CSIRO Land and Water

FullStop at Angas Bremer:

A report on the 2002-3 data to the Angas Bremer Water Management Committee Inc

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Cover Photograph:

Description: Measuring the electrical conductivity of water captured by a FullStop Wetting Front Detector.
Photographer: Heinz Buettikofer
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Summary

This report was prepared for the Angas Bremer Water Management Committee and forms part of the committee's strategy to mobilise a community who want best practice irrigation management in their district. FullStop Wetting Front Detectors were installed at depths of 50 cm and 100 cm on over 100 properties, and growers reported how deep their irrigation water penetrated and the salinity of the water captured by the detectors.

A total of 98 growers sent information back to the committee, detailing the amounts of water applied and when, the response of the wetting front detectors and data on salt content. 72 of these records, all from wine grape growers, were complete in every respect and were used to compile this report.

The average amount of irrigation used was 1.75 ML/ha, with 10 growers applying more than 2.5 ML/ha and 12 applying less than 1 ML/ha. The average number of irrigation events was 29 (the range was 8 to 78). The average application at one time was 7 mm, but this also ranged from an average of 1.2 to 16 mm per irrigation.

The shallower detector at 50 cm responded one or more times on 82% of properties (average of 10 times). The 100 cm deep detector tripped on one or more occasions on 44% of properties (average of 4 times). There was no relationship between the total amount of water applied in the season and the number of times the detectors responded. The detector response was much more influenced by the amount of water applied at one time. Simple modelling studies showed that the width of wetting patterns had a major influence on depth of water penetration and supported the data provided from the Wetting Front Detectors.

Salinity measurements were made by 26 of the 34 growers who activated a FullStop at 100 cm depth. In addition 10 growers who did not get the deep detector to respond returned salinity samples from the 50 cm depth FullStop. A total of 85 samples were measured at 100 cm depth having an average salinity of 2208 ppm (3.7 dS/m). A total of 23 samples were measured at 50 cm depth having an average salinity of 6500 ppm (10.8 dS/m). This data confirms that the FullStops are working as expected; if wetting

fronts do not pass detectors, then salt must be accumulating above them. When they are activated, high concentrations of salt are measured.

Since the FullStop is a very new method for evaluating irrigation practice, the results above need to be supported by soil coring and salt measurements at different positions in the soil profile. Nevertheless some preliminary recommendations can be given. The proportion of growers who regularly activate the deep detectors could reduce their leaching fractions, but the majority need to factor leaching fractions into their irrigation management strategy. An increase or a decrease in the leaching fraction may involve changing only the timing and amounts of irrigation given at one time, not the annual total. Done correctly, salt can be moved to just below the active root zone where it can be stored, since water table levels are generally falling in the district.

The most fascinating insight from this research is the idea of irrigating to an upper and lower salt concentration as opposed to managing soil water content. For crops that are intentionally under-irrigated, precision in soil water monitoring is not required. For crops intentionally stressed at certain times, the soil water content data can be misleading, because the influence of salt increases as the water content declines.

The Angas Bremer Strategy

For more than 20 years the attention of Angas Bremer irrigators has been focused on reducing water use. It started in the early 1980s with the realization that exploitation of deep groundwater for irrigation was occurring at four times the rate that the aquifer was being recharged. After cuts to groundwater licence volumes and then the exchange of most groundwater licences for lake-water (River Murray) licences, growers were determined to avoid the rising water-tables that are so common in other irrigated areas.

The Angas Bremer response to the issues that are faced by most irrigated areas has been remarkable. Between 1980 and 2002 the area irrigated in the district rose by 41% but the total amount of water used fell by 36%, as most irrigators changed from growing lucerne (using 10ML/ha) to growing high quality wine grapes (using 2ML/ha). The achievement has been built on strong local leadership and the active participation of all the 160 growers and their community[1].

During this period, the government introduced a regulatory framework, which included the introduction of Irrigation and Drainage Management Plans, to improve the performance of irrigation. The Angas Bremer Water Management Committee resolved to continue its "bottom-up" practice involving strong community participation. To achieve this, the Committee embarked on a four component strategy:

1. Each grower would report annually on the amount of water they applied
2. Each grower would install a 6 m deep well and use it to measure the depth to the water-table four times a year
3. Each grower would install FullStop Wetting Front Detectors at depths of 50cm and 100cm to monitor the depth of penetration of irrigation wetting fronts.
4. Each grower would undertake to protect and establish two hectares of deep rooted native vegetation for each 100ML of water licence

The strategy tests a model to mobilize a community to achieve a catchment scale outcome. The reporting of the irrigation volumes provides the essential benchmark information. It also highlights the variability in the irrigation practices across the region; outliers from the distribution provide an opportunity for learning on the one hand and motivation for change on the other.

The installation and ownership of wells and the grower-monitoring of the water-levels in the wells, puts the hydrological information into the hands of those managing the irrigation. Hydrologists know that there are preferred sites for wells, with high well densities required in some areas and low densities in others. The Angas Bremer strategy has been to involve every irrigator in the process of monitoring and learning because this social involvement is even more important than the technical optimization of the locations and of the number of wells.

The installation of FullStops added the next layer of information, about what was happening between the dripper at the surface and the water-table. Although numerous growers already used more sophisticated scheduling technologies, the FullStop, installed at the same depths on each property, was chosen as a tool that could provide growers with an overview of district practice.

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[1] Thomson T (2004) Learning together at Angas Bremer. Irrigation Association of Australia conference, May 2004, Adelaide.

Finally the attention paid to planting deep-rooted native vegetation was in recognition that natural resource management requires a whole of catchment perspective.

This report deals only with the third component of the strategy, that of using FullStop Wetting Front Detectors to evaluate how irrigation management could be improved.

What we did

Each grower who has an irrigation licence in the Angas Bremer area installed two FullStop wetting front detectors. The first was installed to record wetting fronts at a depth of 50 cm and the second at a depth of 100 cm. Installation was carried out by one member of the community to ensure that the method of installation was consistent. A hole was dug by auger to the required depth, the detector installed, and the soil was repacked. A visual assessment of the texture of each soil horizon was noted as was the depth at which roots could be seen. Because roots were disturbed during installation, it was necessary to wait some time, while they grew back, before reliable information would be obtained. Installation commenced in September 2001 and was largely complete a year later.

Each grower kept a simple record of the date and hours of each irrigation event and recorded if the 50 and/or the 100 cm detectors were activated (for a discussion on how the Wetting Front Detector works see Appendix 1). The vast majority of growers grew wine grapes and used drip irrigation. The record sheets included entries for the emitter flow rate, the emitter spacing along the row and the spacing between rows so that the hours of irrigation could be converted to mm of water applied. The same record sheet was used by those growers who used sprinkler-irrigation.

The detector placed at 50 cm depth could retain a maximum water sample volume of 30 millilitres, which was sufficient to raise the float. The detector placed at 100 cm depth was modified by the growers so that it could store up to 400 ml of water. The large reservoir was used so that growers could see that the amount of water captured by the detector changed when the irrigation amount was changed (for further discussion see Appendix 2).

Growers were asked to measure the electrical conductivity of water samples collected from 100 cm. If they did not have a salinity meter, they could leave a water sample at the Post Office. One member of the community collected the water samples, measured the salinity and faxed the results to the growers.

