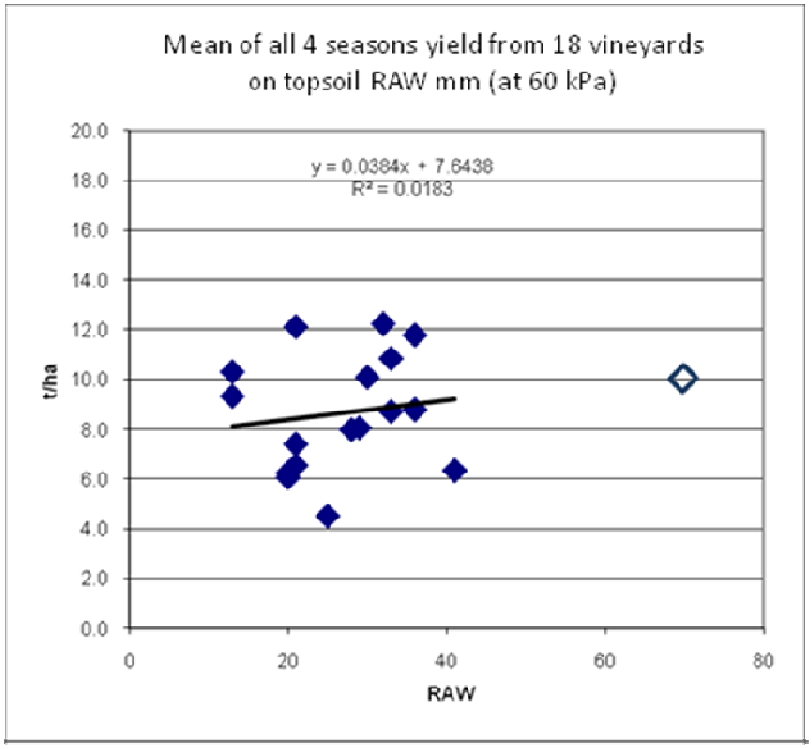


Figure 6. Mean annual yield from 18 vineyards over 4 seasons 2006/07 to 2009/10 according to estimated topsoil RAW mm. (The data point shown in outline, has been omitted from the regression. The value from this deep topsoil site exerts undue influence on the comparison)

Initially it appeared that there was a strong relationship between irrigation efficiency (as tonnes grapes per megalitre) and topsoil RAW. When both irrigation and soil are combined, there is an apparent influence on yield as shown in Fig 7.

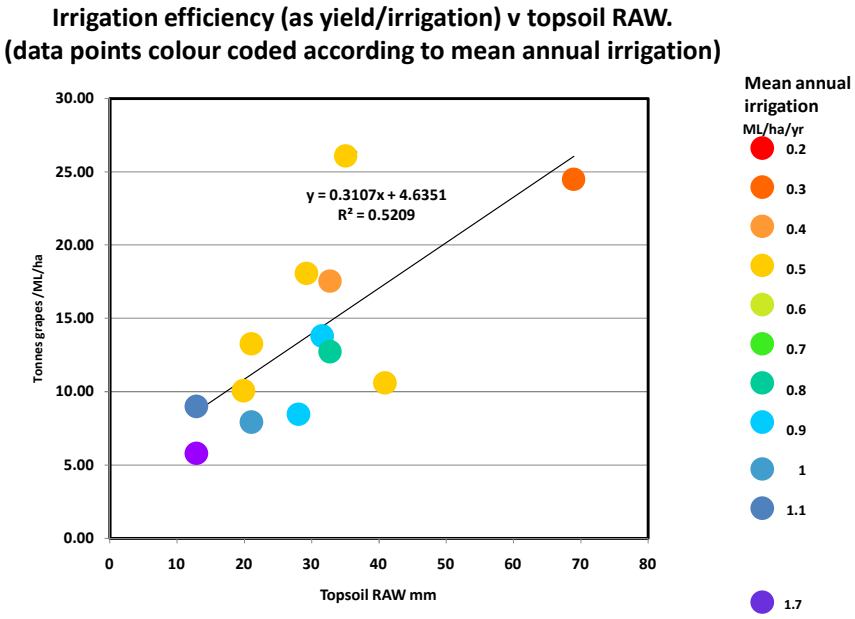


Figure 7. Mean annual yield per ML irrigation from 13 vineyards over 4 seasons 2006/07 to 2009/10 according to estimated median topsoil RAW mm. (Only vineyards with all 4 years' values are shown in the above graph). This graph shows a spurious significant response due to managers favouring shallower topsoils with more irrigation.

Although significant at (P=<0.01), the result is an artefact resulting from the action of irrigators who favour shallower topsoils with more irrigation (see Figure 8). The colour coded data points in the graph above show how this biases the irrigation efficiency (as yield/ML).

When the Biometrician subjected the data to further analyses, his comment was: "The correlation between RAW and t/ha is mildly positive. In a bivariate regression of t/ha (*not* t/ha/ML or t/ML) on RAW and ML/ha for 13 blocks (the one with RAW = 69 I must treat as an outlier, potentially having too much influence) the partial regression coefficients are each significant at around $p < 0.2$, i.e. formally non-significant. From these partial regression coefficients, if RAW is held constant, the t/ha increases by 2.75 for each ML/ha. If the ML/ha is held constant, t/ha increases by 0.1 for each RAW mm."(C. Dyson, pers com.)

Even if there was more confidence in the responses to irrigation, the apparent irrigation response is too modest for practical value. Eden Valley irrigators are restricted in the amount of water available both physically and now legally by water allocation. They have intuitively decided to maximise vineyard area to extract the greatest return on available water.

A response of 0.1 t/ha for every 1mm RAW is approximately equivalent to an extra tonne of yield for every 15 cm increase in sandy loam topsoil. This outcome is an incentive (if any extra incentive were needed) for managers to include topsoil depth as a criterion when choosing new vineyard sites.

The value of this project has been to show that commercially acceptable yields are possible with annual supplementary irrigation of 0.5 ML/ha. One would expect the yield response would be far greater, as it would be at the steepest part of a notional yield on irrigation response curve. A possible explanation for the lack of response is given in section 6.5 where it is argued that the rainfall stored in the subsoil plays a significant role in crop set and maintenance through to harvest.

6.3 Irrigation management

When the annual irrigation amount applied to each vineyard is plotted against the estimated topsoil RAW as shown in Figure 8, it is evident that managers are favouring the vineyards with shallower soils (= lesser RAW) with more irrigation. This is a rational decision as less moisture storage in the topsoil will lead to the more rapid onset of moisture stress following irrigation. If more information were available on the total moisture accessible to the vines (e.g. from deep soil moisture sensors and pits or deep core surveys), better decisions could be made on which vineyards might receive a greater share of the available irrigation.

Vineyards appear to be buffered against short term change to irrigation (Note vineyards 4 and 19 that yielded satisfactorily for at least that season after drastic reduction in irrigation. See Table 1 and Appendix 5.1). This project does not provide the information on how long before and the extent of yield change that takes place following reduction or increase in annual irrigation amount.

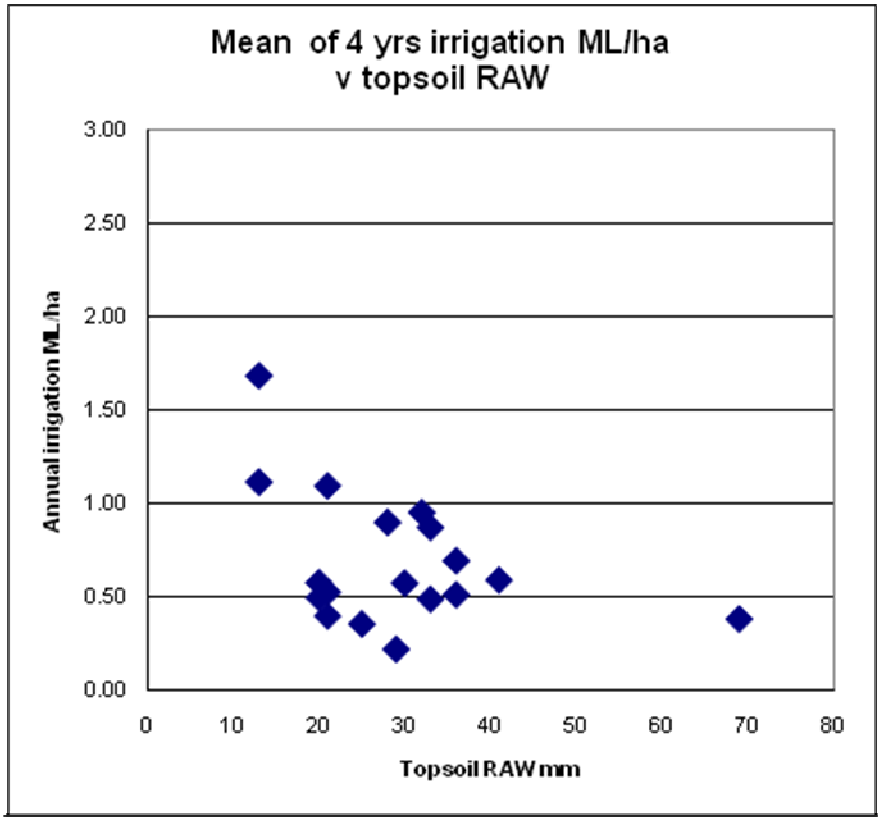


Figure 8. Effect of topsoil depth (shown here as RAW) on management decision on amount of irrigation to apply to a vineyard.

