Modernisation of Irrigation in the Goulburn Murray Irrigation District: The Desirability of Improved Flow Rates On-Farm to Support Efficiency Initiatives

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Executive Summary

This report discusses the prospect of improvement in-field of surface irrigation in the Goulburn Murray Irrigation District (GMID). The Foodbowl Stage 2 investment proposes that benefits will accrue through the provision of improved levels of service from the irrigation supply system to farms. The predominant method of irrigation in the GMID is border check (surface irrigation) which is a significant feature of mixed farming in the GMID and the broader Victorian dairy industry. Whilst a variety of modern irrigation technology is available, affordable improvement of the existing method is appropriate.

Border check irrigation has value because it is adaptable to a variety of farming systems. Flexibility in the farming systems of a region is the major technical driver of resilient regional communities. Furthermore, recent technological developments offer a potential step change in the performance of border check irrigation, providing value to dairy and mixed farming systems alike.

Trials by two independent teams of researchers (UniWater, 2008; & Smith et al., 2009) have demonstrated volumetric savings of 17 per cent and 20 per cent, in improved border check systems for dairy pastures. This improvement can only be achieved where there is access to higher levels of service from the supply system. The bulk of this gain comes from faster watering, but also relies upon improved timing and control of the irrigation.

The capacity for the incumbent farming systems to take advantage of modernisation of the supply system is extensive. On-farm costs for the improvement of border check irrigation to take advantage of higher flow rates range from $1 396 /ha to $3 127 /ha in 2009 figures. Realisation of the water savings from this on-farm modernisation are likely to fully recover this investment in just two years. Further substantial benefits are likely to accrue from a variety of mechanisms, including increased production, reduced contributions to shallow groundwater, these are not quantified in this report.

Modernisation and improved levels of service from the supply system will be the enabling technology for these improvements on-farm. Coupling the infrastructure to effectively manipulate irrigation events, is the premise of modernisation in Foodbowl 2. The Foodbowl 2 Project must exploit the linkages available, through improvements to the physical delivery of water, into regional economics and environment to provide long term tangible benefits.
1. Introduction

The predominant method of irrigation in the GMID is border check (surface irrigation). Coupled with the supply infrastructure, both have the desirable feature of distribution of water via gravity. In the past border check irrigation has been a difficult technology to manage and operate to achieve high levels of performance. Trials by two independent teams of researchers (UniWater, 2008; Smith et al., 2009) have demonstrated volumetric savings of 17 per cent and 20 per cent, in improved border check systems.

Improved border check systems typically have higher flow rates than current practice, but improvement is not due to higher water flow rates per se, rather due to improved management and particularly managed flow regimes over the land being irrigated. Current on-farm infrastructure for border check irrigation is typically manually operated, or if automated, is on a time based program. Sophisticated automation would ideally respond in real time to changes in natural condition affecting the performance of an irrigation event.

Natural features such as soil type, moisture content and surface condition are amongst the variables which affect an individual irrigation event. Variability across fields, between irrigations, and across seasons has been very challenging for manual control of any type of system. This is also true of pressurised irrigation systems, but typically they have included some low level of automated control, hence reducing some of the variability. Opportunities for control of border check systems include manipulating the duration of irrigation, timing with regard to moisture deficit, dimensions of fields and bays, and in the longer term the avoidance of irrigation on certain soil types. Improving flow rate onto a bay combined with changes to duration has been proven to have a direct benefit in reducing the variability of infiltration.

To fully realise the benefits discussed in this report, the supply system must be able to respond in real time to the requirements of the irrigation event occurring on-farm. Current irrigation practice is already limited by an inflexible supply system. More sophisticated management of on-farm irrigation will lead to substantial water savings, if it is enabled by a modernised supply system. Modernisation is best considered as “improved levels of service” and includes:

- Consistent flow rates (in the scale of hours and days);
- Specified flow rates (i.e. actual as ordered);
- Higher flow rate capacity at the farm supply outlet i.e. to the farm; and
- Reduced ordering time (hours) and modification of orders to allow automated systems to respond.

Previous research has already flagged the need for improved levels of service. Uniwater 2008 reported “that maintenance of a more or less constant head in the on-farm channel network is critical for the efficiency of the irrigation system,” and provided a set of examples of fluctuations in supply to the on-farm system (Figure 1). Whilst no target flow rate is shown, the magnitude of fluctuations gives some idea as to the difficulty in achieving high levels of performance of irrigation on-farm.

![Figure 1.](image)

**Figure 1.** Non-uniform flow rates due to variability of head in the delivery channel during a selection of irrigation events at UniWater trial site. The bottom scale is time (days) (Source: UniWater, 2008).

Improvement can be captured through two related scenarios, which both rely on increased levels of service from the water supply system;

1. The use of automation hardware for border check coupled with new optimisation systems for irrigation events, which would circumvent the problems of control of surface irrigation.

2. Increasing the understanding amongst the operators of on-farm irrigation systems, of the mechanisms driving deep drainage, allowing them to focus on volumetric savings as a desirable goal in the farm system. Drought induced reductions in seasonal water allocations and increased water values provide new incentives for this outcome.

The GMID has the desirable feature of gravity distribution of water, and typically on-farm systems can also be low energy (border check / surface irrigation). Substantial
power distribution infrastructure would be required for widespread adoption of higher energy systems, coupled with the prospect of third party impacts of energy use.

1.1. Factors Affecting Efficiency

Soil type is an important factor affecting the performance of all irrigation types, and particularly surface irrigation. Surface irrigation can be manipulated to overcome variation in soil type, but to a limit. There is also a declining benefit from each additional unit of improvement, a term in economics referred to as “diminishing returns”. That is to say, each additional dollar spent on higher flow rates on sites with “poor” soils, only causes a smaller change than the first dollar spent. Investors typically want to know at what point the value of improvement becomes less than the cost. Research in the GMID has worked with a wide range of soil types, but there is not sufficient density of data with regard to irrigation performance to reveal the point of diminishing returns. This point would reveal the soil types which should be excluded from a program which proposes to improve surface irrigation.