During the previous 2001-2 season, when FullStops were still being installed, 17 growers sent in completed records for all or part of the season [2]. For the 2002-3 season, 98 growers completed the FullStop Record Sheets detailing the date and duration of each irrigation, the FullStop responses and, in many cases, the salinity of water samples. Of the 98 grower records, 72 were complete in every respect. All these

[2] Stirzaker R and Thomson T (2003) FullStop at Angas Bremer 2001-2. Report to the Angas Bremer Water Management Committee

related to grape growing under drip. The remaining 26 records had one or more pieces of information missing which meant that the data could not be used reliably and it is excluded from the results that follow.

In addition to the FullStop records, a number of growers provided helpful written comments to explain anomalies. Over 100 people attended the Angas Bremer Annual Public Meeting where the 2001-2 season data was discussed and some opinions were aired. Growers who had experienced difficulties were visited on their farms and 18 growers responded to a written FullStop survey. A number of growers provided data from gypsum blocks and capacitance probes. All this information added invaluably to the understanding of irrigation management at Angas Bremer.

What we found out

The report is divided into four parts

1. **How much water was applied to grapes at Angas Bremer**
2. **The response of the FullStops to irrigation**
3. **The salt concentrations in the collected water**
4. **What we learnt about managing irrigation at Angas Bremer**

1. How much water was applied to grapes at Angas Bremer

Figure 1 shows that 25 growers applied between 151 and 200 mm by drip irrigation over the 2002-3 irrigation season. 31 growers applied less than this and 22 more, with the average being 175 mm or 1.75 ML/ha.

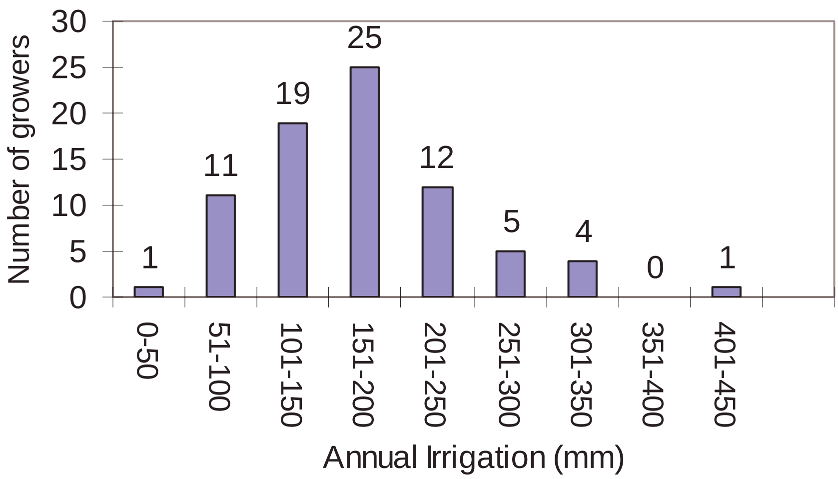

Figure 1. The total annual irrigation and number of growers in each group for winegrapes under drip irrigation

The average number of irrigation events was 29 (the range was 8 to 78) showing that some growers irrigated once or twice per month while others irrigated several times per week. The average application at one time was 7 mm, but this also ranged from an average of 1.2 to 16 mm per irrigation.

What this means

The first question is "how much water do established grapevines at Angas Bremer require?" This is complicated by the relationship between yield and quality. The simplest approach is to use monthly crop factors appropriate for maximum production and a second, lower, set of crop factors for high quality. These crop factors can be multiplied by monthly pan evaporation for Angas Bremer to give the annual crop water requirement, which is then reduced to compensate for rainfall. A target annual irrigation amount is then calculated by assuming that: the active roots go down to 70cm, 60mm of Readily Available Water is stored per metre of soil depth, a target Distribution Uniformity for drip emitters is 85% and a leaching fraction, for water containing 2,000mg/L, is 10%.

The long term annual pan evaporation for Angas Bremer is 1710 mm and rainfall is 390 mm. Using this information, an annual target of 500 mm of irrigation can be calculated for maximum yields, whereas 200 mm/yr is the target calculated for growing high quality grapes. Using the rainfall data for the year 2002-3, in that year, the target irrigation for high quality grapes was 220 mm/y. Compared with this calculation, in 2002-3, 72% of growers applied less water than this target.

The irrigation strategy used by most growers did not follow the target pattern for irrigation water application. According to the Target line in Figure 2, growers should start irrigation in early November and finish in early March. However, the actual starting dates varied from 1 July to 20 September and the finish dates varied from 28 February to 27 June. In the vast majority of cases irrigation started well before the target start date and continued well past the target end date (illustrated by 4 grower records in Fig 2). For December and January the monthly irrigation applied was always less than the monthly targets.

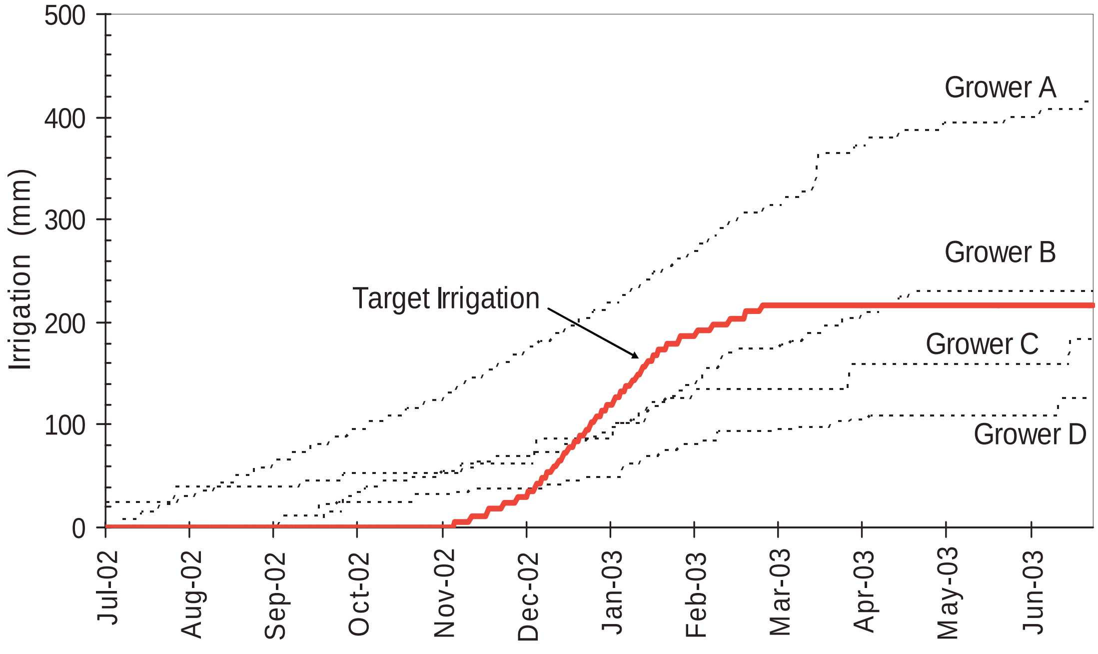

Figure 2. The target cumulative irrigation for producing high quality grapes. The dotted lines show the cumulative irrigation applied by four growers demonstrating the varying irrigation practices being used in the district.

2. The response of the FullStops to irrigation

Of the 72 reports from which we obtained complete data sets, 82% of growers recorded the 50 cm detector tripping once or more times. Forty four percent recorded that the 100 cm deep detector tripped on one or more occasions. These percentages were similar for the smaller sample collected in 2001-2.

Eight of the 12 growers who submitted incomplete records appeared not to have recorded any detector response. Combining these with the 18% of growers with complete records who did not record any detector response brings that total to 24%. In addition none of the 9 records from sprinkler irrigation recorded a wetting front reaching to 50 or 100 cm depths.