After the first two seasons of the project all the vineyards were checked for the extent that vineyard managers had followed the irrigation recommendations devised for each vineyard based on estimated RAW and observed wetted surface area. The results from one vineyard are shown below for the two seasons. In the case of this vineyard and some of the others there was a slight decrease from '06/'07 to '07/'08 in the proportion of total irrigation that was estimated to have drained below the topsoil. However this could easily have been as much due to a reduction in water supply from drought as any attempt to adopt recommendations.

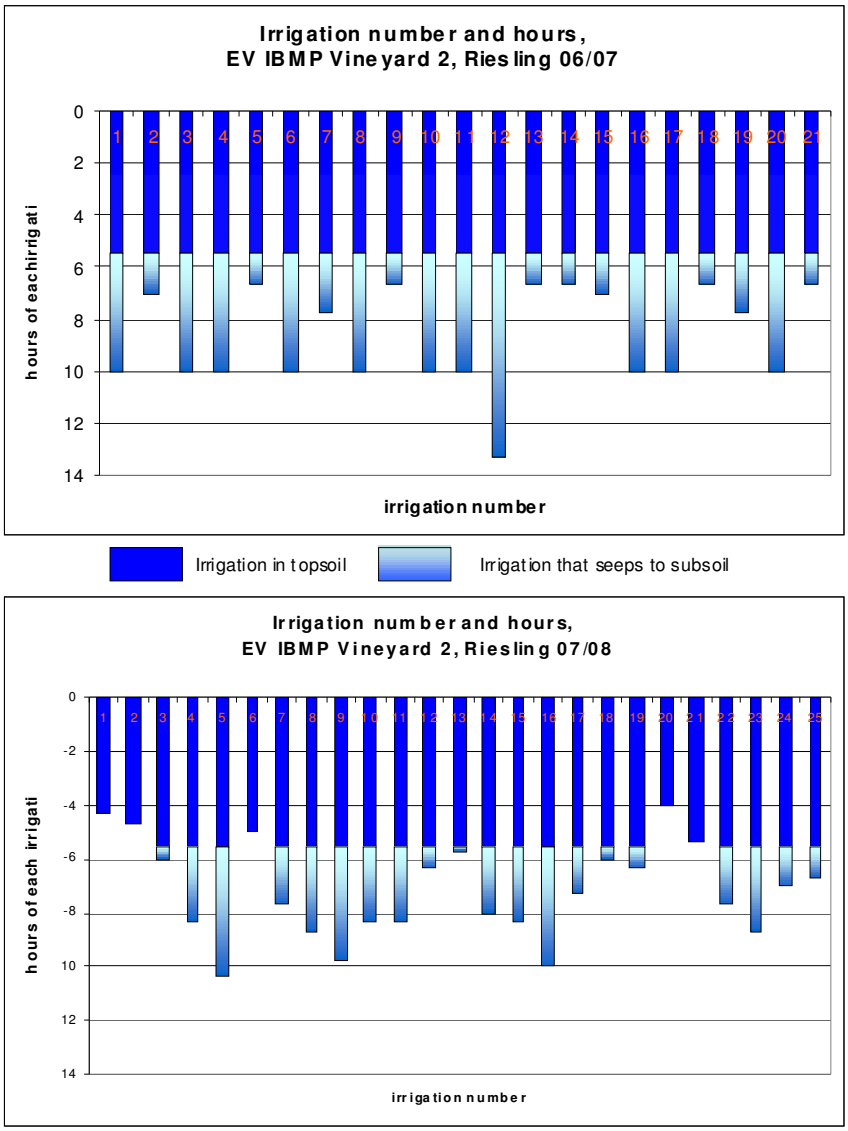


Figure 9. An example from one vineyard of irrigation frequency and estimated topsoil moisture retention over two seasons.

There was no indication that vineyards that more closely matched the irrigation recommendations had any greater yield response than those vineyards that received fewer heavy irrigations. Accordingly, there was no inducement to adopt the recommendations by increasing frequency of irrigation and reducing the amount applied at each irrigation. A check was made on the final year's yields by comparing irrigation frequency with yield and there was no indication of any response.

A possible explanation for at least part of this lack of response was evident at a demonstration prepared for the November 2009 Field Day.

Prior to the Field Day two drip lines were laid parallel with drippers at standard vineyard intervals. One line had water applied at 13 litres per dripper, the estimated amount that should have wetted only the 44cm deep sandy loam topsoil. The drippers in the other line applied double the amount of water. A trench was dug between the drip lines and the drip wetting patterns observed and demarcated for the field day. This admittedly subjective observation indicated that applying double the estimated amount of water did not result in all the extra water seeping to the subsoil. It appeared that the clay at the topsoil/subsoil juncture impeded seepage and the same topsoil volume was wetted more thoroughly.



Figure 10. Visibly moist soil highlighted after a drip irrigation of: 13 litres (left) and 26 litres (right)

At this stage it would appear a moisture sensor below the topsoil/subsoil contact is a more reliable indicator of seepage below the topsoil than an estimate made using soil RAW. Figure 14. illustrates a successful application of recommendations. The moisture sensor in the topsoil reflects the frequent irrigation applications but there are only minimal corresponding deflections in the traces from the subsoil sensor. Major deflections would indicate leakage of irrigation from the overlying topsoil.

6.4 Vine growth and topsoil

In each of the 6 Riesling vineyards 5 trellis panels were selected that covered the spectrum of topsoil depths found in the original topsoil survey. For each of the three vines in the panels, the length of the cane from the first fruiting node to the twelfth node beyond that first bunch node, was measured in cm for 10 canes per vine

The results in Figure 11 show the very variable nature of the measured canes but the fitted log line does match the distribution spread. However the results are too variable to have much value in explaining the role of topsoil in resulting vine vigour.

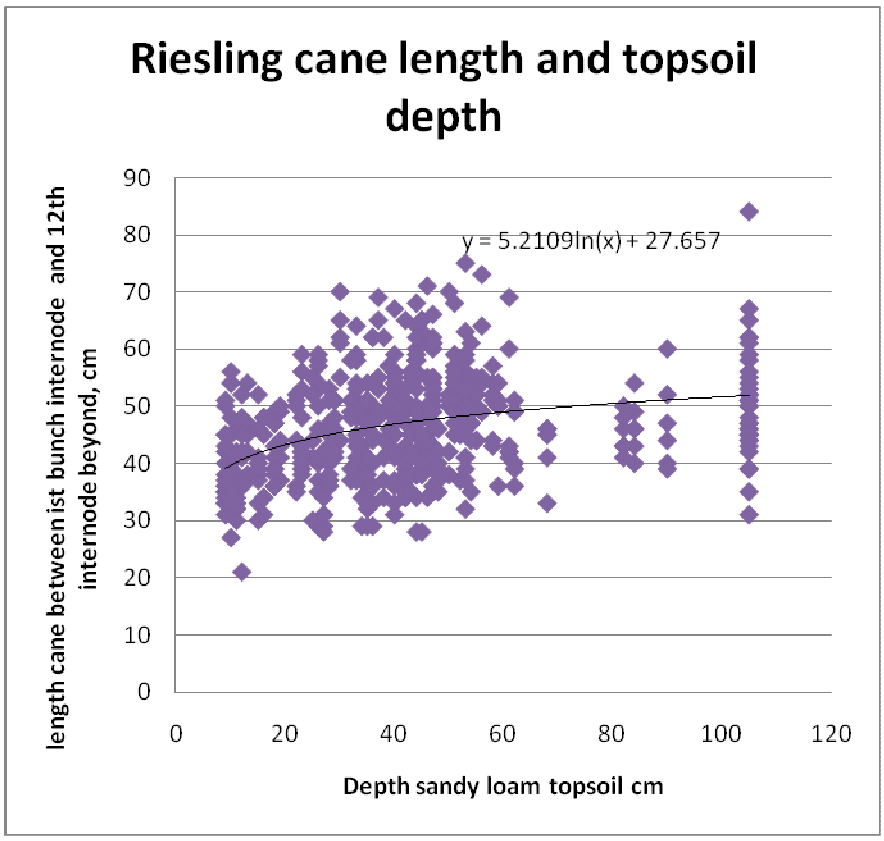


Figure 11. Riesling vine cane length cm according to depth of topsoil at the base of each vine trunk.

6.5 The role of subsoil in annual vineyard water budget

The role of topsoil and the upper subsoil as a moisture store is well known and are incorporated into irrigation scheduling models. Typically the rest of the subsoil is ignored. In order to gain more information on the whole soil profile, five cores were taken from each of the vineyards (except one that had trellises too close for the truck to pass between). The truck mounted corer was capable of penetrating to 3 m in soil and soft weathered rock. The five sites in each of the vineyards were selected for a range in topsoil depth to see if there was any correlation between topsoil and subsoil depth and if so, could the topsoil depth be a useful predictor of subsoil depth?

The samples were too few to be representative of the range of subsoil depths. Nevertheless the grouping of the core results into four depth classes as shown in Figure 12 shows that considerable moisture can be stored in a whole-of-soil profile and in most cases it amounts to more than the annual irrigation budget.