Research in the GMID clearly shows that the whole farming system has a substantial effect on water productivity. Significant change will occur independently of the modernisation process. Different crops, species of pasture, and timing of production for seasons of the year, lead to a variety of production outcomes. These suit different types of enterprises, and it is important for farm systems to have versatile infrastructure to take advantage of new or slightly different market forces. Irrigation infrastructure which is modern, cost effective and easily manipulated allows the irrigated farm sector to respond to change in a sustainable way. In turn, third party impacts are reduced by farming systems which can be manipulated and optimised at least cost.

Reduced time between ordering and delivery, and improved layout due to decommissioning of isolated irrigation lands are secondary benefits which lead to improved enterprise management. The direct value of these benefits has not been measured for the GMID and experience from other situations is relied upon for the proposed extent of improvement (Smith et al., 2005).

Contemporary perennial horticulture/viticulture systems are typically pressurised and not constrained by flow rate to the same extent as broad acre irrigation systems (dairy and mixed). Despite the level of sophistication these production systems are typically run toward the surplus end of the supply spectrum to reduce risk, as the gains for “adequate” supply of irrigation water far outweigh the costs. Opportunities for improvement extend to better matching supply with the required irrigation deficit and
improving reliability of supply. These improvements can be achieved where high reliability of supply is implemented, and the consequent risks of under irrigation are reduced.

Annual production systems are all sensitive to excessive application of irrigation water at establishment, and annual horticulture is no exception. The mechanism for this loss is generic to many farming systems, improvement of the application efficiency for that first event can have as much impact as irrigation type on overall water productivity. The prospect for improvement in annual horticulture is very similar in extent to dairy and mixed farming systems.
2. Higher Flow Rates

The case for higher flow rates is based largely on the bay evaluations performed late in the 2008/09 irrigation season and reported in the paper by Smith et al. (2009) presented at the 2009 IAL conference in Swan Hill. Additional supporting data has been sourced from the published literature. These data show that higher flow rates lead directly to:

- Higher application efficiencies;
- Reduced deep percolation losses and hence reduced accessions to groundwater;
- Reduced time of water-logging and hence increased productivity; and
- Increased flexibility.

2.1. Efficiency

The evaluations indicated that application efficiencies could be increased on average by 20 per cent. By definition this means a volumetric saving of water of 20 per cent which will be available for other uses on- or off-farm. On the bays where the saving is made it also means a 20 per cent gain in water use efficiency, that is, the same production for 20 per cent less water.

Water use efficiency is a term which must be considered in the appropriate context. The current program of water reform in Australia is concerned with volumetric efficiency, whereas previous approaches at indices of WUE have captured improvement in terms of increased production or at a greater temporal scale (for example, DESE, 2004). Interpretation of work in this area suggests there is fourfold difference in water use productivity (milk fat + protein / ML) in the project area (Armstrong et al., 2000). However such broad indicators have confounded the path to improvement. Achieving outcomes for the Federal Program “Water for the Future”, requires a focus on the detail of irrigation system operation and management. Pursuit of application efficiency is a valid path to improvement in this context.

The evaluations performed in 2009 also indicate that most of this gain (approximately ¾) comes from a reduction in deep percolation losses. The remainder of the gain comes from a reduction in tail-water runoff. The benefits from reducing tail-water volumes are a reduction in losses (evaporation and seepage) occurring during recycling of the tail-water and a reduction in recycling (pumping) costs.
While most of the irrigations evaluated showed a benefit from higher flow rates the benefits are more pronounced on the more permeable soils. Here it is imperative that infiltration opportunity times are reduced to limit the depth of infiltration and the excessive deep percolation that can occur on these soils with long irrigation times.

The efficiency gains from higher flow rates were amply demonstrated by evaluation of Site 1, the results for which are described in detail in Smith et al. (2009). This site at Strathmerton is located on a moderately permeable soil. Inflow rate for the first irrigation was restricted by the capacity of its unusual pipe inlet structure to 4.2 ML/d and time to cut-off was 690 min. By reducing the time to cut-off to 600 min the application efficiency is increased from 72 per cent to 82 per cent. Both tail water runoff and deep percolation are reduced. Doubling the inflow rate from 4.2 to 8.4 ML/d and further reducing the time to 260 min increases the efficiency to 90 per cent. In this case there is no deep percolation loss and the runoff is 10 per cent. For the second irrigation at this site the pipe structure was replaced and the inflow rate increased to 14.7 ML/d however application efficiency was reduced to 57 per cent because the irrigation duration of 216 min was far too long. An irrigation duration of 125 min would have given an efficiency of 95 per cent.

It should be noted that the soil moisture deficits were higher (at 50 to 100 mm) for all the evaluations than would be the case in a high allocation year, when water is abundant. Typically for any flow rate, irrigations at high deficits (dry) are more efficient than those at low deficits. This means that:

- The results of the evaluations possibly understate the efficiency gains possible; and

- Even higher flow rates will be required to irrigate efficiently at the more usual deficits of 30 to 50 mm.

Extrapolation of the efficiency gains to the region as a whole is problematic. Nine successful evaluations is a very small sample on which to base any firm conclusions. However the results of the evaluations are supported by the results from the very much larger sample of furrow irrigation evaluations across the sugar and cotton industries (Raine & Bakker, 1996; Smith et al., 2005) where gains in excess of 20 per cent have been and are being achieved. The results are also consistent with estimates of deep drainage made by some workers in the GMID, for example Bethune (2004). If it is assumed that the irrigators who participated in the trial are at the better end of irrigation
managers then it is possible that the potential gains across this region might also be greater than 20 per cent.

