The economics of sprinkler irrigation uniformity: A case study of lettuce on the Swan Coastal plain

Donna Brennan
Policy and Economics Research Unit
CSIRO Land and Water

and Tim Calder
Western Australian Department of Agriculture and Food

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The work contained in this report is collaboration between CSIRO Land and Water and The Western Australian Department of Agriculture and Food. It was partially funded through in-kind and financial contributions by the Western Australian Department of Agriculture and Food.

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Executive summary

The Government of Western Australia has undertaken to develop a statutory water plan for the Gnangara Mound as one of the commitments made under the National Water Initiative. This plan will need to address water allocations to the peri-urban horticultural industry, and may require clawing back of volumetric allocations to address declining groundwater levels. Policies that encourage adoption of water efficient appliances may reduce the impact of reduced allocations, on the irrigation dependent businesses and on the consumers of produce supplied to the metropolitan market.

The opportunity for reducing water use in the horticulture industry will depend on the flexibility of current watering regimes and the scope for improving technical water use efficiency. These in turn depend on the relationships between water use and crop yield, and differences in the capital cost and performance of irrigation systems. The economic benefits of more uniform systems depend on the water-yield relationship which affects revenue, and the variable costs of production including irrigation costs and water prices. These must be compared with the capital costs of achieving better uniformity which include for example, the extra materials components associated with closer sprinkler spacing.

This report contains an analysis of the economic incentive to adopt more water efficient sprinkler systems using lettuce as a case study. The economic model draws on several Department of Agriculture studies on the performance of sprinkler systems and yield-water relationships for lettuces on the Swan Coastal Plain.

Results indicate that growers acting with perfect information regarding the efficiency of their sprinkler systems and the water-yield relationship would, provided they are paid on the basis of yield, have a strong incentive for using water efficiently and for adopting systems with high distribution uniformity. The reason for this is that there is a strong disincentive to over-watering. Farmers lose money by over-watering, due to the leaching of nitrogen at high water application. More efficient sprinkler systems achieve higher economic returns and use less water. Of the systems studied it was shown that twice as much lettuce could be grown with the most efficient system for the same amount of water, and returns would increase by $1,500 to $2,000 per hectare per crop, compared to the least efficient system studied.

A possible explanation for low adoption of water efficient appliances is that farmers do not perceive a financial disincentive from over-watering. The study demonstrated that if the farmer believes that there is no yield (or revenue) penalty from over-watering, they will not anticipate any financial gain from adopting more water efficient appliances, particularly if they are making decisions on a short planning horizon. This situation may arise either through lack of information regarding the water-yield relationship, or even where farmers are aware of the effect of over watering on yield, it could arise if they are not paid on the basis of weight. For example, lettuce sales to supermarkets are largely based on the number of heads sold, rather than the head weight of the lettuce. Another significant disincentive to improving irrigation systems is the uncertainty about how long they may be farming due to land use planning changes, with a number of farms likely to be subdivided for urban development in the short term.

The provision of extension information regarding the nature of water productivity for different crops could provide substantial incentive for improving water use efficiency. Where crops are paid on the basis of weight and there is a yield loss at high water application, there are strong gains from adopting more efficient systems. Further research on the nature of water productivity
for different crops may be required. The importance of the distribution uniformity measure in
determining appropriate water use, economic returns, and the incentive to adopt more efficient
systems confirms the need for extension in this area, but further analysis of other cropping
systems is required to confirm this.

A number of policy options are available for improving the likelihood of adoption of water
efficient systems. These include increasing security of tenure over water and land, which will
extend the farmers planning horizon and reduce capital costs, and the introduction of water
markets. Water markets will increase the incentive for reducing water use in the short term, and
will encourage adoption of water efficient sprinkler systems in the longer term. For example,
where distribution uniformity is around 55%, the farmer is better off reducing water application
by 1.5 ML per crop hectare (20 percent) if the market price is $200 per ML, compared to when
there is no market. Water markets will improve incentives for adoption of water efficient
practices even when the water-yield relationship plateaus and there is no yield penalty from
over-watering.

The potential for using capital subsidies to encourage adoption of more water efficient sprinkler
systems need to be considered in the context of the other incentives for adoption. For example,
if the yield penalty associated with higher water use is shown to exist for other crops, then this
information alone should be sufficient to encourage adoption of more efficient sprinkler
systems. On the other hand, if the water-yield relationship is shown to plateau at high water
application rates then the private incentives for adoption of efficient systems are less
pronounced. The introduction of water markets may reverse this incentive without requiring
public subsidy of irrigation equipment. However, if there is a concern about the environmental
consequences of nitrogen leaching associated with horticultural production on the Gnangara
mound, then a number of pollution control alternatives could be considered, including nitrogen
or water taxes, mandatory water use efficiency standards, and subsidies to reduce the cost of
sprinkler system upgrades.
1. Introduction

The Gnangara Mound is the major source of water for consumptive use in the Perth region, supplying around half of the potable water supply for the urban sector, as well as the peri-urban horticulture industry, industrial, local government and domestic users. In recent years, increased consumptive uses of water, changes in recharge-affecting land uses, as well as a prolonged sequence of low rainfall winters, have all contributed to a substantial decline in groundwater levels. As one of the major users of water on the Mound the horticulture sector is under increased pressure to improve water use efficiency, and there is increased likelihood that policy interventions will be required to achieve a reduction in water use. These interventions may include reducing of licensed allocations, introduction of stricter monitoring and compliance rules, provision of financial incentives for adoption of more efficient technology, mandatory and voluntary regulation of irrigation efficiency standards and increased emphasis on water markets.

