Soil Moisture Monitoring: State of Play and Barriers to Adoption

Richard Stirzaker

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CRC for Irrigation Futures
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1. Summary

Australian scientists have been in the forefront of research into the measurement of soil water, the fundamental processes that drive the flow of water through soils and uptake by plant roots. Australian companies have turned much of this knowledge into commercial products, which are sold around the world. Over the last decade, tens of millions of dollars have been spent by State extension agencies to get these products more widely understood and used by irrigators.

We have good statistics on the use of soil water monitoring products by farmers because questions about irrigation scheduling are included in the agricultural census. The figures show that 13% of irrigators used soil moisture monitoring products in 1996, and this had increased to 22% by 2003. Whereas the increase in adoption rates is heartening, it is sobering to realize that almost four out of every five farmers who derive their living from using water do not measure how much water is in their soil. Moreover, the most recent statistics show that only 9% of growers plan future investment in soil water monitoring equipment.

This study was commissioned to find out why such excellent knowledge and products have only reached one fifth of the irrigation industry. Through discussions with researchers and extension workers, seven obstacles to the adoption of irrigation scheduling emerged. The most obvious barrier was that many irrigators were not convinced that irrigation scheduling should be a priority. They had limited data on the water they actually used, or should use, and there were few accessible champions to learn from. Second the entrenched culture was resistant to change, and inherited knowledge or the status quo was seen as adequate. Third, many lacked the confidence that investing in these new tools would pay off. Fourth there were structural barriers that made it hard to start, like schemes where water is not available on demand, limitations to farm layout, poor distribution uniformities and labour shortages. Fifth, there was concern over the complexity of the tool and the uncertainty of which tools were best suited to which applications.

The final two obstacles concerned the world views of the scientists and extension workers compared to that of the irrigators themselves. Scientists were more concerned about accuracy, whereas irrigators are concerned with managing risk. The technology transfer mindset of the extension worker wants to wean irrigators away from subjective experience onto the solid ground of objective quantification. Yet one of the most intriguing aspects of all the surveys is the central role that local knowledge plays in irrigation management. There are likely to be rich new insights at the interface between scientist and irrigator knowledge systems that are yet untapped.

Despite the relatively low adoption figures and the above barriers, there is cause for optimism. The 10% increase in adoption of soil moisture monitoring tools over the past 7 years has captured many of the leading growers and opinion leaders. These leaders have started to make the irrigation debate more quantitative. Many know how much water they use, how much they can save, and, by monitoring the soil water status, how to do it. Those who do not monitor are slowly being drawn into the quantitative debate, and are beginning to see how much room they have to move.
2. Conceptual Framework

The conceptual framework underpinning the filling and emptying of the root zone is well accepted. The soil has a full point termed the upper drained limit (UDL) which describes the maximum amount of water a ‘drained’ soil can hold. The UDL has a conventional definition – the water content after 48 hours free drainage from a covered soil after saturation – but this is not an intrinsic soil property because in reality it depends on a complex interplay between the antecedent water content, evapotranspiration rate and soil variability. The UDL term has practical value, in that it describes the water content after the large pores have drained, so drainage is a small component of the water balance (usually less than 1 mm/day). It does not mean that drainage stops when the soil reaches UDL; indeed clay soils can drain at measurable rates for months after reaching UDL.

The lower limit (LL) of water storage in the root zone is defined as the soil water content at which the plant wilts, even when the transpiration rate is negligible. The total root zone storage is the difference between the upper and lower limits multiplied by the rooting depth. The rooting depth is usually a function of the crop type and age, but can be severely modified by soil type and irrigation practice.

The refill point (RF) occurs somewhere between the UDL and LL and is often considered the half way point or 50% depletion. Total available water and readily available water to plants are calculated by multiplying (UDL-LL) and (ULD-RF) with the rooting depth for each growing stage of a crop.

Because different soils have differing particle size and pore size distributions they hold different amounts of water at the UDL, RF and LL points. Defining these levels in energy terms (tension) overcomes this limitation, because water moves down an energy gradient from soil to air through a series of soil and plant resistances.

Providing energy definitions for UDL (5 to 10 kPa), RF (30 to 50 kPa) and UDL (1000 to 2000 kPa) does not completely overcome the problem of defining water availability to plants. This is because satisfying plant demand for water involves moving water to roots. Therefore the hydraulic conductivity of the soil at a given tension, the density of roots and the availability of oxygen determine whether the plant can get water at the maximum rate it requires. Since hydraulic conductivity and oxygen availability are strongly influenced by tension, tension is used as a surrogate for availability.

The above explains why a plant in soil at 50 kPa could extract sufficient water when daily potential evaporation is 3 mm but not when it is 6 mm, or why the recommended irrigation point for a clay might be 50 kPa but a sand 30 kPa (hydraulic conductivity limits). It also explains why subsoils frequently stay wet when plants appear to be under water stress (root length too low and/or poorly distributed through the bulk soil).

3. Irrigation Scheduling

Irrigation may be supplemental to rainfall where a few strategic irrigations are given to coincide with sensitive growth stages. This is mostly confined to broadacre grain crops. More often crops are fully dependent on irrigation, with rainfall bringing some respite or possibly being a problem (waterlogging, nutrient leaching, disease control). Nevertheless the aim of irrigation scheduling is to apply water before the crop experiences an unacceptable stress and to replenish, but not overflow, the root zone.
storage. Obviously there are exceptions where deficit or leaching irrigations are required at specific times of the year.