Sensor traces from 7 deep sensor sites show that at most sites there was drying of the profile to at least 100 cm and probably to 150 cm but moisture withdrawal below that was occasional and towards the end of summer. Soil profiles with moisture accessible to roots to 150 cm have a storage capacity of up to 1 Ml/ha.

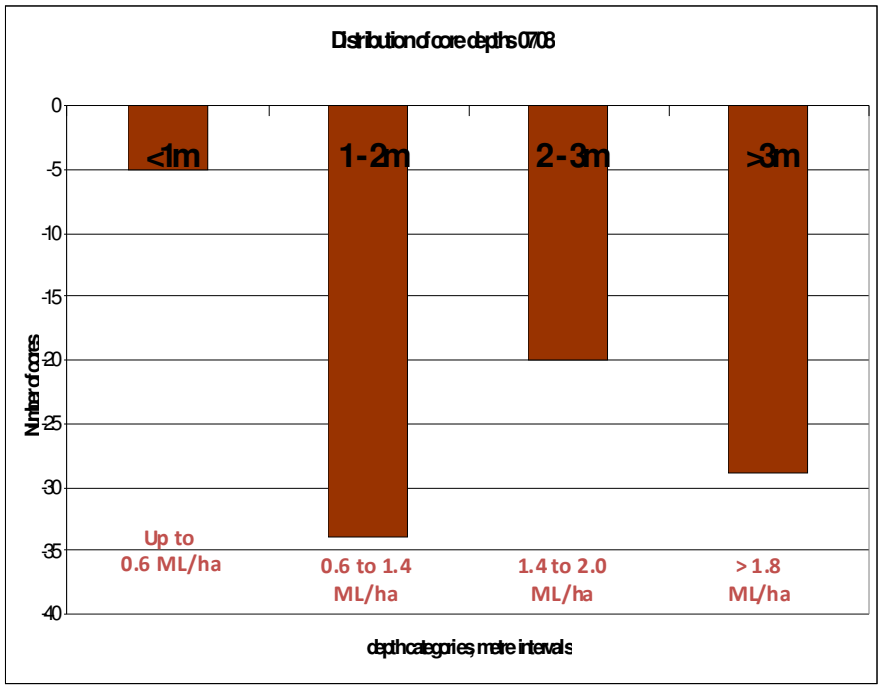


Figure 12. Distribution of 85 soil core samples according to depth and estimated RAW storage capability.

Figure 13 shows the soil profiles from cores taken at intervals down a hill slope in a vineyard. It is possible that on a vineyard scale there is a relationship between median topsoil depth and the underlying subsoil depth. However this example shows that a topsoil sample, does not predict the depth of subsoil immediately beneath it.

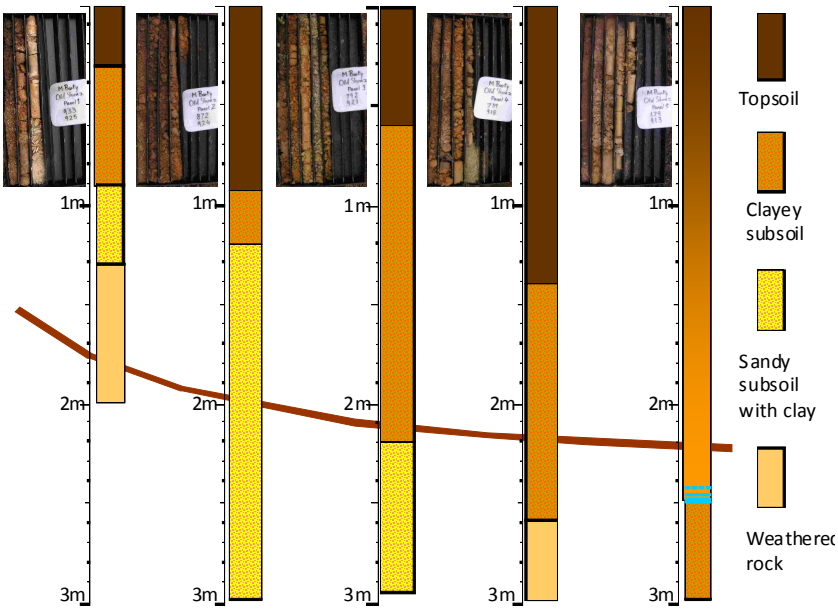


Figure 13. Five soil profiles from cores taken down a slope in a monitored vineyard.

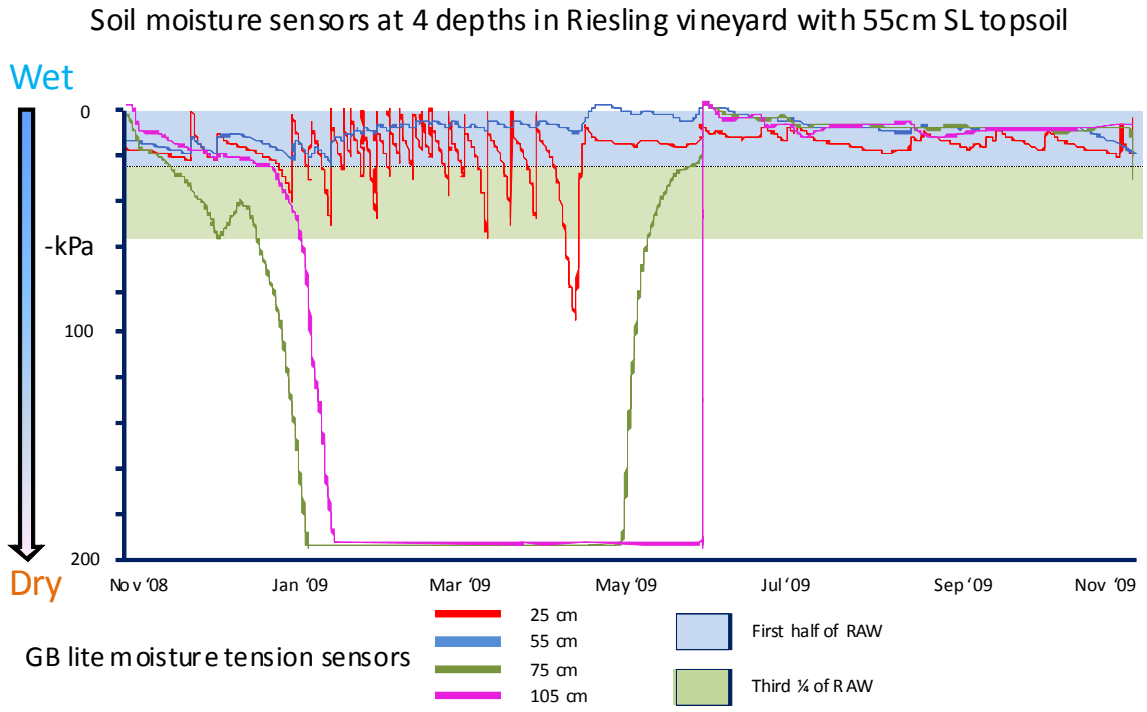


Figure 14. Soil drying expressed as soil moisture tension from 4 sensors in a vineyard soil profile. (Note that tension as –kPa has a relationship with volumetric water content but it is not a straight line relationship and it varies according to soil texture.)

Figure 14. Shows the drying patterns of 4 moisture sensors at different depths. The shallowest sensor is in the topsoil and wetted by the dripper at each irrigation, accounting for the sawtooth line. The sensors at 75 cm and 105 cm in the subsoil indicate steady withdrawal of moisture between November and January. The subsoil was effectively dried out to a depth of a metre from January to May. It is likely that at this site the vines continued to withdraw moisture from below 1 m. The 25 cm sensor was used to schedule irrigation so that moisture tension in the drip wetted zone was maintained between field capacity and -60 kPa. Despite keeping this soil zone relatively moist for virtually the whole season, only a little more than 0.5 ML/ha was applied.

The fact that the sensor at 55cm did not dry out is a phenomenon observed at other monitoring sites and will be explained later in this report.

To provide verification for the supposition that the vines accessed soil moisture below 1m, 7 of the core hole sites were equipped with soil moisture sensors attached to data loggers. The sensors were installed in spring 2008 and reported for the 2009/10 season by when it was presumed, sparse roots at depth had had time to re-establish around the sensor in the backfilled core hole.

Compacted soil or gravel were a barrier to installation of sensors using hand augers. As a result the sensors installed in the monitored vineyards prior to the deep core sites, were never much deeper than a metre. The deep core sites provided new information on deep subsoil water use.

There is every indication that in Eden Valley suitable subsoils can store enough water to ensure that vines are not severely stressed during summer. In most sites the subsoil

appears to be suitable for roots to function. Moisture sensors recorded moisture abstraction during summer from subsoils. Subsoil profiles in soil pits commonly show mottling of clays indicating waterlogged, anaerobic conditions for at least part of the year. These conditions do not appear to prevent roots operating in this soil zone during summer.

An example of sensors buried in the deep core holes is shown below in Figure 15. This deep core site was selected as an example here despite the deepest sensor being only at 1.4m. It has a similar profile to the notional one in section 6.1. This vineyard suffered pump failure in January resulting in only 0.25 ML applied for the season yet returned the highest yield of all the vineyards in 2009/10 season of 15.5 tonnes/ha.