A characteristic of irrigation on the Gnangara mound is the use of fixed sprinkler systems for the irrigation of lettuces and other vegetable produce. The soils of the region are sandy and have low water holding capacity, which together with poor sprinkler uniformity has led to a high level of water use. Several surveys of horticultural properties on the Swan Coastal plain have found evidence of poor uniformity, for example Milani (1991) found that only 10 percent of sprinkler irrigation systems were operated at an acceptable standard. Calder and Lantke (2000) reported an average distribution uniformity of 61%, with some systems as low as 21%, which they attributed to poor design for windy conditions. The standard rule of thumb used to determine whether a sprinkler system is of an acceptable efficiency standard is that distribution uniformity should be more than 75 percent (Lantke 2003). Distribution uniformity is a measure of the spatial distribution of precipitation across a field, being the precipitation in the drier sections of the field relative to mean precipitation. Some aspects of sprinkler design that can improve uniformity are the sprinkler spacing, type of sprinkler, and operating pressure, but usually involve greater capital investment.

Irrigation water is supplied by farmer-owned groundwater bores, and though water use is licensed, historically it has not been monitored. Whilst legislation exists to allow water trading, water use has not been metered and there has been little incentive for markets to develop. The only variable cost of water currently incurred by the farmer is the cost of operating and maintaining water pumps. However, in 2005 the Department of Environment (now taken over by the new Department of Water) embarked on a major program of installing meters on horticultural enterprises on Gnangara Mound. When these meters are used to enforce allocation limits the market should mature, which will create an incentive to save water and encourage investment in more efficient irrigation technology.

The opportunity for reducing water use on existing horticultural properties will depend on the flexibility of current watering regimes and the scope for improving technical water use efficiency. These in turn depend on the relationships between water use and crop yield, and differences in capital cost and performance of irrigation systems. The economic benefits of more uniform systems depend on the water-yield relationship which affects revenue, and the variable costs of production including irrigation costs and water prices. These must be compared with the capital costs of achieving better uniformity which include for example, the extra materials components associated with closer sprinkler spacing.

A number of recent studies conducted by the Western Australian Department of Agriculture and Food provide the necessary empirical information for investigating the efficiency of alternative sprinkler systems, the incentive for adopting more water-efficient systems and practices, and the influence of policy on these incentives. In particular, experimental evidence for lettuce, one
of the major crops grown, suggests that the crop exhibits declining marginal productivity to water use at high water application rates (Teasdale et al. 2001), which they attributed to leaching of nitrogen at high water rates. Lantzke (2003) undertook a detailed investigation of best practices for irrigation management, paying particular attention to irrigation spacing, and water pressure, and measurement of sprinkler uniformity at different wind speeds. A large number of individual sprinkler brands and jets and spacings were assessed for the typical wind conditions on the Gnangara Mound.

1.1. Objectives

The aim of this study was to analyse the factors affecting returns to sprinkler uniformity and to conduct an economic evaluation of a range of sprinkler system designs suitable for conditions on the Gnangara mound. The specific objectives were to:

- Develop a quantitative model of the economic returns to irrigation that accounts for variation in sprinkler uniformity, using experimental data on water-yield relationships for lettuce
- Analyse the factors affecting returns to irrigation, including sprinkler uniformity, wind conditions, and irrigation scheduling.
- Provide an economic evaluation of a range of sprinkler designs that were assessed by Lantzke (2003) for uniformity under Perth wind conditions and examine the economic trade off between capital cost and the benefits of uniformity.
- Provide a discussion of the policy issues affecting adoption of more efficient irrigation systems.

1.2. Outline

The outline of the report is as follows. In the next section, the economic model used to evaluate the costs and benefits of alternative sprinkler systems is presented, and the factors affecting the relationship between distribution uniformity, water use, and economic return are demonstrated. In Section 3, results of the economic evaluation of alternative sprinkler systems are presented and factors affecting incentives for adoption of water efficient systems are discussed. Sensitivity analysis of a number of key factors affecting the economics of alternative systems, including the water-yield relationship, information used to determine irrigation scheduling decisions, and capital costs are presented in Section 4. Section 5 contains an analysis of the impact of introducing a water market on the incentives for reducing water use and for adoption of water efficient sprinkler systems. A brief discussion of the externality implications of the decision to adopt sprinkler systems with low uniformity is provided in section 6. Section 7 provides a summary of the findings and a discussion of the policy implications.
2. Method of analysis

The economic value of alternative irrigation systems is assessed by representing the watering pattern over space, as affected by the distribution uniformity, and estimating the expected gross margin as affected by the wetting pattern and the water-yield relationship. The economic benefit of a particular sprinkler system is the expected gross margin less the cost of capital investment in that sprinkler system. In this report these costs and returns are expressed on a per crop-hectare basis, and capital costs of the long term investment in sprinkler capital are amortized to determine a per crop-hectare equivalent capital charge.

A definition of the basic terms used in the analysis for comparing between sprinklers is provided below, and then a detailed description of the economic model is presented.

Gross margin is the expected cash returns associated with growing lettuce using a particular sprinkler system, where expectations are weighted according to economic returns in each season and the harvest pattern over the year. Expected gross margin expressed in terms of $ per crop-hectare.

Attributed capital cost of a particular sprinkler design is equal to the annualized cost of capital divided by the number of crops per year, expressed in $ per crop-hectare.

Net economic benefit of a particular technology is the expected gross margin minus the attributed capital cost, expressed in terms of $ per crop-hectare.

Water application is the amount of water pumped through the sprinkler system, in ML per hectare. The amount reaching the crop is determined by distribution uniformity as described in the following section.

2.1. Modelling the economic benefits of sprinkler uniformity

In order to assess the economic benefits of sprinkler uniformity it is necessary to account for variation in precipitation over space. The general approach taken in the model is to divide the field area into sections defined by a discrete probability distribution, to represent the range of water application rates that will occur across the field when precipitation is not uniform. These varying levels of precipitation are then used to determine crop yield in each section of the field, according to the water-yield relationship. The mean yield is then calculated to determine expected revenue in a particular season.