Since the change in volumetric water content from UDL to RF is in the order of 5 to 15%, and many instruments can measure to 0.1% precision, the task of irrigation scheduling appears straightforward. Irrigation can be triggered at any time before the RF point, with the maximum amount applied equal to the deficit to UDL multiplied by the rooting depth.

3.1 Status of irrigation scheduling

We can examine the proposition that irrigation scheduling is suited to current management practice by looking at the adoption by farmers. The 1996 census revealed that 13% of irrigation farmers Australia-wide used a tensiometer, capacitance probe, neutron probe or private/public consultant, whereas 93% chose the “local knowledge/other” option (Table 1). Note that the census question invites growers to tick more than one box, because most farmers use more than one method of scheduling.

The tensiometer/probe/consultant category equates with objective or scientific methods, whereas the local knowledge option fits the model of subjective understanding and experience. By this definition the subjective approaches were favoured over the objective by over 7 to 1 in 1996. A massive vote of no confidence in irrigation scheduling as understood by the scientific community.

Table 1: The percentage of irrigation scheduling methods used in Australia and across different states and territories, based on the 1996 Agricultural Census.

<table>
<thead>
<tr>
<th>Percentage of irrigation scheduling methods used</th>
<th>Aust.</th>
<th>States and territories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSW</td>
<td>Vic</td>
</tr>
<tr>
<td>Tensiometers, capacitance or neutron probes, consultants.</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Calendar/rotational scheduling.</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Local knowledge and other.</td>
<td>93</td>
<td>96</td>
</tr>
<tr>
<td>Totala</td>
<td>120</td>
<td>121</td>
</tr>
</tbody>
</table>

a The data sums to more than 100% because multiple answers were permitted (from AATSE 1999).

Tracking adoption trends over the past decade is important for three reasons. First, a range of new instruments, mostly based on the capacitance method, hit the market during the 90’s (Charlesworth 2005). Second, cheaper loggers have made continuous water monitoring feasible at farm level. For the first time farmers could visualize what was happening below the ground during irrigation and the subsequent drying period. Third, several states put huge extra resources into irrigation scheduling through promotion, training, demonstrations and subsidies for purchasing soil water monitoring tools (Okello-Okanya 2004, Meldrum et al 2004).
The 2001 Agriculture survey asked the irrigation scheduling question in slightly more detail than 1996 as follows:

**Question 20c: Tools used to decide when to irrigate and/or how much water to apply**
- Evaporation figures/evaporation graphs
- Tensiometers
- Soil probes, e.g. neutron probe, Enviroscan
- Calendar/rotational scheduling
- Local knowledge/observation
- Other

The 2001 data separates tensiometers from capacitance and neutron probes and private or public service consulting. It also adds the new category of evaporation figures (Table 2).

A similar question was asked in the 2003 census (Table 3). Table 4 shows the change in adoption of soil water monitoring equipment over the period 1996 to 2003.

**Table 2: The percentage of irrigation scheduling methods used in Australia and across different states and territories, based on the 2001 Agricultural Census.**

<table>
<thead>
<tr>
<th></th>
<th>Aust. States and territories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSW</td>
</tr>
<tr>
<td>Tensiometers.</td>
<td>8</td>
</tr>
<tr>
<td>Soil probes (e.g. neutron probe Enviroscan).</td>
<td>8</td>
</tr>
<tr>
<td>Government/commercial scheduling service.</td>
<td>2</td>
</tr>
<tr>
<td>Evaporation figures/graphs.</td>
<td>7</td>
</tr>
<tr>
<td>Calendar/rotational scheduling.</td>
<td>12</td>
</tr>
<tr>
<td>Local knowledge/observation.</td>
<td>81</td>
</tr>
<tr>
<td>Other methods.</td>
<td>6</td>
</tr>
<tr>
<td>Totala</td>
<td>124</td>
</tr>
</tbody>
</table>

*aThe data sums to more than 100% because multiple answers were permitted (ABS 2004).

The census data shows a small increase of 3% in soil water monitoring over the five years between 1996 and 2001, obtained by summing the users of tensiometers, capacitance and neutron probes. The data for 1996 includes consultants, who were used by about 2% farmers – removing this would increase the adoption rate to 5% in 5 years (Table 4).
Table 3: The percentage of irrigation scheduling methods used in Australia and across different states and territories, based on the 2003 Agricultural Census.