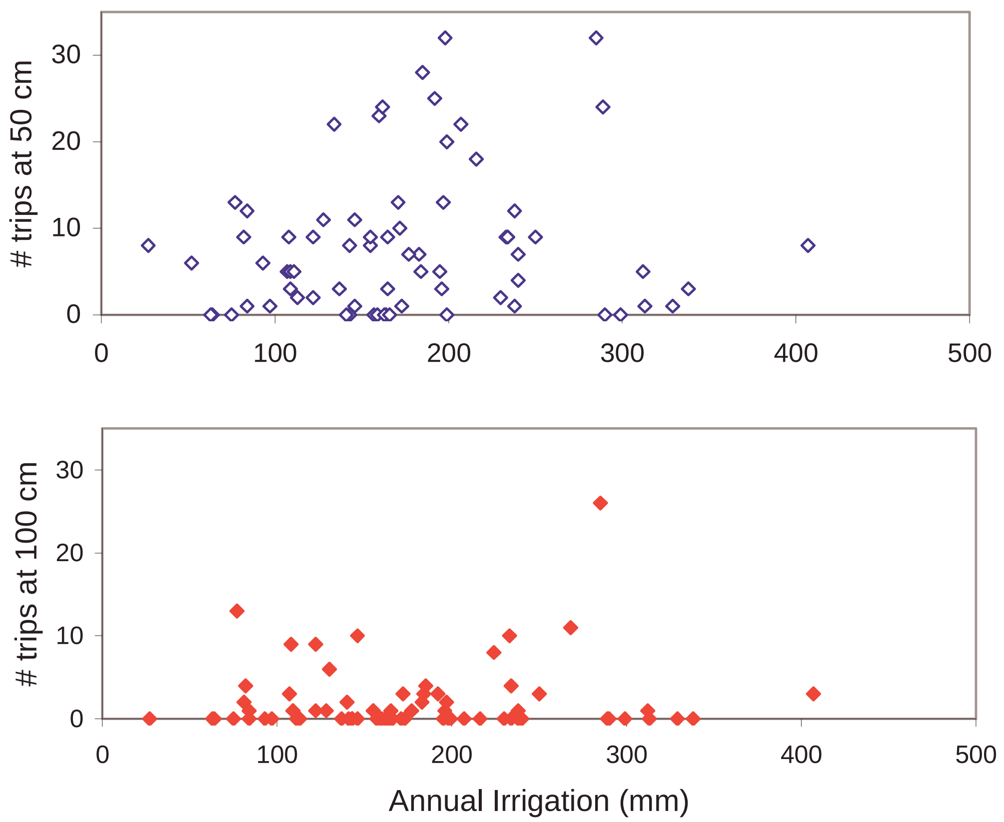

Figure 3 The relationship between total amount of water applied throughout the 2002-3 season and the number of times the FullStops responded at 50 (top) and 100 cm depths (bottom). Each marker on the graphs represents one grower, showing the annual irrigation applied and the number of times (#) a wetting front was recorded at 50 and 100 cm (72 growers).

Figure 3 shows that fewer wetting fronts were detected at 100 cm than at 50 cm, as expected. There is no relationship between the annual irrigation applied and the number of trips of the detectors at either depth. For example some growers applying around 300 mm reported 5 or fewer trips at 50 cm whereas two growers applying less that 100 mm recorded 10 or more fronts at 50 cm.

The lack of a relationship between the amount of irrigation water applied in a season and the detector response is, at first, counter-intuitive. However it is not unreasonable, given that all the grape irrigators applied well below the amount of water the grapes could potentially use. Under these conditions we would expect water loss below 100 cm to be low.

There are three factors that determine how deep a wetting front will penetrate, namely the amount of water applied at one time, the initial water content, and the type of soil.

Amount of water applied at one time:
We can compare two growers from Figure 3 who both applied 143 mm throughout the season. The first irrigated 64 times, never applied more than 12 litres through a dripper at one time and did not activate the shallow detector at all. The second irrigated 39 times, but applied up to 32 litres through a dripper at one time and activated the shallow detector 8 times.

The initial water content
The records indicated that 5 sites had young vines, and in four cases 3 to 9 litres was sufficient to trip the shallow detector. This is because the soil is likely to be wetter before irrigation for a young vine compared to a fully grown one. When the soil is relatively wet before irrigation, a given amount of irrigation infiltrates deeper than if the soil were initially dry.

The soil type
Soil type can have a major impact on how deep a wetting front penetrates under drip irrigation, because the soil type determines how wide the wetting pattern will be around a dripper. Obviously if a wetting pattern is wide it will not penetrate as deep. We used a model called WetUp[3] to investigate the relationship between the amount of water applied and the width and depth of a wetting pattern. The following relates only to drip irrigation.

Depth of wetting pattern (m)

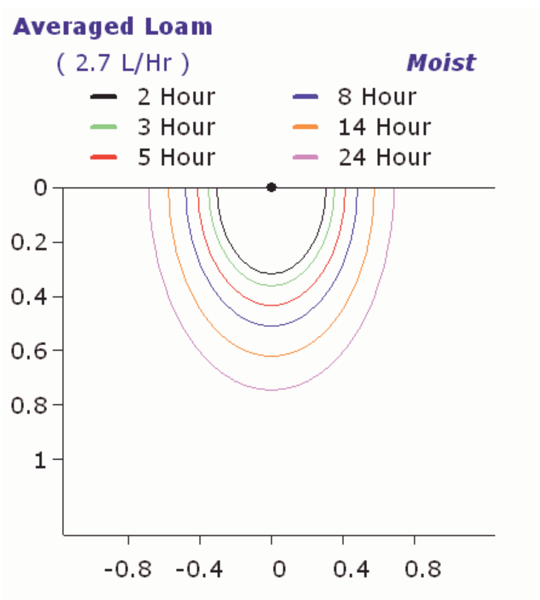

Figure. 4. An example from "WetUp" showing the radius and depth of a wetting front 2, 3, 5, 8, 14 and 24 hours after irrigation commenced from a 2.7 l/h dripper. The simulation shows that it would take around 8 hours for a wetting front to reach a depth of 0.5m, even starting from a moist soil. According to the model the irrigation system would need to be run for over 24 hours to activate a 1.0m deep detector.

Radius of wetting pattern (m)

[3] WetUp; a software tool to display approximate wetting patterns from drippers CSIRO, CRC Sugar, NPIRD

Most of the soils in the Angas Bremer region fell into the sandy loam to clay loam category. Thus we ran WetUp for these soil types and plotted the radius and the depth of irrigation for different amounts of water applied (Figure 5a and b). We then chose two soils which displayed very narrow wetting patterns (Figure 5c and d). In these cases wetting patterns tended to go deeper for a given amount of irrigation, so we would expect more trips of the FullStops in such soils.