The reduction in deep percolation losses has an additional benefit in a commensurate reduction in accessions to groundwater. With groundwater levels very much reduced across the region because of the present prolonged drought, the improved levels of irrigation efficiency would contribute significantly to the maintenance of these low levels. Reduced accessions would markedly reduce the pumping costs required to control groundwater levels (Bethune et al., 2004).

2.2. Inundation Time

Higher flow rates mean shorter irrigation times. This means that the time the surface soils are saturated following irrigation will be reduced. The reduced time of waterlogging ensures that the crop or pasture will begin to actively transpire and grow sooner following irrigation resulting in increased productivity and increased water use efficiency. This is supported by Uniwater (2008) who used the model Dairyman to show the production benefits from faster more efficient surface irrigation. They simulated an optimised border check system producing 2.2 t dry matter /Ml, with short irrigation times, compared to long times producing 1.66 t dry matter /Ml.

In bay irrigated pastures the degree and timing of this surface saturation is not all that well understood in the GMID. On low slopes and/or with thick pasture a considerable depth of water (possibly up to 20 mm in some cases) that would normally be assumed to runoff remains behind on the surface of the bay, trapped in the vegetation. This water ultimately infiltrates and some evaporates but it serves primarily to:

- Increase the depth of water applied above the soil moisture deficit or target depth;
- decrease the application efficiency below that predicted by the surface irrigation simulation models used in the evaluations; and
- prolong the period of saturation or water-logging of the surface layer of soil and most active part of the root zone, thus reducing potential production.

This can be countered by applying a smaller target depth which typically means an even higher flow rate and shorter time than would otherwise be required.

Reducing irrigation time (inundation time) reduces the opportunity for water to percolate below the rootzone. This effect is contrary to the valid observation (by farmers) that the
The surface of the soil “seals” soon after it is inundated, and intake to the shallow layers of the soil is restricted (crack fill). However this is by no means the full mechanism for water flow into and out of the rootzone. The magnitude of the effects observed is important; shallow infiltration may change from an initial rate of 500 mm/hr (over a few minutes) to a final rate of tens of mm/hr, whereas the rates of drainage at the lower edges of the rootzone are typically at the lower end of 0.1 – 20 mm/hr. Examples of infiltration rates from the GMID are shown in Figure 2. The rates of percolation deeper in the soil profile typically increase during extended saturation, depending on the chemical properties of the soil. A further complicating factor is the interaction with shallow ground water. Association of the effects observed on the surface, with a conceptual model of the drainage below the rootzone, is false.

**Figure 2.** Measurements made in VicDPI projects to explore the impact of length of watering and final infiltration on deep drainage below the rootzone (Source: Bethune et al., 2006.)

Certain soil types are unsuitable for surface irrigation, mainly due to the substantial differences in soil infiltration rates, be they the initial or final (steady state) rates. Once again the magnitude of these differences is difficult to grasp by casual observation. Further discussion of soil type and capability for irrigation is given in Figure 4 to 13.

Provision of higher supply rates to farms gives farmers greater flexibility to change irrigation or cropping practices in the future. For example, future change in cropping practices such as fodder cropping or future consolidation of properties might result in a desire for longer bays. On the heavier soil types in the region, for example Lemnos loam, long bays are feasible but will require higher flow rates to maintain application efficiencies.
It should be noted that increased flow rates alone will not deliver the benefits indicated above. Higher flow rates require more sophisticated irrigation management. Firstly, the soil moisture deficit prior to each irrigation must be known with a fair degree of accuracy. This means the application of soil moisture or ET based irrigation scheduling, not to determine when to irrigate but to determine how much to apply when the decision is made to irrigate. When combined with knowledge of the soil infiltration characteristic, a rational decision can be made regarding the most appropriate irrigation on-time.

Higher flow rates also mean shorter on-times. As times reduce the accuracy of that timing becomes more critical and if the required level of accuracy is not maintained it will inevitably result in lowered application efficiencies. The obvious and preferred way to ensure accuracy of irrigation on-times is through automation. Even without optimisation, automation has been shown to deliver higher efficiencies simply through more reliable control of the irrigation duration (Lavis et al., 2008; Uniwater, 2008).

On-farm automation presumes the sensing of features of the field in real time, and manipulation of the irrigation event as it occurs. Natural features such as soil type, moisture content and surface condition are amongst the variables which affect an irrigation event.

“Both spatial and temporal variations in the infiltration characteristic are a major physical constraint to achieving higher irrigation application efficiencies (Shafique & Skogerboe, 1983). Infiltration has been found to vary seasonally by a factor of up to four, with particularly dramatic differences in infiltration found between the first and second irrigation events (Elliott et al., 1983). Differences in infiltration throughout the season have been attributed to surface sealing, soil moisture content prior to irrigation, and the effect of mulch on flow retardation (Raine et al., 1998)” (Emdad et al., 2003)

Ultimately the management of irrigation water application is to refill the soil water content (SWC) of the rootzone, and soil water content of the rootzone is also influenced by rainfall. Automation can respond to this dynamic situation to reduce the events where SWC exceeds the retention capacity of the soil, which would otherwise result in deep drainage. An example of this scenario is shown in Figure 3, where Bethune et al. (2006) measured the soil water content of the rootzone and coupled with irrigation information were able to infer the extent of deep drainage. Clearly deep drainage is a dynamic feature of the study site. Irrigation events overlain by rainfall, and
extended irrigation, lead to positive values for deep drainage. At this site, this occurs as isolated events through both seasons, but as an extended event for January and February in the 05/06 season.

Reducing deep drainage is the major opportunity to improve irrigation in the GMID.