Since both crop water requirements and wind conditions vary over the year, the returns to water application vary according to the planting month. In order to provide a measure of the expected benefits of a particular irrigation technology for a vegetable farm setting, the economic evaluation is conducted by assessing economic returns in the three major seasons (summer, winter and spring/autumn) and providing an expected value based on the temporal pattern on sales into the metropolitan market.

A formal definition of the model is provided as follows.
Expected benefits of uniformity for system j in season t:

\[
B_{jt} = \sum_i^3 P_t E[Y_{ijt}] \phi_{it} - P_N N - P_W W_{jt} - \sum_i^3 C_{ijt} (E[Y_{ijt}])
\]

Expected benefits of uniformity for system j:

\[
B_j = \sum_t^3 B_{jt} k_t
\]

Where

- \(P_t\) is the price of the produce at harvest if planted in season \(t\)
- \(E[Y_{ijt}]\) is the expected crop yield using irrigation technology \(j\) planted in season \(t\) and irrigated under wind speed conditions \(i\)
- \(P_N\) is the price of nitrogen fertiliser
- \(P_W\) is the cost of water, which in the base case is the cost of electricity pumping
- \(W_{jt}\) is the water applied using irrigation technology \(j\) planted in time \(t\), determined by mean precipitation in mm per hour and the hours scheduled for irrigation
- \(C_{jt}\) is the other costs of production, which may include yield related variable costs
- \(k_t\) is a weighting factor reflecting the proportion of annual sales for crop planted in season \(t\)
- \(\phi_{it}\) is the probability that wind speed conditions \(i\) occur in season \(t\)

Water use and expected yield

Lantzke (2003) used a combination of field measurement and computer modelling to provide information on the performance of a range of sprinkler designs for wind conditions on the Swan Coastal plain. More than 160 were assessed, representing variation in sprinkler spacing, water pressure, sprinkler brands, different jet sizes. Results for each system were reported in terms of distribution uniformity at different wind speeds, where the distribution uniformity measured two points in the spatial distribution of water as follows:

\[
U = \frac{\omega_{avg25}}{\bar{\omega}} \times 100
\]

Where:
- \(\omega_{avg25}\) is the average precipitation of the lowers 25 percent of the sample of catch cans in the field
- \(\bar{\omega}\) is the average precipitation of the entire sample

The distribution uniformity can be used, with the mean precipitation rate and an assumed functional form for the distribution, to represent the spatial distribution of precipitation. A log normal distribution was used in this analysis, following Warwick and Gallagher (1982). The spatial distribution was represented by seven discrete points, each representing one seventh of
the spatial distribution. For each sprinkler system, the spatial distribution of precipitation was estimated for three different wind speeds, calm (less than 8 km per hour), moderate (9-16 km per hour), and windy (greater than 17 km per hour). The frequency of occurrence of a particular wind speed in month \( t \) (\( \phi_t \)) was obtained from climatic records, as illustrated in Figure 1.

Having determined precipitation rates in mm per hour, water use (in mm) of a particular section of the crop is determined as:

\[
W_{ltj} = S_{jt} \cdot \rho_{ltj} \cdot D_t
\]

Where:
- \( S_{jt} \) is the irrigation scheduling time for system \( j \) in season \( t \) (hours per day)
- \( \rho_{ltj} \) is precipitation in the crop section \( l \), under wind conditions \( i \) in season \( t \) for system \( j \), determined from the calibrated probability distribution
- \( D_t \) is the crop length from transplanting to harvest in season \( t \), in days

The length of the crop growth period for a crop planted in a particular season was derived from the Department of Agriculture and Food's irrigation model (Department of Agriculture and Food 2005).

The determination of \( S_{jt} \) is a critical factor in this analysis. In most of the results presented in this report it is assumed that the irrigation scheduling time is chosen to maximise expected gross margin in a particular season \( t \).

Source: Derived on monthly wind speed data for Perth reported in Calder (1992).

**Figure 1. Probability distribution of wind speed conditions, by month.**
Yield in crop section $i$ under wind conditions $t$, in season $s$ for system $j$: $Y_{ijst}$

$$Y_{ijt} = f_s(W_{ijt})$$

Teasdale et al (2001) investigated the impact of watering regimes on lettuce yields on the Swan Coastal Plain, which provided evidence of yield decline at high watering application rates, attributed to the effect of nitrogen leaching. Statistical analysis of the experimental results (estimated separately for different nitrogen levels) revealed that the best fit was the functional form: $Y = a + \frac{b + cE}{1 + dE + eE^2}$, where $Y$ is lettuce head size and $E$ is the water applied as a percent of pan evaporation. Equation parameters were not reported in Teasdale et al. (2001) but were obtained from the authors (Dennis Philips, personal communication 2006). The relationship between water and yield for 2 different nitrogen application rates are shown in Figure 2, converted to a yield in tonnes per hectare by assuming a planting density of 60,000 heads per hectare.

![Figure 2. Yield-water relationship used in analysis (best fit)](image.png)

Source: Based on Teasdale et al’s (2001) experiments, Philips (Personal communication).