<table>
<thead>
<tr>
<th>States and territories</th>
<th>Aust.</th>
<th>NSW</th>
<th>Vic</th>
<th>Qld</th>
<th>SA</th>
<th>WA</th>
<th>Tas</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage of irrigation scheduling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensiometers.</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>11</td>
<td>18</td>
<td>17</td>
<td>21</td>
</tr>
<tr>
<td>Soil probes.</td>
<td>13</td>
<td>13</td>
<td>10</td>
<td>10</td>
<td>30</td>
<td>9</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>Government/commercial scheduling service.</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Evaporation figures/graphs.</td>
<td>10</td>
<td>11</td>
<td>7</td>
<td>10</td>
<td>11</td>
<td>13</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>Calendar/ rotational scheduling.</td>
<td>13</td>
<td>11</td>
<td>15</td>
<td>12</td>
<td>15</td>
<td>15</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Knowledge/ Observation.</td>
<td>91</td>
<td>92</td>
<td>92</td>
<td>92</td>
<td>85</td>
<td>89</td>
<td>88</td>
<td>81</td>
</tr>
<tr>
<td>Other methods.</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>143</td>
<td>140</td>
<td>137</td>
<td>141</td>
<td>160</td>
<td>148</td>
<td>150</td>
<td>133</td>
</tr>
</tbody>
</table>

*The data sums to more than 100% because multiple answers were permitted (ABS 2005).

Adoption rates of soil water monitoring equipment increased by 6% between 2001 and 2003. The improved rates over the previous five years can no doubt be attributed to massive government investment in extension and training services, and the provision of subsidies to purchase new equipment.

Table 4: The change in the percentage of irrigators using soil water monitoring tools (tensiometers, capacitance or neutron probes) to assist in irrigation scheduling between 1996 to 2003.

<table>
<thead>
<tr>
<th>States and territories</th>
<th>1996*</th>
<th>2001</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>New South Wales</td>
<td>13</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Victoria</td>
<td>11</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>Queensland</td>
<td>11</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>South Australia</td>
<td>22</td>
<td>28</td>
<td>41</td>
</tr>
<tr>
<td>Western Australia</td>
<td>18</td>
<td>20</td>
<td>27</td>
</tr>
<tr>
<td>Tasmania</td>
<td>21</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Northern Territory</td>
<td>17</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td><strong>Australia</strong></td>
<td>13</td>
<td>16</td>
<td>22</td>
</tr>
</tbody>
</table>

*Includes consultant services

The above statistics still leave many questions unanswered. The question “which tool do you use to decide when and how much to irrigate” tells us nothing about the amount of equipment deployed and the skill with which it is interpreted. A farmer irrigating 10 blocks may only actually monitor two. Irrigation scheduling for some is the occasional look at a single tensiometer and for others a network of continuous soil water monitoring sites radioed back to the farm office.
We know that adoption rates are higher on the larger farms in each commodity class, so it may be that 22% of uptake covers a large proportion of irrigated land (for analysis of uptake by farm size, see Appendix 2). On the other hand the commodities that use much of the water, such as pastures, have the least intensive monitoring systems.

It is also unclear to which category farmers have assigned the gypsum block type equipment. We know that tens of thousands have been sold over the last decade, but they do not show up clearly in the statistics. Since gypsum blocks measure tension, they may have been categorized as tensiometers, and the statistics show gypsum blocks replacing gauge type tensiometers. Growers might also have categorized gypsum blocks as soil probes. This is more likely in 2003, than 2001 because the 2001 question gave examples of this category as neutron probes or Enviroscan. The example was dropped in 2003. Gypsum blocks may have been assigned to the category ‘other’, which comprised 6% in 2001 and 4% in 2003.

Table 5: The number and change in establishments irrigating and the irrigation scheduling methods used between 2001 and 2003 (ABS 2004, 2005). Values in brackets indicate percentage change.

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2003</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishments irrigating.</td>
<td>38,486</td>
<td>43,774</td>
<td>5,288 (14%)</td>
</tr>
<tr>
<td>Scheduling method</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensiometers</td>
<td>3,070</td>
<td>4,119</td>
<td>1,049 (34%)</td>
</tr>
<tr>
<td>Soil probes</td>
<td>3,229</td>
<td>5,806</td>
<td>2,577 (80%)</td>
</tr>
<tr>
<td>Government/commercial</td>
<td>780</td>
<td>1,122</td>
<td>342 (44%)</td>
</tr>
<tr>
<td>scheduling service</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation figures/graphs.</td>
<td>2,519</td>
<td>4,218</td>
<td>1,699 (67%)</td>
</tr>
<tr>
<td>Calendar/rotational</td>
<td>4,801</td>
<td>5,720</td>
<td>919 (19%)</td>
</tr>
<tr>
<td>scheduling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge/observation</td>
<td>31,268</td>
<td>39,799</td>
<td>8,531 (27%)</td>
</tr>
<tr>
<td>Other methods</td>
<td>2,173</td>
<td>1,667</td>
<td>-506 (-23%)</td>
</tr>
</tbody>
</table>

The 2001 census shows 38,486 establishments irrigation compared to the 43,774 in 2003. We do not know if this is a real increase in irrigators, or a difference in census method. The absolute numbers of irrigators using the various methods of decision making increases in every category, but the greatest increase occurs in the local knowledge/observation category (Table 5).

3.2 Scheduling straw man

Twenty years ago, two American researchers published a paper showing that with tensiometers, hooked up to an irrigation controller, they could save huge amounts of water and nutrients to turf with no human intervention in the irrigation decision (Augustin and Snyder 1984). All that was needed was to provide the correct depth of measurement and the trigger points to start or override an irrigation event. More recently, two other papers reporting on different types of sensors have shown the same thing (Stirzaker and Hutchinson 2005). Yet in the intervening two decades automatic scheduling is rare or unheard of. Why?
Most activities in everyday life analogous to filling and emptying a root zone are so well automated that they go unnoticed. When the hot water tap is turned on the cold water replenishing it in the tank lowers the temperature. The thermostat cuts in, powering the heating element till the set point is reached and then cuts out. The temperature sensor need only have a sensitivity of 1 degree and the change may be 10.