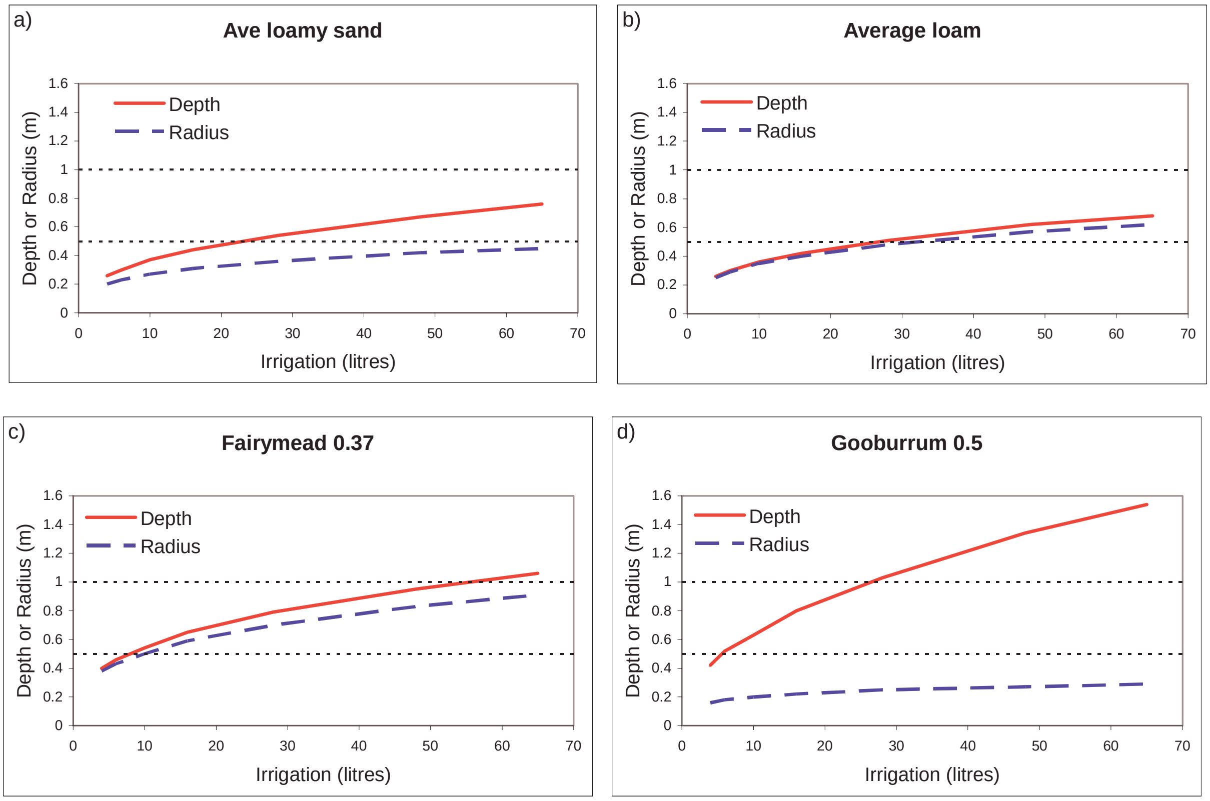

Figure 5. The depth (solid line) and radius (dashed line) we expect water to penetrate for a given amount of irrigation from a dripper in four different soil types. In each case the initial conditions were relatively dry (100 kPa).

Figure 5 shows that we would expect between 6 and 28 litres to set off a shallow detector, assuming we start with a soil at 100 kPa suction (Fig 5a and b). The assumption that the soil is fairly dry (100kPa) is made because the annual amount of water applied at Angas Bremer is 175mm/yr which is about 35% of the 500mm/yr that fully irrigated vines would like to use. According to the WetUp model, even 70 litres will not trigger the 100cm FullStop in the loamy soil typical of Angas Bremer. Even in soils with a narrow wetting pattern (Fig 5c and d) at least 25 to 50 litres are needed to trip the 100cm detector.

The above information is helpful because it tells us that the Fullstop response should be very site specific. For example, at one site with young vines, we regularly recorded a shallow detector responding to just 3 litres of water. We can assume that the soil was wet before irrigation and that the wetting patterns were fairly narrow. However on some sites over 30 litres did not activate a shallow detector. Gypsum block records often showed that the soil was drier than 500 kPa before irrigation. Furthermore a substantial amount of water could be transpired and evaporated on the day of irrigation. For soils like those in Figure 5b, even 30 litres only just activates a shallow detector.

What this means

We wanted to find out whether growers using the most water in a season were over-irrigating. The FullStop record shows that this is not the case. Growers who recorded wetting fronts at 100 cm depth did not, on average, use more water per year than those who did not detect fronts at 100 cm.

There are two important factors that determine how deep a given amount of water will penetrate into the soil. First is the dryness of the soil before irrigation (also related to the age of the vines) and second the shape of the wetting pattern. A grower can only find out how deep wetting fronts penetrate by measuring for their particular situation.

Our second question was whether growers applying more water at one time were more likely to over-irrigate, regardless of the annual amount of water applied. It usually required 20 to 50 litres of water to activate a deep detector, so in most cases growers applying less than 20 litres at one time did not activate deep detectors. However there was an enormous range in the amount of water applied per irrigation and in the depth of penetration, presumably because some soils produce wider, shallower wetting patterns than others.

The active root zone appeared to be less than 1 metre deep, based on visual observation during FullStop installation. This means that the 44% of growers who recorded at least one trip of the 100cm FullStop did push water past the active rootzone at least once during the season. Whether this constitutes excess irrigation or prudent leaching is discussed in the next section.

3. The salt concentrations in the collected water

Salinity measurements were made by 26 of the 34 growers who activated a FullStop at 100 cm depth. In addition 10 growers who did not get the deep detector to trip returned salinity samples from the 50 cm depth FullStop. A total of 85 samples were measured at 100 cm depth having an average salinity of 2208 ppm (3.7 dS/m). A total of 23 samples were measured at 50 cm depth having an average salinity of 6500 ppm (10.8 dS/m).

This salinity data is extremely interesting for three reasons. First, all the salt levels are high for horticultural situations. Figure 6 shows the Maas and Hoffman[4] limits where yield of grapevines starts to decline (the lower dotted line) and where yield would be reduced by 50% (the higher dotted line), so we may expect that salt is substantially impacting potential yield. Second, the salinity is higher at 50cm than it is at 100cm, suggesting that, for a proportion of growers at least, most of the salt is accumulating within the main root zone. Third, the readings that we have collected come only from sites that experience the deepest penetration of water because, where FullStops did not trigger, we did not collect a water sample. The water samples came from sites likely to be the most leached, meaning that our results are an underestimate of the salt levels in the Angas Bremer district.

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[4] Maas EV and Hoffman GJ (1977). Crop salt tolerance- current assessment. Journal of the Irrigation and Drainage Division of the American Society of Engineers, 103: 115-134

The average salinity of the water collected at 100 cm was about 4 times that of the irrigation water, which means that the leaching fraction past 100 cm could be around 25% (there are numerous assumptions in this estimation – we do not know the impact of the 3-D geometry of a wetting pattern). If the notional target of 85% efficiency (15% leaching) past 100 cm was attained then we could expect to see an average salinity of 100/15 ≈ 7 times the 700ppm in the irrigation water or about 5000 ppm in the deep detector. Thus the salt concentrations measured at 100 cm are not unexpected.