Variability across fields, between irrigations, and across seasons has been very challenging for the manual control of border check irrigation systems. On-farm automation overcomes many of these variability issues.

Finally determining the preferred flow rate and cut-off time for any field or farm (whether automated or not) requires evaluations of the irrigation performance under current irrigation management and also at the higher flow rates proposed. While it is desirable that this be done on all farms, once sufficient evaluations have been performed to adequately characterise a particular soil type, rules-of-thumb might be developed to design systems suitable for that soil type. Characterisation of soil types might also reveal the cost benefit of modernisation of surface irrigation, suggesting where different systems might be appropriate e.g:

- Manual control of irrigation on some sites with improved operator knowledge;
- Automated control relying on real time sensing; and
- Avoidance of border check irrigation altogether on some soil types.
3. Case Study of Improvement

Current valuations for on-farm improvement options in the GMID show that an upgrade of an on-farm system to fully automated border check would cost $2 972 /ha (Appendix A). This would achieve flow rates of 0.27 Ml /day /m width of bay. Further investment to achieve 0.40 Ml /day /m width (the point approaching typical peak application efficiency) would cost an extra $155 /ha for the on-farm infrastructure (Table 1). Features of this case study include; water and power available to within 100m of the field edge, outdated border check system in existence, 20 ha farm unit with bays of 450 to 250 m length and 8 irrigation events for the season.

Table 1. On-farm modernisation costs to take advantage of improved levels of service, as at December 2009.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>0.07</td>
<td></td>
<td>0.13</td>
<td>0.27</td>
<td>0.27</td>
<td>0.40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Outlets $/ea</td>
<td>700</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
<td></td>
</tr>
<tr>
<td>Automation $/ha</td>
<td></td>
<td>1,121</td>
<td>1,121</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel $/m</td>
<td>10</td>
<td>11</td>
<td>11</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Culverts $/ea</td>
<td>1,500</td>
<td>2,050</td>
<td>2,050</td>
<td>2,600</td>
<td></td>
</tr>
<tr>
<td>Other costs ($/ha)</td>
<td></td>
<td>228</td>
<td>228</td>
<td>228</td>
<td>228</td>
</tr>
<tr>
<td>Total</td>
<td>27,886</td>
<td>36,980</td>
<td>59,380</td>
<td>62,474</td>
<td></td>
</tr>
<tr>
<td>Total System $/ha</td>
<td>1,396</td>
<td>1,851</td>
<td>2,972</td>
<td>3,127</td>
<td></td>
</tr>
</tbody>
</table>

This would realise benefits in terms of water savings of 0.11 Ml /ha /irrigation event compared to a pre-modernisation system of reasonable flow (0.13 Ml /m /day), and 0.34 Ml /ha /irrigation event over a system of poor flow (0.07 Ml /m /day) which do exist in the GMID. The cumulative savings for a season would be 0.70 Ml /ha and 0.90 Ml /ha respectively. Simplistic valuations of the water savings alone indicated a payback period within 2 years. Further financial gains will certainly be achieved through productivity improvement.
Table 2. Potential on-farm water savings from modernisation and improved levels of service.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>flow Ml /m /day</td>
<td>0.07</td>
<td>0.13</td>
<td>0.27</td>
<td>0.27</td>
<td>0.40</td>
</tr>
<tr>
<td>Efficiency 400 M bay Case 3</td>
<td>48.4</td>
<td>62</td>
<td>69.6</td>
<td>69.6</td>
<td>72</td>
</tr>
<tr>
<td>moderate permeability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56 m wide bays</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saving %</td>
<td>13.6</td>
<td>7.6</td>
<td>0</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Volume applied (Ml/ha)</td>
<td>1.03</td>
<td>0.81</td>
<td>0.72</td>
<td>0.72</td>
<td>0.69</td>
</tr>
<tr>
<td>Saving Ml/ha / event</td>
<td>0.23</td>
<td>0.09</td>
<td></td>
<td></td>
<td>0.02</td>
</tr>
</tbody>
</table>

This case study serves to illustrate that the potential to take advantage of high flows on-farm is extensive. However there are limits to the scenarios explored here, and localised data is required to ensure each site achieves the proposed levels of performance. The approach shown here is appropriate to compare technologies for on-farm modernisation, but is not appropriate to quantify total costs for modernisation which will include connections to the supply system “backbone”.

The remaining sections of this report contain the detailed results from the evaluations and from the generic simulations conducted to evaluate the efficiencies possible from high flow rates. The methodology is described in Smith et al. (2009).
4. Evaluations

4.1. Parameters

Application efficiency is reported according to Equation 1;

Equation 1. Application Efficiency, $E_a$.

\[
E_a = \frac{\text{Volume in Root Zone}}{\text{Volume in Root Zone} + \text{Volume Deep Percolation} + \text{Volume Tail Water}}
\]

Equation 2. Storage Efficiency, $E_s$.

\[
E_s = \frac{\text{Volume in Root Zone}}{\text{Volume in Root Zone} + \text{Unsatisfied Deficit}}
\]

4.2. Efficiencies, Deep Drainage and Tail-water

The calculated performance for each of the irrigations on 7 sites is presented in Table 3. These show an average application efficiency of 69 per cent (with range 46 to 86 per cent). Tail-water runoff averaged 14 per cent (0 to 36 per cent) and the loss to deep drainage was a similar magnitude and is equivalent to an average depth of 12 mm (0 to 26 mm excluding sites 5 and 7 which had abnormally high drainage losses).