Many soil water monitoring tools have the required level of precision for automation, so the question arises why irrigation is typically not automated by a soil moisture sensor. We can only conclude that there is more to the irrigation decision than setting full and refill points and measuring the soil water status between them.

To glean deeper insights into the above conundrum a range of scientists, advisors and extension workers were consulted, both in formal workshop settings and through informal discussions. Seven obstacles to the adoption of irrigation scheduling emerged. The most obvious barrier was that many irrigators simply did not see the importance of scheduling. They had limited data on the water they actually used, or should use, and there were few accessible champions to learn from. Second the entrenched culture was resistant to change, and inherited knowledge or the status quo was seen as adequate. Third there was little confidence that investing in these new tools actually paid off. Fourth there were structural barriers that made it hard to start, like schemes where water is not available on demand, limitations to farm layout, poor distribution uniformities and labour shortages. Fifth, there was concern over the complexity of the tool and the uncertainty of which were best suited to which applications. Sixth there was acknowledgement that irrigators’ and scientists’ perspectives differ – in particular irrigators have to manage much more than just water. Lastly our whole extension model may be wrong.

Each of these seven points is addressed briefly below.

4. Seven obstacles to adoption

4.1 Entrenched culture

When a new irrigation area starts up, water is the last problem to be confronted. Markets, varieties, pests and diseases are the first hurdles to be overcome. Generally it takes a few decades before water becomes the focus, as scarcity, salinity, waterlogging, declining quality and other off-site impacts start to appear.

Most irrigation communities are ill-equipped to cope with such issues. They may have mastered agronomy, marketing, pathology and entomology, yet few grasp the essentials of hydrology. Many have come from a culture where water is taken for granted and are moving into a world of regulation and scarcity.

Hydrological problems, which typically impact well beyond the farm gate, have long time scales and large uncertainty, are very difficult to confront.

Some of the State based programs have actively recognised this. For example the NSW Waterwise initiative was about saying “change is coming, like it or not”, and through WaterWise the government will assist irrigators to adjust to that change. The intent was to apply a basic course across the myriad of water users and across the whole state because all irrigators would sooner or later be impacted by the change.

Thus the program had a social equity component as well as a goal of improving water productivity. If water productivity were the only goal then the focus would have been on working with the bigger growers in the high value industries. In the end a huge effort
was put in at the grass roots level to simply lift irrigator awareness about efficient irrigation and to challenge a culture that takes water for granted.

Culture can be turned around and act as a strong motivating force for adoption. In the Renmark area of SA, for example, it is the cultural norm to use capacitance probes and there is strong adoption. Other areas growing similar crops and with similar problems have low adoption because soil water monitoring is not seen as normal good practice and there is not the same social pressure to adopt. Some have noted that first generation irrigators are more eager to try out new equipment than those of the second generation, and ‘new regions’ show higher adoption than old.

4.2 Don’t see the importance of scheduling

Surveys on the amount of water used on different farms growing the same crops in the same area, rising groundwater, drainage volumes, and on-farm studies all point to the fact that there is substantial room for improving the efficiency of irrigation. Unfortunately we do not know how efficient we should be. There is not a lot of data around that show what the yield could be for a given quantity of water and few farmers systematically collect the relevant data that would inform them.

The contrast with dryland agriculture is striking. The widely held view that the productivity of dryland agriculture is rainfall limited has been shown to be a myth. Frequently the district average is less than half the yield attained by the best farmers, yet rainfall is not substantially different.

Quantifying water productivity for dryland crops has been most enlightening. The 20 kg wheat per mm per ha rule of thumb shows the farmer where they could be. If they are not, there is some other problem that prevents them from using water efficiently. The simple act of reviewing yield against in-season rainfall gives a clear signal that there is room to move, changes to be implemented and money to be made. This simple benchmark throws up the question – water is being used inefficiently –why?

Irrigated agriculture would benefit greatly from such a signal but it is more difficult than dryland for three reasons. First there are many more crops in more areas, making benchmarking all the more time consuming. Second, crop quality can be as important as yield, and water management is a key determinant of quality. Third, whereas most irrigators may know the amount of water used at farm level, few know the applications at field level, so the data cannot easily be related to yield.

Cotton seems to be the first of the industries where the terminology bales/ML is commonly heard; increasingly water productivity data (yield/ML) is heard in the wine, processing tomato and even grazing industries.

4.3 Investment doesn’t pay

Horticultural crops flourish in a moist and fertile environment. Irrigation removes the primary constraint to productivity, but nutrition is quickly revealed as the next constraint of fast growing, often shallow rooted crops grown in soils leached by irrigation.

Once the two major abiotic factors which limit production have been taken care of, the way is opened for a new set of biotic constraints; the now lush but defenceless horticultural crops must face the onslaught from competitor species (weeds), herbivory (insects) and parasitism (diseases). Thus, a whole array of other inputs are needed to back up the investment in irrigation and most of them are more expensive than water.
Even though water is the primary constraint to production, it is one of the cheapest to remedy. The cheap price of irrigation relative to the value of the crop gives rise to a steep input response curve.