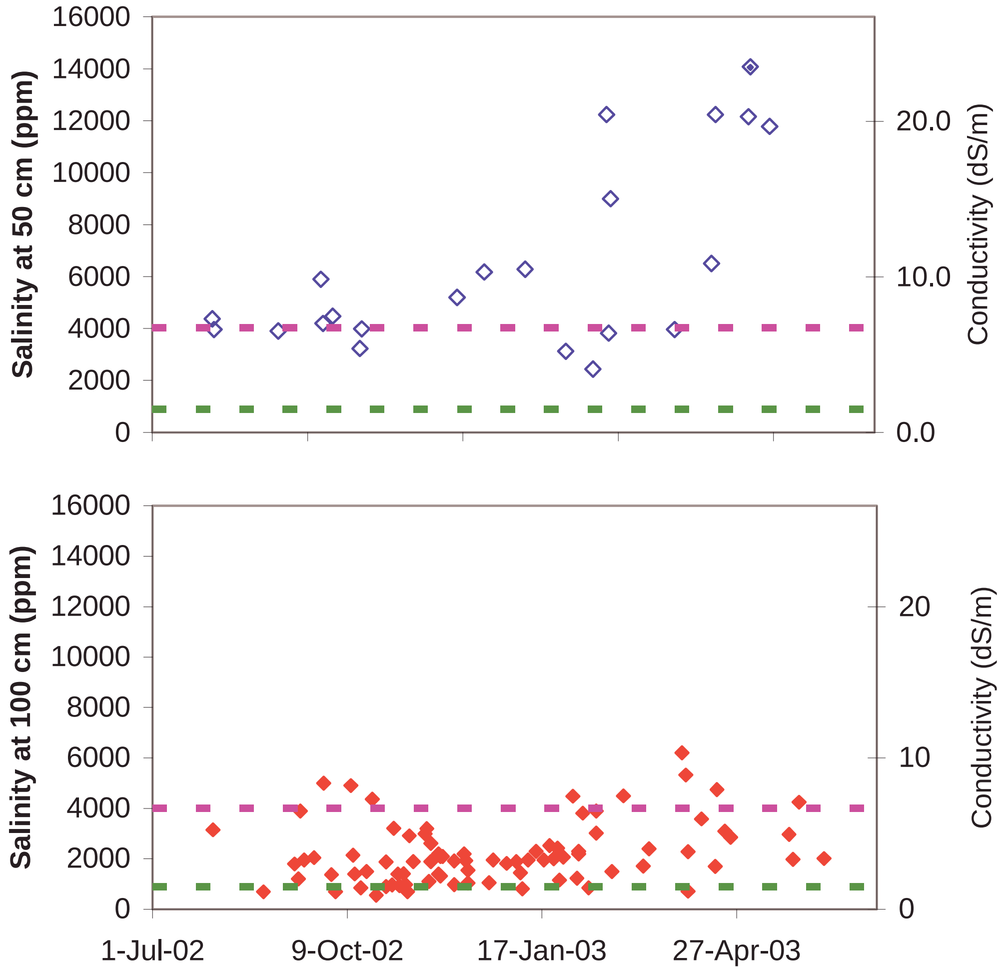

Figure 6. The salinity of water (left axis in ppm and right axis in dS/m) collected from the 50 cm FullStops (top) and 100 cm FullStops (bottom). The lower dotted line shows where yield starts to decline and the upper dotted line where yield could be reduced by 50% according to Mass and Hoffman 1977.

It is the salt concentration at 50 cm that is cause for concern. This concentration was three times the concentration at 100 cm. A couple of growers who requested a site visit because the shallow detector hardly ever responded, recorded even higher salinity levels at 50cm. The trend is clear; the fewer times a FullStop trips the higher is the salinity in the water sample that is collected when the FullStop is activated. This trend confirms that the FullStops are working as expected. If wetting fronts do not pass detectors, then salt must be accumulating above them.

At this stage we do not know how the salt measurement in the water collected by the FullStop relates to the salt level in the soil profile above it. It may be that salt is pushed down the profile in a concentrated 'band', much like sea weed is left in a line on the beach at the high tide mark. The FullStop would record a high salt value, while the soil above is closer to the salinity of the irrigation water. If this is the case the FullStops overstate the salt issue.

Conversely the FullStop may understate the problem because the FullStop is situated in the most leached position of a field, right underneath a dripper. Much of the salt would be accumulating between the drippers. In addition, the FullStop takes a sample during or shortly after an irrigation event. We do not know how well the salt in the soil-water has mixed with the lower salinity irrigation water. Lastly the saturated extract method used in the laboratory to determine how much salt is in the soil extracts water from soil that is at a suction of 1kPa or wetter (a saturated paste). The FullStop can take a sample at 2 or 3 kPa, so the salt is more concentrated. The salt thresholds for yield decline from a FullStop could be even lower than those in the published literature.

Part of the answer to the above questions comes from looking at sequential samples from the same detector (Figure 7). If salt was pushed down the profile as a concentrated band we might expect to see a high salt reading followed by a lower one, closer to the salinity of the irrigation water. In general we do not see this. The top graph of Figure 7 shows four sites where the salt readings keep getting higher, before a large "leaching" irrigation towards the end of the season. The lower graph shows steady or declining trends. In the lower chart, even in the case where salt was being flushed out of the profile it took several large irrigations to halve the salt concentration, raising the issue of leaching efficiency[5].

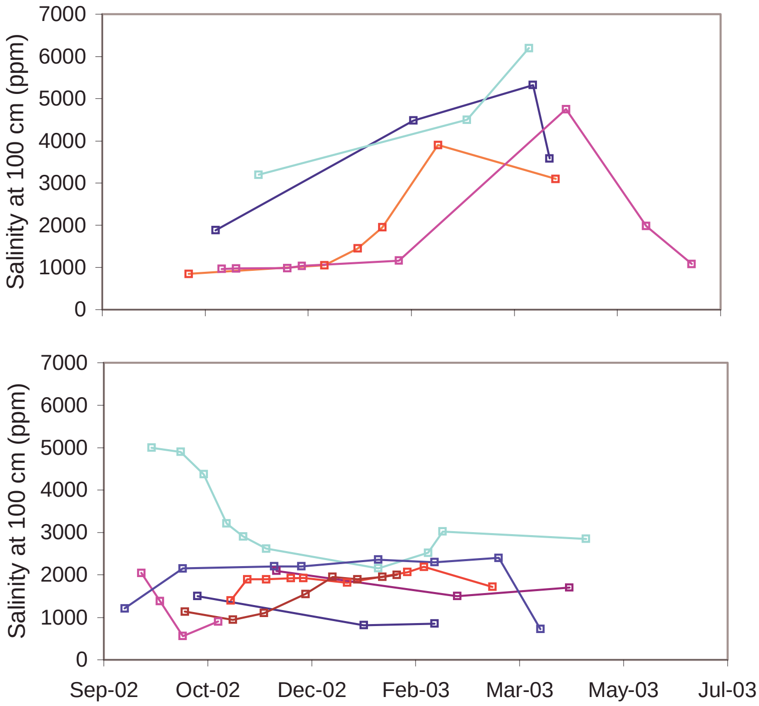

Figure 7. Trends in salt concentration for selected sites. Rising trends at 100 cm are shown in the top chart and steady or falling trends in the lower chart.

[5] Stevens R (2002). Interactions between irrigation, salinity, leaching efficiency, salinity tolerance and sustainability The Australian & New Zealand Grape grower and Winemaker Nov 2002 p 71

What this means

The four components of the strategy to improve the performance of irrigation at Angas Bremer are all directed toward avoiding over-irrigation. However the FullStop data shows that the most important issue may be salt accumulation in the rootzone, rather than the problem of rising, salty water-tables. In fact most wells monitored by growers show that the level of the shallow unconfined aquifer falls during the irrigation season. It is not surprising that the focus has been on avoiding excessive drainage since this is generally considered to be the main problem in irrigation areas. This study suggests that Angas Bremer growers may be applying too little water, or at least not getting the timing and amounts of individual irrigations right. Irrigation is about managing water and salt in the root zone; at Angas Bremer and presumably other regions that are minimising water use, managing salt in the root zone may be the priority issue.