The original data were obtained from Dennis Phillips (Personal Communication, 2006), in order to fit a Mitscherlich type functional form ($Y = Y_m e^{a(x-b)}$). The fitted curve is shown for the highest nitrogen level in Figure 3, and compared to the best fit function. In this report the Mitscherlich functional form is used to compare the relative impact of declining and constant yield-water relationship at high application rates. The results of the Mitscherlich relationship can depict how farmers might behave if they believe there is no yield depressing effect associated with high water use.
Expected yield for season $t$ and sprinkler system $j$: $E(Y_{jt})$

Having determined yield for each of the $l$ sections of the crop under wind conditions $i$, using the water-yield relationship in Figure 2 and the water use $W_{lmjt}$, the expected yield is:

$$E(Y_{jt}) = \sum_{i} \left( \sum_{l} \frac{Y_{ljt}}{7} \right) \phi_{it}$$

(5)

$\phi_{it}$ is the probability that wind speed conditions $i$ occur in season $t$

2.2. Economic parameters

Information on costs of production were derived from (Gartrell 1998, 2003), updated to reflect 2005 prices. Produce prices were based on mean real historic prices. Most of the costs of lettuce production are dependent on the planting density rather than the yield (determined by planting density and individual head weight), and since a constant planting density of 60,000 heads per hectare is assumed, costs are largely independent of yield. However, a variable component associated with post harvest handling and transport was incorporated. Initial assessment of the yield relationships and cost data revealed that the highest nitrogen application rate was the most profitable, and this rate is used to estimate the economic values presented in this report.
Electricity costs for pumping water were based on estimated pump capacity required for different system pressure and bore depths, which ranged from 9.2 kw capacity for a 25 m head and a 45 m³ per hour flow rate, to 22 kw capacity for a 40 m head and an 87 m³ per hour flow rate.

3. Effect of sprinkler uniformity and scheduling decision on economic returns

The effect of sprinkler uniformity on the expected gross margin of a summer lettuce crop (assumed January planting), are demonstrated in Figure 4 over a range of water application rates. The shape of the curves reflect the underlying yield functions, where increasing water application first increases yield and gross margin, but eventually reduces gross margin because of declining productivity. Increasing costs of water application also contribute to a declining gross margin, but it is not the major determinant. The water pumping cost is only around $50 per ML, which means that over the range of water application from 4 ML to 10 ML, the cost of water increases by $300 per ha, whereas the total change in gross margin is $2000 per ha. The peak of the curve represents the level of water use at which gross margin is maximized. As the distribution uniformity is reduced, the gross margin curve becomes flatter, and the peak moves to the right. This is due to the averaging of effects in different parts of the field: drier patches continue to respond to increasing water application rates whilst the wetter patches begin to suffer declining yields.

![Figure 4. Gross margin as affected by water use and distribution uniformity, Best fit yield function, January planting](image-url)
The gross margin relationships were also estimated using the Mitscherlich yield curve and are illustrated in Figure 5. The plateau in the yield curve at around 4 ML per hectare leads to a relatively flat gross margin curve, which only declines at the rate of water pumping cost.

![Figure 5. Gross margin as affected by water use and distribution uniformity, using Mitscherlich yield function, January planting](image)

The optimal water application rate is the amount that maximises expected gross margin, and varies according to the distribution uniformity and the underlying yield curve. Optimal watering rates were calculated for each of the curves illustrated above, and results are shown in Table 1. Optimal application rates are lower for the best fit function due to the effect of the declining yield at high water application rates, and as indicated in Figure 4. Also shown is the water application rate associated with a 'rule of thumb' watering regime, based on the crop water requirement determined from the Department of Agriculture and Food’s IRRICALC model (Aylmored et al. 1994, Western Australian Department of Agriculture and Food 2006), which is 5.1 ML per hectare for lettuces planted in January. This water requirement was adjusted for efficiency by dividing it by the distribution uniformity. The ‘rule of thumb’ watering rate is higher than the optimal water use estimated for either yield function. The difference between the optimal and the scheduling coefficient rule increases as the distribution uniformity increases.

<table>
<thead>
<tr>
<th>DU</th>
<th>Optimal</th>
<th>‘Rule of thumb’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Best fit water-yield function</td>
<td>Mitscherlich</td>
</tr>
<tr>
<td>90</td>
<td>4.85</td>
<td>5.55</td>
</tr>
<tr>
<td>80</td>
<td>5.23</td>
<td>6.07</td>
</tr>
</tbody>
</table>
4. Capital costs of sprinkler uniformity

Total capital costs were determined using the IRRICAD computer model, which calculates the equipment and fittings required to achieve particular performance standards in irrigation. Sprinkler designs tested by Lantzke (2003) included specification of sprinkler type, jet size, sprinkler spacing, and operating pressure, and IRRICAD was used to determine a complete materials list required for a particular sprinkler layout at a given operating pressure. These materials were then costed using quotes from Total Eden Rural Supplies (Personal communication, February 2006). The quotation took account of the typical discounts that might be offered to a farmer making a major investment in sprinkler capital.

Due to time constraints, a subset of 77 sprinkler designs were evaluated in this study, out of a total of 166 tested by Lantkze (2003). The sample covered a large range in layouts and distribution uniformity.

The total capital investment costs for each sprinkler design, expressed on a per hectare basis, are demonstrated in Figure 6, plotted against the mean distribution uniformity. There is not a strong relationship between capital investment cost and performance. Whilst expenditure above $10,000 per hectare is generally associated with higher distribution uniformity, there are many sprinkler systems that have high distribution uniformity with substantially lower investment cost. However, there is much greater variation in performance amongst the cheaper systems. For example, over the cost range $5,000 to $7,000, there is substantial variation in mean distribution uniformity between different systems.

![Figure 6. Estimated total capital costs against sprinkler uniformity](image)
Factors affecting capital costs and distribution uniformity were assessed using regression analysis, using models shown in equation 6 and 7. Results are presented in Table 2. Model 1 examined the effect of design characteristics on costs. The explanatory variables were sprinkler spacing (m²), and jet size in mm. To account for differential impacts of single and double jets, a dummy variable was used on the jet size coefficient. Dummy coefficients on product brands were also examined, and were found to be significant for two brands. All the coefficients estimated in the first equation are significant at the 0.1% level, and the R² was 85%. Investment costs are inversely related to sprinkler spacing and directly related to jet size, with additional costs if double jets are used. The Cropwell systems tested were significantly cheaper and the Toro TR systems were significantly more expensive.