A good farmer would want to operate somewhere around point B in Figure 1, with perhaps a little extra input to cover the uncertainty of where the flat part of the curve really begins. Herein lies the farmer’s dilemma.

Available water and nutrients, particularly nitrogen, fluctuate widely over short periods. Though the technology is available to monitor these changes, few farmers have the time, money or skill to carry out such monitoring in every irrigated field. Because of the uncertainty of position B, and the fear of sliding down the steep response curve towards point A, one strategy is to operate midway between points B and C. This is why well drained soils, with a wide plateau between B and C, are so desirable for horticulture. An extra 100 mm of water plus 50 kg of nitrogen during the season is cheap insurance for a crop with a gross value of between $5 000 and $30 000 ha$^{-1}$.

![Figure 1: A steep input response curve combined with variability, and uncertainty makes insurance irrigation look a better option than going for accuracy (from Stirzaker 1999).](image_url)

The problem of horticulture can be summarised thus: it is too difficult to know exactly how much water or fertiliser or pesticide to apply, and too risky to apply too little. Since inputs are cheap, they can be used in excess to provide insurance. If the excesses of horticulture degrade other resources, the cost of this strategy will be paid for by the community and the environment.

### 4.4 Hard to implement

In many cases scheduling is low on the priority list because other problems must be dealt with first. For example there are schemes where water is not available on demand or there are limitations to farm layout, poor distribution uniformities or labour shortages. In these situations accurate and timely information about soil water status cannot be acted upon and therefore has limited value.
A clear example comes from the South Australian Riverland. During the period when water was conveyed in open channels it was difficult to run an irrigation scheduling program. After the area was converted over to piped/pressurized system irrigation scheduling took off with 60% of growers in some areas using the scientific tools. Large reductions in drainage volume were realized.

Some industries have found it easier to start on the scheduling road than other. Cotton and grapes, for example, have been relatively strong adopters of irrigation scheduling. Others, such as sugar and vegetable production, lag behind. One reason for the uptake in cotton is that soil compaction and waterlogging can have serious impacts on yield. Unlike most irrigation industries too much water or too many irrigation events translate directly to profitability. A somewhat similar situation exists for wine grapes where controlled stress is required for quality.

Low adoption in the sugar and vegetable industries may relate to the fact that these industries typically have a large number of fields all at different growth stages. The number of sites that would be needed for representative monitoring and the time taken to analyse the data would be prohibitive, especially as irrigation is usually at a frequent interval.

Low adoption in the pasture industry is largely because the amount of irrigation applied and the irrigation interval are determined by the irrigation method, and the time it takes to get around the whole farm. The 4 day advance ordering for water in some areas is the major obstacle to scheduling.

Experience has shown that it takes an enormous amount of work to get scheduling to be part of standard industry practice and it usually takes a product champion many long years and financial risk to gain a foothold. The efforts put in by Irricrop, MEA and Sentek over the 70’s 80’s and 90’s for example, lasted much longer than any public initiative would, and required a single minded perseverance that would be difficult to sustain in the public sector.

Even today it seems that the adoption of scheduling in a particular region can be traced back to one or two individuals who could persevere through the problems and make information valuable to farm managers.

Irrigators have reported to extension staff that the lack of extension services, consultants, technical support and backup prevent them from taking the plunge. Others say they are confused by choice and do not understand the difference between the techniques. Lack of exposure, computer literacy and understanding how the technology works, are all considered barriers to adoption. One irrigator suggested a soil water monitoring rental shop - try before you buy.

### 4.5 Complexity and uncertainty

Issues of complexity and uncertainty are closely linked to 5 above. Reference crop evaporation follows a sine curve through the year. Leaf area development follows a sigmoid. The relationship between soil drying and soil water availability is exponential and the relationship between availability and conductivity approximates exponential again.

All these demand/supply functions interact, interspersed with the perturbations of rainfall and heat waves. Social researchers have shown that highly complex non-linear problems are frequently better solved by intuition than by engineering. It’s what we mean by a ‘good manager’ (Hayman 2001).
Added to the above are a number of different irrigation systems superimposed on a myriad of different soil types. It is no wonder that stories abound of growers burnt by experience by wrong choice of equipment, or right equipment installed or interpreted wrongly. In such situations rumours spread, fuelling the uncertainty.

Some of the State agency programs have tackled the problem head on by working with growers through the uncertainty period until a credible case study emerges. Numerous compelling testimonials are emerging that those who persisted with scientific tools reaped the rewards. Even exothermic reactions require energy to be supplied from the outside to overcome the activation energy hump before greater energy is released. It is doubtful that the activation energy hump has been breached across the majority of the irrigation industry.

4.6 Science vs farmer perspectives

Vanclay (2003) gives 12 reasons for the non-adoption of scientific techniques by farmers. Most relate to the failure of the scientist to understand the worldview of the farmer and the constraints under which they operate.