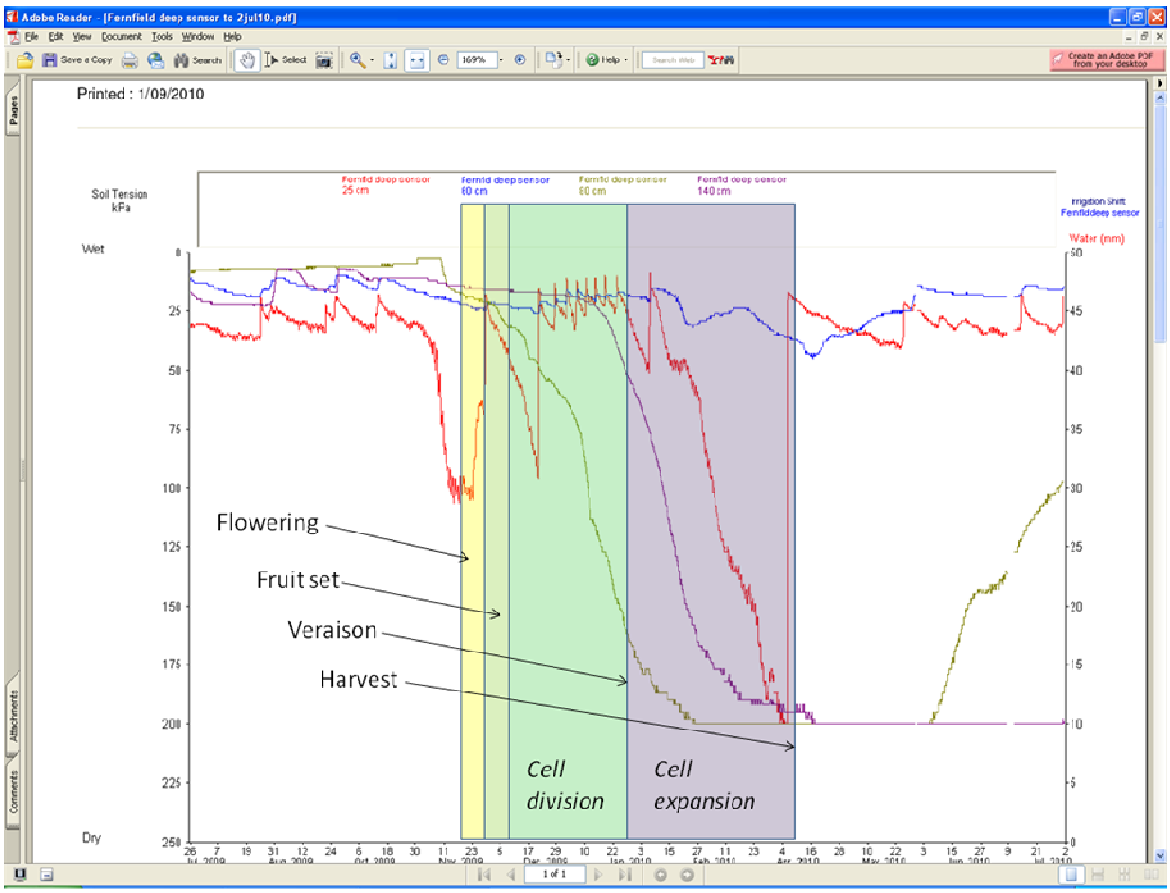


Figure 15. Moisture tension records for Pinot Noir vines growing in a 1.5 m soil profile (predominantly sandy loam texture) with GB Lite moisture tension sensors in the drip wetted soil zone at 25 cm(red) and 60 cm(blue) and in the dry mid row at 80 cm (green) and 140 cm (purple).

The tension traces in Figure 15 show ample moisture in the profile during the time of flowering and fruit set. During the fruit development stage until veraison, the subsoil is progressively drying out but the topsoil is kept moist by irrigation. In the final phase from fruit colouring to harvest there is severe depletion of moisture from the whole profile yet this clearly did not lead to a low crop.

An interpretation of this result is that the berry number component of the crop was completed by berry set and before there was a need for irrigation to mitigate moisture stress. In the summer months that followed, aerial and soil moisture stress combined were not enough to reduce crop by either berry shedding or limiting berry size.

6.6 Irrigation induced soil salinity, sodicity and loss of soil structure

At the October 2008 Farmwalk field day, Dr Mike McCarthy cautioned that the scheduling recommendations promoted through this project, led to frequent light irrigations. These had resulted in soil sodicity in the Barossa Valley.

Accordingly all the monitored vineyards were sampled and tested for indications of sodicity. On Dr McCarthy's advice the narrow contact zone of (usually) higher clay content between topsoil and subsoil was sampled. Separate samples were taken from drip wetted areas and from unirrigated parts of the vineyards as shown in Figure 16.

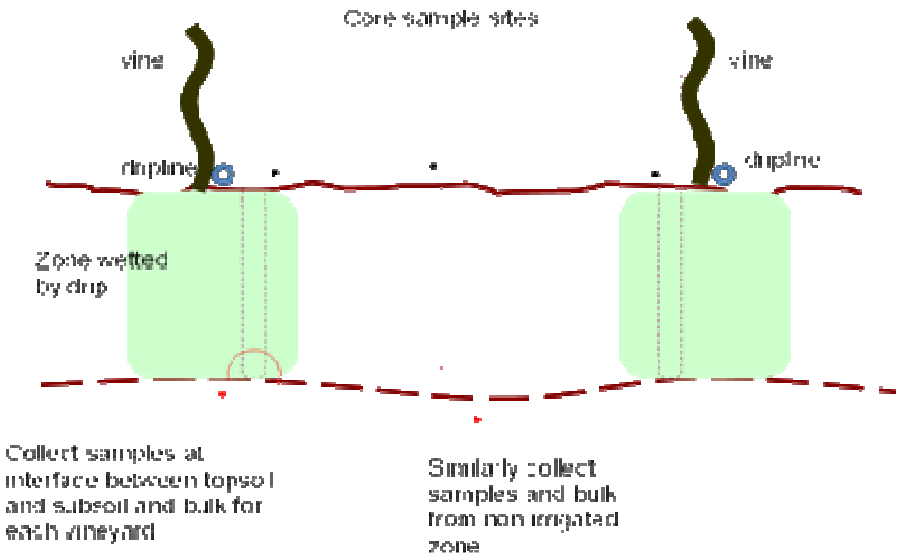


Figure 16. Core sampling to test for sodic effects at the interface between topsoil and subsoil

A simple dispersion test was applied to all samples. While there were no distinct symptoms of dispersion there were symptoms of slaking and sometimes marked differences between irrigated and unirrigated zones (see Figure 17. Information sheet "Eden Valley IBMP-Sodicity and irrigation management").

Advice was sought from Robert Murray, the acknowledged authority on soil salinity and sodicity in SA. His view was that whether it was sodicity or not, some soil amelioration was probably required. He had one of the Eden Valley vineyard set of soil samples analysed. The results showed higher salinity, lower pH and reduced nutrient levels in the drip irrigated sample.

In order to have more information on the cause of the differences between irrigated and non-irrigated soil, all the properties with monitored vineyards were equipped with a drip irrigation collection point and managers made initial records of EC values of irrigation water. Table 2 shows that irrigation water can be moderately saline in Eden Valley vineyards.

There are no other comparable soil studies of the narrow soil zone that is the interface between topsoil and subsoil to provide any guidance on the severity of the problem. At this stage it is not clear whether the problem is likely to worsen. It is not known how much is due to water salinity and how much could simply be effects of soil saturation that occur in the drip wetted zone. This effect alone could account for poorer soil structure and loss of nutrients.

Table 2

Property	EC readings for irrigation water				
A	1448	1520	1710	1593	1774
B	900				
C	500				
D	310	300	360		
E	1900	2300			

Table 2. EC units recorded in irrigation water samples from different properties in 2009/10 season

The lack of moisture use by vines at the point in the profile where there is a more clayey layer at the boundary between topsoil and subsoil can be seen in Figures 14 and 15. This indicates that roots are averse to colonising this region either because of salinity, sodicity or loss of soil structure. In the case of the Figure 14 site, the uncultivated soil adjoining the vineyard was shown to be decidedly sodic at the topsoil–subsoil interface with telltale prismatic structures and the soil produced strong dispersion when tested. At this site at least, the imposition of a vineyard and irrigation has reduced the native sodicity markedly.

It is beyond the scope of this project to provide an explanation of the symptoms of loss of soil structure or to provide recommendations for amelioration. It is likely the symptoms are far more widespread than just Eden Valley and warrants an industry wide investigation. Managers have been asked to continue the monitoring of the irrigation water EC to help construct a database for future investigation of the problem.