The second model examines the effectiveness of the design characteristics on mean distribution uniformity. The model explained only 45% of the variation, and the brand dummy variables were not significant. However, all of the other design parameters that contributed to higher investment cost in the first model had a significant effect on mean distribution uniformity in the second model.

\[
\text{Model 1: Capital cost per ha} = a + b \text{ Spacing} + c \text{ Jet Size} + d \text{ Jet Size if double} + e \text{ (if Cropwell brand)} + f \text{ (if Toro TR brand)} \\
\]

\[
\text{Model 2: Mean distribution uniformity} = a + b \text{ Spacing} + c \text{ Jet Size} + d \text{ Jet Size if double} \\
\]

\[
\begin{align*}
\text{Table 2. Design characteristics affecting capital cost and performance} \\
\begin{tabular}{|c|c|c|}
\hline
\text{Estimated coefficients and fit} & \text{Model 1: Cost per ha} & \text{Model 2: Mean DU} \\
\text{R²} & 85% & 45% \\
\hline
a Intercept & 8,886.93 & 80.86 \\
b Spacing (m²) & -29.24 & -0.14 \\
c Jet Size, mm & 438.59 & 4.08 \\
d Jet size, mm, if double jet & 228.83 & 1.57 \\
e Cropwell dummy & -1,419.67 & - \\
f Toro TR dummy & 1,411.76 & - \\
\hline
\end{tabular}
\end{align*}
\]

5. Evaluation of alternative sprinkler designs

5.1. Economic performance as affected by distribution uniformity

Economic performance, measured as gross margin less capital cost, was evaluated for each sprinkler design. Because the economic performance is expressed on a per crop-hectare basis, capital costs are represented as an equivalent capital charge which is based on full utilization over the economic life of the irrigation equipment. A discount rate of 5% was used, and it was
assumed that 5 lettuce crops were grown per year. The resulting figure is called the ‘attributed capital cost’ in this report.

Economic performance results presented in this section are based on the ‘best fit’ yield function, and assuming that the farmer determines watering time to maximize expected profit. Figure 7 illustrates the strong effect of mean distribution uniformity on optimal water use and gross margin. On the left axis, water use is indicated. The optimal quantity of water use per hectare decreases substantially as distribution uniformity is improved. There is a halving of water use as distribution uniformity is increased from 52% to 91%. The gross margin increases as distribution uniformity increases and water use falls. The difference in returns, between the highest and lowest distribution uniformity tested, is $1,800 per ha per crop, equivalent to 20% of the gross margin of the most profitable system.

![Figure 7. Water use and gross margin for different sprinkler systems, according to mean distribution uniformity](image)

Economic performance depends not only on the gross margin, which has a strong relationship to mean distribution uniformity, but also on capital costs, which as shown in Figure 6, did not have as strong a relationship with distribution uniformity. Both gross margin and net economic return are shown in Figure 8. At any given mean distribution uniformity, variation in expected gross margin is the result of variation in performance at different wind speeds. Variation in net economic return is the net result of differences in expected gross margin and capital cost. The main factor driving differences between systems is the distribution uniformity. This is further illustrated in Table 3 which shows results of a regression of net economic return against capital cost and distribution uniformity. More than 98 percent of the variance in economic benefit is explained by variation in capital cost and distribution uniformity at different wind speeds. The coefficient on the capital cost variable is close to -1, as would be expected: A $1 increase in capital cost will ceteris paribus reduce net returns by $1. Also shown in the table is the elasticity of the variables, estimated at mean values. The elasticity of capital expenditure is low, and the
elasticity of distribution uniformity is highest for performance under windy conditions. For example, a 10 percent reduction in capital cost will increase net return by 0.6 percent, whereas a 10 percent increase in distribution uniformity under windy conditions would increase economic benefit by 7 percent.

![Figure 8. Comparison of expected gross margin and net return of sprinkler systems, as affected by distribution uniformity](attachment:figure8.png)

**Table 3. Factors affecting the economic value of sprinkler systems, dependent variable is expected net economic return in $ per ha per crop**

<table>
<thead>
<tr>
<th>Model</th>
<th>Elasticity of coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted R²</td>
<td>98.4%</td>
</tr>
<tr>
<td>Intercept</td>
<td>-112.38</td>
</tr>
<tr>
<td>Capital</td>
<td>-0.99</td>
</tr>
<tr>
<td>Distribution uniformity at 4 km per hr</td>
<td>2.80</td>
</tr>
<tr>
<td>Distribution uniformity at 12 km per hr</td>
<td>12.99</td>
</tr>
<tr>
<td>Distribution uniformity at 20 km per hr</td>
<td>30.12</td>
</tr>
</tbody>
</table>

5.2. Economic incentives for adoption of more efficient irrigation technology

The decision to adopt a more efficient sprinkler system will depend on the individual situation of the farmer with respect to existing irrigation infrastructure. If a new paddock were being laid to irrigation, or if an irrigation system were in need of complete replacement and the capital was expected to be used for its full physical life, the decision would be based upon a comparison of
the full economic return including cost of capital, between alternative systems. At the other extreme, the farmer may not count the sunk capital cost of existing system, comparing the gross margin earned on the existing infrastructure with the net economic return including capital for the proposed alternative system. This situation could arise for example, where a farmer buys a farm which has recently installed new equipment but is considering upgrading immediately to a more efficient system. In reality most adoption choices would lie somewhere between these two extremes. The two extreme points provide the boundaries on benefits of adopting a more efficient system and are referred to as the ‘greenfields’ and ‘sunk capital’ alternatives below.