A key question is to what extent we are seeing a seasonal effect. Although there is some trend toward rootzone salinity increasing through the season, the salt concentrations appear to start the season at relatively high levels, even at 50 cm depth. This may be due to a recent sequence of dry winters. Alternatively the salt levels may be creeping up season after season.

At this stage growers do not see salt in the root zone as a major problem. This might be because growers are aiming for yields much lower than the potential, and salt is part of the overall stress the vines are under. However soil salinity might express itself in other ways. A steady increase in the salt content of the harvested grapes may be occurring. It may be that the vines are using deeper, less saline water when the top 50 cm is wet but inhospitable for root activity because of salt. Problems may then occur when the deeper water runs out. For example some cultivars or rootstocks may suffer catastrophic collapse under extremely hot, dry conditions.

4. What we learnt about managing irrigation at Angas Bremer

4.1 *Understanding salt*

At least a quarter of the irrigators who were required to install FullStops at Angas Bremer never saw a float rise. They no doubt wonder if their record-keeping was worth doing. However there is a strong relationship between the response growers got from their FullStops and the salinity of the water captured. Those that did not activate deep detectors recorded high salt levels at 50 cm and those with little action at 50 cm recorded even higher salt levels. It may be that those who saw no action have the highest salt levels of all.

The rapid adoption of soil water monitoring equipment in the wine grape industry has overlooked an equally important part of the soil water equation – salt. A plant must not only attract water away from the soil particles (as measured by a tensiometer or gypsum block) but also from the salt. If a grower were irrigating and the tensiometer or gypsum block read close to zero, the soil is wet but the plant must still deal with the salt. The “suction” due to salt is measured using the same units as the tensiometer. For example, at the average salt concentration at 50 cm of 6500 ppm for Angas Bremer (Fig 5), the plant experiences 400 kPa when the tensiometer reads zero (Figure 8).

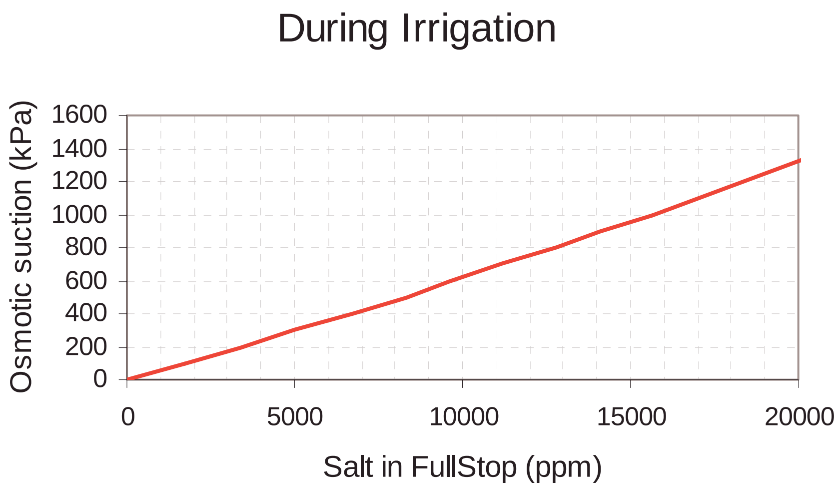

Figure 8. The relationship between the salinity of the water and the osmotic suction experienced by the vine roots. The above example assumes all the salt is NaCl[6].

Figure 8 is only half the story. Growers typically practise regulated deficit irrigation where the soil suction, as measured by a gypsum block, is allowed to dry to 200 kPa or drier. When water is removed from the soil the salt is concentrated. Figure 9 was calculated using real data for a soil at Angas Bremer, showing the total suction that the plant would really be experiencing for different salinities. If the salinity of the water in the soil was 600 ppm (the salinity of the irrigation water) then the plant would experience about 250 kPa when the gypsum block recorded 200kPa (50 kPa due to salt). However at 6500ppm, the average salinity we measured at 50 cm, the plant is experiencing a total of 1,000 kPa, not just the 200 kPa shown by the gypsum block because all the salt is concentrated into less water. In this case, as far as the vine is concerned, the soil is five times "drier" than the gypsum block measurement shows. More detailed work showing how salt builds up around individual roots during the transpiration process suggests the problem could be even worse[7].

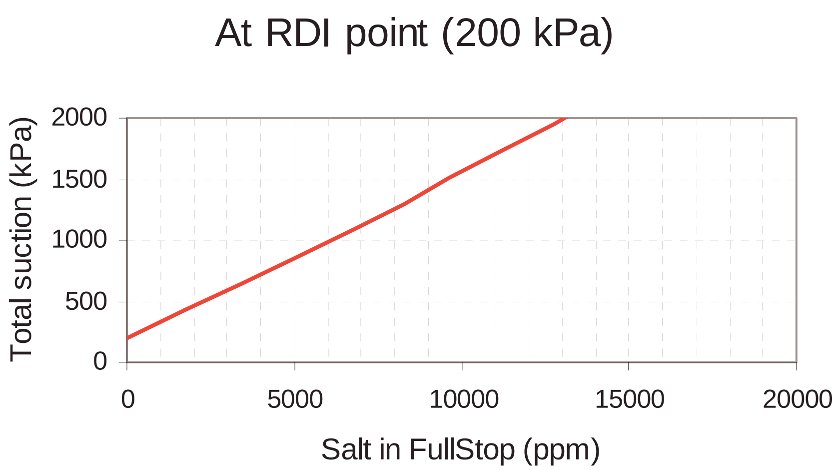

Figure 9. The total suction experienced by the vine as a function of the salt concentration recorded in the FullStop when a gypsum block reads 200 kPa.

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[6] USDA Agricultural Handbook No 60 (1954). Diagnosis and improvement of saline and alkali soils

[7] Stirzaker RJ and Passioura JB (1996). The water relations of the root soil interface. Plant, Cell and Environment 19, 201-208.

4.2 *Other scheduling devices*

Some growers who did not activate the FullStop reported that their independent measurements with gypsum blocks or capacitance probes showed the same result – wetting fronts were not reaching 50 cm. Others who did not activate the FullStop applied small amounts of irrigation at one time. Given the low total applications and the strong prospect that the soil would be dry before each irrigation, small applications would not travel very deep. In a couple of cases the FullStop response did not tally with another monitoring tool. However we question whether these devices can give meaningful water content or suction data at the salt concentration we observed, because salt at these high levels interferes with the measurement. Theory suggests there would be problems[8]. Moreover we have shown that the soil water monitoring equipment used by many farmers is only telling part of the story, because it does not provide a measurement of osmotic potential.

4.3 *Farm visits*

Farm visits made to growers who reported the FullStop "not working" provided the following insights:

- In two cases the 50 cm detectors had responded for the first time after rainfall and the salinities collected were 12 000 and 14 000 ppm, suggesting that very little water had previously passed the detectors and thus we would not expect them to have responded.
- A few growers provided gypsum block records that largely agreed with the FullStop record.
- At another site where the soil was mounded along the vine rows, it was clear that water from the dripper was running off the mound and into the furrow, so there was no way that the detector located under the dripper could respond.
- One grower reported that the "big" irrigation events overestimated the amount of water applied because filters generally blocked after a couple of hours.
- One grower measured the actual emitter output to be half that of the specifications and at another site the emitter above the Fullstop was blocked.
- At a sprinkler irrigated lucerne site, to keep them out of the way of cutting implements, the FullStops were placed beside the fence, at the edge of the field, where applications were likely to be lower than average.