Site 5 is on a highly permeable soil (sand) and only managed to achieve an application efficiency as high as 46 per cent because of the very high deficit of 111 mm. This site is not suitable for surface irrigation. At site 7, the first irrigation of winter pasture, the soil was very dry and very permeable. With a relatively low flow rate the advance did not reach the end of the bay. A much higher flow rate would have been required to complete this irrigation. A lower efficiency is typical for the first irrigation of a season and has been observed frequently in furrow as well as bay systems (Raine et al., 2005).
Table 3. Summary of results from bay evaluations. $E_a$ is efficiency of application, $E_s$ effectiveness of meeting the storage requirement.

<table>
<thead>
<tr>
<th>Site/Test</th>
<th>Measured</th>
<th>Flow</th>
<th>Time</th>
<th>Vol Applied</th>
<th>Deficit</th>
<th>$E_a$</th>
<th>$E_s$</th>
<th>Runoff</th>
<th>Deep Drain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(ML/d)</td>
<td>(min)</td>
<td>(ML/ha)</td>
<td>(mm)</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
<td>(mm)</td>
</tr>
<tr>
<td>S1-1</td>
<td></td>
<td>4.2</td>
<td>690</td>
<td>0.988</td>
<td>71</td>
<td>71.7</td>
<td>100.0</td>
<td>14.4</td>
<td>13.7</td>
</tr>
<tr>
<td>S1-2</td>
<td></td>
<td>14.7</td>
<td>215</td>
<td>1.080</td>
<td>62</td>
<td>57.2</td>
<td>99.3</td>
<td>36.0</td>
<td>7.3</td>
</tr>
<tr>
<td>S2-1</td>
<td></td>
<td>8.3</td>
<td>435</td>
<td>0.999</td>
<td>53</td>
<td>54.1</td>
<td>100.0</td>
<td>21.7</td>
<td>24.2</td>
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<tr>
<td>S2-2</td>
<td></td>
<td>7.1</td>
<td>443</td>
<td>0.841</td>
<td>51</td>
<td>63.0</td>
<td>100.0</td>
<td>6.1</td>
<td>26.0</td>
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<tr>
<td>S3</td>
<td></td>
<td>11.2</td>
<td>324</td>
<td>0.918</td>
<td>101</td>
<td>86.0</td>
<td>78.0</td>
<td>14.0</td>
<td>0.0</td>
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<tr>
<td>S4</td>
<td></td>
<td>4.6</td>
<td>285</td>
<td>0.758</td>
<td>65</td>
<td>84.9</td>
<td>98.5</td>
<td>0.0</td>
<td>11.3</td>
</tr>
<tr>
<td>S5</td>
<td></td>
<td>10.0</td>
<td>612</td>
<td>2.426</td>
<td>111</td>
<td>45.9</td>
<td>100.0</td>
<td>2.5</td>
<td>125.2</td>
</tr>
<tr>
<td>S6</td>
<td></td>
<td>7.3</td>
<td>529</td>
<td>1.007</td>
<td>80</td>
<td>79.3</td>
<td>100.0</td>
<td>14.6</td>
<td>6.1</td>
</tr>
<tr>
<td>S7</td>
<td></td>
<td>2.5</td>
<td>295</td>
<td>1.519</td>
<td>&gt;100</td>
<td>54.1*</td>
<td>90.2</td>
<td>0.0</td>
<td>63.8</td>
</tr>
</tbody>
</table>

Note: * advance did not reach the lower end of the field

In one case (S3) the irrigation failed to fully satisfy the moisture deficit, that is, the storage requirement efficiency ($E_s$) was much less than 100 per cent. The infiltration curve for this site shows an initial rapid infiltration (crack fill) of 35 to 40 mm suggesting that the deficit of 101 mm estimated for this site may be incorrect. If a lower deficit is assumed the storage requirement efficiency ($E_s$) will increase in proportion (Storage requirement efficiency is a measure of how well the irrigation meets the objective of filling the rootzone).

Two additional evaluations (Table 4), on the heavy soil types of Lemnos loam and its equivalent Wanalta loam from west of Kyabram, were sourced from MacDonald and Austin (1998) and Uniwater (2008). The interest from these evaluations is that both were conducted at lower soil moisture deficits than those in Table 3 and both were inefficient with high runoff volumes. Although the magnitudes of the potential savings in these two cases are high by avoiding tail water runoff, only in one case was there scope for a significant reduction in the deep percolation loss.

Table 4. Additional evaluations from published literature.

<table>
<thead>
<tr>
<th>Site/Test</th>
<th>Measured</th>
<th>Flow</th>
<th>Time</th>
<th>Vol Applied</th>
<th>Deficit</th>
<th>$E_a$</th>
<th>$E_s$</th>
<th>Runoff</th>
<th>Deep Drain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(ML/d)</td>
<td>(min)</td>
<td>(ML/ha)</td>
<td>(mm)</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
<td>(mm)</td>
</tr>
<tr>
<td>Lemnos</td>
<td></td>
<td>5.1</td>
<td>234</td>
<td>0.697</td>
<td>33</td>
<td>44.2</td>
<td>91.8</td>
<td>52.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Wanalta</td>
<td></td>
<td>8.0</td>
<td>240</td>
<td>0.505</td>
<td>30</td>
<td>59.4</td>
<td>100.0</td>
<td>23.9</td>
<td>8.4</td>
</tr>
</tbody>
</table>

4.3. Performance Improvement

Strategies to improve the performance of surface irrigation typically involve reducing the irrigation time and/or increasing the inflow rate (for example, Smith et al. 2005). In the study being reported here the strategies and the potential gains vary across the
sites however a readily realisable gain in efficiency of 19 per cent is possible and ranges from 6 to 38 per cent for the different sites evaluated. This is illustrated in Figure 4. In this figure, the depth ratio (depth applied to the field expressed as a ratio of the deficit) provides an indication of the adequacy of the irrigation. A ratio greater than 1 indicates over-irrigation and deep percolation loss. In all cases only those efficiency gains that could be obtained without decreasing the storage requirement efficiency were considered. The target for the improved irrigations is an efficiency of 100 per cent and a depth ratio of 1, and it can be seen that in each case the result is nearer to that point. The potential gains shown in this figure typically require a doubling of the inflow rate, that is, an increase from a mean of 0.12 ML/d/m width (range 0.07 to 0.16) to 0.22 ML/d/m (0.12 to 0.32). The strategies for each site and the potential for improvement are provided in greater detail in Table 5.