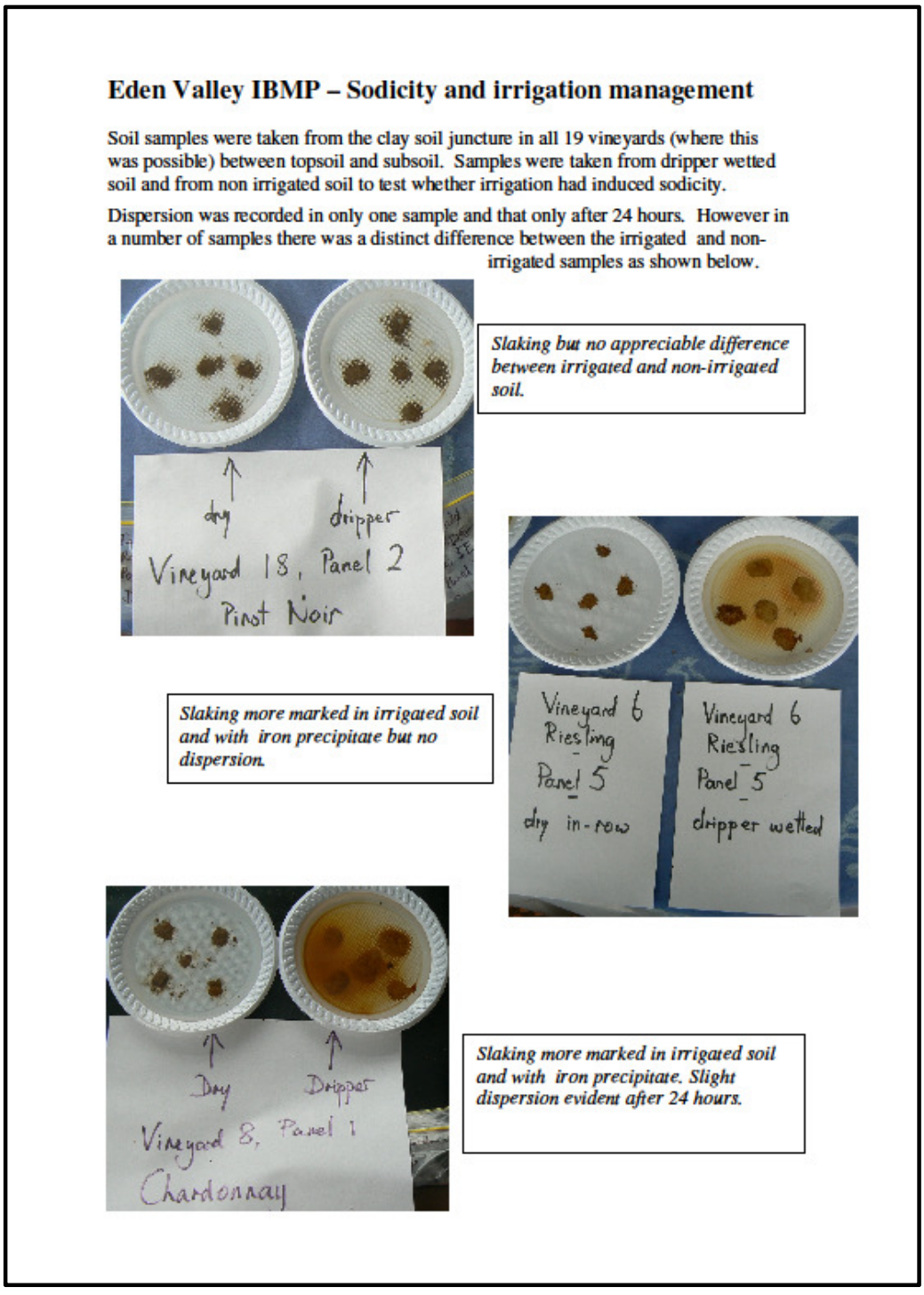


Figure 17. Information leaflet on test results for dispersion and slaking in monitored vineyards. NB. The cloudiness in the two of the samples from irrigated soil is not dispersed clay but appears to be a ferric precipitate.

7. Outcome/Conclusion

7.1 Natural resources requirements

The results from this project show that commercially acceptable yields are possible from annual irrigation budgets of 0.5 ML/ha. There is little incentive to increase the amount of irrigation on the basis of yield tonnage alone. In fact since water is the limiting natural resource, it makes sense to maximise the vineyard area to the supply of water.

The evidence from soil moisture monitoring indicates that rainfall stored in the soil profile while vines are dormant, is an important component of the vineyard summer water budget in Eden Valley. Therefore a 0.5 ML/ha irrigation budget is adequate but with the proviso that there is sufficient moisture storage in the soil profile and that it is accessible to the vine roots.

There was an indication (P=<0.2) that greater topsoil depth increased yield so the statements that can be made from this project's results with regards to natural resources are:

"The soil and water requirements to ensure commercially acceptable yields from a vineyard in Eden Valley are:

1. A moisture holding soil profile accessible to vine roots 1.5 m deep.
2. The deeper the topsoil the better.
3. Sufficient irrigation supply to provide 0.5ML annually."

7.2 Irrigation management

There was a wide difference in mean annual yield over 4 years between the vineyards ranging from 4.4 t/ha to 12.2 t/ha. But only a minor part of that variability could be ascribed to irrigation amount and there was no discernible effect of frequency of irrigation.

Grape bunch primordia are laid down in buds the season prior to their development into fruit. It appears that in Eden Valley, subsequent development from buds into flowers and young berries takes place before there is sufficient moisture stress to make irrigation necessary to prevent crop loss at flowering or fruit set. As well as crop initiation to harvest being a biennial process, the processes that set the potential crop and subsequent times when moisture stress could reduce crop are not taking place during the main irrigation period.

The fact that two of the vineyards (Vineyards 4 & 19) suffered drastically reduced irrigation without precipitous reduction in yield indicates that the vineyards were buffered against a single annual reduction in irrigation. It is possible that provided the total soil moisture store is adequate, irrigation is important in maintaining health of the vineyard and keeping the vigour of a mature vineyard in equilibrium rather than as a determinant of crop amount.

If this is an accurate interpretation of the results, it is not surprising that there is not a marked yield response to irrigation. Certainly on a year to year basis and probably not over a 4 year period such as this project covered.

Nevertheless the scheduling system devised in this project is still recommended for the following reasons:

- An irrigation schedule that confines irrigation to wetting to the topsoil where the root density is greatest and where the majority of available nutrients occur should be more effective in maintaining vine health and vigour.

- The recommendations provide methods for establishing the appropriate amount to apply at each irrigation. The number of possible irrigations can then be calculated from the total annual amount available. This makes managing the water budget easier.
- An irrigation that maintains the wetted zone within tensions of -60 kPa or less should theoretically, be better for quality than one that has few heavy applications that result in severe moisture stress between irrigations. Furthermore the vineyard results shown in the moisture depletion graph in Figure 14 showed that in that vineyard at least, it was possible to schedule using the topsoil sensor and so keep the topsoil at -60kPa or less, yet keep the annual irrigation total to 0.55 ML/ha (Vineyard 2, Riesling 07/08) ..

7.3 Irrigation induced change in soil structure

The subsoil investigations have confirmed the premise that subsoils are an important seasonal reservoir in the water budget of supplementary irrigated vineyards in Eden Valley.

The discovery of structural change in the irrigated soil requires further investigation. It has implications for adoption of improved irrigation management. The symptoms were not known until they were sought in the vineyards. It is not known whether the changes are in equilibrium or will worsen and in particular, worsen if the scheduling recommendations are adopted.

8. Recommendations

8.1 A simplified irrigation scheduling system

In light of the experiences gained during the four years of the project the following system for scheduling is recommended. It still uses substantially the same methods as described in sections 5.2 and 5.3 above.

1. Sample topsoil depth using a sufficiently dense spacing to capture the variability of the topsoil in that irrigation shift. Use a regular spacing so as not to bias the results. (e.g. a constant number of vine rows in one direction and a constant number of vine panels in the other.) An auger, digstick or core sampler will permit a rapid survey. N.B. this in no way replaces the need for a standard 1.5 m deep soil pit survey undertaken by a qualified soil surveyor.
2. If soil texture varies across the irrigation shift, then convert all topsoil values to RAW. If the texture is common to the shift then leave as cm depth.
3. Rank the values and identify the median value as shown in Figure 2.
4. Locate a point in the vineyard where the topsoil corresponds closely to the median value. Check that other vineyard aspects of this site are not atypical. This site will then serve as the soil moisture monitoring site to guide irrigation scheduling.
5. Install soil moisture tension sensors as shown in Figure 16. The shallowest sensor should be in the drip wetted zone of the topsoil. The next depth is in the upper subsoil below the drip wetted topsoil. These two sensors at least, must be sensitive in the range of tensions from field capacity to -60 kPa. The next one or preferably two, sensors are in the mid and lower subsoil away from the influence of drippers. All sensors in the subsoil should have bentonite or an impervious clay added to the backfill where the sensor lead passes through the topsoil/subsoil boundary to

prevent more than normal seepage following the excavated hole and wetting the sensor prematurely.

6. The topsoil moisture sensor will trigger the first irrigation of the season and restart after soaking rain. It will be used to initiate subsequent regular summer irrigations. If irrigation supply permits, it should be kept at -60kPa or less. The sensor in the upper subsoil is to detect seepage from too great an irrigation application. The remaining deeper sensors are to monitor the progressive drying and wetting up of the subsoil moisture storage.

Moisture tension is the more appropriate characteristic to monitor when irrigation is inadequate to fully replace deficits. In these conditions the irrigator is more interested in the level of soil moisture stress that is affecting the crop than refilling the soil moisture storage. Tension figures are also transportable so that results can be applied to other sites. However tension values will be more affected by site in the vineyard than a sensor calibrated for volumetric soil moisture. Accordingly the procedure to find the median topsoil RAW and site the sensor in a corresponding site in the vineyard is given above.

Even sensors calibrated for volumetric soil water will give more representative results if the same procedure is used.