There are still a number of sites not yet visited where the FullStop record differs from what we might expect from the irrigation record. Although research continues on the sensitivity of the Fullstop and possible modifications to the design (see Appendix 3) it appears most anomalies may fit in with one or more of the examples above. What is very clear is that growers appreciate the opportunity of discussing any monitoring data with advisors. The tools on their own are often not enough.

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[8] Scholl DG (1978). A two element ceramic sensor for matric potential and salinity measurements. Soil Sci. Am. J. 42:429-432.

Recommendations

Since the FullStop is a very new method for evaluating irrigation practice, the results above need to be supported by soil coring and salt measurements at different positions in the soil profile. Nevertheless some preliminary recommendations can be given.

Growers who activate 100cm deep FullStops and record salinities below 4000 ppm could change their irrigation practice to reduce the leaching fraction and allow the salinity caught in the FullStop at 100cm to rise above 4000 ppm. Those who record salinities above 4000 ppm at 50 cm could increase their leaching fraction to reduce the FullStop salinity at 50cm to below 4000 ppm. An increase or a decrease in the leaching fraction may involve changing only the timing and amounts of irrigation given at one time, not the annual total. Done correctly, salt can be moved to just below the active root zone where it can be stored. On the floodplain, when the rivers flood and the water-table rises, the stored salt may be flushed out and removed in the flood water.

Experience to date highlights the fact that there is an urgent need to review the arbitrary 15% leaching fraction being promoted by regulators in South Australia. The size of the target leaching fraction should be determined as a function of the salinity of the irrigation water, the sensitivity of the crop to salt and the capacity of the site for salt removal or salt storage.

The most fascinating insight from this research is the idea of irrigating to an upper and lower salt concentration as opposed to managing soil water content. For crops that are intentionally under-irrigated, precision in soil water monitoring is not required. For crops intentionally stressed at certain times, the soil water content data can be misleading, because the influence of salt increases as the water content declines.

Acknowledgements

We thank the Angas Bremer Management Committee for standing firmly behind the project and the growers of the district for being prepared to pay for the supply and installation of Wetting Front Detectors and for compiling a unique set of irrigation records.

APPENDIX 1: The FullStop wetting front detector

The FullStop Wetting Front Detector is comprised of a specially shaped funnel, a filter and a float mechanism. The funnel is buried in the soil within the root zone of the plants or crop. When rain falls or the soil is irrigated water moves downwards through the root zone. The water moves as thin films around the soil particles. When these films of water reach the buried funnel the flow is concentrated so that the soil in the funnel gets wetter and wetter as the cross sectional area of the funnel narrows. The soil at the base of the funnel becomes so wet that water seeps out of it, passes through the filter and is collected in the reservoir[9]. This water activates a light-weight rod which in turn operates an indicator flag above the soil surface.

The detector has no wires, no electronics and no batteries. It uses the convergence of the funnel to fill a container with water from a wetting front and this water triggers the float mechanism. A wetting front is the boundary between wet and dry soil that forms when the soil is irrigated. If the soil is dry before irrigation the wetting front will not penetrate deeply, because the dry soil absorbs most of the water. However if the soil is relatively wet before irrigation it cannot store much more water, so the wetting front penetrates to a deeper soil depth.

A syringe, attached to the tube, is used to extract the water sample. The salinity of the water sample is measured using an electrical conductivity meter.

Although the FullStop has recently become a commercial product (see below), the Angas Bremer irrigators had to use prototype versions. Two prototype versions were built. The first required 20 ml of water to activate a mechanical float, and had to be reset manually. This gave a yes/no answer as to whether a wetting front reached a particular depth. The second had a large reservoir that could hold 400 ml of water, so that the grower could record the total volume of water captured

[9] Stirzaker RJ (2003). When to turn the water off: scheduling micro-irrigation with a wetting front detector. Irrigation Science 22, 177-185.

APPENDIX 2: The FullStop – sensitivity

A funnel is used to collect water from a wide area and bring it down to a narrow area, thus concentrating the flow. However a funnel buried in the soil behaves differently from one above the ground. The movement of water in the films around the soil particles is concentrated as it flows down the converging funnel, but the soil around the funnel can empty it by capillary action. Capillary action occurs when one part of the soil is drier than another; water is pulled from wetter to the drier zone, be it downwards, sideways, or upwards. So the funnel causes water to accumulate and capillarity tries to even things out.

The balance between the concentration and capillarity effects means there is a set point at which a Wetting Front Detector fills faster than it empties. This determines the sensitivity. From a theoretical perspective we define the sensitivity as a certain soil suction. The version used at Angas Bremer will detect wetting fronts wetter than 2 kPa suction.

The rate that water might be moving past a detector without the detector being activated is determined by the sensitivity value and the type of soil. Two examples are given below: one for a clay soil and one for a fine sand. The “irrigation flux” is the rate that irrigation is being applied and the “capture rate” is the rate that the FullStop was collecting water (volume captured divided by the cross sectional area of the funnel.) In both cases the water must be arriving at 0.2 mm/h or more for the detector to trip.

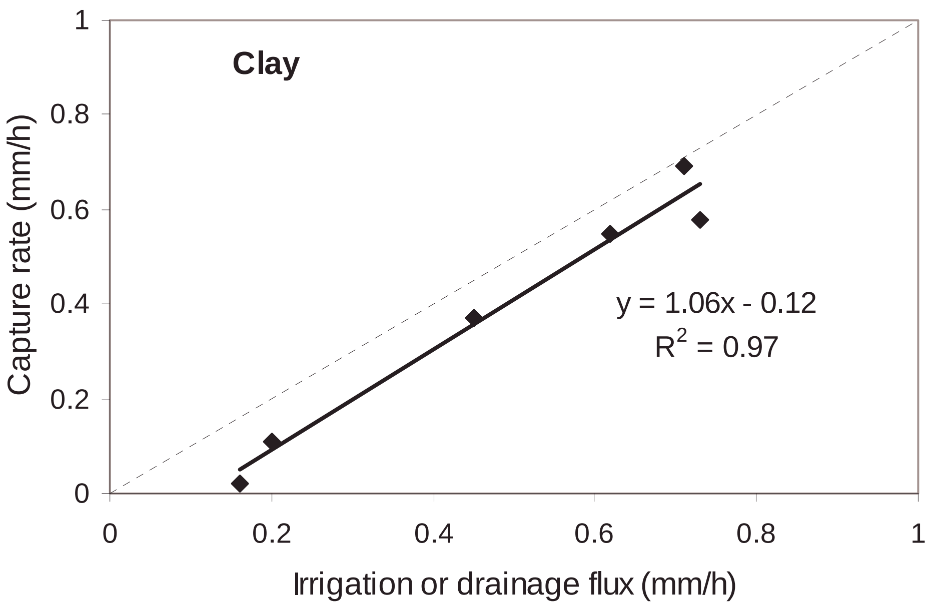

Figure 10. The rate that water is moving past the detector (Irrigation or drainage flux) compared to the rate water is captured at the base of the funnel for a clay soil. The dotted line represents the 1:1 ratio where the capture rate equals the drainage rate.