When considering whether to adopt a more efficient system the farmer will consider the relative performance of the current system compared to the performance of a range of alternative systems which have better economic performance, which will tend to be systems with more efficient distribution. In this report, the adoption decision is demonstrated by comparing alternative sprinkler systems with just one system: the system with the highest distribution uniformity. Under baseline assumptions this system is also the most economically efficient system. The economic incentive for adoption of the most efficient system is measured for any current sprinkler system as the difference in economic returns of the current system and the most efficient one. Results are plotted against the mean distribution uniformity in Figure 9, and the associated water savings from adoption of the most efficient system are shown in Figure 10.

The financial incentive for adoption is directly related to the water savings from adoption of the most efficient technology. As would be expected, the highest financial incentive for adoption and the greatest water savings occur when the current distribution uniformity is relatively low. There is some variation in financial incentive at the same level of mean distribution uniformity; this is driven by differences in capital cost and differences in performance under windy conditions. For the greenfields adoption scenario, where a decision was being made to invest in a particular system compared to the most efficient system, the farmer would be better off in all cases to adopt the system with the highest distribution uniformity. However, where there is usable sunk capital associated with an existing system, the farmer would be financially worse off by adopting the sprinkler system with the highest distribution uniformity, if he currently has a system with distribution uniformity above 82%. In this situation he would be better off delaying the upgrade until the system was at the end of its usable life and was in need of replacement.
Figure 9. **Financial gain/loss from adopting the sprinkler system with the highest distribution uniformity**

Figure 10. **Water saved by adopting the sprinkler system with the highest distribution uniformity, compared to current system**
6. Sensitivity analysis

6.1. Importance of yield-water relationship

The analysis presented in section 3 was based on the water – yield relationships estimated in the Teasdale et al (2001) study, which demonstrated a negative marginal productivity of water as the result of nitrogen leaching. Under these conditions, there exists a strong incentive to adopt the most efficient technology, as a result of the economic penalty associated with over-watering. An alternative functional form for the water – yield relationship is the Mitscherlich form, in which there is no yield reduction from over-watering. If farmers perceive the water – yield relationship to be of Mitscherlich form, they may have less incentive to adopt more efficient sprinkler systems.

Characteristics of the lettuce market also suggest that there is another reason why the Mitscherlich function may be appropriate for some lettuce producers. For those supplying the processing industry (such as fast food companies), prices are paid according to weight and results presented in the previous section are relevant. However, in the case of lettuce produced for the supermarket sector, there is anecdotal evidence to suggest that farmers are paid on the basis of number of lettuce heads rather than on head weight as long as a minimum standard is reached (Dennis Philips, Personal communication). In this situation, even if the head yield is reduced as water application increases, there may not be an economic penalty associated with the yield reduction. In this situation the economic benefits curve may resemble the Mitscherlich form depicted in Figure 5.

The impact of the Mitscherlich function on the economic return provided by sprinkler systems of different distribution uniformity is illustrated in Figure 11. Compared to the ‘best fit’ water-yield relationship, the Mitscherlich functional form results in a much flatter relationship between distribution uniformity and economic return.
6.1.1. Economic incentives for adoption of more efficient irrigation technology

The flatness of the net benefit curve results in a significantly reduced incentive to adopt. The financial gains from adopting the irrigation system with the highest distribution uniformity are compared for the ‘greenfields’ case in Figure 12. Over a wide range of distribution uniformities (from 65 to 90 percent), sprinkler systems are better economic performers than the sprinkler system with the highest distribution uniformity. This is because the flatness of the gross margin curve with respect to water use, which means that the differences in economic performance are largely due to differences in capital cost.
Figure 12. Financial gain from adopting the systems with the highest distribution uniformity relative to current system, greenfields scenario

Figure 13 shows the lower bound on the benefits to adoption, the ‘sunk capital’ case. With a Mitscherlich water-yield response the financial disincentive for adoption is even more pronounced, indicating that even the sprinkler irrigation systems with the very lowest distribution uniformity would not be worth replacing before the end of its useful life.
6.2. Importance of capital costs

Investing in alternative sprinkler systems is a long term decision that involves an up-front capital investment that realises a return over time. Economic timing issues were dealt with in this analysis by using an annuity method which determines an attributed capital cost per ha, effectively payable for each crop grown in the area serviced by the irrigation system. To calculate an annuity payment it is necessary to make assumptions regarding the farmer's discount rate, and the expected life of the asset, as well as the number of crops per year. Variation in these values will affect the calculated capital charge.

6.2.1. Expected life

The assumed life of sprinkler systems was determined by discussion with irrigation system experts and was 5 years for sprinklers and parts, and 15 years for the remainder of the equipment. In the current policy setting where there is uncertainty regarding future water allocations and land zoning, it is possible that farmers are making decisions on shorter time frames than the physical life of the sprinkler system. To explore the impact of economic life on the viability of upgrading sprinkler systems, sensitivity analysis was conducted using extreme assumptions of 5 and 2 year planning horizons. The impact on calculated capital charge is illustrated in Figure 14.
Whilst there appears to be a large difference in capital charges as the economic life is shortened, these charges are small relative to the benefits of improved productivity, at least in the case of a ‘greenfields’ decision. However, as shown in Figure 16 when the sunk cost of capital is also accounted for, a short planning horizon provides a substantial disincentive to upgrading of sprinkler systems. For example none of the sprinkler systems with a uniformity above 70% would be replaced by a farmer if the planning horizon were only 2 years and the existing equipment was in good enough condition to use for that period.