Figure 4. Measured and readily achievable application efficiencies.

Table 5. Simulations of the improved irrigation events

<table>
<thead>
<tr>
<th>Site/Test</th>
<th>Change time only</th>
<th>Double inflow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2-1</td>
<td></td>
<td></td>
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<tr>
<td>S2-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td></td>
<td></td>
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<tr>
<td>S5</td>
<td></td>
<td></td>
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<tr>
<td>S6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemnos</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wanalta</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: * Not a valid strategy at this site, # Required a reduction in flow rate
Selection of the ‘optimum’ or preferred irrigation always requires compromise. Attempts to maximise application efficiency will inevitably result in reductions in the requirement efficiency (adequacy) and uniformity of the irrigation. Further, different irrigators will have different preferences in regard to minimising tail-water or deep percolation. Any recommendations will also have to take into account the irrigators willingness and ability to work with the shorter irrigation times required. In the present study, very much shorter times required for the improved irrigations are only likely with the adoption of automation.
5. Generic Simulations

5.1. Infiltration Curves

The cumulative infiltration curves (cumulative depth of infiltration versus time) for the seven trial sites are shown in Figure 5. These curves can essentially be subdivided into three groups namely, the very highly permeable (sandy) levee soil (S5), the moderately permeable soils (S1 & 4), and the heavier clay loams that exhibit a cracking behaviour (S2, 3, & 6) typified by Lemnos loam.

![Figure 5. Infiltration curves from the evaluations.](image-url)

Additional infiltration curves in Figure 6 were sourced from Austin and Prendergast (1997), Maheshwari and Jayawardene (1992), Uniwater (2008) and Lyle and Wildes (1986). Notable is the curve for the Nanneella fine sandy loam, a Group Ib soil and which provides data for a permeable soil not covered by the evaluations. Also notable in Figure 6 are the two curves for the Lemnos loam which were developed at soil moisture deficits of 70 mm and 33 mm respectively and the Wanalta loam also at a soil moisture deficit of 30 mm.

From the infiltration curves in Figure 5 and Figure 6, standard infiltration curves (Figure 7) were selected to represent the main infiltration groups identified in the study, namely:

- A very highly permeable (sandy) levee soil (Case 4);
- The permeable sandy loams as represented by the Nanneella fine sandy loam (Case 5);
- The moderately permeable loam soils (Case 3); and
- The heavier cracking type (Cases 1 and 2).
For the cracking soils the infiltration curve is well known to be a function of the soil moisture deficit at the start of the infiltration run, with the initial near instantaneous infiltration a direct function of the crack volume. Cases 1 and 2 represent deficits of 40 and 70 mm at the start of the infiltration run, respectively. For the permeable soils the relationship between infiltration and deficit is not clear and for the purposes of this study no relationship is assumed to exist.

5.2. Results of Simulations

A series of simulations were carried out to investigate the relationship between application efficiency $E_a$ and inflow rate. For each of these soils in Figure 7 the simulations considered bay lengths of 200, 400, and 600 m. A target tail-water runoff of 5 per cent was used to ensure that all irrigations easily reached the end of the bay,
hence the maximum possible application efficiency is 95 per cent. For cases 3, 4 and 5 a soil moisture deficit of 50 mm was assumed.

The results for the five soils are presented in Figure 8 to Figure 12. These show the maximum efficiencies attainable for the various soils, bay lengths and soil moisture deficits. All show diminishing gains for increasing flow rates, making the choice of target efficiency and preferred flow rate somewhat subjective. It should be noted that as flow rates increase the irrigation on-time required decreases rapidly for all bay lengths (Figure ) and the likelihood of under-irrigation (ie, $E_s < 100$ per cent) increases. This suggests a preferred flow rate less than that required for maximum efficiency.

Figure 8.   Application efficiency versus inflow rate for Case 1 – cracking soil, deficit 40 mm.

To place these results in context the inflow rates from the case studies are:

- Average measured flow rate 0.12 ML/d/m width (4.8 ML/d for a 40 m wide bay); and
- Average flow rate for the improved irrigations 0.22 ML/d/m (8.8 ML/d for a 40 m wide bay).

These compare to a flow of about 0.25 ML/d/m (10 ML/d for a 40 m bay) required for maximum efficiency for a 400 m long bay on the heavy soils (Figure 8 and Figure 9) and in excess of 0.5 ML/d/m (20 ML/d for a 40 m bay) on the more permeable soils (Figure 10 to Figure 12). It should be noted that these generic simulations were conducted using lower soil moisture deficits than those applying during the field evaluations. This results in higher estimates of the flow rates than were required to optimise the actual irrigations.
Figure 9. Application efficiency versus inflow rate for Case 2 – cracking soil, deficit 70mm.

Figure 10. Application efficiency versus inflow rate for Case 3 – moderately permeable soil, deficit 50 mm.

It is obvious from the results that the very sandy soil (Case 4) is unsuitable for surface irrigation and that alternative methods should be employed on those soils. The permeable sandy loams (Case 5) probably define the limit of permeability for successful surface irrigation and in these soils moderately efficient irrigation is only possible with high flow rates, short bays and a large deficit prior to irrigation.
Figure 11. Application efficiency versus inflow rate for Case 4 – very highly permeable soil, deficit 50 mm.