A farmer is managing a business that has multiple input response curves like that shown in Figure 1. A good farmer will always be looking for the areas where the business is on a steep part of the curve, because it yields the best investment on time and money. As stated previously, it is relatively easy to get to a ‘flattish’ part of the curve for irrigation, so the incentive for the farmer is often elsewhere (unless the supply of water is limited).

A scientist tends to focus narrowly on a problem, because concentrated effort is needed to find a solution. Frequently the concern of the scientist is about accuracy of the information as opposed to its usefulness to the decision maker. For example an international comparison of soil water sensors is showing that tools based on the capacitance and reflectometry methods are not nearly as accurate as the neutron probe, but irrigators are fast replacing the neutron probe with these ‘inferior’ devices (Evett et al. 2002).

Confusion between the accuracy and the usefulness of information arises because most farmers do not use tools in the way described under the heading “Framework” above.

Consider the following example: a cotton farmer uses a capacitance system with data radioed back to his office. Because he is an experienced farmer he knows when the time is approaching for irrigation, but there is value in holding off for a day or two if possible. The thought ‘I need to irrigate soon’ comes with uncertainty ‘am I too early or too late’. Because the soil water data in real time is on the computer the manager can immediately get a second opinion on the question. If the data on the screen tallies with his intuition/experience he makes a decision on when to water. If it does not, he drives out into the field and has a look at the crop and digs a hole. He still keeps the old neutron probe in corner of the office - which he knows is the most accurate tool – but this is only used if he still feels unsure.

In the above example the farmer uses the tool as a second opinion, with his experience being the primary source of information, because he knows that no tool is foolproof. However when his experience and the tool differ he is prepared to learn from the tool. The farmer is calibrating the tool to his experience (so he can tell other workers what to do) and allowing his experience to be informed by the tool. Critical data that the scientist often does not see, like the ‘look’ of the crop, disease pressures, yields and total water use provide the essential feedback that guide the process.
A related ‘farmer based’ method of scheduling is the recently imported “Help Line’ used for some drip irrigated perennial crops. An indicator of how the crop is performing is selected, such as the trajectory of fruit growth from fruit set to harvest. Three adjacent rows are chosen for monitoring. On the first row the drippers are replaced with those with half the application rate and on the third row with double the application rate. As the monitoring of fruit growth proceeds, the irrigator finds out whether growth of the ‘double’ irrigation row is pulling away from the normal, in which case irrigation over the whole farm and increased. If the ‘half’ row is keeping up with the normal, then irrigation is decreased.

An experiment of half and double the irrigation rate seems crude when there is equipment around that measures changes in soil water content to the nearest 0.1%, but growers who use this method almost always use the scientific tools as well. The Help Line brings with it additional benefits. First the system demands a form of benchmarking; the grower works out what the growth trajectory should be from experience and how much water it takes to get there, and there is a process of continual improvement. Second, since there are many factors influencing yield other than water, the growers find out in real time where they could be with a change to the scheduling strategy.

4.7 The wrong extension model

Irrigation scheduling involves setting a full point and a refill point and using a monitoring tool or model to tell you where you sit between these limits. The scientific framework used by most scientists and advisors to convey this information to irrigators often follows the linear transfer of technology approach. This approach assumes that scientists know best, new technology is needed and new technology is better than old. The linear transfer of technology approach tends to have a reductionist approach to research, follows a positivist paradigm, relies on trickle down, focuses on one innovation and contains very little feedback (Chamala 1999).

The gap between the science and practice of irrigation scheduling is traditionally seen as a failure in adoption that should be addressed by extension i.e. the problem has been solved so we must get the target audience to implement it. The trouble with this view is that it makes the assumption that the problem is lack of awareness of solutions on the part of the target audience. However it is possible that research and extension programs have been based on the worldviews of the problem solvers rather than their clients (Blacket 1996). For example, scientists take it for granted that irrigation farmers want to spend time and money on saving water, yet farmer surveys show that this aim is usually not near the top of their priority list.

Good examples are provided by Kaine et al (2005) and Lineham et al (2005), who showed that farmers are more interested in saving time and increasing flexibility than saving water. They showed that many farmers were well informed about the benefit of soil water monitoring tools, but other constraints prevented their adoption.

When the technology transfer approach is struggling, Blacket recommends that we pursue ‘learning based’ approaches. The learning based approach means that we take as our starting point the farmer’s current practice, implicitly valuing their existing skill level. However change incurs risk of under-irrigation, and so there needs to be a process during which information reduces the risk to the point that the farmer is willing to alter practices. In other words the value of the information to the farmer resides in its success in reducing risk to the point that the farmer is willing to change (Pannell and Glenn 2000).
An example of the approach above is that based on Kolb’s (1984) experiential learning cycle. This has four stages, the first being that the farmer decides to take concrete action to do something about their irrigation ‘problem’. This action could be the purchase of a simple soil water monitoring tool. Action leads to observation (look at the data) followed by reflection on the data (what does it say). The next steps are generalization (what’s the pattern) and conceptualization (what it means). From this point the farmer can begin active experimentation (if I do this then that should happen) leading back to observation and the cycle begins again.

This form of adaptive management requires skills that are in short supply in the irrigation industry.