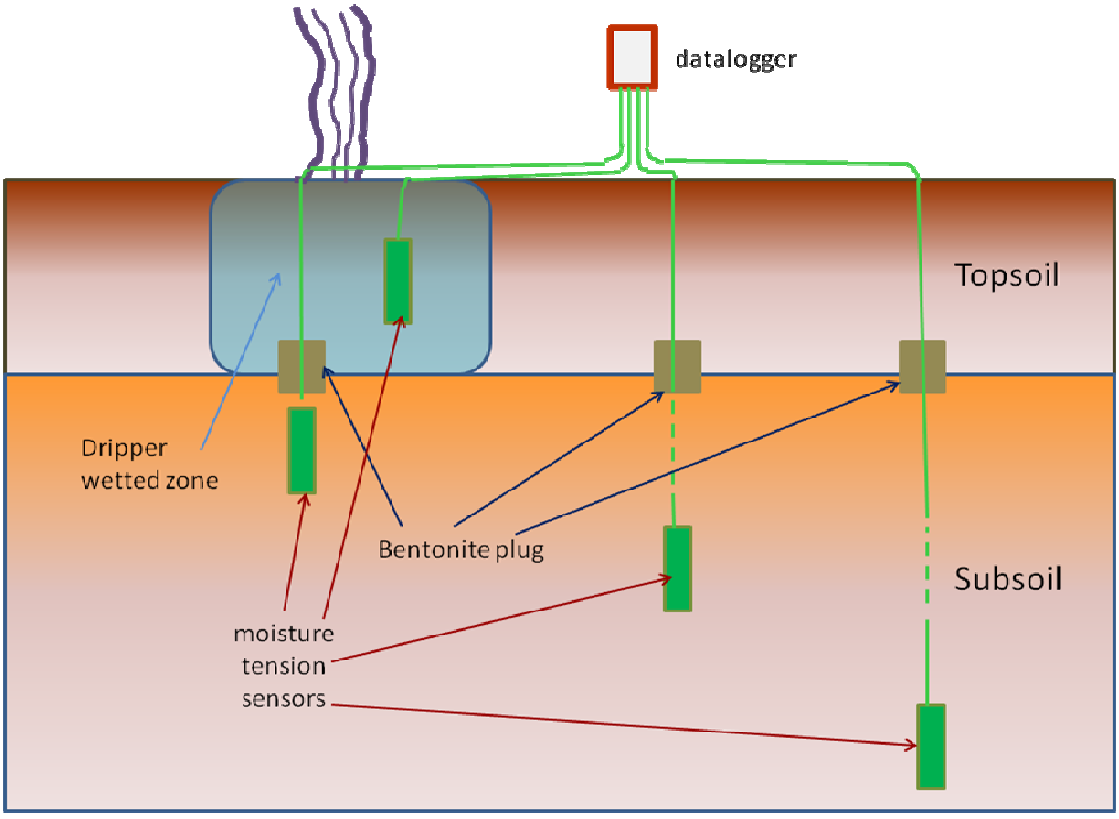


Figure 16. Recommended siting of individual tension soil moisture sensors for scheduling irrigation and monitoring soil profile drying

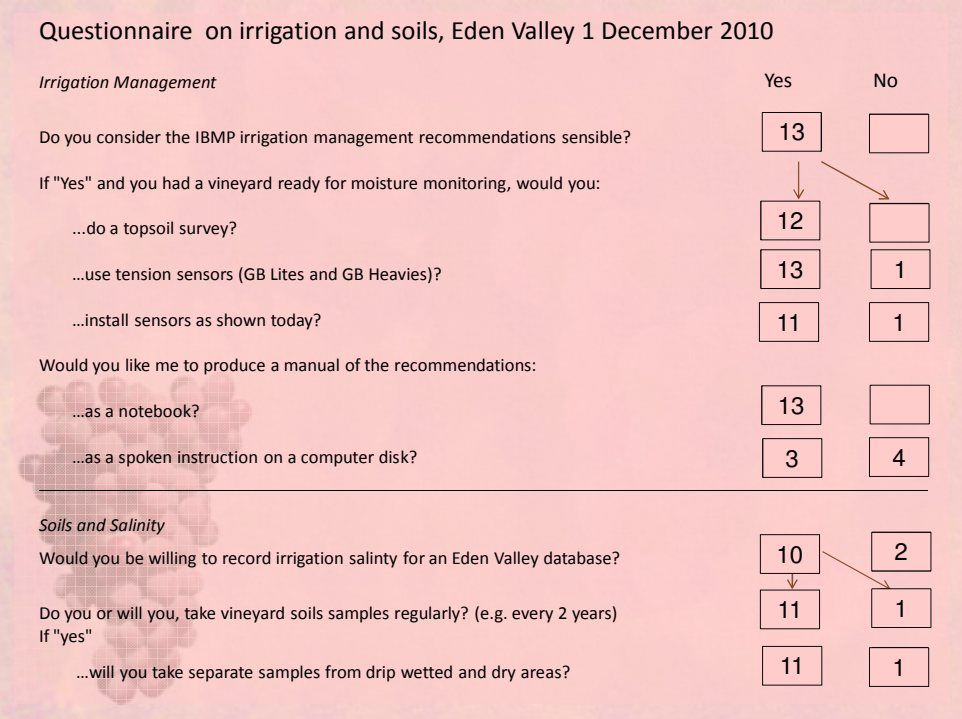
8.2 Adoption of scheduling and soil recommendations

After the farm walk and presentation of four year's project results on December 1st 2011, the attendees at this field day were asked to fill in a questionnaire. Only those involved in vineyard management could respond and had to remain anonymous. The results are shown in Figure 17 superimposed on the form supplied.

The outcome of near total support for the irrigation management recommendations should be tempered by the observed practice reported in section 6.3 where little change in vineyard irrigation frequency took place over the four years of the project.

The few "No" responses to recording salinity for an Eden Valley database in the "Soils and Salinity" section is not dissent but due to the fact that at least 2 attendees were from another district.

If the incipient problem of irrigation induced soil change is set aside, then the scheduling recommendations have potential further afield than Eden Valley. Vineyards in the rest of the Adelaide Hills are obvious candidates but any wine grape growing area where irrigation is supplementary to rainfall, where irrigation supply is restricted and where subsoils are not hostile to root growth, could benefit from similar irrigation management strategies.



Questionnaire on irrigation and soils, Eden Valley 1 December 2010

Irrigation Management	Yes	No
Do you consider the IBMP irrigation management recommendations sensible?	13	
If "Yes" and you had a vineyard ready for moisture monitoring, would you:		
…do a topsoil survey?	12	
…use tension sensors (GB Lites and GB Heavies)?	13	1
…install sensors as shown today?	11	1
Would you like me to produce a manual of the recommendations:		
…as a notebook?	13	
…as a spoken instruction on a computer disk?	3	4
Soils and Salinity		
Would you be willing to record irrigation salinty for an Eden Valley database?	10	2
Do you or will you, take vineyard soils samples regularly? (e.g. every 2 years)	11	1
If "yes"		
…will you take separate samples from drip wetted and dry areas?	11	1

Figure 17. Questionnaire completed by 13 vineyard staff or managers attending the concluding field day where final results and conclusions from the four year project were presented.

8.3 Further investigation into the cause and amelioration of irrigation induced changes to vineyard soils

The differences between dripper wetted soil and dry soil at the topsoil/subsoil interface have been identified (as described in 6.4) but the soil changes in the topsoil-subsoil interface need to be investigated further. The changes outlined in this project have been found in a limited zone of the profile and are also restricted to the drip wetted zone that is between 20% and 30% of the topsoil in Eden Valley vineyards. Winter rainfall will still leach salinity and rainfall will still seep through to the subsoil under the non-irrigated topsoil. Nevertheless Dr Robert Murray (pers. com.) has pointed out that remediation with gypsum will only halt changes, not reverse them. The inference is that any changes involving salinity need treatment soon before they worsen. He also reported at a recent Barossa technical conference that he had recently completed a survey of 22 drip irrigated

vineyards in S.E. Australia and found that poor soil structure was a universal problem. The symptoms reported above may be linked to the problem identified by Dr Murray.

The topsoil/subsoil boundary symptoms were found in most of the monitored vineyards. At this stage one can only speculate on the causes. It is not known how much influence the salinity of the irrigation water and the irrigation management have on the problem. It is not known whether the problem is in equilibrium or will worsen. At one vineyard the neighbouring native soil had distinctive sodicity symptoms including prism structures and displayed marked dispersion. It appeared vineyard establishment and irrigation had considerably reduced the sodic effects.

At the very least vineyard managers should continue to monitor the salinity of their irrigation water at the monitoring sites that were established. This will provide information for future work on the problem.

The irrigation induced soil changes found at Eden Valley will not be unique to the district. The same symptoms will probably be found if tested in other grape growing regions. In the Barossa Valley an observational trial with application by one dripper compared with two separate drippers each with half the output of the single dripper affected the soil structure differently. The double dripper site developed sodic soil symptoms. The results were interpreted as that the double dripper equated to more frequent light irrigations (Dr M. McCarthy pers.com.). At this stage the author does not consider that this outcome should prevent adoption of the scheduling recommendations in section 8.1 above. The high water salinity values recorded on some of the vineyards in 2009/10 are more likely to over-ride any frequency of irrigation effect.