Figure 12. Application efficiency versus inflow rate for Case 5 – permeable soil, deficit 50 mm.

Figure 13. Application efficiency versus soil moisture deficit for Case 3 – moderately permeable soil bay length 400 m.
Figure 14. Irrigation duration versus flow rate for Case X.
6. Conclusion

Improved levels of service for the supply of irrigation water to farms in the Goulburn Murray Irrigation District has the prospect of greatly improving efficiency. The mechanism for this is through the increased performance of the common method of irrigation, border check. The improvement manifests itself as savings in irrigation water, and the potential gains are extensive.

Directing investment which leads to improvement in border check irrigation is a realistic strategy for modernisation of irrigation in the GMID. The work reported demonstrates the mechanism by which improvement can be achieved, typically faster watering. The ability of the farm sector to take advantage of these improved levels of service, would require investment at the lower end of the capital cost options of the target farm systems. Investment in border check systems is likely to represent better value compared to other forms of irrigation. Border check irrigation is a flexible technology which avoids locking the farm sector into high input systems (energy and capital), and provides a certain extent of future proofing.
References


These cost estimates are based on latest industry costs where possible. A number of assumptions must be made. In particular, it is possibly not entirely relevant to work on 20Ha as the basis for costing and then averaging out costs on a per hectare rate. This favours works which tend to be billed on a “per hectare” basis such as laser grading and penalises works that have significant up front costs such as reuse systems or drip irrigation where the pumping establishment costs could serve a much larger area with little or no change to the initial outlay. Farms that are going to make larger investments in layout, large flow irrigation or conversion to say SDI are likely to be larger than .20 Ha

Many items are very cost sensitive and site dependent. The topography defines much of the layout and hence pipe and channel work required with surface irrigation. Soil types and property shape will determine lateral spacing and the number of mainlines and submains.

Accordingly the “test farm” is assumed to be square with medium clay soils suitable to all types of irrigation. The topography is such that a defined drainage line cannot be graded out of existence. This may be typical of a Cohuna/Leitchville or Goulburn Valley farm but perhaps not a Kerang or Pyramid Boort broad acre property.

Costs for SDI and Horticulture taken from “industry” averages. Real figures are hard to get. Contingencies have not been included but 15% could be added to all costs.

Assumptions:

- Farm 20 Ha, square.
- Existing farm is lasered to current standards but is old and farm channels and structures were never properly updated and tend to be undersize, old and leaking. Pasture requires renovation and lasering now 15 years old. All in need of upgrade.
- Water supply is at the north west corner of the farm
- 3 phase power is available 100m away from existing adequate transformer on pole.
- 12 bays existing and 12 bays in new layout
- 894m channel
- 700m drain
- Flow rates, - 10ML/day.
- All costs are GST exclusive

Sketch Plan Existing and Proposed Layout for Surface Irrigation.

Surface Irrigation Components

**LASER LEVELLING**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Preparation, clearing</td>
<td>$100/ha</td>
</tr>
<tr>
<td>Earthworks 400m³/ha @ $2</td>
<td>$800/ha</td>
</tr>
<tr>
<td>Ripping Disc Final Grade</td>
<td>$450/ha</td>
</tr>
<tr>
<td>Say 100m³/ha retopsoiling @ $1</td>
<td>$100</td>
</tr>
<tr>
<td><strong>Cost/ Ha</strong></td>
<td><strong>TOTAL</strong></td>
</tr>
<tr>
<td></td>
<td><strong>$1,450/ha</strong></td>
</tr>
</tbody>
</table>
RE-USE SYSTEM

Capacity say 0.075 x 20 = 1.50ML
Volume to excavate say 2000m\(^3\)
Earthworks $2.50/m\(^3\) $ 5,000
Culverts say 2 @ $700 $1,400
Pumps & diesel motor/ 6ML/d $ 8,000
Pit inlet pipes shed $ 4,000
Installation $ 2,000

TOTAL COST $20,000

Cost/ha $1,020

SURFACE IRRIGATION SUPPLY TO BAYS

1. Typical- 10ML/ Day Flows

12 Bay outlets Padman E3 @ $700 $ 8,400
894m channel @ $10 $ 8,940
4 Culverts @ $1500 $ 6,000
1 Channel Stop @ $1,500 $ 1,500
Push in old farm channel 0.9Km @ $1,500 $ 1,350
Remove old structures 17 @ $100 $ 1,700

TOTAL COST $27,890

Cost/ha $ 1,395

2. High Flow- 20ML/day flows

12 Bay outlets 2.4w x 0.5d $14,400
894m channel @ $12 $10,728
4v culverts @ $2600 $10,400
Max Flow/channel stop @ $1500 $ 1,500
Push in old farm channel 0.9Km @ $1,500 $ 1,350
Remove old structures 17 @ $100 $ 1,700
3. **Pipe & Riser- Typical Flow – 10ML/day**

- Pump & electric motor VSD & ancillaries: $20,800
- 100m Underground power: $10,000
- 894m x 315OD PN4 Floodpipe @ $41/m: $36,654
- Installation 894m @ $12/m: $10,728
- Push in old farm channel 0.9Km @ $1,500: $1,350
- Remove old structures 17 @ $100: $1,700
- Riser Manual 12 @ $700: $8,400

**TOTAL COST** $89,632

**Average Cost/ha** $4,481

4. **Pipe & Riser- High Flow- 20ML/day**

- Pump and electric motor VSD & ancillaries: $37,450
- 100m Underground power: $10,000
- 894m x 450OD PN4 Floodpipe @ $89/m: $79,566
- Installation 894 @ $12: $10,728
- Push in old farm channel 0.9Km @ $1,500: $1,350
- Remove old structures 17 @ $100: $1,700
- Riser Manual 450 12 @ $900: $10,800

**TOTAL COST** $151,594

**Average Cost/ha** $7,580

5. **Automation Of All Surface Supply Systems**

- Assume base cost: $5,000
- Plus $1,200/outlet x 12: $14,400
- Conversion & installation: $3,000

**TOTAL COST** $21,400
TOTAL COST $22,400

Average Cost/ha $ 1,120

CENTRE PIVOT

Assumptions:

- Some regrading, discing etc required prior to work proceeding
- Old channels and structures will be removed
- The pivot covers 20 ha yet existing farm infrastructure is same as for 20ha square farm (which of course is not realistic)
- This pivot would actually require a square area of 25.4 hectares.