5. Adoption by commodity for 2001 census

In 2001, the census for which the most detailed information was available for this study, there were only three commodities in which a scientific method of scheduling had been adopted by 10% or more of irrigators. These include tensiometers in the fruit/nut industry, tensiometers and soil probes in the grape industry and soil probes in the cotton industry (Appendix 1). Evaporation figures are the most common method for the rice, sugar, cereal and pasture industries but still attract less than 10% of growers.

Such statistics are alarming. Tensiometers are a proven, economical and accurate method, which have been freely available for over four decades. They have been consistently promoted by agencies and extension workers, but the adoption rate has stagnated below 10%. A similar case can be made for the use of evaporation figures/models. It is hard to know what adoption or extension model we can put to such data, other than to say that sound techniques have not captured the hearts and minds of the target audience.

The one bright light is the soil probe category, which is now predominantly made up of logging or manual capacitance probes. Recent data shows the adoption curve is still rising. Adoption is likely to continue as the word spreads, the technology gets cheaper and more reliable and confidence in using the equipment grows among irrigators.

Moreover the revolution in communication technology may set off another wave of adoption as information can be collected and delivered cheaply to an office computer without all the hassle of downloading in the field.

However, the optimistic notions above must be tempered. Even for industries like cotton and grapes, which we think of as major adopters, two out of three growers have rejected the help of a tensiometer, soil probe, evaporation figures and consultant in 2001.

6. Trends and barriers from the 2003 census

As stated previously, there was a distinct improvement in the adoption of irrigation scheduling tools between 2001 and 2003, no doubt due to the state-based water use efficiency programs. The 2003 census data provides a more progressive picture of the irrigation industry than the bald adoption of scheduling method statistics. Seven out of 10 irrigators implemented changes to improve irrigation practice over the past 5 years – 46% made the application system more efficient, 37% scheduled more efficiently and 15 % invested in on-farm soil moisture monitoring.
Table 6: Percentage of irrigators who have made changes in irrigation practice, 1998 – 2003, and who intend to make changes in the future (ABS 2005).

<table>
<thead>
<tr>
<th>Percentage change in irrigation practice</th>
<th>1998-2003</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change</td>
<td>30</td>
<td>56</td>
</tr>
<tr>
<td>One or more changes</td>
<td>70</td>
<td>44</td>
</tr>
<tr>
<td><strong>Type of change</strong>^a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>More efficient application system</td>
<td>46</td>
<td>22</td>
</tr>
<tr>
<td>More efficient scheduling</td>
<td>37</td>
<td>17</td>
</tr>
<tr>
<td>On-farm soil moisture monitoring</td>
<td>15</td>
<td>9</td>
</tr>
</tbody>
</table>

^Multiple answers possible.

The investment in soil water monitoring must include further investment by those already using the technology, because we do not see a 15% increase as a percentage of irrigators. Furthermore, many farmers claim to have improved the efficiency of irrigation scheduling without investing in soil water monitoring (or other scientific methods – Table 4). However, increasing irrigation efficiency comprises a diverse array of activities, including benchmarking activities, implementation of new equipment and on-going training. Queensland Rural Water Use Efficiency Program reports give insight into the range of activities involved and the participation of growers^1.

The future looks less promising. More than half the irrigators do not plan further changes in the foreseeable future, and only 9% think they will investing in soil water monitoring. We may be reaching a ceiling in adoption, or the figures may reflect ‘change fatigue’ following intensive government programs.

There are numerous barriers to implementing change, the most important being lack of finances, uncertainty over water allocations and uncertainty over water availability (Table 7). It is interesting to note that only 8% of irrigators doubt that implementing change would provide successful results – this demonstrates faith in the available technology. If we combine this with the 12% who will not implement changes because of age or poor health, then 80% of irrigators would invest in better practices, should the barriers be overcome.

Table 7: Percentage of irrigators identifying barriers to changing irrigation practice (ABS 2005).

<table>
<thead>
<tr>
<th>Percentage of irrigators</th>
</tr>
</thead>
<tbody>
<tr>
<td>No barriers</td>
</tr>
<tr>
<td>One or more barriers</td>
</tr>
<tr>
<td><strong>Type of barriers</strong>^a</td>
</tr>
<tr>
<td>Uncertainty over allocation</td>
</tr>
<tr>
<td>Inadequate water availability</td>
</tr>
<tr>
<td>Lack of finances</td>
</tr>
<tr>
<td>Lack of time or information</td>
</tr>
<tr>
<td>Age or poor health</td>
</tr>
<tr>
<td>Doubt about likely success</td>
</tr>
</tbody>
</table>

^Multiple answers possible.

7. Conclusion

The drought, the on-going water reform process and the massive extension programs carried out by some state agencies over the past five years could have left few irrigators unaware of the requirement to save water. We can safely conclude that the first two obstacles, "Entrenched culture" and "Don't see the value of irrigation scheduling" have been well and truly breached.

A number of industries (e.g. pastures, cereals and sugar) appear to be stuck at the next pair of obstacles – “Hard to implement” and “Investment doesn’t pay”. With adoption of all scheduling methods combined running at under 10% in 2001, it appears the scientific and extension communities have not been able to demonstrate how R&D can be effectively implemented. It seems the precursor problems - water is not available on demand, limitations to farm layout, poor distribution uniformities or labour shortages – must be dealt with before scheduling will really come into focus.