Figure 14. Impact of assumed economic life on capital charge
Figure 15. Economic gain from adopting system with highest distribution uniformity, as affected by planning horizon, greenfields

Figure 16. Economic gain from adopting system with highest distribution uniformity, as affected by planning horizon, sunk existing capital

6.2.2. Discount rate

The analysis was conducted at a discount rate of 5%, reflecting the long term cost of capital. This is an appropriate rate if the farmer is a net lender and is risk neutral. However, if the farmer is a net borrower or if he/she expects a risk premium on the capital invested in agriculture, a higher discount rate might be appropriate. The effect of discount rate on the economic gain from
adoption under the ‘sunk capital’ case is illustrated in Figure 17. The impact of a higher discount rate on the decision to adopt is small, under the assumption of full economic planning horizon.

![Economic gain from adoption vs. Mean distribution uniformity](image)

**Figure 17. Economic gain from adopting system with highest distribution uniformity, as affected by discount rate, sunk existing capital**

7. **Impact of a water market on the economic value of improved distribution uniformity**

Whilst water markets are enabled under current legislation, an active water market has not yet developed in the peri-urban region, largely because licensed allocation limits are not actively enforced. The introduction of metering on the Gnangara Mound will provide more incentive for water trade. Once an active market develops irrigators will make irrigation scheduling and investment decisions in the context of an opportunity cost of water, which should lead to lower water application rates, and an increased incentive to adopt water efficient technologies.

In the analysis that follows, two market scenarios are examined, representing two equilibrium market price levels, $100 and $200 per ML. These prices are for consumptive use of a ML of water, rather than long term rights to water, and are reasonable estimates of the prices that might be expected in a peri-urban water market. By way of comparison, prices generally vary between $50 and $300 per ML in the Murray system in Victoria according to seasonal scarcity, but the Victorian industry contains a more diverse mix of enterprises some of which have very low gross margins. In the analysis presented here no account is taken for seasonal variation in
prices, and the model determines the optimal watering regime accounting for the market opportunity cost of water. It is important to note that the market would provide incentives for adoption of more efficient technology without having a substantial impact on the wealth of the farmer. For example, even if the market price were $200 per ML, farmers would have the right to use existing water allocations without paying for the water, the market price only influences decisions at the margin. For example, they could save some water and sell it on the market, or if they wanted to expand operations they could buy additional water on the market. For the purposes of calculating the income effects of the market-based policy, it is assumed that irrigators are allocated rights equivalent to an expected value of 5 ML per ha per crop.

7.1.1. **Water savings from introducing market**

The immediate impact of introducing a market is to reduce the optimal water application rate. This is because the gross margin benefits of increasing water application (as illustrated in Figure 4 and Figure 5) must be weighed against a higher cost of water. The optimal watering rates were calculated for each sprinkler system under the two market scenarios and using both water – yield functions. The impact of the water market on water application rates are illustrated in Figure 18, where the vertical axis shows the water savings from introducing the water market, defined as water application rate under market conditions less the water application rate in the absence of a market.

Under the ‘best fit’ water-yield relationship, the introduction of water markets results in water savings of between 0.1 and 1.5 ML per ha. Water savings are greater for sprinkler systems with low distribution uniformity, and where the market price is higher. When the water-yield relationship is a Mitscherlich function, the savings from introducing a water market are substantially higher, ranging from 1 ML per ha for the most efficient systems, to 3 ML per ha for the least efficient systems. The reason for these substantially higher savings is that there is a higher level of water use in the absence of the market, so that the irrigator is operating at a point that is far along the plateau of the yield-water response curve. Water consumption can be reduced by a larger amount before the yield impacts of reduced water application are experienced.

![Figure 18. Water saving associated with introducing a market, according to functional form and price. Measured as change over baseline water use for a particular system](image-url)
7.1.2. Effect of market on the incentive to adopt water saving technology

The financial incentives for adopting the most water efficient technology are illustrated for the best fit yield function in Figure 19 and Figure 20, representing the greenfields and sunk capital cases respectively. In both cases, the introduction of a market has a relatively small impact on the financial incentives for adoption where existing sprinkler systems have relatively high mean distribution uniformity. The gap between the savings from adoption under alternative market scenarios is higher where mean distribution uniformity is low. In general, the introduction of a market will provide an increased incentive for farmers to adopt water efficient technology if they have inefficient sprinkler systems that are generally below accepted international standards (less than 75%).

![Financial savings from adopting a particular technology, according to market conditions, greenfields scenario and best fit yield function](image1)

*Figure 19. Financial savings from adopting a particular technology, according to market conditions, greenfields scenario and best fit yield function*
The impact of a market on the incentive for adopting water efficient technology is much more pronounced when the water-yield relationship is a Mitscherlich form. Compared to the absence of a market where there is little incentive for adoption of water efficient technology, when market prices are $100 and $200 per ML, there is a stronger relationship between distribution uniformity and the gains from adopting the most technically efficient technology.

In the case of the ‘sunk capital’ scenario, a similar effect is seen, but in this case the introduction of a water market results in greater incentive for adoption. In the absence of a market there is no incentive for adoption of the most efficient technology, even when existing technology is very inefficient. In contrast, if farmers were operating under market conditions those with sprinkler systems having a mean distribution uniformity of 65% or less would be better off adopting the most efficient technology if the water price was $100 per ML. If the price were $200 per ML then the incentive for adoption would extend to systems that had a distribution uniformity of up to 75%.
8. Externalities

The economic evaluation of sprinkler systems was based on the private incentives for adoption of water efficient systems. However, there may be additional public benefits associated with encouraging adoption of more water efficient systems. These include the public benefits of reduced water consumption, which are in the form of higher residual water for water dependent ecosystems, and reduced nutrient pollution associated with reduced nitrogen leaching. The best method of managing the first issue, environmental consequences of high use by agriculture, is to properly address the allocation of water between sectors. A statutory management plan for Gnangara is under development, and when it is implemented, it will provide a clear and enforceable cap on allocations to agriculture, the environment and other sectors, while at the same time providing a mechanism to encourage water trade within the agriculture sector.