Site Preparation Costs

Remove old channels 0.9km @ $1500 $ 1,350
Remove old structures 17 @ $100 $ 1,700
Site Preparation, clearing $100/Ha $ 2,000
<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthworks say 100m³/ha @ $2- minimal earth</td>
<td>$4,000</td>
</tr>
<tr>
<td>Ripping, discing, final grade @ $400/ha</td>
<td>$8,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$17,050</strong></td>
</tr>
<tr>
<td><strong>Pivot Costs</strong></td>
<td></td>
</tr>
<tr>
<td>Pump Pit, Shed etc</td>
<td>$6,000</td>
</tr>
<tr>
<td><strong>Underground Power</strong></td>
<td></td>
</tr>
<tr>
<td>Electrician</td>
<td></td>
</tr>
<tr>
<td>Pump and Motor</td>
<td></td>
</tr>
<tr>
<td>Control Gear</td>
<td></td>
</tr>
<tr>
<td>Basic Filtration</td>
<td></td>
</tr>
<tr>
<td>Mainline- 316m x 150 PN63. PVC</td>
<td></td>
</tr>
<tr>
<td>Installation 316m @ $12/m</td>
<td></td>
</tr>
<tr>
<td><strong>Pivot Installed</strong></td>
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</tr>
<tr>
<td><strong>PIVOT COST</strong></td>
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</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td><strong>$166,650</strong></td>
</tr>
<tr>
<td><strong>Cost/ Ha</strong></td>
<td><strong>$8333</strong></td>
</tr>
</tbody>
</table>

**DRIP IRRIGATION (PASTURE)**

**Assumptions**

- System delivers 10mm/day
- Lateral Spacing 1m
- Dripper Spacing 0.5m
Site Preparation Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remove old channels 0.9km @ $1500</td>
<td>$1,350</td>
</tr>
<tr>
<td>Remove old structures 17 @ $100</td>
<td>$1,700</td>
</tr>
<tr>
<td>Site Preparation, clearing $100/L</td>
<td>$2,000</td>
</tr>
<tr>
<td>Earthworks say 100m3/ha @ $2</td>
<td>$4,000</td>
</tr>
<tr>
<td>Ripping, discing, final grade @ $400/ha</td>
<td>$8,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$17,050</td>
</tr>
</tbody>
</table>

SDI Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground Power</td>
<td>$10,000</td>
</tr>
<tr>
<td>Pump Pit, Shed etc</td>
<td>$6,000</td>
</tr>
<tr>
<td>Electrician</td>
<td>$2,000</td>
</tr>
<tr>
<td>Pump and Motor</td>
<td>$</td>
</tr>
<tr>
<td>Controller? - Manual System</td>
<td>$</td>
</tr>
<tr>
<td>Filtration</td>
<td>$</td>
</tr>
<tr>
<td>Mainline</td>
<td>$</td>
</tr>
<tr>
<td>Valves</td>
<td>$</td>
</tr>
<tr>
<td>Sub Mains</td>
<td>$</td>
</tr>
<tr>
<td>Laterals</td>
<td>$</td>
</tr>
<tr>
<td>Flushing Mains</td>
<td>$</td>
</tr>
<tr>
<td>Installation</td>
<td>$</td>
</tr>
<tr>
<td>SDI COST (say $9,000/ha)</td>
<td>$180,000</td>
</tr>
<tr>
<td>TOTAL COST</td>
<td>$215,250</td>
</tr>
<tr>
<td>Cost/ Ha</td>
<td>$10,762</td>
</tr>
</tbody>
</table>

DRIP IRRIGATION- HORTICULTURE

Assumptions
- Separate farm – existing horticulture conversion to drip
- System delivers 10mm/day
- Lateral Spacing 1m
- Dripper Spacing 0.5m
- Dripper Flow L/hr

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground Power</td>
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<td>Pump Pit, Shed etc</td>
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<td>Electrician</td>
<td>$2,000</td>
</tr>
<tr>
<td>Pump and Motor</td>
<td>$</td>
</tr>
<tr>
<td>Controller? - Manual System</td>
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<tr>
<td>Filtration</td>
<td>$</td>
</tr>
<tr>
<td>Mainline</td>
<td>$</td>
</tr>
<tr>
<td>Valves</td>
<td>$</td>
</tr>
<tr>
<td>Sub Mains</td>
<td>$</td>
</tr>
<tr>
<td>Laterals</td>
<td>$</td>
</tr>
<tr>
<td>Flushing Mains</td>
<td>$</td>
</tr>
<tr>
<td>Installation</td>
<td>$</td>
</tr>
</tbody>
</table>

Drip Cost say $7000/HA $140,000
TOTAL COST $158,000

Cost/ Ha $7,900

DRIP DIAGRAM (sdi example on the test farm only)
Partner Organisations

Charles Sturt University
CSIRO
Goulburn-Murray Water
Queensland Government
Australian Government
Land & Water Australia
NSW Government
Industry & Investment
South Australian Research and Development Institute
South Australia
SunWater
The University of Melbourne
The University of New England
UniSA
University of Western Sydney
Department of Primary Industries
Cooperative Research Centre for Irrigation Futures

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