The fruit/nut, grape and sugar industries demonstrate greater adoption of scheduling tools as the size of holding increases (Appendix 2). This supports the contention that scheduling is too complex, expensive or time consuming for all but the larger growers who often have higher levels of education, higher incomes and flexibility with labour. Here we meet obstacles 5 and 6, “Complexity and uncertainty” and “Scientists vs farmer perspectives”. The challenge here is for scientists and advisors to understand how relatively straight forward scientific concepts manifest in a more complex production system.

Some basic statistics on water use in Australia will help to shape future efforts on improving irrigation efficiency (Table 8). Cotton is grown on only 1 to 2% of establishments that irrigate, so the industry is relatively easy to service. Conversely nearly half the irrigation establishments irrigate pastures under a wide variety of conditions. The average water use per ha is not high, but probably masks profligate water use in some regions and sub-optimal use in others.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Volume applied (ML)</th>
<th>Area irrigated (ha)</th>
<th>Application rate (ML/ha)</th>
<th>Establishments (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pastures</td>
<td>3,648,343</td>
<td>904,000</td>
<td>4.0</td>
<td>48</td>
</tr>
<tr>
<td>Cotton</td>
<td>1,525,502</td>
<td>234,000</td>
<td>6.5</td>
<td>1</td>
</tr>
<tr>
<td>Cereals</td>
<td>1,374,288</td>
<td>473,000</td>
<td>2.9</td>
<td>17</td>
</tr>
<tr>
<td>Cane</td>
<td>1,293,099</td>
<td>238,000</td>
<td>5.4</td>
<td>6</td>
</tr>
<tr>
<td>Fruit/nuts</td>
<td>659,893</td>
<td>138,000</td>
<td>4.8</td>
<td>20</td>
</tr>
<tr>
<td>Rice</td>
<td>615,375</td>
<td>44,000</td>
<td>14.0</td>
<td>1</td>
</tr>
<tr>
<td>Grapes</td>
<td>588,794</td>
<td>150,000</td>
<td>3.9</td>
<td>20</td>
</tr>
<tr>
<td>Vegetables</td>
<td>447,684</td>
<td>116,000</td>
<td>3.9</td>
<td>13</td>
</tr>
<tr>
<td>Nursery/other</td>
<td>250,104</td>
<td>81,000</td>
<td>3.1</td>
<td>11</td>
</tr>
</tbody>
</table>

a The percentage of establishments irrigating cotton and rice were 2% and 4% respectively in 2001.
b Establishments may irrigate a number of crop categories.

The statistic that continues to be puzzling is the seminal role local knowledge seems to play in the irrigation decision (Table 9). The increase in the use of scientific equipment does not seem to be reducing the role of local knowledge, suggesting that the use of the technology is more complex than it seems. The low use of consultants is also puzzling.
There are likely to be rich new insights at the interface between scientist and irrigator knowledge systems that are yet untapped.

**Table 9: The Change in the percentage of irrigators using irrigation scheduling decision aids between 1996 and 2003**

<table>
<thead>
<tr>
<th>Decision aid</th>
<th>% of irrigators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Water Monitoring Tool</td>
<td>11 16 22</td>
</tr>
<tr>
<td>Local Knowledge</td>
<td>91 81 91</td>
</tr>
<tr>
<td>Consultant</td>
<td>2(^b) 3 3</td>
</tr>
</tbody>
</table>

\(^a\) Multiple answers possible.  
\(^b\) estimate

To date the promotion and extension of soil water monitoring tools has largely operated on a technology transfer principle i.e. the technology ‘works’ and simply needs to be applied. The situation on-farm is more complex, requiring different approaches to ensure technology delivers results. When systems are complex, management interventions are best seen as a series of experiments, rather than the application of a solution. This kind of adaptive management is surely occurring on farms, but is poorly understood and exploited by irrigation professionals.
8. References


APPENDIX 1:
Irrigation scheduling method by crop category (2001 Agricultural Census)

Fruit and Nuts

Grapes

Vegetables
Other crops

<table>
<thead>
<tr>
<th>Method</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation figures</td>
<td>0%</td>
</tr>
<tr>
<td>Tensiometers</td>
<td>10%</td>
</tr>
<tr>
<td>Soil probes</td>
<td>20%</td>
</tr>
<tr>
<td>Scheduling service</td>
<td>30%</td>
</tr>
<tr>
<td>Calendar</td>
<td>40%</td>
</tr>
<tr>
<td>Local knowledge</td>
<td>50%</td>
</tr>
<tr>
<td>Other methods</td>
<td>0%</td>
</tr>
<tr>
<td>Non-Response</td>
<td>0%</td>
</tr>
</tbody>
</table>

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APPENDIX 2:
Influence of crop category and size of holding on irrigation scheduling method (2001 Agricultural Census)
Partner Organisations

Charles Sturt University

CSIRO

Goulburn-Murray Water

Australian Government
Land & Water Australia

NSW Department of Primary Industries

Queensland Government
Natural Resources and Mines

SARDI

South Australian Research and Development Institute

SunWater

The University of Melbourne

UNE
The University of New England

UniSA

University of Western Sydney
Bringing Knowledge to Life

Department of Primary Industries

Victoria

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