Appendix 1: Communication

Results from this project have been communicated to the Eden Valley wine grape growers principally by an annual Farm Walk field day. In October 2008 this attracted a little over 30 attendees and in November 2009 approximately 25 attended. A similar number attended the 2010 field day on Dec 1 when a concluding report was given on the project. Mark Dale gave reports back to the regular EVWGGG meetings and when the chairman considered it warranted, he would advise the growers of a more detailed presentation and Mark Dale would give an afternoon talk and PowerPoint presentation.

An extensive 68 page report was produced after the first (2006/07) season prior to receiving RITA funding. This has been followed by interim reports and presentations.

At least one journal article will be written at the conclusion of the project. This will cover the irrigation management aspects of the project. It is likely that an article on irrigation induced soil changes in Eden Valley will also warrant publication as a journal article particularly if further progress is made in defining the problem.

Unlike most comparable projects this one was not carried out by an organisation with the ability to back up project findings with continuing extension. In this case continued communication will rely on the "over the neighbour's fence" technology transfer and manuals in hard copy and possibly a CD with self-guided tutorial left for distribution with the EVWGGG.

Appendix 2: Intellectual Property

There are no intellectual property considerations arising from this project. All findings have been communicated publicly and any technology that might be considered innovative is derived from proven existing systems.

Appendix 3: References

Irrigated Crop Management Service, PIRSA – Rural Solutions, "Annual Irrigation Requirement for Horticultural Crops" 2nd Edition, October 2000. ISBN 0 7308 4349 1

Wetherby, K.G., "Soil Description Book" 2002 self published, no ISBN

Appendix 4: Staff

Mark Dale is the only project staff. He was employed on a day to day basis. The total salaried time claimed was 29 days over the latter two years.

The EV WGGG and Barossa Grape and Wine Association have provided volunteer assistance and unpaid administrative services.

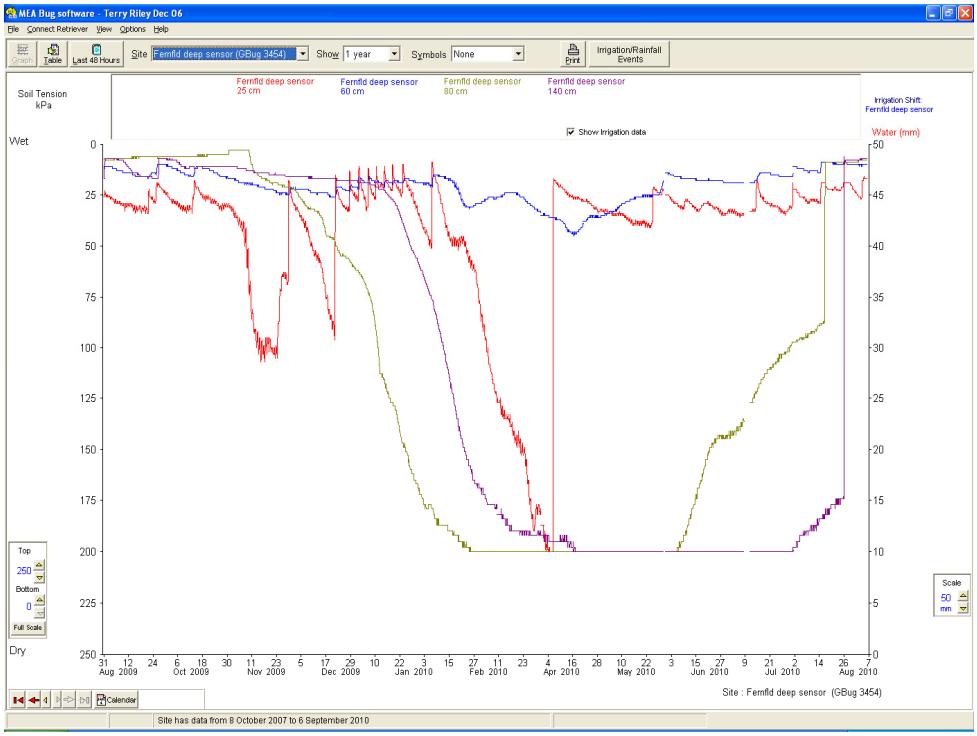
Appendix 5: Detailed records of annual yield, irrigation and soil moisture monitoring.

Appendix 5.1 Annual yield and irrigation from 19 vineyards over four years 2005/06 to 2009/10

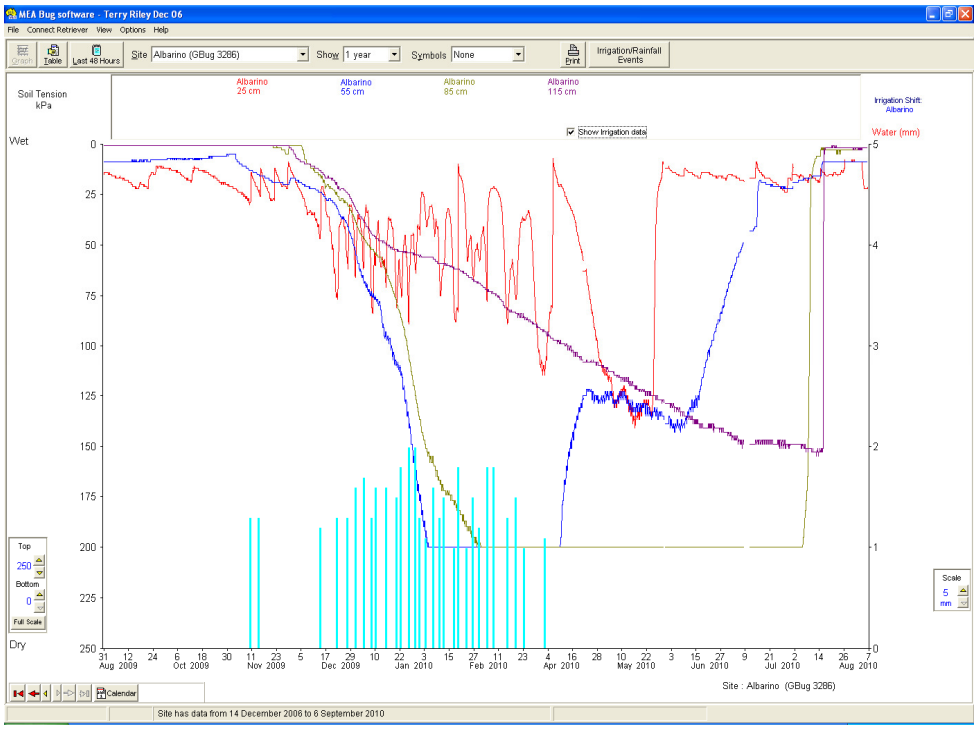
Vineyard	Cultivar	Median Topsoil RAW mm	Total annual irrigation				Yield of fresh wine grapes				tonnes yield /ML irrigation			
			ML/ha 06/07	ML/ha 07/08	ML/ha 08/09	ML/ha 09/10	t/ha 06/07	t/ha 07/08	t/ha 08/09	t/ha 09/10	t/ML 06/07	t/ML 07/08	t/ML 08/09	t/ML 09/10
1	Riesling	20	0.59	0.55	0.54	0.62	3.5	7.8	5.0	7.97	5.93	14.18	9.20	12.85
2	Riesling	33	0.51	0.55	0.57	0.32	8.6	11.0	10.7	4.55	16.86	20.00	18.75	14.35
3	Riesling	28	1.08	1.01	0.89	0.61	8.8	9.6	8.8	4.75	8.15	9.50	9.87	7.79
4	Riesling	29	0.44	0.09	0.04	0.31	5.7	9.0	6.5	11.02	12.95	100.00	162.65	35.55
5	Riesling	69	0.42	0.38	0.55	0.18	8.6	14.2	12.4	3.33	20.48	37.37	22.53	18.92
6	Riesling	13	1.02	1.04	1.09	1.30	4.5	12.3	11.9	12.50	4.41	11.83	10.92	9.62
7	Chardonnay	21	1.74	0.99	0.61	1.03	7.0	7.5	8.4	6.70	4.02	7.62	13.72	6.50
8	Chardonnay	36	0.37	0.40	0.35	0.92	9.4	15.3	9.8	12.62	25.41	38.25	27.97	13.69
9	Chardonnay	13	2.82	1.45	0.93	1.52	8.6	13.9	5.0	9.78	3.05	9.61	5.34	6.43
10	Semillon	32	1.02	1.24	0.49	1.05	9.3	16.6	11.6	11.41	9.12	13.39	23.67	10.86
11	Semillon	36	0.75	0.84			9.3	9.3			12.40	11.07		
12	Sauv Blanc	30	0.49	0.79	0.62	0.39	7.3	13.0	9.9	10.13	14.90	16.46	16.00	25.98
13	Shiraz	41	0.60	0.78	0.52	0.46	5.5	9.0	3.9	6.98	9.17	11.54	7.44	15.34
14	Shiraz	21	0.59	0.72	0.41	0.38	4.9	7.6	5.5	8.23	8.31	10.56	13.29	21.66
16	Cab Sauv	25	0.56	0.34		0.31	1.7	3.9		4.41	3.04	11.47		14.23
17	Merlot	20	0.60	0.60			6.9	6.7			11.50	11.17		
18	Pinot Noir	33	1.04	1.09	0.83	0.52	8.9	17.5	6.0	10.92	8.56	16.06	7.26	21.00
19	Pinot Noir	21		0.49	0.30	0.25		14.6	7.9	15.51		29.80	26.43	62.04