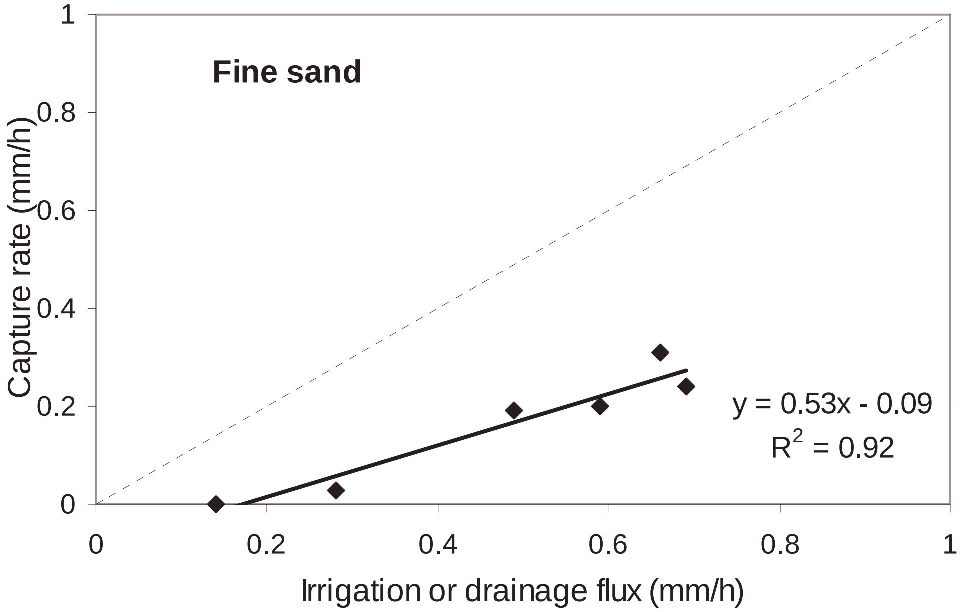

Figure 11. The rate that water is moving past the detector (irrigation or drainage flux) compared to the rate water is captured at the base of the funnel for a fine sand. The dotted line represents the 1:1 ratio where the capture rate equals the drainage rate.

A second important feature of the two graphs is the ratio of what the detector collects compared to what is moving past it. In the case of the clay soil the detector captures water at just under the drainage flux, so long as we are above the threshold of 0.2 mm/h. In the case of the fine sand the FullStop only collects water at about half the drainage flux, because some water is either moving around the funnel or being sucked out of the funnel.

There are three lessons from the above

1. The detector records the passage of a strong front i.e. the soil needs to wet to at least 2 kPa. It is possible that soil water content measuring equipment might show an increase from say 15% to 20% when a detector at the same depth does not respond. This slow wetting by a weak front is usually water redistribution down the soil profile after the irrigation has been switched off.
2. The detector is adequately sensitive for the majority of cases. Sprinkler systems cannot put water on at rates less than 3 mm per hour. A 2 l/h dripper over a wetting pattern with a diameter of 100 cm applies water at 3 mm/h. Apart from certain sandy soils, detectors respond drainage to flux rates of more than 0.2mm/hr.
3. Between different sites the volume of water collected in the detector cannot be directly related to drainage.

APPENDIX 3: The LongStop – changing the sensitivity

The philosophy underpinning the Wetting Front Detector project is to find a balance between simplicity, accuracy and cost. Experience from some sites has indicated that it might be advantageous to increase the sensitivity of a deep detector for certain situations.

Tests under laboratory conditions have shown that the funnel-shaped detector has a "trip" point at around 2 kPa or 20 cm of suction. This corresponded to a flux of 0.2 to 0.4 mm/h across a range of soil types (see Appendix 3). Since application rates by irrigation exceed 2 mm/h, we conclude that wetting fronts produced by irrigation will fall within the detection limits. However, water may move below the detector once the irrigation is turned off. Redistributing water can move at suctions below the detection limit and may result in significant quantities of water moving below the detector.

Since the operation of a detector is determined by the balance between convergence (filling) and capillarity (emptying), it follows that the sensitivity of the detector is determined by the diameter of the funnel and the depth from the rim of the funnel to the filter.

After irrigation or rain ceases, fronts get weaker as they move down through the soil, as each soil layer above retains some of the infiltrating water. When the flux is low, and the background suction around 2 kPa or drier, then a funnel shape is not the best option for producing free water from the unsaturated soil. The low flux means that convergence is not powerful, and the shallow depth of the funnel does not counter capillarity. A narrow, long wetting front detector that we call a LongStop may be a more suitable design for deep placements.

An example of LongStops installed at Angas Bremer

Hutchinson and Bond (2000)[10] describe a "tube tensiometer" that consists of a buried tube, 100 cm long, filled with diatomaceous earth and with a pressure transducer behind a filter at the base. The tube fills with water as water infiltrates into the open end. The

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[10] Hutchinson PA and Bond WJ (2001). Routine measurement of the soil water potential gradient near saturation using a pair of tube tensiometers. Aust. J. Soil Research 39; 1147.

tube is emptied by capillarity. By definition, the suction in the soil at the top of the tube at equilibrium is equal to the distance from the top of the tube to the water table within the tube. The height of the water table in the tube, if present, is measured by the pressure transducer at it base.

The LongStop[11] uses the same principle, although the degree of accuracy provided by the pressure transducer is not required for a Wetting Front Detector. Following the FullStop philosophy, we seek the simplest information that could help a farmer make an improvement to their irrigation management. Thus we set the tube length to the sensitivity required for a particular situation and then by means of the float, provide a yes/no response as to whether a front of a given strength has reached a given depth.

LongStops with a tube length of 60 cm were installed at a depth of 100 cm at four locations in Angas Bremer where deep detectors had not tripped. At three of these sites the LongStops did not respond either, showing that the soil suction was drier than 6 kPa. However at one location the LongStop captured water while the FullStop at the same depth did not. From September through till late November the LongStop contained sufficient water to activate the float, whereas the shallow FullStop was only activated on 3 occasions. We conclude that the suction at 100 cm was between 2 and 6 kPa suction.

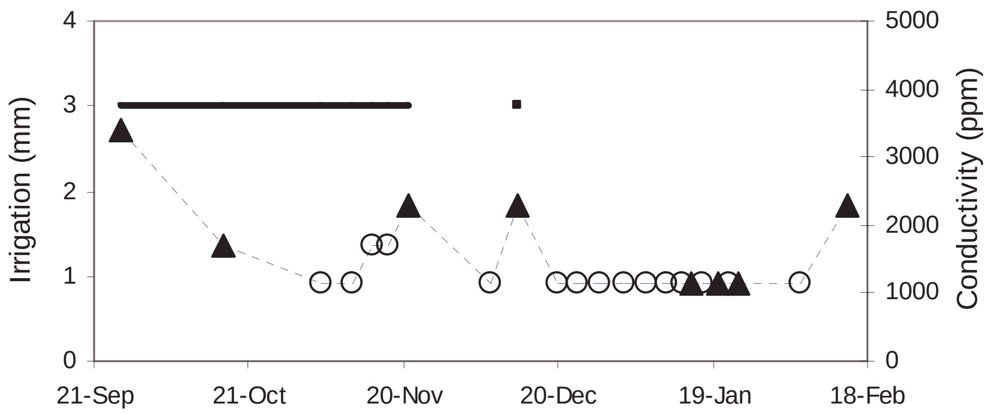

Figure 12. The graph plots the amount of irrigation water applied via drippers at each irrigation date. The marker for each irrigation day is an open circle if no detector was activated and a filled triangle if the 50 cm deep detector was activated. The solid horizontal line shows the period when the LongStop contained water.

[11]Stirzaker R, Stevens J, Annandale J, Maeko T, Steyn J, Mpandeli S, Maurobane W, Nkgapele J & Jovanovic N 2004 “Building Capacity in Irrigation Management with wetting Front Detectors” report to the Water Research Commission No. TT 230/04