The second problem, of nutrient leaching, is more difficult to address because of the non-point source nature of the pollution problem. Since it is difficult to measure and enforce nutrient pollution taxes or permits, a more effective means of providing incentives for reduced nutrient pollution may be to either tax the fertiliser input, or to target water use, which is strongly linked to nutrient leaching. To illustrate this point, evidence of nitrogen leaching associated with different water application rates reported in Teasdale et al (2001), was used to calculate the nutrient leaching associated with the water application rates determined in this study for sprinkler systems of different distribution uniformity. As shown in Figure 23, the more efficient systems are associated with less nutrient leaching because there is a lower water application rate per hectare. Whilst a full examination of the policies for nutrient pollution management is beyond the scope of this study, the relationship in Figure 23 indicates that policies that encourage adoption of water efficient appliances will reduce nutrient pollution and therefore may have positive external social benefits. These benefits may justify public investment in strategies to encourage adoption of water efficient appliances, such as extension, or even capital rebates on efficient equipment. However, as shown in the earlier analysis in this report, information

Figure 22. Financial savings from adopting a particular technology, according to market conditions, sunk capital and Mitscherlich yield function

The economics of sprinkler irrigation uniformity
alone may be sufficient if the yield penalties associated with nutrient leaching also impact on the farmer’s revenue.

![Graph showing impact of distribution uniformity on nitrogen leaching based on modelled water use](image)

**Figure 23: Impact of distribution uniformity on nitrogen leaching based on modelled water use**

9. **Summary and policy implications**

This study examined the economics of sprinkler distribution uniformity using data produced by the Department of Agriculture and Food on performance of sprinkler systems and yield-water relationships for lettuces on the Swan Coastal Plain. Results indicate that growers acting with perfect information regarding the efficiency of their sprinkler systems and the water-yield relationship would, provided they are paid on the basis of yield, have a strong incentive for using water efficiently and for adopting systems with high distribution uniformity. The reason for this is that there is a strong disincentive to over-watering. Farmers lose money by over-watering, due to the leaching of nitrogen at high water application. More efficient sprinkler systems achieve higher economic returns and use less water. Of the systems studied it was shown that twice as much lettuce could be grown with the most efficient system for the same amount of water, and returns would increase by $1,500 to $2,000 per hectare per crop, compared to the least efficient system studied.

A possible explanation for low adoption of water efficient appliances is that farmers do not perceive a financial disincentive from over-watering. The study demonstrated that if the farmer believes that there is no yield (or revenue) penalty from over-watering, they will not anticipate any financial gain from adopting more water efficient appliances, particularly if they are making decisions on a short planning horizon. This situation may arise either through lack of information regarding the water-yield relationship, or even where farmers are aware of the effect of over
watering on yield, it could arise if they are not paid on the basis of weight. For example, lettuce sales to supermarket industry are largely based on the number of heads sold, rather than the head weight of the lettuce.

An important policy and science question is whether or not the true relationship between water application and revenue earned declines with increasing water application, or whether it plateaus as in the Mitscherlich form. If farmers are making water use decisions on the basis of poor information regarding water-yield relationship, then the appropriate policy tool to encourage adoption of water efficient appliances is to provide more information regarding the yield depressing effect of over-watering.

One of the policy factors affecting the decision to adopt water efficient appliances is the time frame of decision making. Uncertainty regarding future land rezoning in a peri-urban context, and uncertainty regarding how water allocations will be made in the future, will contribute to relatively short planning horizons, and increase the cost of capital. Even in the baseline case where there is a yield penalty associated with overwatering, the effect of higher capital costs associated with short planning horizons is to reduce the incentive for adoption. If farmers are able to make do with existing sunk capital, and are reluctant to plan beyond a 2 year time frame, then they will only have a financial incentive to upgrade equipment if the distribution uniformity is less than 70%. In the case where the farmer is operating under Mitscherlich expectations, then the effect of higher capital costs associated with short planning horizons will further reduce already weak incentive for adoption.

The introduction of stronger market signals will improve the incentive for adoption of water efficient practices and systems. Water markets will increase the incentive for reducing water use in the short term, and will encourage adoption of water efficient sprinkler systems in the longer term. For example, where distribution uniformity is around 55%, the farmer is better off reducing water application by 1.5 ML per crop hectare (20 percent) if the market price is $200 per ML, compared to when there is no market. Water markets will improve incentives for adoption of water efficient practices even when the water-yield relationship plateaus and there is no yield penalty from over-watering.

The potential for using capital subsidies to encourage adoption of more water efficient sprinkler systems need to be considered in the context of the other incentives for adoption. For example, if the yield penalty associated with higher water use is shown to exist for other crops, then this information alone should be sufficient to encourage adoption of more efficient sprinkler systems. On the other hand, if the water-yield relationship is shown to plateau at high water application rates then the private incentives for adoption of efficient systems are less pronounced. The introduction of water markets may reverse this incentive without requiring public subsidy of irrigation equipment. However, if there is a concern about the environmental consequences of nitrogen leaching associated with horticultural production on the Gnangara mound, then a number of pollution control alternatives could be considered, including nitrogen or water taxes, and subsidies to reduce the cost of sprinkler system upgrades.
10. References


Milani, S. (1991), Survey of irrigation efficiencies on horticultural properties in the Peel-Harvey catchment, Technical report 119, Department of Agriculture, Bentley, Western Australia.