Appendix 5.2 soil moisture monitoring results from 6 deep core holes 2009/10

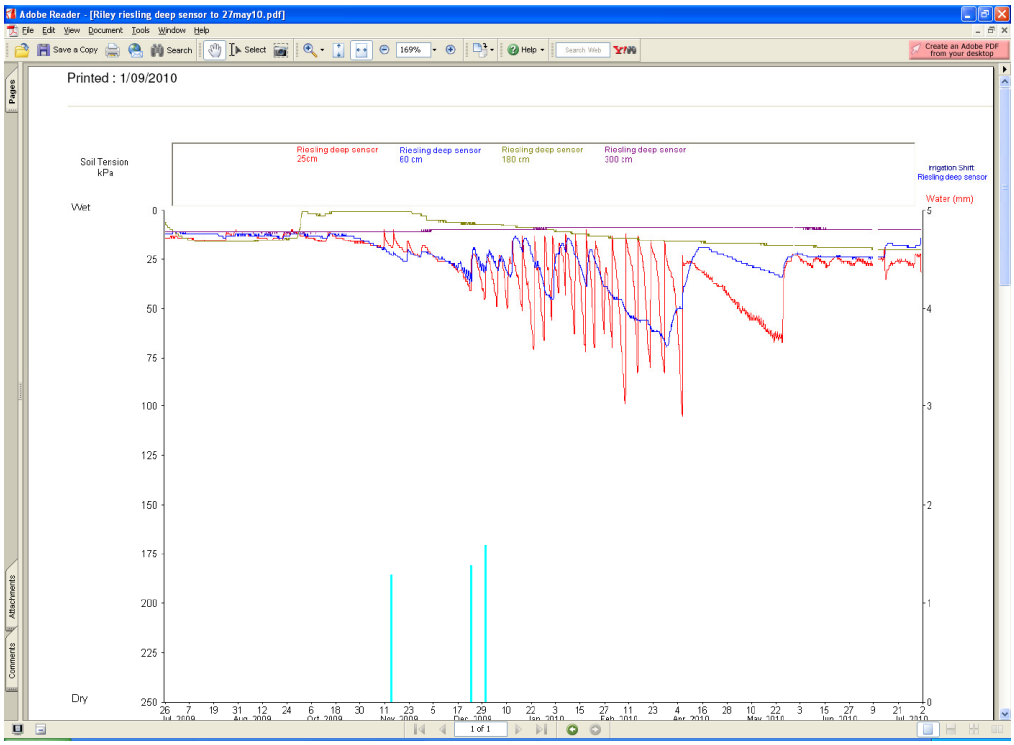
In every case the red line is at 25 cm in the drip wetted zone. The blue line is also in the vine row. The two deeper sensors are away from any drip influence and in the mid –row.



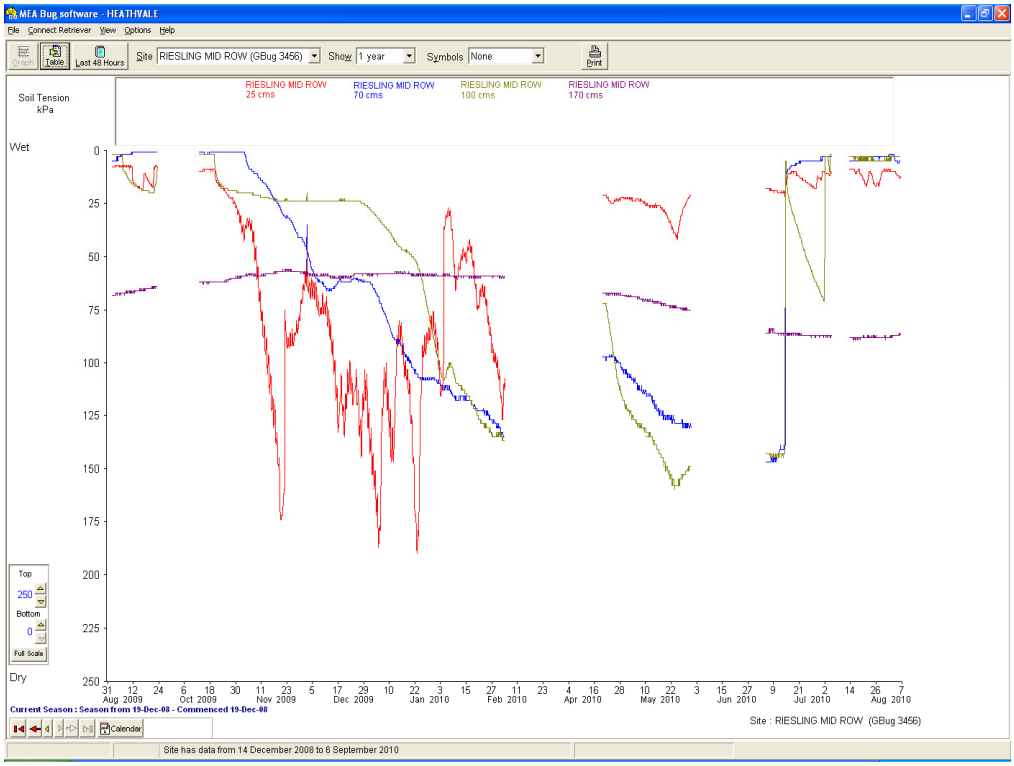
This site shows the vines progressively drying the profile until all soil to 140 cm is at least -250kPa. Re-wetting by rain was gradual until a saturating wetting front penetrated in August .



This relatively shallow soil profile was still drying at 115 cm until mid-July. All sensors were wetted by soaking rain in August that refilled the profile.



In this very deep sandy soil profile, most of the soil below 25 cm has remained moist, indicating a large subsoil moisture store.



In this fragmentary record, the wetting front from winter rain has not penetrated to 170 cm in the winters of 2009 at all or 2010 by August 2010.



This profile is of sandy alluvium and part of a river terrace. There has been moisture withdrawal at 200 cm and evidence that there has been moisture withdrawal at 300cm at the end of summer



There has been vineyard moisture use to100 cm but not at 170 cm

Appendix 6: Budget reconciliation

END OF PROJECT FINANCIAL STATEMENT

Statement of Receipts and Expenditure

At the conclusion of each Project, the GWRDC requires a Statement of Receipts and Expenditure of GWRDC funds received in relation to the Project.

Project Title:	Making the most of moisture in Eden Valley

GWRDC Project Number	Project Start Date	Project End Date
RT 07/03-2	1 December 2007	31 August 2010

Financial Year (e.g. 2006/07)	(a) *Funds brought forward from previous year	(b) #Approved GWRDC Budget (full year)	(c) Total budget available (a)+(b)	(d) Actual expenditure ($)	(e) Difference ($) (c)-(d)
Year 1: 2007/08	–	15,000	15,000	0	15,000
Year 2: 2008/09	15,000	NA	15,000	0	15,000
Year 3: 2009/10	15,000	NA	15,000	15,000	0
Year 4: 20__/__					
Year 5: 20__/__					
TOTAL		15,000		15,000	

* "Funds brought forward" refers to any unspent GWRDC funds from the previous year and approved by the GWRDC to be spent the following year (i.e. column (e) from previous year).
# "Approved GWRDC Budget" is the funding amount specified in the Project Agreement, including any approved Variations after Project commencement.

Was funding expended as approved in the Project Agreement? Yes ✓ No ☐

If NO, please provide reasons:

Has the cash and/or in-kind funding from Contributing Agencies been received and applied to the Project as approved in the Project Agreement? Yes ✓ No ☐

If NO, please provide reasons:

I hereby certify that this statement is true and accurate.

Signature of duly authorised representative

Name: Elise Heyes *Title: Viticultural Development Officer, BGWA* *Date: 11/8/10*

Appendix 7: Acknowledgements

This project was funded by different organisations in each of the 4 years of the project:

2006/07 – Goolwa to Wellington Local Action Planning Action Association (G-W LAP) with funds from the South Australia Murray Darling Basin Natural Resources Management Board (SA MDB NRMB).

2007/08 – South Australia Murray Darling Basin Natural Resources Management Board (SA MDB NRMB).

2008/09 – Barossa Grape and Wine Association (BGWA).

2009/10 – Grape and Wine Research and Development Corporation through the RITA source of funding.

The report author and the Eden Valley Wine Grape Growers Group (EVWGGG) express their thanks to these organisations and the staff I dealt with directly: Tony Randall (G-W LAP), Elise Heyes (BGWA) and Mark Krstic (GWRDC).

I owe much to Chris Dyson who analysed the project data and made it clear what were legitimate claims of irrigation effects and their probability so that I can translate the results into practical recommendations to Eden Valley irrigators.

I am very grateful for the support and co-operation from the eight vineyard managers who provided the day to day management and recording of data from the 19 monitored vineyards. These are:

David Forrest, John Stanton, Mark Bartholomaeus, Terry Riley, Bryce Lillecrapp, Darrel Kruger, Ian Zander and Trevor March.

In particular, I would like to pay tribute to the constant encouragement, enthusiasm and advice from Terry Riley who was chairman of the EVWGGG during the 4 year project.

Mark Dale 28th January 2011.